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EUROPEAN COMMISSION

The march of micro- and nano-manufacture

EU-funded research leads Europe into the world of the ultra-small

Directorate-General for Research, Industrial technologies
2009 Unit G2 'New generation of products' EN

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Cataloguing data can be found at the end of this publication.

Luxembourg: Office for Official Publications of the European Communities, 2009

ISBN 978-92-79-11214-0
DOI 10.2777/60546

Table of contents

Small world, wide horizons, massive potential

The progressive miniaturisation of manufactured devices and components is one of the most striking aspects of today's industrial world. As dimensions shrink towards the nanoscale, there is fierce global competition to establish leadership in the many affected fields. Europe-wide research collaboration is vital in developing the technologies needed to maintain competitiveness and secure future employment.

The miniaturisation phenomenon is perhaps most memorably encapsulated in Moore's law of 1965, which stated that the number of transistors on computer semiconductor chips would double at about every two years. This prediction has proved remarkably robust – and the focus on manufacture at ever-decreasing scales triggered remarkable developments in many more fields of materials, process and product innovation.

The trend is driven by society's aspirations for ever improving yet affordable healthcare, higher standards of living and quality consumer goods, despite the problems posed by increasing energy costs and depleting resources. Squeezing more features and more performance into smaller device dimensions is one way to satisfy these demands, while also addressing the growing concern for sustainability and environmental care.

Mainstream of tomorrow's industries

Although some extreme forecasts for the size of the loosely-defined 'worldwide nanotechnology market' are difficult to justify, it is evident that micro- and nano-manufacturing will become increasingly important mainstream constituents of the future industrial scene.

Size-reduction is being pursued from two converging directions: top-down scaling of macro-manufacturing technologies to handle ever-smaller dimensions and tighter tolerances, and bottom-up exploitation of the phenomenon of self-assembly at the atomic level.

Continuing EU support

In the GROWTH programme of the Fifth Framework Programme, research into these technologies was included as an option within the first topic of its Key Action 1 on 'Innovative products, processes and organisation'.

The growing prominence of micro/nano-manufacturing, and the need for more focussed planning of its research, led to provision for dedicated topics within the NMP (nanotechnology and nanosciences, knowledge-based multifunctional materials and new production processes and devices) Theme of FP6, and on into FP7.

Largest public investor

Over this period, Europe has registered high levels of success in the underlying research, measured in terms of registered patents and published scientific articles, The European Commission alone allocated €1.4 billion to 550 nanotechnology projects in FP6, making the EU the world's largest public investor in this field. Yet, the exploitation of technology transfer to industrialise and profit from the results remains a major challenge.

According to the World Technology Evaluation Centre (WTEC), the EU continues to lead in the more mechanically-based micro-manufacturing (as opposed to the lithography-based technologies of the semiconductor industry). This strength has been enhanced since FP6, largely due to the set-up of flagship projects such as those described in this brochure. It is likely to provide a faster route to practical products such as new automotive parts, micro-fuel cells, micro-batteries, micromotors – and even desktop- or micro-factories.

Overall, however, the Community's global economic competitors continue to invest at rates that Europe has so far failed to equal: its private enterprises contribute a lower proportion of GDP, and public support is fragmented by national/regional budgetary divisions.

Umbrella initiative

As part of a concerted effort to redress the balance, a core of participants and experts, some of which were associated with the FP6 Coordinated Actions µ-Sapient and IPMMAN and the Network of Excellence 4M, created the MINAM (Micro- and nanomanufacturing) initiative.

Launched in January 2008 with the publication of a Strategic Research Agenda, MINAM is also a prime contributor to the existing European Technology Platform Manu*future*. The role of this ETP is to mobilise the joint resources of industry, research organisations and consumers; and to collaborate with national, regional and European funding schemes, including NMP and the Information Society Technologies (IST) programme.

The platform aims to identify emerging trends and provide strategic directions for future investment in R&D to sustain and further enhance the leading positions of European industry in the field.

In particular, its vision addresses research priorities in four key areas:

- manufacturing of nanomaterials;
- processing of nanosurfaces;
- micro-manufacturing processes;
- development of integrated systems and platforms for micro- and nano-manufacturing.

Initial findings from a roadmap drawn up by the members provided input to assist the Commission in planning the first calls of FP7. Priorities identified by MINAM are strongly reflected in both the NMP and IST Themes, which include topics with specific relevance to the MINAM community. In addition, the MNT ERA-NET, launched in 2004 to establish collaboration between Member State programmes, announced its third transnational call in 2008. This gathered the support of 17 funding programmes in coordinating the implementation of micro- and nano-technologies (MNT) within industry.

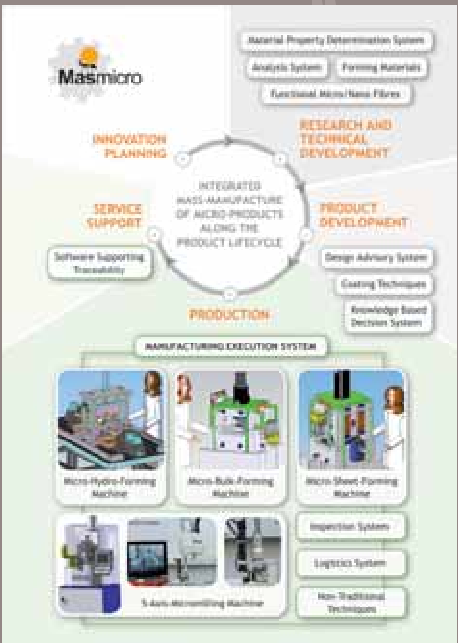
More participants needed

All of this effort is producing world-class results, but the need remains to strengthen and accelerate innovation and implementation activities both within the EU and in wider international collaborations to address global needs and markets.

The project examples presented in the following pages show how it is possible to integrate the work of scientists with the needs of industry to develop applicable results that will boost Europe's competitiveness and help to create new employment opportunities. It is therefore hoped that these insights will generate further interest from large and small enterprises, as well as from investors, to generate industrial successes from the good work started by European researchers.

Technology integration shows the way to cost-effective production

Various competing methods and processes will have roles to play in meeting the growing demand for miniature and micro-manufacturing. MASMICRO adopted an integrating approach, embracing technologies with the ability to contribute to efficient, cost-effective production chains.



MASMICRO lifecycle concept for the development of miniature/micro-products.

Taking micro-manufacturing to more efficient mass-production levels in order to cut costs and meet the demand for micro-products requires an integrated effort and multi-disciplinary approaches. The Integrated Project MASMICRO therefore spread its research over a range of conventional, unconventional and hybrid technologies, pooling the expertise of 36 complementary partners.

Coordinated by the University of Strathclyde, the initiative focused on three main issues:

- development of mass production processes based on micro-forming and micro-mechanical machining;
- development of miniature/bench-top equipment to bridge the gap between costly large-scale systems and micro-machines;
- application of ultra-precision techniques to improve the precision of existing miniature/micro machine designs.

Industry-ready developments

By the end of its four-year term, this project had produced **more than 50 exploitable results**, a number of which were already at an industry-ready stage.

The first machine for high-volume **hydroforming of tubular miniature/micro-parts** has been built, featuring an active hydraulic drive and a new dynamic sealing concept. This is capable of forming tubes with dimensions as small as 0.8 mm diameter and 40 µm wall thickness.

A new desk-top, linear-motor-driven machine has been developed for the **micro-forming of thin metal strips/parts** with thicknesses below 100 µm, at rates up to 1 000 parts/min. The modular machine has a maximum working space of 400 x 400 mm, and a choice of set-up options for flexibility in handling and tooling.

One more MASMICRO breakthrough is a **linear-motor-driven press** for high-throughput cold forming of miniature components. It incorporates an innovative parts-handling system and control strategies, together with the first mass-production system for extruding micro-parts. It is again equipped with a flexible tool system to permit deployment for various micro-forming processes.

Yet another development is the **'Ultra µ-Mill'**: a bench-top five-axis ultra-precision machine for CNC-controlled micro-milling, drilling and grinding of 3D mechanical components and micro-featured surfaces. The compact machine has a resource/energy-efficient design giving submicron precision and nanometric surface finishes.

More key advances include design advisory and analysis systems, new miniature/micro-materials and testing facilities, a laser system and laser-assisted forming tools, optimised micro-EDM, photo-chemical etching and electro-forming processes, new micro-parts handling and inspection systems, and more.

System integration is effected with a Manufacturing Execution System, a Knowledge-based Decision Support System and a Robotic Handling System.

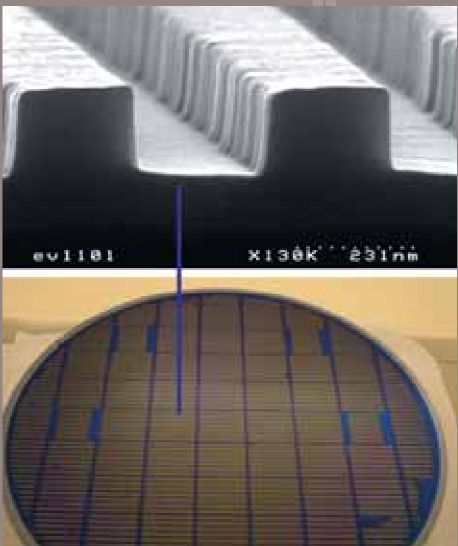
Life-cycle concept

Taken together, these developments reflect a 'life-cycle' concept for implantation in future miniature micro-products industries. Europe-wide implementation of the knowledge and technologies generated within the project is actively promoted via MASMICRO's demonstration, training and SME take-up programmes.

MASMICRO • Integration of manufacturing systems for mass-manufacture of miniature/micro-products
Total cost | **€21 409 000**
EC contribution | **€12 500 000**
Project duration | **July 2004-September 2008 (51 months)**
Coordinator | **Dr. Yi Qin – University of Strathclyde, UK**
More information | **www.masmicro.net**

Nanopatterning processes reach sub-100 nm device feature sizes

There is an acknowledged need to look beyond deep UV lithography as the means of nanopatterning at the scale required for emerging microelectronic, photonic and biotechnological devices. The Integrated Project NaPa has advanced the state of the art in three promising techniques.



200mm Si wafer imprinted with a full wafer NIL process, and SEM picture of the 250 nm dense lines imprinted in a 250 nm thick polymer film.

To address industry needs in higher-added-value sectors such as ICT, pharmaceuticals, biotechnologies, health and medicine, the NaPa project targeted the development of low-cost scalable nanomanufacturing processes for 3D surfaces with features ranging from a few micrometres to well below 100 nm.

The 35-member consortium, coordinated by VTT (the Research Centre of Finland) conducted research in three technology strands: nanoimprint lithography (NIL), soft lithography and self-assembly, and MEMS-based nanopatterning.

At the time of the project launch in 2004, NIL promised early progress towards exploitable results, whereas the two other technologies were still at an embryonic stage. All were supported by development of 'materials', 'tools' and 'simulation'.

Projected outcomes included process libraries and a simulation package for the optimisation of fabrication processes. Other important objectives were to design and construct production tools using the emerging processes, to test the whole manufacturing chain by fabricating devices and demonstrators for the selected application fields, and to prepare a roadmap for the new patterning technologies.

Presented to industry

Shortly before the completion of the four-year initiative, its key achievements were presented at a special industry day held in Berlin on 15 November 2007. Among the highlighted exploitable results were a new **nanomanufacturing tool capable of handling 300 mm wafers, adapted versions of existing semiconductor tools** suitable for nanopatterning of various materials, and **research instrumentation for self-assembly** and scanning probe-based nanofabrication.

© Courtesy of S.E.T., Smart Equipment Technology - S.A.S.

The S.E.T.'s Nanoimprinting stepper NPS300 is a cutting-edge lithography tool that offers E-beam-resolution with higher throughput and lower cost of ownership. The NPS300 features hot embossing, UV-NIL and Micro contact printing capabilities on the same platform. It accommodates wafers up to 300 mm.

A **nano-imprinting stepper device** developed for reproduction of large area stamps, photonic devices and nanoscale bio-analysis platforms uses a small patterned silicon chip as a stamp, the pattern of which is copied onto a polymer layer by imprinting. The polymer layer – either a thermoplastic or UV-cured material – is then used for replicating small sub-100 nm scale geometries onto larger areas. This 'step and stamp imprint lithography' (SSIL) technique is much faster than e-beam lithography, and less expensive than other available systems.

A roll-to-roll printer **combining nanopatterning with gravure printing and flexographic techniques** in one process run is currently in operation at VTT. Roll-to-roll printing, in particular, is emerging a strong candidate in the lighting and automotive industry, for cost-effective manufacture of components such as diffractive elements for displays.

The NaPa **Library of Processes**, which includes processes for the production of polymer-based optical elements, organic LEDs and lab-on-a-chip systems, was officially released in March 2008.

FP7 follow-up

The programme continues in the FP7 project NaPANIL, which will complete the verification of the existing processes, and pursue further innovation in tools, materials, metrology and modelling to support the next wave of innovative applications. The work focuses on three application areas:

- planar diffractive optical elements for the growing LED lighting market;
- light-directional elements integrated in windows to maximise the use of natural lighting;
- emissive head-up displays integrating an array of LED dice onto a transparent substrate, thus eliminating the need for projection optics.

NaPa • Emerging Nanopatterning Methods
Total cost | **€31 135 000**
EC contribution | **€16 000 000**
Project duration | **March 2004-February 2008 (48 months)**
Coordinator | **Jouni Ahopelto – Technical Research Centre of Finland (VTT)**
More information | **www.NAPAIP.org**

Glass micro-moulding delivers superior optical components

Glass micro-lenses and other miniature optical components are needed for new automotive, biotech, medical and consumer devices to underpin future economic growth in Europe. PRODUCTION4µ aims to develop manufacturing processes that will be applicable on an industrial scale.

Glass preform in moulding setup ready for the process to start.

Advanced glass materials generally outperform plastics in terms of optical properties and chemical resistance, but have so far remained too expensive for widespread commercial use in products such as mobile phones, medical imaging equipment and automotive safety systems. Thus, if glass components for micro-optical and micro-fluidics devices could be produced in high volume at acceptable costs, they would generate huge demand.

Moulding route to cost-cutting

Today's micro-production technologies and methods are often complex and cost-intensive, producing single-purpose components and usually including time-consuming manual operations. Moulding is one way to simplify manufacturing and markedly reduce production costs. But there are no established standards, nor procedures for production planning and costing.

The PRODUCTION4µ project is therefore developing moulding-based manufacturing process chains with the flexibility and scalability to respond cost-effectively to the need of system suppliers for complex-shaped glass micro-optical parts. Under the coordination of the Fraunhofer Institute for Production Technology, Germany, 20 partner organisations are researching materials, processes, manufacturing integration strategies and automation technologies for rapid transition from lab-scale prototypes to reliable component output at industrial volumes.

Over the first two years, tooling advances included **improved techniques for precision mould manufacture**, and a **new substrate material** enabling very high accuracies to be achieved using grinding, diamond turning and polishing.

Glass preform, moulded glass lense and glass moulding form insert.

A **simulation process** focussing on aspherical geometries was optimised to provide higher-than-ever predictability of the shrinkage error in manufactured lenses.

Mould **design and construction is underway for three types of demonstrator**: multi-purpose aspheric lenses, double-sided cylinder lens arrays for medical/laser applications, and diffractive aspheric lenses for advanced camera systems.

Among process chain developments are mechanical and adhesive chucks for **automated workpiece fixing and handling**, together with a prototype system providing **directly actuated alignment** and a **box-carrier transfer unit** that enables workpieces to be transported between process stages under sealed conditions.

Various **metrology** techniques – interferometry, deflectometry and 3D profiling – are being pursued in both hardware and software aspects.

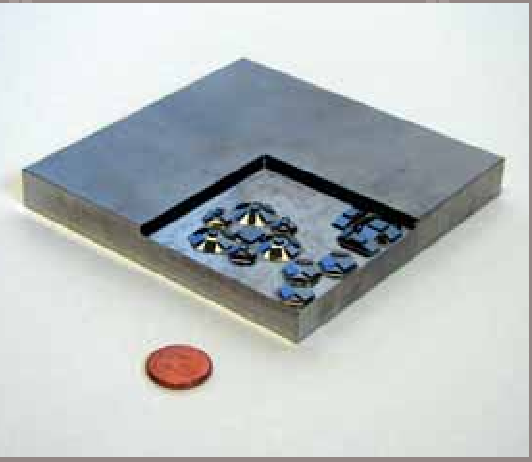
Also in progress are **tools for process chain derivation, product design and cost calculation**, as well as the evaluation of **inspection and control techniques** for quality management.

Realisation of this integrated approach could reduce time to market by up to 60 %, while also halving component costs, bringing European OEMs opportunities to regain ground lost in recent years to US and Asian competitors in a global market predicted to grow by at least 20 % per year.

PRODUCTION4µ • Production technologies for micro systems
Total cost | **€15 436 000**
EC contribution | **€9 000 000**
Project duration | **May 2006-April 2010 (48 months)**
Coordinator | **Dr.-Ing. Thomas Bergs – Fraunhofer Institute for Production Technology, Aachen, Germany**
More information | **www.production4micro.net**

Nano-metrology platform combines flexibility with 3D accuracy

Metrology is required at all stages of product development and manufacture. For conventional industries, programmable coordinate measuring machines (CMMs) now provide flexible off-the-shelf answers to most R&D and process control needs. The NANO CMM project is applying the same principle to the world of micro- and nano-components.



Nano-CMM Silicon Wafer-based Fiducial Mark Arrangements.

A CMM for industrial inspection of micro-parts typically needs to be accurate to 100 nm in the x, y, and z directions. For some applications, however, particularly the calibration of standards and reference parts, accuracy to within 10-20 nm is desirable. Today, this is achieved in 1D and 2D measurements; in the third dimension, improvement by a factor of at least 5 is required.

The NANO CMM project fields 14 partners coordinated by Unimetrik, Spain, to pursue this goal by developing a system employing complementary types of tactile and optical probes, bringing an across-the-board breakthrough in true 3D resolution.

Interchangeable probe system

The intention is to make all probes usable on the same CMM in the same reference coordinate system, so that measurements on various features of a workpiece can be related to one other. This can involve switching probes to measure inside holes with sub-micrometer radii, on steep slopes, or behind obstructions, while navigating around a microscopic object without risking breakage of the delicate sensor tips.

The programme includes the design and construction of a miniature rotating work stage, with provision for adjustable probe orientations/articulations, together with a precision probe changer turret.

In parallel with this, software for machine control and data acquisition is being developed, including on-line visual and CAD-image aids to help the user to find and measure the extremely tiny object structures.

Further aspects of the work are the creation of a new rule set for micro- and nano- part specification and evaluation, provision of physical standards, and methods for machine calibration based on measurement of the standards.

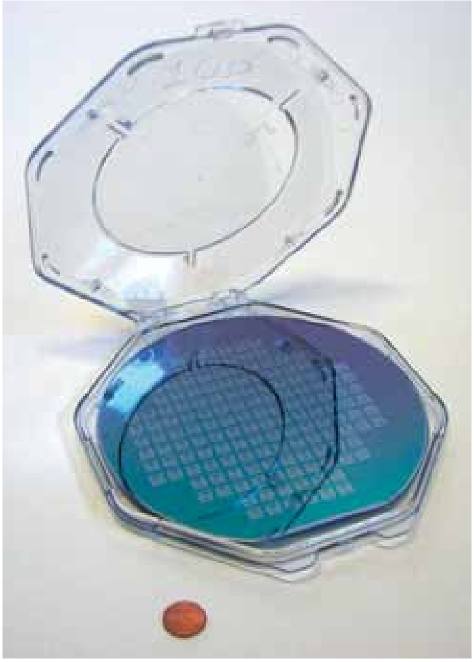
Results achieved during the first two years indicate that the NANO CMM is on course to meet its objectives.

Initial studies have provided a better understanding of the **operational scenario and component requirements**.

Directions for building and integrating the various components – tactile and optical probes, rotary stage, probe and tip changer – into the overall metrology framework via suitable mechanical, electrical and software interfaces are well established.

A set of algorithms and methods exploiting universal fiducial elements and advanced point cloud stitching techniques is in place to **improve accuracy and reduce the uncertainty of nano-metrology** machines with multisensor and multiorientation measurement capabilities.

By providing an appropriate metrology platform and the know-how to apply it, NANO-CMM will boost the development of micro- and nano-products. At the same time, the creation of reference standards and testing guidelines for components, and for the measuring instruments themselves, will remove ambiguities in setting up purchase contracts and in verifying compliance. This project will thus create opportunities for European SMEs to become the suppliers of tomorrow's metrology components and systems.

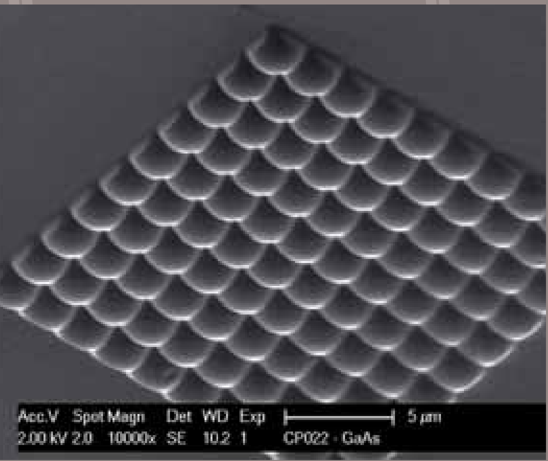


Silicon Wafer with Set of Tactile Probes.

NANO CMM • Universal and flexible coordinate metrology for micro and nano components production
Total cost | **€9 770 000**
EC contribution | **€5 500 000**
Project duration | **December 2006-May 2011 (54 months)**
Coordinator | **Iker Landa – Unimetrik, Legutiano-Álava, Spain**
More information | **www.nanocmm.net**

Ion multi-beam technology breaks the nanoscale barrier

As the size of features on electronic chips and other miniaturised devices shrinks further into the nanometre range, an ion multi-beam technology pioneered in the CHARPAN project promises a flexible, cost-effective alternative to established electron beam lithography techniques for the fabrication of complex masks and nanoimprint master templates.



3D Argon ion beam patterning of microlens array in GaAs.

The semiconductor industry's international technology roadmap predicts that existing electron-beam techniques for the manufacture of integrated circuit masks and templates will reach their technological limits within the next few years. Charged particle multi-beams could provide a reliable and affordable alternative for these and other emerging applications in electronics, photonics, magnetics and biotechnology.

Ultra-high-resolution patterning can be achieved via direct, beam-assisted structuring processes. However, single-beam equipment cannot meet the productivity levels necessary for industrial-scale manufacture. In the Integrated Project CHARPAN, coordinated by Austrian SME IMS Nanofabrication, 19 partners representing nine EU Member States plus Australia, Israel and Russia are collaborating in the development of a multi-beam process known as projection mask-less patterning (PMLP).

Unprecedented flexibility

The PMLP approach is to direct a broad ion beam onto a programmable aperture plate system (APS) with multiple holes that divide the beam into thousands of discrete beamlets of micrometre size. Projection ion beam optics with 200X reduction then compress the beamlets into a multitude of high-intensity, parallel charged-particle streams.

Employing the APS instead of stencil masks gives an unprecedented degree of flexibility, while the ability to use various ion species makes it possible to vary the rate of material removal or surface modification.

A proof-of-concept (POC) tool developed within the first two years of the project achieved 16 nm half pitch resolution (i.e. lines and spaces) over a 25 µm x 25 µm exposure field. Even with an APS demo unit providing four thousand 4.5 x 4.5 µm apertures, nanopatterning smaller than 30 nm was realised.

Projection Mask-Less Patterning proof-of-concept tool.

Operating with argon ions, this successfully demonstrated 3D patterning on silicon, GaAs and glass surfaces, and in chromium and MoSi layers, with outstanding surface and line edge smoothness.

By mid 2007, the POC tool was upgraded with a wired **prototype of the APS** providing some 40 000 beams of spot size below 20 nm. The eventual aperture plate, when equipped with its CMOS electronics, will again give resolution down to 16 nm. Upgrading the beam energy from 10 keV to 20 keV at the substrate is predicted to improve this to better than 10 nm.

Integration of **CMOS-APS units** is in progress, while a **precursor gas injection system** and an **improved tool platform** with a laser-interferometer controlled vacuum stage will also be incorporated into an end-of-project demonstrator.

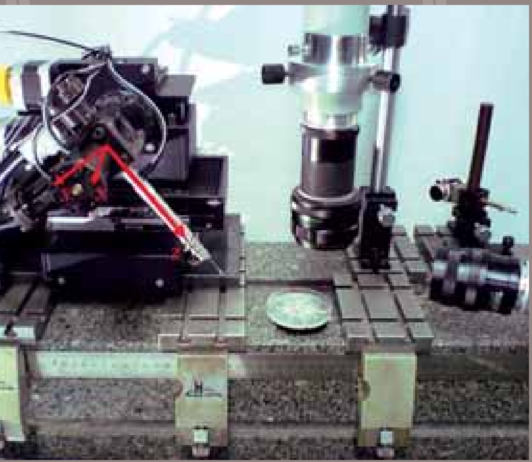
As well as sputtering, PLMP technology is adaptable to several other beam-induced patterning processes, including etching, deposition, polishing, high precision ion implantation and ion beam mixing. In tandem with development of the tool, the consortium is exploring these potential applications and making valuable progress in process simulation.

IMS Nanofabrication plans to produce a CHARPAN engineering tool in 2009. Furthermore, based on the project results, there is strong industrial interest in an ion mask exposure tool (iMET) for the 22 nm technology node and beyond. Long-term projections envisage a wide range of opportunities, many related to new manufacturing processes and new materials relevant to fledgling nanotechnology industries.

CHARPAN • Charged particle nanotech
Total cost | **€16 620 000**
EC contribution | **€9 500 000**
Project duration | **April 2005-March 2009 (48 months)**
Coordinator | **Dr. Elmar Platzgummer**
IMS Nanofabrication AG, Austria
More information | **www.charpan.com/**

Robots and self-assembly: a powerful combination

New levels of manufacturing precision are required to create the complex mechanical, electronic and bio-engineered micro-devices envisaged for tomorrow's world. The partners in HYDROMEL are meeting this need by combining robotics and self-assembly into versatile production systems with sub-micron accuracy.



An integrated microrobotic system for self-alignment assisted manipulation of cells (courtesy of Bulgarian Academy of Sciences).

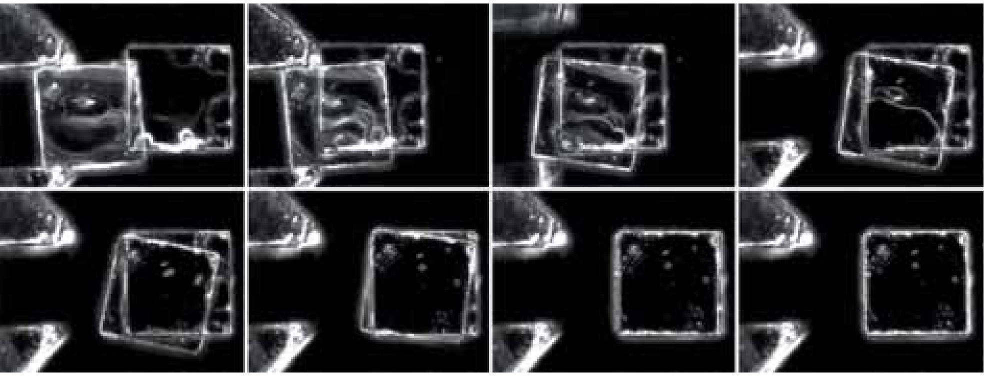
HYDROMEL aims to develop high-precision, flexible and cost-effective methods for the manufacture of complex micro- and nano-products, including devices that cannot be produced using today's technologies. The proposed combination of robotic placement, where individual objects are mechanically manipulated and positioned, with the self-assembly of objects into ordered structures in response to physical or chemical stimuli, is a radically new approach.

Basic challenges are the fact that robots operate serially and, compared with self-assembly, exhibit relatively low precision – while, self-assembly, although massively parallel and very precise, is extremely difficult to control. To reconcile these differences, the consortium brings together 24 partners under the coordination of the Centre Suisse d'Électronique et de Microtechnique (CSEM), Switzerland. A clear objective is to ensure that prototype or laboratory processes can be scaled up to full production volumes.

Five demonstrators planned

Five demonstrators will show how this hybrid mode of manufacture makes it possible to advance the state of the art in many high-tech sectors by replacing conventional pick-and-place operations with more productive parallel processing. Two examples relate to the deposition of small-scale electronic components (MIMs and RFID chips) onto circuit substrates, while a third addresses the targeted injection of biological cells. Another illustrates the assembly of nano-rods and tubes into electronic and photonic devices – while the fifth focuses on automatic manipulation and inspection of laser diodes.

Within the first year of HYDROMEL, the **industrial requirements had been defined for all demonstrators**, and initial designs were drawn up – although these will be adapted according to the advances made during the project. Promising progress has been made



Robot assisted self alignment of micro components of 0.3 mm lateral size (courtesy of Helsinki University of Technology).

in the development of **actuators and sensors**; in **strategies for feeding, handling, and fixing** micro/nano-particles; and in the provision of **new algorithms** for vision feedback and quality control.

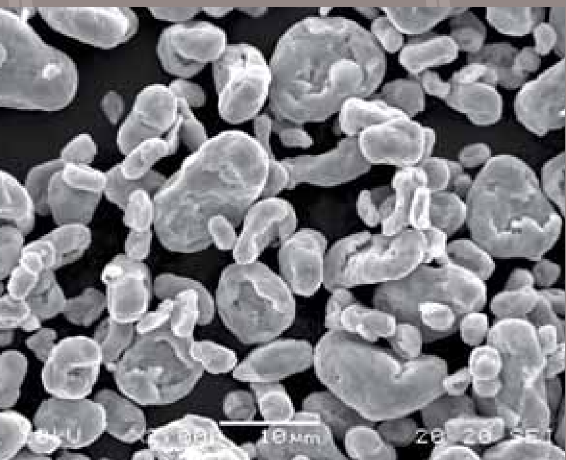
The self-assembly partners have produced **patterned surfaces using specially-made molecules and polymers** to control wettability by switching hydrophobicity under the influence of temperature or electric fields. Systems were also fabricated and tested for hierarchical **assembly of nanowires, nanotubes and biological cells.** And the appropriate micro- and nanoscale **on-line inspection and quality control** techniques have been identified.

The project's multidisciplinary research will generate a highly innovative production concept that could dramatically change the face of future manufacturing. The effective dissemination of HYDROMEL's results to industry will be ensured by communicating project results to an advisory board composed of large companies, while the project website provides extensive information and training material.

HYDROMEL • Hybrid ultra precision manufacturing process based on positional- and self-assembly for complex micro-products
Total cost | **€13 750 000**
EC contribution | **€9 000 000**
Project duration | **October 2006-September 2010 (48 months)**
Coordinator | **Dr. Alexander Steinecker – Centre Suisse d'Électronique et de Microtechnique (CSEM), Switzerland**
More information | **www.hydromel-project.eu**

From design to product in one step

Laser sintering is currently seen as a method for prototyping or limited component production. MANUDIRECT aims to develop it into a one-step process with unprecedented accuracy for volume manufacture of metal and ceramic parts.



Developed nanostructured powder: stainless steel AISI420 powder size 5-20 micron.

Laser sintering produces 3D solids by fusing together successively deposited layers of suitable powdered materials with a high-powered scanning laser beam. The shape of the resultant object is accurately controlled by programming the path of the focused beam with data derived from a dimensional description such as a CAD file.

Although able to shape a wide variety of metals, ceramics and plastics, laser sintering is currently limited to the production of prototypes and short-run components. The objective of MANUDIRECT is to extend the materials and process technology, to deliver a platform for the cost-effective volume manufacture of components directly from powders, with spatial resolution better than 50 μm.

The project involves 18 European partners, coordinated by CSGI, Italy. To achieve the targeted breakthrough, their research encompasses:

- development of integrated engineering and materials design tools;
- formulation of nanopowders with the appropriate mechanical, physical and chemical or bioactive properties;
- provision of a multi-grade powder feeder for gradient-structured layering;
- implementation of laser heating and focusing systems;
- design and fabrication of in-line geometrical and shape layer monitoring systems;
- integration of all hardware and software components into a micromanufacturing platform.

Innovation in materials and systems

Industrial partners in the consortium selected a number of case-study components as test-pieces. These range from cutting tools for surgical procedures and plastics machining, to a flexible gear-wheel, turbine parts and a collimator for an x-ray detector.

Picture of stereovision measuring system.

Process evaluation carried out using already available nanopowder grades led to the decision to focus on Fe-based systems for the structural applications, Ti-based systems for medical devices, and Ni-based systems and intermetallics as high temperature alloys.

By the mid-point of the project, the **elements of the platform had been developed** and integrated – including several notable software and hardware innovations.

Conversion software for translating CAD files into numerically-controlled (CNC) machine programming instructions provides a novel solution for slicing multi-material products into laser-processable segments, with changeable parameters within a layer or volume.

As well as meeting the physical criteria, the **dedicated powder feeder** includes a special nano-powder handling and shipping system to safeguard human and environmental safety.

Optical adjustment of the laser beam diameter between 10 µm and 100 µm allows a speed/accuracy trade-off, while dual optical inspection of the build-up geometry makes it possible to determine whether the finished workpiece will meet customers' accuracy demands.

Impact across industries

Realisation of this bottom-up fabrication method will allow virtual engineering concepts and designs to be translated into products in one step, without the need for prototyping stages. MANUDIRECT will thus have considerable economic impact in many industrial sectors, including microengineering, biomedical devices – and even in the macro-scale manufacture of parts for automotive, aeronautical and other applications.

MANUDIRECT • Direct ultraprecision manufacturing
Total cost | **€7 842 000**
EC contribution | **€5 000 000**
Project duration | **September 2006-August 2010 (48 months)**
Coordinator | **Prof. Ing. Paolo Matteazzi – Consorzio per lo Sviluppo dei Sistemi a Grande Interfase (CSGI), Italy**
More information | **www.manudirect.eu**

Nano-featured film coatings bring added value to commodity materials

The application of nano-featured thin polymer film coatings to substrates such as steel, glass and silicon produces composite materials with a wide range of potentially useful properties. NAPOLYDE is exploring deposition processes combining control at the nanoscale with the demands of industrial mass production.

On line spectroscopic ellipsometrer for real time thickness and composition measurement of nanometric film on a roll-to-roll line.

Coating with polymeric films having controlled nano-scale features – thickness, porosity, roughness, surface structure, nanoparticle inclusions, etc. – can provide substrate materials with radically new chemical or physical properties of relevance to industry. Characteristics such as enhanced barrier efficiency, mechanical protection, hydrophobicity, antireflectivity and conductivity are applicable in sectors from energy production and aerospace to construction and chemicals.

Nanoscale manipulation of thin polymer films is also a route to the miniaturisation of functional micro-devices for computers, communications and sensing. Moreover, the materials are inexpensive, lightweight, flexible, transparent and energy-saving.

Scale-up crucial

Throughput rate is a critical factor for success in traditional sectors such as large-scale steel and glass sheet manufacture. The established coil coating, dip coating and spray techniques are mature, high volume processes – but all deposit relatively high coating thicknesses, and do not exploit the nanostructural potential.

Merging nanoscale control with mass production capability is thus essential to open the door to new generations of high-added-value products. In the Integrated Project NAPOLYDE, this challenge is addressed by a 25-member consortium under the coordination of ArcelorMittal Research, Belgium.

The partners are investigating both plasma-based deposition and wet methods. As well as exploring scalable technologies for tailoring film properties by nano-layering, nano-clustering and nano-texturing, they are developing design tools and measuring instruments for process control on an industrial scale.

At the project's half-way stage, a **research roadmap** had been defined, and a number of **candidate applications** selected for study and life-cycle analysis.

Plasma processing produced interesting results in a number of fields, including **ionic membranes, non-fouling coatings and ultra-high barrier layers**. An **improved multi-step process** led to the production of a polymer barrier which is as effective as a metallic reference for lithium battery encapsulation; while an SiOC polymer coating containing Ag nanoclusters shows excellent antibacterial effects, even with very low Ag content.

Industrial successes were also achieved with **wet processing**. An antireflective coating based on sol-gel nanolayers enabled Austrian partner Konarka to record the world's **highest efficiency for an organic photovoltaic device**, with a yield of 5.21 %.

Development of an *in situ* system for **real-time control of a roll-to-roll production line** is also underway.

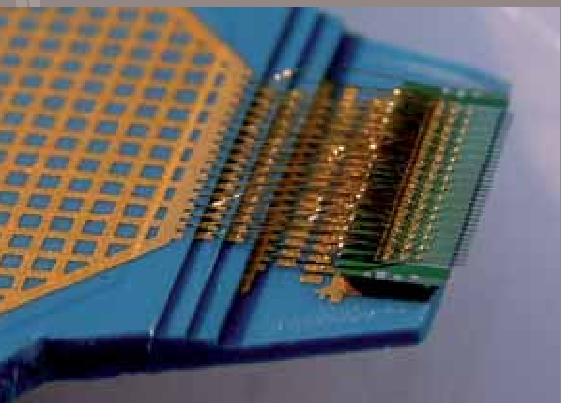
Research continues into coatings for solar panels, embedded microsources and aeronautical components. Some processes are already set for up-scaling, and others are expected to follow within the term of NAPOLYDE.

AntiReflective solgel coating on glass.

NAPOLYDE • Nano-structured polymer deposition processes for mass production of innovative systems for energy production and control and for smart devices
Total cost | **€20 225 000**
EC contribution | **€11 700 000**
Project duration | **April 2005-March 2009 (48 months)**
Coordinator | **Christophe Le Pen – ArcelorMittal, Liège, Belgium**
More information | **www.napolyde.org/**

Fast probe arrays open new nano-application opportunities

Scanning proximity probes are powerful devices for nanoscale analysis, manipulation and bottom-up synthesis, but current single-probe tools are too slow to allow economic throughputs. PRONANO aims to produce massively parallel 2D probe arrays that will unlock the full potential of nano-manufacturing.



Probe with 32 individually addressable cantilevers.

Despite the great promise of nanotechnology, its industrial impact to date has been limited by the lack of means for cost-effective volume manufacture of tools operating on a nanoscale. Scanning proximity probes (SPP) are capable of addressing and engineering surfaces at the atomic level, but have not so far been producible in large enough array sizes to provide exploitable speed of operation.

The goal of the PRONANO project, led by German SME Nanoworld Devices, is to develop the technology necessary to make larger arrays, which could trigger a wealth of new products and processes.

Construction of massively parallel SPPs will allow detailed analysis of controlled force and sensing interactions between the probes and their environment or underlying surfaces. Parallel cantilever arrays will function as the molecular equivalent of inkjet printer heads, allowing much more flexible molecular delivery and writing than is possible with a single probe. They will be useful for the development of various types of measuring and manipulation tools for imaging and synthesis of molecular structures in bioengineering, drug screening, and chemical and bioelectronic sensing systems. Force and displacement measurements at the molecular level will also be feasible over large areas at high speeds.

Multi-purpose package

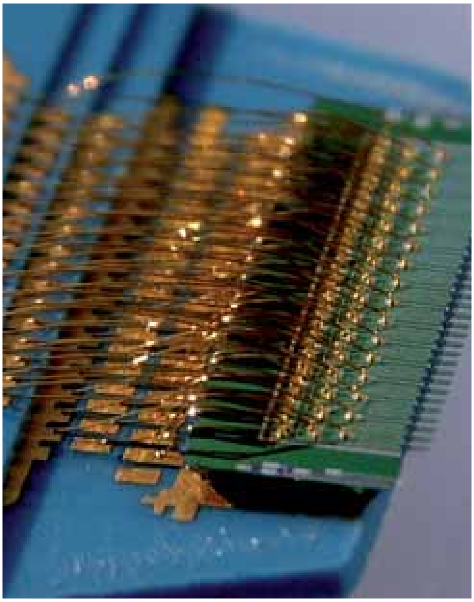
The ultimate product will be a generic platform VLSI NEMS chip (very large scale integrated nano-electromechanical system) incorporating 128x128 probes, packaged with control electronics, readout interconnects and advanced software. SMEs in the 17-member consortium will use the technology in a series of demonstrators performing sub-10 nm metrology for high-throughput manufacturing. Selected key applications and their results will also be used to educate new generations of researchers and technologists.

By the end of the third year, a **first generation of piezoresistive cantilever arrays** had been fabricated, characterised and incorporated into a test measuring machine from German partner SIOS Messtechnik.

Early problems of crosstalk between probes were resolved, leading to a **second generation array design** with greater noise protection. Following the solution of further technical difficulties, work began on the demonstrators.

The components for a **surface scanning system** are being developed and tested, including **hybrid measurement-control electronics** and **software**, plus **ASIC** (application-specific integrated circuit) **controller components** that will eventually replace some of the hybrid blocks.

Development of **FM detector circuitry** is also underway, while testing continues on **single and multi-cantilever probes**.



Probe with 32 individually addressable cantilevers.

Industrial experience

In one actual **pilot demonstrator**, the integration of an atomic force microscope into a scanned electron beam apparatus for the repair of semiconductor photomasks highlighted the need to investigate application-specific effects such as vibration. This experience is enabling the partners to evaluate the usability and economic viability of the new technology under real industrial conditions.

During the period, a first **web-based introductory study course** was announced, attracting over 180 registrations.

PRONANO • Technology for the production of massively parallel intelligent cantilever – probe platforms for nanoscale analysis and synthesis
Total cost | **€14 051 000**
EC contribution | **€8 500 000**
Project duration | **April 2005-March 2010 (60 months)**
Coordinator | **Thomas Sulzbach – Nanoworld Devices GmbH, Germany**
More information | **www.pronano.org**

European Commission

Downsizing: the march of micro- and nano-manufacture

Luxembourg: Office for Official Publications of the European Communities

2009 — 23 pp. — 17 x 24 cm

ISBN 978-92-79-11214-0
DOI 10.2777/60546

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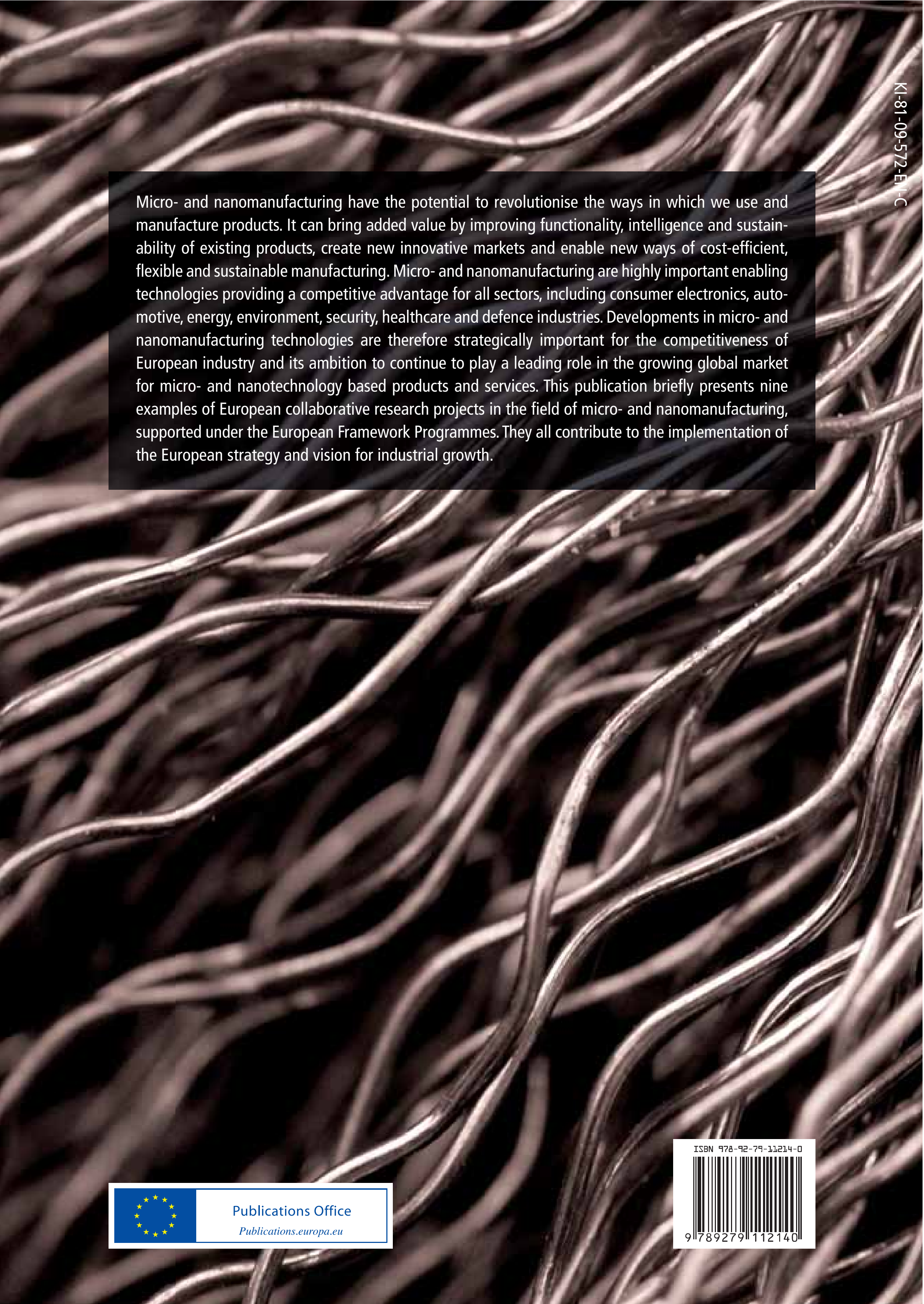
Acknowledgements

Special thanks are expressed to the coordinators and the programme officers of the projects for their contribution, and in particular to Hans Hartmann Pedersen for the coordination work. Furthermore, the collaboration of Mike Parry, Michael Horgan, Charlotte Andersdotter and Bingen Urquijo Garay is acknowledged.

J.L. Vallés, Head of Unit RTD-G2 'New generation of products'



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Micro- and nanomanufacturing have the potential to revolutionise the ways in which we use and manufacture products. It can bring added value by improving functionality, intelligence and sustainability of existing products, create new innovative markets and enable new ways of cost-efficient, flexible and sustainable manufacturing. Micro- and nanomanufacturing are highly important enabling technologies providing a competitive advantage for all sectors, including consumer electronics, automotive, energy, environment, security, healthcare and defence industries. Developments in micro- and nanomanufacturing technologies are therefore strategically important for the competitiveness of European industry and its ambition to continue to play a leading role in the growing global market for micro- and nanotechnology based products and services. This publication briefly presents nine examples of European collaborative research projects in the field of micro- and nanomanufacturing, supported under the European Framework Programmes. They all contribute to the implementation of the European strategy and vision for industrial growth.

Publications Office
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ISBN 978-92-79-11214-0
9 789279 112140