NMP4-CT-2003-500120

NaPa

Emerging Nanopatterning Methods

Integrated Project

Nanotechnologies and nano-sciences, knowledge-based multifunctional materials and new production processes and devices

Final Activity Report

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Revision 1

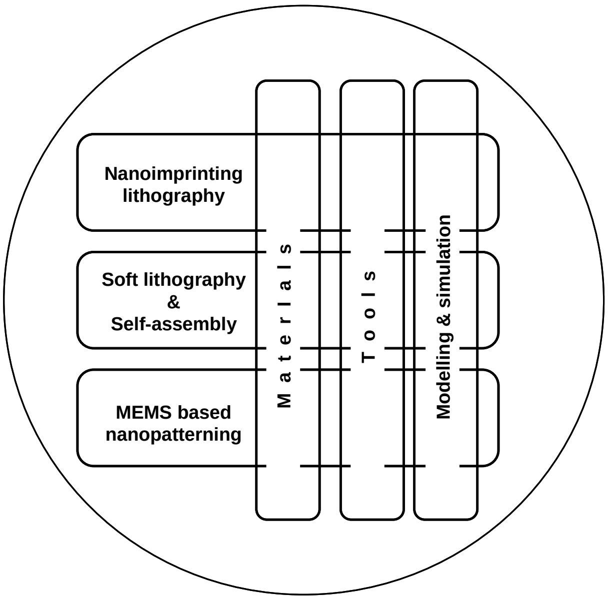
Executive summary

1. Project execution

Project objectives

The four year Emerging Nanopatterning Methods (NaPa) started in March 2004. The NaPa consortium integrated well over 80 % of the viable existing European know-how in nanolithography, the leading institutes and companies active in the field into a single Integrated Project, both anticipating and responding to the increasing need for technologies, standards and metrology required to harness the new application-relevant properties of engineered structures with nm-scale features.

Strategically, the NaPa consortium complemented deep UV technology by providing low-cost scalable processes and tools to cover the needs of nanopatterning from CMOS back-end processes through photonics to biotechnology. To achieve this, research in three technology strands was carried out: **Nanoimprint lithography, Soft lithography & self-assembly and MEMS-based nanopatterning**. While, in the beginning of the project, the first was at a crucial embryonic stage, and required prompt consolidation to yield its first products within one or two years, the latter two were on target to produce applications towards the end of the project. In addition, research was undertaken in three overarching themes required by all strands: **Materials, Tools and Simulation**. Thus, thematically, the consortium embraced and pushed forward the state-of-the-art developments in the physical and engineering sciences with the object-driven mission to provide European industrial and academic researchers with a library of novel nanopatterning processes needed to underpin radical innovations and further scientific developments in nanotechnology.



NaPa project comprised of six subprojects addressing different nanopatterning methods and the supporting actions.

The NaPa project addressed Community socio-economic objectives from many vantage points. In response to the need for the transformation of industry towards higher-added value activities, the consortium was actively steered at the management and R&D levels by the industrial participants to ensure that the research activities integrate design, materials and tool development into high-value production processes and products. The all-encompassing nature of nanopatterning insured that the technologies produced within NaPa provide potential solutions to the higher-value added industries of ICT, pharmaceuticals, biotechnologies, health and medicine. The expected lower costs will make these affordable by all citizens, thus addressing the social cohesion objective of An Information Society for All, and as well addresses the objectives of a Strategy for Sustainable Development, since the latter is enhanced by direct development of manufacturing processes for new product development from nanoscale lithography.

The consortium integrated SMEs, corporate and national research labs, and university partners to insure a strong presence and interaction of varied innovative enterprises to allow a pipeline from strategic research to commercial exploitation. Simultaneously, the structure of the consortium allowed for a continuum of academic education through to hands-on training, thereby enabling nanosciences and new technologies and opening opportunities for industrial applications. Through the active educational activities of the consortium, a genuine enthusiasm for science, and for exploiting science to develop new technologies for sustainable employment, was nurtured. Throughout the research programme, a strong metrology component for materials development and process development is in place to address environmental, safety and health (ESH) implications of the technology. The assessment of ESH issues are integrated directly into the R&D programme to anticipate the most appropriate means for safe-guarding societal, health, ethical and regulatory issues. One of the main outcomes of NaPa project was the NaPa Library of Processes for nanoimprint lithography, soft lithography & self-assembly and MEMS-based nanopatterning. Also were created simulation tools for optimisation of fabrication processes. Very important objective was to design and construct production tools and materials dedicated for manufacturing products using the emerging nanopatterning processes. The whole manufacturing chain was tested by fabricating devices and demonstrators in the fields of nano-optics and bioapplications.

List of contractors

The NaPa consortium consisted of 36 groups from 30 institutes. About one third of the partners came from industry, one third were universities and one third research institutes.

List of Participants

Role	Participant name	Participant short name	Country
CO	Technical Research Centre of Finland	VTT	FIN
CR	University College Cork – National University of Ireland, Cork	TNINIL	IE
CR	Ecole Polytechnique Federale de Lausanne	EPFL	CH
CR	International Business Machines Corporation, Research, Zurich Research Laboratory	IBM	CH
CR	Centre National de la Recherche Scientifique, Délégation Regionale Ile de France, Ouest et Nord	LAAS	F

CR	micro resist technology GmbH	MRT	D
CR	University College Cork - National University of Ireland, Cork	TNICMG	IE
CR	SUSS MicroTec AG	SUSS	D
CR	Centre Suisse d'Électronique et de Microtechnique	CSEM	CH
CR	AMO GmbH (Gesellschaft für angewandte Mikro- und Optoelektronik mbH)	AMO	D
CR	CEMES-CRNS	CEMES	F
CR	Fundación Cidetec	Cidetec	ES
CR	Consejo Superior de Investigaciones Científicas - Instituto de Microelectrónica de Barcelona	CNM	ES
CR	EV Group, E. Thallner GmbH	EVG	AUT
CR	C.R.F. Societa' Consortile per Azioni	CRF	I
CR	Institute of Microelectronics technology, Russian Academy of Sciences	IMT	RU
CR	Fundacion Inasmet	Inasmet	I
CR	Instituto per i Processi Chimico Fisici sezione di Bari Consiglio Nazionale delle Ricerche - Italy	IPCF	I
CR	Commissariat à l'Energie Atomique	LETI	F
CR	Linköpings Universitet	LiU	S
CR	Centre national de la recherche scientifique, Délégation Regionale Ile de France, Ouest et Nord	LPN	F
CR	Laboratoire des Technologies de la Microelectronique	LTM	F
CR	Lund University	LU	S
CR	University of Twente, MESA+ Research Institute	SMCT	NL
CR	Technical University of Denmark	MIC	DK
CR	Biosensia	NC	IE
CR	nanoplus Nanosystems and Technologies GmbH	nanoplus	D
CR	NPL Management Ltd	NPL	UK
CR	Obducat	Obd	S
CR	Paul Scherrer Institut	PSI	CH
CR	Instituto Nazionale Fisica della Materia	TASC	I
CR	Fundación Tekniker	Tekniker	ES
CR	University of Glasgow	UG	UK
CR	Warsaw University of Technology	WUT	POL
CR	Rijksunivesiteit Twente	AMK	NL

CR	SET S.A.S (Former Suss Microtec S.A.S)	SET SAS	F

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The kick-off meeting was held March 18-19, 2004 in Espoo, Finland (above), followed by plenaries in Segovia, Spain, Berlin Germany, Lausanne, Switzerland, Copenhagen, Denmark, Glasgow, UK and St. Georges, Malta.

The final plenary, which acted also as the "kick-out" meeting was held 10-13 February, 2008 in the ski resort of Levi in Kittilä, Finland.

Brief description of work performed and the main results obtained during the project

The overall goals set were met and partially exceeded in the project. The project generated materials, equipments, processes and simulation and metrology tools for nanoimprinting, various soft-lithography approaches and nanostencilling and –dispensing. These were tested in fabricating several demonstrators, such as optical encoder, DBF laser and pinched-flow microfluidic device, among others. The main target originally was to come up with a library of processes to help and guide the take up of nanopatterning processes by start-ups and SMEs and by academia and research institutes. The NaPa Library of Processes has now been published and will be distributed to key sectors and key customers.

One of the major outcomes was the integration of researchers and research activities in Europe. The integration brought about added value arising from the cross-fertilising communication between people from physics, electronics, chemistry and biology. This generated very active discussion across the disciplines within the consortium, as was witnessed, for example, in the six internal miniconferences arranged during the plenary meetings. This European concept of Integrated Project was introduced to broad audience also in Asia and Americas in several NaPa talks.

As an evidence of the success of NaPa, the project was selected as one of the Success Stories in the Sixth Framework Programme.

Below are briefly listed the activities and the main results obtained in each of the subprojects.

The main effort in **Nanoimprint Lithography** subproject in the beginning of the project was focussed on the fabrication of stamps, including stamps with sub-10 nm features, large area stamps with diameter up to 200 mm, stamps with true 3-dimensional features, flexible stamps to control the residual layer thickness and bendable nickel stamps for roll-to-roll nanoimprinting. For fast thermal nanoimprinting, "pulsed-NIL", stamps heated by current pulses were realised. Processes were developed for large area full wafer imprinting, step&stamp imprinting and roll-to-roll imprinting. The processes were tested by fabricating several demonstrators for organic optoelectronics, polymer photonics and microfluidics. An important exercise was benchmarking of nanoimprinting processes for micron size features and for 50 nm lines. To evaluate the state of the art, a "NIL in the World" table was compiled, consisting of groups working on NIL worldwide, their activities and equipment. The three activities in subproject **Soft lithography and self-assembly** covered soft UV lithography, micro-contact printing and self-assembly. A high quality optical ring resonator served as a demonstrator for the developed UV imprinting lithography tool and stamp fabrication techniques. New developments for micro-contact printing were the gradient printing and low diffusion inks. Additive and subtractive printing of biomolecules for sensor and screening device applications was one of the main outcomes in soft lithography. In self-assembly the focus was on directed 2-dimensional and 3-dimensional structures formed by functionalised nanoparticles via molecular recognition. Directed self-assembly by capillary forces proved to be a powerful tool to realise nanostructures. **MEMS based nanopatterning** focused on nanolithography based on adding material on substrate. Nanostencilling utilises evaporation through nanoscale shadow masks and nanodispensing relies on delivering very small volumes of liquids through nanoscale openings. The subproject realised two systems for nanodispensing. The systems are capable to dispense liquid volumes ranging from nanolitres to attolitres. Nanostencilling is now available in wafer scale, and the possibility to combine nanostencil deposition with CMOS technology was demonstrated. The feasibility of dynamic, i.e., moving nanostencil was demonstrated by producing magnetic structures with domain wall constrictions. In **Materials** several new polymers dedicated to nanoimprinting were developed. In addition, various functionalised materials, including polymers with modified surface and materials loaded with semiconductor nanoparticles, have been synthesised for imprint and soft lithography, self-assembly and nanodispensing. Some of the materials have already been commercialised. A dedicated tool derived from an atomic force microscope for measuring nanorheological properties of polymers was introduced. The main outcome from the **Tools** subproject has been a new stepper capable to UV and thermal nanoimprinting on up to 300 mm wafers. Another outcome was an alignment and fixation tool for nanostencilling. The **Modelling** subproject concentrated on modelling the imprinting process and developed a method to simulate the pressure building up and the polymer flow during imprinting. This work has resulted in a software package capable to simulate NIL process for a specific user defined stamp pattern and imprinting parameters. The investigation of the effect of stress building up in a stencil mask during evaporation has provided new design rules for the nanostencil membranes to avoid distortions. The new design has resulted in very robust stencils, preventing the bending of the membranes. The third activity was modelling of the interaction of molecules with surfaces, helping to understand the wettability, self-assembling and ink diffusion.

Management activities have included day-to-day management, reporting, arrangement of project plenary and subproject meetings and communication with project officers representing the European Commission. Eight NaPa plenary meetings have been arranged so far. The average number of participants has been in the range of 60-85. In the last six meetings one day Miniconferences were arranged. The Miniconferences have been very well received by the Consortium members. The “kick-out” meeting, i.e., the final plenary meeting was held in Lapland, Finland, in February 2008.

2. Dissemination and use

Dissemination

The main dissemination channel for the scientific results has been journal articles and international conferences. The number of published journal papers and book chapters is about 160. The NaPa partners have given about 220 oral presentations, including more than 70 invited talks, and presented about 100 posters in international conferences. Partners in the consortium have been active in organising international conferences, such as Micro and Nano Engineering (MNE) and Nanoimprint Nanoprint Technology (NNT), and been acting in the program committees. Dedicated NaPa session were arranged during LITHO2004 in France, and International Microprocessing and Nanotechnology Conference (MNC2007) in Japan. A full NaPa Day targeted to industry in central Europe was arranged in October 2007 in Berlin. The response, based on a questionnaire send to the attendees, was very positive. General NaPa talks have been given in meetings targeted to photonics, to regional nanotechnology development programs and as invited in conferences around the world in Europe, Asian and America.. The concept of integrating resources trans-nationally, as in the Integrated Projects in Europe, has been found interesting outside Europe. The NaPa concept and results were introduced to Japanese industrial representatives in a TMC Seminar in Tokyo. Similar talks were given in Montreal in 2005, in Viña del Mar in Chile in 2006 and in Hainan, China in 2007. The concept and results have been presented also in the high level international nanoelectronics meetings ICN3 in Brussels and ICN4 in Tokyo. NaPa had own stands in

Plastic Electronics 2006, Nanotechnology in Northern Europe 2007 and Semicon Europe 2007. In addition, several press releases were released during the project.

To increase the interest of young children on science and on nanotechnology, a 3-dimensional 10 minute animated video was produced. In the video two young pupils, Nath and Pat, have adventures in the nanoworld. Currently the video is available in English and French, and plans to have translations into other 10 languages are under way.

Training is an integral part of an Integrated Project. NaPa has designed a new format for summer school in nanopatterning, The PANAMA concept: PAtterning at the NAnoscale – Methods and Applications. The two week school consisted of one week of hands-on experiments in nanoimprinting lithography, soft lithography, e-beam lithography and nanostencilling, followed by one week of theory lectures. The teachers were the senior scinentists in NaPa, acting on voluntary basis. The schools were arranged in Toulouse in 2005, 2006 and 2007, each attending by about 25 young NaPa researchers, having background from electronics and physics to chemistry and bio. The response has been very positive. The consortium members have been teaching nanopatterning and related issues also in other summer schools, for photonics and phononics, among others.

One of the main targets in the project was to compile a library of processes based on the results and know-how developed in NaPa. The NaPa Library of Processes on nanopatterning processes and applications has been recently published. The aim of the library is to lower the threshold to exploit nanotechnology and nanopatterning methods in producing new applications and developing new manufacturing processes. The library consists of a tutorial part for “beginners” in the nanopatterning and detailed “recipes” for 26 different processes and applications. The aim of the library is to act as a “cook book” for research institutes and industry to help them to find new manufacturing methods and ideas for new applications. The aim is to provide a starting point and methodology for more dedicated, application defined processes.

Eight plenary meetings were held during the four year project, the kick-off in Helsinki, followed by meetings in Segovia, Berlin, Lausanne, Copenhagen, Glasgow, Malta and the “kick-out” in Kittilä in Lapland. The number of participants varied between 60 and 85. Group photos taken in the first and the last meeting are shown above. For internal dissemination, six one-day miniconferences were held in during plenary meetings, starting from the Lausanne meeting. During the one-day meetings, young scientists in NaPa gave talks covering the most recent results obtained. The miniconferences served two purposes, training the young researches to present their results to international audience, and advancing the integration within the consortium.

Use of knowledge

The NaPa Library of Processes was one of the targets in the project. The compiled library can also be regarded as one of the main exploitable outcomes in the project. It will be distributed to parties representing the key sectors in manufacturing and nanotechnology in Europe.

The three tool makers that participated the project have capitalised the generated know-how in their products. Now the commercially available step and repeat tools, both for UV and thermal nanoimprinting serve as good examples of the products. These versatile tools can be used both for R&D and in production. In addition to equipment already commercialised, several prototypes were tested in the project, including roll-to-roll nanoimprinting tool, tool for capillary assembly of nanoparticles and mask aligner for nanostencilling. The two nanodispensing systems can be exploited in biomedical applications. New polymers for nanoimprinting were developed, including materials for bio applications and materials functionalised with metal and semiconductor nanoparticles. Some of these have been already commercialised.

One of the bottlenecks in exploiting the emerging nanopatterning methods is the lack of non-destructive metrology methods. In the project scatterometry was extended to cover the needs in characterisation of nanoimprinted polymer layers, including the thickness of the residual layer and the profile of the patterns. Plans to develop an on-line next generation monitoring system are on their way. Another bottleneck is the lack of simulation software. In NaPa a coarse grain modelling program to simulate pattern transfer and and stamp deformation during nanoimpriting process was developed. The program runs in a PC and is currently being commercialised.

Proof-of-concept demonstration of several device applications was carried out in NaPa. These include various kinds of photonic devices, bio and microfluidic devices and magnetic devices. These applications are potentially exploitable in future products.

Finally, one spin-off company emerged from NaPa. NIL Technology (http://nilt.com/) manufactures and sells stamps for nanoimprint lithography, provides imprint service and production and consultancy.

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www.NaPaIP.org