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## European and International Forum on Nanotechnology

Examining the state-of-the-art to overcome the barriers: An open debate

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EUROPEAN COMMISSION

# EURONANOFORUM 2003

## European and International Forum on Nanotechnology

Examining the state-of-the-art to overcome the barriers: An open debate

Edited by

**S. Fantechi and R. Tomellini**

Proceedings of the Forum organised by the European Commission, Directorate-General for Research, held in Trieste on 9-12 December 2003 as an official event of the Italian Presidency of the Council of the European Union

Directorate-General for Research
Nanotechnologies and nanosciences, knowledge-based multifunctional materials, and new production processes and devices

2004

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## Acknowledgements

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In particular, we would like to thank the Members of the *Interservice Group on Nanotechnology* of the European Commission for positively supporting the initiative.

The process leading to the EuroNanoForum 2003 event, its strategy, integrated approach and final scientific content is in particular the result of a good collaboration between the Directorate for *Industrial Technologies* and our colleagues of Directorate *Energy,* Directorate *Science and Society*, Directorate *Health* of the Directorate-General for Research, and the Directorate-General for Information Society, which has corresponded to the cross-cutting nature of nanotechnology and strengthened the concerted effort across programs in this field.

***The Editors***

***Sophia Fantechi and Renzo Tomellini***

## Foreword

The development of new products and services depends strongly on the capability to exploit in a more advanced manner the physical and chemical properties of materials. Thus, the investigation of matter and its control at the nano-scale present a huge potential that can bring benefits to society as a whole and in the framework of sustainable development. It could also greatly increase industrial competitiveness.

Research and technology on the nano-level represent a great intellectual and scientific challenge where the traditional scientific disciplines converge. New inter-disciplinary approaches and curricula need to be developed.

To succeed in the challenging world of nanotechnology, research excellence is, however, not enough. Successful strategies for companies and research organisations must include both industrial innovation and attention to environmental and social issues. New manufacturing tools and appropriate standards are also required as well as a novel entrepreneurial attitude.

Considerable resources and efforts are required to meet these challenges in a positive and timely manner. Furthermore, a careful analysis of the current situation has to be carried out. Future initiatives will greatly benefit from co-ordination and focusing, in order to achieve the maximum impact on industry, improve the quality of life of the citizens and enable the new discoveries to generate wealth and employment.

This Forum, organised by the European Commission in the framework of the Italian Presidency of the European Union, has successfully prepared the ground to respond to these challenges, by examining the present situation of the development of nanosciences and nanotechnologies in Europe. This has been done in the context of the international state of the art, and in line with the objectives of the European Research Area, the forthcoming enlargement of the European Union, the international dimension and the integrating character of the $6^{th}$ Framework Programme.

The Forum's programme has been structured to address the main obstacles towards the expansion and reinforcement of nanosciences in general, and to the development and use of nanotechnology-based products and services. Their potential applications and the possible risks have also been analysed.

The Forum aimed to gather key players and specialists in research, education, industry, finance, social sciences, journalism and public administration, with the participation of many top-level scientists and stakeholders. Participants from all over the world were given the possibility to exchange ideas and opinions, listen to Nobel prize-winners and leaders from industry, academia and public administration, build-up new research strategies and collaborations in the many research directions offered by nanotechnology.

The outcome of the Forum and the success of the integrated approach proposed have enabled the Commision to define, at the beginning of 2004, the key elements for a common strategy for the future of nanotechnology research in an enlarged Europe supported by a strengthened international co-operation.

Nanotechnology is thus the subject of a Communication, *"Towards a European strategy for nanotechnology", COM(2004)338*, adopted by the European Commision on 12th May 2004 (www.cordis.lu/nanotechnology).

In this Communication, not only is it proposed that research in nanosciences and nanotechnologies should be boosted, but that several other interdependent dynamics must be taken into account, such as a greater coordination of national research programmes and investments to ensure that Europe has teams and infrastructures ("poles of excellence") that can compete at international-level. In parallel, collaboration between research organisations in the public and private sector across Europe is essential for achieving sufficient critical mass. Other competitiveness factors should not be overlooked, such as adequate metrology, regulations, and intellectual property rights so as to pave the way for industrial innovation to be carried out and lead to competitive advantages, both for large and small- and medium-sized companies. Activities related to education and training are also of great importance; in particular, there is scope in Europe to improve the entrepreneurial character of researchers as well as the production engineers' positive attitude to change. The realisation of true interdisciplinary research in nanotechnology may also require new approaches to education and training for research and industry. Social aspects (such as public information and communication, health and environmental issues, and risk assessment) are further key factors to ensure the responsible development of nanotechnology and that it meets people's expectations. Public and investors' confidence in nanotechnology will be crucial for its long-term development and fruitful application.

***Ezio Andreta***
*Director for Industrial Technologies, Research Directorate-General,*
*European Commission*

## Opening remarks by Ph. Busquin, European Commissioner for Research

NANOSCIENCES ET NANOTECHNOLOGIES :

ELARGIR LA CONNAISSANCE, ENSEMBLE, A LA VEILLE DE L'ELARGISSEMENT DES FRONTIERES DE L'UNION EUROPEENNE

Monsieur le Président,
Monsieur le Maire,
Mesdames et Messieurs,

Tout d'abord, mes félicitations et mes remerciements aux organisateurs, en particulier au Président de la Région Friuli-Venezia, M. Illy, et au Maire de la ville de Trieste, M. Paoletti, pour l'organisation de ce Forum sur un thème aussi essentiel que les nanosciences et les nanotechnologies.
Vous avez devant vous un programme très complet et chargé. En guise d'introduction, je voudrais vous passer quelques messages et réflexions pour vous encourager à continuer à travailler dans ce domaine.
Avec les nanosciences, de nouvelles frontières ont été franchies, offrant un potentiel inédit pour notre société sur différents plans.
L'Europe doit donc saisir pleinement cet enjeu et nous devons être à la pointe du développement technologique.
Ceci est toute la démarche qui se trouve derrière le projet Espace Européen de la Recherche :
- encourager les équipes de recherche à travailler ensemble ;
- concentrer les efforts et les axer sur les grandes priorités ;
- c'est pour cela que la recherche en nanotechnologie doit être reconnue comme une des priorités pour l'Europe. C'est le cas dans le 6ème programme cadre, avec un budget de 1,3 MEuros pour la priotié thématique "Nanosciences et nanotechnologies, matériaux multifonctionnels basés sur la connaissance et nouveaux procédes et dispositifs de production".
Mais, pour faire face à ce défi, nous devons investir davantage dans la recherche, et c'est avec cet objectif que j'ai lancé un Plan d'Action qui vise à atteindre 3% du PNB en investissements recherche d'ici 2010.
C'est un objectif ambitieux mais nous n'avons pas le choix : des mesures et actions doivent être envisagées à tous les niveaux, national, régional, local et européen, pour atteindre cet objectif.
Pour les nanotechnologies, je pense notamment à :
- la nécessité de disposer, à l'échelle européenne, d'infrastructures performantes. Les infrastructures pour faire de la recherche en nanotechnologie sont complexes et coûteuses : nous n'avons donc pas le choix que de le faire ensemble. D'ailleurs, nous avons eu, ici même à Trieste, un débat sur la nécessité d'infrastructures en Europe, qui confirme cette tendance ;

- nous devons nous organiser au niveau européen pour disposer de pôles d'excellence en nano-matériaux, en nano-électronique ou en nano-médicine ;
- nous devons former les jeunes par la recherche : pour valoriser les applications qui résultent de la recherche nanosciences, nous avons besoin de beaucoup plus de scientifiques et d'ingénieurs qui maîtrisent cette science. Cet objectif fait également partie du plan d'action 3%, qui vise à atteindre huit chercheurs sur mille emplois d'ici 2010. Nous en sommes actuellement à 5/1000 ; aux Etats-Unis, 8/1000 et au Japon, 9/1000 ;
- nous avons aussi besoin d'instruments qui facilitent le chemin de l'université à l'industrie : meilleur accès au capital-risque pour stimuler la création de start-up et spinn-off ; des projets intégrés pour combiner, en amont, les connaissances des instituts de recherche et de l'industrie ; des plates-formes technologiques pour identifier les vrais besoins technologiques
- récemment, nous avons lancé une plate-forme technologique pour identifier les besoins et priorités technologiques dans la transformation de la micro- vers la nano-électronique ; accélérer l'adoption d'un brevet communautaire pour mieux se prémunir contre la concurrence accrue venant des Etats-Unis et de l'Asie ;
- enfin, nous ne pouvons pas ignorer la dimension sciences et sociétés. Nous avons besoin des scientifiques qui sachent dialoguer avec la société pour expliquer les nouvelles inventions et leurs applications et pour attirer les jeunes vers les sciences.

C'est dans cet esprit que je vois cette conférence, que je vous souhaite fructueuse, et je suis confiant du point auquel les nanotechnologies sont mobilisatrices pour le XXIème siècle.

***Philippe Busquin***
*Commissaire européen pour la recherche*

# 1. ORAL PRESENTATIONS

## *Session 1 - Nanosciences*

### 2010, Nanospace Odyssey

**H. Kroto**

Sussex Nanoscience and Nanotechnology Centre,
University of Sussex, Brighton, BN1 9QJ UK

As Chemistry and Physics at one borderline and Chemistry and Biology at the other begin to become indistinguishable, multidisciplinary research is leading to the fascinating "new" field of Nanoscience and Nanotechnology (N&N not to be confused with M&M). Ingenious strategies for the creation of molecules with complex exactly-specified structures with function are being developed basically molecules that do things. In fact N&N may be considered "Frontier Chemistry of the 21st Century". When the molecule C60, and its elongated cousins, the carbon nanotubes, were discovered it suddenly became clear that our understanding of the structural factors and the dynamic behaviour of graphite and other sheet materials was limited especially at the nanometer scale. In the Sussex N&N Centre (www.nano.sussex.ac.uk) new experimental vapour and condensed phase approaches, often involving metal cluster catalysis, have led to the production of novel refractory nanostructures. Studies of composites involving these new materials are beginning to exhibit interesting advanced materials behaviour. Fascinating fundamental insights into their formation mechanisms have also been revealed. Possible applications range from civil engineering to electronics promising to transform our economics but if this is to be realised a paradigm shift in synthetic control strategies will be necessary to create really large molecules with accurately defined structures at the atomic level. This presents one of the greatest technical challenges for 21st Century Chemists. From a fundamental research strategy viewpoint it is worth noting the fact that the original C60 discovery experiments were carried out as a consequence of earlier molecular spectroscopy/radioastronomy discoveries relating to material in interstellar space and red giant carbon stars, together with the development major advances in our techniques for studying small refractory clusters.

# Imaging and Manipulation of Matter: The Potential of Self-Assembly

**M. Salmeron**

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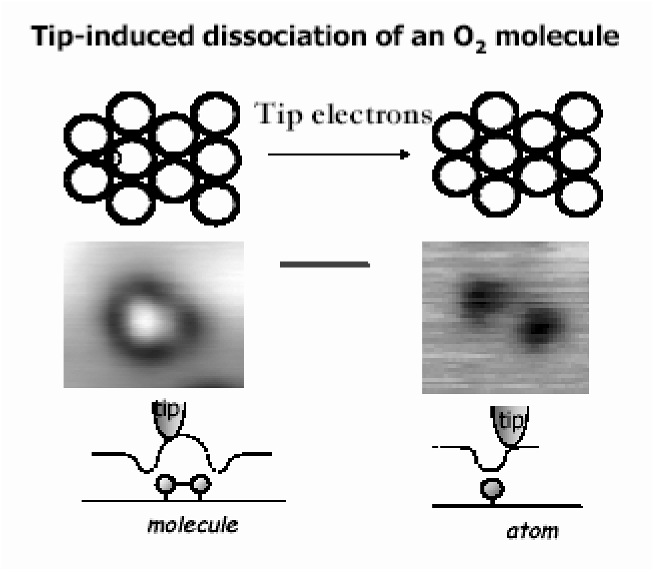
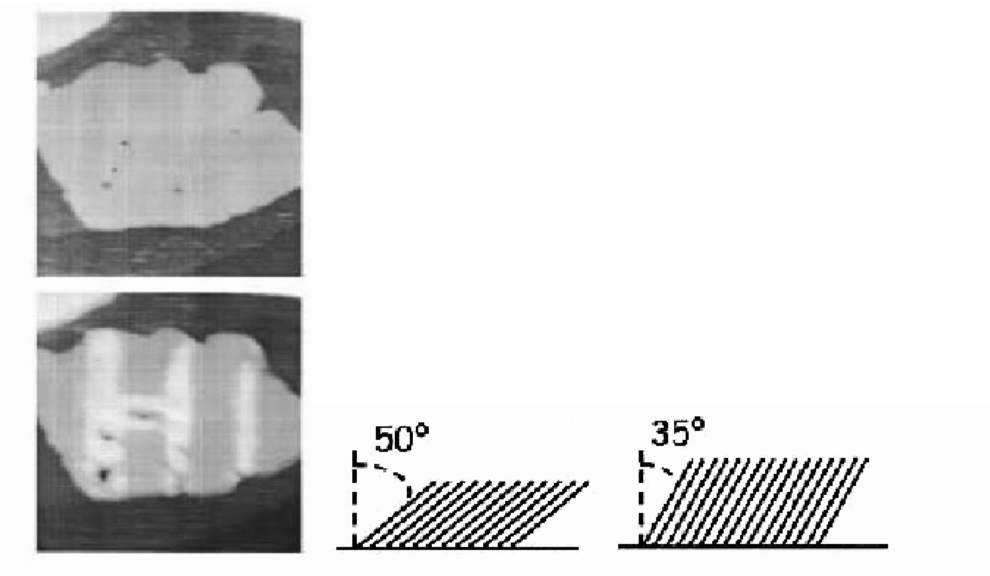
Scanning Probe Methods, including Scanning Tunneling and Atomic Force Microscopy (STM &AFM) have been triggers of the nano-science and nano-technology revolution of our time. These tools make possible the imaging and the manipulation of matter at the level of its most elementary constituent: the atoms and molecules.




Manipulating molecules one by one (moving, exciting, dissociating and causing them to react) occurs by mechanisms that are not yet well understood. The example of the figure in the left shows the intentional dissociation on an oxygen molecule on a Palladium crystal by injecting electrons from the tip. The molecule appears bright in the left image, the two atoms dark in the right. I will review efforts in my laboratory to discover these rules in the case of simple molecules.

I will then review efforts to understand and control the self-assembly of organic molecules such as alkylthiols, alkylsilanes and amines for applications as templates for further development of nanostructures. For example alkylthiols form closely packed layers of nearly upright straight molecules. The height of the film is determined by the tilt angle of the molecules, which is determined by the interlocking of the alkyl chains as they self-assemble. Pressure applied by the AFM tip can be used to change this angle in discrete steps, allowing for example to draw patterns on surfaces. This is illustrated in the example shown in the figure where the top image corresponds to an island with octadecylthiol molecules packed at an angle of 50° from the normal. In the image below it, the tip has applied a threshold pressure in the region of the letters HI, causing the molecules to tilt upwards to a final 30° angle. The manipulation of self-assembled layers by the AFM tip allows also to locally exchange molecules in the film by other molecules present in the solution, forming patters at will that can be used as templates and selective adsorption sites for a variety of biological molecules.



# Nanobiotechnology and its Challenges

**H. Fuchs**

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Nano-Biotechnology exhibits an extremely high potential for the generation of new markets in healthcare, homeland protection and environmental technologies. It targets towards the understanding of the basic physical and chemical mechanisms occurring in biological systems at the molecular scale. In particular, self organizing mechanisms, biomimetic surface modifications and analysis at the molecular scale with respect to topography, chemical composition, mechanical properties and intermolecular interactions are key topics in this field.

Nanoscale Science is strongly driven by Scanning Probe Techniques which allow us to investigate and manipulate individual molecules, thus complementing electron- and ion beam techniques as well as laser spectroscopy. While the imaging capabilities of techniques such as STM, SFM, SNOM etc. dominated the application of these methods at their early development stages, the physics of probe-sample interactions, and the quantitative analysis of elastic, electronic and magnetic surface and transport properties became recently of increasing interest. Force spectroscopy allows us to gain information about folding and unfolding processes of individual protein molecules and other biologically relevant systems. Novel high resolution Near Field Optics enables us to inspect structures and transport phenomena even in living, i.e. biological active systems. Learning from biology, we may find new strategies to design and build up complex self organized systems which do not exist in nature. On this basis also novel synthetic 'bio-inspired' functional materials and systems may be developed.

The University of Muenster and the new Centre for Nanotechnology in Muenster are partners in the Network of Excellence 'Nano2Life' within the 6. Framework programme of the EC.

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## Session 2 - Societal Aspects and Communication

# Nanotechnology: Convergence and Integration

**A. Nordmann**

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As opposed to nuclear technologies, for example, nanotechnology need not be encumbered by the necessities of massive physical containment. It can be embedded at its own scale, its processes and properties held in place not by macroscopic constraints but by neighboring molecules. This is one promise of nanotechnology but also (as in the case of GMOs) a source of public apprehension.
As opposed to large-scale public research investments like the arms race, space conquest, the war on cancer, the Human Genome Project, or AI-research, nanotechnology is not geared to certain, more or less narrowly specified social or political goals. Here, too, the lack of containment serves both as promise and source of apprehension.
Nanotechnology's lack of definition presents a difficulty to policy makers and funding agencies. At the same time it serves them well since the openness of the field energizes researchers across the board, prompting novel interdisciplinary collaborations that could not be planned. Again, this ambivalence is mirrored by an apprehensive public that doesn't know what globalizing effect to fear more - "expensive" nanotechnologies that are controlled by a few governments and multinational corporations, or "cheap" nanotechnologies outside of effective political and social control.
To deal with these ambiguities, further technologies need to be developed. Sheila Jasanoff contrasts "technologies of hubris" and "technologies of humility" for dealing with the risks posed by an uncertain technical future. I propose the development of "technologies of containment" which hover between the heuristic power of hubris and the political requirement of humility. On the side of the research community, these consist of concrete visions about the ways in which properties and processes are to be contextualized (questions of control, retrieval, detection). On the side of policy and funding, these consist of framing social visions for the development of nanotechnology and its convergence with other research agendas (e.g., NBIC convergence, Canada's ecological orientation). On the side of public debate, these consist of debates regarding legitimacy, labeling, ethical codes, regulatory issues, i.e., of "informed dissent" (Jasanoff) regarding the various nanotechnological visions. All these ways of "packaging" nanotechnologies presuppose that the development of nanoscience and -technology, the driving forces behind it, and the cultural shift in the relations of science and society, nature and technology are understood and themselves part of the debate. Indeed, an appreciation of these relations can provide a common language for the proposed technologies of containment and, for example, for the development of a negotiated European approach to the futures of nanotechnology.

# Ethical Implications of Nanotechnology

**G. Hermerén**

Professor, Medical Ethics, Lund University, Lund, Sweden
President, European Group on Ethics in Science and New Technologies, Brussels

Using as a point of departure a number of articles in Science and some other journals, I propose to state and discuss ethical implications of the risk of nanotechnology. In this debate a variety of problems have been discussed, and a first task would seem to identify some of these problems and their relations to each other. What are the prospects and what are the problems? To discuss this it will be necessary to say something about the underlying value-assumptions. I will try to identify some basic values at stake and discuss the consequences of ranking them in different orders. What do we want to achieve, and what do we want to avoid? And which are the obstacles on the way? The ethical implications will be sorted in three main categories, which are not meant to be exhaustive: First, what do we know about the risks at the present, and what conclusions could be drawn from this knowledge (as well as from the present gaps in our knowledge) for the risk-benefit deliberations which are central in this context? Second, given the above, which problems of information concerning risks and risk-benefit assessment will arise in this context, and how should they be handled? Who should inform whom about what when and how? Under what conditions would consent in this situation be free and informed? Thirdly, issues of public acceptance, equity and fairness will finally be briefly addressed. The question of public acceptance is crucial, as we have learnt from the controversy over GM-food. If a technology is expensive, and/or is not generally available, questions about access and financing will arise: who pays and who benefits?

# Societal Aspects of Nanotechnology: Misunderstanding Nanoscience ?

**B. Wynne**

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It has been a repeated response of scientific and policy authorities to expressions of public concern about new technologies, that the cause is 'obviously', public misunderstanding of the science involved. This institutional reflex has over decades prevented intelligent and constructive responses to public concerns about nuclear technology and biotechnology, and it has been maintained as a major form of institutional self-delusion despite copious evidence contradicting this 'deficit model' of public responses to science and technology. Indeed the projection of responsibility for negative reactions as mistaken and falsely founded onto those who express them, has been a constant through many years of experience of such conflicts over important new technologies and the forms of society they bring. This paper will start by reviewing this recent history as a context for the emergence of nanotechnology as an issue facing societal technology assessment. Does Prince Charles statement about the nanosciences potential for producing a world of 'grey goo', either sterile or totally out of human control, resonate with typical public concerns? Is there public concern about nanotechnology? and if there is, should it be laid at the door of public misunderstanding of nanosciences, as if better education would clear up such 'misinformed' concerns?

This technology comes at a time when more participatory modes of TA and risk assessment have been developed across Europe and indeed the world, for dealing with such issues in more robust ways. Despite this broad participatory move encompassing scientific and technical expertise, it has certain key limits and confusions which have not been clarified and treated in policy processes and procedural debates. Two of these are the neglect of innovation and its driving purposes as distinct from consequences and risks as the focus of participatory inputs; and the assumption built into all (p)TA and risk assessment, that prediction of future consequences is the foundational intellectual instrument for TA and management of technological change. I will address both these issues with respect to the key features of nanotechnologies. As Bill Joy, the chief scientist of Sun Microsystems said some years ago, ("Why the Future Doesn't Need us", Wired Magazine, April 2001), in respect of the problems with unpredictable consequences of the biotech revolution, when nanotech intersects with info tech and biotech, "we aint seen nothing yet!". Belief in the possibilities of prediction as a first key step of TA, participatory or not, is recognised by scientists and technologies themselves to be futile with nanotechnology, let alone for its combinations with biotech and infotech.. Especially when the nanoscale imaginable scientific possibilities are intensified by the fervent commercialisation competitive pressures to get things into global markets as fast as possible, traces and lines of causal connection become more and more fluid, unstable and contingent, and thus more difficult to pretend to define.

If this basis for TA or RA is being dissolved and its infeasibility exposed more and more sharply for what it is, then what other basis might there be for societal assessment and decisions about which technological and social trajectories should be pursued and which ones not, or under what conditions and controls? How democratic can this be? I will suggest that the whole philosophy of technology assessment needs to be reconsidered and radically redesigned, making it less vulnerable to illusory prediction as its foundation.

In the final part of this paper I will make some observations which address this question and which place the idea of public misunderstanding of the relevant sciences in a different perspective once one reintroduces the normative idea of democratic control of technology in a globalising world. To give a hint of these observations, the idea of the accountability of scientists involved in innovation research - often in privately controlled research labs - for the imagined human worlds which indirectly inform their basic science, for example the epistemology of reductionism, and of instrumentalism, will be critically examined and questioned. This offers a rather different and perhaps startling perspective on the issue of public understanding of science - is understanding its intellectual contents, or its cultural-institutional foundations the real issue? And if the latter, do scientists themselves understand their science adequately, as a key issue for the responsible development and direction of new technologies?

## *Session 3 - International Co-operation*

# Nanotechnology and Materials Research in Japan

**T. Kishi**

President, National Institute for Materials Science
Vice President, The Science Council of Japan,
Director General, Nanotechnology Researchers Network Center of Japan

Nanotechnology is one of today's most important technology fields, and it is expected to greatly effect on the world in the 21st century. In the Second Science and Technology Basic Plan (2001-2005) drafted by the Council for Science and Technology Policy, the Japanese government emphasized nanotechnology and materials research together with three fields of life science, information technology and environmental science. The nanotechnology and materials science research field is considered to be the key technology for realization of advances in those three fields.

In addition, the Council for Science and Technology Policy has established a project team to promote nanotechnology and materials research and development. Projects involving different government ministries will be carried out in order to foster industrial growth as well as technological progress. At present, projects for a nanodrug delivery system, a nano-scale medical device and innovative structural materials are in the planning stage. A large amount of Japan's national research funds is being invested in nanotechnology projects of the Ministry of Economy and Trade and Industry (METI) and the Ministry of Education, Culture, Sports, Science and Technology (MEXT). Research is being carried out by national research institutes such the National Institute of Materials Science (NIMS), the National Institute of Advanced Industrial Science and Technology (AIST) and the Institute of Physical and Chemical Research (RIKEN) directly, or by the New Energy and Industrial Technology Development Organization (NEDO), the Japan Society for the Promotion of Science (JSPS) and the Japan Science and Technology Agency (JST) through cooperation.

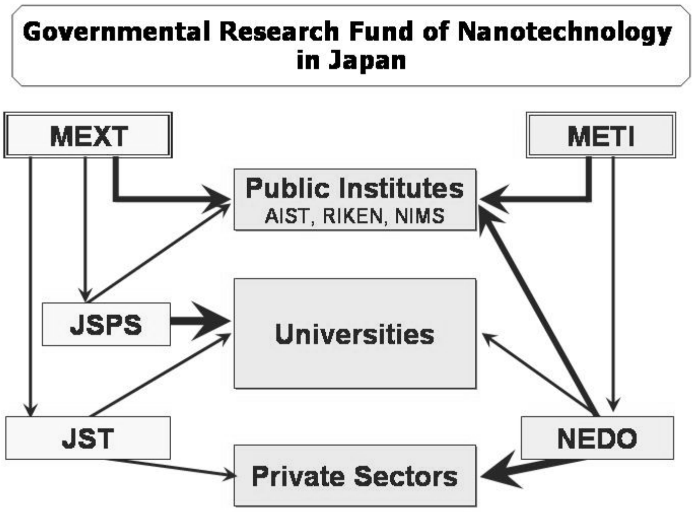


**Figure 1**. Flow of government research fund of nanotechnology in Japan.

An ambitious research project named "Virtual Laboratories" started by JST in 2002 aims at commercialization and industrialization within a time period of 10 to 20 years. NIMS is focusing on materials technology for next-generation information technology as well as technological innovation based on nanotechnology. The goal is to develop new devices needed for an advanced networked information society, including optical devices, optical switching devices, electron wave devices, logic devices and THz devices. Most of this development work is being carried out at the Nanomaterial Laboratory at NIMS.

New ground is being broken in a number of research fields, including nanomaterials for energy and environmental applications, superconducting materials and others. For example, research is underway to create boron nitride nanotubes [1], molecular wire made of nanometer organic molecules and silicon single crystal nanowire. Considerable results have already been achieved in this regard. Japan succeeded in synthesizing the world's first diamond-type photonic crystal as well as developing the world's first nanothermometer [2].

Furthermore, MEXT started a new type of research and development project program, Leading Projects, to support revitalization of Japan's economy. Research and development projects in five fields, including the four fields mentioned above, are now underway for this purpose. Universities, special corporations, independent administrative agencies and private sector enterprises are participating in these projects with an eye to utilization of the projects' research results.

As noted above, nanotechnology is a broad technical area that will have a great impact on the development of life science, information technology and environmental science. For this reason, the construction of a network to enable researchers to exchange and collaborate is very important. In recognition of this, MEXT started its Nanotechnology Support Project in 2002, and the Nanotechnology Researchers Network Center of Japan (Nanonet Center) was subsequently established. The Nanonet Center provides flexible and integrated support for promoting researcher cooperation at universities, national institutes and private sector enterprises with respect to research facilities, information dissemination, workshops, symposiums, etc. Further information about the Nanonet Center can be found at the following URL: http://www.nanonet.go.jp/english/.

In 2001, METI and NEDO started a new nanotechnology program to provide support to industry. The program's 'nanomaterials and processing sub-program' consists of nine projects: four materials-oriented projects (polymer, glass, metal, carbon), three processing-oriented projects (particles, coating, material design), a supporting material metrology project and a project to systemize overall program know-how. A synergistic effect is expected, and this ambitious program is expected to advance nanotechnology development through the integration of different materials research based on a new principle and by looking at materials from the vantage point of atoms and molecules without the constraints associated with conventional materials such as metals, ceramics and polymers.

AIST and the research organizations and private sector enterprises participating in the METI / NEDO nanotechnology program have already achieved some remarkable results. For example, development of a carbon nanotube fuel cell and application research related to FED has progressed rapidly. In addition, since technical development related to carbon nanotube mass production is moving forward, early utilization of this technology is expected. Tie-ups and competition between Japanese companies and overseas companies is advancing remarkably in the carbon nanotube field. Promising results have also emerged from research on nanotechnology glass.

As part of the government's Focus 21 effort, METI and NEDO recently launched several new projects to accelerate greater research and development, especially by private sector enterprises. Several new projects in the nanotechnology and materials field are included as part of Focus 21. Utilization of the technology results from this research is expected within a short time frame of three to five years. Moreover, METI and NEDO are supporting the Nanotechnology Business Creation Initiative launched by the private sector in October 2003. In order to promote nanotechnology, NEDO is also compiling a mailing list and organizing international conferences, such as nanotech2003 and nanotech2004 (http://www.ics-inc.co.jp/nanotech/index_e.html), to disseminate information related to nanotechnology programs and project results.

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# Nanotechnology Research in Russia

**M. V. Kovalchuk**

Member of the Russian Academy of Sciences, Scientific Secretary of the Council of Science and High Technologies under the President of the Russian Federation, Director of the Institute of Synchrotron Radiation Researchers, Director of the Institute of Crystallography, Russia

<u>Specific features of Science today:</u>
- From Micro to Nano
- Combination of inorganic and organic technology
- Multidisciplinarity

• New materials – main priority for scientific development

• "The Main Principles for Science and Technologies development of Russian Federation till 2010 and future", signed by the President of Russia, is the basic programme in the field of science in Russia

• List of critical technoliogies includes various nanotechnologies:

Materials for micro and nanoelectronics, microsystem technique, synthetis super-hard materials, nanometric technologies of processing, controle, assembling. Element basis of micro- and nanoelectronics, quantum computers.

• Twelve Ministries and State agencies are engaged in the field of nanoscience and nanotechnology

• Main lines of nowadays activity in Russia:

1. "Routine"(existing) soloid state microelectronic development to nanoscale
2. Devlopment of new nanoelectronic devices with the combination of present electronic technology and new nanoelements.
3. Micromechanics,
4. New nanomaterials, nanoelements, and nanosystems (*powders, composites, carbon tubes, fullerfens etc.).
5. Nanobioorganic materials and systems.
6. Nanobiotechnology: self assembly, drug design and delivery, bioengineering, capsulation, 3-d and 2-d protein crystallization in labs and space (microgravity).
7. Nanodiagnostics and nanotools.

Examples of achievements of nanoscience and nanotechnology from many Russian research and industrial organizations.

Closing remarks about the new stage of the research organization in the globalizing world: from clusters to networks.

# Nanotechnology in USA and an International Perspective

**M.C. Roco**

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Nanotechnology has opened an era of scientific convergence and technological integration with the promise of broad societal implications. The National Nanotechnology Initiative (NNI) is a long-term visionary program announced in January 2000 that coordinates 16 departments and independent agencies with a total budget of $850 million in fiscal year 2004. The federal government nanotechnology investment per agency since the beginning of NNI is given in Table 1.

**Table 1.** Contribution of key Federal departments and agencies to NNI investment (each Fiscal Year (FY) begins on October 1 of the previous year and end on September 30 of the respective year)

| Federal Department or Agency | FY 2000 Actual ($M) | FY 2001 Actual ($M) | FY 2002 Actual ($M) | FY 2003 Plan ($M) | FY 2004 Request ($M) |
|---|---|---|---|---|---|
| National Science Foundation (NSF) | 97 | 150 | 204 | 221 | 249 |
| Department of Defense (DOD) | 70 | 125 | 224 | 243 | 222 |
| Department of Energy (DOE) | 58 | 88 | 89 | 133 | 197 |
| National Institutes of Health (NIH) | 32 | 40 | 59 | 65 | 70 |
| National Institute of Standards and technology (NIST) | 8 | 33 | 77 | 66 | 62 |
| National Aeronautics and Space Administration (NASA) | 5 | 22 | 35 | 33 | 31 |
| Environmental Protection Agency (EPA) | - | 6 | 6 | 5 | 5 |
| Homeland Security (TSA) | - | - | 2 | 2 | 2 |
| Department of Agriculture (USDA) | - | 1.5 | 0 | 1 | 10 |
| Department of Justice (DOJ) | - | 1.4 | 1 | 1 | 1 |
| **TOTAL** (% of 2000) | **270** (100%) | **465** (172%) | **697** (258%) | **770** (287%) | **849** (314%) |

As government investments worldwide has reached $3 billion, higher expectations of nanotechnology R&D results, commercialization of new products, and concerns about unexpected societal implications are raised and need to be answered to the public's satisfaction. Nanotechnology has evolved into a field of broad international interest, increasing collaboration and stimulating competition. In 2003, the worldwide government investment in nanotechnology, in part stimulated by NNI, has a sevenfold increase as compared to about $430 million in 1997 (Table 2).

**Table 2.** Estimated government nanotechnology R&D expenditures in 1997-2003 (in $ millions/year). Explanatory notes: "W. Europe" includes countries in EU and Switzerland; the rate of exchange $1 = 1.1 Euro until 2002; and $1 = 0.85 Euro in 2003; Japan rate of exchange $1 = 120 yen in 2002; "Others" include Australia, Canada, China, Eastern Europe, FSU, Israel, Korea, Singapore, Taiwan and other countries with nanotechnology R&D; ( )* A financial year begins in USA on October 1 of the previous calendar year, six months before in most other countries. ( )** denotes the actual budget recorded at the end of the respective fiscal year. Estimates use the nanotechnology definition as defined in the NNI (this definition does not include MEMS), and include the publicly reported government spending.

| Region | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 |
|---|---|---|---|---|---|---|---|
| **W. Europe** | **126** | **151** | **179** | **200** | **~ 225** | **~ 400** | **~ 700** |
| **Japan** | **120** | **135** | **157** | **245** | **~ 465** | **~ 720** | **~ 800** |
| **USA*** | **116** | **190** | **255** | **270** | **465**** | **697**** | **770** |
| **Others** | **70** | **83** | **96** | **110** | **~ 380** | **~ 550** | **~ 800** |
| **Total (% of 1997)** | **432** (100%) | **559** (129%) | **687** (159%) | **825** (191%) | **1,535** (355%) | **2,367** (547%) | **3,070** (710%) |

An overview of the main research and development themes, outcomes in the first three years of the initiative, and plans for the future is presented.

- Research is advancing towards systematic control of matter at the nanoscale faster than envisioned in 2000, when NNI was introduced with words like "Imagine what could be done . . . 20-30 years from now." After three years, in 2003, the NNI supports about 2,500 active awards in about 300 academic organizations and about 200 small businesses and non-profit organizations in all 50 states. The time of reaching commercial prototypes has been reduced by at least of factor of two for key applications such as detection of cancer, molecular electronics, and special nanocomposites. A good indicator for publications is provided by searching the "high impact papers" of the Institute for Scientific Information, Inc. About 50% of the highly cited articles (citations after two years) in the most recent search (using nano* in the title of the respective articles) originate from the US.
- Systemic changes are in preparation for education, by earlier introduction of nanoscience and reversing the "pyramid of science" with understanding of the unity of nature at the nanoscale from the beginning. In 2002, NSF announced the nanotechnology undergraduate education program, and in 2003, the nanotechnology high school education program. In the next years, we plan to change the language of science even earlier and involve science museums to seed that language to K-12 students. About 7,000 students and teachers have been trained in 2003 with NSF support. All major science and engineering colleges in US have introduced
- Significant infrastructure has been established in over 60 universities with nanotechnology user capabilities. Five networks (Network for Computational Nanotechnology, National Nanotechnology Infrastructure Network, Oklahoma Network for Nanotechnology, the DOE large facilities network, and the NASA nanotechnology academic centers) have been established.
- Industry investment has reached about the same level of investment as the NNI in the medium and long-term R&D, and almost all major companies in traditional and emerging fields have nanotechnology groups at least to survey the competition. For example, Intel has

reported $20 billion revenues from nanotechnology in 2003. About 75% of patents (about 6,400 of 8,500) related to nanotechnology as recorded by the US Patent and Trade Office in 2002 are from US while the NNI funding is about 25% of the world government investment (about $0.77B of $3.0B). About 75% of startup companies in nanotechnology in second part of 2003 are in US (about 1100 of 1500 worldwide, according to NanoBusiness Alliance). Despite the general economic downturn, nanotechnology venture funding in US doubled in 2002 as compared to 2001, and in US there are more start-up companies than all other countries combined. The NNI needs to further encourage small businesses. For example, NSF supported more than 100 small businesses with an investment of $36 million between 2001 and 2003.
- Societal implications were addressed from the start of the NNI, beginning with the first research and education program on environmental and societal implications, issued by NSF in July 2000. In September 2000, the report on "Societal Implications of Nanoscience and Nanotechnology" was issued. Today, in 2003, the number of projects in the area has grown significantly, funded by NSF, EPA, NIH, DOE and other agencies. Awareness of potential unexpected consequences of nanotechnology has increased, and Federal agencies meet periodically to discuss those issues.

One should not sidetrack the efforts for sustainable development by delaying or halting the creation of new knowledge in nanoscale science and engineering. At the international "Nanotech 2003 and Future" conference in Japan on February 26, 2003, during the keynote address, I made an appeal to researchers and funding organizations "to take timely and responsible advantage of the new technology for economic and sustainable development, to initiate societal implications studies from the beginning of the nanotechnology programs, and to communicate effectively the goals and potential risks with research users and the public" (Roco, J. Nanoparticle Research, Kluwer Academic Publ., Issue 3-4, August 2003). Since then, contacts on this topic have been established with representatives from EC, APEC, Switzerland, UK, Taiwan, China, Australia, and other countries. International collaboration is necessary in a field that does not have borders, where the products are sold internationally, and the health and environmental aspects are of general interest.

New NNI priorities are envisioned in exploratory research for nanomedicine, energy conversion, food and agriculture, realistic simulations at the nanoscale, molecular nanosystems, and improving human performance. Transiting to technological innovation will accelerate for nanostructured materials, nanoelectronics, catalysts, and pharmaceuticals, development of tools. Emphasize will continue on advancement of societal goals such as education and sustainable development. The convergence of scientific disciplines is reflected in a series of new education concepts. Broader societal implications, including the legal aspects, must be addressed with anticipatory measures.

Nanotechnology has opened an era of scientific convergence and technological integration with the promise of broad societal implications. The National Nanotechnology Initiative (NNI) is a long-term visionary program announced in January 2000 that coordinates 16 departments and independent agencies with a total budget of $850 million in fiscal year 2004. As government investments worldwide approach $3 billion, higher expectations of nanotechnology R&D results, commercialization of new products, and concerns about unexpected societal implications are raised and need to be answered to the public's satisfaction. Nanotechnology has evolved into a field of broad international interest, increasing collaboration and stimulating competition.

An overview of the main research and development themes, outcomes in the first three years of the initiative, and plans for the future will be presented. New NNI priorities are envisioned in exploratory research for nanomedicine, energy conversion, food and agriculture, realistic simulations at the nanoscale, molecular nanosystems, and improving human performance. Transiting to technological innovation will continue for nanostructured materials, nanoelectronics, catalysts, and pharmaceuticals, development of tools. Emphasize will continue on advancement of societal goals such as education and sustainable development. The convergence of scientific disciplines is reflected in a series of new education concepts. Broader societal implications, including the legal aspects, will be discussed.

# Nanosciences and Nanotechnologies in the European Union Sixth Framework Programme for Research and Technological Development

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*Key words: nanotechnology, nanosciences, nanotechnologies, European research, Sixth Framework Programme, international co-operation, industrial research, revitalising European economy, responsible research*

Progress in science, technology and industrial innovation introduces important changes in our daily life more and more rapidly, with great advantages and unexpected challenges. Together with the development and introduction of new technologies, globalisation is having a multiplying effect, boosting dynamism and potential.

Nanotechnology is nowadays probably the greatest scientific and technological challenge in terms of science, engineering, approach to production, skills demanded, expected benefits and impact on society. Materials sciences and nanotechnology allow us now to go one big step further, adding added value and "intelligence" to materials, components and systems. This will offer tools for shifting from a production-oriented approach to a use-and-performance-driven industrial sustainable society.

To pass from a "macro-"or "microcentric" approach to a "nanocentric" one, we need a vast multidisciplinary knowledge, a strong ability of integration and a positive attitude to complexity. We need to leave rigid and pre-determined schemes and the ability to develop new excellence in research and education, also through new study courses and curricula vitae.

Europe has a leading role in several nanotechnology-related domains, in particular in areas with long-term applications and very high technological risks. Public funds devoted to research in Europe come from the Member States and from the European Union (via the "Framework Programmes"). Although less in funding, the research funded by the Union plays a pilot role and acts as catalyst of a much larger critical mass.

The EU Framework Programmes (FP) had dedicated funds to nanotechnology already in FP4 and FP5, and significant progress has been achieved. In the case of the 6$^{th}$ Framework Programme (period: 2003-2006), nanosciences and nanotechnologies are a priority, and the role played by the EU research is proportionally of paramount importance here. The aim is to create a favourable ground for the development of nanosciences and nanotechnologies in Europe in order to benefit to the quality of life of citizens and to the European society as a whole, in particular for strengthening the scientific and technological bases of Community industry and encouraging it to become more competitive at international level, as stated in Article 163 of the Treaty.

Nanotechnology is an important subject in the creation and implementation of the ERA and will on the other hand greatly benefit from it. The 6$^{th}$ Framework Programme has been tailored to help better structure European research and to cope with the strategic objectives set out by the European Heads of State and Governments in Lisbon in 2000. The commitment is clear: a sustainable development.

There are many barriers and challenges. A large critical mass is required in terms of both human and material resources, also to be reached at wide international level. This implies a new way of co-operation being more open, reinforced, transparent and verifiable. More knowledge means more power. More power demands more responsibility. The potential offered by control at the nano-level must be matched by an appropriate analysis and control of the possible risks. The education of the new players should be underpinned by a sound ethical consciousness and by responsible attitude.

Europe does not plan to go alone. In order to gather the critical mass so to achieve the goals more effectively and more rapidly, the 6$^{th}$ Framework Programme is open to international co-operation. Researchers from virtually all Countries of the world can participate. Reinforced co-operation is enforced with those Countries which have a bilateral scientific/technical agreement incorporating materials sciences and nanotechnology.

These pages do not represent any commitment on behalf of the European Commission. Please refer to official documents or see http://europa.eu.int/comm/research/fp6/index_en.html; http://www.cordis.lu/fp6 and http://www.cordis.lu/nanotechnology.

## Session 4 - Accession Countries and Associated States

# State-of-the-Art of Nanotechnology in the Candidate Countries

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Nanoforum coordinator
http://www.nanoforum.org/

The EU Summit in October 2002 endorsed the Commission's findings that 10 candidate countries (Cyprus, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia) fulfil the political criteria for membership while for Bulgaria and Romania the target for accession is 2007. Negotiations for Turkey’s accession have yet to commence.

Although the R&D status of the candidate countries lags somewhat behind that of most of the current member states it is certain that scientific research is one of the areas where enlargement will offer the greatest potential benefits – both to the Member States and to the candidate countries. (Science in Slovenia, 2002).

European Commissioner Philippe Busquin and the responsible ministers from the EU´s candidate countries signed an association agreement for the Sixth Framework Programme (FP6) on 29 October 2002 which gives to the candidate countries for the first time the same entitlements as Member States. To encourage participation contributions from the candidate countries have been reduced during the first two years.

Nanotechnology will play a prominent role in strengthening the R&D collaborations between established EU member states and the candidate countries, due not only to its potential for alerting the face of manufacturing but also as a result of the dedication of thematic area 3 of the Sixth EU framework programme for RTD (FP6) to nanotechnology, materials and production technologies.

This paper based on a Report published by Nanoforum, a pan-European network in Nanotechnology funded under the EU will present an overview of the state of Nanotechnology in the candidate countries, which will join the EU in 2004 or later. The report was originally published for distribution at the first of a series of Nanoforum workshops dedicated to strengthening the European nanoscience and nanotechnology base which was held in Romania in October 2003 and is available for download from the Nanoforum website www.nanoforum.org.

The report gives an overview of EU initiatives to foster EU-Candidate country collaborations in the area of nanotechnology followed by an outline of the status quo for each country dealing with strategic priorities and national specialities in nanotechnology in the country, and highlighting the key players in government, research and industry working on nanotechnology. There are many different models for how the candidate countries deal with Nanotechnology.

An analysis of the expressions of interest (Cordis) for Priority Three 3 (Nanotechnologies and nanosciences, knowledge-based multifunctional materials and new production processes and devices) shows that several of the candidate countries feature including Poland (9%) and Turkey (4%). Governments and research communities in the candidate countries are beginning to emphasise the strategic importance of nanotechnology for their national economy and RTD scene. Most countries include nanotechnology or nanostructured materials among their national research priorities.

This paper gives an overview of the main research centres, universities and companies involved in nanotechnology research and product development, and highlights regional examples of government strategies and national programmes or centres of excellence including: the Bulgarian National Centre on Nanotechnology, the Czech Republic Foresight exercise, the Estonian Research and Development Strategy 2001-2006 “Knowledge Based Estonia”, the Polish High Pressure Research Centre and nanotechnology networks, the Institute of Microtechnologies in Romania, the NanoSMART Centre of Excellence in nanomaterials in Slovakia and the SINANO network in Slovenia.

# Nanotechnology in Slovenia

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Scientific research and development activity is one of the main political priorities for the economic and social progress of Slovenia. In 2001, Slovenian gross domestic expenditure on R&D (GERD) amounted to 1.51 % of the national GDP, which is relatively close to the EU average and leading among the EU candidate countries. Slovenian future strategic objective is to increase the share of funds intended for science so that total investment should reach the EU strategic goal of 3% of GDP for R&D and innovation. Main strengths of Slovenian research and development are a relatively high share of GDP invested in R&D, well-established international scientific cooperation and a relatively high number of researchers.
Slovenia co-operates in science and technology with more than 75 countries worldwide. It has joined the FP5 formally in August 1999 and has average success rate 30% regarding participation. The results in FP5 are comparable to EU average participation. The first estimation of the participations in the calls of FP6 indicates that Slovenia is also well prepared for the current Framework Programme.

As in the most technologically oriented countries the Slovenian economy is aiming at being based on knowledge and new technologies. Slovenian national research programme is therefore an integral part of the national development strategy. Up to now, nanoscience or nanotechnology is not explicitly mentioned among the priority research fields. We believe that this will change in a new National Research Programme, which is in a process of adoption.

There are several of excellent research teams working in the field of nanotechnology at the national research institutes (e.g. National Institute of Chemistry, Jozef Stefan Institute, Institute of metals and technology) as well as at institutions of higher education (e.g. University of Ljubljana, University of Maribor and Nova Gorica Polytechnic). Examples of the outstanding nanoscience and nanotechnology are in the fields of novel nanostructures (eg nanotubes and nanowires), nanomaterials with exciting functional properties (eg field emission, lithium storage), nanoelectronics, nanobiotechnology and some applications in areas such as health, environment and energy. Some small and medium size companies are starting to use or are developing the knowledge in the fields of nanostructured materials and nanoelectronics.

Nanotechnology is promoted in Slovenia through many activities. Slovenian network on nanotechnology SINANO has been established in 2001 in order to build a critical mass, contribute to advancing knowledge and provide access to infrastructure for the researchers in the academia working in the field of nanoscience and nanotechnology.
A symposium on new achievements in science and technology of nanomaterials – SLONANO was successfully started in 2002. Also in 2003 SLONANO symposium has demonstrated the recent achievements of Slovenian researchers and promoted the benefit of nanotechnologies for the industrial sector. Recently the initiative to form a multi regional centre of excellence in Slovenia in the field of nanotechnology has been launched with the

objective to form an innovation platform. The network should better connect academic institutions with industry, develop further the research infrastructure and help building an economy based on new technologies and innovation.

In summary, in Slovenia there are several excellent research teams working in the field of nanoscience and nanotechnology that are well connected to some of the best research groups worldwide. A further upgrade in research infrastructure and a good link of academic researches to the innovative industry will enable a further progress in the fast developing field of nanotechnology in Slovenia.

# Nanotechnology in Switzerland: the Results of Promoting Science, Technology and Innovation for More than Ten Years

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Nanoscience and Nanotechnology in Switzerland were started well before an international wave even began to bring research and development in this field.

It materialized with the invention of the STM in 1981 by Binnig and Rohrer at the IBM Research Laboratory in Rüschlikon. Shortly after followed the setting up of STMs and later AFMs in most of the Swiss Universities – and individual financial support from SNF and CTI was given. The first joint effort within the NRPs (National Research Programs) was the supplement to NRP 24 (Chemistry and Physics of Surfaces), followed by NRP 36 (Nanoscience) and the Swiss Priority Program, MINAST (Micro- and Nanosystems). Parallel to TOP NANO 21 a NCCR (National Center of Competence in Research for Nanoscale Science) has been created. Today, Switzerland is very well positioned in the international area of Nanoscience and -technology. There is no doubt that the scale of the nanometer has also entered Swiss industry and the application Nanotechnology is rapidly gaining significance.

The Technology oriented Program (TOP NANO 21), an initiative of the ETH-Board, implemented by the Commission for Innovation and Technology (CTI) focused on four topics: 1. Extending the scientific horizon to include the relevant sectors at the research centres and consolidating the awareness of technology. 2. Strengthening the Swiss economy through the development and application of new technologies based on the NANOMETER. 3. Integrating the subject of the NANOMETER in teaching. 4. Encouraging preparations for the founding of new companies.

To make use of Nanotechnology in industry, the Nano Innovation System was developed. It includes complementary activities for the commercial exploitation of new scientific findings and set the ground for industry to implement Nanotechnologies in innovations.

The three major elements of framework (Figure 1) are:

Frame work conditions
Transfer factors
Enterprises as innovation dynamo.

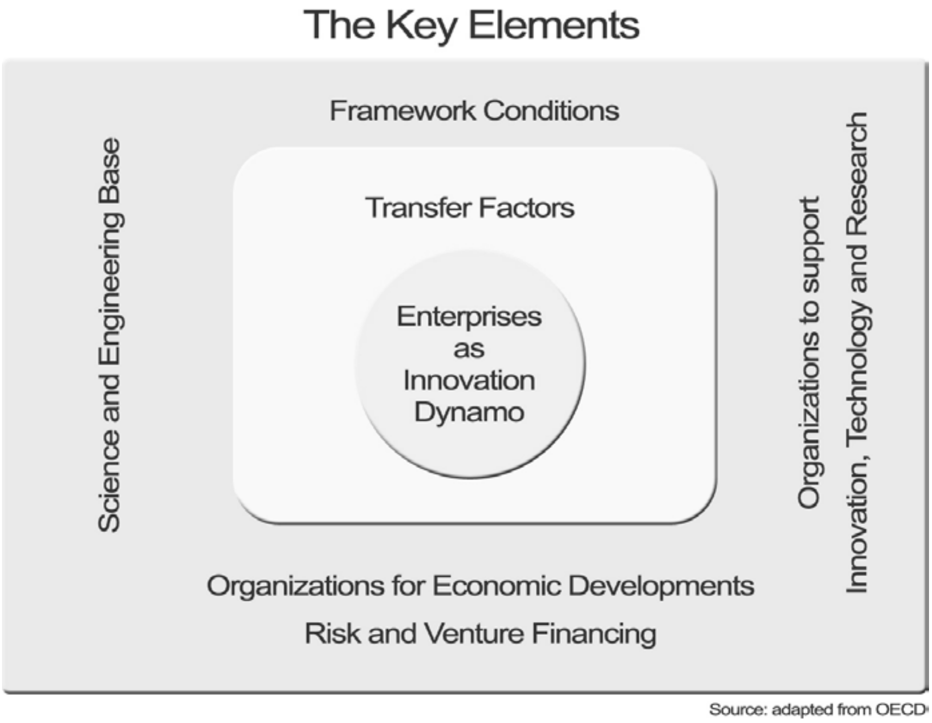


**Figure 1**. Swiss Nano Innovation System.

## 1. The framework conditions

The framework conditions comprise the research and public education settings, the funding organizations in science, technology and innovation support, and local development agencies, together with companies providing seed, risk and venture capital.

In a first phase of the program we motivated the researchers in academia to promote their findings towards the industry and to communicate them as untouched potential for products with new functionalities and new processes. These findings were the results of preceding funding programs and national activities such as the NFP 36, the MINAST program and other programs.

In the second phase we set a higher priority to fund fundamental research projects and put the focus on the extension of the scientific horizon. We identified the needs for addressing knowledge deficits that revealed themselves in practical applications. Here, we support the enterprises by providing the basis for a profound understanding of production processes and laying the ground for functional and safe products. This trade of existing knowledge on one hand with the continuous contribution of new challenges from industry was one of the key factors (
Figure *2*) for success in the program. It was the unbroken link between university and industry and the willingness of research to address fundamental questions arising from applied technology in industry. The innovation committee was the key element for the stimulation of sustainable developments and innovations. Visionary entrepreneurs and outstanding scientists together have raised ideas for pioneering applications of nanotechnologies, which are currently realized in common projects. These projects are known for their interdisciplinary approach, and for their exceptional and sustainable results.

Research and education in the nanometer domain: TOP NANO 21 supported the enrichment of existing and the creation of new education related activities on the level of:
Universities and ETH's
Universities of Applied Sciences
Schools for professional education

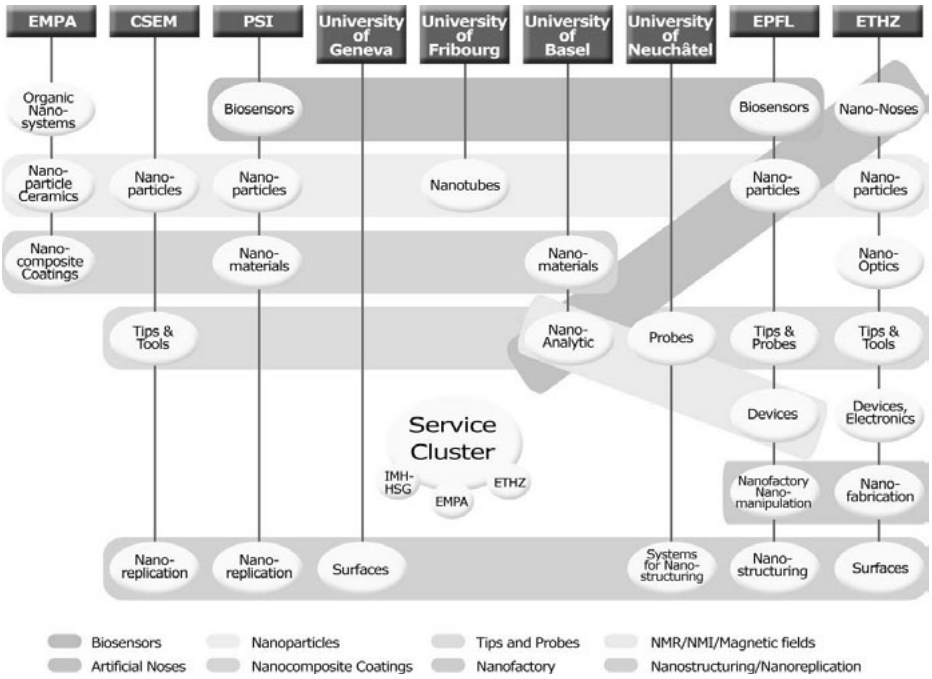


**Figure 2.** Clusters of competence.

Thus, the programs set the cornerstones for any successful knowledge and know how transfer from academic research into industry: a.) At the university level the program actively supported PhD students and motivated university graduates to embark upon a PhD study. b). On the level of the University of Applied Science we encouraged and assisted the creation of a nano platform with the goal to develop national teaching courses in nanotechnologies on this education level. c.) Vocation specific modules at the schools for professional education aim at acquainting going-to-be professionals with the analytical tools in the nanometer dimension and addressing them with new processes for applied nanotechnology.

## 2. The transfer factors (Figure 2)

These factors enable the bridging of science and economy. Unleashed potential is visualized and catches the attention of enterprises, networks and associations. A key factor of success is hereby the creation of a genuine risk culture embracing experiment and feasibility tests.
Industry-specific seminars: As cross-section discipline the nanotechnologies will penetrate all industries. Depending upon industry different questions are raised. However, within a sector the questions are often quite similar and can be commonly solved in the pre-competitive stage. For this reason special attention was given to the mobilization of industries. In the context of the industry-specific seminars selected scientists informed the entrepreneurs about

new scientific findings and potentials of nanotechnologies. In the sense of the interaction of science and economy, the entrepreneurs have reported about their current and future tasks.
Strategic talks (
Figure *3*): The competitive ability of enterprises strongly depends on their innovation ability. The concrete potentials of Nanotechnology for an enterprise can be compiled efficiently and confidentially by individual discussions with specialists from science and technology. In many enterprises these talks led to the initial steps in nanotechnology.

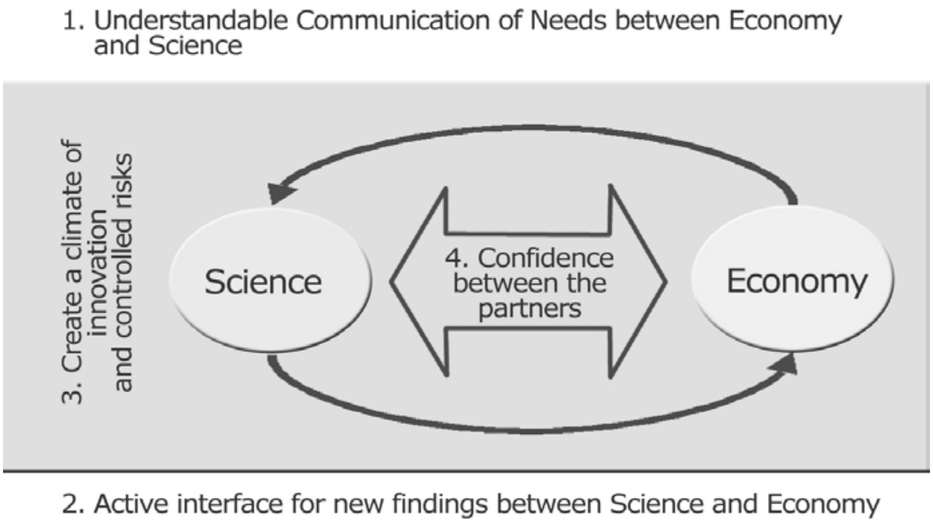


**Figure 3**. The Bridge between Science and Economy.

The transparency over all activities supports the dissemination of results and best practices: The TOP NANO 21 website: www.ethrat.ch/topnano21, with all information to the program and its activities; The Annual report including all granted projects and their results; The News Ticker with selected information from the national and international Nano community.

### 3. Enterprises as innovation dynamo

Enterprises play a key role to enable innovations. They are the innovation carrier and implement research results in products, processes and services. Figure 4 shows an actual picture of the Swiss Nano business sector.

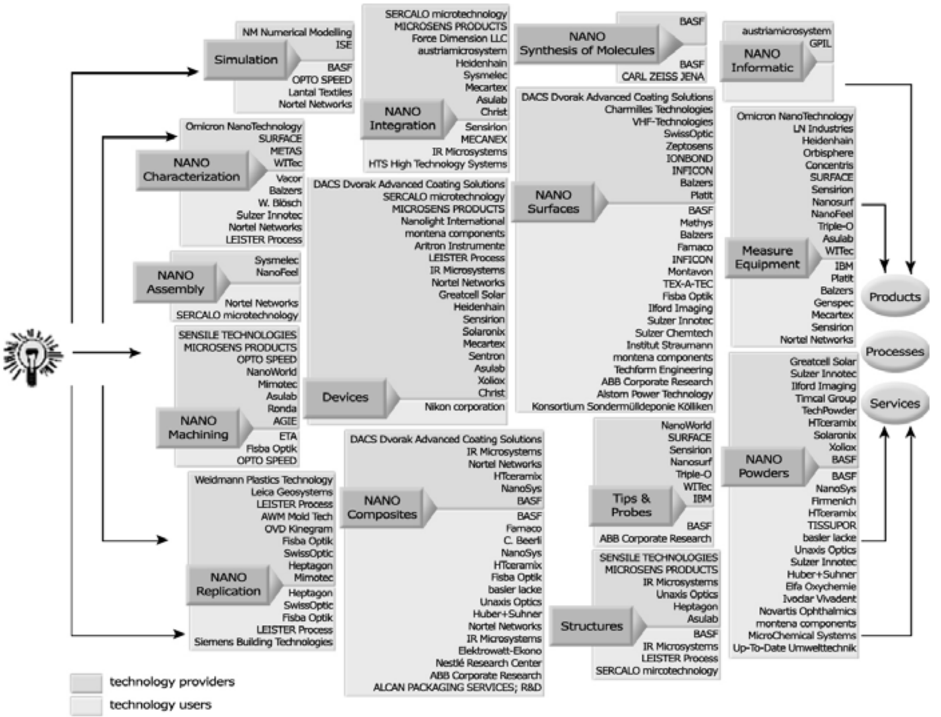


**Figure 4**. Swiss Nano Business Sector.

## 4. Outlook

New funding programs have been initiated to continue the success story of TOP NANO 21. Since the beginning of this year the CTI domain Nanotechnologies and Microsystems ensures a continuous transition of TOP NANO 21 to the well-established CTI approach (www.bbt.admin.ch).

In parallel the NCCR Nanoscale science with the leading house University of Basle, Prof. H.-J. Güntherodt will ensure the continuous basic science research (www.nanoscience.unibas.ch/nccr).

On the international level, many Swiss research centers are partners in IP's and NoE of the FP6.

## *Session 5 - Education and Training*

# New Roles and Challenges for the Universities

**V. Bayot**

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Education and training are the roots of our developed societies and, in this particular framework, of our rapidly developing technology-based industries. You can put as much money as you want in research and development, ideas from smart and well trained people are mandatory to get anything worth out of it. These are well known statements which are so obvious that everybody agrees with, and our educational systems are supposed to take care of that. So, what is so special about educational needs for nanotechnologies that we would have to question ourselves about the adequacy of traditional education for efficient nano-training? After all, most of us followed well established academic tracks and we surely feel some satisfaction of the work done. Nanosciences and nanotechnologies have been booming for years thanks to physicists, chemists, biologists, material scientists, that came out of the regular academic system where students follow specific tracks that fit the traditional scientific disciplines. Why should we worry about the future of nanotechnologies in terms of education and training, and not just government funding and technology transfer?

The problem is two-fold: 1) provide the type of education that fit best specific needs of nanotechnologies, and 2) get as many good students as possible to provide the required workforce. Let's try to identify the specificities and suggest possible solutions.

Nanotechnologies are different. The traditional disciplines are merging together in terms of characteristic dimensions and this shared playground is where nanotechnologies develop. Nanosciences and nanotechnologies are at the crossroads of the traditional disciplines and that's probably what makes nanotech so attractive and promising for future scientific and technological breakthroughs. If we want to make it happen, we need to optimize our educational approach so that coming scientists will be best trained to efficiently explore this new world. But what are the issues raised by the converging traditional disciplines?

First of all, we have to recognize that scientists from different disciplines have developed specific ways of talking about what they are studying. As a physicist, when I meet chemists or biologists, it takes me quite a while before I can understand a fraction of what they are talking about - and there eyes tell me it is largely reciprocal. But that's not just a question of terminology. The way of approaching things are different; different concepts as well as the way to deal with complexity put a frontier between us. Since the most promising developments of nanosciences and nanotechnologies probably reside in multi-disciplinary studies where, for example, the sharp tools developed by physicists are used to explore unresolved biological questions, or serve as the background for biological sensors, this frontier needs to be lowered, drastically. A background education in all main scientific disciplines is hence necessary, including ethical aspects. I do not mean eliminating specialists, which we obviously need to bring some valuable input, but providing a reasonable background education in all disciplines that would introduce concepts, terminologies and main scientific knowledge, all in view of enabling fruitful interactions with other-side specialists and address societal issues.

When you take a look at recent breakthroughs in nanotechnologies, it is clear that a large fraction of them come out of close collaborations between scientists originating from different departments. When I read whatever "nano-news" I often say to myself: why did nobody told this was a major unsolved question in biology or chemistry? or: I didn't know that biologists or chemists could help finding that physicist "Holy Grail". The ability to collaborate and to brain-storm with specialists of other disciplines is, and will be more and more, a key skill for unveiling nano-jewels. Beyond lowering the frontiers mentioned above, it is a specific skill to develop which will also have a positive impact on building a positive global society and strengthening European spirit. Favouring collaborative skills is more a question teaching methodology and group-based learning where students question and teach each other. It is already in place in many institutions - including the one I am affiliated to, and is a proven efficient way to reach that goal. Implementing that methodology shouldn't be detrimental to scientific content.

A third aspect, not specific to nanotechnologies but more critical given the multi-disciplinary approach involved, is the effectiveness to solve problems, and more than that, in more and more complex situations in a rapidly accelerating technological development. In addition to the multi-disciplinary and collaborative skills, it requires live-long learning and problem solving strategies. These points must also be addressed by the educational system if we want the next generations to "ask the good questions and find the good answers". Again, educational strategies exist that develop these skills; they are called project based learning and problem based learning and are already in place in some institutions. My personal experience of these approaches is very positive. They tend to increase very substantially the motivation of students. In that framework, it is of course a good idea to place some multi-disciplinary projects after enough background is in place. Cross-departmental project-based courses that put together students with different backgrounds is a way to achieve the goal.

Nanotechnologies are mostly experimental sciences, and education should fit that characteristic by providing "hands-on" projects so that students can experience real "lab" life. Since nanotechs are strongly multi-disciplinary, this point raises the issue of research environments that should offer such multi-disciplinary hands-on opportunities. For both research and education needs, research entities should match the specific need of nanotechs: multi-disciplinarity. This means bringing specialists from basic disciplines and engineering to share common facilities. In addition to virtual networks at national, European and worldwide levels, local multi-disciplinary entities are mandatory for day-to-day research where scientists from different disciplines build things together. The organisation of research entities should probably be organized with a fractal-like structure that would unable most efficient interactions at all levels. By the way, by means of strong local interactions, it would bring new complementary skilled scientists to nanoscience and nanotechnologies. This is another important way of solving the workforce issue.

It is nice to develop well thought multi-disciplinary problem-based learning courses, but attracting students to take them is crucial, at least for the purpose we are pursuing. From my experience, nanotechs are very attractive for young people. Not only because the speaker is usually very excited himself - even though it surely plays a role -, but the results are usually very "beautiful" and, probably because it is a relatively recent discipline, easier to explain than the very last developments of a very focused and research field. I would recommend taking nanotechs out of the labs and showing them to high school students, as well as taking teens to the labs. This is also at least as important to do with first years undergrads; and why not putting them at work on nanotechnology oriented problem-based or project-based learning ? When you have convinced them of the interest of nanotechnologies, it remains to set up attractive final-years programs with strong and adaptative nanoscience and nanotechnology multi-disciplinary contents. Academics have usually strong inertia, but the bachelor-master-thesis system to be setup in Europe is probably a good opportunity to introduce new master degrees oriented toward new challenges.

What is above intends to address the needs of the 15-25. But they are surely not the only ones to consider. For the older, live-long training is essential to keep on track in such a rapidly moving field. This is also particularly important for decision makers that are usually in the second-half of their careers, and hence a bit far from university classrooms. Education to other disciplines is again essential. There is definitely room for more summer schools, training courses and seminars that would take care of the specificities of nanotechnologies.

If it were just to ensure that government funding is efficiently spent, we should rapidly start to implement strategies that address the many educational and research organisation issues raised by nanotechnologies.

# Nanotechnology and the New Corporate Training

**F. Menzel**

Degussa AG, Germany

The first scientific publications dealing with effects of nano scale particles date from the first half of the $20^{th}$ century. Just in the 1980's nanotechnology became a new and independent research area with the newly available measurement devices such as atomic force microscopy or high resolution scanning electron microscopy which made the nano-scale visible. It took another 10 years to establish nanotechnology as an interdisciplinary science which overruled some old fashioned principles of the basic sciences. From today's perspective, the last 10 years again changed the understanding of nanotechnology from a pure academic science to an application driven science.

Although, some industries have dealt with sub-micron and nano scaled technology since many years, the interdisciplinarity was not fully accepted in all areas. One of these industry sectors is the nano-scaled material business which will be used as an example to explain the change in the industrial understanding of nanotechnology and the change in the requirements of human resources.

Unfortunately, nanotechnology is not a given to end consumers but has to be explained. The science of nanotechnology is the fundament of the business, but often engineers, material scientists, and chemists discuss the properties of available materials among themselves. To strengthen the dialog with customers with the right skill level of the application was and is still one of the key success factors. The European funding system today takes this approach into account and started to preferably fund nanotechnology projects with both scientific and industrial objectives.

Today, most nanotechnologists are still scientists. But with the development of the business the key players have to have good business experience. Some scientists very often shared their visions and derived business opportunities but did not take marketplace rules into account. As soon as a product changes its experimental status a professional marketing is needed to guarantee business success.

Some nano-scaled metal oxides like silica, alumina, and titania have been available in industrial scale for many years now. These materials are widespread in many applications where they induce the right performance of the product even when used in low concentration. In this business the understanding of the application itself is very important. But the major success factor is the open dialog between the producer of the nano-scaled material and the customer, whose core competency is the knowledge of the application.

The trend to focus the nanotechnology business on the applications will be even more pronounced in the future. This will result in specialized products for dedicated applications. For the development of these products well-educated scientists are required. These scientists do not only optimize the production process of the materials but must explain the physico-chemical and application properties to the customers. Due to the required high quality standard the production of the products also requires well-educated employees. The high price of nano-scaled materials, as well as the special applications, finally recommend a professional marketing. Finally, the business success depends on the whole team and its interdisciplinarity.

# Nanotechnology Research and Training Requirements for Sustainable Development in the Countries of Younger Industrialization

**O.L. Malta**

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To face the problem of the interaction between scientific and technological knowledge to overcome the obstacles in the way towards a sustainable development definitely requires a deep change of paradigms. The *Agenda 21*, a document subscribed by 179 countries on the occasion of the Conference of the United Nations on Environment and Development (Rio de Janeiro, Brazil, 1992), has chosen "Science and Technology for Sustainable Development" as a central theme. The document is mainly grounded on an "Ethical Modernity" and not only on a "Technical Modernity". The technical modernity turns the means out into the ends themselves. On the other hand, the ethical modernity considers in a deeper way human values and their relationships with the environment, incorporating the ecological and anthropological knowledge into the technical knowledge and recognizing that the rationalization and consolidation of this synergism is the point of paramount importance to attain a sustainable development.

While the competitiveness of industrialized economies is based on national systems of innovation, in the economy latecomer's countries the situation is characterized by national systems of learning technologies (passive or active), which leads to severe limitations in the competitiveness of their industrialized products. Moreover, the systems of learning technologies usually try to compensate the low competitiveness of their products by locally applying low prices of manpower and raw materials, inevitably contributing to social inequalities and, at medium and long term, to an unsustainable coexistence with the environment. The comprehension by the governments of the importance of a well-defined program of science and technology, emphasizing an adequate formation of human resources, to handle and to solve these problems is of rather common knowledge. However, it is not evident, in general, that behind this comprehension the fundamental and crucially necessary idea of sustainable development is consolidated.

In this new millennium Nanoscience & Nanotechnology (N&N) has appeared as a scientific and technological scheme that opens a great number of new possibilities in the construction of scientific and technological policies grounded on the concept of sustainable development, in agreement with the *Agenda 21*. From the environmental point of view one of its great characteristics is that nanotechnology may be viewed as a "clean technology". Operationally, to succeed these policies must rationally gather the efforts from the academic, technological and industrial media, by qualifying human resources based on the concept of an ethical modernity. On the other hand, the implementation of an ethical modernity, in a "globalized world", requires an effective bilateral cooperation between industrialized and economy latecomer's countries based on moral compromises.

In this talk the above aspects will be discussed focusing on the role of N&N for sustainable development and on proposals that might be of worth to scientific and technological projects for a better future.

# *Session 6 - Research, Industrial Innovation & Entrepreneurship, Financing Instruments*

## From Basic Research to a New "Nano" Company

**H. Schmidt**

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Material based technology plays a very important role in the industrialized nations. About 70 % of any production is directly or indirectly based on materials. This means that new materials play a very important role in industrial innovation and nanostructured based or nanoparticle based technologies have been proved to be an extremely interesting tool for this innovation. However, restrictions are coming from the specifics typical for materials on their way from the basics to the market. Time-to-market is at least 10 years, development costs are high and selling material means operating on the first and lowest level of added value. For material suppliers, as a consequence, this means that they have to find market volumes large enough for having sufficient payback.

The degree of innovation of most of the materials, however, very often does not so strongly depend on the material market volume. In many areas like optics, life science, surface technologies or microelectronics, the amount of material needed is rather small, but despite this fact, they play the role of an enabling technology and can be considered as key products. Bottle necks exist between the material science producing many new results and the application due to the lack of processing the appropriate technologies for the users. This, as a rule, is not carried out by the material producers. The bottle neck is shown in figure 1. In order to overcome this bottle neck, it is desirable to generate infrastructures which are operating on a so-called vertical interdisciplinarity which means that basic results can be processed down to a level where the industrial company in question according to their skills and possibilities can take over these results and develop them to a commercializable technology. Vertical interdisciplinarity means to link together the basics (chemistry, physics, biology, medical and others) to disciplines bringing a product down to the market. This means chemical engineering, mechanical engineering, materials engineering, production technology, quality control, marketing and sales have to work together within the same institution.

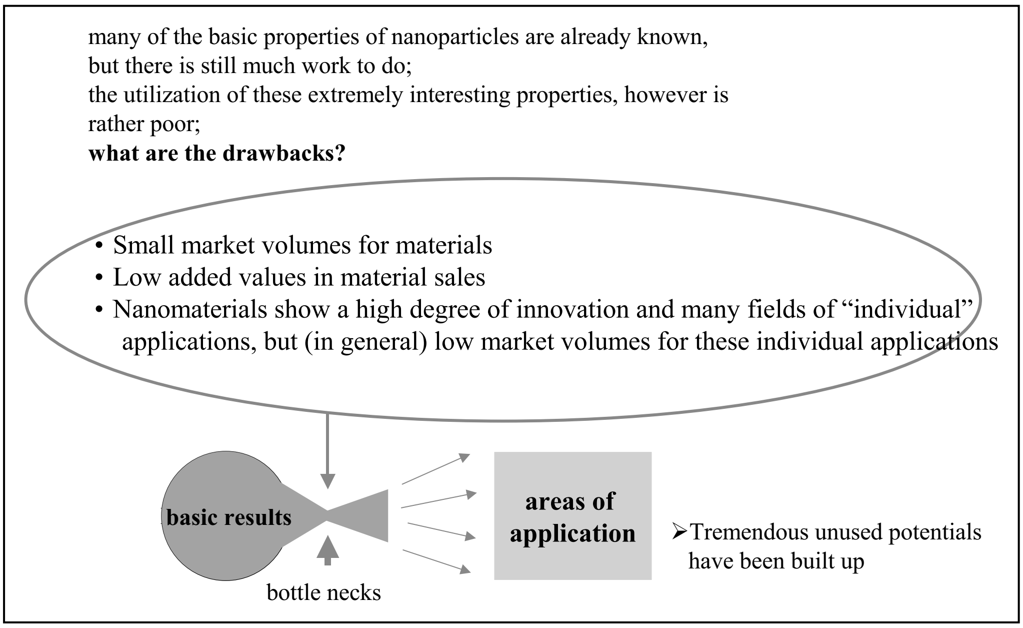


**Figure 1**. Bottleneck for the utilization of well-known nanoparticle properties in materials.

This will be demonstrated on two examples. In 1995, a European project has been started to develop iron oxide nanoparticles for MRI where INM's part was to develop iron oxide particles having a positive surface potential and being able to remain unagglomerated under physiological conditions. It was necessary to build up this system on a nanoscale in order to get a superparamagnetic behaviour, that means a switchable magnetism which only is switched on in presence of a magnetic field. During this project, contacts have been built up to Charité hospital (Berlin) to the group of Dr. Jordan who got interested in utilizing these particles for a different purpose, in this case to build up a focused hyperthermia technology for tumor treatment. It was discovered during this collaboration that specific amino coatings on the nanoparticle lead to a well-working discrimination between tumor cells and healthy cells by the nanoparticle. They only were able to penetrate into tumor cells. The detailed mechanisms are not known yet, but intensively investigated. The work was continued in a public funded project, financed to 50 % by BMBF. INM's role was to reproduce nanoparticle fabrication technology according to the German Federal Medical Product Regulations. This was done through the chemical engineering. Dr. Jordan's group with a newly founded company, MagForce, developed an applicator and did all the biomedical tests. During these tests, it was found that after injecting the nanoparticle suspension in a tumor in the first hyperthermal treatment, a homogeneous distribution of the particles and the tumor takes place, but the adjacent healthy tissue is not infiltrated at all. For this reason, a repeated treatment was able. The first patients who could not be treated by any other means could be released healthy from the hospitals. Another 12 patients are under a successful treatment up to now.

The example demonstrates clearly the vertical interdisciplinarity. Basic nanoparticle science by INM, the chemical engineering part carried out by INM, the development of the applicator done by an electronic company, the biochemical and application tests carried out by MagForce with Dr. Jordan and the Charité hospital. The developments in the nanoparticle technology are continued by INM which plays the role of the future technology source. Due to the intensive preliminary research work, the realization of the basic ideas to the practical solutions has been shortened in the collaborative work with the companies to about a 6 years periods which is rather short for this type of technology.

The second example is related to another technology of INM. In this case, a coating has been developed on the basis of $SiO_2$ nanoparticles. The idea was to flexibilize inorganic coatings by changing the free dimensional cross linking. By using nanoparticles coated with so-called network formers (according to the glass nomenclature) as shown in figure 2.

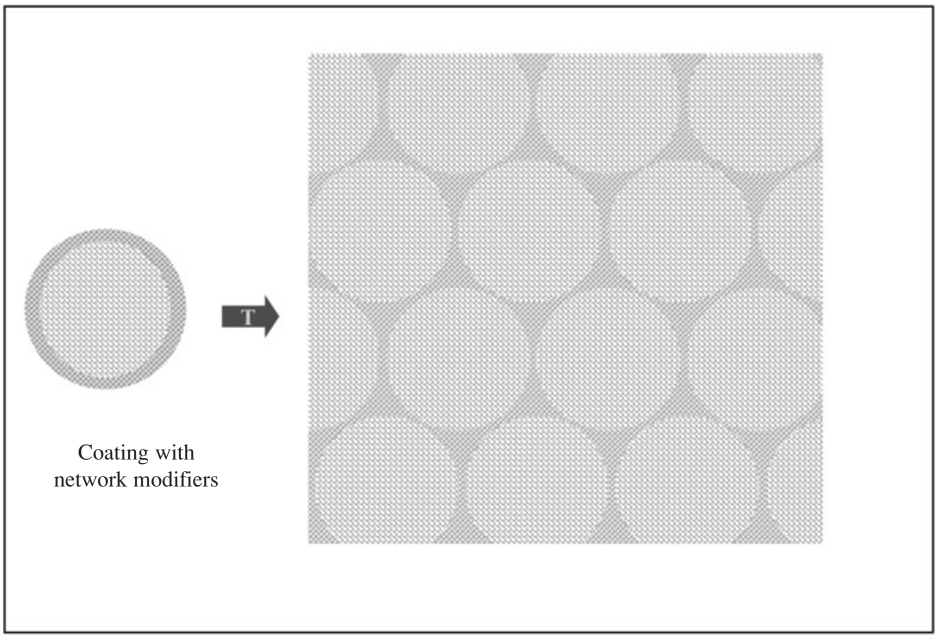


**Figure 2**. Model of a nano glass structure.

The overall composition would be that of a completely inorganic sodium silicate glass after densification. In opposition to sol-gel derived coatings on stainless steel, which can be obtained up to about 1 µm and which are very brittle and cracked during bending, the new system was employed in thicknesses of 5 µm and can be moulded without cracking. The first application of this new nanostructured inorganic coating was the coating of iron plates by a spray coating technique in order to maintain the flexible properties that firing technique has to be carried out in a way that now interdiffusion takes place to homogenize the system. Then, a very easy mounting process as indicated in figure 3 can be employed. The whole technology starting from the application technology to a pilot production up to 20.000 pieces per week has been developed by contract paid by a new company (EPG). The development duration in this case was 9 months up to a quality ensured process. EPG now is building up a new fabrication plant since global players have been involved in the whole business and a global marketing takes place.

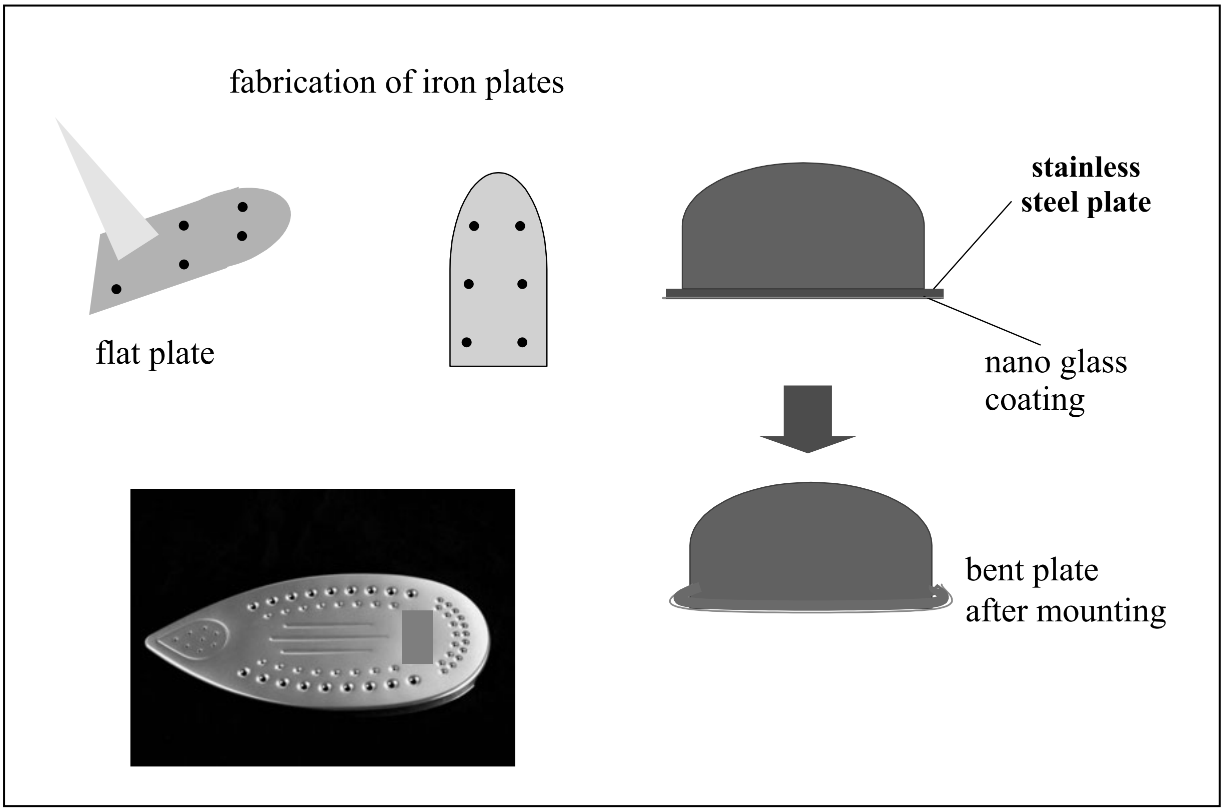


**Figure 3**. Low cost fabrication of a nano glass coated iron plate.

This model involving INM as a technology source for basic research, but also for being able to build up the pilot technology to a level where the company can take over the technology, was one of the key issues of the whole system as well as the incorporation of a global player. One of the important topics for the engagement was the existence of the technology source as well as a very well working collaboration between the technology source and the technology development and production company. The whole technology development starting from the first projects to the commercialization took a little bit more than one year which is rather fast for a completely new product. The advantages of the mounting technologies are significant because no complex processes are necessary. This basic technology is planned to employ in a variety of other fields.

## Summary

Summarizing it is to say that the vertical interdisciplinary approach in nanomaterials opens new ways for approaching markets, but requires a new infrastructure, that means a well-managed vertical interdisciplinarity, not only inside the R&D center, but also involving development and technology companies as well as global acting companies. In this case, the time-to-the-market can be shortened remarkably and the risks can be minimized significantly.

# Towards a New Research Capital Relationship: A Case Study

**A. Sfiligoj**

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## The drive towards structural change in the risk-capital industry

In the nanotechnology industry, as well as in other fast growing markets in their infancy stage, small entrepreneurial knowledge-based firms are a determinant source of innovation.
In fact, larger companies increasingly demonstrate difficulties in financing R&D and managing innovations that fall outside of their previous experience. As the costs of marketing and distributing products and services on a global scale increase, corporations tend to shift investments from R&D towards marketing and manufacturing, which offer shorter term benefits than research. Especially in the case of nanotechnology, where the number of new applications is particularly large, corporate R&D becomes more difficult to focus, and thus riskier. As a consequence, established firms increasingly buy innovations from the outside – most often from start-up companies - usually often progressing from a "supplier-buyer" to a partnering relationship that eventually leads to acquisitions through *corporate venturing* programs that emulate venture capital.

To facilitate company growth in fast growing markets, investors such as Venture Capital (VCs) and business angels have a critical enabling role which goes beyond funding. The best investors focus on a particular sector or industry and bring access to markets (customers, business partners, human resources), as well as funds, terms, controls, expertise that make firms more likely to succeed. Unfortunately such proactive VCs are still rare.

Furthermore, risk capital is not equally available to entrepreneurs in all countries[1]: in 2001, 62% of global private equity was invested in North America, 21% in Western Europe. Even more critical, VCs strongly favour particular geographical regions and clusters – to the disadvantage of less developed areas which lack key experts and human resources such as lawyers, patent attorneys, bankers, technology and market consultants. As a consequence, until now, VCs tend to invest *close to home* in order to improve control and to minimize the costs of forming and managing the ventures. On the other hand, the lack of VCs is an important barrier to technological advancement.

This is all ripe to change, thanks to the availability of advanced information technologies such as broad band based internet innovations, combined with advanced knowledge management tools that revolutionize e-commerce and corporate practices - thus making geographical proximity less and less important.
Meanwhile, following also the adoption of ever strict rating based criteria for credit lending (Basel II capital adequacy legislation), the demand for risk capital is increasing. Simultaneously, at present enormous liquidity is available – but it must be properly

[1] PricewaterhouseCoopers, 2002

channelled in structured ways to profitable investments (in Europe less than 3 % of submissions get funded[2]).
Under the combined above driving forces, the VC industry is pushed to radically evolve from a "boutique industry" into a larger, structurally networked industry, capable to proactively support early stage investment - relying upon communities of experts and investors utilising advanced internet features, knowledge based tools, standardised transaction procedures. The resulting change will be, for the risk capital industry as dramatic as what has happened to traditional banking years ago.
The need to evolve towards this scenario has been pointed out by the EC Communication to the Council and the European Parliament on "Innovation in a knowledge-driven economy", which stresses the need to accelerate the development of widespread micro-entrepreneurship and to improve key interfaces between companies and financial markets, R&D and training institutions, advisory services and technological markets. The document also highlights the crucial role to be played by Regions in this respect.

**New pilot solutions: the Venture Route (VR) project**

Venture Route[3] is an ongoing demonstration project, co-financed by the European Community in the framework of the programme e-Content, in order to foster the development of the European early stage "risk capital industry". VR is building upon the experience of PMIFinance[4], a pilot Italian project involving over 300 investors and approximately 3500 firms.

VR is a highly networked and structured on-line platform environment allowing entrepreneurial projects to match and interact with the right investors, experts and partners in an "easy, fast and efficient way" The distinguished features of VR are:

- Tools[5] to foster the provision of "smart money" as well as the evolution of the consultants' role from "service providers" to "solution partner" supporting new partnering models with clients.
- Roadmap structure: a "route" is proposed assisting the entrepreneur from proposal submission to the closing of the deal, providing at each step standardised forms, templates, service workflows and procedures.
- Integration of regional systems into a larger EU system. The role of regional partners and investors (including public or semi-public investment companies) is to act as front office; to accredit and graduate ventures; to involve regional funds and business angels; to arrange financial incentives as available from regional sources; to provide generalist management support; to syndicate investments joining local funds and external industry-specialised investors.

Beneficiaries of VR are:

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[2] The Pratt's Guide to Venture Capital
[3] Project Leader: Sviluppo Italia Toscana, e-Content code name e-NEC, partners in Italy, Slovenia, Ireland, Germany, Austria, Belgium and Estonia
[4] The match-making procedure has been developed, and tested, by the VR partner CCM (University Bocconi and Milan Chamber of Commerce).
[5] Matching of demand and offer (of venture projects, know-how, contacts and capital) is partially automatic and partially personalized. Knowledge management tools are being developed for the purpose of competence matching, technology and market due diligence, etc.. Off-line personalised service support is offered through local regional partners.

- Entrepreneurs: *improved availability of private funding also for the smaller - yet promising - deals which are normally left out*;
- Investors: *lower investment costs*, *better profitability and investment liquidity through enhanced exit mechanisms* (typically easier *trade sales* to corporate investors);
- Corporations: *better access to promising research results through easier to manage relationships* with external R&D teams;
- Experts: *larger service markets*, more cost efficient and focussed relationships with clients
- catalyst organisations (e.g.) incubators: *improved impact on regional economic development*.

In conclusion, VR represents a pilot example of a highly structured, multi-regional and multi-country knowledge-based strategy and tool-set enabling to channel private investment into early stage companies through the convergent partnership of different actors which, as of today, poorly interrelate among themselves. "Smart money"; i.e. the provision of funding bundled with skills and interdisciplinary competencies are particularly critical for nanotechnology firms, which rapid growth is essential to support scientific development and industry progress in Europe.

# EIB Actions for R&D and Innovation: Looking Ahead to 2010

**O. Arango**

European Investment Bank

*The financing of innovation will remain a key priority for the Bank as far ahead as 2010. Although the i2i programme came to the end of its initial three-year term in 2003, the objective set under the Lisbon Strategy continues to be valid. In line with the conclusions of the Stockholm (March 2001) and Barcelona (March 2002) European Councils, at its annual meeting on 3 June 2003 the EIB's Board of Governors approved the renewal of this programme as the Innovation 2010 Initiative.*

The Innovation 2010 Initiative is rooted in the EIB Group's experience with implementing the Innovation 2000 Initiative launched in June 2000 to take forward the conclusions of the Lisbon European Council, aimed at fostering the development of a knowledge and innovation-based European economy.

Designed both to continue and refocus the Innovation 2000 Initiative, "i2i-2010" reflects the long-term nature of the Lisbon and Barcelona objectives. It provides a framework for EIB Group action until the end of the decade and establishes an new indicative lending envelope of EUR 20 billion for the period June 2003 to December 2006. The EIB Group will then conduct a mid-term review to fine-tune the initiative's priorities and instruments up to the end of 2010.

To recap, i2i disposes of:

- medium and long-term EIB finance, often in the form of risk-sharing or structured loans, and
- EIF equity participations and counter-guarantees designed to stimulate the creation and development of small business by providing equity in the form of venture capital or facilitating access to bank credit.

## An Integrated Approach

Innovation 2010 is based on an integrated approach focusing on the links between knowledge creation and the market. It covers all phases of the process, from education to R&D and the transformation of innovation into investment, generating productivity gains and enhancing the competitiveness of the European economy. Such an approach is key to effective support for innovation, as a driver of economic growth and job creation.

In the light of its experience acquired during the 30 months' implementation of the first i2i (see box), its policy dialogue with the Commission and its contacts with public and private-sector economic operators, the EIB intends the new initiative to concentrate on three priority areas:

- **Education and training**, including lifelong learning in industry and the service sector, integration of research into tertiary education projects, digital literacy and e-learning (eEurope), development and dissemination of knowledge via new media.

- **R&D and downstream investment**, especially by the private sector in products and processes. This component particularly concerns pan-European R&D projects and the financing of public or international research facilities; support for private-sector (especially SME) R&D initiatives, "pooled R&D" and the combined application of research for the purposes of industry or services; backing for incubator-type structures catering for the needs of start-up companies; co-financing of research programmes underpinned by the 6th EU Framework Programme.

- **Creation and dissemination of information and communication technologies (ICT)**, e.g. relating to hardware, ICT-supported content and applications. Under this objective, emphasis will be placed on the roll-out of fixed and mobile broadband networks and access technologies (e.g. AsDSL, DSL, UMTS) as well as R&D; digital terrestrial television (DTTV) platforms; investment in on-line services (e-commerce, e-health, e-government); development of intelligent transport management systems (e.g. Galileo) and deployment of European standards for transport (ERTMS, ETCS, LCTC, GSM-Rail) or emergency (TETRA) networks; and more generally, support for projects under the "eEurope 2005" and "eEurope+" programmes.

By regarding the innovation process as a "Knowledge Net" the EIB Group is able to focus its activity on: the enablers, i.e. the infrastructure for carrying and disseminating knowledge; the intermediates applying this knowledge; and lastly the producers of the commercial content and products constituting the output of the innovation chain in European society.
In view of the variety of investment in the knowledge transformation process, the new i2i will involve more lending for intangible assets (e.g. training and research programmes, patents), alongside the Bank's traditional financing of tangible assets (such as infrastructure, buildings, scientific and technological equipment).
Moreover, the EIB Group will accord priority to projects furthering or resulting from synergies between the public and private sectors, since mobilising their combined efforts is crucial for attaining the ambitious R&D investment target of 3% of Europe's GNP by 2010, set by the Barcelona European Council in March 2003.

**Enhanced Co-Operation with the Commission**

It goes without saying that enhanced cooperation with the Commission has had a marked impact on EIB activity in areas eligible for i2i financing.

It takes a number of forms:

- coordination (and, where possible, co-financing) of key initiatives backed by the 6th EU R&D Framework Programme launched in November 2002;

- implementation of agreements with DG-Info on a European approach to financing technology networks and schemes involving ICT content and applications;

- creation of synergies with DG-Culture for the support and financing of European audiovisual projects;

- conclusion of cooperation agreements with the Commission aimed at optimising synergies between the two institutions in the fields of regional development and integration of the Accession Countries, especially with a view to maximising the effectiveness of the European Structural Funds.

**A Pan-European Dimension**

As with the first initiative, Innovation 2010 will give absolute priority to projects located in regional development areas: the creation of centres of excellence in the less favoured regions of the EU or the countries due to become Members in 2004 is undoubtedly a key factor in ensuring European citizens' equal access to technologies in a changing world. It also helps to offset the tendency for investment to be concentrated in the wealthiest parts of a unified economic area. Accordingly, 66% of the Bank's lending between 2000 and 2003 under the first i2i went to projects in the least developed regions of the Union and the Acceding Countries, a testimony to the high value added of the Bank's involvement and its commitment to bringing about a transfer of knowledge to the areas lagging furthest behind.
Encouraged by this positive experience, the EIB's Governors decided to broaden the geographical scope of the Innovation 2010 Initiative by linking it to the creation of a European Research Area, an objective declared by the Heads of State and Government at the Barcelona Summit in March 2002.

The following will therefore be eligible for EIB support under the new i2i:

- the existing Member States (EU 15), with special emphasis on projects located in assisted areas and Cohesion Countries;
- the ten Acceding States set to join the Union in May 2004;
- the Accession Countries: Bulgaria, Romania and Turkey;
- the Western Balkan countries, where, as the Bank's support for reconstruction and development begins to bear fruit, major needs in the form of educational facilities and technological networks will have to be addressed.

**Substantial Funds**

Adding to the approximately EUR 17 billion approved by the EIB for the first i2i, the indicative envelope of 20 billion decided by the Bank's Governors for the period mid-2003 to end-2006 will bring the EIB Group's financing in pursuit of the Lisbon Strategy objectives to an average of EUR 6.5 billion per year. Taking into account the business volume already committed and the needs expressed by the economic operators, it is realistic to assume that this annual average will be maintained over the whole decade. Thus, the EIB Group's support for i2i-targeted sectors will amount to well over EUR 50 billion by the end of 2010.

# The Strategy of a Multi-National Company

**M.T. Gatti**

Director, Research and Innovation, Advanced System Technology
STMicroelectronics

Semiconductor companies are facing deep changes in markets, competition, business models.

Systems are converging and ICs are more and more converging with systems. The fundamental issue is how to translate knowledge and competences coming from different fields into single architectures. The tendency towards convergence not only involves applications and methodologies within a single market branch, but expands further to technologies and scientific disciplines belonging to different branches, e.g., mechanical engineering, microelectronics and biology.

The challenge is to innovate by learning from the world. A crucial factor is to build the right organizational models and to attract the right people, combining a perfect execution machine with a creative environment for innovation. This means to build a learning environment where creativity and conscious risk are encouraged, empowerment and accountability for results are a way of life, diversity and fairness are recognised values.

The new big opportunity is to build competitive advantage by connecting globally dispersed, different sorts of knowledge. To build this advantage, a company needs to compete on three levels: identifying new sources of relevant technology (**sensing**), to bring this new knowledge into products and market opportunities (**mobilizing**), to translate all of this into efficient, flexible and cost-effective manufacturing (**operating**).

It is crucial to build an organization for innovation, with the right mix of creativity, personal initiative and execution skills.

The first crucial factor is to attract excellent people. For companies, this means to be recognized as good places to work, to be innovative, to be good “corporate citizens” in all respects.

However, selecting excellent people is only a part of the game: the key is to create an environment where people have the opportunity to grow and fulfill their dreams.

The critical task is to assign the right job to the right individuals, building both on their technical competences and human factors. In this picture, managers have the role to drive companies by mobilizing energies and bringing them down into products and processes.

# The Vision and Integrated Approach of NSF

**T.A. Weber**

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The United States National Science Foundation (NSF) is an independent agency of the United States government established by President Harry S. Truman in 1950. NSF currently has a budget of over five billion dollars and is responsible for funding all areas of fundamental science, engineering, and education except for medical science and space based astronomy.

The NSF Vision is "to enable the nation's future through discovery, learning and innovation…". The NSF outcome goals are:

1. To train a diverse, internationally competitive workforce of scientists, engineers and well-prepared citizens (People);
2. To foster discovery at and across the frontier of science and engineering in the service to society (Ideas); and
3. To provide broadly accessible, state-of-the-art information bases and shared research and education tools (Tools).

To accomplish these goals, the NSF portfolio includes a wide spectrum of funding mechanisms: individual investigator awards, small groups, and large centers. About 25% of the NSF budget is spent on supporting facilities from synchrotron radiation centers, research vessels, large telescopes, etc.

The two proposal review criteria foster NSF's vision and goals:

**What is the intellectual merit of the proposed activity?**
How important is the proposed activity to advancing knowledge and understanding within its own field or across different fields? How well qualified is the proposer (individual or team) to conduct the project? To what extent does the proposed activity suggest and explore creative and original concepts? How well conceived and organized is the proposed activity? Is there sufficient access to resources?

**What are the broader impacts of the proposed activity?**
How well does the activity advance discovery and understanding while promoting teaching, training, and learning? How well does the proposed activity broaden the participation of underrepresented groups (e.g., gender, ethnicity, disability, geographic, etc.)? To what extent will it enhance the infrastructure for research and education, such as facilities, instrumentation, networks, and partnerships? Will the results be disseminated broadly to enhance scientific and technological understanding? What may be the benefits of the proposed activity to society?

NSF also gives careful consideration to the following in making funding decisions:

**Integration of Research and Education**

One of the principal strategies in support of NSF's goals is to foster integration of research and education through the programs, projects, and activities it supports at academic and research institutions. These institutions provide abundant opportunities where individuals may concurrently assume responsibilities as researchers, educators, and students and where all can engage in joint efforts that infuse education with the excitement of discovery and enrich research through the diversity of learning perspectives.

**Integrating Diversity into NSF Programs, Projects, and Activities**

Broadening opportunities and enabling the participation of all citizens women and men, underrepresented minorities, and persons with disabilities is essential to the health and vitality of science and engineering. NSF is committed to this principle of diversity and deems it central to the programs, projects, and activities it considers and supports.

In January of 2000, President Clinton announced the National Nanotechnology Initiative. Currently the United States is spending $850M on this initiative of which NSF accounts for $220M. The Division of Materials Research (DMR) is a major participant in this initiative within NSF. DMR also recently launched an initiative to encourage collaboration between US scientists and foreign scientists. Currently there are programs in place between NSF and six countries in North and South America; NSF and seventeen European countries; and NSF and the European Commission.

In 1994, NSF established the Materials Research and Education Centers (MRSECs). The key features of the MRSECS are:

1. Interdisciplinary and multidisciplinary research of a scope which could not be accomplished by an individual investigator;
2. Educational outreach which can span from K-12, undergraduate, graduate education and to outreach to the American public;
3. Industrial interactions; and
4. A shared instrumentation program.

This presentation will detail specific examples on how the MRSECs meet the objectives of the program. In addition, examples will be given of how the international collaboration at the centers.

## *Session 7 - Infrastructure, Equipment and Metrology*

# Towards a European Vision on Infrastructures and the Case of the Synchrotron

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Nanotechnology is based on the capability of observing, controlling and manipulating materials down to the atomic level, and this capability is used to build nanodevices or nanostructured materials which take advantage of the laws governing matter at these atomic levels.

In November 2003 was held the “European Strategic Forum on Research Infrastructures” (INFRA/ERA 2003). This event consisted of a part based on keynote talks describing the role of research infrastructures in environmental, human, biomedical and material sciences, and a second part to present ESFRI and its activities and discuss new access opportunities, given by the entry of new Member States and new ICT technologies. Proposal aring from this discussion may be relevant to European policy-makers as well as for further actions supporting the growth of the ERA. The main strategic conclusions relevant to nanotechnology will be presented in the EuroNanoForum 2003.

The speech will also address the technology and use of synchrotron light (SL). Several techniques, which have contributed to allow this manipulation and control, are based on the use of light of sufficient intensity and coherence to act down to the level of few atoms, either to excite them for measuring and observational purposes or to manipulate them. Such light beams are produced either by “table top” lasers or by SL.

Table top lasers are, until now, limited in producing discrete or narrow bands of wavelengths up to the ultraviolet range, while the synchrotron light may span continuosly from the microwave to the hard X-Ray band, thus allowing measurements and manipulations going from collective molecular or electronic motions to the single atom’s positions. Synchrotron light is produced basically by “wiggling” or “undulating” a high energy electron beam and this is made either in an “accumulation ring” or in a linear “Free Electron Laser (FEL)” configuration.

SL laboratories play a sizeable part in the development of the Europen Research Area, given the vast number of researchers who have access to them through either “variable geometry agreements” or EU FP support in the “Infrastructures” actions. Europe is well endowed with a network of eight (plus three under construction) SL laboratories, in three of them a Free Electron Laser is operating. These laboratories are service laboratories and mainly serve outside users, each one having around 1000 users per year. In my presentation I will show mainly data on the Elettra Laboratory in Trieste, but the network of european laboratories is strongly interconnected and many users apply to, and use, more than one laboratoy, depending on the specializations and strengths of each one. One of the Laboratories is internationally owned (by 11 EU countries) and is optimized for the production and use of hard X-rays: this is the ESRF (European Synchrotron Radiation Facility) in Grenoble. FEL sources are available in Utrecht, Hamburg, Orsay and Trieste. They were, until recently, limited up to the Infrared light band, but new technological developments are now allowing a further increase of their capabilities towards the Soft and Hard X-ray bands and this will bring to an increase in their numbers, complementing the network of existing “ring” sources. The reason for this trend is that FEL sources are able to produce very intense and short “flashes” of light, allowing to observe both the inner structure and the dynamics of materials down to the atomic response times: this will allow both to “photograph” and to “take movies” of what happens inside the materials, in particular at the nanometric or even at single macromolecular level.

Each SL facility is composed by a light source and several “Beam Lines”, feeding different “Measuring (or photolitographic) Stations”, they may be of the order of 20 to 30 in the case of “ring” sources or up to about 10 in the case of the FEL sources. The laboratories work around the clock to accommodate users. The use of these facilities is open on two parallel access policies: basic research users who will publish their results, are admitted free of charge after an international selection following their application for beamtime in (typically) two international calls per year, the ratio between applicants and accepted users being normally around 3 to 1. Industrial users, or other users, who want to keep the results proprietary, pay according to the costs of the services provided in the use of the light and of the support laboratories.

The talk will also give an overview of the some available significant SL techniques to observe and manipulate materials and nanodevices, as well as on their general and perspective availability in Europe for the industrial and the basic research comunities.

# Nanotechnologies Era :
# A Challenge for Research Infrastructures

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Entering the nano-era requires an increasingly significant effort in research and development. In addition to the well-known “top-down” approach, the emergence of a complementary “bottom-up” approach to fabrication of structures requires the integration of competencies from many different fields of expertise. Moreover, assembling devices one molecule at a time using molecular building blocks requires a skill set not typically found in a traditional semiconductor environment as well as the development and timely availability of specific equipments.
Nanotechnology as an industry will benefit from these breakthrough technologies if we are able to manage the integration of applied micro-electronics and micro-technologies background with more fundamental nano-sciences inputs.

So, in order to build a favourable environment for the growth of the nano-industry, we cannot rely on existing research structures because we have to face new issues:

- **Complexity** which needs a new approach based on a real pluridisciplinarity and an increased competences networking.
- **Cost increases** cannot be avoided and the access to the key equipments and materials for research requires sharing access to these enablers.
- **Innovation for industry** is the goal and success will go through a continuous transfer to the partners which are in charge of industrialization.
- **Education** is key to insure a future for this domain and we have to take care of attractivity towards young students, allowing them to be closer to research teams.

To reach these goals, some large national initiatives aiming to establish new schemes for centers of excellence in the field of nanotechnologies were launched recently worldwide.

In this presentation, we will review some of the key challenges linked to this important evolution and we will present different intiatives launched in Europe, USA and Asia.

# The "Kompetenzzentren"

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In 1998, the German Federal Ministry of Education and Research (BMBF) established 6 competence centers on "nanotechnology" to support the self-organization of research in the field of nanoscience and to advance the industrial application of nanotechnology.
The tasks of the competence centers are public relations work, training and further education, establishment of an economic attractive environment and consultancy of all interested parties from public organizations, politics and society to industry in the corresponding field of nanotechnology. Besides this a coordination of the R&D activities and project plans as well as consulting of applicants through the competence centers is done. For more information see www.kompetenznetze.de and www.nanonet.de.

The following competence centers have been established:

1. Production and use of lateral nanostructures in Aachen (www.nanoclub.de)

2. NanOp-applications of nanostructures in the field of optoelectronics in Berlin (www.nanop.de)

3. Center of Excellence ultra-thin functional films Dresden (leson@iws.fhg.de)

4. Nanotechnology: Functionality by means of chemistry CC-NanoChem in Tübingen, and Saarbrücken (www.ipc.uni-tuebingen.de/nanotech)

5. Ultra-precise surface treatment in Braunschweig (www.upob.de)

6. Competence Center in Nanoscale Analytics with divisions in Hamburg, Münster and München (www.CCN.de)

On the basis of gathered past experience these centers have been reorganized in 2003 with the goal of focusing the activities and building regional nanotech clusters. Several different private/industry/public funded centers have been built, including e.g. additionally to the above the Institute of Nanotechnology of the Forschungszentrum Karlsruhe (www.fzk.de) and the DFG center for Functional Nanostructures (www.cfn.uni-karlsruhe.de) or the CC-Nanobiotech in Kaiserslautern(www.cc-nanobiotech.de).

The former Competence Center Nanoanalytics regionalized into the hansenanotec in Hamburg (www.nanoanalytik-hamburg.de), the CeNTech in Münster (www.centec.de) and the Excellence Network NanoBioTechnology in München (www.ENNaB.de).

The ENNaB combines in a local Bavarian network with headquarter in München about 40 different research groups both from industry and from academia. This joint effort is embedded in the greater München Nanotech/Biotech region with a very active community of Universities, Max-Planck Institutes, start-ups and established companies as well as public and private equities and business consulting companies active in Nanotechnology (see brand new brochure NanoBioTechnologie – made in Munich, to be downloaded from www.ENNaB.de).

According to a recent Standort-study of the Boston Consulting Group the projected global added value in Nanobiotechnolgy is up to 18 billion US$ per year in 2015, with about 160.000 jobs linked to it. The Bavarian region could participate with about 5%-10% corresponding to 1-2 billion US$ and 8000 -16000 jobs. According to this high future potential of BioNanotechnology it is mandatory that the European community acts as a global support structure and a source for actions on the local scale. To avoid the brain drain of young high potentials into the US or Japan we must support the beginning of nanotech activities from academic young research groups up to young start ups. This is exactly what ENNaB has in its very focus.

# Demonstrators and Nano-Fabrication Centres - Towards a UK Network of Facilities and Support for Industry

**N. Mundy**

Chair of the DA Group, United Kingdom

## 1. The Goals of a UK MNT Network

In January 2003, DTI (the UK Government Department of Trade and Industry) invited the 9 Regional Development Agencies and 3 Devolved Administrations to work together to devise and take forward a means of improving the commercialisation of Microsystems and Nanotechnology in the UK. The recommendations of the Taylor Report published in 2002 have informed the Network Group.

The paradigm will cover in more detail the relationship between the role of the UK Development Agencies and objectives of the UK MNT Network. The UK MNT Network concept is intended to assist industry to close the gap between front-end research and commercial manufacturing facilities, by building UK infrastructure and support and catalysing its use through incentivised (part-funded) collaborative research projects bringing industrialists and academics together. To deliver this vision, the Network concept was developed to catalyse the commercialisation and benefits of MNT.

The UK MicroNanoTechnology (MNT) Network will provide a market-oriented focus for the facilities, people and organisations engaged in MicroNanoTechnologies in the UK. This Network will lower entry barriers and will drive the widespread market development & exploitation of these technologies. The Development Agencies (DAs) also provide various ways to access finance through Venture Capital Funds, Co-investment and Proof of Concept Funds. The Benefits of the Network of demonstrators and nanofabrication centres will include:

- Improving the access to a critical mass of world-class knowledge and facilities in the UK, the EU community and beyond and allow better international cooperation on a wider scale between other national activities.
- A catalyst to drive the specialist training and development of people to fuel growth in these emerging markets.
- Facilitating the integration of the complete supply-chain and better use of facilities, to take 'blue-skies research' through to high-volume and high-value-added manufacture by UK companies.
- Identifying the demand for, and working with stakeholders to provide the new facilities needed to build the UK MNT capability.
- Encouraging a coordinated approach to applied research programmes and business support.
- A focus for information and advice to provide the support for UK business to drive innovation and new products.
- Provide access to business incubation and early stage funding

## 2. Progress of the UK MNT Network Group to Date

Since inception in late January 2003, the Network Group working with DTI, has built a foundation to take the Network concept forward. Central to this collaboration are two beliefs:

- That the UK is better placed to compete on the world stage in nano-technology through combining all Regions facilities and infrastructure to generate the greatest possible MNT 'Critical Mass'.
- That *existing* UK excellence should be supported and built from, to develop a world-class UK capability.

From this basis, the Network Group has recognised the different Regional strengths and facilities and defined a common set of goals, marking a significant change from competing Regional agendas towards a genuine co-working on a National agenda. This has been reinforced by the Network Group agreement of (with every DA signing up to) a set of formal Governance Procedures setting out the mode of operation for the collaboration. This marks the first time that all 12 DAs have formally worked together in this way.
An asset register has been prepared for MNT facilities in the UK, which is validated and used by the Network: which is due to be completed by end of December 2003.
Recruitment for the position of Director of the UK MNT Network is underway. The DTI has offered initially £90m funding involving the Network, in part to be spent on projects to improve the UK asset base (up to £30m facilities funding and up to £10m operational costs), and at least £50m to be spent on a collaborative research programme. It is intended that DAs also provide funding, typically to facilities projects within their regions that add to the UK asset base. This funding will be available to SMEs, start ups as well as larger companies (within State Aid rules).
The DTI has established a National Strategy Advisory Group (NSAG), which meets quarterly. This Group brings together DTI, the Network Group (through three elected representatives), industry, academia, venture capital & banking interests, and the UK Research Councils. NSAG was established to guide the DTI in the implementation of the micro and nano manufacturing initiatives.

## 3. The Timetable for Network Delivery

By end-December 2003 the Network Group with DTI, and assisted by consultants, will have

- A completed Network design, and Management Hub design covering core nano-fabrication and demonstrator facilities in the UK;
- The outline business case for the Network
- The UK MicroNanoTechnology asset register will have been validated.
- A process and assessment criteria to evaluate projects will have been developed and agreed. This will be followed through NSAG to approve the first tranche of Network-funded UK facilities projects.

## 4. The Presentation

The presentation will cover in more detail the UK approach and scope of facilities including incubators, access to finance and support for SMEs and the methodology and experience of the UK MNT Network Group.

# The Role of Metrology

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## Introduction

In the evolution of natural sciences, scientific research and establishment of measurement tools go hand in hand. Without proper measurement tools we do not know how to measure; and without the scientific concepts we do not know what to measure.
When developing a new science into a new technology, proper measurements are indispensable. Because technology is executed globally and serves the global market, both producers and users need a common measurement language to ensure that product specifications are universally comparable and understood.
The above is of course true in the field of nano-science and technology, one of the seven pillars of the sixth framework programme and the only pillar that is motivated by the wish to development a new science. It is therefore relevant to consider the role of metrology in this development.

## What is metrology?

Metrology is the science of measurements. It involves all aspects of measurements, although the word metrology is often associated with the very accurate measurements that are required only by the most demanding branches of science and technology. However, this is a largely unwarranted connotation, because modern metrology is as much related to appropriate measurement for specific purposes as to the seeking ultimate accuracies; and often these two aspirations are working hand in hand.
Classical metrology is related to measurements of importance to trade. Units were defined in a trade area for the purpose of easing trade within this area, and at the same time protecting trade from outside "intruders". To day, trade going on at the global market, and the protective aspects of metrology is vanishing as a result of the Agreement on Technical Barriers to Trade (TBT) of the World Trade Organisation.
Metrology for the purpose of health and the environment is gaining increasing importance; but this is not so important in the case of nano-metrology.
In practice, metrology is about establishing units and scales; and to make sure that these are stable and readily available, so that they can be disseminated to practitioners of measurements. For instance, the unit of length at the highest level is established in terms of a stabilised He-Ne laser, stabilised to a particular absorption line of the $I_2$ molecule. The scale is established by calibrating gauge blocks, callipers and rulers, dependent of the needed accuracy. Equivalence in measurements is ensured through a hierarchy of comparisons that extend the units and scales globally so that a meter is the same everywhere on earth, and products specifications, for instance certain dimensions, can be read globally without corrections. Comparisons are executed and compiled under the auspices of the Metre

Convention and its executive agency the Bureau International de Poids et Mesures (BIPM), and results are store in the key comparison database KCDB to be found at www.bipm.org.

**Status of nano-metrology**

The challenge in nano-metrology lies in extending scales downwards in the "nano-range", not in defining new units. The definition of the metre and other units will not change because of advent of nano-science, but the scales will have to be extended in a reliable way. The status of this work has now reached the stage where the first international comparisons have been made and data are being analysed. The indication is that the leading national laboratories are in accordance with each other so that a globally uniform scale in the nano-meter range is available at the national metrology institutes for specific measurements such as two-dimensional measurements whereas three dimensional measurements have not yet been tested for global uniformity. Two dimensional "rulers" in the nano-meter are now commercially available.

Of course, nano-technology is not only related to measurement of at small distances. Electrochemical measurements, electrical surface conductivity and others are now becoming available at nano-meter resolution.

**Where is nano-technology applied?**

From the figure above and the analysis of the commercial clients for nano-metrology, it is interesting to investigate which industrial sectors are currently employing nano-technology.

- Precision Engineering (Prec. Eng.):

Although this is a very big sector, its entrance into nano-technology is still to manifest itself. This may be related to the fact the this sector is dominated by big enterprises that have difficulties in absorbing new technologies.

- Opto-and micro-electronics (Electronics)

This is quite a demanding sector. It is composed of a mix of both big and small enterprises.

- Biotechnology.

This appears to be the most active nano-metrology sector. It is dominated by small enterprises.

**The way forward for nano-metrology**

The sixth framework programme has had a very bad start for metrology, since no national metrology institute has so far been successful in getting funding

## *Session 8a - Nano-manufacturing and Instrumentation*

# Scanning Probe Methods: The Eyes for the Nano-World

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The enormous advance in nanotechnology has been driven by scanning probe methods [1]. The investigation of the fundamental relationship between nanostructure and nanophysical properties is a very important issue in nanoscience. The talk is focused on the application of scanning probe methods to various classes of materials including semiconductors, metals, oxides, magnetic, superconducting, and molecular systems. Phenomena on the nanometer scale are usually dominated by quantum effects being related with energy scales on the order of several milli-eV. They can be visualized in a fascinating way by using scanning tunneling microscopy and spectroscopy at low temperatures and in high external magnetic fields.

We have studied 0D-2D electron systems in InAs. 2D electron systems at the InAs(110) surface were induced by adsorption of submonolayer Fe, Co, or Nb [2-4] whereas 1D electron systems were discovered below charged step edges at the InAs(110) surface [5]. In both cases the local density of states could directly be visualized in real space as a function of energy and magnetic field. Scanning Tunnelling Spectroscopy (STS) has also been applied to investigate the single electron states and the corresponding squared wave functions of individual strain-induced InAs quantum dots grown by MBE on GaAs(001) substrates [6].

In addition to mapping the spatial distribution of squared wave functions we can also determine the spin character of the electronic states by applying Spin-Polarized Scanning Tunnelling Spectroscopy (SPSTS) [7-19]. We have used this method to study the correlation of structural, local electronic, and magnetic properties of nano-scale magnetic systems at low temperatures and in applied magnetic fields. We will also show applications of spin-sensitive SPSTS to individual atoms and molecules on magnetic substrates [20].

Low-temperature Magnetic Force Microscopy (MFM) in ultrahigh vacuum has been applied to study the temperature and magnetic field dependence of vortex states in high-Tc superconductors. Vortex lattice melting and recrystallization have directly been observed in real space. We will also present atomic-resolution studies of insulating oxides and molecular systems. Finally, new developments of SPM can be foreseen based on further improvements in instrumentation and the realization of extreme conditions.

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# Nanometer Scale Fabrication

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There are a range of technologies that are currently used to fabricate and contact to nanostructures. These range from techniques found in the semiconductor industry, such as optical and electron beam lithographies, to self-assembly methods where the natural growth of a structure is controlled at the nanometer scale by, for example, providing a patterned seed layer from which growth occurs. Perhaps the greatest challenges lie at the limit of the length scale in the sub 20nm region, where issues such as the contacting to single molecules becomes critical.

I will describe three very different technologies that have been developed though EU funded programmes that attempt to address some of the general issues surrounding nanofabrication. The first, based on electron beam lithography, is the development of a new type of photo resist that combines sub 10nm resolution with direct write capability for a range of materials. The second, based on a scanning stencil, allows for the precise fabrication of nanostructures at predetermined surface sites without any lithographic process. The third relies on a self-assembly process to form complex 3D nanostructures of a range of materials with extraordinary morphologies.

# Nanodevices and Single Electronic Devices

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Fifteen years has passed since the realization based on submicron aluminium electrodes by Fulton & Dolan[1] of the first single electron transistor (SET). In this device, the current is modulated by the charge induced on a coupling capacitor with a period equal to the electronic charge *e*. This breakthrough experiment actually set the beginning of single electronics and has motivated a considerable amount of interest in the past decade. Their operating principle is based on the quantization of charge in intermediate electrodes, so-called islands, when the access resistance of the coupled electrodes are sufficiently resistive (higher than the resistance quantum *h/2e*~26 k)
Indeed many other kinds of single electron devices, involving a wide spectrum of nanomaterials have since been obtained. It involved among others: semiconducting channel and quantum dots, metal nanoparticles, clusters, molecules and even single atoms. It ubiquitous presence in nanotechnology is due to the very basic nature of the physical principles responsible for this effect, namely Coulomb interactions and the "quantum' granularity of the charge.
After a brief introduction of these principles, I will review the state-of-the-art of experimental works in the field of single electronics as well as an overview of the fabrication techniques. I will insist on the development of devices focused on a better understanding of electron transport in well settled conditions (i.e : artificial atoms based on 2D electron gases, atomic contacts and superconducting devices). Some prospects to implement a quantum bit based on the interplay of Coulomb blockade with Josephson junctions will be mentioned.
Then I will present possible applications of single electronics: broad applications such as information storage as well as niche applications: thermometry, current metrology, and electrometry. I will insist on the numerous technological bottlenecks for implementing large scale integration of single electron devices working at room temperature, and present some recent achievements such as methods based on Self Assembly, which help to overcome some of these difficulties.

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# Nanomanufacturing and Instrumentation: The Industrial Point of View

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## 1. Introduction

The impressive physical properties of carbon nanotubes and carbon nanofibers (CNT, CNF) have stimulated an enormous interest from the scientific community, leading to numerous predictions of revolutionary economic impact within the next few years, and a transformation in technology over the succeeding decades. Indeed, scientific progress is announced daily for development of new tools and applications using CNT and CNF. These reports have validated and further fueled the enthusiasm with which this novel material has been embraced by scientists and technologists worldwide, and offers great promise that CNT and CNF will serve as *enabling* materials for applications ranging from molecular electronics to large structural components. In contrast, as for realization of the economic predictions, the business arena is beginning to express signs of impatience.

The impatience for economic gains develops from a general misunderstanding of the pathway from scientific discovery to commercial application that is applicable to insertion of a disruptive technology into the marketplace. Included among these is the need to overcome both technical and non-technical barriers to commercial use. In the meantime, a number of *substitutional* applications exist where CNT is playing the role of a low volume additive to provide performance enhancements in engineered polymers.

The promise of nanocomposites lies in the power of being able to achieve the perfection of constructing composite material at or near the atomic level, and capturing dramatically improved physical properties over a macroscopic domain. Models describing the strength and modulus of short fiber reinforced composites suggest that carbon nanofiber (CNF) can be used to produce excellent engineering composites with properties comparable or in excess of aluminum, provided that a sufficient fiber aspect ratio is obtained, critical degrees of orientation are achieved, and a suitable fiber/matrix interphase is achieved. These criteria illuminate the relatively immature state of development for CNT and CNF applications: While the principles and methods for composite design, fabrication and synthesis have been well-established for glass fiber and carbon fiber, the rules for surface functionalization, optimum composite interphase, compounding, molding, and alignment of the reinforcement in preferred directions have yet to be fully developed for carbon nanofiber. Until the past three years, most of the promise for this class of reinforcement has been shown through theoretical arguments; however, the development of larger production volumes of CNT have recently enabled processing trials of composites at laboratory and bench scale levels, and development of processing strategies needed to achieve the factors of dispersion, aspect ratio, interphase and orientation needed for high performance composites. Results from the first experimental efforts to assess the potential of CNT as reinforcements in composite have demonstrated improvements in several physical properties. These findings can provide a guide to inform the insertion of CNT into the marketplace in the near term.

## 2. Technology Considerations

Carbon nanotubes (CNTs) manifest the ultimate in mechanical and transport properties that can be achieved with carbon. The term "nanotube" has been loosely applied to a broad spectrum of submicron diameter filaments; however, the technical community reserves the term for single wall or multi-wall filaments having diameters in the range of 1 to 10 nanometers, above which one dimensional quantum effects are no longer significant. Typical length is on the order of 1 micrometer. (Carbon *nanofibers* are the class of submicron filaments having diameters above 10 and up to 100 nanometers, although here again the term is frequently applied to any submicron diameter filament.) Due to the ultimate in perfection of the graphene planes, carbon nanotubes presumably hold the ultimate theoretical values in strength, modulus of elasticity, electrical conductivity, and thermal conductivity, although experimental verification is problematic. Experimental measurements of modulus of elasticity for carbon nanotubes are in the range of 1 TPa, and early attempts to measure tensile strength indicate values of around 50 Gpa, values that are roughly a factor of five and two orders of magnitude higher than respective values available from steel. From a practical perspective, capturing these values in a composite structure depends on achieving load transfer via the matrix material, probably requiring functionalization of a chemically inert surface, and the trade-offs associated with introduction of defects thereby. The use of these structures in engineered materials is also currently hampered by unknowns in growth of longer filaments or generation of a yarn, difficulty in dispersion into the matrix material, and the inability to manufacture CNTs in high volumes and at low cost. Because of these limitations, the more likely near term applications for carbon nanotubes are low volume, specialized, but nonetheless commercially and socially significant applications such as molecular electronics, MEMS, and medical devices and therapies.

Carbon nanofiber is a submicron diameter reinforcement that overcomes many of the costly production steps and processing limitations existing for continuous carbon fiber in that it is produced in a manner similar to carbon black, and also may be blended and molded into composite articles using simple and economic processing. Metal catalysts such as iron are introduced into a gas stream collocated with a hydrocarbon gas feed. The nucleation rate can be markedly enhanced through addition of a small quantity of sulfur, which apparently forms an iron sulfide eutectic, and enables liquid phase diffusion of carbon through the catalyst[I] The growing fiber remains in the furnace for a short time, resulting in a fiber with sub-micron diameter and length on the order of 100 microns. Since the fiber is entrained in the gas flow, it is easily blown out of the furnace on a continuous basis. Compared to PAN and pitch-based carbon fiber, the morphology of CNF is unique in that there are far less impurities in the filament, providing for a graphitic and turbostratic graphite structure, and the graphene planes are more preferentially oriented around the axis of the fiber. As would be expected, the properties of the nanofiber are strongly influenced by this morphology. Consequences of the circumferential orientation of high purity graphene planes are a lack of cross-linking between the graphene layers, and a relative lack of active sites on the fiber surface, making it more resistant to oxidation, and less reactive for bonding to matrix materials. Also in contrast to carbon fiber derived from PAN or pitch precursors, CNF is produced only in a discontinuous form, where the length of the fiber can be varied from about 100 microns to several centimeters, and the diameter is of the order of 100 nanometers. This fact has significant implications with respect to composite fabrication, since the textile handling

methods used for continuous carbon fibers derived from PAN and pitch are not immediately applicable to CNF.
The hollow core Pyrograf III is a carbon nanofiber competitive with smaller diameter carbon nanotubes manufactured in a continous process, where several computer controlled production units can be operated by few personal. This makes the product highly competitive to other high quality products with considerably higher weight loading. ENF100 alternatively is a low energy intensive product, which fits specific needs for applications requiring fast applications.
Both nanofibers are applicable for high quality commercial products and are sold for considerably less than 1000 Euro/kg for reasonable orders . Pyrograf-III has proven to be a top fiber in respect to mechanical, electrical and thermal behaviour. It is supplied in tons rather than kilograms and current capacities are 30 tons per year. A new production facility is currently in planning able to supply up to 100 tons/year (?). This facility involves full automation of nanofiber processing, and will further reduce the production costs by approximately a factor of 2.

## 3. Market Considerations

Hi-Tech Business Models usually work as simple as that:
1. Having an idea or early stage technology available
2. ask your corporate or a VC partner to throw lots of Euros in it
3. capture a huge segment of the market (which probably does not exist at this point)

This model requires:
1. Huge numbers - MONEY
2. Huge opportunities - MARKET

But the Nano market does not work like this. In fact it is a market with only a few stand-alone products, which have not existed before. It is a classical enhancement or substitution market, maybe comparable to the replacement of vacuum tubes with dicrete semiconductor transistors. While there was no technology change for other passive components, germanium and later silicon transistors slowly replaced heavy weight vacuum tubes within radios, television sets, computers and industrial electronics. The real revolution started with the invention of silicon planar technology, when industry discovered that the new paradigm of integrated design and manufacturing of circuits on the surface of a silicon wafer significantly enhanced performance and lifetime, and made electronics affordable for any consumer product. Since then products have been created, which are based only on this technolgy and could have never been made without it.
This stage of nanotechnology change, which has being described in its unpleasant form by the novelle "PREY" from Michael Crichton is still more than ten years ahead and could perhaps really bring us something like nanorobots with swarm intelligence, if mankind considers such artificial creatures as useful for their evolution.
Currently the most important down-to-earth commercial market is the enhancement and substitution market, which requires different strategies for manufacturing and marketing. Carbon Nanofibers have to compete against existing solutions for various applications. There are particle and fiber commodity products on the market on a very low price level and competing to each other. While several carbon materials could be classified as nanotechnology products, e.g. carbon blacks are typically between 10-1000 nm particle sized, fibers are usually top-down products and in the range of current microengineering technology. Typical commodity products to be substituted are:

- glass fibers
- steel fibers
- carbon fibers
- aramid fibers
- graphite flakes
- carbon blacks
- clays

Carbon nanofibers and nanotubes can replace many of those additives in polymers, have the advantage of simultaneous enhancement of several properties and the potential to save labor and capital costs. The applications are well known and reach from tensile strength improved composites, over conductive and antistatic polymer products towards flame retardant properties (eg. for cable products). The ecological benefit is given by non-toxic, disposable and even recyclable additives, allowing to reduce weight, energy consumption and emission levels. The total costs of the substitution process still compares favourable to the total costs of not applying this technology. This is very similar to the old vacuum tube replacement by discrete transistor elements, where the total cost of the final product turned also out to be much lower and allowed therefore much faster market growth but rather nonspectacular.
The best business model for nanotechnology is currently the Strategic Partnership model. Within the supply chain of large companies their smaller supplier companies can deliver the innovation needs they need to keep their leadership unchallenged. It is mostly outside the scope of large companies to develop and mature such technologies within their own framework. Their part is to create the market for the final product and to mature this market, which is an extremely difficult task anyhow. This is outside the scope of the smaller suppliers, which have qualified as traditional suppliers to their large counterparts. So introducing new materials into their supply chain, having long term business contracts established and working together in cost reduction programs is the best way to insure fast business growth for such products. This requires some expertise in dealing with the partner and requires knowledge of his needs. This has to be supplied by specific intellectual property, which ensures that long term relationsships survive the first contracting period. It is therefore be important to use also tough marketing and also dealing practice to ensure best results for transfering know-how into solid business. We made the experience that dealing on a pure academic level does not always give the desired results.

So what would be a good marketing practice for nanotech products like carbon nanofibers:

1. Longterm thinking has big advantages against short term profit thinking (see Japanese model)
2. Creating a solid business plan based on market research and experience, try to be conservative
3. Technology driven products are programmed to fail. You should not think you can push technology, but you must get pulled by the market
4. Identify the largest customers which could need your product
5. Understand their products and roadmaps
6. Check your freedom to practice
7. Be sure that your IP and trade secrets are tied up early enough
8. Find out what your customers really need
9. Try to get funding and tax incentives in place
10. Get top management involved and make a fair deal

Applied Sciences, Pyrograph Products and Electrovac have formed a strategic partnership in developing the European market for Carbon Nanofiber products. This is significant, as these fibers have important applications e.g. in polymer systems which are used in key industrial sectors of the European industry. We believe that nanoproducts in general have been overemphasized in the past also leading to frustrations in the investment community. Carbon Nanofibers are high quality products available in large amounts with proven properties in enhancement of composites for existing commercial applications. They are also enabling improvements in processing technologies and are readily applied with existing manufacturing equipment. They compare therefore favourably to other nanotechnology products as they have been developed over many years long before nanotechnology became a sort of hype technology. Actually carbon nanotubes have been described as early as 1975 by Professor Endo, currently teaching on the Shinshu University in Japan.
Technology is a very sexy thing by itself, but market strategies are the final bottleneck of new technologies. Many clever start-ups failed to take the market serious enough and just tried to push their technology. The fact that this sometimes works does not allow considering this as a general rule.
Good marketing requires good manufacturing, i.e., a profound understanding of the costs involved in the manufacturing process and a excellent estimation of potentials how to further reduce costs. This usually requires full process simulation and Methods of Time Measurement (MTM). Full cost analysis and cost reduction planning requires also good knowledge of raw material prices, different forms of supply contracts for raw materials and equipment. Energy and labor can be optimized by early transfer to low cost regions or by low labor- and energy-intensive processing.

## 4. Intellectual Property Considerations

Freedom to apply nanotubes is not always clarified. Applications of nanofibers at submicron range are much saver.
Furthermore, the very slow European Patent examination and granting procedure increases the risk of lost investment, if protection cannot be achieved.
There is freedom to practice CNT and CNF Production, if you respect the specific process IP of competitors. Early product and process know-how exists as state of the art.

## 5. Outlook

There are a variety of applications into which the nanofibers can be inserted without additional development. These include addition of the nanofibers to polymers to add electrical conductivity, add mechanical modulus and strength, or act as a CTE moderator.

### *Additive for Electrical Conductivity*

The high inherent electrical conductivity of the fiber can confer significant electrical conductivity on a corresponding composite. The level of conductivity realized in a specific matrix depends on the exact morphology of the nanofiber, the loading level, the type of processing required to prepare the composite, and, to some extent, the properties of the matrix resin. Some of these effects are illustrated in Figure 1. The carbon nanofibers can be debulked to various bulk densities. The process used to do the debulking operation results in generation of small fiber bundles and some reduction of fiber aspect ratio. This, in turn, impacts the resultant electrical resistivity and mechanical properties in a composite. In addition, the process used to incorporate fiber into a specific matrix resin also affects the fiber aspect ratio. Both these effects must be considered when choosing a method for incorporating carbon nanofibers into composites. The process that exposes the fiber to the least amount of shear forces, with the least reduction in fiber aspect ratio, will produce the composite with the highest level of electrical conductivity. In contrast, mechanical properties benefit from the use of processes that reduce the fiber aspect ratio during fabrication, resulting in improved resin permeation and lower void content. The effect of fiber aspect ratio on electrical resistivity is shown in Figure 1. The ASI and LD designations refer to two different debulking methods. The ASI method produces fiber with higher aspect ratio than the LD method. These results show that while graphitization of the fiber having equal aspect ratio yields composites with improved conductivity, the same values of conductivity may be recovered using un-heat treated fiber which has a high aspect ratio.

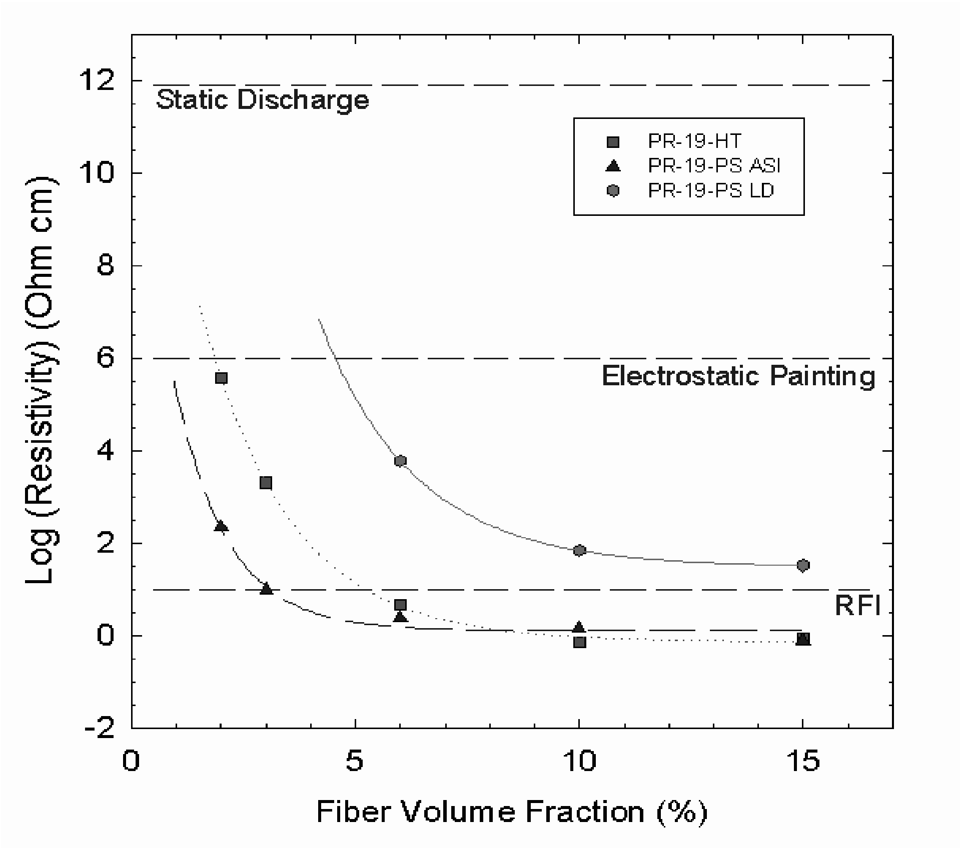


**Figure 1**. Effect of Debulking on Electrical Resistivity of Carbon Nanofiber PP Composites.

There are currently three primary applications that require conductivity enhancement to polymers. The first is static electricity dissipation, which is needed wherever a spark might threaten property or human safety or comfort. Examples are in electronic chip fabrication facilities where static can damage sensitive integrated circuits or areas where there is a risk of combustible fumes building up. Static dissipation is relatively easily satisfied, with a resistivity of about $10^{10}$ Ω-cm being sufficient for all applications. Nanofibers can provide this at extremely low concentrations.

The second is for electrostatic painting of panels, such as for polymer body panels for automobiles. Here the surface to be painted must have a resistivity in the range of $10^4$ – $10^6$ Ω-cm. Many variations of carbon nanofiber achieve this at some concentration, and graphitized nanofibers do so at a concentration of 3% or less. Note that commercial carbon fibers are not appropriate for this use because of their large diameter, which makes a painted surface palpably rough. Nanofibers, however, are small enough to provide a Class A finish.

The third application is shielding of electromagnetic interference (EMI) and electromagnetic signature control. To impact this field, a material must have resistivity on the order of 1 Ω-cm or lower. Graphitized nanofibers achieve this level at moderate to high loadings, with values as low as 0.07 Ω-cm having been shown in some materials. Note, however, that a high loading of nanofibers of 20% is typically much lower than that required for metal fillers to achieve the same results. Metal particles have a high intrinsic conductivity, but have more difficulty forming a conductive network due to their very low aspect ratio. This is important particularly for elastomeric polymers that are used to form gaskets or seal seams in structures. Such materials depend on high resilience and deformability to perform their function. High loadings of metal particles typically degrade these qualities, limiting performance, reliability, and lifespan. The lower concentration required by nanofibers can lead to a better overall product.

### *Reinforcement for Mechanical Properties*

One of the goals for nanofiber application is to provide mechanical reinforcement comparable to that achieved with continuous tow carbon fiber at a price that approaches that of glass fiber reinforcement, and with low cost composite fabrication methods such as injection molding. Theoretical models by Cox [II] and Baxter [III] suggest that reinforcement by discontinuous fibers, such as the nanofibers, can closely approach that of continuous fibers as long as the aspect ratio of the fibers is high and the alignment is good. Work is ongoing to improve the mechanical benefits of nanofibers through fiber surface modification to provide physical or chemical bonding to the matrix. Such modifications have resulted in strength and modulus improvements of 4 to 6 times the values of the neat resin; however, these values are still a modest fraction of what may be anticipated from idealized fiber/matrix interphase and alignment of the fibers within the matrix. The more immediate opportunities for application in structural composites lie in the prospect for modifying the properties of the matrix material. For example, use of small volume loadings in epoxy may allow for improvement of interlaminar shear strength of PAN or pitch-based composites. Nanofiber additives to fiberglass composites could provide benefits to a suite of properties, including thermal and electrical conductivity, coefficient of thermal expansion, and mechanical properties, as suggested by the data in Table 2.

**Table 2**. Thermoset Polyester / Pyrograf-III Composite Properties.

| Sample No. | Fiber Content Wt. % | Tensile Strength MPa | Tensile Modulus GPa | Electrical Resistivity ohm-cm |
|---|---|---|---|---|
| 1 | 17% PR-1 | 51.5 | 4.55 | 3.2 |
| 2 | 17% PR-1, ox | 47.4 | 4.55 | 7.1 |
| 3 | 5% PR-1<br>10%1/4² glass | 44.1 | 11.52 | 5.0 |
| 4 | 5% PR-1, ox<br>10% 1/4² glass | 33.8 | 8.92 | 7.0 |

The use of carbon nanofiber fillers can lead to very significantly enhanced electrical conductivity while contributing to desired mechanical properties. In the examples provided in Table 2, the use of glass fiber in combination with carbon nanofibers yields a lower resistivity than has been observed with comparable fiber loadings in thermoplastic-based composites, suggesting synergistic effects through blending of both reinforcements.

## 6. Markets

The worldwide annual market for carbon nanofibers is approximately 120,000 kgs., with pricing in the range of about Euro 500-1000 per kg. The largest markets for carbon nanofibers are necessarily those which exploit the performance improvement for electrical and electromagnetic applications, including static dissipation for automotive fuel lines, semiconductor manufacturing, and emi shielding for electronics. In such applications, loadings of less than 5% by volume enable desired performance, while minimizing the effect on polymer flow and molding properties. Markets also exist for larger volume use as carbon materials in Li ion batteries, fuel cells, and supercapacitors.

Markets for structural applications also are emerging, where the carbon nanofiber is not used as the high volume primary reinforcement, but as an additive to improve the mechanical, electrical, and thermal conductivity of the matrix materials. These applications have goals of improved interlaminar shear strength, through the thickness thermal conductivity, modification of the coefficient of thermal expansion, and improved electrical conductivity.

Markets are anticipated to experience significant growth in the next 5 to 10 years, as higher volume production comes online and prices drop to below Euro 100 per kg. The market for highly loaded structural applications is expected to grow significantly when the price for CNF drops below Euro 10 per kg., and as ongoing research efforts continue to improve composite processing technology for nanoscale reinforcements. At this price point, applications in automotive and other commodity markets are enabled, generating demand for over 100 million lbs. per annum. Additional factors are that the United States federal government is investing $600 million per year in nanotechnology development, with many state governments following suit with smaller programs. These efforts are being matched almost dollar for dollar by both the European Union and Japan, with other Asian countries developing similar programs. Not surprisingly, these investments are already stimulating new and ever more exotic applications, and leading to spin-off manufacturing operations around major university centers as many able researchers focus their efforts in this general field.

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# Industrial Production of Nano-Scaled Powders: A Case Study

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According to different business research institutes nano-scaled materials have a bright future with excellent growth rates. In particular, already existing materials will have the brightest future. The biggest increase is expected for silica, alumina, and titania.

A variety of nano-scaled powders have been produced in industrial scale since many years. Besides carbon black and precipitated materials, the metal oxides made by flame hydrolysis like silica, alumina, and titania are examples with a long history. This business and the special features of the production of these powders will be explained in the presentation.

Fumed silica is a prominent example for a mamo-scaled product produced in large scale. In fact, it is a family of specialty products with a broad variety of applications. The synthesis of fumed silica is known as the AEROSIL®-Process, a high temperature hydrolysis of a volatile metal precursor in a hydrogen-oxygen flame. The resulting nano-scaled particles vary in size from approx. 7 nm in diameter for the smallest primary particle to several 100 nm for aggregates or agglomerates, respectively.

Besides the pure silica powders, surface modified products are available. For the use in unpolar substrates or special polymer systems the interface of the silica can be adjusted to the application requirements by after treatments like hydrophobization or mechanical treatment.

## *Session 8b - Functional Materials*

# Magnetism of Atomic-Scale Nanostructures

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The physical and chemical properties of nanometer-scale structures are unique functions of their size and shape, and can be very different from those of bulk matter. Particularly fascinating phenomena occur if the nanostructures are subject to lateral boundary conditions on a length scale where quantum behavior prevails. Recent experimental advances have provided the unique ability to fabricate and characterize magnetic nanostructures with dimensions comparable to the exchange interaction length.
I will survey our recent experimental results in the detection and manipulation of magnetism at the spatial limit. Our experiments demonstrate that the spin and orbital components of the magnetic moment of atomic-scale Co nanostructures on Pt surfaces are a strong function of size and shape, more precisely of the local atomic coordination. Compared to thin films and bulk crystals of Cobalt, the 0D and 1D structures are characterized by very large localized orbital magnetic moments and giant magnetic anisotropy energies. For monatomic chains of Co atoms the anisotropy energy is large enough to stabilize ferromagnetism below 10K.
The results are not only important for a fundamental understanding of low-dimensional magnetism but bear also important implications for magnetic data storage technology. Currently nearly $10^6$ atoms (spins) are needed for the construction of a stable magnetic bit in the hard disc of a personal computer. The measured anisotropy energies for the Co nanostructures indicate that not more than a few hundred cobalt atoms might be needed in tailor-made structures for constructing a stable magnetic bit at room temperature.

# Surface Engineering and Technologies for Nanostructured Coatings

**P. Piseri**

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The ability of controlling surface coatings at the nanoscale is of paramount importance for a large scale industrial development of nanotechnology. At present many physical and chemical methods are available for the nanofabrication of layers and coatings with nanometric control of the structural and functional features, however the scale-up of these methods remains a major challenge.

During the last century, physical vapor deposition (PVD) techniques have been developed to a high degree of maturity for the production of structural and functional coatings for optical, mechanical, biomedical, electronic and chemical applications. Conventional vapor phase coating processes are easy to scale up but they do not allow a fine control on the nanostructure of the deposited layers.

Recently several innovative solutions have been proposed to overcome these limitations and to bridge the gap towards large scale nanomanufacturing processes based on PVD.

In this talk I will describe the common features and requirements necessary for a PVD-based nanomanufacturing approach. I will also discuss, as a case example, the deposition of supersonic cluster beams for the large scale synthesis of nanostructured coatings ranging from organized nanoislands to nanostructured thin films. In particular the surface engineering of nanostructured coatings for the batch fabrication of multi-element micro- and nano-sensing devices will be addressed.

# Nanocomposites: Stakes and Challenges

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According to the very general definition of the Oxford dictionary, a composite is a material made of various parts. In a more scientific context, we term *composite* a material consisting of different phases. This material becomes a *nanocomposite* when one of the phases has at least one dimension in the nanometer range. A fundamental advantage offered by composites is the possibility to adequately select the constituting phases for optimum and synergetic combination of their individual properties in the resulting material. Interestingly, in the case of nanocomposites, new properties can possibly arise from the relatively large volume of the interfacial region which may act as an additional phase.

Based on the above definitions, nanocomposites encompass organic/inorganic, ceramic/ceramic, ceramic/metal, metal/metal compounds. Stricto sensu, colloids which are often used as precursors of hybrid solid nanocomposites, could also be included in this generic classification. Nanocomposites include various materials such as:

- Nanostructured metal/metal, metal/ceramic, ceramic/ceramic materials, films and coatings;
- Organic/inorganic (hybrid) nanocomposites (e.g. nanoparticles, nanorods, nanotubes, platelets embedded in polymer matrices);
- Colloids (e.g. metal or ceramic nanoparticles dispersed in liquids);
- Composite nanoparticles, nanorods, nanotubes (e.g. polymer-encapsulated ceramic nanoparticles or carbon nanotubes; metal or ceramic-coated nanoparticles).

All these kinds of nanocomposites are designed to fulfil specific requirements for various applications including mechanical, thermal, electrical, dielectric, optical, magnetic, electromagnetic, optoelectronic, thermoelectric, catalytic, and biomedical applications. Major industrial areas can benefit from these new materials, such as for example:

- Automotive industry, Aeronautics and Metallurgy (e.g. shape-memory alloys; light weight tough materials; hard coatings for wear reduction and for corrosion protection; smart damage control or repair; thermosets and thermoplastics);
- Microelectronics and Micromechanics (e.g. piezoelectric ceramics; printing inks; adhesives);
- Pharmaceuticals and Medicine (e.g. smart health monitoring; cosmetics);
- Telecommunications (e.g. optical fibers; optoelectronic devices);
- Information Technology (e.g. data storage);
- Energy and Environment (e.g. smart sensors; photovoltaic devices; membranes for fuel and petrochemical production, biochemistry purifications, environmental remediation, fuel cells; gas barrier materials for articles containing highly compressed air; catalysis; gas storage media).

Nanocomposites perhaps represent the field where nanotechnology will make the most significant commercial impact over the coming years.

The enthusiasm for nanocomposites started from the demonstration of an increased flexure strength by adding silicon carbide nanoparticles into a microcrystalline alumina matrix. Then

researchers from all over the world tested several ceramic/ceramic and metal/ceramic nanocomposite systems to increase both strength and toughness. Homogeneous distribution of the phases and consolidation for obtaining a fully dense material while retaining the nanostructures remain key issues. Besides, most of nanocomposites actually refer to a nanoscale phase dispersed in a micron-scale phase (nano-micro composite) and very few composites with a nanocrystalline matrix have been produced so far.
Simultaneous evaporation of two phases by ion-assisted techniques (e.g. magnetron sputtering or arc PVD) results in the inclusion of ceramic, metallic or carbon clusters in ceramic films which are used as hard coatings for wear reduction and corrosion protection. The relative concentration of the phases is controlled by adjusting the deposition parameters. But, the size and the morphology of the embedded nanocrystalline phase which appear to have an important impact on the final mechanical properties still need to be mastered.
The size of metal or semiconductor dots in a matrix is also a critical parameter to be controlled in order to take full advantage of the quantum confinement effects for novel optoelectronic properties.
A standard technical approach to fabricate hybrid nanocomposites consists in mixing the inorganic nanophase (nanoparticles, nanorods, nanotubes, platelets) into the organic phase (polymer or liquid). But, agglomeration of the nanocrystallites and segregation of the phases often prevent a homogeneous dispersion of the nanophase material into the matrix. A possible remedy is the functionalization of the inorganic nanophase with appropriate molecules. It should however be kept in mind that the functionalization must not debase the resulting properties of the nanocomposite by changing the properties of the nanophase or by adversely altering the composition of the interfacial region.
In an effort to circumvent these difficulties, inorganic-organic hybrid materials have been developed via sol-gel routes where bridges are formed between inorganic clusters and organic entities. As for colloids, they are also being used to generate 3D periodic nanostructures. New one-step methods are now being considered, as for example the synthesis of colloidal metal particles in a forming gel matrix by photo-reduction followed by polymerization *in situ*. Even though these methods can in principle yield relatively large quantities of material, the expensive precursors prevent low-cost production in the short term.
As the technology is continuously progressing with new developments in synthesis methods, it now appears that novel nanocomposites are rather “molecular composites” in which the *two* phases consist in molecular entities and the resulting material would be considered as a new molecular compound rather than a mixture of phases.

Even though tremendous improvements have been made leading to novel nanocomposites with proved amazing properties, remaining challenges still mobilize research efforts. For example:

- The size of the nanophase and its homogeneous distribution in the matrix are difficult to control specially in the case of dense materials and hard coatings;
- The internal organization of the nanocrystallites within the matrix is far from being mastered although the fabrication of periodical structures would be of great interest for electronic and photonic devices;
- The characterization of the interfacial domain whose composition is crucial to optimise and tailor the final properties still represents a technical challenge as appropriate tools still need to be developed;
- A better fundamental understanding of the formulation/structure/property relationships should lead to an optimum design of the nanocomposites for the targeted applications;

- The development of high throughput low-cost production techniques is an absolute requirement to impact industry and society.

It is obvious that these challenges cannot be resolved by isolated teams, but on the contrary they require joint efforts of several international research groups with complementary expertises in order to jump the next step forward.

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# Functional Organic Nanomaterials: The Case of Liquid Crystals

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Liquid crystals spontaneously self-assemble into ordered nanomaterials. They share the typical long-range order of crystals with the fluidity of liquids. Liquid crystals are part of our everyday life and are frequently encountered in applications such as liquid crystal display of our computer and TV screens. Beside these conventional applictations, scientists have started to combine liquid crystalline character with semi-conducting properties in a new class of nanomaterials. This unprecedented class of materials is made of disk-shaped molecules that stack into columns. The columns behave as nanowires that conduct electrical charges. The beauty of these nanowires arises not only from their self-assembled character but also from their ability to self-heal structural defects. Self-healing ability is common for living organisms but is rather unique in materials. The potential of discotic liquid-crystalline semi-conductors as functional materials will be highlighted in optoelectronic devices, and their perspectives will be discussed [1].

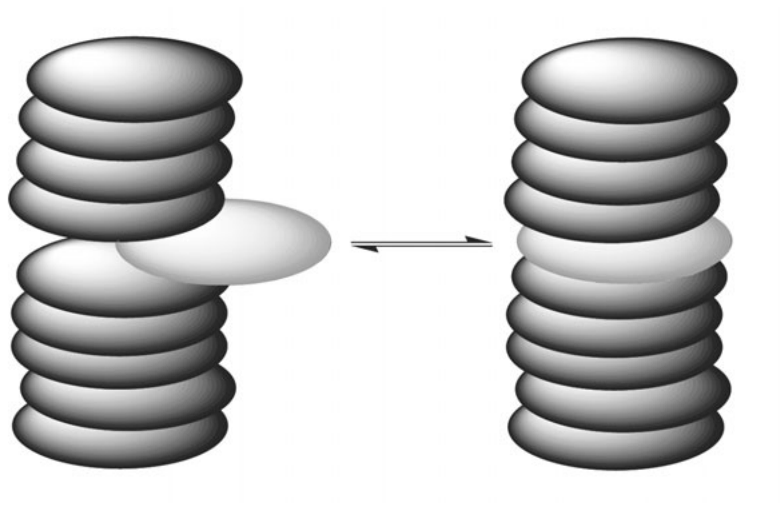

**Figure 1**. Schematic representation of the self-healing ability of discotic liquid crystals.

[1] Part of this work has been conducted in the framework of the DISCEL project funded by the European Union (DISCEL G5RD-CT-2000-00321). Information can be found at: http://dbs.cordis.lu/fep-cgi/srchidadb?ACTION=D&SESSION=157072002-9-5&DOC=1&TBL=EN_PROJ&RCN=EP_RCN_A:54552&CALLER=PROJ_FP5

# Computational Catalysis: From Quantum Mechanics to Nano-Scale Materials Design

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Theoretical methods based on density functional theory have reached a level of accuracy and efficiency that they can be used to describe and understand quite complex systems in many branches of science and engineering. They may even be used to help designing new materials at the nano-scale. The new possibilities will be illustrated by three examples. First, it will be shown how the calculations can be used to completely map out a catalytic reaction on a metal surface. Using ammonia synthesis as the prime example, it is shown how the concepts developed on the basis of the calculations can be used to understand variations in catalytic activity from one metal to the next. The second example concerns the description of low temperature fuel cells, and will illustrate how the calculations can be used to design new, more efficient anode materials. This leads on to the final discussion of the prospects of using electronic structure methods more generally in the search for new materials. It will be illustrated how one can perform materials screening on the computer by combining the density functional calculations with efficient evolutionary search algorithms.

# Session 8c - Ambient Intelligence

## Systems Engineering for the Nano Worlds

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Micro and nano technology based (sub)systems are increasing in complexity both as stand alone components and highly interconnected / integrated systems. In essence, micro/nano systems technology is advancing towards the realisation of, multi-functional, intelligent devices such as the lab-on-a-chip for diagnostics or miniaturised inertial measurement units for aerospace / automotive applications. These sub-systems will, in future, become integrated within larger systems to form part of an, intelligent, ambient environment populated with sensors, actuators and wireless transceivers. In such complex environments, intelligence will be distributed and shared via, ad-hoc, wireless networks and data/knowledge will be processed in real-time. The essence of such an ambient intelligent environment forms the basis of a world of systems of systems.

### 1. Engineering "micro" Systems

#### *1.1. Systems Engineering*

Two aspects characterise microsystems, namely; (i) the multi-disciplinary nature of the underlying technologies and (ii) the level of integration required to develop multi-functional devices. It is either, or both, of these characteristics which place microsystems in a unique position from the perspective of an overall systems design and/or its evolution as well as the intended application.
Systems engineering, as a discipline, addresses all aspects which provide a framework for the integration of people, processes, tools and technologies in order to improve the management of risk, product configuration and technology insertion. This process is equally applicable to the design and commercialisation of microsystems-based components as shown in Figure 1:

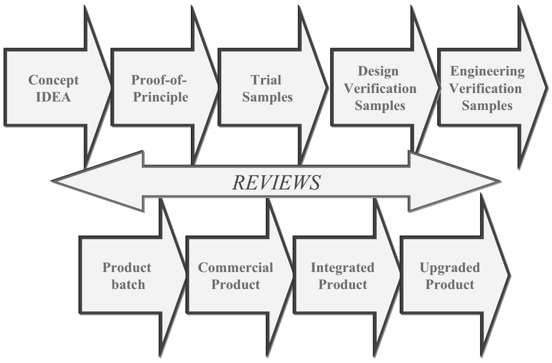


**Figure 1**. Systems Engineering – Product Lifecycle.

The diagram illustrates how, given the lifecycle of a product from its conceptual stage to its production (and cradle to grave), a number of specific design and review steps are pursued in order to mitigate the risks associated with novel concepts, technologies and, possibly, new applications. These aspects tend to be associated with microsystems as a general rule).

In essence, systems engineering, as a science in its own right, addresses the salient issues associated with the development and evolution of complex and interactive technologies, namely:

- Evolving system complexity through change in requirements and/or uncertainty
- Product evolution, lifecycles and obsolescence: basically, from concept through to sustainable maintenance
- Human factors and human interactions: Man-machine integration within the ambient, intelligent, environment
- Information and data processing, knowledge management and data dissemination, exploitation and security
- Intelligent autonomy and decision making
- Monitoring and diagnostics; leading to self analysis, re-use and reconfiguration and, possibly, self-assembly
- Modelling, simulation and prototyping.

### *1.2. Systems of Systems*

The relevance of some (if not all) of these issues has become increasingly important to all fields of engineering projects which are characterised by their multi-disciplinary technologies and systems such as microsystems. This is particularly the case for complex multi-national projects incorporating a diverse set of expertise from across the world. The European Union's framework 6 Integrated Projects are a case in point.

Microsystems, although on a different scale, are also tending towards increasing complexity. In essence, microsystems technology is advancing towards the realisation of, multi-functional, intelligent devices such as the lab-on-a-chip for diagnostics or miniaturised inertial measurement units for aerospace / automotive applications. These sub-systems will, in future, become integrated within larger systems to form part of an, intelligent, ambient environment populated with sensors, actuators and wireless transceivers. Intelligence will be distributed and shared via, ad-hoc, wireless networks and data/knowledge will be processed

in real-time. The following diagram in Figure 2 illustrates, schematically, how the ambient intelligent environment forms the basis of a system of systems;
In essence, future components will need to be designed and configured as part of a complete system scenario. The integration will be inherent and the interface ambient and seamless.

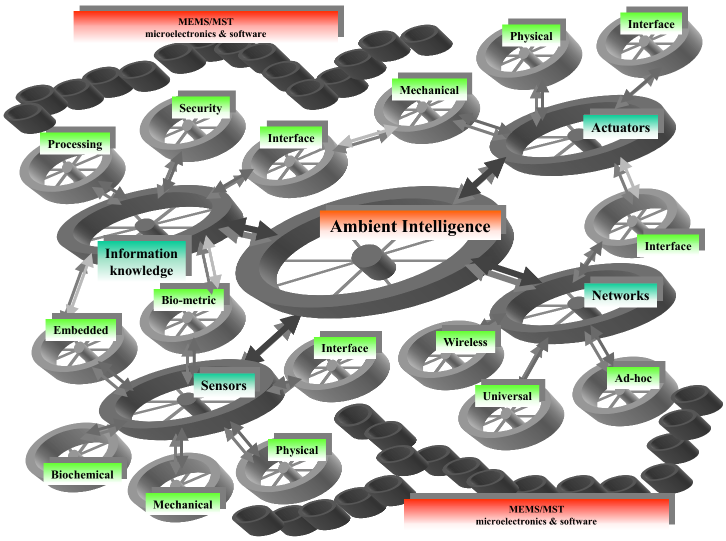


**Figure 2**. The Ambient Intelligent System of Systems.

## 2. The SEIC

In common with many other companies, BAE SYSTEMS has realised the need to focus itself on the challenges inherent in emerging classes of complex systems as well as be able to address future trends in applications which will be demanding higher levels of integration and inter-operability. In this context, BAE SYSTEMS and Loughborough University have jointly set up a centre of excellence in Systems Engineering based at Loughborough in the heart of England. The initiative is a manifestation of the unique partnership that has existed for many years between Loughborough University and BAE SYSTEMS.
Underpinned by commitments from BAE SYSTEMS and Loughborough University as well as support from emda (the East Midlands Development Agency), the Systems Engineering Innovation Centre (SEIC) has been set up to become an internationally recognised resource for systems engineering expertise and knowledge based in the UK.

### *2.1. SEIC Objectives*

To date, the SEIC has attracted top research scientists and engineers from academia and industry. The Centre is currently being designed to provide state of the art research laboratories, including synthetic environment laboratories, virtual engineering capabilities as well as office accommodation, conference facilities, a lecture theatre, exhibition area and a highly integrated communications infrastructure.

These facilities are being set up to address the following key objectives:

- To focus on the core competencies underpinning profitability and growth, namely Systems Engineering and Project Management
- To promote and enhance the Systems Engineering Discipline across industry
- To address the Systems Engineering challenges associated with increased complexity, degree of integration, risk and novelty
- To attract higher levels of leveraged funding through a high profile national Centre with focused support from the EU, NATO, the DTI, EPSRC, MoD, etc.
- To connect with other centres of excellence and academic partners providing leveraged collaborative research
- To obtain cross-fertilisation of ideas by involvement with partners in other sectors and applications

## 3. The Presentation

The presentation at the EuroNanoForum outlined the basis of systems engineering in the context of micro-nano technologies within the framework of an ambient intelligent environment. The presentation explained the issues underpinning systems engineering and those relating to the lifecycle of micro and nanotechnology developments and commercialisation.

## 4. Acknowledgements & Contacts

EnablingMNT: http://www.enablingMNT.com

The SEIC: http://www.seic-loughborough.com

# Embedded Energy: A Key for Realizing Ambient Intelligence

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The topic of micro power generation is of increasing interest to match the demand of longer lasting power supplies for autonomous devices. Because of their high energy densities fuel based systems have considerable advantages over conventional chemical batteries. In this respect Micro Fuel cells have been paid the major interest and their imminent commercialisation has been announced by many large players. DMFC have been demonstrated with efficiencies over 40% but in-spite of that fuel cells are rather slow in response and have relatively low power densities with respect to micro combustion systems. There is then a variety of applications where the fast chemical-physical kinetics offered by micro combustors is an opportunity which is given very high concern. In this respect we will briefly review the technologies under development distinguishing between two major classes: systems without moving parts and systems having moving parts. We will then concentrate and emphasize the presentation on the description of the peculiarities of fast chemical reactions in a nanostructured "environment". Taking as a reference the inhibition and enhancement of spontaneous emissions of atoms and molecules in microcavities and photonic crystals, we demonstrate that fast chemical reactions are influenced by the geometry of the media where they take place. Specifically, spectral measurements on combustions of hydrocarbons in an ordered nanoporous media show much lower infrared signatures than those exhibited by the same combustions when taking place in free-space or in proximity to smooth surfaces. The results, which are here demonstrated for the first time, will be explained in terms of both in-cavity mode inhibition-enhancement and energy transfer to the structure which in turns re-emits in a spectrum defined by the ordered media rather than by blackbody radiation. To implement ambient intelligence confined combustion can be exploited in selective and high efficiency direct chemical to electrical conversion power supply systems and in a variety of novel optoeletronics devices as well as.

# Drivers for Nanotechnologies to Ambient Intelligence

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Drivers for nanotechnology, drivers for innovation, drivers for economic growth. Many people say that the key to anticipating future growth is to first understand the underlying motivation for current trends today. According to this belief, by drawing a line from the past to the present, we are able to predict the future by extrapolation. The now infamous Moore's law is an example of this endless march down the road of technology development. For many years now scientists have been predicting that modern IC production technology has finally reached a limit but, miraculously, technology continues to push the envelope, and Moore's law is maintained. Maintaining a position on the leading edge of technology requires a combination of both momentum and maneuverability: momentum to keep-up with industry laws and maneuverability to react quickly to technological ruptures coming from research.

But what should happen if there is a rupture in this natural progression? The grand challenge of technology scientists is to determine whether the top-down approach or the bottom-up one will be the basis for our future nano-technologies industry.But industry development requires a strong need for products used in our daily environment.

Hopefully, new communication modes, based on instant and ubiquitous interactivity are developing to build the so-called ambient intelligence environment. These two key evolutions of technology and usages are the basis for our future and are strongly related, far more than is apparent to the common citizen. In fact, no strong evolution of usages can be achieved without an increased capability brought by technology. In this paper, we will try to illustrate, with some examples this enabling link: we will show that the nano-inside concept, using nano-sized materials in electronics and sensors, when needed, where needed is essential to handle the increasing flow of information required by ambient intelligence.

The move to the nano-world, being top-down or bottom-up is more evolutionary than revolutionary and will need a complementary approach mixing technology background and multiscience knowledge. New research results will emerge from this cross-boarder fertilization and will be converted in innovation thanks to the competencies of engineering staff, because assembling devices one molecule at a time using molecular building blocks requires a skill set not typically found in a traditional microtechnologies environment. These innovating technologies will be the building blocks of components, integrated later in sub-systems and systems. Communication between these systems allows the development of a new form of interactivity, whatever your needs, wherever you are. This is one face of ambient intelligence.

The on-going era of microtechnologies allows us to built mobile objects handling information in a discrete way. They sense it through numerous sensor technologies, they register it in mega-memories, they compute it with a microprocessor, they diffuse it through RF channels or displays. Electrons and photons are the vectors of today's information, in the future they will be joined by ions, living materials, fluids, all moving together in inter-connected networks.

The future will use research inputs from nanosciences and technologies to handle information in different ways. Sensors will be integrated at the source of the information, they will be everywhere, collecting information in living materials and forwarding it to ubiquitous nanochip.

# Micro and Nano Technology for Medical Diagnostics

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Advances in ubiquitous computing, sensors and telecommunications have impacted considerably on the average consumer. In the area of mass health care, rapid advances are also evident, however, for specialised areas of health care addressing particular patient groups, such as the young, elderly and the disabled, advances have been somewhat limited and, in some areas, non-existent. To some extent, there is an almost complete lack of in-built intelligence and the devices are entirely passive in their interaction with all user groups (clinicians, patients, medical equipment providers), despite the fact that the quality of life of large numbers of people is affected by the quality of their assistive devices. Often, these people lack the necessary information to make truly informed decisions in their respective areas of interest: safe usage; prescription and monitoring; or innovative design advances. The functional integration of man-made devices and biological systems represents one of the great challenges of science and technology. Efficient real-time exchange of information and/or materials across the molecular scale interface between biological and physical systems is a core platform requirement to realise this vision.

Addressing these issues, the convergence of micro and nano technology (MNT) with biology promises tremendous advances and potential cost reductions for medical applications and health care in general. Solutions that specifically address the seamless integration of concepts, processes and technologies across the enabling disciplines and dimensions of MNT, will provide the opportunity to realise unique systems for medical diagnostics (ie, point-of-care). Such techniques will rely on a combination of factors: the development of enabling technologies for the modular components (biorecognition elements, sensors, microfluidics); the integration of key components into a useful system using novel, low cost techniques; the interfacing of the system to the external environment and the informed understanding of system level requirements from the user community.

Today, we see that the development of intelligent systems for sensors around and on the human body is evolving to more autonomous systems, demanding miniaturisation in size and power. Microsystems contribute to this in many ways (microsensors, power scavengers, microactuators), with even greater functionality of systems is facilitated via the emerging role of nano technology. In particular for diagnostic applications specifically addressing the needs for point-of-care, biosensors based on MNT are of great interest, with the main driving force for their development based upon their small size, increased functionality, faster response and the opportunity for lower costs. The particularities of microsystem technologies like miniaturisation, mass (batch) fabrication which facilitates standardisation and cost reduction, arrays (parallelism), as well as system integration are exploited in all the fields involved in biosensor development. With the increasing number of fabrication methods available, the diversity of the materials is continuously expanding, thus providing new opportunities for development of platforms that exploit this micro-nano-bio interface.

In this presentation, some of the key issues challenging MNT development for medical diagnostic applications, addressing the main enabling technologies (sensors, packaging, power, communication) will be introduced. Several examples from our recent work are presented to illustrate the inter-disciplinary nature of this activity, including sensors for DNA, proteins and neurons. An example of early system implementation in a medical care environment will also be presented, illustrating an ambient intelligent system for the remote monitoring of patient ECG/EEG levels.

## *Session 9a - Nanoelectronics*

# Interfaces with Biomolecules

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We describe two basic approaches to fabricate biomolecular electronic devices. The first approach relies on the physisorption of DNA bases in the gate of a planar field effect transistor structure. The device exploits the self organisation capability of the polar DNA bases, which form a crystal of ribbons in the solid state. The device operation and performances are discussed and compared to the carbon nanotube devices.

The second approach exploits the covalent bonding (chemisorption) of metalloproteins (azurin) whose charge transfer activity is exploited to elicit a current in the gate of the transistor. In this case, the functionalisation of the gate results in a hybrid device, whose performances are quite interesting. The sequential oxidation/reduction of the immobilised proteins (a sort of inverse respiratory process) leads to a very effective transistor operation, at room temperature and in the solid state.

# Molecular Electronics

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Molecular electronics is the scientific domain aimed at developing electronic devices and circuits based on nanoobjects like (bio)molecules, clusters, and nanowires including carbon nanotubes. Molecular electronics has recently raised prospects as a potential complement or even successor to the present day information technology based on CMOS circuits.
The CMOS technology evolution is still governed by Moore's Laws which have been proven true for the last 30 years. However, Moore's Laws, under the form of the International Technology Roadmap for Semiconductors (ITRS), predict that the CMOS technology will reach fundamental limits in terms of miniaturization and energy consumption by ca 2015, concurrently to a dramatic increase of the cost of the production units. This is a prompt for the development of alternative technologies for information processing.
Molecular Electronics is increasingly studied as a candidate alternative technology for three main reasons. First, it inherently deals with the size of molecular objects. Indeed, it is foreseen as a possible answer to the miniaturization problem if those very tiny objects can be assembled into functional systems. Second, it is a natural field for the use of self-assembling techniques. As stressed in the IST-Technology Roadmap for Nanoelectronics [1], self-assembly, and more generally, bottom-up approaches appear today as the only reasonable way to assemble ultra large numbers of molecular objects into circuits. Moreover, self-assembly is also identified as the most promising way to reduce significantly the fabrication costs compared to what is expected for silicon based devices. Third molecular electronics, dealing with objects of inherent quantum nature, is a perfect field for testing and developping new paradigms of architecture, which may prove efficient in terms of energetical cost of computation compared to CMOS.

Molecule based functional units development has been at the heart of molecular electronics during the last 8 years. Following pioneering experiments on molecular transport[2], various techniques to contact single or a few molecules and theoretical models have now been developed allowing to understand the relationship between the molecular structure and the corresponding transport properties [3, 4]. Furthermore, functions have been demonstrated based on molecular units. This includes, diodes [5], negative differential resistances and their application to memory[6], electromechanical [7, 8] or electrochemical switches with memory applications [9] and single electron transistors [10].
Among the objects Molecular Electronics builds upon, carbon nanotubes (CNT) occupy a unique place. In particular they exist as semiconducting or metallic wires and have been used to demonstrate molecular devices like transistors, diodes, RDT or SET. During the 2001 summer, a sudden acceleration of the field occurred with the demonstration of room temperature SET[11], and of NT transistors showing gain [12]. This was immediately applied to the realization of logical gates mimicking the CMOS ones but with a lateral channel extension reduced to 1 nm. These breakthrough together with recent demonstrations showing that for a comparable geometry CNT FET surpasses CMOS FET,[13] constitute one more

evidence that CNTs represent today a potential alternative to the silicon based information technology.
Finally, nanowires have also been recently shown to be manipulable and suitable for the fabrication of devices including optoelectronics ones, which opens up new possibilities [14].

Beside the ongoing developments of new or improved devices based on molecules, clusters or nanotubes, the present day challenge is to go beyond the device level and attain the circuit level. This implies to tackle two fundamental problems: what is the appropriate architecture for the mùolecular computerand how to fabricate circuits and systems employing ultra large numbers of molecules?
A few experiments have shown examples of logic circuits, memories including possibly dense ones [6, 9, 15] and proposition exists for reconfigurable computers and evolvable hardware. Other paradigms of computing have been proposed like neuromorphic computation with networks of self-assembled and interconnected quantum dots, bioinspired systems, monomolecular computing or quantum computing [16]. These paradigms deserve to be tested since they may offer solutions to the energetical cost of computation problem.

The issue of practical implementation of the architecture, whatever it is, has only begun to be addressed. Self-assembly is at the front line there. It has been shown to be a useful tool for assembling nanoobjects on a surface [6,17] or between themselves [18]. Its full potential is certainly not realized yet since the fantastic self-organisation possibilities of biomolecules have only begun to be used as templates for assembling functional nanoobjects into devices and circuits [19].

Molecular electronics has seen an extremely rapid development during the last 8 years and raised fantastic prospects. Its expansion depends on not expecting too much in a too short time and on a proper positioning with regard to the present and future CMOS technology. Indeed Si-based CMOS will remain a tremendously efficient technology with profound evolution toward the use of non-traditional CMOS materials and concepts (e.g. metallic gates or Cu for interconnection,  and Si nanowires and single-electronics for memory) aiming at tackling the immense challenge of the continued scaling of semiconductor technology. It therefore seems likely that molecular-electronics solutions will come into play through hybrid integration of CMOS and molecular circuits. This offers the combination of advantages of the two worlds. It also echoes the fundamental problem of interfacing the molecular computer to the outer world. This constitutes one of the major bottlenecks of the field with differences in length, energy, current, and frequency scales between the (future) molecular computer and the micro-nanotechnologies. To overcome this barrier and allow medium to large scale evaluation of molecular electronics solution on a 5-10 years timeframe- a key point for the reinforcement of the domain-, requires to go beyond today's achievements in particular in terms of mastering the precision (likely down to 10 pm) to assemble the molecular computers themselves and to their interface. This may prove valuable even for conventional microelectronics itself.

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# Implications of Nanotechnology for Electronics

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Nanotechnology impacts electronics in both incremental and paradigm-shifting ways. There is great excitement and publicity surrounding examples - such as carbon nanotube circuits - of the latter, but advances as mundane as characterization of wafers by force microscopy and mask repair using focused ion beams have already become part of the toolkit of microelectronics.

Another aspect of nanotechnology is that it places new demands as well as provides new opportunities for microelectronics at the systems as well as components level. The talk will describe these several influences of nanotechnology on microelectronics, with a view as to how nanotechnology is central to the maintenance of Moore's law.

## *Session 9b - Nanobiotechnology for Health*

# The Cancer Nanotechnology Plan. A Roadmap for Deployment of Nanotechnology in the Fight Against Cancer

**M. Ferrari**

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A challenge goal has been issued by The National Cancer Institute that by the year 2015 there will be no more suffering and death due to cancer. Nanotechnology will provide a fundamental and vital contribution towards the accomplishment of this historic objective. By the year 2015, nanotechnology will be in the clinic, with a broad spectrum of intelligent, multifunctional nanosystem products for the prevention, early detection, diagnosis, treatment and system management of neoplastic diseases. Nanotechnology will become a fundamental component, integrated in clinical, basic and applied research, training and translational programs at all leading institutions.

The key events for the full fruition of the power of nanotechnology in the conquering of cancer will be the demonstration that nanotechnology provides:

a. The operational counterpart of molecular biology in medicine;
b. The integration of prevention, diagnostic, and therapeutics on a single platform; and, ultimately;
c. The opportunity to develop in the laboratory a sequence of progressively more powerful approximation, that converges to a model inspired by the ultimate cancer-controlling apparatus: the immune system.

Opportunities exist for nanotechnology-based advancements in all areas of cancer research, including prevention, early detection, screening and monitoring, diagnostics, therapeutics as well as chronic symptom management for aggregate patient-centered medicine. The highest priority developments center around 1. Multifunctional nanoparticulates (synthetic organelles) for intravascular administration, 2. Implant Nanotechnologies, and 3. Proteomic and Early Detection Nanotechnologies, as these developments have broad applicability as well as the potential for rapid clinical integration.

For the potential benefits of oncological nanotechnology to be realized, a most difficult challenge must be successfully met: bridging the gap between the expert developers of nanotechnology and those that possess the vision and knowledge for providing advances against cancer, in the clinic and the laboratory. Through implementation of a community consultation plan, adequate and appropriate funding modalities and establishment of intramural catalyst facilities, great achievements will be made in the fight against cancer and usher in a new era in science, medicine and most importantly, the quality of life for everyone.

# Protein Engineering for Nanotechnology: Applications to Drug Discovery and Human Health

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Proteins are intrinsically suitable for nanofabrication: their dimensions are in the nano-scale, they are able of specific binding and catalysis, they can spontaneously self-assemble in complex nano-structures. Protein engineering offers an extremely powerful tool not only for the fine tuning of the properties of existing proteins and enzymes, but also for the creation of fusions suitable for immobilisation or for concerted functions, as well as for the *de novo* construction of artifical systems or the creation of *ad hoc* catalytic systems by directed evolution.

One example of a combination of complementary protein engineering approaches is the Molecular Lego developed in our laboratory that uses protein modules for assembling nanodevices for applications in drug discovery, human health, diagnostics and environmental monitoring. Protein domains are used as catalytic (P450 BM3 haem domain and human liver P450s) or electron transfer (flavodoxin and P450 BM3 reductase) modules. The modules are fused at genetic level and they self-assemble in active complexes when expressed in *E.coli*.

The objectives are to build assemblies with improved electrochemical properties, to construct soluble human P450 enzymes to be used in a "liver chip", and to generate libraries of new P450 catalytic modules to be exploited in biocatalysis for drug/fine chemicals synthesis.

Rationally designed, gene-fused assembly are obtained from the soluble haem domain of cytochrome P450 BM3 from *Bacillus megaterium* and flavodoxin from *Desulfovibrio vulgaris.* The assemblies are successfully expressed and characterised in their active forms, displaying improved electrochemical properties.

The human cytochrome P450s constitute an important family of monooxygenase enzymes that play a central role in drug metabolism. Research in our laboratory has shown how the major human liver isoforms, 3A4, 2C9, 2C19, 2D6, 2E1, 1A2, can be expressed in a soluble and catalytically self-sufficient form, by fusing key elements of the human P450 genes with the reductase of P450 BM3. The resulting P450 assemblies are used for the construction of an arrayed human liver chip based on electrochemical detection and to be used for drug discovery.

Another project developed in our laboratory deals with the directed evolution of P450 enzymes to engineer novel catalysts able to carry out specific reactions produced only at very low yields in conventional chemical synthesis. The bacterial P450 BM3 is engineered to be able to carry our enzymatic oxidations of specific drugs as well as polyaromatic and polychlorinated hydrocarbons. These novel catalysts can also be assembled on electrochemical chips to be used as biosensors for diagnostics abd environmental purposes as well as biocatalysts for drug discovery.

# Challenges and Perspectives for Tissue Engineering. The Scientific Consideration

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Tissue Engineering is a multidisciplinary emerging field that applies the principles of biology, chemistry, physics and engineering to develop tissue substitutes to restore, maintain or improve the function of diseased or damaged human tissues. The concept considers different mechanisms of action, being the most interesting the following:

- One approach involves the use of a multicomponent system prepared by the seeding of biodegradable scaffolds with donor cells and growth factors, and after a determined process of cell growth, proliferation and multiplication “in vitro”, the implantation of the system in the local point where it is necessary for the regeneration and growth of a new, healthy tissue.
- The second approach is based on the direct application of a support (in general polymeric, but also can be formulated on the basis of bioactive ceramics and composites) into the damaged area, together with the corresponding growth factors and other drugs that protect the damaged zone, and stimulates the regeneration of the damaged tissue. In this case it is possible the application of systems by injection without surgery or with a minimum invasive surgical process. One interesting point is that this kind of systems can be applied in a pre-cured state and undergo a curing process after the application in the required zone, giving rise to the formation of a support with enough physical and mechanical properties and excellent accommodation to the surface of the geometry of the damaged area.

The application of one or other depends on the localization and extension of the damaged tissue and the time required for the restorative process. Tissues are organized into three-dimensional structures in the body, by distribution and dissemination of cells in a extracellular matrix, which is built by the own cells. This architecture contributes significantly to the development of the biological functions of the cells and in particular the nutritional processes as well as the spatial organization of the cells. Therefore, the human tissues are organised in complex structures with three main structural components: - Cells organized into functional units; - The extracellular matrix segregated by the cells, and – scaffolding architecture that provides the medium for the development of the cells function. Obviously, the design of artificial tissue substitutes is based on the natural structures, and the main objective of the developments in Tissue Engineering are based on the biomimetic approach to offer systems as close as possible to the natural progenitor. In this sense the most important components of the regenerative process are the cells, the scaffold and the adequate nutrients and growth factors.

Scaffolds can be seeded with adult-derived cells that are capable of undergoing subsequent differentiation after being cultivated “in vitro”. In this category are included cells of the skin, cartilage, muscle, tendon, ligament, bone, endothelial, and others. However, the most attractive are the stem cells localized mainly in the marrow and other points of the body or the hematopoietic and immune system. The specific host cells can be seeded in acellular scaffolds to multiply the population without loss of the final phenotype, until reaching the enough cellular concentration to be implanted. At this point, the physico-chemical characteristics and even the geometry of the scaffold is one of the most important issues to be considered for the preparation of a good scaffold- cellular- growth factors complex systems for implantation. Considering the nature of the scaffold, a great variety of ceramics, polymers and composites can be used as biocompatible and biodegradable or resorbable components in the form of solid films, gels or macroporous systems. Polymers offer enormous possibilities considering the chemical composition, such as aliphatic poly(hydroxyesters): poly(glycolic acid), poly(lactic acid) , copolymers of lactic and glycolic acids, poly(hydroxyl butyrate), polyanhydrides, poly(amino acids), poly(ortho esters), are high molecular weight biodegradable systems widely used for the preparation of resorbable scaffolds because of their good biocompatibility, mechanical behaviour and cell adhesion and tolerance. Other polymer systems from natural origin such as collagen, chitosan, alginates, fibroin, and hyaluronic acid are interesting systems chosen from the nature for the preparation of a great variety of scaffolds. In addition much of these polymeric systems can be prepared in the form of elastic and soft films, hydrophilic or hydrophobic depending on the composition, micro or macroporous blocks for the seeding of cells with good biological response.

Respect to the application of the cell/scaffold system into the body, there are two general strategies that are based on the implantation of foams, sponges, films, blocks, using an open surgical procedure, or introduced in a minimally invasive manner utilizing syringes or endoscopic techniques. The typical injectable forms of materials include hydrogels, microbeads or two components self curing formulations.

A challenge to the large-scale development and application of Tissue Engineering is the immunologic barrier. This concept can not be generalised because of the individual character of the inmunogenical processes, which limits the development of a universal donor cell type that could be used to design and fabricate a cell/scaffold system available commercially in the next future.

However, the benefits of the development of Tissue Engineering techniques, and in particular those based on the application of a support and the necessary growth factors and stimulating agents is reasonable, and advances in this techniques are found currently in scientific publications from academic and industrial teams. The societal and economical impact of the development of Tissue Engineering is clear and the progress in the next years will be of enormous importance in the implantation of new concepts in Medicine, Biotechnology and Materials Sciences. The importance of these aspects has been recognised by the most advanced industrial companies and the investment in new developments based on the techniques mentioned above will be decisive not only on an academic basis, but also in the commercial field. Respect to the activities of companies, it seems that USA companies are developing much more activity that those installed in European Countries.

In conclusion, the success in this attractive and advanced interdisciplinary field needs the coordination of good specialists in different fields of the Science, from the Medicine to the Biology, Chemistry, Physics, Pharmacy and Engineering. The advance will be based on the development of new and specific scaffolds, the availability of stem cells and the application of new techniques non-invasive or minimally invasive for the implantation of the complex cell/scaffolds systems.

# Atomic-Force Microscopy in Medicine

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## Summary

Modern methods of laboratory diagnostics are mostly based on immuno-enzyme analysis (ELISA) of proteins, antigens, antibodies and on the polymerase chain reaction (PCR), the latter being employed for infectious material assays. ELISA has limited sensitivity (up to $10^{-12}$-$10^{-15}$ M) which is insufficient for an early diagnostics of diseases. The method has some other disadvantages: it is not strictly quantitative, takes a lot of time, requires costly reagents and highly specialized personnel; as for PCR-based methods, they are also characterized by some disadvantages, such as possible contamination of the DNA and RNA samples assayed, laboriousness and, again, a need for costly reagents. At the same time a number of entirely new techniques for the revelation and identification of individual molecules - enabling, instead of measuring their concentration, just to count them - are finding an increasing application. One of these is atomic force microscopy (AFM). Usage of AFM biochips with various types of immobilized macromolecules (proteins, nucleic acids and others) allows the investigator to simultaneously diagnose a variety of diseases through registering the probe/target complexes. The examples of identification of single molecules and their complexes by use of atomic force microscopy are given. Such an approach will enable to enhance the concentration sensitivity of the AFM in the sample volume up to a single-molecule level.

## Introduction

Nanotechnological systems are those working on a nanometer scale [1]. Nanotechnology-based medicine (i.e. nanomedicine) aims to register disease markers by use of nanotechnological methods. Such technologies allow the investigator to enhance assay sensitivity while lowering sample volume by several orders. Thus, the sensitivity of nanotechnological methods may even reach a single-molecule level with sample volumes being diminished to $10^{-18}$-$10^{-21}$ [2]. Efficient application of nanotechnologies (e.g. for an early diagnosis of many social diseases) is only possible upon revelation and identification of protein markers at an exceedingly high (femto-zeptomolar) level of sensitivity [3]. Clearly, further progress of nanomedicine is predicated on the development and implementation of highly sensitive methods for the registration, identification and characterization of functionally important protein complexes in biological systems.

In later years the increasingly numerous reports devoted to the AFM analysis of proteins and protein complexes at a single-molecule level has been published [4-7]. The abundance of these researches is explained by the ability of the AFM to readily register (without labeling of molecules) and to visualize the macromolecules and their complexes in near-native conditions. In what follows we shall characterize the AFM technology and consider the prospects of its application in medicine.

## Visualization of molecules and molecular complexes

AFM enables to visualize proteins, protein complexes, oligonucleotides and other macromolecules in near-native conditions. The scanning AFM technique [8] registeres the force of interaction between the probe tip of the cantilever, fixed onto the piezoelectric crystal, and the surface of the sample immobilized onto the atomically flat surface. With native proteins, the method ensures the vertical resolution of ~ 0.1 nm and the lateral resolution of up to 0.5 nm [4, 9]. The lateral resolution is less precise owing to the tip-broadening effect.

AFM application made it possible to visualize a broad spectrum of water-soluble proteins and their complexes, such as immunoglobulins, ferritin and their complexes [10]; phosphorylase, phosphorylkinase and their complexes [11]; member proteins of a monoxygenase cytochrome P450cam system [5] and others. Interesting results were obtained in our studies of the complicated water-soluble cytochrome P-450cam monoxygenase system involving three proteins - cytochrome P450cam, putidaredoxin (Pd) and putidaredoxinreductase (PdR) [5]. Demonstrated was the ability of the AFM to identify binary and ternary complexes of these protein partners in multicomponent systems and to distinguish, in these systems, the binary from the ternary complexes - the latter finding being especially important for proteomic researches [5]. It is very important that the AFM technology may be used to visualize of membrane proteins in near- native conditions. Thus in the study of [12] the image of the membrane protein P4502B4, incorporated into the phospholipid bilayer was taken.The topography of the extracellular surface of the protein porin OmpF with a vertical resolution of 0.1nm and a lateral resolution of up to 0.6 nm was obtained [13]. Also, our study of the microsomal membrane-bound cytochrome P452B4 monoxygenase system involving three membrane proteins: cytochrome P4502B4, cytochrome P450 reductase and cytochrome b5 was carried out and binary [5] and ternary complexes between the partners were revealed - by the increased heights of imaged objects upon complex formation.

The unique ability of the AFM technology to recognize individual proteins and their complexes may be used in such an important area of medical diagnostics as immunoanalysis. The analytical procedure involves at the first step the immobilization onto the support of one protein molecule, e.g. the antibody molecule. Then this support is incubated in the biological fluid. With the immobilized protein's partner (i.e. antigen) being present, the formation of the antigen/antibody complex is registered. Based on the analysis of a series of such antigen/antibody pairs, it was shown that the heights of the complexes formed exceed the heights of individual protein molecules. For instance, the heights of individual human serum albumin (HSA), of anti-HAS and of their complexes differ essentially amounting to 0.6 nm. 1.9 nm and 3.1 nm [14].

In our study, the hepatites diagnostic marker images of antibodies to HbsAg, HbsAg and HbsAg/anti-HbsAg complexes were taken. It was found that the heights of the complexes formed (6-10 nm) exceed the heights of the isolated antigen (4 nm) and antibody (2 nm) molecules.

Thus a convincing evidence has been provided to date that it is possible to register formation of antigen/antibody immunocomplexes by their increased heights, which opens up the opportunity of using AFM in immunoanalysis for the diagnostics of social diseases accompanied by the appearance of markers – i.e. such diseases as cancer, myocardium infarction and others.

Naturally the question arises of whether the AFM technology is sensitive enough to be used in practical medicine. Given below is the assessment of the AFM potential in revelation of protein markers for various diseases.

## Revelation of proteins and their complexes by use of the AFM technology

In the review of [3Anderson &Anderson, 2002] the clinically important dynamic range of proteins' content in plasma is discussed. As is noted in this review, the requirements of commercial clinical laboratories to this range lie in the interval between 10-3 M (for albumin) and 0-10-13 M (for interleukin-6). For tissue proteins (whose concentration in passing to plasma is lowered manifold) the required threshold of diagnostic sensitivity lies in femtomolar concentrations (10-15M) and below. Therefore, one major objective of modern researches may be defined as the revelation and identification of proteins in plasma with exceedingly low concentrations.. One major problem of the present-day proteomics lies in the absence of the PCR-like reaction that allows the copying of various molecules thereby the increase in the concentration of the assayed biological material is achieved. In view of this there is a certain methodological barrier in proteomics: protein molecules whose concentration level is below 10-15 M cannot be identified. The attempts of investigators to descend to this level at the cost of using large amounts of biological material were not very successful. Routine methods of immunoenzyme analysis exhibit a sensitivity not surpassing 10-15 M [3 Anderson& Anderson (2002)]). The methods for proteins' identification based on a combination of 2D electrophoresis [15] or chromatography with mass spectrometry [16] or on a combination of optical biosensoring with mass spectrometry [ 17] yield a sensitivity of ~ 10-8 -10-12 M. At the same time the resolution of the AFM is comparable with the currently used methods. However, upon the application of special procedures the resolution may be increased manifold. For instance, upon using colloid-gold-labeled antibodies (size, 40 nm), the sensitivity was 40-folod higher than with radioimmunoassay and ELISA [18]. The concentration sensitivity threshhold of the method is determined by the reversibility of the redox partners' complex formation reaction. According to calculations, when the complex formation reaction is irreversible, the AFM technology allows for the revelation of proteins at a concentration of 10-18M.

Thus the AFM sensitivity is sufficient for the successful revelation, by use of this technology, of such diseases which are accompanied by the appearance of immunocomplexes. Comparative simplicity of the sample preparation procedure makes the AFM attractive for use in medicine.

## Conclusions

The applicability of the AFM in medicine allows for the diagnostics of diseases at a single-molecule level. Widening the scope of its application may be attained through the overcoming of the inherent limitations of the method in its present form. One essential limitation of the AFM is its slow operation time. For instance, the commercial device Solver P47H (Russia) is able to carry out the revelation and analysis of proteins and their complexes on the 20x20 μm area for 20 min. This time may be essentially shortened at the cost of replacement of one-channel probes with tip arrays. [19] report on the development of arrays comprising 50 cantilevers, which allowed these authors to enhance the imaging speed by two orders. In the study of [20] the development of 144-channel arrays is described. Many-channel arrays make it possible not only to enhance the sample throughput but also to increase the concentration sensitivity – which is highly necessary for creation of diagnostic devices. Thus the real basis is provided for creation of an AFM-based diagnostic system with a sensitivity which is several orders higher compared to existing ones and which is fast acting enough.

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## *Session 9c - Energy*

# Organic Solar Cells

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Photovoltaic devices are based on the concept of charge separation at an interface of two materials of different conduction mechanism. To date this field has been dominated by solid state junction devices, usually made of silicon, and profiting from the experience and material availability resulting from the semiconductor industry. The dominance of the photovoltaic field by inorganic solid state junction devices is now being challenged by the emergence of a third generation of cells, based for example on nanocrystalline oxide and conducting polymers films. These offer the prospective of very low cost fabrication and present attractive features that facilitate market entry. It is now possible to depart completely from the classical solid-state cells which are replaced by devices based on interpenetrating network junctions [1-4]. The presence of a bulk junction having an interface with a huge area endows these systems with intriguing optoelectronic properties.

The presentation will summarize recent advances in the area of organic solar cells and hybrid devices containing both inorganic and organic constituents. The phenomenal progress realized recently in the fabrication and characterization of nanocrystalline materials has opened up vast new opportunities for these systems. Contrary to expectation, devices based on interpenetrating networks of mesoscopic organic and inorganic semiconductors have shown strikingly high conversion efficiencies, which compete with those of conventional devices. The prototype of this family of devices is the dye-sensitzed solar cell (DSC), which realizes the optical absorption and the charge separation processes by the association of a sensitizer as light-absorbing material with a wide band gap semiconductor of mesoporous or nanocrystalline morphology [1,2].

The principle of operation of the dye-sensitized nanocrystalline solar cell is shown in Figure 1. Photoexcitation of the sensitizer (S) is followed by electron injection into the conduction band of an oxide semiconductor film. The dye molecule is regenerated by the redox system, which itself is regenerated at the counter electrode by electrons passed through the load. The open circuit voltage of the solar cell corresponds to the difference between the redox potential of the mediator and the Fermi level of the nanocrystallline film under illumination indicated with a dashed line. The currently reached conversion efficiency under full sunlight (air mass 1.5) has reached 10.6 % and the cell has passed the stability tests (thermal stress and light soaking) specified by the European norms for outdoor photovoltaic installations.

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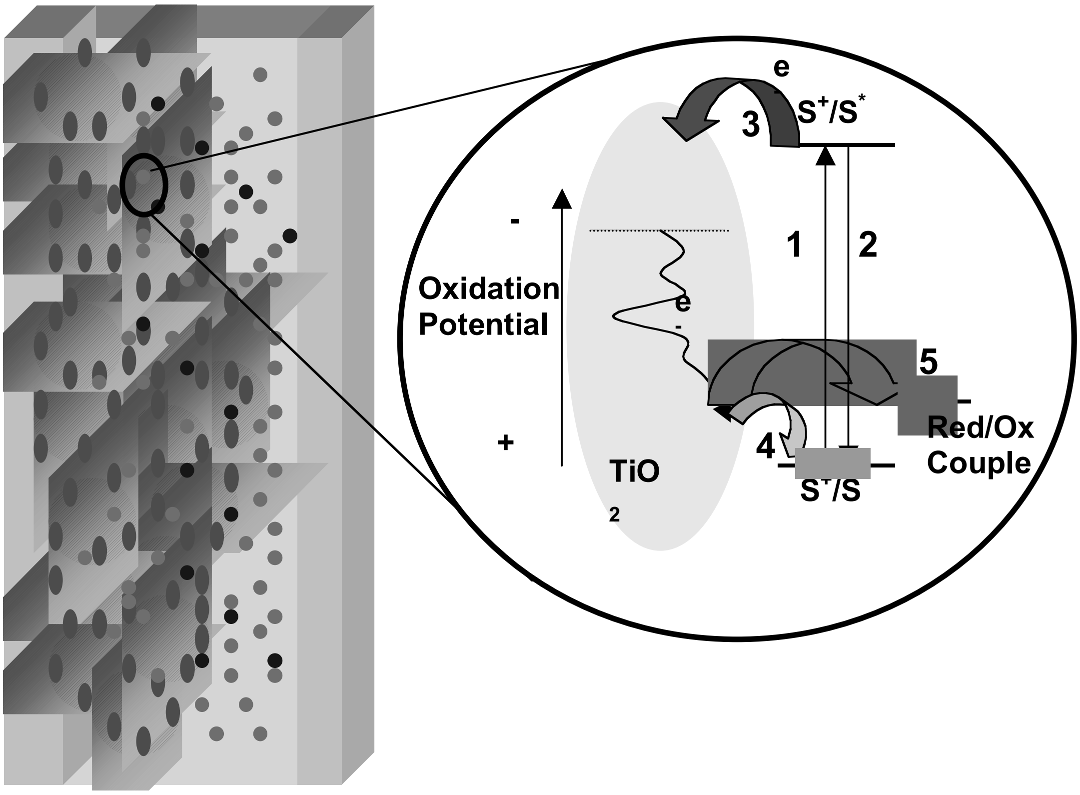


**Figure 1**. Operational principle of a dye sensitized nanocrystalline solar cell.

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# Nano-Structures for Photovoltaic- Quantum Dots and Quantum Wells

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One major factor limiting the conversion efficiency in conventional single-junction solar cells is that the absorbed photon energy above the semiconductor gap is lost as heat through electron-phonon scattering and subsequent phonon emission, as the carriers relax to their respective band edges. Another important loss mechanism that has to be overcome to reach high efficiencies is the transmission of the sub-band-light (Photons with energies lower than bandgap). Many concepts have been suggested, and some even tested, to reduce these losses and improve the conversion efficiency by adapting the solar cell materials and/or the device structure to the solar energy spectrum. Among the different approaches, there are tandem cells, hot carrier cells and those based on carrier multiplication due to impact ionisation and impurity photovoltaic effect. Besides, approaches exploring capability of giving efficiencies closer to thermodynamic limit are currently studied. In particular, low dimensional structures seem to show promise due to the small dimensions and new features offered, thanks to the technological innovations in this domain. The use of quantum wells (QWs) and quantum dots (QDs) embedded in classical solar cells seem to be one promising option.

Although quantum wells (QWs) and, more recently, quantum dots (QDs) have dominated opto-electronic research and development for the past two decades since they are used in photodetectors, optical modulators, lasers and LEDs, there are few studies on the use of QWs (QDs as well) as photovoltaic devices. The proposal for these devices is motivated by the goal of enhanced energy efficiency, and is based on the hypothesis that quantum wells (dots) could extend the spectral response and increase the photocurrent of solar cells without degrading their characteristics. Besides, QWSCs have advantages in terms of temperature dependence of efficiency, which is important in concentrator and thermophotovoltaic applications, and in radiation tolerance.

In this talk, a review on the different concepts implying nanostructures which involve QW and QDs as active parts of the solar cell will be presented. The advantages and limiting factors of such nano-materials based cells will be reported. The different present concepts will be discussed and the latest realisation will be discussed. Some QD solar cell configurations based on inorganic or organic materials will be described.

Other solar cell concepts based on luminescence convertors that use nanostructured materials will be also presented. Preliminary experiments taken from literature which demonstrate enhancement in photons conversion will be shown.

# Nanostructured Functional Materials for Energy Conversion and Storage Systems

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## 1. Introduction

Most of today's energy needs are met by fossil fuels that have finite reserves and will in due course become in short supply. In 2050, the global population is anticipated to have grown to 10 billion. The economic growth, the increase in energy and food production, and the needs for protection of the global environment represent a Trilemma, which can in part be challenged by a more renewable energy-based society.

Fossil fuels may be abandoned much sooner in favor of renewable energy sources as soon as these are more attractive alternatives, environmentally and economically. The missing links for a sustainable energy system are an efficient competitive, non-polluting and safe energy storage scheme and an energy carrier. Energy storage technologies include amongst others rechargeable batteries and hydrogen.

Renewable energy sources that produce electrons, like solar cells, can be connected to the energy infrastructure to directly reduce carbon dioxide emissions from current fossil fuel combustion. However, the use of solar energy requires storage. Hereto, materials are being studied for rechargeable Lithium-ion batteries and for direct photoelectrolysis of water to store solar energy in the form of hydrogen. The conversion of the chemical energy of hydrogen into electrical energy using a fuel cell produces electrons and only water vapor as a waste product.

The state-of-the-art solar cells are all silicon based. The introduction of a dye-sensitized solar cell by O'Regan and Grätzel [1] has stimulated investigations on nanostructured materials for 3D solar cells. Besides, in studies on materials for rechargeable Lithium-ion batteries the nano-scale has been introduced too. For the characterization of the opto-electrical and electrical properties of nanostructured materials for application in these systems Electrochemical Impedance Spectroscopy (EIS) is widely used. In addition, nanostructured solar cell materials have been studied with Intensity-Modulated Photocurrent Spectroscopy (IMPS). With this method the mechanism of photocurrent generation can be unraveled [2-4].

In this lecture the synthesis and characerization of selected nanostructured materials for advanced 3D solar cells and of materials for rechargeable Lithium-ion batteries will be presented.

## *Synthesis Techniques*

Heterojunction solid-state solar cells can be obtained using Atomic Layer Chemical Vapor Deposition (AL-CVD, or Atomic Layer Deposition, ALD). This thin-film technique is a modification of Chemical Vapor Deposition (CVD) and is based on a self-limiting growth mechanism. Due to a sequential introduction of the reactants into the AL-CVD reactor, gas-phase reactions are inhibited. By carefully tuning the relevant process parameters extremely thin films of high purity and a well-defined thickness are obtained. AL-CVD of thin films of p-type $CuInS_2$ for nanostructured 3D solar cells will be presented. In addition, aerosol-assisted deposition of 3D inorganic-polymer solar cells will be presented [5].
A new citric acid complex synthesis method to prepare nanosized powders of doped inverse spinel lithium-ion battery electrode materials will be presented.

## 2. Nanostructured 3D Solar Cells

Dye-sensitized solar cells of the Grätzel type [1] comprise anatase $TiO_2$ nanoparticles that are sintered together to form a three dimensional nanostructured network with dye molecules chemically bonded to the $TiO_2$ surface which inject electrons into the conduction band of $TiO_2$ when optically excited. Regeneration of the dye molecule occurs with a redox electrolyte.
In order to replace the redox electrolyte the Extremely-Thin-Absorber (ETA) solid-state solar cell has been proposed [6-8]. Due to its suitable band gap (1.5eV) $CuInS_2$ (CIS) is a promising absorber material for the production of high efficiency ETA solar cells. Impedance spectra recorded on heterojunctions n-$TiO_2$/p-$CuInS_2$ versus DC potential were used to analyze the space-charge capacitance.

The Mott-Schottky plot, $1/C^2$ versus V, revealed an acceptor density of $2x10^{18}$ $cm^{-3}$, which demonstrates the good quality of the deposited CIS film (Fig. 1).
IMPS spectra of nanostructured anatase $TiO_2$ have shed light on the mechanism of electron migration [3, 4].

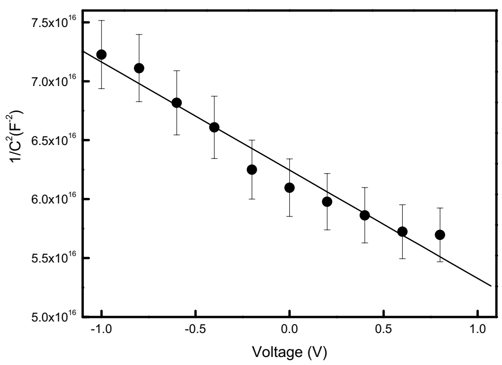


**Figure 1**. Mott-Schottky plot for Cspace charge

## 3. Lithium-Ion Batteries

Composite lithium-ion conducting electrolytes are of interest in battery technologies due to their enhanced conductivity and mechanical properties. The charge transport mechanisms are not understood in detail. Using EIS a number of composite materials based on fully amorphous polyether urethane with lithium salts have been characterized. To this various ceramic materials have been added, including nano-structured $TiO_2$ and $Li_xBPO_4$, and micron-sized $Li_{1.3}Al_{0.3}Ti_{1.7}(PO_4)_3$ (LATP) to examine the influence of these materials on the lithium-ion conductivity of these composites. Using equivalent circuit fitting, we have elucidated details of the charge transport mechanisms within these complex systems.
Lithium-ion intercalation effects in extremely thin films of anatase $TiO_2$ have been studied using Mott-Schottky analyzes. Inverse spinel vanadates such as $LiCoVO_4$ and $LiNiVO_4$ are promising cathode materials for lithium-ion batteries due to the high voltage of 4.3V versus Li for $LiCoVO_4$ and 4.8V versus Li for $LiNiVO_4$. These mixed conducting inverse spinels exhibit low electronic conductivity [9]. Dopants can improve electrical conductivity and stability. Here iron, copper and chromium dopants have been studies as their ionic radii are quite large which decreases the packing density and hence may favor lithium ion migration. Trivalent dopant ions lower the valence state of $V^{5+}(3d^o)$ to $V^{4+}(3d^1)$ and hence result in enhanced electronic conductivity. Recent EIS results will be presented.

## 4. Conclusions

EIS and IMPS are useful techniques to characterize electrical and opto-electrical properties of ionic and mixed ionic-electronic conductors for lithium-ion batteries and opto-electrical properties of solar cell materials, respectively.

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# Nanoscale Materials for Hydrogen Storage

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The major bottleneck for commercializing fuel cell vehicles is onboard hydrogen storage. The presently available systems are high pressure tanks or liquefied hydrogen in cryogenic vessels, which both possess severe disadvantages, e.g., large size and low consumer acceptance concerning safety aspects. Storage of hydrogen in light-weight solids could be the solution to this problem.

During the last 10 years many novel nanoscale materials have been synthesized. Owing to the nanostructure, these materials possess new properties as compared to conventional bulk materials. However, these new effects are not understood and fundamental investigations are needed. For hydrogen storage these materials may show new kinetics of adsorption and desorption as well as new thermodynamic properties. Hydrogen may be stored in solids by two principle mechanisms: i) Adsorption of hydrogen molecules on surfaces, i.e., physisorption. ii) Hydrogen atoms dissolved or forming chemical bonds, i.e., chemisorption. Fig. 1 shows a schematic comparison of the gravimetric and volumetric storage densities for different hydrogen storage systems. Recent developments in novel physisorption materials and new hydrides show how nanoscale materials may drastically improve the hydrogen storage properties.

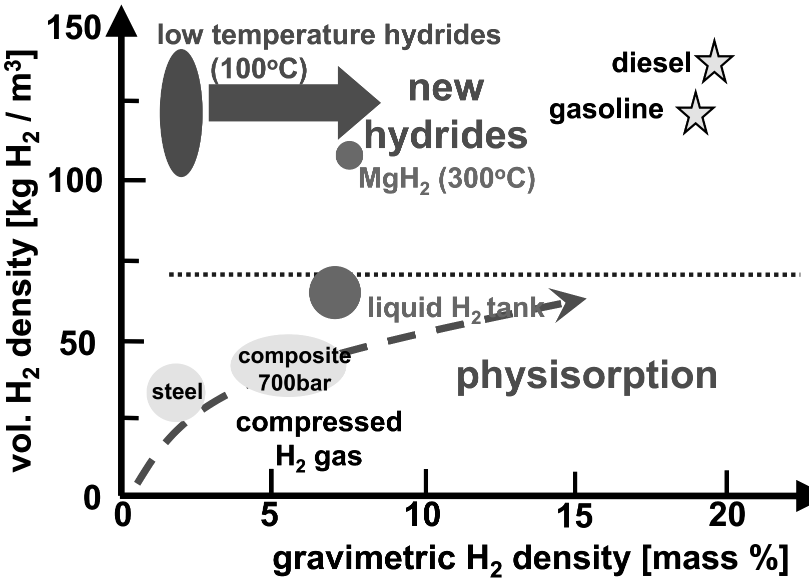


**Figure 1**. Gravimetric and volumetric storage densities of hydrogen for different systems. The blue line gives the volumetric density of liquid hydrogen, which represents an upper limit of the storage density in the form of hydrogen molecules. The directions of future research are shown in red based on recent very promising results on nanoscale materials.

For physisorption new nanoscale materials with high specific surface area are needed. During the past six years this area was dominated by announcements of high storage capacities in carbon nanostructures. However, the experimental results on hydrogen storage in carbon nanomaterials scatter over several orders of magnitude. Furthermore, the various data are obtained at different temperature and pressure regimes. Up to the present, the experiments claiming very high values could not independently be reproduced in a different laboratory. Especially, for hydrogen storage under conditions of room temperature and ambient pressure a clear controversy arose [1,2], which has been recently discussed [3,4]. A critical review [5] shows, that in the view of today's knowledge, which is mainly based on experiments with small quantities and poorly characterised samples, carbon nanostructures around room temperature cannot store the amount of hydrogen required for automotive applications. Despite these rather disappointing results on carbon nanostructures, new nanostructured materials with extremely large specific surface areas, e.g., metal-organic frameworks (MOFs) [6,7] or nanosized polyphenylene dendrimers [8] may be more promising for hydrogen storage by physisorption.

Chemisorption or storage in metal hydrides possesses the drawback of either low storage capacity or high release temperature. Applying nanoscale materials two recent developments show promising routes toward an improvement. Firstly, magnesium hydride ($MgH_2$), which has been nanostructered by ball milling and adding small oxide particles, shows an enormous enhancement of the absorption and desorption kinetics of hydrogen [9]. Secondly, for a long time alanates were belived to be irreversible hydrides under technologically relevant conditions, until Bogdanovic and Schwickardi [10] demonstrated that with titanium doping sodium alanate ($NaAlH_4$) is a reversible hydride with a storage capacity of up to 5.6wt% and a desorption temperature around $140^0$C. Newest results show that using titanium nanoclusters consisting of only 13 atoms can drastically improve the reaction kinetics with hydrogen and lower the release temperature even further [11,12].

In conclusion, these three examples show the potentials of nanoscale materials in the field of hydrogen storage. Carbon nanostructures and other novel nanostructured materials with extremely large specific surface area possess a high potential for hydrogen storage by physisorption at lower temperatures, which, e.g., may be used for cryogenic storage in long-term satellite missions. Secondly, nanostructured magnesium hydride with added oxide particles exhibits drastically improved absorption and desorption kinetics of hydrogen. Finally, complex hydrides can be reversibly operated in a temperature range required for fuel cells by applying nanoclusters of catalyst. Therefore, the goal and vision of future studies on nanoscale materials is to understand the nature of the processes occurring on the nanoscale and, finally, be able to design optimized hydrogen storage materials for technical applications.

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# Nanostructured Catalysts for Hydrogen Production

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Catalytic phenomena have a very strong industrial and economical importance. They are involved in a large range of materials and fuel production, which represents more than 90% of worldwide industrial chemical processes.
Despite this intense fundamental and applied scientific interest and almost two centuries of research, the development of a new catalyst still results from relatively empirical “trial and error” processes.
Recently however, significative advances have been accomplished in understanding a number of basic principles which govern catalytic processes. These advances have allowed to design new catalysts, essentially from first principles, which have been specifically taylored to optimize the efficiency of two different industrial catalytic processes (1, 2).
A first fundamental step for clarifying the role of transition metal’s electronic structure has been the discovery that their chemical reactivity is determined by the center of mass of the metal d band with respect to the Fermi Energy (3, 4). This accomplishment has been possible by Density Functional Theory calculations (used as computational experiments) for a systematic determination of adsorbate adsorption energies and of molecule dissociation (4) activation barriers.
A second very important step has been the discovery of a universal principle, valid for simple chemical reactions (5), which correlates the most important energy barriers of a catalytic process (6, 7). It has been shown that in several significative cases it is possible to describe a catalytic reaction, as governed by essentially two principal reaction barriers (see Fig. 1): an “entrance barrier” Ea (which is usally the dissociation energy of a reactant molecule) and an “exit barrier”, E’ (which is related to the energy for releasing reaction products into the gas phase).

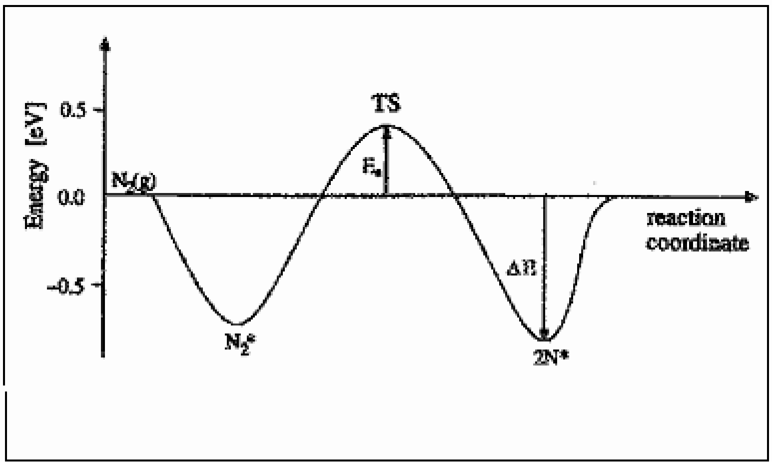


**Figure 1**

The most important result has been the finding that these two barriers are strictly correlated by a linear relationship, when one varies the chemical reactivity of the catalyst (5, 7): the higher the entrance barrier Ea, the lower the exit barrier E' and vice-versa.
This behavior gives an explanation of the well known concept of "volcano-plots" which has been found to govern the Turn-Over-Number (TON) of many different catalytic reactions as a function of different catalyst's reactivities.
These concepts have two very important implications:
1) the best catalyst for a given catalytic reaction is a material with a reactivity such that the two barriers are roughly equal;
2) DFT calculation can be used to "taylor" a material (typically a transition metal intermetallic compound (8)) to obtain exactly the right reactivity which optimizes a catalyst's performance.
It should be noted that these calculations are powerful enough to determine not only the chemical composition, but also the atomic geometry at the nanoscale level of the active sites which optimizes the TON. As an example of the power of the method, Fig. 2 shows the activation barrier for the dissociation of methane on three different local configuration of a Rhodium catalyst (9).
One last breakthrough (10) in understanding the relationship between the electronic structure of a catalyst's and its local chemical reactivity has recently come from an experiment carried out at the SuperESCA beamline at ELETTRA (11, 12) combined with DFT calculations performed at CAMP by Norskov and co-workers.
It has been demonstrated that by following in-situ time-lapsed spectra of Surface Core Level (SCL) shifts, it is possible to measure the time evolution of a catalyst's local chemical reactivity during a chemical process (10).

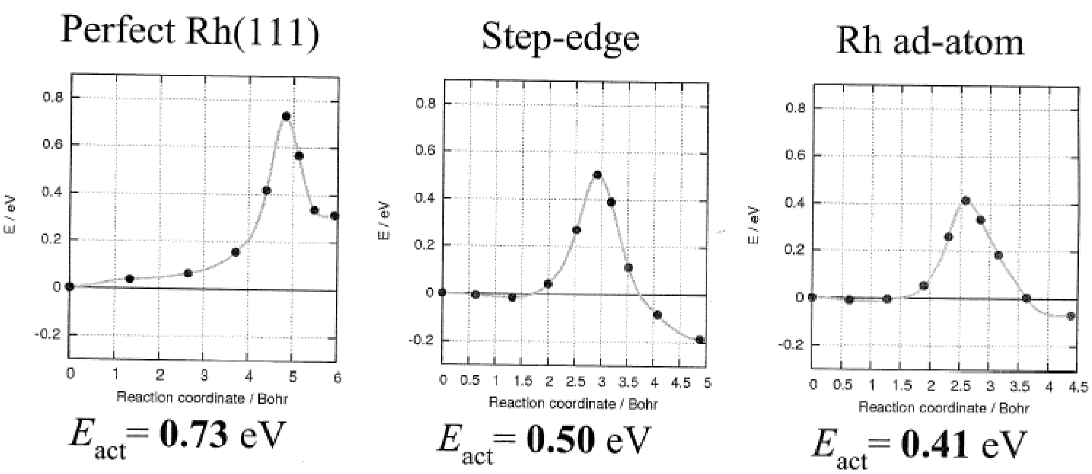


**Figure 2**

Fig. 3 shows the striking linear relationship between shift's changes of SCL in various substrate-adsorbate configurations, and local chemical reactivity changes (as determined by the shift of the "d" band center of mass).

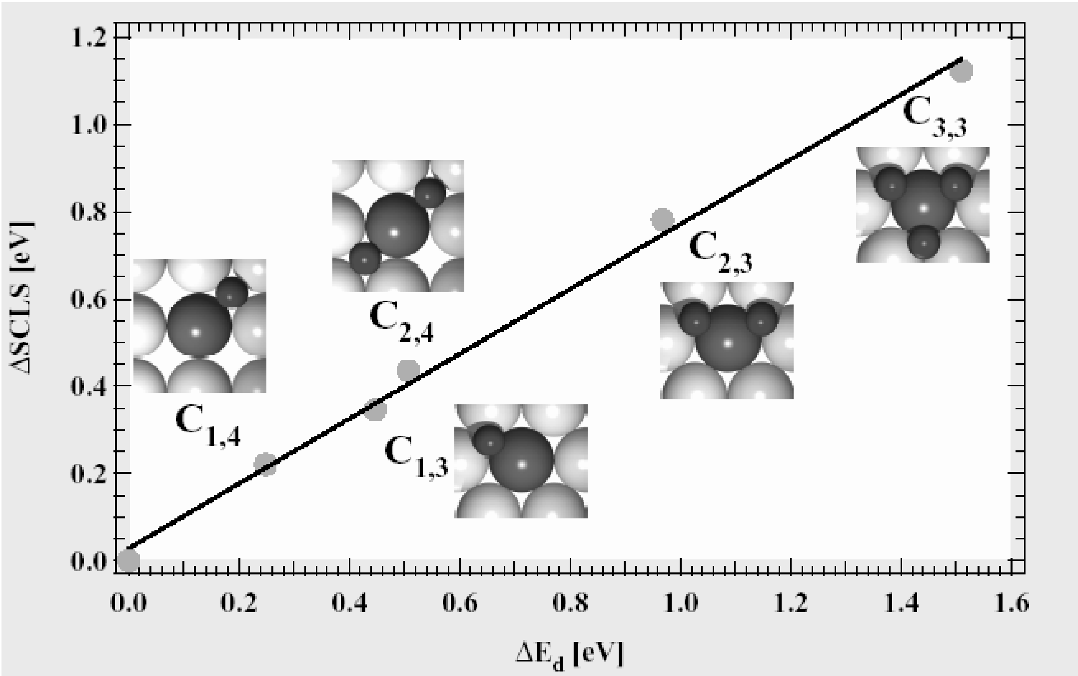


**Figure 3**

Experimental computational work is now in progress for determining the geometry and composition, at nano-scale, of optimized catalysts for a number of energy-related catalytic reactions (CH4 steam reforming, CO selective oxidation, CH4 partial oxidation).
In conclusion, I believe that the new nano-science concepts and experimental techniques which have been recently developed, may represent, in the near future, a breakthrough in the way novel catalytic materials may be developed for energy applications and, more in general, for the chemical industry.

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## Session 10a - Nano-Robots and NEMS

# Nanomechanics: Opening New Frontiers in Bio Analyses and Diagnostics

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Biosensing tools are currently undergo a further stage of development increasing efforts have therefore been put into the development of cantilever-based sensors for the detection of physical phenomena and chemical and biological reaction. Biological and chemical processes are transduced into nanomechanical motion using a microfabricated silicon cantilever array, allowing quantitative and qualitative detection in gaseous and liquid environment. The motion is tracked by optical beam - deflection using a time multiplexed scheme. Miniaturized sensors show fast responses high sensitivity and are suited for parallelization into integrated devices. We report the first microarray of cantilevers to detect multiple unlabelled biomolecules simultaneously down to picomolar concentrations within minutes. Ligand-receptor binding interactions, such as DNA hybridization or protein recognition, occurring on microfabricated silicon cantilevers generate nanomechanical bending, which is optically detected in-situ. Differential measurements including reference cantilevers on an array of eight sensors can sequence-specifically detect unlabelled DNA targets in 80-fold excess of non-matching DNA as a background and discriminate 3 and 5 overhangs. Our experiments suggest that the nanomechanical motion originates from predominantly steric hindrance effects and depends on the concentration of DNA molecules in solution. We show that cantilever arrays can be used to mechanically investigate the thermodynamics of biomolecular interactions, and have found that the specificity of the reaction on a cantilever is consistent with solution data. Hence cantilever arrays permit multiple binding assays in parallel, and can detect femtomoles of DNA on the cantilever at a DNA concentration in solution of 10 pM. The significant improvement of functionalisation enables the detection of specific gene fragments within a complete genome suggesting that PCR (Polymerase Chain Reaction) could be circumvented. The general applicability of the method to biochemical processes was furthermore demonstrated by monitoring continuous label-free detection of cardiac biomarker via measurement of surface stress generated by antigen-antibody molecular recognition. This underlying nanoactuation mechanism has more wide-ranging implications. The forces involved ~1 nN, are sufficient to operate micromechanical valves and related fluidics devices which would also permit operation of micro and nanomechanical machinery. Since the transductions does not rely on external control systems delivery devices could be triggered directly by signals from single cell, gene expression, or immune responses.

# Super-Precise Nanopositioners for Nanotechnology

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High-precision positioning is one of the principal technologies of modern high-tech. But in an overwhelming majority of cases the use of this technology, most of all – in precision machine-tools production, is drastically limited by the impossibility to provide for accurate displacement of the corresponding units and gears with any significant forces and on any extended base.

The rare-earth alloy Terfenol-D ($Tb_{0.27}Dy_{0.73}Fe_{1.95}$), developed in the end of the 1970-s, allowed to proceed to the practical use of the "giant magnetostriction" effect for powerful positioning, since in this case the relative extension in magnetic fields ~0,5 T ran up to$10^{-3}$, and the originating force ran up to 100 $N/mm^2$ of the strictor's cross-section. Therefore, a strictor 1 cm long and of the same diameter could provide for powerful positioning within 10 μ with a force of up to $10^5$ N.

Linear nanopositioner created in NANOTECH provided for displacement within 4 mm, with resolution of 0.6 nm and manual control. This data was confirmed by independent measurements conducted in Bureau des Poids et Masures (Sevres, France). A similarly assembled linear nanopositioner, in which magnetic system positioning was performed by a computer-guided step-motor, provided for a minimal displacement increment of 0.01 nm. These results were confirmed by measurements that were conducted in the All-Russian Research Institute of Metrological Service (ARIMS).

The plan-support of the universal engraving machine-tool with a magnetostrictive power actuator, which was developed by us in accordance with measurements conducted by the Experimental Research Institute of Machine-Tools, provided for displacement on a 300-mm base with precision of 30 nm, i.e. tens of times more precise than the best German and Swiss analogues. Our studies of the dependence of the optical elements' resolution on the precision of their making have shown that after a slight revision this machine-tool could be successfully used for creating precision elements of defractional, Fresnel, and aspherical optics.

In our opinion, the key element in the creation of new technologies is an X-Y automatic NanoTable with a 160x160(300x300)-mm displacement base and precision of displacement 0,1-2.5 nm. Such a table could serve as the base for a new-generation steppers, since it could lead to an increase in the precision of positioning by 30-80 times as compared with the best modern steppers (precision of positioning – 80 nm) produced by the leading world manufacturer ASM-Lithography (Veldhoven, Netherlands). At present, NANOTECH is working on the first version of such an XY-nanopositioner with a 160x160-mm movement base and a 2.5-nm displacement increment. In the process of this development, a prototype model of the heterodyne interferometer was created, with measurement precision of 2.5 nm, on a base up to 100 mm long.

In view of the complexity of providing for alignment within a dynamic range $3x10^7$, the layout of the nanotable's arrangement was chosen to be of the two-stage type. The rough stage shall provide for displacement within a 160-mm range, precision ~3 μ, which shall allow to work within a dynamic range of $5x10^4$. The fine stage shall be displaced on a base of

~10–20 μ, with a discreet of 0.1 nm, with the help of 3 superprecise magnetostrictve power actuators, which shall allow to work in a dynamic range of $2x10^5$. Strictors whose magnetic systems provide for the necessary alteration of local magnetic field strength values at the surface of every strictor in accordance with a computer program, which uses data about the fine stage's coordinates received with the help of the appropriate interferometric measurements, conclude the fine stage's final adjustment with a discreet of up to ~0,1 nm within a displacement range of 10-20 μ and constant interferometric control, providing for precision of positioning better than 5 nm. The system of measuring the fine stage's position, which uses an X-Y measuring system based on heterodyne interferometers, allows measuring the fine stage's position in the entire range of coordinates' alteration (0-160 mm) with precision of ~1 nm.

In the proposed design of the NanoTable, displacement is achieved by means of two stages - rough displacement stage and fine displacement stage situated on it. One of the significant issues in the course of the displacement of the fine displacement carriage is this stage's longitudinal deviation upon displacement along each of the coordinate axis. That is why the position of the fine displacement stage along transverse spatial values shall be controlled by capacitive sensors with a feedback system, with displacement linearity no more than 50 nm and position reproducibility of 2.5 nm, and along the longitudinal coordinate - by an interferometric indicator of the fringe's fractional part, with precision no less than 2 nm. The entire device shall either operate in a vacuum, or the atmosphere's refraction index shall be provided with the precision of $\delta n / n \leq 10^{-8}$.

The XY-nanotable is also the key element of 3D-lithography with dynamic clarification which should allow to obtain three-dimensional matrix for the efficient technology of producing details of micro- and nanorobotics, micro stamps with a complex surface relief, superprecise intaglio plates for high-security printing with a wide range of macroscopic visualization effects, and master matrixes for protective holograms whose forgery is practically impossible.

One of the most promising NanoTable applications is to use it as a sample holder in an installation for investigation of 3D-protein's molecules structure by electron holography method. This method allows you to determine the distribution of scattered electrons at almost any atom of the protein molecule under investigation and thus to determine the coordinates of scattering centers, i.e. the molecule atoms topography. The first results obtained with the help of computer simulation showed that it is principal possible to determine molecule structure from electron hologram. As an example we recovered electron holograms, with very high level of noise, of $C_2H_5OH$ and $C_{18}H_{14}O_2NCl$ molecules.

# Single Molecule Nano-Robots

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Within the macroscopic world, robots are usually defined as mechanisms that substitute human beings in carrying out particular - often mechanical and repetitive - tasks. On the microscopic level, nature has developed evolutionary "*molecular motors*" which react on mostly chemical, but also on optical or electronic stimuli.
A "*molecular motor*" is an object consisting of at least two parts, from which one can be moved relative to the other. The most complex systems are extracted machineries from nature which have been adapted to perform specific actions, like the filament functionalized ATPase immobilized on a substrate to perform filament rotation[1] or the motor protein kinosin functionalized surfaces to move microtubulis[2]. However, the complexity of these systems consisting of numerous perfectly organized molecules has not yet been reached by today's synthetic designs.
At this stage, man-made mechanical systems range from two stage switches like e.g. azobenzenes to assemblies of several molecules like supramolecular catenanes and rotaxanes. Ligand functionalized azobenzenes display switchable complexation properties due to the mechanical motion of the azobenzene linker[3]. Rotaxanes consist of an axis with a mechanically locked ring and catenanes consist of two interlocked rings. Taking catenanes as examples, suitable functionalization of the individual rings allows to trigger the rotation of one ring relatively to the other. Such motions have been shown with appropriate electrochemically active organic[4] or coordinative[5] subunits. In a recent example the controlled motion of small rings on a larger ring has been reported by sequences of photochemical rearrangement reactions of the larger ring[6]. Such systems perform well defined and carefully analyzed motions in solution.
Finally, to integrate such objects in devices, they have to be immobilized on substrates under persistence of their functionalities. The integration of catenanes and rotaxanes bearing electrochemical addressable units in electronic memory devices was reported[7,8]. Although the nature of the observed switching behavior is still a subject under investigation, it demonstrates a first example exhibiting the perspectives but also the problems of "*molecular motor*" integration[9].
The immobilization and therewith the utilization of these molecular motors has to be explored in details and is currently a driving topic in nanotechnology.

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## *Session 10b - Optics and Photonics*

# Quantum Dots and Photonic Crystals for Nanophotonic Devices

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Nanophotonic approaches permit to optimize the performance of materials and devices for a wide variety of optoelectronic applications. In nanophotonics geometries in the sub 100 nm range are used to qualitatively improve the performance of a given material for the target application.
Quantum dots as one major ingredient to nanophotonics are three dimensional islands (diameter about 20 nm) of a material with low band gap which are embedded in a barrier material with higher band gap. Due to the three dimensional confinement of electrons and holes in the quantum dots these structures may be thought of as "artificial atoms". Similar to real atoms the electrons occupy three dimensionally quantized states. However, the energies of these states can be tuned by changing the size of the dots. Using quantum dots as active material of semiconductor lasers provides significant advantages for a variety of applications: (i) quantum dots allow to extend the wavelength range on a given material compared to two dimensional quantum well layer structures significantly. For example, InGaAs quantum dots permit to reach the 1.3 µm wavelength range on GaAs which would be impossible using InGaAs quantum wells. (ii) The atomic like energy structure is allows to realize uncooled/low cost high performance telecom lasers (iii) quantum dots are expected to minimize dynamic laser line broadening effects as well as the sensitivity of lasers to back scattered light.

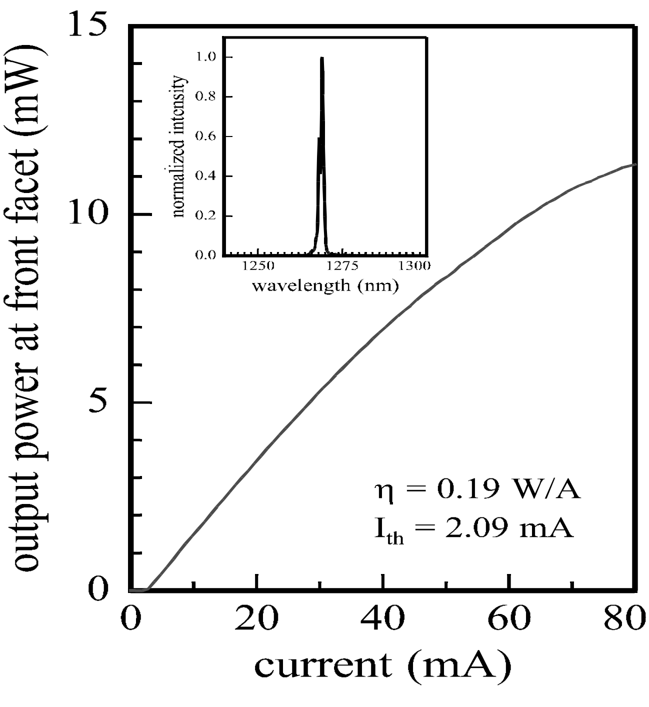


**Figure 1**. Light output versus laser current for a GaAs quantum dot laser emitting slightly below 1.3 µm (see laser spectrum in inset). The low threshold current value of about 3 mA is a direct consequence of the use of quantum dots in the device.

Another nanophotonic approach addresses the light propagation. By patterning a high refractive index material on the wavelength scale of light in one, two, or three dimensions e.g. with air holes a photonic crystal can be formed. The strong periodic variation of the refractive index results in the formation of a band structure for photons. Most importantly the design of the photonic crystal can be chosen appropriately that there are wavelength ranges in which the photon propagation is forbidden. The photonic energy gaps can be used to define miniaturized reflectors which may be used as e.g. laser mirrors, boundaries of waveguides, filters etc.

Several examples of nanophotonic devices employing quantum dots and photonic crystals will be presented. These include high power lasers at 980 nm. At this wavelength we have realized single mode lasers which allow operation over a temperature range of close to 200°C, about a factor of three larger than reported for quantum well lasers. The broad gain available in quantum dot structures allows furthermore to realize tunable single mode lasers with a much wider tuning range than obtained in quantum well devices. Furthermore ultra low threshold single mode lasers based on GaAs for the 1.3 µm range are reported

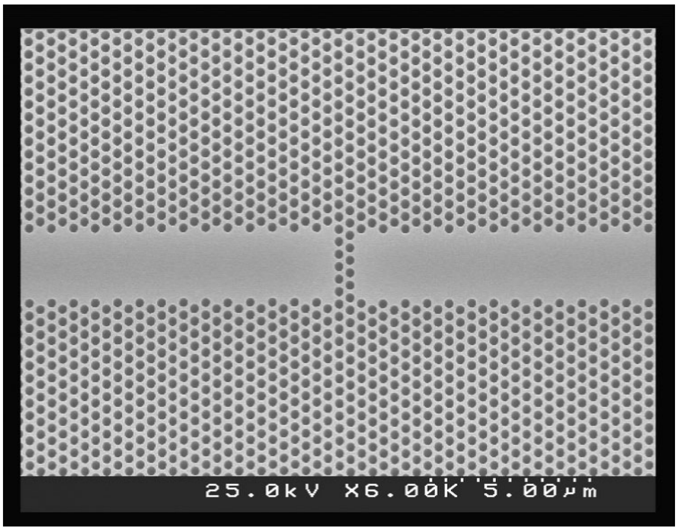


**Figure 2**. Top view of a photonic crystal based tuneable laser structure. The laser is based on two waveguides surrounded on all sides by a photonic crystal hole pattern. On the short side of the waveguides the photonic crystals serves as a controlled coupler (center of figure) and as end high reflectivity mirror (not shown here). On the long sides of the waveguides the photonic crystal is used for optical confinement of the laser light.

The potential of photonic crystals will be demonstrated using different passive devices like straight and curved waveguides and filters. Using 1D and 2d photonic crystal mirrors microlasers with lengths down to 12 µm have been obtained. In order to obtain single-mode operation, photonic crystal intracavity mirrors have been implemented, permitting single-mode operation with a sidemode suppression ratio of over 35 dB. Lasers based on coupled defect cavities formed in photonic crystals are presented.

# Nanotechnology for High Power Semiconductor Lasers

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The talk will be focused on new light sources for industrial, environmental and medical applications. I will attempt to review innovative research in that area which are carried in Poland with a particular emphasis paid to high-power and high-brightness lasers. High power semiconductor lasers are needed for many applications ranging from YAG laser pumps, erbium doped fiber amplifiers (EDFA) to many medical and industrial applications. The development of erbium-doped fiber amplifiers (EDFA) has enabled the proliferation of high-bandwidth data networks. Er3+-doped fiber amplifiers coherently amplify 1550-nm signals through the conversion of 980-nm pump laser light. Despite many years of research and development there are still areas where more research has to be done. That particularly concerns the beam quality and spatial coherence of the high power laser output and wavelength range. I will review our recent research on unstable laser resonators which allow for the lateral mode control in high power lasers. All practical 980-nm lasers are based on the ternary AlGaAs and InGaAs alloys. Medical applications, in particular photodynamic therapy of cancer cells, which is currently investigated all over the world, including Poland, require lasers with specific wavelength matching absorption bands of biological tissues and special chemicals used in the treatment. Thus the basic goal is to extend wavelength range of semiconductor lasers available. This can be done by using as an active region of SCH QW lasers quaternary material InGaAlAs, which allows for going with wavelength down to 760 nm. The expected main advantages of the InGaAlAs/GaAs lasers, are possibility of obtaining higher powers, due to better thermal conductivity of quaternary material, similar to InGaAs/GaAs technology and relative easiness and reproducibility of obtaining desired emission wavelength. In that sense the InGaAlAs/GaAs lasers surpass the other types of semiconductor lasers available.

The development of modern epitaxial techniques and progress in nanotechnology have had a powerful impact on semiconductor lasers. Nowadays diode lasers successfully compete on the market with other coherent light sources.

Their technology is experiencing major structural changes due to recent advances of band structure engineering and exploitation of a new design concepts based on quantum phenomena. By the very nature of their operating principle, the quantum devices are less dependent on the materials they utilize and allow for a great freedom to shape their parameters for specific applications

# Nanophotonic Integrated Circuits: The Potential and the Challenges

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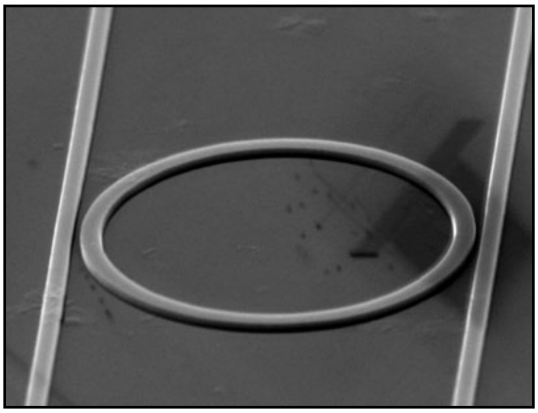
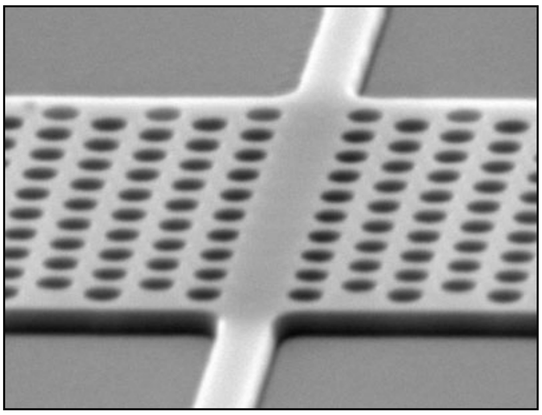
Photonics is the field that deals with generation, transport, processing and detection of light. Since a few years it is recognised that within this field there is a very important role for interaction of light with material features with a scale in the range of a few nm to a few 100 nm. Hence the name nanophotonics.
The interaction of light with such small features leads to a variety of special physical effects: interaction with semiconductor particles – quantum dots – leads to electronic enhancement of the dielectric properties, interaction with metal particles leads to surface plasmon resonances, interaction with wavelength scale structures with high index contrast leads to optical enhancement by means of microcavity or photonic bandgap effects.
Especially the latter, possibly in combination with the other effects, may be the enabling technology for photonic integrated circuits with a similar level of integration as in microelectronics. High index contrast waveguides with typical cross-sectional dimensions of the order of the wavelength of light allow to make ultra-compact photonic functions, such as micro-lasers, filters, wavelength demultiplexers, optical logic gates, etc. While the smallest features in such structures may be large – several 100 nm – from a nanotechnology perspective, it is very important to understand that there accuracy needs to be controlled down to the nm-level.
The figure below shows two generic examples of basic components within a nano-photonic circuit. The structure at the left is a ring resonator – a basic component that is





usable for many different functions (filtering, switching, gating…). The waveguides are about 500 nm wide and the ring radius is below 10 micrometer. The structure at the right is a photonic crystal waveguide in which the holes have a diameter of 340 nm on a pitch of 500 nm.

While progress in this field has been very rapid in recent years, there remain many challenges, both in the underlying physics as well as in the required technology.
One of the key problems relates to losses. In a nanophotonic circuit the propagating light is interacting with many high index contrast interfaces. Every such interface is a potential cause for (massive) loss of light, either because of inaccurate placement or orientation or because of nano-roughness. It takes a very judicious design as well as very precise fabrication to reduce these losses to acceptable levels. The design is made difficult because it necessitates the use of very demanding rigorous 3D electromagnetic simulation tools.
In terms of technology there is a need for high performance lithography methods together with dedicated dry etching methods. The nano-photonics field can take advantage here of the strength of CMOS technology. Certain photonic functions can be implemented in Silicon-on-Insulator (SOI). In this material system one can readily make use of the technologies used for deep sub-micron CMOS. IMEC has demonstrated record-low losses in SOI nanophotonic waveguides by means of the combination of deep UV lithography and dry etching.
In summary one can state:

- Nano-photonic ICs based upon wavelength scale high index contrast structures have a huge potential and can bring LSI-level integration into the world of photonics.
- The understanding of the physics, the development of modelling tools and the technologies are all making rapid progress.
- Nano-photonic ICs can take advantage of the nanostructuring technologies developed for next-generation micro-electronics.

# Silicon-Based Nanophotonics

**U. Gösele**, P. Werner, and M. Zacharias

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Silicon is the main base material for modern microelectronics. Du e to its indirect bandstructure it is not ideally suited for optoelectronic purposes. Nevertheless, because of its importance in microelectronics major research and development efforts have been undertaken to change silicon into a desirable photonics mate rial. The present lecture will highlight two areas in which silicon promises to have an increasing impact in the area of photonics. The first area is that of photonic crystals and the second will deal with approaches on how to transform silicon so that it can be used as an efficient light emitter. A photonic crystal is a periodic array of dielectric objects. This first suggested by Eli Yablonovitch and Sajeev John in two independent publications in 1987, for approriate materials and geometries such structures can have a so-called complete photonic bandgap which means that in a certain frequency range photons can not propagate. Photonic crystals in principle allow to manipilate photons in the micrometerrange. The photonic crystal structures have to be accurate geometrically in the typical range of present day nanotechnologies. Silicon can be used for photonic bandgap structures in a frequency range in which it is transparent to light, i. e., basically for photon energies below the electronic energy gap of 1.1 eV. These energies also include the wavelength range of 1.3 -1.54 eV which is important for fiberoptics-based telecommunications. It will be discussed how two-dimensional photonic crystals (including also defects, microcavities, and wave-guides) can be fabricated by well-controlled electrochemical etching of crystalline silicon. Potential approaches for using photonic crystals for switching purposes will also be discussed. First results on getting from two-dimensional to three-dimensional silicon-b ased photonic crystals will be presented. The second part of the talk will deal with the on-going quest for inducing silicon to emit light efficiently, starting from etched microporous silicon to the present more promising approach to embed silicon nanocrystals in silicondioxide. Methods to get a tight control of size and density of nano-crystals will be presented in some detail. Optically or electrically stimulated light emission from strained SiGe-superlattices with quantum dot character, which is the result of a close co-operation with the Ioffe Institute in Sankt Petersburg, Russia, will be the topic of the final part of the lecture.

# 2. OVERVIEW

The four-day Commission event allowed an open debate on the state of the art in nanotechnology and brought together key players from around the globe in public administration, research, education, industry, banking, financing, social sciences and the media. Participants were asked to identify technical and non-technical barriers to the expansion and reinforcement of nanosciences in general, and to the formulation, development, application and use of nanotechnology-based products and services.

The articulated and integrated approach to nanotechnology proposed was very well received. Participants had various background and interests (researchers, students, politicians, sociologists, journalists, investors, medical doctors, …). They had the possibility to present, listen and discuss about their core business, as well as about all the other related aspects of this truly multidisciplinary field. Research, science and technology, as well as their applications and implications were dealt with giving a coherent and complete picture of nanotechnology for the 21st century, and beyond.

The following sections give an overview of the contents and debates of the thematic sessions held after the introductory session on Nanosciences at the Teatro Verdi. The state-of-the-art in the various areas and the discussions held are summarised as they have been presented during the closing session.

The texts below represent the conclusions of the Authors (the Rapporteurs of the Sessions) and do not commit neither the Editors of these proceedings nor the Speakers of the Sessions.

## *Session 2 - Societal Aspects and Communication*

***Rapporteur: R. Gennaro (University of Trieste, Department of Biochemistry, Biophysics, and Chemistry of MacroMolecules)***

### The state-of-the-art

Apart from the scale factor, the attempt to provide a precise definition of nanotechnology does not exist yet in the circle of the experts of the field. This lack of consensus is due to the multi-disciplinary nature of nanotechnology, a science which is constantly growing and linking different disciplines that were previously thought of as being distant from each other. The heterogeneous nature of nanotechnology, and the need of considering multiple technologies at the same time, complicates the discussion on the societal implications it may involve and the risks that might arise from its use.

Contrary to other large-scale scientific projects (e.g. atomic energy, space exploration, war on cancer, the human genome project), nanotechnology does not respond to specific social and political goals. At present nanotechnology rises high expectations on its possible outcomes but clear examples of devices that may be obtained by the use of this science are still rare.

Nanotechnology is also not yet affecting the perception of the public at large and then public reactions against the use of such a technology have not materialized yet at EU level, such as it has happened for other modern technologies (think of the public debate on GMOs).
The fact that nanotechnology is a science that is now making its fundamental heuristic and technological steps and will certainly achieve tangible results in a near future is now showing the need of addressing its societal and ethical implications. This would allow the technology to develop in a climate of public discussion-acceptance, which is the basis of a transparent participation of the public to the use of new technologies. If nanotechnology will not develop in harmony with public acceptance and will not respond to societal needs, the public may oppose its use and reject this prominent research sector.

**The expected impact**

A central issue to consider is the environmental impact of nanometerials and the possible risks for the human health that may arise from nanotechnology. Certainly specific risk assessment studies are needed which would take into account the proper features of nano-materials, including ultra-fine nanoparticles. The interaction between biological systems and nanomaterials is an area which will also deserve special attention from a risk assessment view-point.
But such studies would need not only a stochastic analysis of those risks that may derive from nanotechnologies, but also a deeper knowledge of a science so complex and heterogeneous. In absence of the above factors, it will be difficult not only to carry out risk assessment studies but also to define the weight that impact studies on nanotechnology may acquire in the assessment of this technology. Gnoseologic and technical risks have to be considered jointly.
Other issues that may need special attention are the protection of privacy and integrity of citizens with regard to any possible use of nanodevices to control and track people. Specific measures to guarantee the autonomy of persons involved and the protection of their fundamental rights, including their physical and mental integrity, will be then needed.

**The challenges**

As the expected applications of nanotechnology are being explored to date, it is difficult to predict the possible repercussions they may involve for the society at large. Some implications we may envisage include:

- How to communicate to the public in order to convey science and not science fiction?
- How to prevent magnification of the risk by the media ?
- How to define-analyse the environmental and health impact of nanotechnologies, taking also into account the experimental nature of such a technology ?
- How to avoid equating nanotechnology with biotechnology in the perception of the public ?
- How to promote debates on technology assessment of nanotechnology and guarantee the public participation to these discussions ?
- How to define-discuss regulative approaches to such a technology based on democratic participation ?
- To what extent “expensive nanotechnologies”, controlled by few governments and multinational corporations, and “cheap nanotechnologies”, outside the effective political and societal control, would involve different risks and societal concerns ?
- To what extent would be eventually necessary to prepare specific regulatory frameworks on nanotechnology which would require specific measures to fulfil (for example

the request of risk assessment studies prior the introduction of new nanomaterials into the market) ?

**Key messages**

To avoid that the public would perceive nanosciences and nanotechnologies in a negative sense, several suggestions have been proposed by the speakers:

1. Information on nanotechnology has to be easily accessible and understandable. In addition, one-way information has to be replaced by dialogue.
2. Public concern about nanotechnology must not to be interpreted and dismissed in the terms of the "deficit model", i.e. public misunderstanding of the science involved.
3. International collaboration is needed (a) to coordinate the definition and implementation of shared rules on nanotechnology (EU, USA, Japan, China, Russia, etc.), (b) to promote international agreements for a mutual exchange of information between the relevant actors at a global level, (c) to establish risk assessment studies on the environmental and health impact on nanotechnology, the study and the implementation of specific measures for the respect of dignity, integrity and privacy of human beings, as stated in the Charter of fundamental rights of the European Union. The efforts above should intimately refer to the multi-cultural aspects of our societies that may change in different time-frames the rank of their fundamental values.
4. Training and education on the social and ethical implications (or the socially perceived implications) of the use of nanotechnology for scientists is needed
5. Education at the PhD level on safety and ethical issues concerning new nanomaterials and nanodevices is needed.
6. Funding of projects aimed at understanding societal implications of nanosciences and nanotechnologies and monitoring their potential effects is also needed.

Considering that the nanotechnology challenges cannot be faced by a single country, an international council or forum for nanotech (after the UK Genetic Commission) has been proposed for a dialogue between the relevant stakeholders (scientists, technologists, philosophers, citizens, and public authorities). Such a forum should monitor the progress of nanosciences and nanotechnologies and guarantee its transparent progress, a basic condition to help the public confidence and acceptance of such a promising technology.
In this respect a key issue to explore will also be the military use of nano-research and/or the development of nanotechnologies for military or intelligence uses.

## *Session 3 - International Co-operation*

***Rapporteur: R. Marzari (University of Trieste, Department of Biology)***

**The state-of the-art**

E. Andreta, Director of "Industrial Technologies", Research Directorate-General, European Commssion, introduced this third session of the conference, devoted to International Co-operation. T. Kishi, Vice-president of the Science Council of Japan briefly described the initiatives on nanotechnology being undertaken in Japan. These initiatives include research projects and support to industry as well as the construction of a network for the exchange of

knowledge and collaboration among scientists. As far as the specific topic of the present session is concerned, the speaker reported that in the course of 2002/2003, many of the meetings and workshops held in Japan were organized in conjunction with American and European Institutions.
M.V. Kovalchuk, Member of the Russian Academy of Sciences and Director of the Institute of Synchroton Radiation, presented the results obtained in the field of nanotechnology in Russia and the principal directions for new activities, with particular reference to construction of new materials. He also underlined the fact that one of the drawbacks of this kind of research is the size the expense of the facilities involved which are presently still used by few scientists. One possible way of solving this problem is represented by international co-operation that would enable countries to limit costs through joint research programs.
M.C. Roco, Coordinator of the National Nanotechnology Initiative, USA, presented an overview of the activities of this long-term program which is focussed not only on the development of new nanosystems, but also on related studies including social issues such as education and sustainability.
R. Tomellini, Head of the "Nanosciences and Nanotechnologies" Unit of the Research Directorate-General of the European Commission, reported on the opportunities offered by the EU Sixth Framework Programme. In particular, international co-operation is implemented through joint research projects carried out at the transnational level and, significantly, these multilateral scientific initiatives are open also to participation by non-EU countries.

**The expected impact**

According to the speakers, besides the importance of nanotechnology in the field of technological innovation, the most foreseeable impacts of nanotechnology will be represented, on one hand, by the educational opportunities offered to young scientists, and on the other, by the implications for sustainable development (Roco).
Support to industry seems to be one of the major strategies pursued by many national institutions. The Japanese government, for example, fosters industrial growth by coordinating joint projects carried out by different ministries (Kishi).

**The challenges**

The setting-up of programmes focused on the environmental sciences is a response to concerns about the impact of nanotechnologies on the environment. However, the possible negative effects should be avoided by early assessments of risks at the international level (Roco and Tomellini). Other problems are connected to possible limitations in access to knowledge (Tomellini).

**Key messages**

In this exciting new field, international scientific co-operation and scientist mobility is probably one of the most effective ways of meeting the challenge that nanotechnologies represent for society, involving as they do legal questions, environmental risks, human health, and sustainability.

## *Session 4 - Accession Countries and Associated States*

***Rapporteur: L. Tassan Zanin (Central European Initiative – CEI)***

### The state-of-the-art

A recent survey of the state-of-the-art in nanotechnology in the Accession Countries was done at the "Nanomaterials and Applications" workshop held in October 2003 in Sinaia, Romania, and at the "Nanoscience and Nanotechnology 2003" workshop organised in November 2003 in Sofia, Bulgaria. Accession Countries consider the European Research Area (ERA) as the main streamline for their full integration and participation in European research and technological development activities contributing to the goals of the Lisbon Summit to achieve a more competitive and dynamic knowledge-based economy in Europe. At the moment R&D in the Accession Countries is behind the EU average, with most countries investing less than 1% of GDP; exceptions are the Czech Republic (1.25%) and Slovenia (1.51%).

Many Accession as well as Candidate Countries have created programmes to integrate their research into the ERA. Basic research systems in Accession Countries have a long tradition and many involve very highly qualified researchers. The new field of nanoscience opens new possibilities for younger generations, especially in Central and Eastern Europe: all Accession Countries have some nano-research, but some are investing more resources than others, e.g. Romania, Poland, Czech Republic, Bulgaria and Slovenia are organising their efforts in this new and emerging science. Slovenia, even being a small country, has considerable research potential in the field of nanotechnology with a special focus on nanomaterials, nanoelectronics and nanostructured surfaces. Within FP6, expressions of interest from Accession and Candidate Countries range from 9% for Poland, 4% for Turkey, 2% for the Czech Republic to 1% or less for the others.

Experience from some Associated States, such as Israel and Switzerland, could be very useful especially with regard to measures of promotion of science, technology and innovation, which revealed to be extremely appropriate. Accession Countries cannot directly follow US 21st Century Nanotechnology R&D Act neither Israeli INNI initiative, but have considerable potential to develop nanotechnologies.

Let us underline that in the posters hall, approximately 35 out of 90 projects were presented by the Accession and Associated States as follows: Croatia (4), Hungary (3), Poland (2), Romania (3), Serbia & Montenegro (1), Slovenia (5), Switzerland (13), and Turkey (4).

About 100 participants from Accession and Candidate Countries and about 20 from Associated States participated in EuroNanoForum 2003.

### The expected impact

The expected impact is unpredictable, but we can imagine a deep influence on the economic development of the new regions and generally on the everyday life of their citizens. Israel has already envisaged considerable impact on the future development of the entire state since it has decided that it is one of the most important priorities in the future development of the country (e.g. water desalination, energy saving and health).

## The challenges

The challenges, especially for Accession Countries and the whole Central and Eastern Europe, are enormous, since the development of nanotechnology does not rely on specific natural resources. To meet these challenges, research potentiality in Accession Countries and Associated States should be better integrated into EU projects within the framework of international cooperation. The industrial take up in nanotechnology is in most Accession Countries at the very beginning: a strong potential aspect is entrepreneurship. It should be stressed that EU integration processes will provide industry with more engineers and scientists. This could lead to the proper capacity building and, if supported with proper infrastructure facilities and coordination of national research at European level, could be internationally competitive. One of the major challenges is linked to the increasing costs of technological leadership.

As a result of the absence of innovation policies, the lack of coordination between policies, limited human and financial resources, and a weak capacity for business to absorb innovation, the major challenges to be faced by Accession Countries in the near future are risk aversion, under-investment in R&D and limited research-industry co-operation.

We must also be aware of the possible drawbacks of the new technology as we were with the stem cells issue. Up to now public awareness on nanotechnology potential threat is not visible. Availability of funds, the nano-bubble and a certain lack of business focus have been identified as possible risks in the field of nanotechnology.

## Key messages

The recommendations to be addressed to the public authorities concerned are the following:

1. Accession Countries and Associated States have to promote the new nanosciences and nanotechnologies potential using PR and general media, and incorporate promotion through legal actions, as the Israeli National Nanotechnology Initiative or the US 21st Century Nanotechnology Research and Development Act.
2. Furthermore, countries should be encouraged to prepare National Research Programmes with clear research priorities which should be technology driven. Nanotechnology could be among them.
3. The creation of European networks devoted to trans-national and international cooperation is recommended in order to advance knowledge and foster economic development. With regard to the universities, promotion of interdisciplinary research and teaching, as well as realisation of centralised laboratories should be taken into account.
4. The Swiss experience should be taken into consideration when investigating further R&D policy strategies: small countries have difficulties in reaching the critical mass but have the advantage to be dynamic and to rapidly achieve some tangible results in particular for knowledge exchange.
5. The Israel experience on the Academic-Industrial-Venture Capital collaboration in a framework of international cooperation could be useful for some Accession Countries with similar conditions (e.g. Slovenia).

Comments and discussion points proposed by the audience have been:

- Croatia is quite active in the nanotechnology field and is willing to increase opportunities in international cooperation: many of the Slovenian bilateral nano-research projects in the last 4-year period have been developed with Croatian partners (in 2001, 115 out of 590, second to the Slovenian partner was USA with 80 projects).

- Romania stressed the need for a better coordination of infrastructure development dedicated to nanotechnology: they propose to build a European Infrastructure as an European funded research project and they would avoid to set up structures that are intended to be supported lifetime. Infrastructures need to be strongly committed to some key research projects in order to be useful and are to be dismissed when not necessary or out-of-date (nano-equipment becomes often obsolete). With regard to education, they recommend programmes for PhD students' mobility.
- Slovenia would recommend special measures to foster the development of Venture Capital initiatives in nanotechnology in Associated Countries.

## Session 5 - Education and Training

***Rapporteur: G. Piacentini (Centre for Research on the Applications of Telematics to Organizations and Society, Università Cattolica del Sacro Cuore, Milano)***

### The state-of-the-art

Nanotechnology is among the first examples of the coming age of the Knowledge Society, or if one prefers, of the new "concrete" Knowledge Economy.
To ensure success from our investments in nanotechnology, we need Academia, Politicians, Industries, and generally speaking our Society, to become aware of this revolution which will be the driving force for future economic growth.

Education and Training will play a major role in this revolution in order to obtain:

- A class of smart and well trained people (in sufficient quantity to satisfy industrial needs)
- An evolution of industry towards nanotechnology projects
- Political rules and funds to guide Society in this knowledge era.

The educational system also needs to adapt to the needs of the new era.

We need new educational systems and new teaching methodologies:

- Multidisciplinary (Physics, Chemistry, Biology, Engineering, Business)
- Group-based learning (cross-fertilization)
- Project and Problem-based learning (from pure basic science to application oriented science).

The main goal is to train people to gain the following characteristics:

- Multidisciplinary approach/background (i.e. with a background education in all main disciplines)
- Collaborative skills (to share knowledge and solutions)
- Customer oriented: i.e. able to identify a specific problems or need and find a solution (Project/Problem solving oriented).

### The expected impact

On Academia:

1. Be active in more interdisciplinary work projects (i.e. stronger inter-departmental collaboration).
2. Prepare teaching methodologies based more on project/problem solution.

On the Industrial Side:
1. Need of workforce (trained and expert staff in nanotech) and new skills (multidisciplinary expert).
2. Need to avoid obsolescence of exiting workforces and managers.

On the Financial Side:
Need to better understand the nanotech business model in order to have opportunity for new positive investments.

**The challenges**

These are mainly three:
1. New research areas (food, pharmaceutical, health, electronics…etc.).
2. New jobs.
3. Opportunities for new industries and for new applications with high added values.

Two possible negative effects have also been identified:
1. Nanotechnology Divide
2. Business Ethics.

**Key Messages**

1. Support the evolution of Academia (new teaching methodologies, curricula, national projects, seminars, courses etc.).
2. Support Masters in nanotech (those who have related labs facilities to be project-oriented).
3. Prepare actions and plans to attract young people to the nanosciences.
4. Provide incentives to Industries and Universities who develop collaboration for:
   - Training courses (on nanotech) and seminars for existing workforces and managers.
   - Common research projects oriented to an immediate industrial application.
5. Ensure that researchers and engineers can move between academia and industry (inter-sectorial mobility) by e.g. addressing any obstacles in the valorisation of careers (i.e. publications versus patents).
6. Organize meetings/conferences/seminars/videos with the aim of making society aware of the “nanotech revolution” (both for opportunities and risks).
7. Support, in every region, a yearly prize for new innovative projects in nanotechnology with possible industrial applications.
8. Encourage Banks and Foundations to support nanotechnology training courses.

## Session 6 - Research, Industrial Innovation & Entrepreneurship, Financing Instruments

***Rapporteur: N. Pangher (ITAL TBS Medical Equipment)***

**The state-of-the-art**

There is already a very important activity in scientific laboratories developing the basic scientific knowledge, important technologies and many prototypes in the nanotechnology field. The key issue is to bring this "idea pool" to the market: successful industrial projects are an essential element for the development of nanotechnology in the EU.

**The expected impact**

The impact of nanotechnology on industry will be dramatic and could change the rules of the "market" game in several fields, ranging from the biomedical sector to the production of new materials. Therefore, all economic players, ranging from the large corporations, start-ups and SMEs, to public agencies, and investors, are looking at how to speed the technology transfer process.

**The challenges**

The key element in the transformation of "research" into "products" is the entrepreneur: the entrepreneurial activity is asked not only for starting-up companies, but is also a key element in promoting innovation in large corporations. It is therefore necessary to put into action all possible measures to develop and reward an entrepreneurial attitude in the nanotechnology community.

**Key messages**

1. Funding should be directed to projects with a clear application potential.
2. There is the need to create and support research institutes that are able to go from basic research to the set-up of small scale production.
3. There is the need to educate technologists in marketing and finance.
4. There is the need to promote smaller scale funding (seed capital) to help researchers to pursue industrial applications of nanotechnology.

## Session 7 - Infrastructure, Equipment and Metrology

***Rapporteur: F. Antonangeli (ELETTRA - Synchrotron Light Laboratory)***

**The state-of-the-art**

There is an undisputed awareness that the development of nanotechnology requires a novel approach to research management, the keyword being "integration" at different levels:

1) Integration of different competencies (physics, chemistry, life sciences, etc.).

2) Integration in networks of the activities carried on by different centres of excellence.
3) Integration of the interests of scientists, entrepreneurs, credit institutions.
4) Integration of the efforts of single companies and of single countries.

**The expected impact**

At national level, many European countries already undertook integration efforts of the kind described by points 1), 2) and 3) above. Different aspects have been illustrated during the session such as:
- Networking of the skills of the best centres of excellence through competition for "glue-money" from public authorities.
- Increasing the awareness for the application of multidisciplinary research centres, by promoting the exchanges with industrialists, both by proximity to advanced industrial facilities and by incentivation (part-funding) of collaborative research projects.
- Sharing the access to costly key equipment and materials.
- Evaluating projects which deserve to access financing through tailored instruments such as venture capital funds, co-investment and proof-of-concept funds.

At transnational level, it is important to underline the role of research infrastructures as points of attraction to favour the cultural exchange of scientists coming from different disciplines and from different countries.

**The challenges**

More than 80% of the research investments in Europe is still managed by the single Member States. In the effort for the creation of the common European Research Area, it is necessary that the available resources are efficiently exploited to avoid wastes and duplications. The funding from the European Commission must act as a catalyst to promote networking (and steering) of the activities of the single Member States, also as far as national infrastructures are concerned.
This effort for a Europe-wide rationalization must be reconciled with another (apparently conflicting) need, namely that in order for science and research to reach the hearts and brains of the people, it is necessary to preserve the regional character of excellence initiatives.
As disappointing it might sound, also according to the experience gained in the USA, no golden rule exists on how to accomplish the best compromise between these two requirements.

No negative effects are envisaged as far as health or environment issues are directly concerned. However, a negative remark has been expressed concerning the apparent lack of a European approach to nano-metrology, as witnessed by the lack of dedicated funding in the 6$^{th}$ Framework Programme. This lapse is perceived as a potential hindrance in the systematic exploitation of nanotechnology and hence in the process of overcoming the difficulties that big enterprises have in absorbing these new technologies.

**Key messages**

A (maybe) obvious message has come out, i.e. that the (healthy) competition of Europe with the USA or Japan cannot be sustained without a financial support of comparable size.
Furthermore, it must be kept in mind that, as any other activity, research is carried out by humans, which makes the human capital the most important "infrastructure" in any branch of

research. Therefore, it is necessary to invert the present tendency according to which the career in research or in research-related activities is perceived as unattractive by talented young people. On this respect, nanotechnology is in a favourite position with respect to other research fields since, according to updated surveys, no negative mistrust feelings from the broad public are associated with it.

## *Session 8a – Nano-manufacturing and Instrumentation*

***Rapporteur: E. Brusa (University of Udine, Faculty of Engineering, Department of Electrical, Managerial and Mechanical Engineering)***

### The state-of-the-art

Nanomanufacturing provides technological processes to design and build, at the nanoscale, structures and integrated systems, by following either bottom-up or top-down approaches. Bottom-up processes include self-directed assembly, template growth, colloidal aggregation, 2-photons confocal processing, contact printing, imprinting, spinodal wetting, laser trapping, electrostatics (coatings, fibres); top-down processes are mainly based on lithography (e-beam, ion beam, scanning probe, optical near field), thin film deposition and growth, laser beam processing, mechanical tooling (machining, grinding, lapping, polishing), and electrochemical material removal.

Current advanced trends in nanomanufacturing concern: nanomaterials manipulation and structuring; information technology nanodevices production, nanobiotechnology (diagnostics, bioengineering, drug delivery), integrated nanosystems construction, including actuators, sensors, filters, MEMS/ NEMS and nanomachines.

Critical issues of nanomanufacturing have been identified in: (1) the strong integration of nanosystems, requiring a concurrent engineering based on interdisciplinary competences (chemistry, physics, mechanics, electronics, material and computer sciences and biology); (2) the wide range of products including both nanoproducts (powders/sinterized nano- structures, wires, tubes, composites) and devices to assembly, operate, manipulate components at the nanoscale (grippers, probes, catalysers, enzymes…); (3) the need for instrumentation to characterize physical, chemical, mechanical and electrical properties (strength, electrical resistivity/conductivity, optical absorption,…) at the nanoscale; (4) the need for prototyping, measuring, modelling and simulating tools, which have the same relevance as the manufacturing facilities.

### The expected impact

A great social impact of nanotechnology is worldwide foreseen, based on the development of a wide range of applications: chemical (cut and wear resistant coatings, pigments, pharmaceutical products), electronic (semiconductors, optics, thin films, photonics), computer science (quantum computers), biological (biosensors, DNA diagnostics, functional fluids), mechanical (propellants, power, powders, injection moulded nanocomponents, materials and biomaterials), mechatronic (NEMS, robots).

Key features of manufactured nanosystems are typically miniaturization of devices, enhanced computing and storage capabilities in information technology, biocompatibility, surface smoothness, self-assembling skills.

For the effectiveness of the above-mentioned systems several conditions should be guaranteed, from the point of view of manufacturing and equipment:

(1) Manufacturing should be massively parallel and fault tolerant.
(2) "Manufacturing itself must not be laborintensive. Nanomaterials have to be produced in relative low yields and have to compete against low-cost mass products. A high degree of automation and continuous flow of process is necessary. In contrast to semiconductor industry, where precision is paid per part, nanomaterials have to be precisely manufactured particle by particle, although delivered and priced in kilos or tons".
(3) Equipment for measuring and characterizing nanosystems (for instance to measure friction forces) have first to be provided, where absent or up to now dedicated to microscale, have to be either modified or designed by making accessible an easy calibration, the highest modularity and flexibility (also to contain costs of the instrumentation), and multi-analysis.
(4) Theoretical and numerical tools for simulating and predicting the behaviour of the nanosystems and to guarantee the product reliability have to be tested at the nanoscale to ensure that phenomena are those implemented in models, considering the role of scaling effects, and to deal with the multi-physics domain.
(5) Some specific technological bottlenecks have to be solved by reaching lower limits in scale for manufacturing and measuring (for instance, nanofabrication on the sub-10 nm scale, nanophased powders arranging and phase constituting, measurements resolution of the nm order, improvements in instrumentation in extreme magnetic field and temperature conditions).

**The challenges**

(1) To reduce the current technological limits in manufacturing and measuring, top-down and bottom-up approaches should be increasingly integrated. The latter requires that biology and physics/engineering have to find the highest level of communication, starting from the education of new interdisciplinary professionals for nanomanufacturing.
(2) Chemical synthesis, self-organization and self-assembling have to be furthermore developed to build new components with higher performance at the nanoscale, to contain both costs and requirements for the manufacturing process, for instance those of lithography, in massive production.
(3) Instrumentation has to enable the analysis of extremely small samples with high resolution and predict properties for several kilograms of production lots.
(4) Multi-physics domains have to be modelled, implemented and analysed at the nanoscale, by following interdisciplinary systematic approaches (like in case of bioNEMs).
(5) Investments in nanotechnology have to be used to enhance tools capability, like in computer science and information technology, to increase the growth of nanosystems.

The possibility of negative affects has also been discussed.
"Improving nanotechnology means moving to processes with no waste, or with a small amount of materials. Being a new technology potentially negative social effects, due to unexpected release of materials into the environment, have to be taken into account. Indications so far show that the advantages of nanotechnology by far outweigh the potential unexpected consequences. For example, nanoparticles can eventually target cancer cells and visualize illnesses before they happen. At the same time, nanoparticles may have effects that are not yet fully determined".
The development of nanotechnology must be done in responsible way. Manufacturing should be the most critical step of the technology in terms of environmental and health issues. In this

respect, a fast assessment of the technological processes, and then of international standards, will be the only way to contain and predict possible drawbacks.

**Key messages**

1. The above mentioned peculiarities of nanomanufacturing and instrumentation make the development costs quite expensive. A straightforward cooperation between academy and industry has to be encouraged and disciplined. Furthermore, industry could benefit from cooperation more than competition. The constitution of a specific agency or sub-agency and network for manufacturing, with budget for research, should improve the assessment of the technology.
2. The strong interdisciplinary character of nanotechnology call for a massive action to build an interdisciplinary culture as well as new professions, based on several levels of education, which nowadays are not yet available.
3. Although several methods for manufacturing are already available and currently being improved, the need for innovative concepts for manipulating, probing, tailoring at the nanoscale is still present and has to be encouraged. Basic research on materials, chemistry, biology, mathematics and engineering has to be developed as well as on specific nanodevices (for instance: in nanoeletronics the effect of the presence of the Coulomb interactions and the "quantum" granularity of the charge requires a better understanding of the electrons transport; in nanomechanics, on the other hand, advanced research on contacts can improve nanoidentation).
4. A systematic organization of short, medium and long range priorities in nanomanufacturing should be welcome to promote standards' definition and plans of activities in research and industry.

## *Session 8b - Functional Materials*

***Rapporteur: M. Prato (University of Trieste, Department of Pharmaceutical Sciences)***

**The-state-of-the-art**

Functional materials can be defined as materials that play a function. Such a definition, broad by necessity, includes, among others, optical, electrical, magnetic, mechanical and biomedical materials, with important applications in everyday life. Health issues, automotive engineering, energy systems, environmental advances, are all affected by the continuous discovery of new materials with enhanced functionality.
The key to a successful development of a new functional material lies in rational design strategies. This can only be achieved through the understanding of fundamental interactions at the molecular level and therefore through the combined effort of chemists, physicists, medical doctors and engineers. It is "interdisciplinarity" the winning keyword of Materials Science and Nanotechnology.
Prof. Klaus Kern (Max Plank Institute, Stuttgart) has explored magnetic systems that bear important implications in magnetic data storage technology. The construction of stable magnetic systems has enormous consequences in computer industry. Prof. Kern has shown single atoms moving with Brownian motion through high resolution electron microscopy while using self-assembly of magnetic nanoparticles.

In the field of nanostructural materials, surface engineering is of paramount importance. While many chemical and physical methods are available for the nanofabrication of layers and coatings, the industrial scale-up of these systems is still a great challenge. Dr. P. Piseri (University of Milan) has described a physical vapour deposition-based nanomanufacturing approach, which allows the batch fabrication of multi-element micro- and nano-sensing devices (quantum dots, nanocomposites, nanostructures).

Nanocomposites designed to fulfil specific requirements for various applications have been reviewed by Marie-Isabel Baraton (CNRS, Limoges). Many ways of creating improved nanocomposites have been summarized, with many results reported and many challenges to face. Possible applications of nanocomposites include membranes, flame retardant, packaging, photovoltaics, and biocompatible materials.

Liquid crystals are key components in displays for computers and TV screens. They are functional materials that self-assemble spontaneously into ordered nanosystems. In his talk, Prof. Yves Geerts (Université Libre de Bruxelles) has described an unprecedented class of materials, made of disk-shaped molecules that stack into columns. The potential of these novel materials in optoelectronic applications, such as light-emitting diodes (LEDs), photovoltaic diodes (PVDs), field-effect transistors (FETs) has also been highlighted.

In the final talk of this session, Prof. J. K. Nørskov (Technical University of Denmark) has demonstrated how computational methods can help the design of new materials at the nanoscale. With the help of some specific examples, the speaker has discussed the general prospect of using electronic structure methods in the search of new materials.

**The expected impact**

Functional materials are recognized to be fundamental in developing different types of advanced technologies. Scientists, as human beings, are required to create novel functional materials in order not only to improve our future, but also to preserve the resources and the environmental treasures of our planet.

**The challenges**

The development of novel materials must involve full interdisciplinarity in total systems engineering processes, taking into account resources, design, synthesis, characterization, processing, applications and waste control of the materials.

Health or environmental damage of the uses of new functional materials is a fundamental issue, which still needs investigation. Not much is known yet about the possible consequences induced by new materials. This suggests the necessity of in depth studies (health, environment, etc) of the new functional materials before their market submission.

**Key messages**

Materials science and nanotechnology lie at the crossroad of many different disciplines, such as chemistry, physics, engineering and medicine. A first priority in the development of this exciting field is to invite groups to share their different expertise. The creation of infrastructures which may favour science merging and blending should be strongly encouraged. This will also strengthen the cohesion and impact of the European contribution to this scientifically and potentially economically important field by emphasizing the contact between materials science and industrial research. The impact on areas of fundamental and applied science should not be underestimated and specific priority should be given in national studies as well as in EU training actions.

## Session 8c - Ambient Intelligence

***Rapporteur: A. Trovarelli (University of Udine, Department of Science and Chemical Technologies)***

### The state-of-the-art

The state-of-the-art of ambient intelligence includes the following research areas: (1) ubiquitous computing: wired, wireless networking, system integration, portable devices; (2) context awareness: sensors, tracking and positioning, smart devices, wearables, intelligent clothing for example for health management; (3) natural user-system interaction: ambient technologies, studies on user-systems interactions; (4) embebbed energy: confined combustion, microfuel cells, scavenging-harvesting.

### The expected impact

For ambient intelligence to become a reality it should completely involve humans without constraining them. The impact on society and the way we live and work will be enormous. Rather than struggling and fighting with devices and machinery, we will relate to them personally. Applications ranging from safe driving systems, smart buildings, home security, smart textiles, smart body sensors and medical health, to manufacturing systems and rescue and recovery operations in hostile environments are to become part of human life. Embedding logic in fabric will be possible within a few years; and miniaturized sensors placed within the body will improve people health comfort and safety by 2007. This in turn will give a more efficient treatment of disease through easier, facilitated and accepted diagnostics. The vision of a future filled with smart and integrating objects offer an enormous range of fascinating possibilities. Just as an example, parents will no longer have to keep track of their children if position sensors and communication modules are placed in their clothes. Similar devices in our body could keep track of our health, and give us an alarm when something changes. The benefit of a world full of smart objects does not stop here; ambient intelligence would also facilitate a range of new applications and new business models and the way we approach culture, leisure and entertainment.

### The challenges

The ability to develop advanced products and services depends on excellence in designing and realizing integrated micro and nanosystem components. The embedding of computing and networking capabilities into several objects and environments results in a real time form of computation that poses severe demands on micro and nanodevices in terms of functionality, design, power, robustness wireless easy communication and cost. The application know-how must be integrated more than ever. This requires increasingly rare interdisciplinary expertise in many areas of science and technology and, in particular, bioengineering, chemistry, nano- and micro-electronics, informatics. In addition, freedom in mobility, in terms of both personal transportation and portable devices, depends on the way we will produce and use energy. Embebbed energy will be a challenge for the next decade.

Although many concepts and devices have been already tested commercially or as prototypes, the repercussions of such extensive integration of computer technology into our everyday lives are difficult to predict. Certainly, problems may arise in the area of personal privacy: ambient intelligence has the potential to create an invisible and comprehensive surveillance network covering an unprecedented share of public. The widespread use of silicon technology might lead to environmental problems related to the ways of producing chemicals.

**Key messages**

The main question appear to be: how can intelligent systems made be accessible to all? Administrations should facilitate the access to the necessary resources to make acceptable the use of ambient intelligence in the everyday environment. The new technology should not become a source of exclusion for a part of society.

## *Session 9a - Nanoelectronics*

***Rapporteur: L. Sorba (INFM-TASC, High-Mobility and Quantum Group)***

**The state-of-the-art**

During the last few years a lot of effort has focused on the development of electronic devices and circuits based on objects with dimensions in the nanometer range, like biomolecules (DNA), clusters, and nanowires including carbon nanotubes. Molecular electronics has recently raised prospects as a potential complement or even as a successor to the information technology based on CMOS circuits.
Several pioneering experiments on molecular transport and theoretical models have been developed allowing the understanding of the relationship between the molecular structure and the corresponding transport properties.
Furthermore, several devices based on molecular units have been demonstrated, which include diodes, negative differential resistances and their application to memory, electromechanical or electrochemical switches with memory applications, and single electron transistors.

**The expected impact**

The impact of nanoelectronics will be mainly economic. As a matter of fact, the International Technology Roadmap for Semiconductors (ITRS) predict that the CMOS technology will reach fundamental limits in terms of miniaturization and energy consumption by 2015. To overcome these limits it is very important to exploit and develop alternative technologies. Molecular nanoelectronics is a candidate alternative technology due to the small size of molecular objects. Moreover, self-assembly fabrication processes are also identified as the most promising way to reduce complexity and, significantly, the fabrication costs. Finally, due to the inherent quantum nature of biomolecules, power consumption reduction is expected from nanoelectronic devices.

**The challenges**

Molecular electronics will provide new opportunities on the basic research level and also to the more industrial applications.
Several devices based on molecular units (biomolecules, clusters and carbon nanotubes) have been demostrated, but a lot of activities are in progress for improving device performance. At present, the challenge is to go beyond the device level and attain the circuit level. The implementation of new architectures of circuits based on nanoelectronic devices will be the challenge for the future.
No negative effects on health or environment are expected from the nanoelectronic activity.

**Key messages**

The availability of a new class of devices based on molecular units will provide new opportunities in microelectronics. Significant reduction of the fabrication costs of molecular-based devices is expected with respect to the silicon-based technology. The reduced size of the molecular objects will help to overcome the fundamental limit in terms of miniaturization of the conventional semiconductor based technology.

## *Session 9b - Nanobiotechnology for Health*

***Rapporteur: A. Dobrina (University of Trieste, Department of Physiology and Pathology)***

EuroNanoForum 2003 has provided clear evidence for current prominence by technology in nanoresearch, after basic science has supplied almost complete grounds of the knowledge required for technical nano-processing. Moreover, nanoresearch results appear already implicit, most probably in a short time, given our time itself is more and more approaching the nanoscale. Rather, depending on nowadays research capacity of integration, as outlined by Dr R. Tomellini in Session 3 when identifying in "*integration* and *cooperation*" the top priorities of the next 6$^{th}$ EU Framework Program for Research and Development.
A series of such potential integrations applied to health science investigation were suggested in the session, related to already experienced research fields by research advisers of relevant biomedical institutions such as Mauro Ferrari (Ohio State University), Gianfranco Gilardi (Imperial College of Sci., Tech. and Med., UK), Giulio San Roman (Dept of Macromol. Chem., University of Madrid), and A. Archakow (Russian Academy of Medical Sciences).
Prof. Ferrari emphasized that guidelines of the nanotechnology plan of the US National Cancer Institute (NCI) were clinic driven, the challenge goal of NCI being "Vision 2015" (no more suffering and death due to cancer within 2015). Major trends in cancer nanoresearch refer to prevention (polyepitope vaccines, cancer preventing agents, nutriceuticals), detection (imaging diagnostics, proteomic nanotech: protein chips and bio-FET arrays), screening and monitoring (implantable biosensors, smart injectable targeted contrast agents), and therapy (multi-therapies, self-addressing drugs, nanopore beads for sustained controlled drug delivery). One suited example of targeted drug in cancer therapy is anti-angiogenic silicon nano particles directed to microvessel endothelial cells carrying angiogenic factor (VEGF) receptors. Similarly, nanopore beads bearing immunoisolated xenografts, e.g. pancreatic islands freely releasing insulin were proposed in tipe I diabetes.
Besides encapsulation of pancreatic as well as liver cells, grafting of autologous differentiated cells after *in vitro* replication, or stem cells after *in vitro* growth and differentiation represents

a new chance to reconstitute tissue loss. Examples of tissue regeneration include epidermis, skin vessels, bone, cartilage up to nerve and brain cells. Bioactive, biodegradable materials, including porous metals, porous ceramics, collagen and polylactic acid built to form three dimensional scaffolds favor tissue regeneration after implantation. Notably, the three dimensional structure of the scaffolds is able to orientate the direction of tissue regeneration as well. Growth factors linked to the scaffolds may further promote cell growth.
Progress in top-down research now deals with protein engineering and creation of fusions of protein modules to be assembled as biosensors on electrochemical chips, of potential interest for diagnostics, environmental monitoring and drug discovery. Finally, *integration* between diagnostic goals and technology involves use of AFM to detect $10^{-15}$ M concentrations of a given protein in biological fluids.

## *Session 9c - Energy*

***Rapporteur: R. Rosei (ELETTRA - Synchrotron Light Laboratory, University of Trieste, Department of Physics)***

### The state-of-the-art

New nanoscience concepts have emerged in the last few years concerning the local chemical reactivity of nano-scale clusters and the understanding of their physical properties. Within this session a wide variety of applications have shown to be very promising in all the different subfields of energy management: production, storage and conversion.
The following scientific and technological advances have been put into focus:

- the use of nanocrystalline materials for a new class of low cost, high efficiency solar cells;
- the use of Quantum Dots and Quantum Wells for the enhancement of photon conversion;
- the use of advanced synthesis techniques (like Atomic Layer Chemical Vapor Deposition) for the fabrication of 3D nanostructured solar cells;
- the use of mass selected atomic clusters (in particular 13 titanium atom clusters) for the construction of novel hydrogen storage materials;
- the use of advanced theoretical and experimental techniques for designing new classes of nanostructured catalysts for hydrogen production.

### The expected impact

The expected impact is extremely far reaching. Indeed the use of nanosciences and nanotechnologies in the strategic field of energy management, by solving some of the most pressing problems (by favouring enhancement of performance and/or cost abatement of materials and devices), could result in completely new ways of processing, storing and using energy.
In time, this may signify a quick evolution of the economical impact of energy sources different from the nowadays pervasive oil.
The social impact could be just as revolutionary since it would most likely imply distributed energy generation, versus today's concentrated energy production at very large plants.

**The challenges**

The challenges are still rather impressive and they encompass all the steps from basic research to technological advances and, finally, industrial take-up.

At fundamental level, Density Functional Theory (DFT) computational methods have enabled to reach an impressive level in the understanding of nanostructured material properties. All the subfields of nanotechnology applications in energy production, storage and conversion, would strongly benefit from larger cooperation efforts between theory and experiment.
At the experimental level, although important advances have been made, it is imperative to maintain the present momentum, especially in the improvement of a-priori designed nanostructures and their thorough characterization.
The step of producing industrial-scale quantities of uniform quality nanostructured materials is even more challenging.

Possible negative effects of the technologies proposed within this session have not been discussed. As a personal opinion of the Rapporteur, no particular negative effects can be envisioned. Of course, when producing large quantities of materials in the form of nano-clusters, care will have to be taken not to disperse them into the environment. Nano-clusters tend to have enhanced chemical reactivity, and inhalation or ingestion may have adverse health problems.

**Key messages**

The key message that can be drawn from this session is the need of building a larger network of suitable infrastructures capable of exploring new avenues for both the production and the characterization of nanostructured materials, with the aim of making them available to an ever larger community of scientists and industrial researchers.

## *Session 10a - Nano-robots and NEMS*

***Rapporteur: K. Höhener (Temas AG, CTI - Commission for Technology & Innovation, Switzerland)***

**The state-of-the-art**

In this session three topics of nanorobotics have been addressed:
1. Top-down (classical) robots for assembling and manipulation with sub nanometer resolution: top-down technology resolutions today go down to $1{:}10^7$ over distances of up to 160 mm and increments smaller than 0.1 nm.
2. Single Molecule Nano-Robots as bottom up approach: bottom-up technology, follows the example of nature (ATP-Ase), and main applications are:
a. rotary motors with two rings with a relative motion between the rings
b. linear motors (molecular "Otto motor") for synthetic muscles
3. Biosensing tools with the approach of transducing biological and chemical processes into nanomechanical motions using micro fabricated cantilever arrays. Micro- and Nanomechanical (MEMS and NEMS) sensor arrays with ultra high resolution, fast response

for parallelization into integrated devices can detect multiple unlabelled biomolecules down to picomolar concentration within minutes.

**The expected impact**

1. Bottom-up technology:
- Information memories (molecular electronics)
- Motion systems for robots, artificial muscles, smart materials
- Clamping systems
- New technological approach for existing and future requirements (markets), improve quality of life for an aging society.

2. Top-down technology:
New ultra high precision manufacturing an assembling processes and equipments, functional modules for nanometer lithographic processes, ultra high resolution motion equipments for analytical instruments etc.

3. Sensors:
New class of low cost, ultra high sensitive, online analytical systems and instruments for biological, chemical and physical processes. New sensor arrays to analyse several parameters simultaneously.

**The challenges**

- Integration of "top down" and "bottom up" approaches to fill the gap from the nano-world to the macro-world.
- Simple reliable sensors with ultra high resolution and sensitivity, new replication processes, robots for the nano- and micro scale.
- New findings in the nano dimension motion elements and systems, interfacing to the micro- and macro-world.

Possible negative effects seem not to be a real issue at this time. Emotionally, nano robots have already a "science fiction" image, this needs to be addressed in a more realistic way. (which could be seen as a negative starting point).

**Key messages**

1. Support the exchange of information, no panic and emotional actions !
2. To date there is no potential for regulations. Professional communication and dialog with the public has to be addressed first.

## *Session 10b - Optics and Photonics*

***Rapporteur: R. Bozio (University of Padova, Department of Physical Chemistry)***

**The state-of-the-art**

Photonics deals, in quite general terms, with the generation, transport, processing and detection of light. Thus, it is quite natural to associate photonics with IT technologies and to compare it with micro- and nano-electronics as for the ability to perform its relevant functions on a nanometre scale. In this respect, diffraction is a fundamental handicap for photonics to go nano. However, advances in the last decade show that both (i) nanotechnology can contribute to the progress of optics and photonics and that (ii) near field optical interactions, ultra-sensitive optical detection techniques and non-linear optical processes can provide viable solutions to specific nanotechnology problems.
Examples of point (i) above are: nanoporous and nanostructured silicon turning into a material of interest for optoelectronics; quantum wells, wires and dots of compound semiconductors or their alloys that allow engineering of absorption, emission and NLO properties; supramolecular and self-assembled structures that, by mimicking biological systems, perform the funnelling of photon energy into reactive centers to perform photochemical or photophysical processes or vectorial electron transfer.
Scanning near field optical microscopy is the most obvious example of point (ii) above but linear and non-linear optical interactions enhanced by surface plasmons or local fields at the interface with nano-objects are not less relevant for nanotechnology applications. The growing number of optical techniques for single molecule detection with increasing potential for providing structural and dynamical information (including the ultrafast regime) provide powerful tools for investigating nanosystems of chemical and biological interest.
Resonant multi-photon processes in semiconductor nanoparticles, complex molecular, supramolecular and dendrimeric structures present sound perspectives for applications in many fields ranging from sub-micron manufacturing to biological imaging to photodynamic therapy.
Photonic crystals are possibly one of the best examples to illustrate how almost all of the above aspects can be integrated in a single technology. They can be prepared either by a top-down approach using conventional or holographic lithography or by bottom-up, self-assembly methods (based on latex beads, sol-gel processing, etc.). Photonic band gap systems can be impregnated with organic NLO molecules and conjugated polymers to perform optical switching by intensity modulation of the optical bandgap. Optical microcavities or wave-guiding structures can be prepared by properly engineered defects in the photonic crystal. 3D wave-guiding patterns would be highly desirable and microfabrication performed exploiting the inherent spatial resolution of multi-photo absorption is being investigated as an appropriate processing technique.

**The expected impact**

Society will benefit from developing nanostructured materials for optics and photonics for the IT sector. Optical telecommunications have already had a large impact on promoting a knowledge-based society and on improving the quality of life in general. Nanotechnology can help deploying the full potential of optical networking by providing innovative solutions for components and devices, from light sources and modulators to displays.

Further benefits will arise from the emergence of new processes and products that exploit novel optical phenomena for manufacturing, control and sensing as well as for biomedical imaging, diagnostics and therapy.

**The challenges**

Interdisciplinarity (from chemistry to optical engineering) is a key success factor.
The most effective strategy to fulfil this requirement is probably the training of young researchers in a multidisciplinary environment, yet with top class skills in a definite field.
There is a strong need for multiscale modelling tools (including inter-particle and environmental interactions, materials and devices).
One obstacle to reach critical mass in this field is the high cost of research (even if carried out in small groups) due to the expensive equipments (e.g., lasers and associated technologies). Access to shared (nanofabrication) facilities equipped with clean rooms could greatly help provided they are supported (both for personnel and equipment) and spread over Europe.

Nanotechnology-based optics and photonics will impact on sectors that are characterized by niche rather than mass productions. Therefore, major environmental problems should not arise. However, as an example, should the use of compound semiconductor nanoparticles be spreading, careful monitoring of possible negative impact is required and appropriate recycling procedures should be worked out and applied.

**Key messages**

1. Develop interdisciplinary training.
2. Support multiscale computational modelling tools.
3. Develop a mechanism to share experimental and modelling facilities through Europe in an efficient way to face the high costs of such facilities.

# 3. THEMATIC WORKSHOPS

The texts below represent the conclusions of the Authors and do not commit neither the Editors of these proceedings, nor the Organisers, nor the Participants and Speakers of the Workshops.

## *Workshop 1: International Co-operation in the NMP Programme*

### Special Outreach Event for International Co-operation with Latin America and South Africa

**D. Jering**

European Commission, Research Directorate-General, Industrial Technologies Directorate

The meeting served to raise awareness among representatives from Latin-America and South-Africa on the possibilities to participate with funding in the European Research Framework Programme 6. The participants (see annex) had been invited by the European Commission, Directorate Industrial Technologies in order to receive accurate information on how to seize this opportunity. The session focused in particular on how to join a European consortium that submits a proposal in the currently open call for proposals in the area of nano-sciences, nanotechnology, materials research and production technology (NMP). In addition, participants were invited to visit EuroNanoForum 2003 which attaches also great importance to the aspect of international co-operation and where they could meet potential partners for co-operative activities.

Ms. Jering from the European Commission, Research, in charge of promoting international co-operation in the Industrial Technologies Directorate, introduced into the **3 major routes in the 6$^{th}$ Framework Programme for international scientific co-operation:**

- 1. Collaboration within the thematic priorities like life science, genomics and biotechnology for health, Information Society technologies, nanoscience and technologies and -sciences, knowledge-based multifunctional materials, new production processes and devices, aeronautics and space, food quality and safety, global change etc. (allocated budget €285 million)
- 2. Dedicated activities supporting the European development aid policies, like fight against poverty, the EU water initiatives, and commitment towards the Millennium Development Goals (allocated budget €315 million)
- 3. International mobility of researchers actions see www.cordis.lu/fp6/mobility.htm, and in particular Marie Curie Action see http://europa.eu.int/commm/resarch/fp6/mariecurie-actions/home offering training, mobility and career development

She explained that proposals can only be submitted in response to a call and introduced into the current NMP call (http://fp6.cordis.lu/nmp/calls.cfm). She then invited Dr Ruben who has successfully initiated a project within 7 months from the idea to the realisation to share his experience in proposal preparation
(see http://www.cordis.lu/fp6/stepbystep/prep_proposal.htm).

Discussions focused on practical issues like **partner search** (exploit existing contacts, CORDIS data base http://partners-service.cordis.lu/ or National Contact Points also on http://www.cordis.lu/fp6/ncp.htm**), eligible costs for funding** (all economic and necessary cost for the project are covered like personnel, consumables, durables, travel, management, IPR), cost models (Additional Cost model covers all additional to the recurrent cost of a participant and normally applied for universities and non-commercial and non-profit organisations) and **next steps**. All participants agreed that they should try as a first step of a long term collaboration strategy try to join a **European project proposal** (with a European co-ordinator). Experience could also be gained as **independent evaluator** for assessing the proposals; Ms. Jering drew attention to the possibility that any scientists and researcher may to apply as prospective independent expert in order to be included in the Commission's database of experts for the 6th Framework Programme - see http://www.cordis.lu/experts/fp6_candidature.htm

The second part of the meeting was devoted to detailed presentation of the participants of their research policies in industrial technology, their infrastructure and their organisations and their competencies. In this context it became clear that strong ties have already been established with the European research community which should be exploited to reinforce the collaboration.
Ms. Jering promised to pass the documentation provided by the participants (also additional info to be provided) to the network of European Contact Points for the nano/materials /production technology priority of the 6th Framework Programme.

She thanked all participants for joining this event and their informative contributions. She took note of the commitment of all participants from Latin-America and South Africa to pass this report to their relevant organisations, networks and ministries and to suggest publicising the funding opportunity for collaboration with European through their appropriate channels.

The presentations by Dr. Ruben and the representatives from South Africa and Latin America are available on a CD-Rom and can be obtained from Ms. Jering
(Email: Dietlind.Jering@ceceu.int)

**ANNEXES**
- Agenda
- Participants

# AGENDA

***8th December***

- ***13.00h to 13.45h working lunch***

- ***13.45h***

Presentation of the industrial technologies work programme update for 2004 (nanosciences and nanotechnologies, multifunctional knowledge based materials, new production processes and devices)

- ***14.15h***

Mechanisms of NMP call for proposals (opening due December 2003):
how to write a successful proposal (Dr. Mario Ruben)

- ***15.00h***

Third country participation in FP6 (funding for Third Countries); results from participation in first NMP call

- ***15.30h***

Presentations from representatives from Latin America and South Africa on their industrial research capacities and needs (each participant 15 min)

- ***18.30h***

Summary and conclusions

- ***19.30h***

Invitation to dinner by European Commission

***10th December***

- ***17.00h***

Presentation of CORDIS database at Exhibition (http://www.cordis.lu/fp6/nmp.htm)

***11th December***

- ***13.00 – 15.00h***

Meeting with interested parties for exchange of first ideas for collaboration in Sala Tiepolo (working lunch)

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# Workshop 2: SPINELIX-Nanotechnologies for Life

## Nanotech Bridge of Knowledge: From the Financial World to the High Tech SMEs

**M. Caria**

Spinelix-Nanotechnologies for Life
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The workshop had an average audience of 50 participants.
Spinelix presented the case as a Nanotech start up based on a technology platform. It is not easy with this model to raise money from VC. Choosing a company model oriented to the market of first choice it is not easy either as the company is not qualified in the market. Raising it from private industrial partner is not possible as they see the product either too far or too risky expecially in certain areas like in vitro diagnostic were regulations make the end users reluctant to innovation.
Public money has also shown difficulty to adequately address the need of SMEs. National initiatives are few, little financed and too narrow (the start ups technologies and market are worldwide spread), EU has not addressed the need of SME but rather of big corporations by the large Integrated Projects or Network of Excellence.
The ideal Nanotech start up is a right mix of all this financial and know how.
In US the private and public funds are a factor of 10 higher. In particular early product developments are financed by the government.
It appeared at the end a consensus on the following recommendations:

- share the risk and enhance risk attitude in conservative economy
- finance the R&D of a SME at the same level of US (close to 1Billion)
- the funds must be managed at a pan-EU level but giving mandates to regional actors
- federating the regional actors cross country when specialised in certain areas to reach critical mass
- get ALL financial actors involved (banks, VC, regional incentives funds, foundations)
- get INDUSTRIAL customers in as early as possible for little money bu rather know how
- do it ASAP at the European Commission level; start Pilot Project in the 6th Framework Program

Xeptagen presented the case of switching from a pure biotech company in the diagnostic field, to the need of going down to the nano-scale for more sensitive and accurate tests as the market calls for in the field of clinical human diagnostic.

In addition the facts that the revenues in US in 2002 were estimated in 80Billions in 2005 was judged as a further push to invest in Nanotech as the expected return to investment is even higher than the Biotech sector standards.

Technostart presented the current trends of a limited amount of very specialised VC in the Nanotech field and recommendations. TO the VC: follow up closely and only if you understand the technology. Of course it is recommended to have a deep technical and scientific background to approach a Nanotech investment opportunity and to appreciate it. The return can be very wealthy but you have to be patients (5 years or more). Each VC will have his own speciality. Funds can be available if a cutting edge technology shows a potential leading position also in the market.

NEDO summarised the fact that also Japan is trying to push for Nanotech investment but the system is very conservative and VC funds in the area are practically non existent. Government money is being steered but still limited to the public research (more than 70% of the Nanotech funds are in the hands of the Ministry of Education) and practically absent for the SMEs (at the level of 1% or so). More extended awareness of the industrial problem is being perceived by the government now.

Sviluppo Italia presented the relevance of the Nanotech concept of regional investments federation as an essential although not only ingredient of the synergies needed. In particulary the classical financial investors and VC plus Market Makers (industry manufacturers, commercial actors and end users customers) work together with SMEs and other parties interested to catalyse around the Nanotech industry.

Technofi illustrated the work performed by the Euromaplive consortium to fill the gap with respect to the US funding in Nanotech industry. A strong public presence was detected as the only and proven tool to get new projects down the road (the SBIR scheme in US). The consortium identified catalysts for public and industrial and financial private money around Nanotech SMEs initiatives as being: a stronger networking role of regional investors and actors (incubators etc..) and of EU officers. A new grant scheme of 2 steps, one for feasibility and technological evaluation financed for a limited amount and the second step to finance the product development in its entire route to market is recommended.

**ANNEXES**

- Agenda
- List of Speakers and Contact Details

# AGENDA

THEMATIC WORKSHOP

**NANOTECH BRIDGE OF KNOWLEDGE:**
**FROM THE FINANCIAL WORLD TO THE HIGH TECH SMEs**

Organized by Spinelix-Nanotechnologies for Life
Tuesday, December 9th 2003, 9.00 - 13.30

Introduction

**The bridge between finances and nanotech:**
**the difficulty to raise private and public money for a nanotech based SME**
Mario Caria, Spinelix-Nanotechnologies for life, France

The Life Science Examples

**Genomic diagnostic: early financials, revenues, VC and business angels**
Giorgio Fassina, Xeptagen, Italy

The difficulty and the challenge of private finances on nanotech:
the VC point of view

**A EU experience: the difficulty on analysing a nanotech based Business Plan**
Stephan Kaltz, Technostart, Germany

The Public Financial Approach

**The Japan initiatives to boost private and public investment on Nanotech**
Hironori Nakanishi, Nedo Us, Japan

**Public and private funding in Italy: the Sviluppo Italia concept**
Antonio Sfiligoj, Sviluppo Italia Friuli Venezia Giulia, Italy

**The EU financing situation: the Euromaplive initiative**
Serge Galant, Technophis, France

Conclusions

# LIST OF SPEAKERS AND CONTACT DETAILS

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| Stephan Kalz | Technostart | skalz@technostart.com | Germany |
| Hironori Nakanishi | Nedo Us | | Japan |
| Antonio Sfiligoj (represented by Elena Colonna) | Sviluppo Italia Friuli Venezia Giulia | asfiligoj@sviluppoitaliafvg.it | Italy |
| Serge Galant | Technophis | | France |

## Workshop 3: NANOTRIB

### Nanostructured Tribological Coatings – Concepts, Materials, Processes and Applications

The workshop was organised under the umbrella of the NANOTRIB cluster, which establishes synergies between the consortia of six GROWTH funded projects – HIDUR, LUBRICOAT, MICLUB, NANOCOMP, SMART QUASI CRYSTALS, and TRIBO - working concurrently in the field of nano-scale protective and lubrication films and low-friction surfaces. A contribution from project NANOSPRAYING (not member of the cluster) was also presented.

#### *Constitution, Microstructure and Properties of Magnetron-Sputtered Nanocomposite Coatings*

**M.Stueber, H.Holleck**

Forschungszentrum Karlsruhe, Institute of Materials Research I, P.O.Box 3640, D-76021 Karlsruhe, Germany (Project NANOCOMP)

An ambitious objective in the development of self-lubricating wear-resistant coatings is to make use of lubricious phases such as graphite, amorphous carbon or MoS2 incorporated into coatings. A series of (Ti,Al)(N,C) coatings with different carbon contents (0-28 at.%) have been deposited by reactive magnetron sputtering of TiAl in a mixture of Ar, N2 and CH4 gases. The microstructure and constitution of these coatings have been investigated using EPMA, AFM, XPS, TEM (HRTEM), Raman spectroscopy, X-ray diffraction and pole figure analyses. Starting from a pure TiAlN coating significant changes in the microstructure of the coatings were observed dependent on the carbon concentration. Under optimum conditions nanocomposite coatings with a structure of a coexisting metastable hard, nanocrystalline fcc (Ti,Al)(N,C) phase and an amorphous carbon phase have been deposited. The localization of an amorphous carbon phase has been shown by HRTEM.

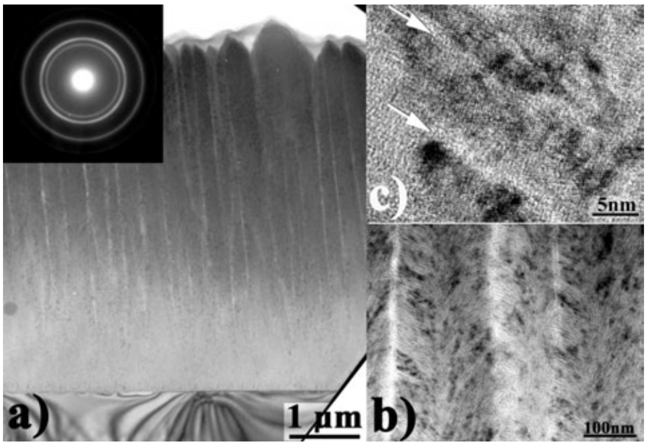


**Figure 1**. The structure of (Ti,Al)(N,C) coatings with high C concentration (C >20 at.%) is homogenous with a nanocrystalline structure in the near substrate region and transforms into columnar with increasing film thickness. The diameter of the columns is about 200-300 nm for films with 28 at.% C and the column boundaries are well-defined. The phase contrast images clearly show that columns are composed of frond-like lamellae (Fig.b). According to the high-resolution TEM images (Fig.c) the frond-like lamellae are separated by an amorphous phase. The grain size of the (Ti,Al)(N,C) phase in this composite structure is 3 - 6 nm while the thickness of the frond-lamellae is about 2 - 3.5 nm and the length of the lamellae is 40 – 60 nm.

## *Nanostructured Wear Resistant Coatings by Thermal Spraying and Laser Cladding*

**Igor Smurov**

ENISE (Project TRIBO)

The improved performance of machinery and aerospace friction joints may be realised only by the essential increase of the allowable contact loads and operating temperatures. This in turn requires the development of advanced high-performance Solid Lubricant Coatings (SLC) through materials engineering approach in which required properties will be finely tuned by: (1) designing an appropriate matrix for the solid lubricant as a high performance material: nanostructured, functionally graded; (2) synthesising by Mechanomaking (the industrial evolution of mechanical alloying and mechanosynthesis) of nanostructured powder materials to be applied for coating fabrication. Essential for the deposition process to be applied, would be the definition of an appropriate power source and deposition strategy, which would respect the nano-phased structure of powders being used. The project applies co-axial laser cladding and HVOF spraying for elaboration of SLC with advanced performance. Process optimisation is strongly supported by the advanced optical diagnostics.

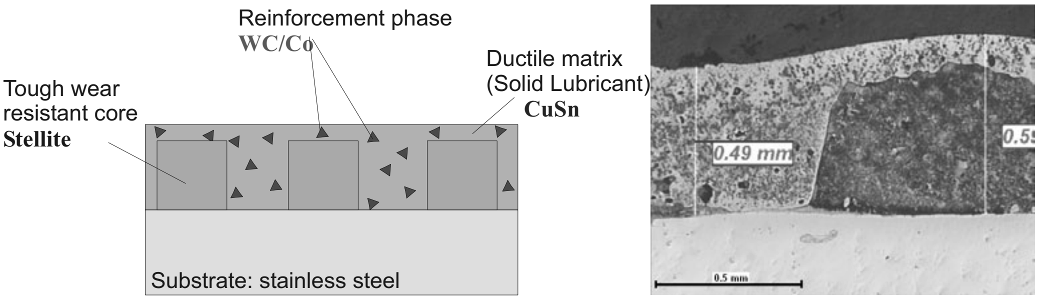


**Figure 1**.The microstructure of laser cladded coating with tough stellite core, covered with SL CuSn reinforced by nanostructured WC/Co.

## *In-Process Micro- and Nano-structuring of Functional Coatings Surfaces for Microlubrication*

**Henry Haefke and Yvonne Gerbig**

Micro and Nanomaterials Section. CSEM Swiss Center for Electronics and Microtechnology, Inc.
rue Jaquet-Droz 1, CH-2007 Neuchâtel, Switzerland
(Project MICLUB)

It is well known that structuring of surfaces can enhance or even create new functionalities. Therefore it is not surprising that different attempts for microstructuring of surfaces were made using e.g. embossing, chemical etching, laser as well electron-beam treatments of surfaces, or *in-process* structuring. The use of *in-process* structuring applied to hard coatings is one way of creating lubricating surfaces on the micro and nanoscale, with superior tribological properties and improved lifetime. The potential of such functional surfaces by *in-process* structuring of CrN thin films, which exhibit a very good mechanical stability as well as excellent thermal and chemical resistance, was investigated using a plasma-assisted physical vapor deposition (PAPVD) process. Through defined variation of selected conditions in the PAPVD process (e.g. ion energy, ion-to-atom flux ratio), the surface structure of the deposited CrN films were modified in a wide range. Furthermore, the dimensions of the morphological features could also be varied in certain ranges.

# *Nanomaterials Powders for Tribological Coatings*

**Paolo Matteazzi (1) and Diego Basset (2)**

(1) CSGI, Interuniversity Consortium Via della Lastruccia 3, 50100 Sesto Fiorentino (FI) Italy
(2) MBN srl, v. G. Bortolan 42, 31050 Vascon di Carbonera, TV- Italy
(Projects TRIBO and Nanospraying)

The generation of nanostructured coatings is a major challenge for breakthroughs in tribological behaviour. Thermal spraying techniques are being explored to deposit “thick” (i.e. above 100 microns) nanostructured coatings thanks to two projects in the FP5 (“Tribo” and “Nanospraying” www.nanospraying.com ). Key factor is the development of suitable nanostructured powders overcoming the difficulties in managing nanoscale particles (including health hazards problems). The presentation illustrated the achievements in generating carefully controlled micron sized particles (typically 20 to 60 microns, tuneable) made of stable agglomerates of crystals of 10-20 nm in several systems of interest (for example WC/Co and alloys). According to results of Nanospraying project, after a considerable work on process and powders development the coatings obtained has been demonstrated to be nanostructured as revealed by TEM picture below. The wear behaviour is considerably improved and applications to industrial components ongoing.

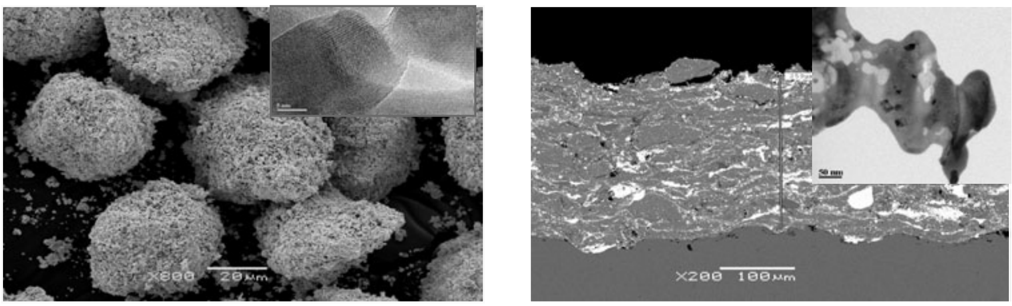

**Figure 1**. Nanostructured powders (left) and coating (right).

## *Tribology in the Nanoworld – Characterisation of the Performance and Wear Mechanisms of Nanostructured Coatings*

**Alan Savan, Vladislav Spassov and Henry Haefke**

Micro and Nanomaterials Section. CSEM Swiss Center for Electronics and Microtechnology, Inc.
Rue Jaquet-Droz 1, CH-2007 Neuchâtel, Switzerland
(Project NANOCOMP)

Nanostructured thin films are being developed in response to needs of European industry. Severe demands are placed on next-generation cutting and forming processes in terms of reducing their ecological impact and eliminating detrimental health and safety aspects, while simultaneously improving cost efficiency and productivity. However technologies to cope with the high abrasion, high temperatures and lack of fluids for lubrication and cooling must be developed.
The nanoscale engineering enables to realise the concept of quaternary nanocomposite coatings consisting of a very hard wear-resistant matrix, which has its inherently high friction coefficient drastically reduced through the engineered addition of a solid lubricant phase. The high performance state-of-the-art ceramic nitride coatings from industrial job-coater partners are being modified by the addition of carbon and $MoS_2$ nanoclusters. Tribotesting has demonstrated reductions in the friction coefficients of the resulting thin films by as much as a factor of 5, while the wear rate was lowered by a factor of 10.

## *Perspectives of Plasma Surface Treatment at Ambient Pressure for the Deposition of Nanostructured Multifunctional Coatings*

**Karen Vercammen**

VITO, Materials Technology, Mol, Belgium
(Project LUBRICOAT)

Plasma treatments at intermediate and atmospheric pressure represent a promising alternative with enormous potential. The main advantage of this method is that environmental friendly (solvent free) processing is combined with the ability to work in-line and at relatively low cost. Furthermore the technology represents cost effective and scalable techniques and the rather low operation temperature makes treatment feasible of virtually any kind of substrate material. Especially DBD, microwave and RF discharges have proven to be very useful for various surface treatments. Surface modifications possible with these technique range from achieving a predefined surface topology and improving self lubricating and low friction behaviour to tailoring of the surface wettability properties, modifying chemical bonding capabilities and incorporating reactive elements. Aerosol particles can be injected in the gaseous precursor mixture, and therefore the choice for including elements at the surface is almost infinitely. These plasma techniques could be highly beneficial for deposition of nanostructured or ultra-smooth coatings to reduce friction, or for chemical modification of surfaces to reduce adhesion or create e.g. a low surface energy.

## *The Microlubrication Effect, Experiments with Laser Textured Surfaces*

**P. Andersson[1], J. Koskinen[1], S. Varjus[1], Y. Gerbig[2], H. Haefke[2], S. Georgiou[3], B. Zhmud[4] and W. Buss[5]**

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The scientific objective is to analyse and describe the mechanisms of minimum lubrication (microlubrication effect) of topographically microstructured surfaces at high contact pressure in metal forming processes. Surfaces of the specified surface texture were designed on model samples using laser ablation methods. After refinement of these textures by microstructural analysis, they were evaluated in tribological tests. The effect of laser texturing to the steel surface in starved lubrication conditions was investigated by using reciprocating sliding tests. The effect of sliding speed, load and texture type was investigated with different types of lubricants. A clear enhancement of lubrication was demonstrated as a result of surface texturing. Optimum surface textures will be used to develop in-process structured hard coatings by using advanced PVD methods. Special dedication is given to optimise environmental compatibility (e.g. biodegradable lubricants) and worker friendliness of the fluids.

## *Thermal Modelling of Disk Brake Rotors for Exploitation of Nanocomposite Films*

**K.L. Dahm (1), H. Weiss (2), J. Layfield (3) & P.A. Dearnley (1)**

(1) The School of Mechanical Engineering, University of Leeds, UK. (2) Labor fur berflachentechnik, Siegen University, Germany. (3) Bentley Motors Ltd, Crewe, UK
(Project HIDUR)

Aluminium alloys combine good thermal properties with low density and are therefore ideal candidates for lightweight automotive disc brake rotors. The poor wear resistance of these alloys however necessitates the use of wear-resistant coatings on the rubbing surfaces. Nanocomposite thermal spray coatings are being investigated for this role. However the low melting point of aluminium alloys imposes thermal criteria (in addition to the frictional and mechanical properties) on the coatings. Using simple thermal models, two coating strategies were determined for aluminium brake disc rotors. This paper describes these strategies and gives details of initial investigations into the friction response of a titanium matrix nanocomposite-coated aluminium rotor.

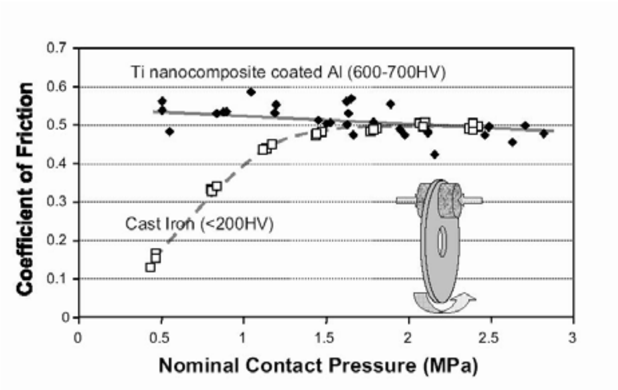


**Figure 1**. Comparison of the frictional behaviour of grey cast iron (GCI) and Ti-nanocomposite coated Al rotors against standard organic brake pads in a bench-scale brake test machine.

## *The Use and Potential of Nanotechnology in the Automotive Industry with Focus on the Powertrain*

**Bertil Stenbom and Per H. Nilsson**

Volvo Technology Corp. (Project LUBRICOAT)

Some of the most important driving forces for development of new materials (material combinations) and improved surface properties in the automotive industry are cost, fuel economy, increased service intervals and lifetime, safety and environmental demands. The field of nanotechnology seem to have a large potential for finding applications in the automotive industry.  Examples of potential use as well as current applications of nanotechnology, mainly in the powertrain, are listed and discussed. Nanostructured (PVD) coatings are e.g. already in use for fuel injectors and piston rings. Material properties of special interest are low friction, wear and scratch resistance, load carrying ability etc.

## *Wear of Nanocomposite Coatings in Piston-Ring Environments*

**K.L. Dahm (1), K. Panagopoulos (1), H. Weiss (2) & P.A. Dearnley (1)**

(1) The School of Mechanical Engineering, University of Leeds, UK. (2) Labor fur berflachentechnik, Siegen University, Germany
(Project HIDUR)

The sliding wear response of thermally sprayed alumina-silicon carbide ($Al_2O_3$-SiC) nanocomposite coatings has been investigated. Despite extensive spray parameter and powder property optimisation, plasma sprayed nanocomposite coatings showed poor wear resistance compared to existing piston ring coatings in high-speed lubricated sliding tests against cast iron (simulating the piston ring-cylinder liner tribological couple). Examination of the worn coating surfaces showed evidence of two wear mechanisms: (i) micro-scale cohesive failure (pull-out) and (ii) smooth wear. The latter mechanism resulted in lower wear rates. Simple abrasive wear testing (in which an abrasive pin slid against the coated periphery of a steel wheel) confirmed these same mechanisms and the poor wear resistance of the plasma sprayed coatings. High-velocity oxy-fuel (HVOF) sprayed nanocomposite coatings however showed superior wear resistance to pure HVOF sprayed alumina coatings in the simple wear tests, the wear resistance increasing with increasing silicon carbide content.

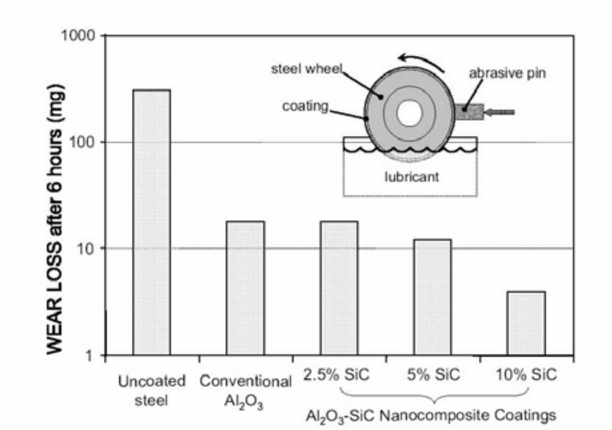


**Figure 1**. Comparison of the abrasive wear resistance of HVOF nano-composite coatings with uncoated steel and pure ceramic coatings.

**ANNEXES**

- Agenda
- List of Contacts

## EuroNanoForum 2003 – Trieste, Italy, 9-12 December 2003

## NANOTRIB Workshop

## Tuesday, 9th December 2003

## Stazione Marittima, 9.00am– 1.00pm

**Title:** Nanostructured Tribological Coatings – Concepts, Materials, Processes and Applications
**Location:** Room „Vulcania 1"
**Moderator:** Isabel Vergara, European Commission

**Programme**

09:00 Michael Stueber, Forschungszentrum Karlsruhe (Project NANOCOMP)
Constitution, microstructure and properties of magnetron-sputtered nanocomposite coatings

09:20 Karen Vercammen, VITO (Project LUBRICOAT)
Perspectives of plasma surface treatment at ambient pressure for the deposition of nanostructured multifunctional coatings

09:40 Igor Smurov, ENISE (Project TRIBO)
Nanostructured wear resistant coatings by Thermal Spraying and Laser Cladding

10:00 Paolo Matteazzi, MBN (Project TRIBO)
Nanomaterials powders for tribological coatings

10:20 Jari Koskinen, VTT (Project MICLUB)
The microlubrication effect, experiments with laser textured surfaces

10:40 Henry Haefke, CSEM (Project MICLUB)
In-process micro- and nanostructuring of functional coating surfaces for microlubrication

11:00 Alan Savan, CSEM (Project NANOCOMP)
Tribology in the nanoworld - characterisation of the performance and wear mechanisms of nanostrcutured coatings

11:20 Karl Dahm, Leeds University (Project HIDUR)
Thermal modelling of disk brake rotors for exploitation of nanocomposite films

11:40 Bertil Stenbom and Per H. Nilsson, Volvo Technology Corp. (Project LUBRICOAT)

The use and potential of nanotechnology in the automotive industry with focus on the powertrain

12:00 Karl Dahm, Leeds University (Project HIDUR)
Wear of nanocomposite coatings in piston-ring environments

12:40 Lunch (location: buffet hall "Nordio")

**Poster presentations**

- Andras Kovacs, MFA (Project NANOCOMP) et al.
Microstructural characterisation of magnetron-sputtered Ti-Al-N-C nanocomposite coatings with increasing carbon content

- Ulrich Albers, FZK (Project NANOCOMP) et al.
Properties and performance of low friction nanocomposite coatings in the system Ti-Al-C-N

Closed Cluster Meeting on December 11th, 9 – 12 am.

# LIST OF CONTACTS

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# Workshop 4: Nanotec IT/AIRI

## Nanotechnologies in Italy: A Survey

**Nanotec IT / Airi**

Viale Gorizia, 25/c, I - 00198 Roma
info@nanotec.it
www.nanotec.it

### 1. Introduction

Italy has not escaped the hype on nanotechnology and there is now a rather intense activity, albeit mostly research, which occurs in national research institutions, in large companies and also in SMEs. It is widely believed, however, that the efforts need to be stepped up, better focussed and more co-ordinated if one wants to make nanotechnology a factor of growth and competition for the national industrial system.

To promote a co-ordinated national effort, the assessment of the framework to start and confront with is mandatory: to pin point the players both in the public research institutions and the industry, ascertain the size of the resources (human and economical) available, identify the fields where the activity is preferentially addressed, point out strengths and weaknesses.

The census started by Nanotec IT and presented in its preliminary results at EuroNanoForum 2003, tries to answer these questions and it is the first one of this type in the Country. The investigation is being carried out by sending a detailed questionnaire to a large number of research institutions and enterprise, big ones as well as SMEs, with personal contacts and interviews, web search. So far around 500 questionnaires have been sent out and tenths of people and web sites have been contacted.

The resulting picture, based on the information received, is not yet exhaustive, but what has been gathered till now can be considered rather representative of the situation in Italy in this field.

### 2. General overview

The high costs of experimenting with emerging technologies, such as nanotechnology, that cover a wide range of disciplines and which generally have rather long time-horizon before reaping the large economic returns often forecasted, makes it hard for industry to invest heavily in it, at least in the early stages.

Governmental funding is crucial for the developments of these technologies and in fact in all advanced countries such funds have been the main driving force behind the steep surge of activity on nanotechnology seen in the past 5-6 years. During that period this support has been steadily increasing and in 2002 in Western Europe, USA, Japan and a score of other countries such as South Korea, Australia, Canada, China and Taiwan, it has reached the respectable sum of about US$ 2100 million, up from about US$ 430 million in 1997.

In Italy too the research on nanotechnology has become increasingly popular during the above said period, but specific public funds addressing nanotechnology have been limited. The research in this field, as well as that on its cousin, microtechnology, has been financed essentially in the framework of CNR (National Research Council) "finalised" projects for microelectronics and advanced materials started on 1998 and through the Fund for Investment in Basic Research (FIRB) made available for the period 2001-2003 which, finally, had specific funds also for nanotechnology.
A precise calculation of public funding for nanotechnology is therefore hard to make, but it can be estimated that from the above programs around Euro 70 million have been made available for R&D in the fields nanoscience and nanotechnology in the years from 1998 to 2003.

This sum makes Italy lagging behind other big European countries such as Germany, France and UK that in the same period have devoted to the research on nanoscience and nanotechnology at least 6-7 times more. Even in a small country such as Switzerland the funding in this field has been sensibly higher.

A recent study just presented at the International Forum on Micronano Integration in Postdam (Germany) the 3rd of December 2003 by Dora Marinova of Murdoch University, Australia, has confirmed that Italy is a follower respect to the three big European countries above.

This study shows the results of an investigation undertaken at the USA Patent Bureau to ascertain the number of all patents related to nanotechnology (therefore also those without nanotechnology necessarily in the title) granted the period 1975-2001.

During the said period the patents from Italy were 531 while those from Germany, France and UK were 2458, 2407 and 890 respectively. Considering the world "production" of patents in this field the Italian patents represented the 0.92% of the total while those of Germany were the 4.27%!

Even when only the patents with nanotechnology in the title are considered, there is no game. Italy has a paltry 7 contrary to Germany, France and UK where they result to be 87, 86 and 15 respectively.
In the last couple of years, due to an increased general awareness about the potentialities associated with these technologies, new initiatives have seen the light all aimed to increase and favour the commitment on nanotechnology.
The national public research institutions have created Institutes and/or centres of excellence with nanotechnology as their specific mission, sometimes aggregating scattered competencies (and research units/labs) around common goals and projects, some other focussing or converting entire research departments to this field. Some of the major large companies have stepped up their effort to ride the wave, often benefiting of their activity on microtechnology and a score of SMEs are born, many as spin off of research organisations.

Very recently a specific district to promote nanotechnology and its applications has been created with public funds in the Veneto region. It will offer facilities and financing for R&D projects, promote the co-operation between industry and academia primarily in the region.

Although important, those initiatives should be considered essentially a starting point and more should be done to build and sustain a nanotechnology based National industry. The Nanotec IT census has tried to highlight the situation to begin with.

## 3. Conclusions

The Nanotec IT census is not yet 100% completed, and certainly a further scrutiny and refinement of the information gathered is necessary. Nevertheless, the most part of the Italian players presently active in the field of nanotechnology have been identified and the entity of the resources, the areas of interest and the fields of activity sorted out. The picture emerged can be considered rather representative of the situation.
The census has shown that the research in nanotechnology occurs in Italy primarily at public research institutions although important initiatives have been spotted also in the industrial sector.
This fact can be considered in the norm for in the other advanced countries it happens more or less the same. When confronting with emerging technologies enterprises are naturally more cautious. Only quite recently industry priorities have started to include nanotechnology in the list and moreover, the long time-horizon of some of the most promising application, makes many to wait or even not sufficiently understand the potentialities associated with these technologies. The contribution of public research institutions is therefore fundamental for the development and the diffusion of nanotechnologies.
The survey has shown that Italy is for several counts behind the major advanced countries when it comes to nanotechnology, paying a price for starting later respect to them. Things hare changing and the census has acknowledged this trend. It is possible that some of the industrial players are still missing and that other enterprises will eventually answer, but the picture won't change too much.

All major Italian public research institutions have focussed important resources and conduct a quite dynamic activity in this field. The census has found that around 1000 people are doing research in nanotechnology within the institutions that have answered and, most of all, that several initiatives have been activated by the various organisations to streamline activities and to build enough critical mass, by grouping resources and creating centres dedicated to (or prevalently focussed on) nanotechnology. This in the framework of general reshaping of the national research organisations under way to increase the effectiveness of their action that should likely benefit all activities.
That happened at CNR where12 research units scattered in different locations were aggregated around common goals to create three Institutes prevalently focussing on nanotechnology (CNR-IFN, CNR-ISTM, CNR-ISMN). At INFM 4 centres (NNL, TASC, S^3 and NEST) have found in nanotechnology the leading mission. At INSTM research units gave birth very recently to 5 centres of excellence dedicated to this field.
Specific public R&D funds were finally made available for nanotechnology and, lately, also a technological district has been created with public funding to promote nanotechnologies and their applications.
Also on the industrial side things are moving. Three important companies such as CRF FIAT, Pirelli Labs and STMicroelectronics result to dedicate quite relevant resources to nanotechnology and there exist also a score of SMEs, often spin off or start ups, that are

active in this field. Around 200 people are involved in the research on nanotechnology. The activity is quite well focussed and of high level, but nevertheless the effort in the industrial side seems still limited.

In conclusion, the census has pointed out that in Italy are now available relevant capabilities in the field of nanotechnology that could propel the development and the diffusion of these technologies at advantage of the national industrial system.

The initiatives under way, however, cannot be considered more than a starting point. Public economic support is still scarce (hopefully the new National Programme for Research (PNR) will give a high priority to nanotechnology).

The activities of the public research institutions seem too loosely connected with the risk of dispersing resources or, worse, creating unduly conflicts. The industrial side, in particular the SMEs, must be better helped to exploit these technologies.

In order to really succeed to create a competitive nanotechnology based industrial system in Italy the way to follow should be the implementation of a co-ordinated national strategy that involves industry, public research community and government. Nanotec IT will give its contribution to support such action by diffusing information, favouring contacts and the creation of networks, promoting initiatives to form and train people and for technology transfer.

**ANNEXES:**
- Agenda
- List of Speakers and Contact Details

# AGENDA

THEMATIC WORKSHOP

**THE NANOTECHNOLOGIES IN ITALY: A SURVEY**

Organized by Nanotec It/ Airi
Tuesday, December 9th 2003, 10.30 - 14.00

**Introduction**
E. Andreta, Director of "Industrial Technologies", Research Directorate-General, European Commission

**The Nanotec IT initiative and the nanotechnology census**
G. Frigessi di Rattalma, AIRI vice president; E. Mantovani, Nanotec It director

**Nanotechnologies in Italian industries:**
CR FIAT, Gianfranco Innocenti
Pirelli Labs, Massimo Gentili
STMicroelectronics, Salvatore Coffa
A.P.E Research, Marco Peloi
Veneto Nanotech, Renato Bozio

**Nanotechnologies in Italian public research organisations and academia:**
CNR (Italian National Research Council), Florestano Evangelisti
INFM (National Institute for the Physic of Matter), Giorgio Rossi
INSTM (Consortium of Italian Universities for Science and Technology of Materials), Mauro Graziani

**Conclusion:**
Is there a need for a national programme on nanotechnologies?

# LIST OF SPEAKERS AND CONTACT DETAILS

| Name | Organization | e-mail | Country |
|---|---|---|---|
| Ezio Andreta | Research Directorate-General, European Commission | | |
| Guido Frigessi di Rattalma | AIRI | frigessi@airi.it | Italy |
| Ezio Mantovani | Nanotec It | mantovani@nanotec.it | Italy |
| Gianfranco Innocenti | CR FIAT | gianfranco.innocenti@crf.it | Italy |
| Massimo Gentili | Pirelli Labs | massino.gentili@pirelli.com | Italy |
| Salvatore Coffa | STMicroelectronics | salvo.coffa@st.com | Italy |
| Marco Peloi | A.P.E Research | peloi@area.trieste.it | Italy |
| Renato Bozio | Veneto Nanotech | renato.bozio@unipd.it | Italy |
| Florestano Evangelisti | CNR - Italian National Research Council | evangelisti@ifn.cnr.it | Italy |
| Giorgio Rossi | INFM - National Institute for the Physic of Matter | rossi@tasc.infm.it | Italy |
| Mauro Graziani | INSTM - Consortium of Italian Universities for Science and Technology of Materials | graziani@units.it | Italy |

## *Workshop 5: Sviluppo Italia*

# Risk Capital - Integrating Regional and International Resources to Support Nanotech Companies

**Sviluppo Italia Friuli Venezia Giulia**

Via Flavia 23/1,
34148 Trieste
info@sviluppoitaliafvg.it

**Sviluppo Italia Veneto**

Via delle Industrie, 9
30175 Venezia Marghera
info@sviluppoitaliaveneto.it

www.sviluppoitalia.it

The workshop had an average audience of 100 participants.

Giancarlo Galan, Governor of the Veneto Region, introduced the workshop and welcome attendees.

Ezio Andreta, Director of "Industrial Technologies", Research Directorate-General, European Commission, pointed out that is necessary to turn manufacturing processes upside-down and invest in new technologies; this is the only way for the North-Eastern Italy to oppose de-industrialization and decline and to grow and progress. Nanotechnology has a tremendous potential and represents an industrial revolution. Manufacturing processes are turned upside-down: nowadays we have heavy, low tech products – going from large to small. With nanotechnology you go from small to large, putting high-technology into the products. Financial forecasts confirm the development of this business: the nanotechnology sector is expected to reach a turnover of 1300 billion Euros by 2010. 700 million Euros have been allocated to promote the industrial applications of this technology and the European Commission foresees grants covering 50% of the related costs. But, the possibility of receiving funds will depend on the capability of the various organisations to build a critical mass and create networks.

Luigi Rossi Luciani, President of Veneto Nanotech and of the Industrial Federation of Regione Veneto presented Veneto high tech cluster on nanotechnology applied on materials.
The principal aims of the cluster are:

- To create an international area of excellence by attracting and training talented human resources
- To build internationally excellent R&D centers devoted to applied research projects;
- To transfer technology to existing companies and to develop new technological entrepreneurship.

In the medium term, Veneto Nanotech will create a virtuous circle involving research institutions, innovative companies and private and public investors to foster leading entrepreneurship in nanotechnologies applied to materials.

Mario Caria, CEO of Spinelix, presented the case as a Nanotech start-up based on a technology platform. It is not easy with this model to raise money from VC. Choosing a company model oriented to the market of first choice it is not easy either as the company is not qualified in the market. Raising it from private industrial partner is not possible as they see the product too far and too risky, expecially in certain areas like in vitro diagnostic were regulations make the end users reluctant to innovation.
Public money has also shown difficulty to adequately address the need of SMEs. National initiatives are few, little financed and too narrow (the start ups technologies and market are worldwide spread), EU has not addressed the need of SME but rather of big corporations by the large Integrated Projects or Network of Excellence.
The ideal Nanotech start up is a right mix of all this financial and know how.

Donald Fitzmaurice presented the case of Draper Fisher Jurvetson, a successful example of Venture Capitalist, investing in innovation. The market driver in the framework of nanotechnology lies in the need of aging knowledge-based society seeking sustainable living patterns. Successful companies will meet this by:

- Providing cures for the diseases that impact adversely on the quality of life
- Providing tools that allow information be used to create new knowledge
- Reducing energy cost and environmental impact of chosen life-style.

The innovative products and processes that meet these needs will be enabled by the following technologies: biotechnology, information and communication technology, nanotechnology.
The milestones of a nanotechnology based society will see:

- The development of new nanotools and nanomaterials by new established companies in the short term;
- The development of improved products and processes by established companies in the medium term
- The development of disruptive new products and processes by start-ups and established companies (in-house start-ups).

Antonio Sfiligoj, CEO of Sviluppo Italia Friuli Venezia Giulia, presented the relevance of the Nanotech concept of regional investments federation as an essential although not only ingredient of the synergies needed. In particular, the classical financial investors and VC plus Market Makers (industry manufacturers, commercial actors and end users customers) work together with SMEs and other parties interested to catalyse around the Nanotech industry.

**ANNEXES**
- Agenda
- List of Speakers and Contact Details

# AGENDA

THEMATIC WORKSHOP

## RISK CAPITAL - INTEGRATING REGIONAL AND INTERNATIONAL RESOURCES TO SUPPORT NANOTECH COMPANIES

Organized by Sviluppo Italia Friuli Venezia Giulia and Sviluppo Italia Veneto
Friday, December 12th 2003, 16.00 - 19.00

**Welcome and Introduction:**
Giancarlo Galan, Governor of Regione Veneto, Italy

**Future Nanotech Scenarios, Strategies For Forthcoming EU Actions**
Ezio Andreta, Director of "Industrial Technologies", Research Directorate-General, European Commission

**The Nanotech Scenario, An International Investor Perspective**
Donald Fitzmaurice, Partner of Draper Fisher Jurvetson, e-Planet Ventures, USA

**The Veneto Nanotech Cluster Formula To Support Research And Technology Transfer**
Luigi Rossi Luciani, President of Veneto Nanotech and of the Industrial Federation of Regione Veneto, Italy

**The Partnering Role Of Semi-Public Regional Investor**
Antonio Sfiligoj, CEO Sviluppo Italia Friuli Venezia Giulia, Italy

**The Needs Of A Globally Oriented Nanotech Start Up**
Mario Caira, President and Chief Executive Officer of Spinelix - nanotechnologies for life, France

**Galileo Sgr, Innovation Financing Instruments**
Giampaolo Molon, Chief Executive Officer of Sgr "Galileo", Italy

# LIST OF SPEAKERS AND CONTACT DETAILS

| Name | Organization | e-mail | Country |
|---|---|---|---|
| Giancarlo Galan | Regione Veneto | presidente@regione.veneto.it | Italy |
| Ezio Andreta | Research Directorate-General, European Commission | | |
| Luigi Rossi Luciani | Industrial Federation of Regione Veneto - Veneto Nanotech | info@apiveneto.it | Italy |
| Donald Fitzmaurice | Draper Fisher Jurvetson, e-Planet Ventures | dfitzmaurice@dfj.com | Usa |
| Antonio Sfiligoj | Sviluppo Italia Friuli Venezia Giulia | asfiligoj@sviluppoitaliafvg.it | Italy |
| Mario Caria | Spinelix-Nanotechnologies for life | mario.caria@spinelix.com | France |
| Giampaolo Molon | Sgr “Galileo” | | Italy |

# 4. TECHNICAL VISIT

## Technical Visit to the Synchrotron Light Laboratory ELETTRA

AREA Science Park, Basovizza SS 14, km 163,5 - 34012 Trieste - Italy
Tel. +39 040 375 81 Fax +39 040 9380902
e-mail: info@elettra.trieste.it http://www.elettra.trieste.it

### Introduction

During EuroNanoForum 2003, 100 participants, including journalists, were given the opportunity to visit the Synchrotron Light Laboratory ELETTRA on 10-11 December 2003.

The Synchrotron Light Laboratory ELETTRA, located at the AREA Science Park, produces and uses high-brilliance electromagnetic radiation in the ultraviolet to hard X-ray spectral band. The range of applications available attracts researchers from universities and laboratories in Italy and elsewhere in Europe; from national and foreign scientific institutions (among which CNR **-** National Research Council, INFM - National Institute for Matter Physics, ICTP - International Centre for Theoretical Physics, and the Austrian and Czech academies of science) for joint programmes – both in terms of funding and personnel – in basic and applied research; and from industries in Italy and abroad, for pre-competitive research. There are sixteen currently active beamlines, with a further three in commissioning phase. Another six beamlines are under development.
Current figures indicate around 800 Laboratory external users each year: 40 % from Italy, 46% from other countries of the European Union, and 14% from non-EU states.
250 persons are working at AREA Science Park. In addition, around two hundred researchers from other national and international institutions work permanently at ELETTRA.

### The LILIT beamline at the TASC Laboratory

During their visit to the Synchrotron Light Laboratory ELETTRA, EuroNanoForum 2003 delegates were accompanied by researchers from the **INFM** - National Institute for Matter Physics – **LILIT Group - TASC** Laboratory to the LILIT beamline.
LILIT was the original name of the X-ray lithography beam line installed at the ELETTRA storage ring, name that afterward was extended to the homonymous research group.
LILIT (Laboratory for Interdisciplinary LIThography) is devoted to fabrication of structures with spatial resolution ranging from microns to few nanometers.

## *Research activities*

The wide field of activity in the domain of nanofabrication and microfabrication for novel physics experiments, as well as for applications ranging from bio-medicine to microsurgery to nanoelectronics and nano-optics, has found a very fertile ground at LILIT. The quick growth of interest from many scientists and technologists about nano-patterned/nanofabricated objects and systems has imposed a substantial broadening of experimental approaches to nanofabrication, beyond the beamline specialty of near-contact X-ray lithography.

The main technique used in the LILIT activities is the combination of X-Ray lithography (XRL), thus a parallel (high speed) writing tool, and electron beam lithography (EBL), a direct writing (from a computer draw to the semiconductor sample), small area, high resolution (20-30 nm) system.
Usage of EBL to realize XRL masks allow the fabrication of hi-density (thousands of square mm) and hi-resolution devices.
The peculiarity of the beamline design consists mainly in its wide lithographic window that can be selected to work from soft (1.5 keV) to hard (10 keV) X-Rays wavelengths. The soft X-ray range (photon energy between 1 and 2 keV) is devoted to achieve the highest lithographic resolution (30-40nm). Sensitive materials of thickness of tens of microns can be exposed in the hard X-ray region (photon energy higher than 5 keV).

The LILIT team is made up of specialists in techniques such as e-beam lithography, focus ion beam (FIB) lithography, contact printing, and in-situ lithography, which are strongly complementary and substantially needed in order to provide a state of the art facility for nanofabrication of advanced functional objects and devices.

The LILIT Lab has the knowledge and the facilities that allow using extensively micro and nanofabrication methodologies necessary to the fabrication of innovative devices.
Extremely important are the role of lithography, deposition techniques, etching, growth etc. for the miniaturization and the functionality of the devices where the control falls in the micro and nanometer region.

The LILIT technical activities and micro and nano process development include:

- FIB (Focused Ion Beam)
- Resist characterization for optical, electron and X-ray lithography
- RIE processes development for Si, Si3N4 , GaAs, SiO2
- Electrochemical growth characterization for Ni, Au, Cr, Cu
- Processes optimization for high resolution, high aspect ratio and deep lithography
- Lift-off process development
- Deep RIE process development for GaAs/AlGaAS and Si
- Micromachining process development applied to gas sensors
- Micromachining process development applied to devices for space applications.
- 3D lithography process development for photonic crystals and micromachining for drug delivery
- Development of calculation tools for diffractive optics and optical tweezers
- Structural and microfluidic modeling

### *Know-How and Technologies*

The advanced performance of ELETTRA stimulates research in areas such as:
- solid state structures and dynamic surface phenomena;
- superconductors;
- structure of metals and composites;
- biological structures.

The research programmes in progress focus on three particular avant-garde fields:
- structural biology, for the study of protein and virus structures;
- study of magnetic materials: second only to semiconductors, these represent the most widespread technology on the market, and are used in areas like the manufacture of memory supports such as hard disks for computers or integrated in conventional electronic devices;
- microelectronics for integrated circuits and micromechanics: manufacturing of gears and components for miniature mechanical devices, with applications including the biomedical field.

### *Products, Services and Applications*

The synchrotron beamlines find application in a very wide variety of sectors, in particular:
- molecular, atomic and electronic structures of materials and of organic and inorganic substances in all states of aggregation;
- services of metrology, advanced electronic design, data control and analysis (including remote applications);
- electron and X-ray microlithography;
- production of radio-frequency equipment for electron accelerators.

# 5. OPEN DOORS INITIATIVE FOR THE YOUTH

## "Nanotech for the Young"

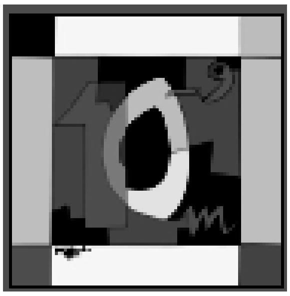
December 10th, 2003
Congress Centre, Stazione Marittima, Trieste

***An open doors event organised in the framework of:***

## "NanoTechYoung"

**Scientific exhibition and workshops for the young**
November 18$^{th}$ - December 5$^{th}$, 2003
Sala Giubileo, Via Mazzini, Trieste, Italy

"*Nanotech for the Young*" has been organised in the framework of "NanoTechYoung", event attended by almost 1000 scholars from the last year classes of secondary schools of Trieste and surroundings, namely the Friuli Venezia Giulia Region. In particular, *"Nanotech for the Young"* has been an open doors session, which took place on December 10$^{th}$ 2003, in parallel with *EuroNanoForum 2003*, with the objective of raising awareness about nanotechnology among university and high school students.



Young PhD students coming from the local universities and experts in nanotechnology who attended and participated in the Forum were available to illustrate to organised groups of young students the science and applications behind nanotechnology.

"NanoTechYoung" has been a nanotechnology scientific exhibition and a series of workshops for the youth, held in the city of Trieste between 18$^{th}$ November and 5$^{th}$ December 2003.

The exhibition was based on a combination of visual material (posters, nanomaterials samples, scientific instrumentation, artistic elaborations of scientific pictures and animated videos, films), interactive instruments (microscopes with sample materials, PCs with interactive software) and daily oral presentations by young scientists from the several local Institutions active in the nanotech field.

Each day of the exhibition two scientists (from the physical/chemical and the biological/medical fields) offered their assistance to the secondary schools visiting the Exhibition. Moreover, they held talks on specific nanotechnology topics twice in the morning and twice in the afternoon. Adequate rotation of the speakers during the workshops covered the entire nanotechnology activity in Trieste.

The initiative involved more than 20 scientists from both public and private Institutions in Trieste. During the 15 days of the event, many classes from the secondary schools of the Regione Friuli and Regione Veneto visited the exhibition for a total of about 1000 students.

For further information on this initiative, please contact:

*Marco Peloi*
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Tel.: +39 040 375 7908

*Giulia Quondam*
INFM - TASC Laboratory
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# 6. CONCLUSIONS

## *EuroNanoForum 2003: a high-level, unique debate on the development of nanosciences and nanotechnologies in Europe*

The EuroNanoForum 2003 event (conference, workshops, posters sessions, exhibition, media briefings, and youth initiative) has gathered key players and specialists in research, education, industry, financing, social sciences, journalism and public administration, with the participation of many top-level scientists and stakeholders, and has had a very good international dimension, with more than 1000 participants from the 5 continents. Moreover, about 1000 students participated in an ad-hoc event of the Nanotech-Young initiative especially organised in parallel to the Forum. Five ancillary specific workshops were held, covering research, financing and venture capital, national nanotechnology initiatives, and international collaboration, including several minor ad-hoc events dedicated to foster contact with "INternational COoperation Countries" (INCO) and their participation in the European 6$^{th}$ Framework Programme for Research and Technological Development. An exhibition of 20 stands highlighted EU and international nanotechnology initiatives, programmes, projects and companies. Six dedicated press events have been organised for the almost 50 journalists who participated; a much greater number of papers has been issued in the international press to date.

The Forum has proposed an integrated approach to nanotechnology, through 15 sessions devoted to key issues. It enabled the definition of elements targeting a common strategy for the future of nanotechnology research and technological development in an enlarged Europe supported by a strengthened international co-operation.

The previous chapters of these Proceedings illustrate the many high-level contributions to the Forum, in both the oral sessions and workshops, and highlight a number of key cross-cutting issues for action and follow-up:

1. Nanotechnology research and development is intellectually challenging and exciting, economically profitable and generates products and services with higher added value and better in-service performance to the benefit of the European citizens.
2. There is a need for developing new knowledge in nanosciences, including instruments for manipulation and characterisation, and metrology. Interdisciplinarity (including the "converging technologies" model) is a main challenge, as well as, for instance, self assembly, in-service performance and stability of 3D nanostructured systems. Also for the possible drawbacks there is need for additional knowledge. No "moratoria" were requested at the Forum.
3. Due to the intrinsic complexity and the high technological risk, public funding is essential at the present stage. It is necessary to fund integrated, ambitious nanotechnology research projects with application ("breakthrough") potential.
4. Availability and access to world-class infrastructure (from big science to fabrication) in Europe is essential. A coherent approach at Community level would be greatly beneficial.

5. Research teams are called upon to play a crucial role by taking ideas from basic research and turning them into innovative production schemes. Many researchers are thus turning into entrepreneurs.
6. To attract capital, new nanotechnology companies are requested by the financing bodies to prove scientific and technical excellence, clear property of their rights (IPR), management skills and operation in fields that do not present ethical or environmental problems.
7. New entrepreneurs would like financing bodies to provide more assistance when supplying risk capital (rather than credit), as well as for management tasks. The "death valley" effect is always a risk for new companies.
8. Existing, well established industries may be hesitant in the face of nanotechnology. On the one hand, missing the pace of progress in nanotechnology may leave them vulnerable to lose competitiveness, and on the other hand, they might be able to devote only limited funding to research and innovation. A change of culture is also usually a challenge.
9. Interdisciplinarity and outreach are two challenges for researchers, educators and students. Specialisation in traditional disciplines should be accompanied by interdisciplinary opening ("sandglass model") so to allow new ideas being developed in research and production. New university courses could be launched at European level, particularly in synergy with new infrastructure. "Hands on" approaches are encouraged in teaching (e.g. the "teaching in hospital" model or the "learning factory"). It is never too early to start with the interdisciplinary approach !
10. Researchers should take into account the demands of the civil society, first of all responsibility in their actions and due information. New forms of dialogue should be explored. Transparency builds trust. However, nanotechnology can be very complex and this presents a challenge to science communicators.
11. International co-operation has great potential to achieve larger critical mass where appropriate, such as in studies on health and environmental impact and, possibly, to establish a "code of conduct" at global level (some mechanisms were proposed such as an international high-level advisory group). The avoidance of a "knowledge apartheid" is also essential to allow all Countries to profit from the benefits of the nano-approach.

The Forum has also addressed key technological fields and nanotechnology applications in specific technical sessions. The state-of-the art in the most representative areas has been presented and discussed.
Enormous progress has been made by nanotechnologists and a strong knowledge base has been created worldwide which has now to be exploited and developed:

✓ Nanotechnology has made already remarkable progress in the healthcare area with (i) targeted drug delivery, (ii) biocompatible tissue regeneration and (iii) new sensors. Early cancer diagnosis and its treatment are a primary goal.

✓ In electronics, nanotechnology offers remarkable possibilities for progress and the industry is already well advanced in the production route. In the long term, spintronics, quantum computing, molecular and biomolecular electronics, photonics and plasmonics are ambitious research domains.

✓ Design at the atomic or molecular level is leading to remarkable improvements in material functionality and improved in-service performance of the final products (e.g. in energy, transport, textiles, surface sciences, optics, security, etc.), and this also under extreme conditions (e.g. in space). Interdisciplinary approaches and manipulation tools are main challenges for the near future.

✓ In the manufacturing field, conceptually speaking, there are two main paths that can be followed: further miniaturisation of devices ("top-down" approach) or development of new devices starting from the atoms or molecules to build micro-, mini- or macro-structures, somehow mimicking nature ("bottom-up" approach). The former can be linked to manufacture via assembly and the latter to manufacture via synthesis. Once self-assembly technologies will be realised, the introduction of totally new production routes will be formulated. This puts forward a true new and revolutionary way of processing and represents the ultimate challenge to the transformation of industry.

## *Towards a European strategy for nanotechnology: a Communication from the European Commission*

The outcome of the Forum and the success of the full integrated approach proposed have enabled the Commission to define, at the beginning of 2004, the key elements for a common strategy for the future of nanotechnology research in an enlarged Europe supported by a strengthened international co-operation.
The set of recommendations to the Member States are the subject of a recently published Communication from the European Commission, "*Towards a European strategy for nanotechnology*", *COM(2004) 338*.
Adopted on 12th May 2004, the document seeks to bring the discussion on nanosciences and nanotechnologies to an institutional level and proposes an integrated and responsible strategy in an enlarged European Research Area, to enhance knowledge creation and investment in nanotechnology R&D and turn it into better quality of life, competitiveness and jobs.

The main action lines of the Communication are summarised in its executive summary, which we reproduce hereunder.
The full text can be downloaded in several languages from the web site www.cordis.lu/nanotechnology.

*Nanosciences and nanotechnologies are new approaches to research and development (R&D) that aim to control the fundamental structure and behaviour of matter at the level of atoms and molecules. These fields open up the possibility of understanding new phenomena and producing new properties that can be utilised at the micro- and macro-scale. Applications of nanotechnology are emerging and will impact on the life of every citizen.*

*Over the last decade the European Union (EU) has established a strong knowledge base in nanosciences. Our ability to maintain this position is in doubt since the EU is investing proportionately less than its main competitors and lacks world-class infrastructure ("poles of excellence") that muster the necessary critical mass. This is despite the fact that investment in national EU programmes is growing in a rapid but independent way.*

*European excellence in nanosciences must finally be translated into commercially viable products and processes. Nanotechnology is emerging as one of the most promising and rapidly expanding fields of R&D to provide new impetus towards the dynamic knowledge-based objectives of the Lisbon process. It is crucial, however, that a favourable environment for innovation is created, in particular, for small and medium sized enterprises (SMEs).*

*Nanotechnology must be developed in a safe and responsible manner. Ethical principles must be adhered to and potential health, safety or environmental risks scientifically studied, also in order to prepare for possible regulation. Societal impacts need to be examined and taken into account. Dialogue with the public is essential to focus attention on issues of real concern rather than "science fiction" scenarios.*

*This Communication proposes actions as part of an integrated approach to maintain and strengthen European R&D in nanosciences and nanotechnologies. It considers the issues that are important to ensure the creation and exploitation of the knowledge generated via R&D for the benefit of society. In this context, the time is right for launching a debate at an institutional-level in view of coherent action to:*

– *increase investment and coordination of R&D to reinforce the industrial exploitation of nanotechnologies whilst maintaining scientific excellence and competition;*

– *develop world-class competitive R&D infrastructure ("poles of excellence") that take into account the needs of both industry and research organisations;*
– *promote the interdisciplinary education and training of research personnel together with a stronger entrepreneurial mindset;*

– *ensure favourable conditions for technology transfer and innovation to ensure that European R&D excellence is translated into wealth-generating products and processes;*

– *integrate societal considerations into the R&D process at an early stage;*

– *address any potential public health, safety, environmental and consumer risks upfront by generating the data needed for risk assessment, integrating risk assessment into every step of the life cycle of nanotechnology-based products, and adapting existing methodologies and, as necessary, developing novel ones;*

– *complement the above actions with appropriate cooperation and initiatives at international level.*

*The actions described in this Communication are also in line with the European Councils of Lisbon 2000, declaring the commitment to develop a dynamic knowledge-based economy and society, of Gothenburg 2001, aiming at sustainable development, and of Barcelona 2002, targeting 3% of GDP funding for research[1]. It also contributes towards the development of the European Research Area (ERA)[2] and profits from it.*

The extensive debate held at the Forum contributes to the definition of several initiatives and international collaborations that the Commission could launch in the field.
The great enthusiasm created suggests that the event could become the first one of a series. The integrated and responsible approach to nanotechnology has appeared to be determinant to support nanotechnology in Europe within a vision of sustainable development.

[1] Presidency conclusions can be downloaded from http://ue.eu.int/en/Info/eurocouncil/index.htm
[2] "The European Research Area: Providing new momentum - Strengthening - Reorienting - Opening up new perspectives" COM (2002) 565 final.

# 7. ANNEXES

## *Programme*

## *THEMATIC WORKSHOPS (ON DEMAND)*

### Monday 8th December

**13.00 - 19.30** **INTERNATIONAL CO-OPERATION IN THE NMP PROGRAMME -** Special Outreach Event for Latin America and South Africa.

### Tuesday 9th December

**09.00 – 13.00** **SPINELIX-NANOTECHNOLOGIES FOR LIFE -** Nanotech bridge of knowledge: from financial world to the high tech SMEs

**09.00 – 13.00** **NANOTRIB -** Nanostructured Tribological Coatings Concepts, Materials, Processes and Applications

**10.30 – 14.00** **NANOTEC IT/AIRI -** The Nanotechnologies in Italy: A Survey

### Friday 12th December

**16.00 – 18.45** **SVILUPPO ITALIA -** Risk Capital – Integrating Regional and International Resources to support Nanotechnologies Companies

## *FORUM*

### 9 DECEMBER

### OPENING SESSION

**Moderator:** ***E. Andreta,*** *Director of "Industrial Technologies", Research Directorate-General, European Commission*

**15.00 – 15.15** ***R. Illy****, Governor of Regione Friuli-Venezia Giulia, Italy,* ***and local authorities***

**15.15 – 15.30** ***G. Possa****, Deputy Minister for Education, University and Research, Italy*

**15.30 – 15.45** *Address by* ***Ph. Busquin****, European Commissioner for Research*

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| **15.45 – 16.30** | *Coffee break and films projection* |

## SESSION 1: NANOSCIENCES

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| **Chair**: | ***A. Fursenko,*** *First Deputy Minister of Industry, Science and Technologies of the Russian Federation, Russia* |
| **16.30 – 16.45** | Special address from the Chair |
| **16.45 – 17.30** | 2010, NanoSpace Odyssey<br>***Sir H. Kroto****, Nobel Prize Laureate, The School of Chemistry, Physics and Environmental Science, University of Sussex ,United Kingdom* |
| **17.30 – 18.00** | Imaging and manipulation of matter: the potential of self-assembling<br>***M. Salmeron****, Lawrence Berkeley National Laboratory, California, USA; Advisor on Nanotechnology of the Catalan Government, Spain* |
| **18.00 – 18.30** | Nanobiotechnology and its challenges<br>***H. Fuchs,*** *Münster University, Germany* |
| **18.30 – 18.45** | Discussion |

## 10 DECEMBER

## SESSION 2: SOCIETAL ASPECTS AND COMMUNICATION

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| **Chair**: | ***M. C. Roco****, Coordinator of the National Nanotechnology Initiative, Senior Advisor, NSF, and Chair of the National Science and Technology Council's Subcommittee on Nanoscale Science, Engineering and Technology, USA* |
| **9.00 – 9.25** | Nanotechnology: convergence and integration<br>***A. Nordmann,*** *University of South Carolina, Columbia, USA; Technische Universität Darmstadt, Germany* |
| **9.25 – 9.55** | Ethical implications of nanotechnology<br>***G. Hermeren****, Lund University, Sweden* |
| **9.55 – 10.25** | Impact on environment and health<br>***V. Colvin****, Rice University, USA* |
| **10.25 – 10.50** | Societal aspects of nanotechnology: misunderstanding nanoscience ?<br>***B. Wynne,*** *Professor of Science Studies and Deputy Director, Centre for the Economic and Social Aspects of Genomics (CESAGen), Lancaster University, United Kingdom* |
| **10.50 – 11.00** | Discussion |
| **11.00 - 11.30** | *Coffee break* |

## SESSION 3: INTERNATIONAL CO-OPERATION

**Chair:** ***E. Andreta,*** *Director of "Industrial Technologies", Research Directorate-General, European Commission*

**11.30 – 12.00** NANOTECHNOLOGY AND MATERIALS RESEARCH IN JAPAN
***T. Kishi****, Vice-president of the Science Council of Japan, National Institute for Materials Science, Nanotechnology Researchers Network Centre of Japan, The Science Council of Japan, The University of Tokyo, Japan*

**12.00 – 12.30** NANOTECHNOLOGY RESEARCH IN RUSSIA
***M. V. Kovalchuk*****,** *Member of the Russian Academy of Sciences, Scientific Secretary of the Council of Science and High Technologies under the President of the Russian Federation, Director of the Institute of Synchrotron Radiation Researchers, Director of the Institute of Crystallography, Russia*

**12.30 – 13.00** NANOTECHNOLOGY IN USA AND AN INTERNATIONAL PERSPECTIVE
***M. C. Roco****, Coordinator of the National Nanotechnology Initiative, Senior Advisor, NSF, and Chair of the National Science and Technology Council's Subcommittee on Nanoscale Science, Engineering and Technology, USA*

**13.00 – 13.20** NANOSCIENCES AND NANOTECHNOLOGIES IN THE EUROPEAN UNION SIXTH FRAMEWORK PROGRAMME FOR RESEARCH AND TECHNOLOGICAL DEVELOPMENT
***R. Tomellini****, Head of Unit "Nanosciences and Nanotechnologies", Directorate "Industrial Technologies", Research Directorate-General, European Commission*

**13.20 – 13.30** DISCUSSION

**13.30 – 15.00** *LUNCH BREAK*

## SESSION 4: ACCESSION COUNTRIES AND ASSOCIATED STATES

**Chair**: ***Z. Stančic*****,** *State Secretary for Science, Ministry of Education, Science and Sport, Slovenia*

**15.00 – 15.25** STATE OF THE ART OF NANOTECHNOLOGY IN THE CANDIDATE COUNTRIES
***M. Morrison****, The Institute of Nanotechnology, United Kingdom*

**15.25 – 15.50** NANOTECHNOLOGY IN SLOVENIA
***P. Venturini****, National Institute of Chemistry, Slovenia*

**15.50 – 16.15** NANOTECHNOLOGY IN SWITZERLAND: THE RESULTS OF PROMOTING SCIENCE, TECHNOLOGY AND INNOVATION FOR MORE THAN TEN YEARS
***K. Höhener****, El. Ing. HTL, Temas AG, Switzerland, Member of the Management Team of the Technology-oriented Program TOP NANO 21 and the Commission for Technology and Innovation CTI, Switzerland*

**16.15 – 16.50** A VISION ON NANOTECHNOLOGY
***S. Peres,*** *Nobel Prize Laureate and Former Prime Minister, Israel*
represented by ***D. Vilenski*** *(Chairmen of Applied Materials Israel and board member of the Israeli National Nanotechnology Initiative (INNI))*

**16.50 – 17.00** DISCUSSION

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| **17.00 – 17.30** | *COFFEE BREAK* |

## SESSION 5: EDUCATION AND TRAINING

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| **Chair**: | ***H. Fuchs,*** *Münster University, Germany* |
| **17.30 – 18.00** | NEW ROLES AND CHALLENGES FOR THE UNIVERSITIES<br>***V. Bayot****, Université Catholique de Louvain, Belgium* |
| **18.00 – 18.25** | NANOTECHNOLOGY AND THE NEW CORPORATE TRAINING<br>***F. Menzel****, Degussa, Germany* |
| **18.25 – 18.50** | INITIATIVES OF MAKING YOUNG PEOPLE AWARE OF SCIENCE - A DOOR OPENER TO WAKE UP INTEREST IN NANOSCIENCES AND NANOTECHNOLOGIES IN DUE COURSE<br>***J. Fröhlich****, Vienna University of Technology, Austria* |
| **18.50 – 19.20** | NANOTECHNOLOGY RESEARCH AND TRAINING REQUIREMENTS FOR SUSTAINABLE DEVELOPMENT IN THE COUNTRIES OF YOUNGER INDUSTRIALISATION<br>***O. L. Malta****, Federal University of Pernambuco, Brazil* |
| **19.20 – 19.30** | DISCUSSION |

## 11 DECEMBER

## SESSION 6: RESEARCH, INDUSTRIAL INNOVATION & ENTREPRENEURSHIP, FINANCING INSTRUMENTS

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| **Chair**: | ***R. Zobel****, Director of "Components and Subsystems. Applications", Information Society Directorate-General, European Commission* |
| **9.00 – 9.25** | FROM UNIVERSITY RESEARCH TO A NEW "NANO" COMPANY<br>***H. Schmidt****, Managing Director, Institute of New Materials (INM GmbH), Germany* |
| **9.25 – 9.40** | TOWARDS A NEW RESEARCH-CAPITAL RELATIONSHIP: A CASE STUDY<br>***A. Sfiligoj****, Sviluppo Italia Friuli-Venezia Giulia, Italy* |
| **9.40 – 10.00** | THE DIALOGUE WITH THE FINANCIAL OPERATORS<br>***O. Arango****, European Investment Bank* |
| **10.00 – 10.20** | THE STRATEGY OF A MULTI-NATIONAL COMPANY<br>***A. Cuomo****, Corporate Vice-President STMicroelectronics and General Manager of Advanced System Technology, STMicroelectronics, Italy*<br>represented by ***M.-T. Gatti*** |
| **10.20 – 10.50** | THE VISION AND INTEGRATED APPROACH OF NSF<br>***T. A. Weber****, Division Director, Division of Materials Research, Directorate for Mathematical & Physical Sciences, NSF, USA* |
| **10.50 – 11.00** | DISCUSSION |
| **11.00 – 11.30** | *COFFEE BREAK* |

## SESSION 7: INFRASTRUCTURE, EQUIPMENT AND METROLOGY

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| **Chair**: | ***T. A. Weber,*** *Division Director, Division of Materials Research, Directorate for Mathematical & Physical Sciences, NSF, USA* |
| **11.30 – 11.50** | TOWARDS A EUROPEAN VISION ON INFRASTRUCTURES AND THE CASE OF THE SYNCHROTRON<br>***C. Rizzuto****, Chairman of Sincrotrone Trieste, Italy*<br>*represented by* ***C.J. Bocchetta*** |
| **11.50 – 12.10** | NANOTECHNOLOGIES ERA: A CHALLENGE FOR RESEARCH INFRASTRUCTURES<br>***D. Barbier,*** *Director CEA-Leti, France*<br>represented by ***J.-C. Guibert*** |
| **12.10 – 12.30** | THE "KOMPETENZZENTREN"<br>***W.M. Heckl****, L.M. Universität München, Germany* |
| **12.30 – 12.50** | DEMONSTRATORS AND NANO-FABRICATION CENTRES – TOWARDS A UK NETWORK OF FACILITIES AND SUPPORT FOR INDUSTRY<br>***N. Mundy****, Chairman of the DA Group, United Kingdom* |
| **12.50 – 13.20** | THE ROLE OF METROLOGY<br>***K. Carneiro****, Director of the Danish Institute of Fundamental Metrology, Denmark* |
| **13.20 – 13.30** | DISCUSSION |
| **13.30 – 14.45** | *LUNCH BREAK* |

## SESSIONS 8-10: PARALLEL SESSIONS

## SESSION 8A: NANO-MANUFACTURING AND INSTRUMENTATION

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|---|---|
| **Chair:** | ***E. Di Fabrizio,*** *Istituto Nazionale di Fisica della Materia, Italy* |
| **Co-chair:** | ***A. Gentili,*** *Unit "Products, processes, organisation", Directorate "Industrial Technologies", Research Directorate-General, European Commission* |
| **14.45 – 15.15** | SCANNING PROBE METHODS: THE EYES FOR THE NANO-WORLD<br>***R. Wiesendanger****, Institute of Physics, University of Hamburg, Germany* |
| **15.15 – 15.45** | NANOMETER SCALE FABRICATION<br>***M. Welland****, Cambridge Interdisciplinary Research Centre on Nanotechnology, United Kingdom* |
| **15.45 – 16.05** | NANODEVICES AND SINGLE ELECTRONIC DEVICES<br>***V. Bouchiat****, Centre de Recherches à tres basses temperatures, Grenoble, France* |
| **16.05 – 16.25** | NANOMANUFACTURING AND INSTRUMENTATION: THE INDUSTRIAL POINT OF VIEW<br>***E. Hammel****, ELECTROVAC GmbH, Austria* |

**16.25 – 16.45** INDUSTRIAL PRODUCTION OF NANO-SCALED POWDERS: A CASE STUDY
***D. Kerner**, Degussa, Germany*

**16.45 – 17.15** *COFFEE BREAK*

## SESSION 8B: FUNCTIONAL MATERIALS

**Chair**: ***I. Dumitrache,** Rector of the University Politechnica of Bucharest, Romania*

**Co-chair:** ***R. Tomellini**, Head of Unit "Nanosciences and Nanotechnologies", Directorate "Industrial Technologies", Research Directorate-General, European Commission*

**14.45 – 15.15** MAGNETISM OF ATOMIC-SCALE NANOSTRUCTURES
***K. Kern**, Max-Planck Institut für Festkörperforschung, Germany*

**15.15 – 15.35** SURFACE ENGINEERING AND TECHNOLOGIES FOR NANOSTRUCTURED COATINGS
***P. Milani**, Department of Physics, University of Milano, Italy*
represented by ***P. Piseri***

**15.35 – 16.00** NANOCOMPOSITES: STAKES AND CHALLENGES
***M. I. Baraton**, University of Limoges, France*

**16.00 – 16.25** FUNCTIONAL ORGANIC NANOMATERIALS : THE CASE OF LIQUID CRYSTALS
***Y. Geerts**, Université Libre de Bruxelles, Belgium*

**16.25 – 16.45** COMPUTATIONAL CATALYSIS: FROM QUANTUM MECHANICS TO NANO-SCALE MATERIALS DESIGN
***J. K. Nørskov**, Technical University of Denmark, Denmark*

**16.45 – 17.15** *COFFEE BREAK*

## SESSION 8C: AMBIENT INTELLIGENCE

**Chair:** ***W.M. Heckl**, L.M. Universität München, Germany*

**Co-chair:** ***D. Beernaert**, Head of Unit "Micro- and nano-systems, and displays", Directorate "Components and Subsystems. Applications", Information Society Directorate-General, European Commission*

**14.45 – 15.15** SYSTEMS ENGINEERING FOR THE MICRO AND NANO WORLDS
***A. El Fatatry**, BAE Systems, United Kingdom*

**15.15 – 15.45** EMBEDDED ENERGY : A KEY FOR REALISING AMBIENT INTELLIGENCE
***P. Perlo**, Centro Ricerche Fiat, Italy*

**15.45 – 16.15** DRIVERS FOR NANOTECHNOLOGIES TO AMBIENT INTELLIGENCE
***J.-C. Guibert**, MINATEC, Grenoble, France*

**16.15 – 16.45** MICRO AND NANO TECHNOLOGY FOR MEDICAL DIAGNOSTICS
***A. Campitelli**, IMEC, Belgium*

**16.45 – 17.15** *COFFEE BREAK*

## SESSION 9A: NANOELECTRONICS

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|---|---|
| **Chair:** | ***M.T. Gatti****, Advanced System Technology Research and Innovation Director, STMicroelectronics, Italy* |
| **Co-chair:** | ***P. Van Hove****, Unit "Future and Emerging Technologies", Directorate "Emerging Technologies and Infrastructures. Applications", Information Society Directorate-General, European Commission* |
| **17.15 – 17.55** | CARBON NANOTUBES AND BEYOND: THE ERA OF NANOELECTRONICS ?<br>***S. Iijima,*** *National Institute of Advanced Industrial Science and Technology, Japan* |
| **17.55 – 18.20** | INTERFACE WITH BIO-MOLECULES<br>***R. Cingolani****, University of Lecce, Italy*<br>represented by ***R. Rinaldi*** |
| **18.20 – 18.45** | MOLECULAR ELECTRONICS<br>***J.-P. Bourgoin,*** *CEA Saclay, France* |
| **18.45 – 19.15** | IMPLICATIONS OF NANOTECHNOLOGY FOR ELECTRONICS<br>***G. Aeppli,*** *University College London, London Centre for Nanoscience, United Kingdom* |

## SESSION 9B: NANOBIOTECHNOLOGY FOR HEALTH

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|---|---|
| **Chair:** | ***M. V. Kovalchuk,*** *Member of the Russian Academy of Science, Scientific Secretary of the Council of Science and High Technologies under the President of the Russian Federation, Director of the Institute of Synchrotron Radiation Researchers, Director of the Institute of Crystallography, Russia* |
| **Co-chair:** | ***T. Ingemansson****, Unit "Biotechnology and Genomics", Directorate "Health", Research Directorate-General, European Commission* |
| **17.15 – 17.45** | THE CANCER NANOTECHNOLOGY PLAN: A ROADMAP FOR DEPLOYMENT OF NANOTECHNOLOGY IN THE FIGHT AGAINTS CANCER<br>***M. Ferrari****, The Ohio State University, USA* |
| **17.45 – 18.15** | NANOBIOTECHNOLOGIES AND APPLICATION TO HEALTH<br>***J.-M. Grognet****, CEA, France* |
| **18.15 – 18.35** | PROTEIN ENGINEERING FOR NANOTECHNOLOGY: APPLICATIONS TO DRUG DISCOVERY AND HUMAN HEALTH<br>***G. Gilardi****, Imperial College of Science, Technology and Medicine, United Kingdom* |
| **18.35 – 18.55** | CHALLENGES AND PERSPECTIVES FOR TISSUE ENGINEERING: THE SCIENTIFIC CONSIDERATION<br>***J. San Román****, Institute of Science and Technology of Polymers, Spain* |
| **18.55 - 19.15** | ATOMIC-FORCE MICROSCOPY IN PROTEOMICS<br>***A. I. Archakov****, Institute of Biomedical Chemistry, Russian Academy of Medical Sciences, Moscow, Russia* |

## SESSION 9C: ENERGY

**Chair:** ***G. Scoles,*** *Scuola Internazionale Superiore di Studi Avanzati (SISSA) and Elettra Synchrotron, Trieste; and Princeton University, USA.*

**Co-chair:** ***C. Tuniz,*** *Counsellor, Australian Embassy in Austria and Mission to the United Nations Organisations, Australia*

**17.15 – 17.40** ORGANIC SOLAR CELLS
***M. Grätzel****, Laboratory for Photonics and Interfaces, Swiss Federal Institute of Technology, Switzerland*

**17.40 – 18.05** NANO-STRUCTURES FOR PHOTOVOLTAICS - QUANTUM DOTS AND QUANTUM WELLS
***A. Slaoui****, Laboratoire PHASE-CNRS, Centre National de la Recherche Scientifique (CNRS), France*

**18.05 – 18.30** NANOSTRUCTURED FUNCTIONAL MATERIALS FOR ENERGY CONVERSION AND STORAGE SYSTEMS
***J. Schoonman****, Delft University of Technology, The Netherlands*

**18.30 – 18.55** NANOSCALE MATERIALS FOR HYDROGEN STORAGE
***M. Hirscher****, Max-Planck-Institut für Metallforschung, Germany*

**18.55 – 19.15** NANOSTRUCTURED CATALYSTS FOR HYDROGEN PRODUCTION
***R. Rosei****, Sincrotrone Trieste S.C.p.A, Italy*

## 12 DECEMBER

## SESSION 10A: NANO-ROBOTS AND NEMS

**Chair:** ***K. Höhener****, El. Ing. HTL, Temas AG, Switzerland, Member of the Management Team of the Technology-oriented Program TOP NANO 21 and the Commission for Technology and Innovation CTI, Switzerland*

**Co-chair:** ***S. Fantechi****, Unit "Nanosciences and Nanotechnologies", Directorate "Industrial Technologies", Research Directorate-General, European Commission*

**9.00 – 9.30** NANOMECHANICS: OPENING NEW FRONTIERS IN BIO ANALYSES AND DIAGNOSTICS
***C. Gerber****, NCCR National Center of Excellence for Nanoscience Institute of Physics Univ. of Basel and Nanoscalescience group IBM Research Lab. Rueschlikon, Switzerland*

**9.30 – 10.00** SUPER-PRECISE NANOPOSITIONERS FOR NANOTECHNOLOGY
***V. Rakhovsky****, Nanotech Ltd, Moscow, Russia*

**10.00 – 10.30** NANO-ROBOTS
***A. Bourjault****, Laboratoire d'Automatique de Besançon, France*

**10.30 – 11.00** SINGLE MOLECULE NANO-ROBOTS

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| | ***M. Mayor**, Institute for Nanotechnology, Forschungszentrum Karlsruhe GmbH, Germany* |
| **11.00 – 11.30** | *COFFEE BREAK* |

## SESSION 10B: OPTICS AND PHOTONICS

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| **Chair:** | ***P. Venturini**, National Institute of Chemistry, Slovenia* |
| **Co-chair:** | ***M.-I. Baraton**, University of Limoges, France* |
| **9.00 – 9.30** | QUANTUM DOTS AND PHOTONIC CRYSTALS FOR NANOPHOTONIC DEVICES<br>***A. Forchel**, University of Würzburg, Germany* |
| **9.30 – 10.00** | NANOTECHNOLOGY FOR HIGH POWER SEMICONDUCTOR LASERS<br>***M. Bugajski**, Institute of Electron Technology, Department of Physics and Technology of Low Dimensional Structures, Poland* |
| **10.00 – 10.30** | NANOPHOTONIC INTEGRATED CIRCUITS : THE POTENTIAL AND THE CHALLENGES<br>***R. Baets,** IMEC, Belgium* |
| **10.30 – 11.00** | SILICON-BASED NANOPHOTONICS<br>***U. Gösele**, Max-Planck-Institut für Mikrostrukturphysik, Germany* |
| **11.00 – 11.30** | *COFFEE BREAK* |

## CLOSING SESSION

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| **Moderator:** | ***R. Tomellini,** Head of Unit "Nanosciences and Nanotechnologies, Directorate "Industrial Technologies", Research Directorate-General, European Commission* |
| **11.30 – 12.30** | PRESENTATION OF THE CONCLUSIONS OF THE FORUM SESSIONS<br>***The Chairpersons and Rapporteurs*** |
| **12.30 – 12.55** | DISCUSSION |
| **12.55 – 13.05** | CLOSING REMARKS<br>***E. Beltrame**, Regional Assessor for European Affairs and International Relations* |
| **13.05 – 13.15** | CONCLUSIONS<br>***E. Andreta**, Director of "Industrial Technologies", Research Directorate-General, European Commission* |

## List of Speakers

**Aeppli G.**
Department of Physics and Astronomy,
University College London, and
London Centre for Nanoscience
UNITED KINGDOM

**Arango O.**
European Investment Bank
LUXEMBOURG

**Archakov A.I.**
Institute of Biomedical Chemistry
Russian Academy of Medical Sciences
RUSSIA

**Baets R.**
IMEC, Gent University,
INTEC - OCS
BELGIUM

**Baraton M. I.**
Université de Limoges
FRANCE

**Bayot V.**
Université Catholique de Louvain, Electrical engineering department, Microelectronics laboratory (DICE), Research center on micro and nanoscopic electronic materials and devices, CERMIN
BELGIUM

**Bocchetta C.J.**
Sincrotone Trieste S.C.p.A.
ITALY

**Bouchiat V.**
Centre de Recherches sur les très basses températures, CNRS
FRANCE

**Bourgoin J.-Ph.**
CEA/Saclay
FRANCE

**Bugajski M.**
Institute of Electron Technology, Department of Physics and Technology of Low Dimensional Structures
POLAND

**Campitelli A.**
IMEC
BELGIUM

**Carneiro K.**
Director, Danish Institute of Fundamental Metrology
DENMARK

**Colvin V.**
Executive Director of the Center for Biological and Environmental Nanotechnology,
Associate Professor of Chemistry,
Rice University
USA

**El Fatatry A.**
Customer Manager
Systems Engineering Innovation Centre (SEIC),
BAE SYSTEMS,
Advanced Technology Centre
UNITED KINGDOM

**Ferrari M.**
Associate Vice President for Health Science Technology and Commercialisation, Professor of Biomedical Engineering, Professor of Internal Medicine, Professor of Mechanical Engineering, Professor of Material Science and Engineering, Associate Director Dorothy M. Davis Heart and Lung Research Institute - The Ohio State University
USA

**Forchel A.**
University of Würzburg,
Department of Physics & Astronomy,
Institute of Experimental Physics, Technical Physics
GERMANY

**Fuchs H.**
Münster University,
CENTECH Center for Nanotechnology
GERMANY

**Gatti M.T.**
Director, Research and Innovation, Advanced System Technology, STMicroelectronics
SWITZERLAND

**Geerts Y.**
Université Libre de Bruxelles,
Faculté des Sciences (Department of Polymer Chemistry)
BELGIUM

**Gerber Ch.**
Director of scientific communication,
NCCR National Center of Excellence for Nanoscience, Institute of Physics Univ. of Basel and Nanoscalescience group IBM Research Lab.
SWITZERLAND

**Gilardi G.**
Università degli Studi di Torino, Dipartimento di Biologia Animale e dell'Uomo
ITALY

**Gösele U.**
Max-Planck-Institut für Mikrostrukturphysik
GERMANY

**Grätzel M.**
Laboratory for Photonics and Interfaces,
Swiss Federal Institute of Technology
SWITZERLAND

**Guibert J.-C.**
CEA-LETI,
CEA Grenoble
FRANCE

**Hammel H.**
ELECTROVAC GmbH
AUSTRIA

**Heckl W.M.**
Ludwig-Maximilians-Universität München, Institut für Kristallographie und angewandte Mineralogie
GERMANY

**Hermeren G.**
Chairman of the European Group of Ethics of Science and Technology,
Lund University, Department of Medical Ethics
SWEDEN

**Hirscher M.**
Max-Planck-Institut für Metallforschung
GERMANY

**Höhener K.**
El. Ing. HTL, Temas AG, Switzerland,
Member of the Management Team of the Technology-oriented Program TOP NANO 21 and the Commission for Technology and Innovation CTI,
TEMAS AG
SWITZERLAND

**Iijima S.**
**-** Director of the Research Center for Advanced Carbon Materials at the National Institute of Advanced Industrial Science and Technology [AIST],
**-** Meijo University, Department of Materials Science & Engineering (Director, Research Center for Advanced Carbon Materials/ AIST, Research Director JST/SORST "CNT Project" & NEC Special Research Fellow)
JAPAN

**Kern K.**
Max-Planck Institut für Festkörperforschung,
GERMANY

**Kishi T.**
Vice-President of the Scientific Council of Japan, National Institute for Materials Science Director General, Nanotechnology Researchers Network Center of Japan Representative Member, The Science Council of Japan Professor Emeritus, The University of Tokyo
JAPAN

**Kovalchuk M. V.**
Member of the Russian Academy of Science, Scientific Secretary of the Council of Science and High Technologies under the President Federation, Director of the Institute of Synchrotron Radiation Researchers, Director of the Institute of Crystallography
RUSSIA

**Kroto H.**
The School of Chemistry, Physics and Environmental Science, University of Sussex
UNITED KINGDOM

**Malta O. L.**
Department of Fundamental Chemistry,
Federal University of Pernambuco, CCEN
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**Mayor M.**
Institute for Nanotechnology,
Forschungszentrum Karlsruhe GmbH
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**Menzel F.**
Degussa AG
GERMANY

**Morrison M.**
Coordinator of Nanoforum,
The Institute of Nanotechnology
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**Mundy N.**
Chairman of the DA Group,
UNITED KINGDOM

**Nordmann A.**
Institut für Philosophie, Technische
Universität Darmstadt
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**Nørskov J. K.**
Department of Physics,
Technical University of Denmark
DENMARK

**Perlo P.**
Centro Ricerche Fiat, Department of
"Tecnologie Optomeccaniche"
ITALY

**Piseri P.**
Dipartimento di Fisica, Università di Milano
ITALY

**Rakhovsky V.**
Nanotech Ltd
RUSSIA

**Rinaldi R.**
University of Lecce, Dipartimento di
Ingegneria dell'Innovazione,
ITALY

**Roco M. C.**
Coordinator of the National Nanotechnology
Initiative, White House; Senior Advisor,
NSF, and Chair of the National Science and
Technology Council's subcommittee on
Nanoscale Science, Engineering and
Technology
USA

**Rosei R.**
Sincrotrone Trieste S.C.p.A.
ITALY

**Salmeron M.**
Materials Science Division, Lawrence
Berkeley National Laboratory,
USA

**San Roman J.**
Head of Department of Macromolecular
Chemistry, Instituto de Ciencia y Tecnología
de Polímeros, CSIC,
SPAIN

**Schmidt H.**
Managing Director and Scientific Head,
Institute of New Materials (INM GmbH), Department
of chemistry and technology of non-metallic
inorganic materials,
GERMANY

**Schoonman J.**
Delft University of Technology, Faculty of Applied
Sciences, Laboratory of Inorganic Chemistry,
Department of Chemical Technology (Delft Chem
Tech),
Section for Anorganic Chemistry
THE NETHERLANDS

**Sfiligoj A.**
Sviluppo Italia; Amm. Delegato,
Bic Friuli Venezia Giulia SpA
ITALY

**Slaoui A.**
Laboratoire PHASE-CNRS,
Centre National de la Recherche Scientifique
(CNRS)
FRANCE

**Tomellini R.**
European Commission,
Head of "Nanosciences and Nanotechnologies" Unit,
Directorate "Industrial Technologies", Research
Directorate-General,
European Commission
BELGIUM

**Venturini P.**
Director, National Institute of Chemistry of Slovenia
SLOVENIA

**Vilenski D.**
Applied Materials Israel,
Israeli National Technology Initiative
ISRAEL

**Weber T. A.**
Director, Division of Materials Research,
The National Science Foundation
USA

**Welland M.**
Cambridge Interdisciplinary Research Centre on
Nanotechnology,
University of Cambridge,
Department of Engineering,
UNITED KINGDOM

**Wiesendanger R.**
Institut für Angewandte Physik und
Zentrum für Mikrostrukturforschung,
Universität Hamburg
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