



6th Framework Programme

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Project acronym: DESYGN-IT
Project title: Design, Synthesis and Growth of Nanotubes for Industrial Technology
Instrument: Specific Targeted Research Project

Publishable Executive Summary

Period covered: from October 1st 2005 **to** September 30th 2006

Date of preparation: September 2006

Start date of project: October 1st 2004 **Duration:** 36 Months (3 years)

Project coordinator name: Prof. Werner Blau

Project coordinator organisation name: The Provost Fellows and Scholars of the College of the Holy and Undivided Trinity of Queen Elizabeth near Dublin, (TCD)

Revision: October 2006

Executive Summary

General Overview of Project Objectives:

The primary Scientific and Technical objective of this project is to establish Europe as the International Scientific Leader in the Design, Synthesis, Growth and Application of nanotubes, nanowires and nanotube arrays for Industrial Technology. The nanomaterials will be prepared using clean technology. The DESYGN-IT consortium contains several of Europe's leading researchers in the nanotube and nanowire field. There are several high-tech SME partners who are well placed to assess the outputs of the project and benefit from the proposed research. Major contributions to the fundamental understanding of the synthesis, processing and properties of nanotubes, nanowires and arrays can be confidently foreseen.

The scientific objectives of our work are to:

- Create know-how and encourage European Industry to be first to market with a cost effective mass production of high quality nanotubes i.e. make nanotubes accessible for European industry
- Reply to the demands of industry for low cost, high purity nanotubes and related products and in turn increase high-tech exports
- Demonstrate to industry the enhanced performance and cost benefits of nanotubes in their applications and provide the European industry with a practical understanding of the capabilities of nanosize materials
- Increase the number of publications and patents in the nanotube and nanowire field.

Our output will be high purity and high quality nanomaterials at low cost. In summary, the main technical objectives of the DESYGN-IT project are to

- Develop a low cost, clean process to produce high quality nanotubes
- Manufacture nanotubes with defined electronic and mechanical properties
- Provide nanotubes in a form that can be readily handled by industry
- Advance state-of-the-art in the development of metal and semiconductor nanowires
- Develop industrial prototypes for demonstration to industry: sensor device, SPM tip, actuator etc.

List of Participants

Role*	Participant. no.	Participant name	Short name	Country
CO	1	Trinity College Dublin	TCD	IRL
CR	2	National University of Ireland, Cork	UCC	IRL
CR	3	Institute Josef Stefan	JSI	SI
CR	5	University of Ulster	UU	UK
CR	6	Queen Mary College Queen Mary	QM	UK
CR	7	Queens University Belfast	QUB	UK
CR	8	Fraunhofer Fraunhofer	FF	DE
CR	9	University of Cambridge UDAM	DENG	UK
CR	10	Toughglass Ltd	TG	UK
CR	11	Sensor Technology & Device Ltd	ST&D	UK
CR	12	Mid Sweden University	MSU	S
CR	13	NTERA Ltd	NTL	IRL
CR	14	Mo6 B.V	B.V.	NL
CR	15	University of Latvia	UL	LV

where:

CO = Coordinator
CR = Contractor

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Work Performed / Results Achieved to date:

The Consortium maintains the primary Scientific and Technical objective going forward, which is to establish Europe as the International Scientific Leader in the Design, Synthesis, Growth and Application of nanotubes, nanowires and nanotube arrays for Industrial Technology, to be prepared using clean technology.

Technically, the progress on DESYGN-IT has been steady, and the Consortium are satisfied that the majority of the deliverables can be met as per Work plan, as laid out in Annex 1, 'Description of Work' version 6. This was confirmed at the Mid Term Review which took place in March 2006.

Regular assessments of the outputs from this project are being made by the lead researcher on a and the Workpackage, (WP) leaders. The WP leaders update the technical coordinator and the project manager. Reporting has taken place largely on an informal basis along with the formal biannually project meetings, (see section on Consortium Management for further information on meetings). Each WP leader is responsible to ensure that the work in his/her WP is delivered in a timely fashion. Any slippage of tasks is handled via coordination of the WP leader and Technical coordinator with the research team. Some delays have occurred to date but generally, advance warning of problems has lead to extensions on the end date of tasks at risk.

Assessment of milestones will be an ever-important tool for measuring project success.

- Develop a low cost, clean process to produce high quality nanotubes
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At this stage in the project most of the academic partners have reported new developments in the international peer reviewed literature, following the internal approval for publication procedure for DESYGN IT, see details in Appendix 1: Plan for Using and Disseminating Knowledge. The SME's have already obtained adequate protection of their basic intellectual property (IP) and are using the new knowledge generated by DESYGN IT to enhance their products and market opportunities.

With reference to the particular workpackages, an overview of each is given below.

<p>WP1: Large-Scale Synthesis of High Quality, High Purity Nanotubes Large Scale Synthesis of quality Carbon and MOSix Nanotubes, as envisioned, has been achieved using a number of methods.</p>
<p>WP2: Surface Engineering and Functionalisation of Nanotubes The Nanotubes produced in WP1 are being successfully functionalised for sensor, Raman and biological binding applications.</p>
<p>WP3: Controlled Growth of Nanowires and Nanoarrays Best in class nanoarrays have been grown using a variety of techniques and further improvements are in the pipeline</p>
<p>WP4: Characterisation of Nanotubes, Nanowires and Arrays The project partners have expertise in a wide range of characterisation techniques which are being applied to all samples in a structured fashion.</p>
<p>WP5: Development and testing of nanotube based actuator and nanotube reinforced polymer composites Research on actuator and reinforcement applications is on target and proceeding at a rate that is competitive internationally.</p>

WP6: Applications of Nanotubes and Nanoarrays: Prototype Devices and New Materials

As planned, the SME's are now seriously involved in incorporation of NTs into their devices. Initial indications of significant improvements have been reported. Some partners are looking at new fundamental effects which should lead to a step change and have promising long term potential.

WP7: Commercialisation Assessment and Technology Transfer

The SMEs are carrying out a Commercial Assessment of the developments from the project based on the Book of Specifications that has been written. A workshop took place as part of a major international conference. The final year of the project will see the website coming to the forefront as a dissemination tool.

WP8: Project Co-ordination and Management

This phase of the project has been characterised by a degree of formalisation in exploitation planning, progressing towards deadlines and setting in re-affirming procedures for work, (both technical and administrative). The co-ordinators view their role as vital to the achievement of project objectives, and have achieved full co-operation from all partners through a high level of frequent communication.

Intentions for Use and Impact:

Applications for nanotubes are being developed by automotive manufacturers, chemical firms, electronic manufacturers and display firms, among others. Current commercial applications for nanotubes include conductive polymers, advanced composites, fibres and displays. The results generated by DESYGN-IT will allow European SMEs to be first to a global market for carbon nanotubes that is expected to be in the region of \$700 million. For a high tech SME working in the nanotube area to capture just one-half of one percent of for example the flat-panel display market (valued at \$20 billion), the income stream generated via licensing and royalty payments would be considerable.

As the demand for nanotubes increases, the SMEs will have the edge over their competitors because of the technical knowledge generated by the project. The Economic Impact will be twofold: to add value to existing industry and to generate a new nanotech enabled industry. DESYGN-IT is progressing nanotube technology beyond the current state-of-the-art and this will ensure that:

- Nanotubes and related materials will be readily accessible for European industry.
- New knowledge will generate valuable IP, accelerate product development and in turn lead to increased high-tech exports.
- Europe can address global market needs for low cost, high purity and high quality nanotubes and nanowires.
- Industry will be aware of the enhanced performance and cost benefits of nanotubes in applications across all sectors, in the short, medium and long term.

Results of the Plan for Using and Disseminating the Knowledge:

The dissemination of results through conferences, workshops, publications and patents will attract new customers and target applications that cannot be addressed by current technologies and materials. The generation of valuable IP will be a key aspect in the long term and will generate licensing opportunities and spin-off potential.

Conferences:

The Consortium members have promoted DESYGN-IT at several conferences in the last 12 months. A list of the major conferences attended in this reporting period by the partners was compiled and is presented below:

- The International Conference on Science and Technology of Synthetic Metals(ICSMT), July 2006, Dublin Ireland
- IPP summer school for plasma physics, September 2005, Greifswald Germany.
- European Materials Research Society Meeting, May 2006, Nice France
- 20th International Winterschool on Novel Materials Molecular Nanostructures, IWEPNM, May 2006, Kirchberg Austria.
- ADC/NanoCarbon 2005; 8th International Conference on Applications of Diamond and Related Materials/1st NanoCarbon Joint Conference, Argonne National Laboratory, May 2005, Argonne USA
- Metallurgical Coatings and Thin Films ICMCTF, May 2006, San Diego, California, USA.
- Quantum Physics of Nanostructures, September 2006, Stratford-Upon-Avon, UK
- NT05 - 6th International Conference on the Science and Application of Nanotubes, June/July 2005, Gothenburg, Sweden
- ACTUATOR 2006 10th International Conference on New Actuators, June 2006, Bremen, Germany
- NANO9/STM06 – International Conference on Nanoscience and Technology / International Conference on Scanning Tunnelling Microscopy, July/August 2006, Basel, Switzerland
- Tenth International Conference on Plasma Surface Engineering PSE2006, September, 2006 Garmisch Partenkirchen Germany
- 2nd Latvian Conference "Functional materials and nanotechnologies", March 2006, Riga Latvia

Workshops and Fairs:

The representatives of all partners in the DESYN IT took part in the first of the DESYGN-IT workshops that was held in July 2006. The aim of the workshop was to showcase emerging technologies, new products and devices through DESYGN-IT. It was held in conjunction with 'The International Conference on Science and Technology of Synthetic Metals' (ICSMT) held July 3rd-7th at TCD. The workshop had a large attendance, as it was open to all of the ICSMT conference delegates and had been promoted in the conference literature. At the time of reporting, it is envisioned that the second of the workshops will take place in month 36. However, this will be dependant on identifying a suitable venue for the event.

One Post Doc. student attended Experiment at Fast-Lab, a workshop held in April 2006 at the University of Southampton England.

Partner 8 will be attending The 5th ESF-Nanotribology Workshop 23 – 27 September 2006, Antalya, Turkey and has attended the following fairs:

- Nanosolution 8.-10. November 2005 Cologne Germany
- NanoEurope, September 2006, St. Gallen Switzerland

Publications:

- Pulsed laser deposition of nanostructured Ag films, Tony Donnelly, Brendan Doggett and James G. Lunney, Appl. Surf. Sci. 252 (2006) 4445-4448
- Cott, D. J.; Petkov, N.; Morris, M. A.; Platschek, B.; Bein, T.; Holmes, J. D. 'Preparation of oriented mesoporous carbon nano-filaments within the pores of anodic alumina membranes' J. Am. Chem. Soc. 2006, 128, 3920-3921.
- Li, Z.; Zhang, H.; Tobin, J. M.; Qiu, J.; Attard, G.; Holmes, J. D. 'Synthesis of bamboo-structured carbon nanotubes on MgO supported Mo/Cu catalysts' Diamond and Related Materials 2006, submitted.
- Li, Z.; Andzane, J.; Erts, D.; Tobin, J. M. Wang, K.; Attard, G. Holmes, J. D. 'Supercritical fluid growth of high quality carbon nanotubes' 2006, in preparation

- Li, Z.; Papakonstantinou, P.; Tobin, J. T.; Wang, K.; Vohrer, U.; Morris, M. A.; Attard, G.; Shailesh Kumar, S.; Holmes, J. D. 'Supercritical Fluid Growth of Porous Carbon Nanocages' 2006, in preparation.
- "Transport properties of Mo₆S₃I₆ nanowire networks", B. Bercic et al., Appl. Phys. Lett. 88, 173103 (2006)
- "Conductivity of single Mo₆S₉-xI_x molecular nanowire bundles", M. Uplaznik et al. Nanotechnology 17, 5142 (2006)
- "Resistivity measurements of Mo₆S₃I₆ nanowire networks", B Bercic et al., Phys. Stat. Sol. (b) 243, 3306 (2006)
- Erdem A, Papakonstantinou P, Murphy H, "Direct DNA hybridization at disposable graphite electrodes modified with carbon nanotubes", Analytical Chemistry, Vol. 78, (2006) 6656-6659
- Murphy H, Papakonstantinou P, Okpalugo T I T, (Mar 2006) "Raman study of multiwalled carbon nanotubes functionalized with oxygen groups", Journal of Vacuum Science Technology B, 24, 715-720
- Magnetotransport in Fe-Filled Carbon Nanotube Systems', S. Hudziak, M. Baxendale, poster, Quantum Physics of Nanostructures, 18th-20th September, Stratford-Upon-Avon, UK
- 'Quantum Conductance in Carbon Nanotube Systems', M. Baxendale, M. Melli, Z. Alemipour, I. Pollini, submitted, Physical Review Letters
- Plasma Modification of Carbon Nanotubes and Bucky Papers
- D. Erts, A. Lohmus, J. D. Holmes, H. Olin. Probing of nanocontacts inside a transmission electron microscope. (Chapter in book "Fundamentals of Friction and Wear on the Nanoscale", Springer (in press, November 2006)

Website & Logo:

The project public website can be accessed through
<http://www.tcd.ie/Physics/DESYGNIT/index.php>

The area of the website accessible to the public outlines the project objectives and the consortium members. In the final 12 month period of the project, the website will be developed further to include publishable results of the project, links to the sites of similar framework 6 projects and a counter to monitor the level of interest in the site. It is the intention of the consortium to have a more accessible and appealing site. Work will also be done to have links to the DESYGN IT on other related websites.

The logo, for the DESYGN project, has been developed for some time now; see above. This appears on all the DESYGN IT publishable material. At the time of writing, it has been used on the following media: reports, slides, website, brochures and posters.