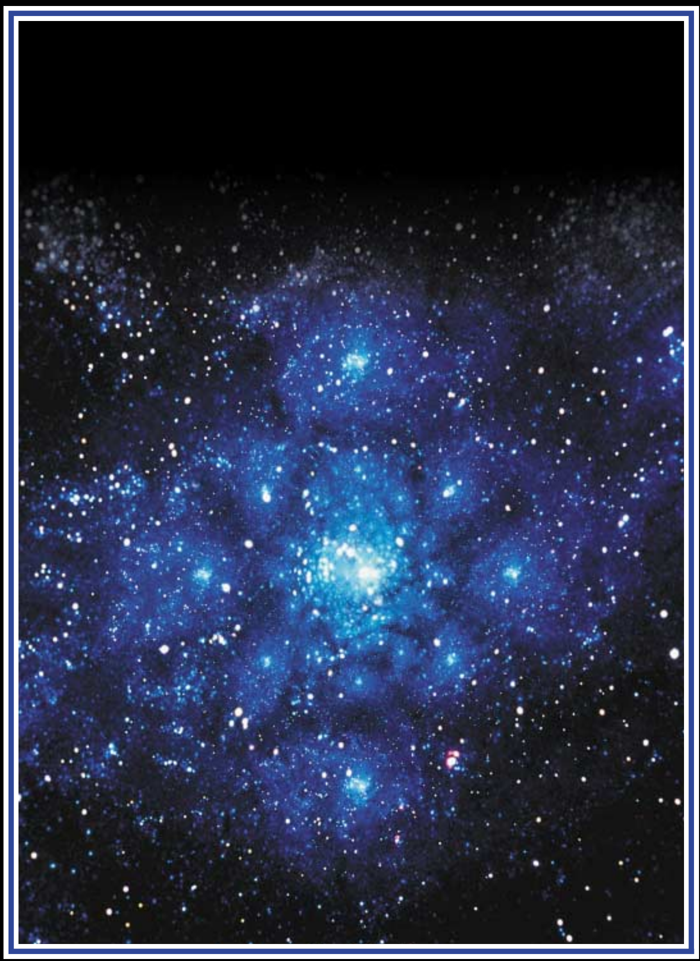
4th Joint EC-NSF Workshop on Nanotechnology

Tools and Instruments for Research & Manufacturing



CEA, Grenoble (France),
12 - 13 June 2002

The Workshop has been hosted by MINATEC

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EUROPEAN COMMISSION

4^{th} Joint EC - NSF Workshop on Nanotechnology

Tools and Instruments for Research and Manufacturing

Edited by
Anne de Baas and Hervé Péro

Workshop organised by
the European Commission and
the National Science Foundation
of the United States of America

Hosted by MINATEC
CEA, Grenoble (France), 12 - 13 June 2002

Directorate-General for Research

Professor Franz Himpsel,
Dept. of Physics, University of Wisconsin, Madison,
was the academic organiser for the U.S. contribution

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Preface

The NSF-EC Nanotechnology Workshop on Tools and Instruments for Research and Manufacturing was held 12-13 June 2002 at the premises of CEA-LETI in Grenoble, hosted by MINATEC. The workshop owed its success to the organisational efforts of the host and to the enthusiastic participation of around 90 experts, leading researchers and young investigators in the field of nanomanufacturing, coming from academia, industry and government laboratories.

The workshop was organised within the framework of the co-operation between the National Science Foundation (NSF) and the European Commission (EC) on materials sciences and nanotechnology. Its aim was that of fostering international collaboration in research and education by the identification of future co-operative activities and joint actions in the entire area of nanoscale processing and manufacturing.

It followed the former NSF-EC Workshops on nanotechnology held in Lecce and Puerto Rico, which were organised early 2002, to define the research milestones that will have a catalytic effect at international level in exploring and mastering the emerging field of nanotechnology.

The workshop highlighted approaches to help generating real breakthroughs for radical changes in current production and consumption patterns. Systems competitiveness and support for sustainable development require an enormous effort to renew basic knowledge in a constantly changing world, greater integration of expertise and resources, the development of new industrial concepts, and especially, better innovation capacities. It should be very clear that this objective cannot be achieved without an increased effort from the private sector, to complement the public effort.

In Europe and the USA nanotechnology is one of the core elements in the research strategy. The characteristics of "nano" research (multi-disciplinarity, amount of funding requested, etc.) demand that this should be carried out in a structured and integrated manner. In Europe this will be assured through the new instruments of the 6^{th} Framework Programme, which is an essential support for the strengthening and structuring of the European Research Area (ERA).

Furthermore, nanotechnology research is today at the centre of huge international co-operation and is stimulating high level scientific exchanges both within Europe and between Europe and the United States. It is envisioned that the ongoing NSF-EC co-operation, and in particular this series of workshops, will provide a critical thrust for new scientific developments and engineering applications that will have a mutually beneficial impact for both the U.S. and European research partners.

T. Weber, National Science Foundation
H. Péro, European Commission

After this 4th Joint NSF-EC Workshop on Tools and Instruments for Research and Manufacturing the series of workshops will continue with the fifth one in Boston December 2002.

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4th Joint EC / NSF Workshop on Nanotechnology:

Tools and Instruments for Research and Manufacturing

Workshop – 12-13 June 2002 – Grenoble (France)

Programme

and

List of organisers

Workshop Programme

4th Joint EC / NSF Workshop on Nanotechnology:

Tools and Instruments for Research and Manufacturing

Introduction session I

9:30- 9:40 **Welcome by Christian NGO, CEA, France**

9:40- 10:00 **Introduction of Workshop objectives by EC and NSF**
by H. Péro, EC and T. Weber, NSF
herve.pero@cec.eu.int and tweber@nsf.gov

10:00 -10:30 **The US National Nanotechnology Initiative**
James Murday, Naval Research Laboratory, Chemistry Division, USA
murday@ccf.nrl.navy.mil

10:30-11:00 **Future research for nano-manufacturing**
Jean-Charles Guibert, Minatec-Leti, CEA-Grenoble
Avenue des Martyrs, 38000 Grenoble, France
GUIBERT@chartreuse.cea.fr

Session IIA Equipment for nanomanufacturing

Chair: Anne de Baas, EC, anne.debaas@cec.eu.int and
Guebre X. Tessema, NSF, gtessema@nsf.gov

In the future industry will be mass producing nano-materials and nano-devices. This industrial activity in nanomanufacturing will require instruments, tools and equipment, which do not yet exist. This section aims at outlining the research that could lead to the necessary production equipment.

11:15-15:00

Electron Beam Direct Write- Equipment for Nanomanufacturing
Dr. Timothy Groves, Olaf Fortagne, Leica Microsystems Lithography GmbH,
Goeschwitzer Str.25, 07745 Jena, Germany
Timothy.Groves@leica-microsystems.com

Nano- and micro-engineering with pulsed lasers
Jim Fieret, Exitech Ltd, Hanborough Park, Long Hanborough, Oxford OX29 8 SL, United Kingdom
j.fieret@exitech.co.uk

Circuit and Structure Fabrication at the Nano Level Using X-rays
James Taylor, CNTech and University of Wisconsin-Madison, USA
jwtaylor@xraylith.wisc.edu

Nanostencil: a tool for surface large-scale nanopatterning beyond lithography
J. Brugger, EPFL, STI-IMM, BM 3-116 Ecublens, 1015 Lausanne, Switzerland
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CVD Technology as a Tool for Nanotechnologies
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M.Heuken@aixtron.com

Nanofabrication: Exploring equipment for the Top - Down and Bottom-Up Approach
Dieter P. Kern, Institut für Angewandte Physik , Universität Tübingen, Auf der Morgenstelle 10, D-72076 Tübingen, Germany
Dieter.kern@uni-tuebingen.de

15:00-16:00
Round table discussion

Session II B Analysis, Monitoring and Control at Nanoscale

Chair : Sophia Fantechi, EC, sophia.fantechi@cec.eu.int and
Lynnette Madsen, NSF, lmadsen@nsf.gov

When manufacturing nanomaterials and devices, the process will have to be controlled and the results measured. To support these aspects of manufacturing speakers are invited to outline the research into control and standards necessary.

11:15-15:00

Industrial Deposition of Advanced Surface Engineering – Nano-Layered Coatings
Rafael Rodriguez, AIN Center of Advanced Surface Engineering, 31191 Cordovilla, Pamplona, Spain rrodriguez@ain.es and Jonathan Housden,Tecvac Ltd, Buckingway Business Park, Swavesey, Cambridge CB4 5UG, United Kingdom, tecvac.jh@dial.pipex.com

Control of manipulation of organic molecules at solid surfaces by infrared spectroscopy
Jerzy A. Mielczarski, U.M.R. 7569 du C.N.R.S. LEM/NPL
15 Avenue du Charmois, BP 40, Vandoeuvre-lès-Nancy 5450, Cedex, France
jerzy.mielczarski@ensg.inpl-nancy.fr

Intuitive analysis of nanoscale engineered devices and processes
Kevin Lyons, Manufacturing Engineering Laboratory, National Institute of Standards and Technology, Building 220, Room A357, 100 Bureau Drive, Mail Stop 8263, Gaithersburg, MD 20899-8263, USA
kevin.lyons@nist.gov

Control of magnetic nanostructures
Eric Fullerton, IBM Almaden Research Center, K63/E3, 650 Harry Road, San Jose, CA 95120, USA
eef@almaden.ibm.com

Control of nanomagnetic fluids during the production of composite parts components
António Torres Marques, Department of Mechanical Engineering and Industrial Management, Faculdade de Engenharia da Universidade do Porto – Rua Dr. Roberto Frias, 4200 – 465 Porto, Portugal
marques@fe.up.pt marques@inegi.up.pt

15:00-16:00
Round table discussion

Session III A Instruments for research at nanoscale

Chair : Anne de Baas, EC, anne.debaas@cec.eu.int and
Lynnette Madsen, NSF, lmadsen@nsf.gov

Currently research in nano scale materials and devices is taking place in the laboratory. Researchers in this field are invited to present the new equipment needs. (scanning, analysis, …) Future research projects could then aim to develop new equipment that meets these objectives.

09:00-14:45

From Images to Interactions, and Back Again: Dynamic Atomic-Force Microscopy
Martin Stark, MPI fuer Biochemie, Abt. Molekulare Strukturbiologie, Martinsried, Germany
stark@biochem.mpg.de

Development of a nano-fabrication system based on AFM
S. Gauthier, CEMES, 29 rue Jeanne Marvig, BP 4347, 31055 Toulouse Cedex 04, France
and C. Viguier , OMICRON EURL, Le plan d'Aigues, RN. 7, 13760 St. Cannat, France
gauthier@cemes.fr

Multipurpose tool for device fabrication at nanometer-scale
Ricardo García, Instituto de Microelectrónica de Madrid, CSIC,
28760 Tres Cantos, Madrid, Spain
rgarcia@imm.cnm.csis.es

Bio-nanotechnology: single molecule detection and manipulation tools
Martin Bennink, Program director Nanolink, MESA+ research institute,
University of Twente, PO Box 217, 7500 AE Enschede, The Netherlands
m.l.bennink@tn.utwente.nl

New Tools and Challenges for Measuring Nanomechanical Properties
Terry A. Michalske, Center for Integrated Nanotechnology, Sandia National Laboratories,
Albuquerque, NM, USA
TAMicha@sandia.gov

Hard X-ray characterisation on the micro- and nano-scale; applications and new optics
Kenneth Evans-Lutterodt, Bell Labs, Agere, USA
kenne@agere.com

Macro Magnets and Nano-Tools to Investigate New Materials
Alex H. Lacerda, Los Alamos National High Magnetic Field Lab., Pulse Facility Los Alamos National
Laboratory, MS E536 Los Alamos, NM 87545, USA
lacerda@lanl.gov

Intermolecular Interactions for Precise Placement and Connection of Molecules
Paul Weiss, Dept. of Chemistry, The Pennsylvania State University, University Park, PA 16802-6300, USA,
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Simulation Challenges in Nanotechnology
Jürgen Lorenz, Fraunhofer-Institute of Integrated Circuits, Device Technology,
Schottkystraße 10, 91058 Erlangen, Germany
lorenz@iis-b.fhg.de

The impact of converging nano-bio and IT technologies
Minoo Dastoor, Office of Aerospace Technology, National Aeronautics and Space Administration (NASA),
USA
mdastoor@hq.nasa.gov

Bio-analytical tools: Integration of technologies, concepts and processes from different disciplines and dimensions
Dr. Andrew Campitelli, MCP Division, IMEC, Kapeldreef 75, 3001 Leuven, Belgium
campi@imec.be

14:45-15:30
Round table discussion

Session III B Industrialisation , Training and Education, Networking

Chair : Sophia Fantechi, EC, sophia.fantechi@cec.eu.int and
Guebre X. Tessema, NSF, gtessema@nsf.gov

The new ways of operation and production will require a workforce with new skills This session is addressing the training needs.
As nanotechnology is a multidisciplinary topic, it is anticipated that there will be a growing need for integrating training and research in one environment.
Manufacturing will change and impact on employment is to be anticipated.

09:00-10:00 (Industrialisation)

From Lab Scale to Manufacturing with cold plasmas
Francesco Fracassi, Dipartimento di Chimica, Università di Bari, Italy
fracassi@chimica.uniba.it **or** fracassi@area.ba.cnr.it.

Nanoscience Challenges in the Chemical Industry
David Londono, DuPont, USA
J-David.Londono@usa.dupont.com

Self-assembled magnetic nanoparticle arrays
Sarah Majetich, Department of Physics, Carnegie Mellon University, Pittsburgh, PA, USA 15213-3890
sm70@andrew.cmu.edu

10:30-12:30 (Training and education)

Envisaged changes in manufacturing areas through nanotechnology ;
Jacques Joosten, DSM N.V., Het Overloon 1 - P.O. Box 6500, 6401 JH Heerlen, The Netherlands
jacques.joosten@dsm.com

Training European Industry in Nanotechnology
Eva Ormrod, Building 70,Cranfield University, Bedfordshire MK43 0AL, United Kingdom
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Impact on University curricula
François Grey, MIC - National Micro and Nanotechnology Center, Technical University of Denmark, Ørsteds Plads, Building 345 east, 2800 Kgs. Lyngby, Denmark
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Nanofabrication training
Stephen Fonash, Penn State University, USA
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Multi-disciplinary environments for research and training in nanotechnology
Prof Vincent Bayot, Research center in micro and nanoscopic electronic devices and materials CERMIN - Université Catholique de Louvain, Place du Levant 3, 1348 Louvain-la-Neuve, Belgium
bayot@dice.ucl.ac.b

14:00-14:45 (Networking)

Nanometrology in support of nanotechnology
Jørgen Garnæs, Danish Institut of fundamental metrology ,
B 307 Matematiktorvet, DK-2800 Kgs. Lyngby, Denmark
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The national nanofabrication users network
Sandip Tiwari, Cornell University, CNF/Knight Laboratory, Ithaca NY 14853, USA
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Nanomanufacturing Facilities Infrastructure
Haris Doumanidis, Design, Manufacture and Industrial Innovation, Directorate for Engineering, NSF, 4201 Wilson Blvd., VA 22230 Arlington, Virginia, USA
cdoumani@nsf.gov

14:45-15:30
Round table discussion

Final session IV (plenary)

16:00- 16:30 Reports of the sessions by the chairpersons

16:30- 16:45 Opportunities for joint NSF/EC activities
T. Weber, NSF
Tweber@nsf.gov

16:45- 17:00 Future activities in FP6
Hervé Péro, EC
herve.pero@cec.eu.int

17:00- 17:30 Final Round table and conclusions

Posters

Nanomachining by focused ion and electron beams
Christoph Lehrer, Fraunhofer Institute Integrated Circuits, Device Technology and Chair of Electron Devices, University Erlangen, Schottkystr. 10, 91058 Erlangen, Germany
lehrer@iis-b.fhg.de

Magnetron Sputering In Coating Technology For The Production Of Nanocomposites
Victor Bellido-González, Gencoa Ltd, Liverpool, United Kingdom
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Integrated optical in situ characterisation methods for MEMS manufacturing
Christophe Gorecki, Laboratoire d'Optique P.M. Duffieux (UMR CNRS 6603), Université de Franche-Comté, 16 Route de Gray, 25030 Besançon Cedex, France
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Devices based on complex materials: growth control and manipulation on an atomic level
Dave H.A. Blank, Program director MASIF, MESA+ research institute
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Optical Probes for Nanomanufacturing Technology
M. Gusenbauer, Profactor GmbH, Wehrgrabengasse 5, A-4400 Steyr, Austria
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Silicon etching processes for nanostructure fabrication
Irina Kleps & al, National Institute for Research and Development in Microtechnologies (IMT-Bucharest) P.O. Box 38-160, 72225, Bucharest, Romania
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Approaching large scale production of nanomaterials
Paolo Matteazzi C.S.G.I., Interuniversity Consortium for the Development of High Interphase Systems Head Office: Via della Lastruccia 3, 50100 Sesto Fiorentino, FI, Italy
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Nanostructured PVD coatings for future applications in tribology
M. Stueber, Forschungszentrum Karlsruhe, Institute of Materials Research, PO Box 3640, 76021 Karlsruhe, Germany
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Electrochemical deposition of thin film alloys
Magda Lakatos-Varsányi and Erika Kálmán,Bay Zoltán Foundation for Applied Research, Institute for Material Science and Technology, Fehérvári u. 130, 1116 Budapest, Hungary
mlakatos@bzaka.hu

Atomic Scale Modelling of nanotechnologies : Thin Film Gate Oxide Simulation
M. Djafari Rouhani, Laboratoire d'Analyse et d'Architecture des Systèmes, LAAS-CNRS, 7 Ave. Colonel Roche, 31077 Toulouse, France
djafari@laas.fr

Software solutions for simulation and interpretation needs at the nanoscale
Gaston Nicolessi, Nanotimes, Incubateur Midi-Pyrénées, 29, rue Jeanne Marvig, 31400 Toulouse, France
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High-resolution imaging and temperature measurement technique in micro-engineering
Igor SMUROV, ENISE, 58, rue Jean Parot, 42023 St-Etienne, France
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Nanoimprint Lithography: an alternative nanofabrication approach.

Clivia M Sotomayor Torres, Institute of Materials Science and Department of Electrical & Information Engineering, University of Wuppertal, 42097 Wuppertal, Germany
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Potential of interferometry for the deposition of regular molecular arrays

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The New Institute for the New Science

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Extending the Capabilities of Scanning Tunneling Microscopy

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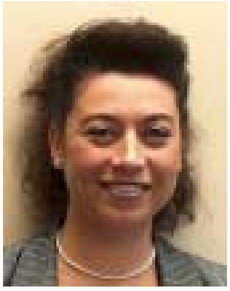

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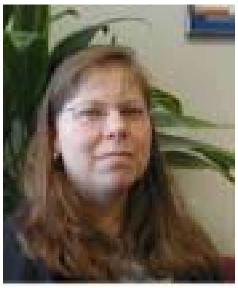

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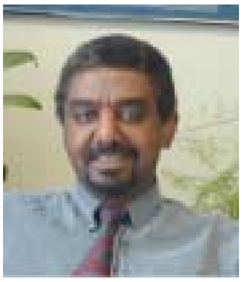

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4th Joint EC/NSF Workshop on Nanotechnology

Tools and Instruments for Research and Manufacturing

Workshop – 12-13 June 2002 – Grenoble (France)

Abstracts introductory speeches

4th Joint EC / NSF Workshop on Nanotechnology: Tools and Instruments for Research and Manufacturing

Introduction

Hervé Péro
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The nanotechnology revolution has started. It already fuels innovative applications in industries as diverse as IT, automotive, cosmetics, chemical, and packaging. Nanotechnology also holds considerable promise to generate radical new applications – and whole new sectors of activity, amongst them energy storage, detection, measurement and testing, bio-analysis and drug delivery, robotics and prosthetics.

Due to the scale of the research effort, nanotechnology also transcends geographical borders and is a prime focus for international cooperation today.

Following the Toulouse event in 2000, the Puerto Rico event on "Nanomanufacturing and Processing" and the Lecce event on "Revolutionary Opportunities and Societal Implications" earlier this year, the 4th Joint NSF-EC Workshop on "Tools and Instruments for Research and Manufacturing" has been organised in Grenoble from 12 to 13 June 2002, hosted by CEA-Minatec.

Some 90 participants including 15 US speakers, 21 EU speakers, 14 EU and 1 US poster presenters and 6 EC and NSF representatives are participating. One objective of the workshop is to facilitate a free and open discussion of EU and US experts in the field of "tools and instruments for research and manufacturing", and to stimulate preparation of joint activities in the coming years.

The program includes several keynote speeches addressing different national and international research initiatives, as well as extensive discussions on research milestones, training and networking challenges and effective EC-NSF collaboration. The Workshop is addressing in particular

(1) Research milestones in
- (a) Equipment for nanomanufacturing;
- (b) Instruments for research at nanoscale, and
- (c) Analysis, Monitoring and Control at Nanoscale;

In the future, industry will be mass-producing nano-materials and nano-devices. This industrial activity will require instruments, tools and equipment that do not exist yet. Processes will also have to be effectively controlled. Today, however, it appears somewhat difficult to separate the development of new instrumentation and techniques from the advances of the basic research itself. Topics for technical discussions will cover a broad range (tools and instruments for manipulation of atom and molecules, self-assembled *nanostructures, microscopy, advanced lithography techniques, ion beam technology, nanodevices, nanometrology, nanomanufacturing infrastructure, etc.). Researchers are invited to express their views as well as their needs.*

(2) Industrialisation , Training and Education, Networking

The new ways of operation and production will require new skills of personnel and, as nanotechnology is a multidisciplinary topic, it is anticipated that there will be a growing need for integrating training and research as well as anticipating changes and impact on employment.

(3) EC-NSF Collaboration

One of the main goals of these Workshops is to join the forces of the National Science Foundation (NSF) with the European Commission (EC) research and innovation Framework Programme in order to catalyse progress in research and education in the emerging field of nanotechnology and nanomanufacturing. It should also stimulate exchange of information, enhanced mobility of researchers and, whenever possible, preparation of joint research proposals that have a mutually beneficial impact. In this context, a particular stimulus will be the launching of the 6th EC RTD Framework Programme, with new contractual instruments allowing the setting-up of Integrated Projects and Networks of Excellence.

Your role …

It is hoped that the conclusion of the workshop will emanate from the community of experts themselves. It should be highlighted that, since application-oriented groups often carry out research with little interaction with researchers of other fields, resulting in non-optimal approaches, it will be useful to identify *generic technological trends* to be supported as well as effective *research mechanisms* at international level. To help steering discussions, and in view of the limited time, we have prepared some background documents and draft synthesis of the various abstracts…

Have a good workshop !

Biographical information

Hervé Péro

Since 1999, he has the responsibility of the unit “Innovative Products, Processes and Organisation” within the EC, DG research, and is assisting the director in preparing the next EC research programme on industrial technologies. He worked before as advisor to the director in charge of “Industrial & Materials Technologies”, “Standards, Measurements & Testing” and “Steel Research” programmes (1993-98), and as Administrator in the BRITE & BRITE/EURAM programmes (1986-1993). As french engineer, he had working experience within the industry, from 1977 to 1986 (in particular Head of department in Vallourec, Large Welded Pipelines Division), and within university, in South America (Technological Institute of Caracas, 1973-77).

Introduction of Workshop objectives by NSF

Thomas A. Weber
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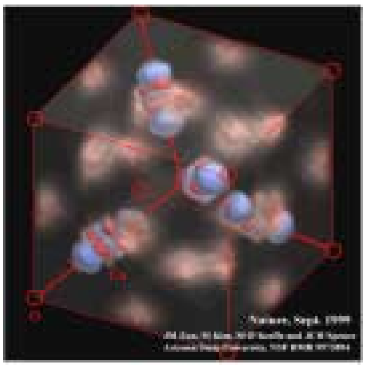
Nanotechnology is nothing new as evidenced by the Lycurgus Cup that dates from Roman times. The original, which is housed in the British Museum, appears green in reflected light and red when light is transmitted from the inside of the vessel. This is an example of what might be called accidental nanotechnology because the craftsman who created it didn't realize that the effect was from nanoparticles of metallic gold. But today, with advanced instruments and clever experimental techniques, researchers are able to produce materials with nanoscale dimensionalities that possess new properties.



Spence and co-workers at Arizona State University using sophisticated instruments along with calculations have been able to directly observe electron orbitals in a high temperature superconductor. The length scale observed is on the order of one nanometer. The d-orbitals are clearly visible in the photograph. In addition, the advances in microscopies have allowed manipulation of single atoms and molecules.

During the past seven years the National Science Foundation has sponsored a series of international workshops on materials to enhance collaboration in materials research, education and technology. The first concrete action was a joint EC-NSF coordinated call for proposals. To date three such calls have been held under the Fifth Framework. This workshop grew out a proposal generated in a joint EC/NSF Workshop that was held in Toulouse France in October of 2000 for four topical area workshops to explore how NSF could cooperate with the EC in the Sixth Framework. In addition, NSF is exploring ways in which we can collaborate with individual National Funding Agencies around the world.

Biographical information

Thomas A. Weber

- Born in Tiffin, Ohio on June 8, 1944.
- BS in chemistry, University of Notre Dame (1966).
- PhD in chemical physics, The Johns Hopkins University (1970).
- Member of Technical Staff, AT&T Bell Laboratories, Murray Hill, NJ (1970-1987).
- Program Officer for Theoretical and Computational Chemistry, Chemistry Division, National Science Foundation (1987-1988).
- Division Director, Advanced Scientific Computing, NSF (1988-1992).
- Division Director, Information Systems, NSF (1992-1994).
- White House, Executive Office of the President (1993 detail).
- Executive Officer, Directorate for Mathematical and Physical Sciences, NSF (1994-1995).
- Division Director, Materials Research (1995-Present).
- Meritorious Executive Presidential Rank Award, 1994.
- Fellow, American Physical Society.
- Phi Beta Kappa, 1970.
- Research interests are in the field of computational chemistry and materials, using computer simulation to study air pollution, polymers, glasses, liquids, metals and semiconductor materials

4th Joint EC/NSF Workshop on Nanotechnology

Tools and Instruments for Research and Manufacturing

Workshop – 12-13 June 2002 – Grenoble (France)

Synthesis of contributions

Synthesis of contributions

The NSF-EC Nanotechnology Workshop on Tools and Instruments for Research and Manufacturing has been held within the framework of the co-operation between the National Science Foundation (NSF) and the European Commission (EC) on materials sciences and nanotechnology. Its aim has been that of fostering international collaboration in research and education by the identification of future co-operative activities and joint actions in the entire area of nanoscale processing and manufacturing.

It has gathered together 90 experts, leading researchers and young investigators in the field of nanomanufacturing, coming from academia, industry and government laboratories. It has naturally followed the former NSF-EC Workshops on nanotechnology held in Toulouse, Lecce and Puerto Rico, which have been organised to define the research milestones that will have a catalytic effect at international level in exploring and mastering the emerging field of nanotechnology.

This 4th Joint Workshop has enabled to exchange ideas on the future research needs and to put forward strategic views on the following two key topics:

Equipment for research or nanomanufacturing
Economics, Training, Education and Networking

The goal of the conference was to find out about mutual interest, establish contacts and discuss networks and formulate projects to foster future collaboration between EC and NSF. The ideas presented and discussed in the round table session are described in this document.

1. Scientific and technical needs

1a. Equipment for research or manufacturing

Equipment needed by researchers in their laboratories <u>and</u> by industrials in their manufacturing plants was discussed.

Manufacturing and R&D applications have differing requirements. Manufacturing requires high throughput, and fully automated, turnkey operation. By contrast, R&D requires high resolution, while throughput and automation are less important. The most important measure of technical performance concerns the fundamental trade off between resolution and throughput. However, it is highly desirable to have only one technology to perform these basic functions.

1b. Individual presentations

From the presentation the following technical needs were destilled.

<u>Manufacturing via manipulation, deposition and removal</u>

Still difficult today is deposition of a controlled amount of material exactly at the required locations. If this could be reached it would make further processing steps obsolete on arbitrary surfaces and for a variety of deposited materials.
Connected to precision is a nanopositioner to position the cantilever aperture of an AFM on the sample with great accuracy and repeatibility, even blind placing is envisaged.
Such a positioning system should be 3D and should include a control system for a probe array for measurements on the sample.
Manipulation tools should be able to position the individual molecular complexes in any predefined configuration, to create nanostructures, to connect functional molecules to the outside world, and to serve as test structures for measurements on single or bundled molecules.
Coating machines should be designed and constructed, specifically to enable close control of the nanolayer deposition process.

Scaling of deposition processes to industrial production is to be addressed.

Tools to measure the relation between coating deposition parameters on the physical characteristics of the coating produced are needed. Mathematical models existing for composite materials should be adapted, so they can be successfully applied to ASE nanolayers. Measurements and models should be combine to produce models to predict the physical (and performance) characteristics of ASE nanolayer coatings.
Plasma assisted deposition of nanometric polymer films should be elaborated (the process, analysis and evaluation) to arrive at a tool which predicts process performances ‘ab-initio’ that is from the basicgas properties.
An evaporation system highly collimated on the cantilever is targeted.

We should explore the potentials of quantum interferometry for the deposition of regular molecular arrays, which may be complementary to SPM manipulation methods used so far.

Resolution enhancement of lasers by the use of shorter pulses, shorted wavelengths and high numerical aperture optics is to be obtained.

The feasibility of parallel electron beam based lithography is to be explored as well as metrology schemes in terms of resolution, precision, throughput along with the development of novel resist materials in an interdisciplinary approach involving physics, chemistry and engineering.

Monitoring

Manufacturing equipment should have in-situ monitoring of the quantum structure growth (forces and displacements) as an add-on to help in reducing development time and costs. This would in its turn improve innovation cycles and the time-to-market of novel devices since the growth of the material would be monitored in real time on a nanometer scale. Here new instruments are envisaged like new sensors.
A combined AFM-QCM tool is necessary. Even dynamic AFM is envisaged where a time-resolving technique enables to resolve transient phenomena relevant in surface wetting, catalysis, and biochemistry. This monitoring is of course also needed for self-assembled molecular layers.
Monitoring at nanoscale requires the appropriate experimental techniques and infrared external reflection technique could serve this purpose. The interaction of the infrared beam with the examined adsorbed molecules should be investigated and the technique should be supported by computer simulation of surface composition and structure.
Integration of scanning probing techniques into synchrotron facilities is needed.

Control

Methodology to control the manufacturing process of tailored surfaces with desired functionality is envisaged to be executed with nano-devices.
Quality assessment procedures to guarantee repeatability and reproducability should be established.
Control of the reaction exothermicity in heating and modifying nanostructures (chemical functionalising) is to be obtained with molecular-scale measurements of this process, and approaches to circumvent such problems.
Manufacturing with nanostructured magnetic materials is dominated by thermal fluctuations and interfacial effects and new approaches should be discussed that should allow continued scaling to higher densities.
Control of the influence of magnetic fluids in process parameters in RTM, a process to produce advance composite materials, is needed. (This is a process where magnetic nanofluids are mixed with a thermosetting resin and applying a magnetic field which will force the flow in the directions that are needed.)
The magnetism of magnetic nano-particles provides a variable for control, as well as the magnetic properties of the arrays into which they are assemble.

The possibility of controlling particle orientation and movement in self-assembly is to be discussed.

Characterisation tools

Advanced characterization tools for materials and processes (e.g. for nanomagnetism with synchrotron radiation) are to be developed. Time-resolving capabilities, down to sub-picosecond time resolution, are also to be developed (to address magnetic switching dynamics, as well as equilibrium and non-equilibrium dynamics in phase transitions).
The technology should be non-destructive, other parameters of importance are cost, speed and efficiency.

Evaluation tools

A tool to evaluate device produceability and affordability concurrent with initial laboratory successes and concept development should be developed.
Virtual reality techniques and computational models should be developed to present the user with key feedback regarding the nanometer scale device or process.
Evaluation tools of performances are to be developed (wettability, adhesion, resistance to corrosion, gas transmission rates, bacterial colonization, etc.).

Measurement and Testing

Mechanical test devices at nanoscale for measuring (e.g. of nanoscale adhesion and stiction) as well as failure testing are to be developed, which themselves have to consist of nanoscale components.
Uniform measurement procedures and written standards are a must. The range of measurement and metrology is to be broadened. The parameters to be measured are sub-surface composition/structure/properties.
The precompetitive technology needed to be measure critical dimensions should be developed in synchronisation with other branches of microscopy. The technology should allow in-situ and real time measurements.
Traceability and equivalence (calibration) between different labs and industrial manufacturers is necessary.

Integration

As nanotechnology is at the joint of physics, chemistry and biology it has to integrate top-down methods (such as lithography and patterning), bottom-up methods (self-assembly of molecules), single molecule detection, single molecule manipulation and hybrid technology (combining biomolecules with silicon-based nanostructures).
Integration of detection/localisation, diagnosis/recognition/property analysis, manipulation, modification of the individual atom or molecular complexes and interfacing the nano-object with the macroscopic world are needed to test whether they are functioning as desired within the nanostructure. This multi-purpose tool should have a local character, be non-destructive and have independent mechanisms for positioning and

interfacing, parallel operation. The tool should be compatible with ambient pressure and have *colorful* sensitivity (i.e., sensitive to different chemical, electrical and mechanical interactions).
As equipment for research and manufacturing can not be separated, equipment should have a switch that modifies the resolution to different scales ranging from nanometer to microns. Another switch for functionality is to be elaborated that switches from imaging to spectroscopy or nanofabrication. The equipment should be compatible with sampling biomolecules and quantum dots.
Also the integration between the nano and micro world in the form of interconnect and integration technologies is to be addressed.

Theory, Modeling and Simulation

Ever more accurate and predictive physical models are required. New effects and variables have to be considered (e.g. stress in all steps, quantum effects and fluctuations). New processes and new materials have to be dealt with. An enhanced computational infrastructure will be required to investigate molecular assemblies and to understand interactions that occur over a wide variety of time and length scales.
Mathematical simulation will allow a better understanding of technology and will shorten the development cycles of any technology. This requires the introduction of 3D models as well as their experimental verification and further development. These models should work on relationships between structure, properties, processing and performance.
The adaptation and extension of methods originally developed in the well-established field of microelectronics simulation could be executed to direct the development of nanostructures and avoid costly trials. From these developments, especially models and tools to simulate the generation and properties of nanogeometries, and phenomena leading to the formation and partly even self-organization of atomic complexes and nanoclusters, like Ostwald ripening, are important for nanotechnology.

Applications

An application of the e-beam lithography tool should not be limited to IC fabrication. Data storage and nanometric sensing are further challenging applications requiring high density nanometer pattern generation with highest efficiency for a potential mass market. ULSI-NEMS (Nano ElectroMechanical Systems) cannot be fabricated without powerful and flexible pattern generation systems and processes.

Lasers can be applied in novel applications for micro hole drilling, solid-state laser scribing, and refractive index modulation in optical materials.

In the field of micro/nanosystems there is an increased need to expand our capability to fabricate novel types of structures at various length-scales on unconventional surfaces, with high throughput and at low-cost. Challenging surfaces are for instance (bio)chemically functionalized patterns for molecular electronic and lab-on-the-chip applications, or fragile elements for resonant micro- and nanomechanical sensors.

Atomic and molecular interferometry: The feasibility of nanoprobe techniques as detectors in molecular quantum interference devices as well as the use of molecular de Broglie interference for the production of nanostructures should be investigated.

Biomaterials, polymers and carbon nanotubes are future challenges in CVD technology for improved systems with more functionality based on nanotechnologies.

In the future systems should exist that possess autonomy to "think for themselves"; self-reliance to identify, diagnose and correct internal problems and failures; self repair to overcome damage; adaptability to function and explore in new and unknown environments; and extreme efficiency to operate with very limited resources. Convergence of Nanotechnology, Biotechnology and Information Technology will provide the capabilities needed.

1c. Possible cluster themes

At the workshop the attendees discussed in the round table sessions how to cluster the individual needs in order to group them into Integrated Projects or Networks of Excellence.
The themes they proposed are

- Imaging and manipulation of 2D interfaces embedded in a 3D medium
- Non-destructive imaging of soft biomaterials
- Analysis and diagnostics at scales ranging from nano-objects to microscale sizes. Chemical identification and characterisation of materials and current processes is to be included.
- Multi purpose tools, integration of top-down and bottom-up processes and tools with multi probes.
- Nanostructuring, which includes of course very many technologies ranging from lithography, through pattern transfer, imprint lithography, nano-stencils to self-assembly.
- Multiscale simulation ranging from meso to molecular to quantum mechanics.

1d. The nanomanufacturing factory of the future.

As a possible future Integrated Project was mentioned " the nanomanufacturing factory of the future". Its modules could be

- The module 'research' could envisage to create an infrastructure where the prototype equipment and tools described above are developed and tested.
- A module 'application centre' could address the development, demonstration and take-up. E.g. a Lithography Application Centre for Nanotechnology /Micromachining for different application under industrial aspects was already proposed.
- The module 'testing' could test the equipment in close cooperation between chip manufacturers, toolmakers and advanced research institutes

- The module ‘standards’ could be a network on quantitative microscopy, synchronising initiatives within branches of microscopy and nanoanalysis. Precompetitive technology is needed to measure critical dimensions.
- The module ‘policy and ethics’ could work on those topics.
- The module ‘training’ could a.o. be targeting new curricula.

1e. Network of Excellence

A network should be established as a multi disciplinary environment that assembles experts from all sectors involved in nanotechnology.
This network should target seamless integration of technologies, concepts and processes across disciplines and dimensions/sizes.
Especially in bio-nanotechnology user acceptance should be prepared.

2. Non-technical requirements

Economics

The Nano- Lithography tool market has recently progressed from limited research and development application into more extensive manufacturing application.
High resolution gaussian electron beam writer as a next-generation system for direct write applications for the new high resolution MEMS/MOEMS.

Lithography and related processes are the main driving factor of chip and SOC (system on chip) manufacturing.
The aggressive development plans of IC companies force the lithography development to investigate new technology solutions within few years, to continue after the 50 nm node techniques.

Training

High industrial growth is predicted and there are insufficient trained personnel to meet the demand. Training in multidisciplinary technologies is necessary as today scientists and engineers working in the fields of precision engineering, micro engineering and nanotechnology are highly specialized. Development of multidisciplinary designs that are economic and practical in terms of manufacturing are often the result of 'hybrid' technologies and a workforce developing this is to be educated.

To meet the growing demand for young researchers with an interdisciplinary background in nanotechnology, new bachelor, masters & ph.d. education in nanotechnology should start. The curriculum should include courses in nanotechnology from the first semester in parallel to introductory courses in physics, chemistry, biology and mathematics. This combination allows the classical disciplines to be continuously spiced with examples from recent progress in nanoscience and -technology.

Hands-on experience is a factor of great importance and industrial stages might be an answer to this. Industries should thus play a major role in new activities and help attract young people to nanotech, creating a new culture.

E-science like open logbooks is also an approach worthwhile considering.

Resource sharing with specialisation courses jointly provided for several institutes but also school teachers teaching at different schools is an idea to be elaborated.

And training for both the young and older (life-long learning) should be provided.

Networks

Large multi-disciplinary networks are needed to sustain the above activities. From an economical point of view it would be wise to share the very expensive facilities. But also knowledge and experience in different fields could be shared. Large multi-disciplinary virtual networks might be the best suited research environment. However, in constructing all of these networks we should be aware that proximity factors are a prime parameter. Fractal groupings might be a solution.

Ideas proposed are open common large facilities where researchers can come to do their research using the available equipment and supporting staff. This idea is currently being implemented in the US and could be carried further by starting open centra where in addition research is done on the equipment and tools themselves, developing the laboratory and manufacturing plant of the future.

Hence these networks should have the resources to support education, facilities and research and novel application ideas. Also dissemination could be a task of these networks to encourage interactions, attract attention to developments and opportunities in nanomanufacturing.

3. Future co-operation between NSF and EC

3a. The 6th Framework Programme context

In the FP6 new modalities are envisaged: the Integrated Projects (IP) and Networks of Excellence (NoE).
An IP should contain a coherent set of activities, like research, technology development, demonstration and training. The IP can span the full spectrum from basic to applied research and is expected to be multidisciplinary in nature. Further should there be dissemination and transfer of knowledge and activities on analysis and assessment of the technologies developed and of the factors relating to their exploitation. Projects may also include support for the take-up of the new technologies, in particular by SMEs.
The NoE is an instrument to address the fragmentation of European research and should deliver a durable structuring and shaping of the way that research is carried out. The NoE should be open and spread excellence. Training is an essential component.
Further info can be obtained at the website www.cordis.lu

Ideas for IPs and 'frontier of excellence projects' (the continuation of the former modality RTD projects) are mentioned in the former sections.

Consortium could be formed according to the thoughts expressed in the session dedicated to networking. The players will be research institutes, manufacturers, training institutes, standardisation bodies, ethical committees etc. Representatives of the EC and member states could be on the management board with the objective of making their research programmes complementary.

An idea for a NoE could be a consortium of the centres in Europe executing manufacturing research. They could act as one 'research institute' and develop joint research programmes to address the topics named above. E.g. a virtual group consisting of a few researchers in each country could jointly work on new characterisation tools.

The above IP and NoE could complement each other and generate further ideas for research projects at the frontier of knowledge and support measures (studies, workshops, conferences etc.)

The EC plans to hold yearly nano conferences on nanotechnology from 2003 onwards.

3b. Joint EC-NSF actions

The NSF has issue a 'dear-collegue-letter' inviting people to present proposals in nanomaterials and for academics only.
The EC has recently issued a call for Expressions of Interest (EoI) from which hopefully ideas for future research will sprout. These will be published on the web (www.cordis.lu).

Recent activities envisage a conference in 2004 jointly organised by the Europeans, Americans and Japanese.

3c. Next steps

We encourage everybody to continue the discussions with their peers. The attached abstracts give you the e-mail addresses of people working on particular topics. On our web you might discover who is working on certain modules and you might be able to join forces with them to obtain the scale required for integration and so mount a real IP or NoE.

Don't hesitate to discuss your pre-proposals with us!

Signed:

The EU and NSF team

4th Joint EC/NSF Workshop on Nanotechnology

Tools and Instruments for Research and Manufacturing

Workshop – 12-13 June 2002 – Grenoble (France)

Abstracts of presentations

(ordered alphabetically by author)

Multi-disciplinary environments for research and training in nanotechnology

Prof. Vincent Bayot
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Most research fields operate on a mono-disciplinary scheme which reflects in the organisation of research environments and curricula, e.g. universities are organised following a "roots-like" structure: the smaller the entity, the most specialised it is. As efficient this scheme might be for mono-disciplinary research and education, it is definitely obsolete for nanotechnology which is multi-disciplinary in essence. For example, the integration of biologists in research teams including physicists, chemists and engineers is considered as a key ingredient for the development of bio-nanotechnologies. The issue of multi-disciplinarity for research and training in nanotechnology has been rising rapidly, motivated, first by scientific needs, and quickly after by funding agencies expressing legitimate concerns about the efficient spending of the tax-payer money and workforce availability for nanotech booming.

This paper discusses first the issue of the best suited research environment with respect to nanotech needs in the framework of the large scale virtual networks building up at national and European levels. While large scale virtual networks have huge potentials, interactions between researchers are naturally weaker than on a local scale. Indeed, as in any human organisation, proximity favours interactions simply because the energy barrier is weaker. Multi-scale networks of multi-disciplinary entities, organised in a fractal-like structure, are proposed as a possible solution for providing efficient interactions between researchers at all levels.

The research center in micro and nanoscopic electronic devices and materials (CERMIN) is then presented as an example of multi-disciplinary research environment aimed at research and training in nanotechnology. Recent results ranging from high-resolution lithography to nano-magnetic microwave devices, nano-biotechnology, growth simulations, nanoelectronics, ... are presented as prominent examples of researchs that were only possible thanks to a close day-to-day interactions between researchers from different disciplines. Future projects are also reviewed. Lowering the barrier between researchers from different disciplines needs more than proximity. Background training in all basic disciplines relevant to nanotechnology is at least as crucial. The importance of multi-disciplinary curricula and research environments for efficient training to nanotechnology will be raised, in connection with educational methods. The experience of CERMIN in training to micro and nanotechnologies will be presented.

Biographical information

Prof. Vincent Bayot

Vincent Bayot was born in Belgium, in 1963. He received is Engineering degree in Applied physics in 1986 from the Université catholique de Louvain (UCL) and his PhD degree from UCL in 1991.

After staying at Princeton University for a postdoc until 1992, he joined the FNRS (Fonds National de la Recherche Scientifique, Belgium) until 1998 and then became professor at UCL. Since his PhD he has been involved in low-dimensional electronic systems and mesoscopic physics, mostly in III-V compounds (quantum Hall effect, ballistic transport), but also in carbon nanotubes, semi-metals, nano-magnetic materials, nanofabrication techniques, SOI quantum devices and nanoelectronics. He has more than 170 publications in international journals and conferences. He is currently president of the multi-disciplinary "Research Center in Micro and Nanoscopic Materials and Electronic Devices" - CERMIN (www.nano.be) - at UCL which groups about 120 people mainly from nano-physics, nano-materials, nano-electronics, nano-biotechnology, microelectronics and microsystems.

Bio-nanotechnology: single molecule detection and manipulation tools

Martin Bennink
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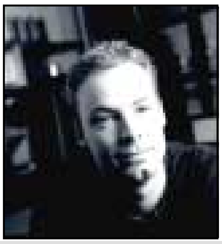
We have been working on merging top-down technologies such as lithography and patterning with bottom-up approaches such as self-organization of molecules to bridge the gap between silicon structures and single molecules. In addition to this techniques have been developed that enable us to probe these molecules, using atomic force microscopy, optical tweezers, confocal and near-field optical microscopy.

As a next step, in this project we would like to design and realize functional nanodevices using biological molecules, such as nucleic acids (DNA, RNA) and proteins. Nature provides us with a large number of very powerful nanosized structures and devices, which form excellent components for the nanodevices to be developed. Standard lithographic nanofabrication methods can be used to construct a nanostructured environment, in which the single biomolecular systems can be positioned. Here we would like to focus on two issues that remain to be explored and developed. Firstly there is a need for technology to combine individual biological molecules or complexes with a silicon-based nanostructure, a so-called 'hybrid technology', such that the biomolecular systems are integrated within the structure, without loosing their activity. Secondly we need to explore and develop new single molecule detection and manipulation tools to position the individual molecular complexes in any predefined configuration and to check whether they are functioning as desired within the nanostructure. Combining different highly specialized functions of biomolecules within one single nanostructure, enables the construction of higher order functions, which will find their future applications in the field of drug-targeting, nano-sensoring and high-throughput screening.



Biographical information

Martin Leon Bennink

PERSONAL
Dr. ir. Martin Leon Bennink, born May 9th, 1973, Dutch nationality

EDUCATION
September 1991 – October 1996:
University of Twente, Applied Physics (ir.)
Masters work done in Biophysics: Development of a detection method in flow cytometry.
Special courses in Biophysics
Special courses in Chemical Technology (Physical Chemistry, Organic Chemistry)

WORK EXPERIENCE
October 1996 – January 2001:
University of Twente, dept of Applied Physics, iBME research institute
PhD project, finished with thesis: "Force spectroscopy of single DNA-protein complexes, an optical tweezers study"
Task description
Setting up new research to study interactions between individual biomolecules, such as DNA and proteins.
January 2001 – September 2001:
University of Twente, MESA+ research institute
Post-doctoral work, focused on the development of a combined AFM-optical tweezers set-up, for detecting individual proteins as they sit on a single DNA molecule, which is suspended in between two micron-sized beads
October 2001 – now:
University of Twente, MESA+ research institute
Program director of research within Nanolink.
Task description:
Coordinating on-going multidisciplinary projects (8 projects on the borderline of applied physics, chemical technology and electrical engineering) and creating new ones with the field of Nanolink.
Setting up a new line of multidisciplinary research focused on single molecule chemistry, physics and biology.

Nanostencil: a tool for surface large-scale nanopatterning beyond lithography

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In this presentation a new method for forming micro and nanoscale structures without photoresist and lithography techniques will be discussed.

In the field of micro/nanosystems there is an increased need to expand our capability to fabricate novel types of structures at various length-scales on unconventional surfaces, with high throughput and at low-cost. Challenging surfaces are for instance (bio)chemically functionalized patterns for molecular electronic and lab-on-the-chip applications, or fragile elements for resonant micro- and nanomechanical sensors. A new powerful method is "nanostencil", a shadow evaporation technique using thin mechanical membranes with tiny apertures. Evaporation through the nanostencil deposits a controlled amount of material exactly at the required locations, making further processing steps obsolete. The technique is capable of making structures with a high dynamic size range (<50 nm up to >100 µm) in a single process step and therefore provides a unique link between micro and nanoworld. We demonstrate the technique on arbitrary surfaces (Silicon, Oxides, organic SAMs, micromechanical structures) and for a variety of deposited materials. The in-vacuum method is intrinsically pure and allows the preparation of clean surfaces, interfaces and contacts, therefore allowing new experiments in material science to be made, and leading to new device application.

Fundamental research on the nanostencil concept and first prototype tools are currently being developped in the frame of "ATOMS", an EU funded 5th Framework IST project. It is important now to discuss the issues to levitate the prooven concept into a manufacturing tool able for large-scale production of nanopatterns in an industrial environment.

Biographical information

Jürgen Brugger

Jürgen Brugger received the Ph.D. degree in 1995 from the University of Neuchâtel, Switzerland for a work on microfabricated tools for the atomic force microscope, which included a 1-year stay at Hitachi Research Laboratories in Tokyo, Japan. He then joined the Micro- and Nanomechanics Group at the IBM Zurich Research Laboratory, Rüschlikon, Switzerland. Since 1999 he is directing the "NanoLink" Strategic Research Orientation at the MESA+ Research Institute, University of Twente, The Netherlands, focusing on cross-disciplinary activities in micro- and nanotechnologies combining TopDown Engineering with BottomUp self-assembly.

In 2001 he moved to the Swiss Federal Institute of Technology Lausanne (EPFL), Switzerland on a new assignment as Assistant Professor Tenure Track. His main professional interests include the development of techniques and tools at the length scale between 10 nm and 1 μm, in particular to novel microtools for nanoscience, and to conceive strategies for low-cost nanoscale device fabrication. One objective thereby is to link miniaturization engineering approaches with self-assembly strategies. He has recently been appointed as Associate Editor for the Journal of Nanoscience and Nanotechnology, and he has been elected as board member of the European Network of Excellence on Nanoelectronics 'PHANTOMS.

His private pursuits include outdoor activities such as traveling and mountaineering but also indoor sports such as the combination of Single Malts and Jazz Music.

Bio-analytical tools: Integration of technologies, concepts and processes from different disciplines and dimensions

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The integration of engineered biomolecules with solid-state micro- and nano-electromechanical devices, nanoparticles or structured surfaces promises tremendous advances and cost reductions in biotechnology and medicine. However, one critical success factor will be focussed on the integration of technologies, concepts and processes for different disciplines and dimensions. Cross fertilisation of different disciplines and like materials research, biochemistry, physics, micro- and nanoelectronic fabrication techniques will create new ways of interpreting and interacting with the biological world and open the door to new scientific and commercial opportunities. In order to exploit these opportunities, the transition between these different disciplines needs to be seamless in order to share, access and disseminate common information.

Important for the future of clinical medicine are potential applications of nanotechnologies in the engineering of surfaces of suitable composition and topography to act as templates for the growth, by self-organisation, of artificial tissues and in the creation of biocompatible coatings for artificial implants. The challenge is to develop surfaces whose nanoscale composition and topography provides ideal binding sites to immobilise a wide range of biomolecules without significant defunctionalisation. Fundamental knowledge on the preparation and manufacturing of biological surfaces will find wide application in a new generation of biosensors and bio-analytical platforms with increased functionality.

One key area that offers enormous potential and significant promise concerns the self assembly of molecules, such as the self ordering and functionalisation of molecules, proteins, enzymes, DNA, RNA, etc., via nanoimprinting, nano-lithographic or direct electronic control techniques, using micro- and nano- technologies. Expertise in the area of surface functionalisation at nanometer scale will be one of the key technical issues for the future biochip manufacturing process in the coming years. In order to achieve this, a greater understanding and identification of the underlying biological events and processes must be reached. The methodology for control and quantification needs to be established for the realisation of tailored bio-surfaces of desired functionality. Here the role of quality assurance is paramount, for the repeatablity and reproducibility of the biological processes, particularly in a future manufacturing environment.

A second key area concerns the manipulation of molecules, tissues, or organisms using micro-nano- intervention tools. The challenge here lies in the development of nano-tools that have a "micro and macro interface" to facilitate user control and interpretation of the nano-scaled materials under investigation.

As an example of some of lessons learnt when considering "integration across different disciplines and dimensions," we present a bio-analytical system that combines an atomic force microscope with a biosensor providing a novel platform for investigation of biological species at the nanoscale.

Biographical information

Andrew Campitelli

Dr. Andrew Campitelli received the PhD degree in Electronic Engineering, specialising in Sensor Technology, from the RMIT University, Melbourne, Australia in 1997. A one year Post-doctoral research position at LPMO-CNRS, Besançon France, was then undertaken developing new systems integrating different sensing platforms. Since November 1998, Dr. Campitelli has been a Project Manager with the Microsystems Group at IMEC, Leuven, Belgium, and in January 2000, he was appointed Group Leader of the new Biosensor Group at IMEC. His main research interests concerns the design, simulation and fabrication of biosensors, with particular emphasis on the engineering system design and implementation of portable, cost effective and viable solutions for point-of-care applications.

The Impact of Converging Nano-Bio and IT Technologies

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NASA's mission encompasses Space and Earth Science, Fundamental Biological and Physical Research (OBPR), Human Exploration and Development of Space (HEDS) as well as a responsibility for providing advanced technologies for Aerospace Trans-portation systems. Virtually all of NASA's vision for the future of space exploration is dependent upon mass, power requirements, and the size and intelligence of components that make up launch vehicles, spacecraft, and rovers. Dramatic increases in the strength-to-weight ratio of structural materials offers the potential to reduce launch and flight costs to acceptable levels. Such structural materials can also lead to increases in payload and range for aircraft which can translate into U.S. dominance of the world marketplace. To do this, NASA space systems will have to be much more capable than they are today. They will have to have the characteristics of autonomy to "think for themselves"; self-reliance to identify, diagnose and correct internal problems and failures; self repair to overcome damage; adaptability to function and explore in new and unknown environments; and extreme efficiency to operate with very limited resources. These are typically characteristics of robust biological systems, and they will also be the characteristics of future aerospace systems. Acquisition of such intelligence, adaptability and compute power go beyond the present capabilities of microelectronic devices.

It is envisioned that a convergence of Nanotechnology, Biotechnology and Information Technology will provide the capabilities needed for meeting NASA challenges in the new millennium.

Nanomanufacturing Facilities Infrastructure

Haris Doumanidis, Kesh Narayanan *and* Kamlakar Rajurkar

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Over the past decade, the National Science Foundation in the United States has funded a number of Engineering Research Centers, Industry-University Cooperative Research Centers, Science and Technology Centers, and Materials Research in Science and Engineering Centers related to manufacturing at the nanoscale. In the context of the National Nanotechnology Initiative, NSF also supports six new Nanoscale Science and Engineering Centers and the National Nanofabrication Users Network, with five nodes. Our present initiatives focus on integrating these nanoscience and 2-D nanofabrication facilities into a complete, comprehensive and versatile nanomanufacturing infrastructure network. This will complement the existing centers with new nodes focusing on nanomanufacturing building blocks, coatings and surfaces, consolidates and composites, biochemical dispersions and structures, processing and integration, system architectures, modeling tools and instruments, electronic/magnetic systems, photonics and optics, biodevices and systems, and environmental, energy, health and safety systems. The necessity for such nanomanufacturing facilities was suggested by the research community in a number of workshops with participation of the federal agencies, small businesses and the European Commission, in order to support evolving needs for discovery, innovation and applications of nanotechnology. The new facilities will feature new instrumentation and machinery with emphasis in 3D manufacturing, scale-up integration, measurement and metrology, and modeling and control of both top-down and bottom-up manufacturing technologies. The network is designed to broaden participation of academe, industry and federal laboratories by geographical distribution and cyberspace teleoperation (telefabrication and telecharacterization) of the equipment. This infrastructure is intended to foster interdisciplinary research, with education and training of the workforce integrated at all levels, and with opportunities for engaging the social sciences and addressing the societal impacts of nanomanufacturing.

Hard X-ray characterisation on the micro- and nanoscale; applications and new optics

Kenneth Evans-Lutterodt
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The characterization of materials routinely includes techniques that use hard X-ray photons, for example, diffraction and the various spectroscopies. This is because photons in this energy range have wavelengths comparable to the typical inter-atomic spacing in materials, and most elements have absorption edges in this range. Unfortunately, the typical size of a beam from a laboratory or synchrotron source is millimeter sized, while some of the materials to be studied, for example micro-electronics devices, are best studied with nanometer resolution. Fortunately, for the last 10 years there has been a revolution in the field of optics for hard X-ray photons, enabling beam sizes as small as 100nm. I will discuss one application that requires these small X-ray spot sizes, and some of the new optics, diffractive and refractive, that will allow the extension of these hard X-ray techniques to a spatial resolution of at less than 100nm, and may make practical some new techniques such as sub-micron imaging.

Biographical information

Kenneth Evans-Lutterodt

Education and previous employment :
PhD Physics MIT 1989
Worked at Bell Labs, Lucent Technologies as member of staff from 1989 to 2001

Present employment :
Agere Systems, a spinoff of the Micro-electronics manufacturing part of Lucent Technologies.

Nano- and micro-engineering with pulsed lasers

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Lasers, by virtue of the short pulse lengths that can be produced and their wide range of available wavelengths, are well suited to produce nano- and microstructures. Excimer lasers and, more recently, diode-pumped solid-state lasers have now matured into industrially reliable tools and, once integrated with CNC control, process monitoring and automation, are capable of production processes at economically viable speeds and quality. The fundamentals of laser nano and micro-machining are reviewed, and examples in micro-electronics, fibre optics, solar energy generation and displays are discussed. Current research topics include resolution enhancement by the use of shorter pulses, shorted wavelengths and high numerical aperture optics, and novel applications for micro hole drilling, solid-state laser scribing, and refractive index modulation in optical materials.

Biographical information

Jim Fieret

Jim Fieret obtained graduate diplomas from Rijswijk and Delft Universities in the Netherlands, and a PhD in Applied Physics from the University of Hull in 1995. He has been working with lasers for macro- and microfabrication since 1985, and joined Exitech in 1997 where he is R&D Group leader and responsible for Exitech's nationally and European- funded R&D projects.

Nanofabrication Training

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At the Penn State Nanofabrication Facility, a site of the National Science Foundation`s National Nanofabrication Users Network, we have been working to share the resources of our NNUN site both for nanofabrication R&D and for nanofabrication education. We have been applying this concept of resource-sharing across the spectrum of K-12 (primary and secondary school) education, teacher education, two-year degree education, four-year degree education, and graduate work. In the three years of this effort we have developed the Nanofabrication Manufacturing Technology (NMT) Partnership, a consortium focused on Nanofabrication Education. The partnership has grown to consist of 30 colleges and universities, the State of Pennsylvania, industry, and NSF. In July 2001, the NSF

designated the NMT Partnership as a Regional Center for Manufacturing Education in Nanofabrication. This NSF Center is engaged in further expanding the K-12 nanotechnology student and teacher education activities, in expanding associate degree programs in nanofabrication to all Pennsylvania community colleges and in developing baccalaureate degree programs addressing nanofabrication at a number of Pennsylvania universities.

Specific nanotechnology educational activities of the PSU Nanofabrication Facility include holding "Chip Camps" for middle school and high school students from across Pennsylvania. These camps, ranging from one to three days and covering subjects from bio-chips to microelectronic chips, require a company, school, church, or a community or professional organization, to step forward to organize and select a group of "campers" at the local level. The Penn State Nanofabrication Facility administrative staff then schedules the visit to the Nanofabrication Facility and arranges for dormitory space and recreational activities at Penn State. The Nanofabrication Facility engineering staff provides the teaching that opens the door to the world of nanotechnology. Roughly 400 middle and high school students have attended chip camps over the past three years. A related K-12 educational activity is the three-day professional development workshops for school educators, including middle and high school science teachers, vocational-technical school teachers, and guidance counselors. Workshops are also offered for post-secondary educators (i.e., faculty members at colleges and universities) as well as for industry personnel. Approximately 250 educators and industry personnel have attended these hands-on professional development workshops over the past three years.

A major focus of the educational activities of the PSU Nanofabrication Facility centers on sharing the facility to teach six sophomore nanotechnology courses. These hands-on courses are taught ***in*** the PSU Nanofabrication Facility as a service for the 30 colleges and universities of the NMT Partnership. They are used by the two-year degree colleges as one semester of a four semester NMT program. They are used by the four-year degree institutions as a semester of the freshman or sophomore year of physics, engineering, chemistry, and biology degree programs. These six courses are offered at the PSU Nanofabrication Facility for the spring, summer, and fall semesters. This sharing of the PSU nanofabrication Facility equipment, cleanroon suites, and engineering staff for this NMT education has led to Pennsylvania being the first state to grant degrees in nanotechnology.

From Lab Scale to Manufacturing with cold plasmas

***Francesco Fracassi[1], Riccardo d'Agostino[1], Pietro Favia[1], Fabio Palumbo[2]**
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This presentation describes some possible utilizations of plasma processes in nanomanufacturing which deserve to be explored. In particular, the plasma assisted deposition of nanometric polymer films, with or without nanostructured morphologies, for several possible applications of industrial and technological relevance will be presented. It will be shown that with the use of proper diagnostic techniques it is possible to obtain an *in situ* and continuous tool which allows an efficient process control and an easier scale up from laboratory to manufacturing. The approach utilized can be summarized as follows:

1. study of the plasma process by means of optical diagnostics (both Visible Emission and IR adsorption) in order to detect the gas phase precursors of the process;
2. analysis of the nanomaterial by means of XPS, FTIR, AFM, SEM, etc;
3. evaluation of the performances (wettability, adhesion, resistance to corrosion, gas transmission rates, bacterial colonization, etc.).

The combined use of these diagnostics allows to find out the links:

gas phase precursors ↔ film composition and structure ↔ material performances

When this link is found for a selected process, one has a simple self adjustment tool:

in situ optical diagnostic ↔ process performances

The improvement for scaling up to industrial reactors is obtained since this approach picks out the "*inside*" parameters by which the processes are regulated.

The following issues will be discussed:

Product	Application
Nanometric films for superbarrier coatings	Food and pharmaceutical packaging
Nanocomposites metal/polymer films with reduced bacterial infection	Prostheses, active food and pharmaceutical packaging
Nanostructured fluoropolymer films featuring superhydrophobicity and olephobicity	Stain resistant clothes, garments and glasses
Nanometric coatings for corrosion protection	Car and aeronautic industry
Nanometric and micro-structured films for cell contact guidance on polymers	Tissue engineering and biosensor

(*) speaker

Biographical information

Francesco Fracassi

Associate professor of Chemistry at the Department of Chemistry of University of Bari (Italy), his scientific activity initiated in 1985 in the laboratories of the Plasma Chemistry Center of CNR in Bari. He was visiting scientist at IBM Almaden Reserch Center (CA). The main scientific interests of professor Fracassi are in the following fields:

plasma–surface interaction (dry etching, PECVD of SiOx coatings, PECVD & treatment of polymers);
surface analysis (XPS, FT-IR);
environment (waste production and atmospheric emissions of gases during plasma processes, thermal plasma treatment and inertization of wastes).

He is coauthor of more than 70 scientific works and contributions to congresses in the field of plasma treatments of materials.

Control of magnetic nanostructures

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Areal densities of magnetic recording media are currently doubling every year in both laboratory demonstrations and hard disk drive products. Increasing the areal density in magnetic recording has mainly been achieved by scaling the head and media parameters to smaller dimensions. This approach has resulted in critical dimensions on the nanometer scale and is leading to increased need to control the magnetic response on these length scales. Such control is increasingly difficult in the presence of thermal fluctuations and interfacial effects that dominate nanostructured magnetic materials. For instance, thermal fluctuations in the recording media, often referred to as the "superparamagnetic effect", is thought to limit areal densities of magnetic recording. In the face of these issues several new approaches and characterization techniques will be discussed that should allowed continued scaling to higher densities.

Multipurpose tool for device fabrication at nanometer-scale

Ricardo García

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'The future is not a simple extrapolation of the present knowledge'. However, scientists and engineers project their goals based on present achievements. In this presentation, it will be argued that extensive fabrication of structures, devices and machines at nanometer-scale would be optimized by the development of a multipurpose tool for diagnosis, modification and interfacing the nano-object with the macroscopic world. Several features should characterized the proposed tool, chiefly among them, a local character, non-destructive, independent mechanisms for positioning and interfacing, parallel operation, compatible with ambient pressure and *colorful* sensitivity (i.e, sensitive to different chemical, electrical and mechanical interactions). As a reference some features of scanning probe microscopy methods will be described.

Biographical information

Ricardo García

Dr. Ricardo García 15/08/1960) is a senior scientist in the Instituto de Microelectrónica de Madrid (CSIC). He also heads the Dept. of Fabrication and Characterization of Nanostrustures. He received a Ph.D. degree from the Universidad Autónoma de Madrid in 1990. After a one year postdoc at the University of New Mexico and two year at the Institute of Molecular Biology (University of Oregon) he joined the Instituto de Microelectrónica (CSIC).

Garcia's main research is on of the fundamental relationship between nanometer-scale structure and physical properties. In particular he has devoted a large effort to the study of the morphological, mechanical, chemical, tribological and electrical properties of a variety of structures at nanometer level such as quantum dots, nanotubes and biomolecules. Dr. García has participated in the development of novel methods for nano-scale imaging and characterization such as amplitude modulation atomic force microscopy and sub-picoampere scanning tunneling microscopes.

His present research interests emphasize three topics, the development of a nanolithographic method for large scale patterning of surfaces in ambient conditions. The method is based on the spatial confinement of a chemical reaction between an AFM tip and the sample surface (Local Oxidation Nanolithography). He is also actively involved in the development of new scanning probe methods for high resolution imaging of biomolecules in their native environment. The last topic is the understanding of the dynamic properties of a vibrating nanometer-size object in the proximity of a surface.

Present Position
Head Dept. Fabrication and Characterisation of Nanostructures (IMM-CSIC)

Academic career

1993-	Research Associate at the Instituto de Microelectrónica de Madrid (CSIC)
1991-1993	Associate scientist, University of Oregon (USA)
1990	Post doctoral fellow, University of New Mexico (USA)

Academic background

1984	Graduate in Physics, Universidad de Valladolid (Spain)
1990	PhD in Physics, Universidad Autónoma de Madrid (Spain)

Nanometrology in support of nanotechnology

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Research and manufacturing of nanometer scale devices offers an exceptional challenge to measurement technology by requiring three-dimensional, atomic-scale measurement capabilities over large areas. With emphasis on scanning probe microscopy (SPM), which can measure the three-dimensional surface structure, particle sizes, etc. of almost any surface and potentially with atomic resolution, the presentation will give a survey of *state of the art* and future challenge. It will be shown that there is a need for traceable measurements, commonly accepted nanometer scale transfer standards, uniform measurement procedures and written standards. Elements of this work has been initiated as coordinated international work in, for example, the EC supported network on Quantitative microscopy, in the discussion group Nanometrology under the International Bureau for Weight and Measure (BIPM) and in workshops on applications on SPMs held by NIST. However, a common programme is needed to continue and coordinate this work and it would benefit from a synchronisation with initiatives within other branches of microscopy and nanoanalysis.

Acknowledgement: The authors has collaborated with a large number of persons and institutions including PTB, NPL, University of Huddersfield, Nanosensors, Ibsen Photonics and Image Metrology

Biographical information

Jørgen Garnæs

Jørgen Garnæs is a Ph.D. and Staff scientist at DFM since 1992. Coordinator for the EC funded R&D project: Transfer standards for scanning probe microscopy 1996 to 2000 and participated in Development of a basis for 3D surface roughness measurements; Member of the scientific committee for the seminar series Quantitative microscopy. Member of the discussion group Nanometrology under the International Bureau for Weight and Measure (BIPM) and participated in nanometerscale key-comparisons. Co-author of more than 40 scientific papers.

Development of a nano-fabrication system based on AFM

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The aim of this project is to develop all the necessary tools to build nano-devices in a ultra high vacuum (UHV) environment. One of the objectives is to connect a molecule between two or more electrodes deposited on an insulating substrate. The lithographic technique consists in using an AFM cantilever as a stencil mask [1]. A UHV OMICRON STM/AFM head is under modification to accommodate the necessary tools, namely:

A flexural-hinge guided XY nanopositioner stage (100 µm x 100 µm, repeatability a few nm) with a closed loop control based on capacitive sensors in order to allow 'blind' (ie without AFM imaging control) positioning of the cantilever aperture on the sample.

An evaporation system highly collimated on the cantilever

A XYZ positioning system for a metallic microcantilever probes array for electrical measurements on the sample [2]

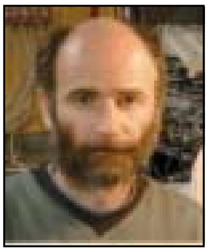
An optical microscope to control the positioning of these microcantilever probes.

The design of this apparatus will be presented.

[1] "Parallel nanodevice fabrication using a combination of shadow mask and scanning probe methods", R. Lüthi, R. R. Schlittler, J. Brugger, P. Vettiger, M. E. Welland, J. K. Gimzewski, Applied Physics Letters 75, 1314 (1999).

[2] "A metallic microcantilever electric contact probe array incorporated in an atomic force microscope", T. Ondarçuhu, L. Nicu, S. Cholet, C. Bergaud, S. Gerdes and C. Joachim, Review of Scientific Instruments., 71(5) 2087 (2000)

*: Speaker



Biographical information

Sébastian Gauthier

Sébastien Gauthier, born in 1956, married, 3 children. "Directeur de Recherche" in "molecular electronics" group at Cemes-CNRS (Toulouse). Current scientific interests : Scanning probe microscopies on single molecules adsorbed on metallic or insulating surfaces. Development of instrumentation for scanning probe microscopies and nanosciences.

ODIN: an Open Distributed Initiative for Nanoeducation

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"It is the supreme art of the teacher to awaken joy in creative expression and knowledge" – Albert Einstein

Times are changing. Education is not what it was 20 years ago – or even 5 years ago. The rapid development of eLearning and a younger generation that is now highly computer literate on entering University set challenging expectations to new education programs. Another trend is that undergraduate education is increasingly expected to stimulate student creativity by engaging students in hands-on research in a real scientific environment.

In nanotechnology, the education challenge is even greater, because the research field is new and rapidly evolving, and there is no consensus on its exact definition, even amongst experts. There is also no established curriculum for nanotechnology in Universities, nor is there a clear pedagogical understanding of how to teach such a multidisciplinary subject, which draws on physics, chemistry, biology, electrical and mechanical engineering, as well as other fields.

Finally, there is an increasing tendency for young researchers in Europe to start or join high tech SMEs on finishing their education. This is a very positive development for European competitiveness, and is highly relevant to the field of nanotechnology, where the distance between idea and product is shrinking rapidly. But this trend sets further demands on a successful education program, which must effectively integrate education about the commercial and entrepreneurial opportunities of nanotechnology.

The aim of ODIN is to address all these challenges, by developing an education and training program in nanotechnology that is not confined to a single University, but instead benefits from the combined strengths of several Universities in the Øresund region that are at the forefront of developing nanoeducation programs. This "core group" will produce the following results:

- a curriculum that is dynamic and diverse enough to keep pace with nanotechnology's rapid development
- a testbed for developing effective eLearning tools that enable geographically distributed students to benefit from local expertise
- a program of hands-on experimental projects that draws on resources distributed throughout a region

It is envisaged that the results of the core group will be disseminated throughout Europe by a range of activities, including

- exchange of personnel between the core group and other European Universities, to ensure the uptake of best practice across Europe,
- extending the testbed to enable eLearning across Europe, and developing a pan-European network of contributors to the web-based education material,
- developing other regional networks of experimental facilities and related programs for nanoeducation,
- Studying the social impact of this education, to ensure that it is effectively adapted to local linguistic, social and cultural expectations.

Biographical information

François Grey

Francois Grey is Vice Director of MIC, the National Micro and Nanotechnology Center at the Technical University of Denmark. Since 1994, he has been group leader of nanotechnology research at MIC, which is based on developing new microcantilever-based tools for nanotechnology. He has helped develop a Ph.D. level course on nanotechnology which involves three universities in the Øresund region. In 2002 he was appointed Professor in Nanotechnology at DTU.

Electron Beam Direct Write- Equipment for Nanomanufacturing

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The Nano- Lithography tool market has recently progressed from limited research and development application into more extensive manufacturing application. As such, a composite growth of 30-40 percent per year is reasonable to assume. This trend is expected to continue for the next 5-8 years, based primarily on strong growth in the IC, GMR magnetic recording, compound semiconductor based wireless communication, and optoelectronics manufacturing applications. The Leica GB-3100 high speed, high resolution gaussian electron beam writer is proposed as a next-generation system for direct write applications for Semiconductor manufacturer to pursue aggressive development plans to safeguard international competitiveness as well as for the new high resolution MEMS/MOEMS. The development and testing of such techniques- under close cooperation between chip manufacturers, toolmakers and advanced research institutes-is thus of strategic importance to the success of the European Semiconductor and MEMS /MOEMS industry. For the same reason, similar activities are strongly supported by government in the Japan and USA. Lithography and related processes are the main driving factor of chip and SOC (system on chip) manufacturing. The aggressive development plans of IC companies force the lithography development to investigate new technology solutions within few years, to continue after the 50 nm node techniques.

Manufacturing and R&D applications have differing requirements. Manufacturing requires high throughput, and fully automated, turnkey operation. By contrast, R&D requires high resolution, while throughput and automation are less important. The most important measure of technical performance concerns the fundamental trade off between resolution and throughput. This basically states that one can obtain high resolution, or modestly high throughput, but not both at the same time. It is highly desirable to have only one technology to perform these basic functions.

The GB-3100 tool represents an important technology step for the future in direct write e-beam lithography applications. Leica will work with Research- and Industrial Partner in a common Development and Application Program funded by German Government or EU including set up a Lithography Application Centre for Nanotechnology / Micromachining for different application on 6 / 8/ 12 inch wafer and Nanostructure with high-aspect ratio and using high sensitive resists (CAR) under industrial aspects. The proposed development program will be combined with leading edge microtechnologies in order to ensure a large degree of application orientation from the very beginning. The BEOL (Back-End-Of-Line) module in IC fabrication is well-accepted as challenging topic for pattern generation with respect to feature size and aspect ratio. This is true for low-volume (highly specialized and flexible) semiconductor fabrication as well as for high-end applications like the damascene approach in combination with copper based metallization and low *k* dielectrics as interconnect technology for IC fabrication. Nevertheless, an application of the e-beam lithography tool GB 3100 should not be limited to IC fabrication. Data storage and nanometric sensing are further challenging applications requiring high density nanometer pattern generation with highest efficiency for a potential mass market. ULSI-NEMS (Nano ElectroMechanical Systems) cannot be fabricated without powerful and flexible pattern generation systems and processes.

Biographical information

Timothy R. Groves

Dr. Timothy Groves is Director of Technology with Leica Microsystems Lithography. He is responsible for Leica's e-beam development programs, spanning Leica sites in Cambridge (UK), Jena (Germany), and Best (Netherlands). He joined Leica in 2000.

Prior to this, he was Senior Engineering Manager for Electron Optics Systems with IBM's Semiconductor Research and Development Center in East Fishkill, New York. From 1983-2000, he was engaged in development of IBM's next-generation e-beam lithography equipment for research, development, and manufacturing applications.

From 1978-1983 he was Member of Technical Staff with Hewlett Packard Research Laboratories in Palo Alto, California, working on e-beam development.

He received his BS degree in Physics at Stanford University in 1968, and his Ph.D. degree in Physics at the University of Chicago in 1975. He is presently Consulting Professor of Electrical Engineering at Stanford University, and Conference Chairman of the Electron, Ion and Photon Beam Nanolithography (EIPBN) Symposium for 2003.

Future research for nano-manufacturing

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Nanotechnologies is today a buzz word but the set-up of a nanotechnology industry is one of the most relevant challenges we are facing. The proof of concept is one of the key steps within the long way from the idea to the industrial realization and performing equipments are needed to validate research results. We know how much some scientific leading results never flew out of the lab due to the lack of available pre-industrial tools. This talk will try to point out some fields of research which could lead to the development of the necessary equipments to validate timely new scientific results in the nano-sized field.

Biographical information

Jean-Charles Guibert

Jean-Charles Guibert is born in 1957. He graduated in 1981 from Languedoc University "Institut des Sciences de l'Ingénieur de Montpellier" in Materials science and then in 1983 from Strasbourg University "Ecole d'Application des Hauts Polymères" in Polymer science.

In the last two decades Jean-Charles has been actively involved the development of lithographic processes at LETI-CEA, one of Europe's largest microelectronics research centres. In 1997 he was appointed microelectronics program manager in LETI. Later he launched the EURACCESS European network program, focused on advanced microelectronics, and the French PREUVE program on EUV lithography. Since January 2001, he has been a major force in the CEA Pôle d'Innovation in Micro and Nanotechnologies (MINATEC) project group, one of the largest European platforms in micro and nanotechnologies, where one of his many tasks is programs and strategic partnerships.

CVD Technology as a Tool for Nanotechnologies

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Quantum well LED and quantum dot laser, sub 100 nm CMOS circuits, as well as organic LED displays are systems using nanotechnology. Chemical vapor deposition (CVD) is a key technology to fabricate these devices.

To facilitate the easy and straight forward transfer from research scale experimental setups to large area substrates for mass production AIXTRON offers the whole scale of CVD solutions from single wafer systems to large scale production machines for up to 95 wafers. The easy configurability of the systems in terms of up-scaling of wafer sizes up to 7×6 inch for phosphide and arsenide compound semiconductor and up to 8×4 inch for nitride compound semiconductor in concurrence with easy maintenance, high reproducibility and high uniformity across the wafer and from wafer to wafer make the AIXTRON systems the ideal solution for mass production of nanostructures. The growth principle common to all AIXTRON MOCVD systems allows the easy up-scaling of established processes to larger configurations, even from single wafer AIX 200 systems to production type Planetary Reactors®.

Add-ons like in-situ monitoring of the growth process by reflectometry or Reflectance Anisotropy Spectroscopy (Epi-RAS®) help in a considerable reduction of the development time and costs, hence improving innovation cycles and the time-to-market of novel devices since the growth of the material can be monitored in real time on a nanometer scale.

Biomaterials, polymers and carbon nanotubes are future challenges in CVD technology for improved systems with more functionality based on nanotechnologies. Our CVD approach to serve the customer needs in research and production will be explained using our in house technology roadmap. The roadmap consists of new materials, improvements of CVD control on a nm scale especially in situ monitoring of quantum structures. A technology will be developed to produce these nanostructures in large scale CVD production reactors to meet the cost requirements maintaining the advantages of the nanotechnology.

The mathematical simulation of the processes will be developed further to allow a better understanding of the technology and to shorten the development cycles of the CVD technology. That requires the introduction of 3D models as well as their experimental verification and their further development.

Biographical information

Prof. Dr. Michael Heuken

Prof. Dr. Michael Heuken was born in Oberhausen, Germany on November 17, 1961. He received the Diplom-Ingenieur degree and the Dr.-Ing. degree in Electrical Engineering from Duisburg University in 1985 and 1989, respectively. He joined the Institut für Halbleitertechnik at RWTH Aachen as senior engineer and has been working in the field of metalorganic vapor phase epitaxy for electronic and optoelectronic devices. In 1997 he joined AIXTRON AG in Aachen-Germany where he is now Vice President Corporate Research & Development. In 1999 he was honored as Professor at RWTH Aachen. His main research interests are in the fields of Semiconductor growth by MOVPE, materials characterization, device technology, electronic and optoelectronic devices and circuits.

Prof. Heuken is author and co-author of more than 300 publications in international journals and several invited papers at international conferences. He is member of DGKK and VDE/ITG and referee for international Journals. He is member of the board of OptecNet e.V. and president of DGKK (German Crystal Growth Association). He has been granted several patents in the field of CVD technology.

Nanofabrication: Exploring equipment for the Top - Down and Bottom-Up Approach

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The availability of nanolithography within the past two decades has enabled tremendous advances in knowledge on function and applicability of nanostructures, not only in such well established fields as electronics and photonics, but also in new areas such as nanofluidics and bio-nanotechnology. Based on the combination of vertical structuring by layered growth with lateral structuring by means of lithography and pattern transfer demonstrations of the feasibility of utilizing quantum and Coulomb blockade effects, spintronics, photon confinement etc. have been possible. At the same time these achievements also show that in many cases the requirements in resolution, accuracy and quantities for realistic applications will amount to sub-10nm structures (and spacings) with close to atomic precision and millions to billions of identical structures working together. While the dream of any fabricator to make materials and structures by building them up from atomic and molecular building blocks, to grow the structures, the bottom-up approach, is being explored in many ways and yet has to lead to tangible results, it appears worth while to push the limits of the top-down approach, since on the one hand there will be immediate benefits for scaling today's applications and on the other hand more near term solutions and further feasibility demonstrations of novel concepts will be available. The ultimate manufacturing solution may involve a combination of both approaches.

While the semiconductor industry's roadmap seriously considers 30nm dimensions to be pursued with extensions of present photon based lithographies and possibly electron or ion beam technology, approaching the 10nm regime will require novel approaches. UV-interference lithography is yielding highest precision in the 100nm regime. Can it be extended to EUV? Can the wave nature of electrons be harnessed? Electron beams certainly exhibit the required resolution. Are there resist materials in which this localized energy can be adequately utilized at a dose that enables reasonable throughput. What are the prospects of parallelism in scanned probe techniques ranging from multiple electron beams to arrays of tunneling tips and cantilevers? Where are the limits of replication and pattern transfer techniques?

Our primary interest and expertise lies in exploring feasibility of parallel electron beam based lithography and metrology schemes in terms of resolution, precision, throughput along with the development of novel resist materials in an interdisciplinary approach involving physics, chemistry and engineering.

Biographical information

Dieter P. Kern

Professor, Physics of Computer Science (Physikalische Grundlagen der Informatik), Applied Physics Department, University of Tübingen

Education: Dr. Kern received his Physik-Diplom and Ph.D. in physics from the University of Tübingen, Germany in 1970 and 1978, respectively. His Ph.D. research was in the area of electron optical design, in particular the development of design methods for field emission systems.

Experience: Since 1971 Dr. Kern has worked on particle optics applications to materials analysis and modification as a research assistant in the Applied Physics Department of the university of Tübingen. After obtaining his Ph.D. in 1978 he joined IBM Research at the Thomas J. Watson Research Center, first as a visiting scientist and after obtaining permanent residency in 1981, as a Research Staff Member. The work was mainly centered around electron optical design for high resolution and high accuracy electron beam lithography systems, electron beam testing systems, also basic modeling of electron beam lithographic processes, including a novel fundamental approach to proximity effect correction, and of reactive ion etching.

In 1982 Dr. Kern became a manager in the Semiconductor Science and Technology department heading a group responsible for high resolution electron beam lithography. His research focused on developing techniques, materials and equipment for ultra small structure fabrication including electron beam nanolithography, beam induced CVD using electron beams and STM, dry and wet etching. He also coordinated and participated in a multitude of collaborations with groups in IBM and in external laboratories to apply these techniques. This work includes exploring the limits of device scaling in silicon MOS technology, transport in ultra small semiconductor and superconducting structures, x-ray nanolithography, diffractive optics for x-ray microscopy and spectroscopy. More recently he was involved in the development of miniaturized electron optical systems, formulating basic scaling rules, developing design and evaluation tools as well as contributing nanofabrication methods.

In June of 1993, Dr. Kern left IBM Research to take on his new position at the University of Tübingen, with research interests focusing on fabrication science and its application to novel structures and devices in physics, nanoelectronics, chemistry, biology and medicine. The nanostructures laboratory established since then provides fabrication and testing capabilities for semiconductor nano-devices, micro-and nanomechanics and miniaturized electron optics based on silicon technology. In addition, scanning probe technologies are explored for device fabrication and characterization.

Macro Magnets and nano/micro - Tools to Investigate New Materials

Dr. Alex H. Lacerda,
Head of Users Program NHMFL, Los Alamos National High Magnetic Field Lab., Pulse Facility Los Alamos National Laboratory,
MS E536 Los Alamos, NM 87545, USA, e-mail: lacerda@lanl.gov

Magnetic field is an excellent tool to investigate the nature of the interactions to better understand new materials. To this end, this talk will focus on recent developments related to nano/micro tools at the National High Magnetic Field Laboratory (NHMFL) to investigate new materials at extreme conditions of high magnetic fields and low temperatures. Taking advantage of recent advances in membrane technology, it is possible to fabricate strong, thin silicon nitride membranes that can be used to fabricate miniature devices for heat capacity measurements. Using these micro-calorimeters we have measured the specific heat of microgram-sized single crystal samples of the first neutral radical molecular organic conductors, which present a structural transition at 350 K, accompanied by an increase in two orders of magnitude in the electrical conductivity. Nano technology and fabrication also played a very important role in the selection of composite materials for wires that will be used in pulsed magnet fabrication. We will also describe recent spectroscopy results related to quantum dot systems. Finally, we will elaborate on the new US Department of Energy Center for Integrated Nano Technologies and the role to be played by the NHMFL.

Nanoscience Challenges in the Chemical Industry

J. D. Londono, K. Stika, G. Blackman
Corporate Center for Analytical Sciences, CRD, DuPont
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Chemical industry giants like DuPont, Dow Chemical and Eastman Chemical are turning to innovation to meet rising expectations of revenue growth from products introduced in the last five years. Nanotechnology is touted as the future source of novel material properties that will be applicable to a multitude of end-uses. Nanoscience is thus expected to develop the control, measurement and understanding that will underpin those new products. This opportunity poses a considerable challenge for analytical science, which supports the development of those new processes and methods. Some of the urgently needed measurement and sensing capabilities do not yet exist, and more stringent expectations are put on established techniques. In addition, nanotechnology creates by necessity an interdisciplinary research environment, which forces communication across old demarcation lines. Further challenges thus exist in bringing competing approaches to synthesis, which often results in unique ideas and original measurement techniques. An account will be given of how these challenges are being met in the industrial research setting.

Biographical information

J. D. Londono

J. D Londono obtained B. Sc. Physics (1985) and Ph.D. Crystallography (1989) degrees from Birkbeck College, University of London. During his graduate degree he worked on the high pressure phases of ice, with extended periods at the Institut Laue Langevin and the Spallation Neutron Source ISIS. He held Research Associate positions at Oak Ridge National Laboratory, and a Research Faculty position at The University of Tennessee. During this period he worked on the structure of supercritical and complex fluids, polymer blends and the structure of molten polymers. Since joining DuPont in 1997, he has worked extensively at the Advanced Photon Source, DND-CAT. He has applied U/SAXS, WAXS, microbeam and grazing incidence techniques to study, for example, the structure of single filaments, ionomers, and fibers in-situ during spinning. He has been an invited speaker and organizer at a number of technical symposia, and has served as a reviewer for NSF and the major polymer technical journals.

Simulation Challenges in Nanotechnology

Jürgen Lorenz
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Fabrication of components and systems on the nanometer scale is faced with both the problems and possibilities emerging from length scales approaching atomic dimensions and, in turn, the microscopic structure of the material more and more influencing its behavior. Simulations based on physical, chemical or biological models are highly important to support the development of the technologies required and the optimization of components and systems.

In this presentation it will be summarized how nanotechnology can benefit from state-of-the-art tools and ongoing developments in simulation, focussing especially on the adaptation and extension of methods originally developed in the well-established field of microelectronics simulation. From these developments, especially models and tools to simulate the generation and properties of nanogeometries, and phenomena leading to the formation and partly even self-organization of atomic complexes and nanoclusters, like Ostwald ripening, are important for nanotechnology also outside the field of electronics. Furthermore, an overview of the extension of optical methods used in lithography towards nanofabrication and -characterization will be given. From this, suggestions for further developments required by nanotechnology will be derived.

Biographical information

Jürgen Lorenz

Dipl.-Phys. Dipl.-Math. Jürgen Lorenz joined FhG in 1983. Since 1985 he is in charge of the technology simulation department of the then newly founded FhG-IISB. His main subjects are the development of physical models and programs for semiconductor process simulation and the required algorithms, in which field he also completed his Ph.D. (Dr.-Ing.). He authored or co-authored about 90 papers. During the last 12 years he has been involved in 17 European projects, of which he acted as coordinator for ESPRIT PROMPT and PROMPT II, the network NEWSSTAND, the ESPRIT User Group UPPER on the development of industrial specifications for process simulation, and currently for IST MAGIC_FEAT on 3D mesh generation and the IST Working Group UPPER+ on industrial specifications for process and device simulation. Following requests from industry he also contributes since 2000 as expert to the preparation of the International Technology Roadmap on Semiconductors, and is chairman for its Modeling and Simulation Chapter in 2002.

Intuitive Analysis of Nanoscale Engineered Devices (NEDs) and Processes

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To support time critical evaluation of issues confronted at the nanometer-scale there is a need to have tools and methods available that enable the user to rapidly explore measurement and engineering/manufacturing options and in identifying other critical problems in a non-intuitive environment. The user can be an engineer, biologist, physicist, or a chemist. To achieve this, one must explore new architectures that support the development of applications that can span across millimeter, micrometer, and nanometer-size dimensions while accounting for the associated physics that govern the device and environ ment interaction at each specific size scale. This work presents a model-centric approach that shifts the focus from the functionality of the application to the ability of the model to adequately represent the key attributes of the device and processes used to measure, engineer, or manufacture it. This promotes the interoperability of emerging applications by separating the core information (models) from what you do with the information. Through the use of virtual reality techniques and these computational models, one is able to present the user with key feedback regarding the nanometer scale device or process in a meaningful, and more intuitive way. Ultimately this capability could serve as a powerful tool to evaluate device produceability and affordability concurrent with initial laboratory successes and concept development.

Self-Assembled Magnetic Nanoparticle Arrays

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Highly monodisperse, iron and iron platinum alloy nanoparticles are synthesized and self-assembled into arrays, and their structural and magnetic properties are characterized.

These arrays have potential applications in data storage, magnetoelectronics, magnetic refrigeration, and biological sensors. There are two critical issues that must be understood in order to realize these possibilities. The first is the self-assembly process. Here the magnetism of the particles provides an additional variable for control, and may be critical for making complex patterned structures and moving particles within nanostructures. The second concerns the magnetic properties of the arrays themselves, and how they differ both from bulk ferromagnets, but also from thin films and randomly ordered nanocomposites.

Monodisperse, surfactant-coated nanoparticles self-assemble into two- and three-dimensional arrays rather than chains because the magnetic forces are smaller than the dispersion forces. We show how different interactions between particles affect the resulting structures of the arrays. The effect of patterning on self-assembly and the possibility of controlling particle orientation and movement is discussed. The magnetic properties of the arrays are studied as a function of the particle size and interparticle spacing. using SQUID magnetometry. Each sample is compared with a dilute sample of the same particles. The results for different particle separations are compared with the predictions of magnetostatic and Anderson superexchange models. The experimental values of the average local field are related to mean field theory calculations to understand collective switching behavior, and the requirements for switching particles independently.

New Tools and Challenges for Measuring Nanomechanical Properties

Director Terry A. Michalske
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The mechanical properties of materials at the nanometer length scale have important implications including the development of new wear resistant coatings, control of adhesion and stiction in MEMS devices, and the exploration of fundamental biological processes. Atomic Force Microscope (AFM) is playing a critical role in exploring the physics of nanoscale deformation. At the heart of an AFM is a passive micromachined cantilever-based force sensor. We are developing actively controlled micromachine structures to provide new approaches for controlling forces and displacements on the nanoscale. The Interfacial Force Microscope uses a microfabricated force feedback sensor to eliminate the stored elastic energy associated with AFM. We are using this new device to make direct measurement of critical deformation events such as dislocation nucleation in solids or confirmation changes in self-assembled molecular layers. We are also designing and fabricating micromachined test devices for measuring nanoscale adhesion and stiction as well as failure testing. Since decreasing the size of the measuring device reduces the noise threshold, one would ultimately want to explore test devices that are built entirely from nanoscale components. This paper will address some of the key challenges associated with current and future needs for mechanical testing at the nanoscale.

Control of manipulation of organic molecules at solid surfaces by infrared spectroscopy

Dr. hab. eng. Jerzy A. Mielczarski
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Monitoring of the formation of organic surface mono-molecular layer and their structure at nanoscale requires the appropriate experimental techniques. For this purpose we have developed infrared external reflection technique that has very unique properties. Infrared spectroscopy is functional group selective, so it is particularly well suited to detect small changes of the molecular microenvironmental properties as those emerging at the interface. There is very gentle interaction of the infrared beam with the examined adsorbed mole-cules, which ensures its stability during measurement. This technique supported by computer simulation of surface composition and structure allows obtaining almost all the information about the adsorbed molecules at interfaces including: (i) the nature of the adsorbed product(s), (ii) the adsorbed quantity of surface product(s), (iii) the surface distribution (uniform layer or patches with determined thickness), (iv) molecular orien-tation of the adsorbed species, (v) lateral interaction between adsorbed molecules, (vi) various kinetic phenomena of the surface processes such as kinetics of adsorption / desorption, stability of the surface products and structures, mobility of adsorbed molecules on solid surface.

There is almost no experimental limitation for system under investigation. Deposition of organic molecules on any type of solid sample can be investigated, from the transparent to non-transparent for infrared radiation. The developed technique has very unique ability to study interface phenomena at a molecular level for heterogeneous and multicomponent deposited organic layer or solid substrates. The variety, precision and reliability of infor-mation about interface phenomena delivered by this technique is incomparable to other single techniques. The experiments are fast and non-destructive. High sensitivity (starting from 20% of monolayer), in situ collected information in a multiphase system even in the region of a strong absorption of substrate makes this technique a very valuable experi-mental tool. The complexity of recorded reflection spectra, their sensitivity to any variations of the optical properties of all investigated phases in the system is in fact the major strength of the technique. The possibility to explore very complex systems is probably the most unique capability of the technique.

Biographical information

Jerzy A. Mielczarski

Current professional situation: Research Director CNRS

Principal scientific objectives:

There are plenty of experimental observations showing that the macroscopic phenomena are governed by interactions at molecular and atomic levels and they are related to the nature and structure of the first produced monolayer.
Study of dynamics and mechanisms of interactions of organic molecules with solid surfaces at molecular and atomic levels in order to modify their surface properties applying self-assembled structures and surface recognition phenomena are major subjects of my work. The understanding of these processes is fundamental to make possible control, modification and prediction of performance of the surface structures and to design efficient nono-scale driven technologies.

I have wide experience in carrying out experimental studies of surface phenomena at nanoscale by the means of different spectroscopic techniques. For this purpose I developed an infrared external reflection technique supported by computer modeling that has very unique ability to study the organic molecules adsorbed at any type of solid surface. The variety, precision and reliability of information delivered by this technique are superior to any other known single technique. The experiments are fast and non-destructive.

The major aim of these studies is controlling and modification of surface properties of solids for different applications. For example selective and consecutive hydrophobization of different components of complex mixture by selective adsorption (submonolayers) of specific organic molecules could provide very economic technology for selective separation of valuable components from gangue. Specific adsorbed sub- and mono-layers structures could have numerous applications in all processes in which interface phenomena play a critical role. They are major processes that take place in nature and developed technologies.

I am author and co-author of 84 papers and 64 non-published reports. I am member of different French, European and American scientific societies. I am member of Advisory Board of journal “Colloids and Surfaces”. I already worked as researcher and professor at different universities in Poland, Finland and the United States.

The US National Nanotechnology Initiative

Dr. James S. Murday
Director, National Nanotechnology Coordinating Office
Head, Chemistry Division, Naval Research Laboratory
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Just as the development of surface analytical tools in the 1960s stimulated the first nanoscience revolution (surfaces/interfaces, where one dimension is constrained to the nanoscale), the development of the proximal probes in the 1980s has stimulated a second revolution where all dimensions can be nanoscale. Worldwide, the science and technology investment in nanoscience/nanotechnology in the coming year will be well over $2B. In fiscal year 2002 the US NNI has approximately $600M invested in nanoscience / nanotechnology, apportioned amongst basic research, grand challenges, networks/centers, infrastructure and societal implications. The continued development of more sophisticated tools for measurement and manipulation will delimit the rate of progress in this second revolution. In response to this constraint, the U.S. National Nanotechnology Initiative has introduced a new Grand Challenge, Nanoscale Instrumentation and Metrology. A January 2002 EC/NSF workshop on Nanomanufacturing identified challenges for nanomanufacturing. A second new NNI Grand Challenge, Manufacturing at the Nanoscale, addresses the need for instrumentation and metrology for product quality control. The NNI is also attempting to create centers and networks that provide ready access to expensive, state-of-the-art, nano-analytical tools. This presentation will provide an overview of the US NNI with special attention to the instrumentation and manufacturing S&T challenges and the new efforts to meet them.

Biographical information

Dr. James S. Murday

Dr. James S. Murday received a B.S. in Physics from Case Western Reserve in 1964, and a Ph.D. in Solid State Physics from Cornell in 1970. He joined the Naval Research Laboratory (NRL) in 1970, led the Surface Chemistry effort from 1975-1987, and has been Superintendent of its Chemistry Division since 1988. From May to August 1997 he served as Acting Director of Research for the Department of Defense, Research and Engineering. He is a member of the American Physical Society, the American Chemical Society and the Materials Research Society; and a fellow of the American Vacuum Society (AVS), and the UK Institute of Physics.

His research interest in nanoscience began in 1983 as an Office of Naval Research program officer and continues through the NRL Nanoscience Institute. He has organized numerous International STM/NANO conferences and their proceedings. Under his direction, both the AVS and the International Union for Vacuum Science, Technology and Applications created a Nanometer Science/Technology Division. He is Executive Secretary to the U.S. National Science and Technology Council's Subcommittee on Nanoscale Science Engineering and Technology (NSET) and Director of the National Nanotechnology Coordinating Office.

Training European Industry in Nanotechnology

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Only high quality training in multidisciplinary technologies will result in aiding innovation in new product designs and manufacturing techniques. Many scientists and engineers working in the fields of precision engineering, micro engineering and nanotechnology are highly specialized. This specialization can prevent the development of multidisciplinary designs that are economic and practical in terms of manufacturing, as these are often the result of 'hybrid' technologies. For SMEs particularly, limited staff numbers combined with specialized training may result in a lack of awareness in alternative and complementary economic technologies. To reduce this problem, euspen is currently developing multidisciplinary awareness-training events and facilities at post-graduate level under a new EC Virtual Institute programme, acronym VISIONONLINE.

These training events will be aimed at future industrial requirements. Therefore there will be seminars in which the latest commercial technical challenges, new market possibilities and problems are faced. Technical topics cover aspects of certain processes for the manufacture of micro- and nanostructured components used in the field of IT technologies, fibre-optics and light guiding systems. On the basis of theoretical presentations and additional practical demonstrations all participants will gain essential know-how of these technologies. The transaction of open forums will increase the efficiency of discussions and the willingness of knowledge transfer.

An important issue in the provision of industrial training is cost efficiency and accessibility to SMEs. Syllabus difficulties arise as the candidates derive from chemistry, physics, engineering and materials backgrounds. Furthermore, many SME candidates are unable to leave their place of work for any great length of time. This presentation will describe the techniques used to best serve this community, including the provision of training prior to major conferences, training weeks geographically spread over Europe and also using on-line versions. The various merits of each and initial feedback received from delegates will be discussed.

Biographical information

Eva Ormrod

Eva Ormrod studied archaeology and earned her first class honors degree at the University of Wales, Cardiff. Since 2000 she has worked as an archaeology research assistant with the 'British Institute in Eastern Africa" in Kenya, Tanzania and Sudan.
Eva received her MSc in Management and Information Systems in 2002 at Cranfield University.
She is currently the European Project Liaison Officer at eu**spen** (European Society for Precision Engineering and Nanotechnology) headquarters. Her responsibilities include marketing and coordinating the new EC Virtual Institute programme, VISIONONLINE.

Industrial Deposition of Advanced Surface Engineering - Nano-Layered Coatings

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A new generation of ultra hard coatings (HV > 40 GPa) can be obtained by creating a specific nano-structure during deposition processes (PVD or CVD). The two strategies more investigated till the moment have been the deposition of nano layers where high compressive stresses are induced by energetic bombardment during the process and the creation of nano-composite layers where a stable nano-structure is produced by segregation of a new phase by spinodal decomposition of the deposited material. In the first case the mechanical properties are preserved till 400ºC, but the nano-composite coatings could keep their hardness and other properties even at 1000ºC.

Nano-layering of Advanced Surface Engineering coatings is in its infancy and shows great potential for producing the next generation of ASE coatings with enhanced properties including enhanced wear and corrosion resistance. By adding nano-layers at or near the substrate-coating interface or other specific locations within bulk coatings or by multilayering coatings on a nano-scale, coatings could be designed to suit specific applications. The properties of nanolayered ASE coatings can show the benefits associated with the types of coatings layered together but the nano-layering leads to properties being enhanced so that the performance is greater than the sum of the constituent parts. The ASE industry could doubtless benefit through Technology Transfer from the microelectronics field and research institutes where nano-coating technology is more advanced. Nano-layers could help facilitate "whole life" design where coatings are utilised and need to be removed for tool or component recycling. One massive potential area of application of ASE nanolayer coatings is in the replacement of Wet Chrome plating which is a huge industry but which produces toxic waste in the form of hexa-valent chromium as dealt with in the EC draft directive "WEEE" 27.7.98.

ASE nanolayer coatings require more research together with transfer into industrial scale production.

Research (and development) required:
ASE Nanolayers are an accident of coating machine design and geometry. (A bold but true statement!) We must turn this around and design and build coating machines specifically optimised for the deposition of ASE Nanolayer coatings. To achieve this, R&D is required to:

- *measure the effect of coating deposition parameters on the physical characteristics of the coating produced.*
- *adapt mathematical models existing for composite materials, so they can be successfully applied to ASE. nanolayers.*

- *combine these measurements and models to produce models to predict the physical (and performance) characteristics of ASE nanolayer coatings.*
- *design and construct coating machines specifically to enable close control of the nanolayer deposition process.*
- *Optimum nanolayer designs for specific applications can then be predicted using the models and can be realised by deposition in a closely controlled manner in purpose built, industrial coating machines.*

This contribution reviews the state-of-the-art of the nano-structured coatings, their advantages in comparison with the actual standard coatings, the difficulties for scaling the deposition processes to industrial production, the problems in the control of processes and in the measurement of nano-structure and properties and the main possible applications in strategic industrial sectors. Some results of EU-funded projects like GROWTH 2000 – 25556 COMING-DRY will be commented in this context.

Biographical information

Rafael J. Rodríguez

Dr. Rafael José Rodríguez Trías was born 26 September 1960 in Pamplona

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Otras publicaciones para la difusión de tecnología:
> 100 artículos en periódicos y revistas de difusión industrial.
(Metalurgia y Electricidad, Ingeniería Química, Industria Internacional…)

Biographical information

Jonathan Housden

Date of Birth: 6th April 1957

Present employment: Jan 1990 – Present.
Research and Development Manager, Tecvac Ltd.
Tecvac is a high-tech Vacuum Engineering company specialising in Surface Treatments. I develop new products from conception into production and improve quality, productivity and profitability of processing equipment and techniques. I represent the company on external R&D programmes, apply for external R&D funding and am Project Manager of several projects co-funded by government and industry. I also manage EU funded research projects with partners in five countries. I support the sales and marketing teams on customer enquiries and applications development and deal with patents and trademarks. I have three technical assistants working with me.

Previous employment:
University of Cambridge Jan 1987-Jan 1990.
Postdoctoral Research Associate, Department of Materials Science and Metallurgy, Laser Microprobe Research Group.
Ph.D. Physics 1980-1986, University of Newcastle upon Tyne.
Junior Technician 1980, Ship-owners Refrigerated Cargo Research Association, Cambridge.
Mud-logger 1980, Exploration Logging Ltd. Oil exploration.
B.Sc. 1976-1979, First Class (Hons) Science

Teaching Experience:
Newcastle and Cambridge Universities.
Tecvac - introducing customers to the principles of Surface Engineering.

From Images to Interactions, and Back Again: Dynamic Atomic-Force Microscopy

Dr. Martin Stark
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The scanning tip used in an atomic force microscope (AFM) allows not only the visualization of objects in the size of single molecules - but also to touch and squeeze, pull and push them. To take advantage of the broad capabilities of AFM, precise knowledge about signal- and contrast formation is essential.

Focusing on dynamic AFM, concepts and methods are presented not only to describe this technique, but also to complete the available set of information about the sample.

Starting from a 1D harmonic model, contrast in phase images is discussed. The influence of rough topographies is estimated from high-resolution images of Protein membranes.

Conceiving the AFM as a multi-dimensional resonator, further parameters like contact duration become accessible.

Eventually, in the framework of Linear-Response Theory, the signal-formation process is inverted to reconstruct the time-course of the acting force. This last step renders dynamic AFM a time-resolving technique that enables to resolve transient phenomena relevant in surface wetting, catalysis, and biochemistry.

Biographical information

Martin Stark

March 2002 – now: Postdoctoral fellowship at the Max Planck Institute of Molecular Cell Biology and Genetics in Dresden. Focus on dynamic force-spectroscopy of single membrane proteins. And: Visiting scientist at the Max-Planck-Institut für Biochemie in Martinsried.

July 2001 – Dec. 2001: Postdoctoral fellowship at the MPI für Biochemie. Focus on structure of dynamic force microscopy.

Oct. 1997: Diploma in physics at the LMU, Munich

Circuit and Structure Fabrication at the Nano Level using X-rays

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Electronic devices – CPUs and memory chips – as well as structures in the 50-30 nm range are difficult to produce except by writing with a high voltage e-beam. This process is slow and expensive. Proximity X-ray lithography(XRL) using either radiation emitted from a storage ring or from X-ray point sources is an alternative to e-beams despite the difficulties in mask construction at nanometer dimensions. With proximity X-ray masks, diffraction effects become a serious factor at feature sizes below 50 nm. Higher energy X-rays can be used to reduce the effects of diffraction, and a DARPA-funded collaborative effort between the Center for NanoTechnology (CNTech), MIT, University of Vermont, JSAL, Mitsubishi Electric Company (MELCO), and Louisiana State University(LSU) is working to employ X-ray energies in the 2.7 keV range with diamond masks to demonstrate the feasibility of printing 35 nm wafer features. (On the International Technology Roadmap for Semiconductors, 35 nm resist features will be needed in 2007 for CPUs and 2013 for memory chips.) CNTech has prepared such a beamline on the Aladdin storage ring at the University of Wisconsin-Madison that can be operated at 2.7 keV(0.46 nm) as well as at 1.55-1.38 keV(0.8-0.9 nm) energy. This beamline will be described as well as the justification for the diamond masks.

Phase masks in optical lithography have pushed circuit dimensions to smaller and smaller values. In like manner X-ray phase masks can be utilized for nano-feature imaging. Two types of clear phase masks will be described. The first is a clear edge phase mask that can produce wafer features in the 50 nm range from very large mask features. The second is a so-called Bright Peak Enhanced X-ray Phase Mask (BPEXPM) that takes advantage of the interference between two edges to produce a wafer feature that is a factor of 5-6 smaller than the coded mask feature. Interference from the BPEXPM appears at much larger gaps than for conventional proximity XRL, and the two phase mask approaches are ideal for device applications where the wafer density is not large, such as CPUs. Experimental verification of the two phase mask approaches will be presented along with modeling results that suggest that the BPEXPM may have applications down to 20 nm features on the wafer as well as applications producing contact holes where modeling results indicate that a 2-D BPEXPM can produce contact holes in the 20-30 nm region with fairly large mask features.

Structures in the 20-50 nm in size range can be produced by utilizing the resist images as a template. Deposition of metals, semiconductor materials, magnetic materials, or layered materials can be accomplished to produce structures of very large height-to-width(aspect) ratios. In this fashion, micro-machining can become nano-machining or the structures can be used for other scientific purposes.

This work is supported by DARPA MDA 972-99-1-0013, MDA972-00-1-0018, and MDA792-01-1-0039. The BAE Systems and Shipley collaboration is as a BAE Systems DARPA subcontract under MDA972-00-C-0004, and the BPEXPM device work is a subcontract to BAE under N00421-02-C-3029. The Synchrotron Radiation Center is funded by the National Science Foundation under Grant DMR-0084402.

The national nanofabrication users network

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The mission of the National Nanofabrication Users Network (NNUN) is to provide the nation's researchers with effective and efficient access to advanced nanofabrication equipment and expertise. The NNUN enables research by providing state-of-the-art facilities, training, and project support. NNUN helps expand the application of nanotechnology by providing technical liaison personnel, and outreach education through workshops and short-courses, and by acting as a bridge between disciplines to create research opportunities that might otherwise not be apparent to specialists in narrow disciplines. NNUN currently consists of two hub facilities on the east and west coasts at Cornell University and Stanford University, and three additional sites at Howard University, the Pennsylvania State University and the University of California at Santa Barbara offering expertise in specific areas.

In the past seven years the NNUN has served users from 40 states and 12 foreign countries. In 2001, more than 1800 users, a large number of who are graduate students, used NNUN facilities in performing their research. Our user population has been growing at a rate ~30% during the past year and doubled in last 4 years. The education of many thousands of graduate students has been made possible by the availability of NNUN facilities. Hundreds of undergraduates have been exposed to a research environment that they otherwise would not have seen. More than hundred small start-ups and large corporations have been able to prototype new product ideas and NNUN has been very successful in bringing research ideas to commercial fruition. I will discuss, how NNUN effectively provides the tools and instruments in the context of the integration of processes. Typically, experiments need to be integrated on numerous such tools and instruments in order to successfully complete an experiment.

Control of nanomagnetic fluids during the production of composite parts components

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A research has started to demonstrate the possibility of obtaining nanocomposites with the aid of the RTM – Resin Transfer Moulding process and the inclusion of nanofluids. The finds obtained so far will be described in the paper together with the problems that will need further research. The idea is to use the magnetic nanofluids mixed with a thermosetting resin and applying a magnetic field which will force the flow in the directions that are needed. The research will have to address the influence of magnetic fluids in process parameters, mainly with cure conditions, as well as the influence in mechanical properties. Being RTM more and more used to produce advance composite materials, particularly for aeronautic applications, there is a need to assure that full permeability (micro and macro) is obtained, to avoid dry fibres and voids), in other words to get a sound part. It will also be necessary to see if the nanomagnetic particles will stay in the structure after cure or if it will force to go to an area that will be cut afterwards. If they remain in the structure a research will have to be made to tailor magnetic properties.

* : speaker

Biographical information

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Born in Porto at 12th September **1950**

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Graduated in Mechanical Engineering (Option Mechanical Constructions) at Faculty of Engineering da University of Porto in **1972.**
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Institute of Mechanical Engineering and Industrial Management - INEGI
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Intermolecular Interactions for Precise Placement and Connection of Molecules

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We use intermolecular interactions to direct molecules into desired positions to create nanostructures, to connect functional molecules to the outside world, and to serve as test structures for measurements on single or bundled molecules. We use and develop scanning probe microscopes to determine both local structures and the electronic and other local properties. We have applied these to isolate molecules with electronic function to determine the mechanisms of function, and the relationships between molecular structure, environment, connection, coupling, and function. We have been able to demonstrate that single molecules can function as multistate switches, and have determined important aspects of the mechanism, function, and persistence of switching. We will discuss the origins of switching and the relevant aspects of the molecular structure and environment required.

We apply selective chemistry and self-assembly in combination with conventional nanolithographic techniques to reach higher resolution, greater precision, and chemical versatility in the nanostructures that we create. The key to these approaches is using precise, robust molecular layers that attach selectively to specific patterned substrate materials. In one approach, we apply precise-thickness multilayers (termed "molecular rulers") to nanolithographically created structures and use these multilayers as resists for lift-off. The thickness and thus the spacing of the resultant structures can be controlled down to 5 nm, with control to 1 nm or better. We have demonstrated this approach both with e-beam generated structures as well as those based entirely on self-assembly. An additional advantage of molecular rulers is the inherent capability to displace the molecular resist chemically, and thus to remove the resist material simply and completely. We can also use molecular rulers with carefully designed parent structures to create complex structures that would be difficult to generate by conventional means. These can be made still more complicated by the selective application and use of sacrificial intermediate or parent generation structures. We will discuss our approaches to pattern design and creation using this method. Another approach involves forming nanostructures and then chemically functionalizing them selectively to produce substrates with patterns in chemical and physical properties. These can be used for further selective patterning, or as bases for molecular devices and device arrays. Of particular concern in reacting such structures is the role of the reaction exothermicity in heating and modifying the underlying nanostructures. Our molecular-scale measurements of this process, and approaches to circumvent such problems will be presented.

4th Joint EC/NSF Workshop on Nanotechnology

Tools and Instruments for Research and Manufacturing

Workshop – 12-13 June 2002 – Grenoble (France)

Abstracts - Posters

(ordered alphabetically by author)

Potential of interferometrical lithography with large molecules

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In recent years matter wave optics has experienced a tremendous progress in both atomic and molecular interferometry. We suggest to investigate the feasibility of nanoprobe techniques as detectors in molecular quantum interference devices as well as the use of molecular de Broglie interference for the production of nanostructures.

Our own experiments with fullerenes [1] have shown that perfect interference with large and hot objects in the 1000 amu region is feasible and we are currently expanding this technique to more massive and more complex objects, like peptides and proteins. While we can currently produce regular patterns with 1000 nm period using near-field interferometry we hope to push molecular lithography to structure sizes down to 50 nm or below. One advantage of quantum interferometry, in contrast to simple shadow imaging using masks, is the fact that the masks may be much more robust since near-field interferometry can lead to a size reduction in the imaging process.

Molecular nanostructures are currently discussed with respect to several novel technologies. Arrays of endohedral fullerenes – e.g. C_{60} filled with an atom that possesses a nuclear spin - , have been proposed as potential systems for quantum computation [2]. Regular structures of organic molecules on surfaces may lead to data storage elements, nanoscale optoelectronic devices and (bio)-chemical transducer elements [3].

Taking up this general idea, we are currently starting to explore the potentials of quantum interferometry for the deposition of regular molecular arrays, which may be complementary to SPM manipulation methods used so far [2,3].

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Magnetron sputering in coating technology for the production of nanocomposites

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There are many research areas in nanoclusters and nanocomposites produced by Magnetron Sputtering and other Physical Vapour Deposition Techniques. We could find four main current groups of interest according to their final applications.

1 - Mechanical applications (Tribology)
2 - Catalytic applications.
3 - Energy
4 - Other applications

Within the mechanical applications we have:

a). The new SUPERHARD MATERIALS with relative hardness in the order of diamond.
b). Low friction tribological coatings
c). Combinations of composites HARD and TRIBOLOGICAL coatings.

All these three mechanical applications lack of maturity. There is certainty about the need of such kind of coating materials which find uses all across the main manufacturing processes, transport, etc.

Within the catalytic applications we have:

a). Industrial catalytic chemical reactions.- MAIN aim substitution of precious metals by atom clusters with desired catalytic properties.
b). Photochemistry - MAIN aim to use solar induced selective reactions and to mimic some "nature" processes.
c). Bioinorganic - MAIN aim will be to mimic some "nature" processes and recations where some metals or inorganic structures are involved.

Within the Energy sector applications:

a). Regeneration of fuels and fuel cell reagants - AIM to regenerate fuels and the reactant for fuel cells in a low cost basis, partly using solar energy and photosynthesis and party by low energy catalytic routes.
c). Photovoltaic devices - AIM to increase the solar cell efficiency.

Other applications:

a). Optical, decorative and safety, for example high intensity colour pigments, interference colour pigments,...
b). Instrumental, such us gas and electrochemical probes. AIM to increase the number and sensitivity of selective probes for better process control.

Our vision is that...

The decline in current global energetic resources will drive most of the strategic research in the industrialised countries. The increase in demand for energy and energy saving methods for all, but especially for developing countries, will force the EU to be an energy technology provider. At the same time the EU will have to increase its energy independence from non-EU resources. Additionally ISO 14000 production methods will be extended across the EU with quality, energy and environmental issues forging the future transformations of our industry and business ethics with other countries and industries.

Devices based on complex materials: growth control and manipulation on atomic level

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In this presentation new quantum-functional materials and devices, based on correlated electron systems will be discussed. With a 'correlated electron system', we mean a state in which the charge-carriers have a strong interaction with each other, leading to long-range ordering. This order can be (ultra fast) influenced by external stimuli, which may cause large changes in e.g., electrical, magnetic and optical properties. These effects become even extremely large if one can realize them in systems of which the dimensions approach the characteristic length scales of the long-range order, which is often in the 1-100 nanometer range. This research involves new materials and requires the integration of nano-dimensions and nano-techniques. 'Nano' in this case can refer to the dimensions of the structures, film-thicknesses, or the precision aimed at in certain operations. We will discuss the need for nano-technology for materials, which will provide the ability to work at a molecular level and to control and use the fundamental 'building blocks' that have specific physical and electrical properties.

Integrated optical in situ characterisation methods for MEMS manufacturing

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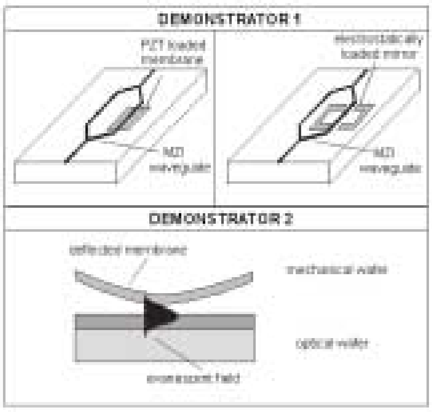
The last decade is characterised by impressive progress in manufacturing processes of MicroElectroMechanical Systems (MEMS). While testing electrical properties in microsystems is a well-developed art, the testing of mechanical properties of MEMS-based devices is not. For this reason, there is a great need for techniques that will permit the

evaluation of MEMS subassemblies and finished products. This need to be made in all stages of manufacturing, with respect to material and micromechanical properties. Optical testing methods offer the advantage to do not influence the mechanical behaviour, neither do they require the attachment of monitoring functions to the moving parts of the micromechanical system. Integrated Optics (IO) offers the possibility of monitoring behaviour at condition of integrating the testing functions. IO can monitor only at definite points of the mechanical structure, often giving information about an average over a small lateral area also affording for a high longitudinal resolution.
In this contribution we will focus on a new approach, based on various opto-mechanical demonstrators, covering the successive steps of manufacturing. Table 1, shows the architectures of proposed on-chip demonstrators covering the process optimisation and the long-term behaviour evaluation. Both the demonstrators will be based on actuated MEMS structures (vibrating membrane and rotatable micromirror) monitored by use of IO read out based on a Mach-Zehnder interferometer (MZI) monolithically integrated into the micromechanical part (Demonstrator 1). In this case silicon oxynitride will be applied as a core waveguide material to achieve relative small refractive index contrasts (SiON sandwiched between two SiO_2 layers). Demonstrator 2 will show how displacements that are associated with vibrating membranes or micromirrors can be monitored by using evanescent field based MZI read out, containing two Si wafers (one containing the mechanical system, the other the integrated optical chip). In this case silicon nitride will be applied as a waveguide material to achieve large refractive index contrasts, producing the refractive sensing (Si_3N_4 on top of SiO_2 layer) or absorptive sensing (free standing Si_3N_4 beam).
This approach will be validated industrially by implementing of proposed methodologies in microsensors for avionics.

Table 1



Optical Probes for Nanomanufacturing Technology

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Companies producing epitaxial semiconducting devices face an increasing pressure towards higher yield, higher throughput and reduced time to market. At the same time the complexity of semiconductor technology structures increases, yielding more stringent requirements on tolerances and uniformity.

To meet these requirements and to be able to scale up to larger substrate diameters in situ or at least in-line embedded sensors have to be used. In industrially used MOCVD environments, or in flow cells only optical (including X-ray) techniques can be used to monitor and possibly control the deposition process and the fabrication of the actual devices, because they are nondestructive and there is no steric hindrance. However, their main disadvandtage is that the information obtained is indirect.

Different materials and different device structures (nanocrystalline materials, colloids, polycrystalline silicon, 2D and 3D photonic crystals) will require parallel and fast techniques able to assess their nanoscale physical properties with *macroscopic* measurement devices. For photonic crystals, losses in 2D waveguides in photonic crystals are still the key issue arising from 3 sources[1]: a) scattering losses at imperfections, b) out-of plane losses, and c) losses caused by TE/TM coupling.

In the contribution it will be proposed, how "ordered" roughness on length scales much less than the wavelength λ can be well estimated by spectroscopic ellipsometry, respectively by a complete polarimetric characterization Mueller matrix (MM) ellipsometry, relating the 4 components of the Stokes vector of the incident light to ($I_x + I_y$ (= I_0), $I_x - I_y$, $I_{+45} - I_{-45}$, $I_L - I_R$) to the Stokes vector of the reflected light. Recently, two designs have been proposed for either a complete Müller matrix measurement[2,3] for specular reflections as well as a 3 axes optical scatter instrument for out of (incidence) plane ellipsometry measurements[4]. The later design would in principle allow to perform polarization measurements within all solid angles (comparable to a three axis X-ray diffraction measurement).

After the presentation it should be discussed with other participants if such measurement devices can prove useful for characterization of which kind of nanostructures.

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Silicon etching processes for nanostructure fabrication

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Silicon etching processes were studied and developed in the Nanotechnology Center from IMT-Bucharest with the aim to obtain nanostructures for various applications. Thus, by electrochemical anodisation process, different porous silicon structures for light emission or electron emission and for biomedical applications have been realised; by isotropic and anisotropic wet or dry etching processes we have obtained pyramidal or conical structures for electrochemical nanoelectrodes and for field emission devices. The silicon etching processes used for different nanostructure fabrication are relative chip; they don't involve complicate and expensive equipment.

Using these processes, during the next years (2002-2004), we intend to develop the following two projects:

(a) "Porous silicon matrix obtained by electrochemical anodisation process for applications in biology and for controlled drug delivery"
Porous silicon structures, by appropriate control of pore size and porosity, can cover virtually the entire bioactivity spectrum.
The objectives of this project are:
study of cell culture growth on the surface of the microporous silicon;
study of mesoporous silicon implant for controlled drug delivery "reservoir".
Micro- and mesoporous silicon structures will be prepared by electrochemical etching process.

(b) "Bio-chips obtained on silicon etched substrates for the detection of biological media electrochemical activity"
Isotropic and anisotropic wet and dry etching processes will be used for pyramidal or conical nanostructure fabrication.
An array of nanoelectrodes (NE) was built on a chip for cyclic voltammetry pollution control measurements. The electrode array conception and design were done by the National Institute for Research and Development in Microtechnologies (IMT - Bucharest). Some of the technological processes were effectuated at the Institute of Microtechnology Mainz (IMM) under the project no. HPRI-CT-1999-00023 funded under the IHP-Programme of the European Commission. This technology will be particularly adapted to allow the fabrication of nanoelectrodes for biological purposes; we intend to realise a biochip for investigation the electrochemical activity of the bacteria.

Electrochemical deposition of thin film alloys

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Electroplating is a common, cost effective technique for the mass production of functional coatings. With applying pulse electro-deposition (PED) technique one can produce pure metal, alloy coatings and multilayers at ambient temperatures from aqueous solutions.

Research Plan

- Development of a process to deposit Ni, and Zn-Ni coating on a suitable metal substrate from an aqueous solution bath containing different complexing agents and inhibitors aiming to minimize the grain size of the metal coating. The final goal is to develop a precise process for the deposition of nanostructured layers of Ni, and Zn-Ni-alloys with an average grain size less than 50nm.

- Application of stripping techniques for fast determination of both chemical and phase composition of electrodeposited zinc- nikkel alloys.

- Determination of surface and physico-chemical characterization of nano-structured layers using X-ray diffraction procedures, Scanning Electron Microscopy (SEM) and Atomic Force Microscopy (AFM).

The alloying of zinc coatings by Ni improves the corrosion resistance and the lifetime of the coating. Using Zn-Ni coating ensures appropriate corrosion protection even in a thinner layer. PED technique, which is applied for the deposition improves further the properties of the alloy coating by increasing the mechanical strength and corrosion resistance.

Preliminary experiments are also carried out for the production of multilayered magnetic structures with ultrafine alternating magnetic and nonmagnetic layers (Fe / Cu multi-layers).

Description of current work

Recently we have been working on the deposition of nanostructured Ni and Fe coatings. In the frame of this research work the solution composition (special attention to the additives), the temperature and the impulse parameters are examined as a function of the grain size and the reproduction of the results. The deposited layers are qualified by different methods: surface analytical, electrochemical techniques (cyclic voltametry and cronoamperometry). The mechanical examination of the coating was also investigated. For this proposes, nanoidentator was used to measure the hardness of the nano nickel layers.

The nanostructured Ni passivation and the growing kinetic of the passive layer are examined in alkaline aqueous solution.

The anodized nanostructured Ni coating is good catalyst for anodic oxidation of alcohol in alkaline solution. It is expected that the nickel –oxide film could be applied as a sensor for the amperometric determination of aqueous ethanol samples.

Furthermore we deal with production of nano-iron onto different substrates in thick layer by the previously mentioned electrochemical way. In order to get nano-iron with special magnetic properties, the 3-5 nm grain size should be reached. Currently we are working on to reach this very low limit by the modification of the composition of the solution and increasing the pulse current.

Nanomachining by focused ion and electron beams

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Focused Ion Beams (FIB) and Focused Electron Beams (FEB) allow local structuring of nanodevices. Direct sputtering by ions or beam induced chemical reaction are applied to locally remove or deposit material. It offers a fast and well controlled way to realize even complex nanostructures. This method allow the generation of nanostructures with lateral dimension well below 100 nm and high aspect rations (>10) even on samples with pronounced topography, not suitable for lithography based structuring. Control of beam induced machining can by done by in situ secondary electron imaging. This approach of ion/electron beam nano processing is especially suitable for prototyping of nanodevices.

In this contribution, we will introduce some applications of ion/electron beam induced processing we have developed. Focused ion/electron beam nanomaching allows the fabrication of tailored scanning nanoprobes, like AFM based SNOM probes, microwave nanoprobes, or field emitter structures for vacuum electronics. From these applications, some technical limitations of beam induced processing will be discussed. Today, beam parameters, depletion of chemical precursors, angle dependent processes and scattered particles limit the resolution laterally to 20 to 50nm. Beam induced damage has to be controlled as well as parasitic chemical processing. Optimized pattern sequences and strategies for material removal and deposition are a key issue.

A short outlook will stress the potential of this technique and further requirements for research and development to overcome today's limitations will be addressed. Especially the beam induced processes has to be further investigated with respect to improved materials properties, reduced parasitic effects and lateral resolution. E-beam based processes still lack some critical etching steps.

Extending the Capabilities of Scanning Tunneling Microscopy

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We strive to gain an atomic-scale understanding and control of materials properties by exploring, probing, and manipulating interactions and dynamics at surfaces and interfaces. We use and extend scanning tunneling microscopy (STM) to explore the structures, motion, and perturbations on surfaces due to adsorbed atoms and molecules and due to surface features such as substrate steps and defects. This has required the development of new tools with atomic-scale views of the surface. We have developed a high frequency (GHz) alternating current (AC) STM for semiconductor dopant profiling with nm resolution, a photon emission STM for characterization of nanoparticle systems, and digital image processing techniques to characterize the temporal behavior of single molecule electronic devices. We measure and characterize surface bound or adsorbed nanometer-scale features with the high spatial resolution of STM and the additional information (e.g. electronic properties, chemical environment) gained from our hybrid tools.

Approaching large scale production of nanomaterials

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The interesting properties of nanophased materials but also the processing possibilities offered by mechanochemical and other routes, allowed already the instalment of significant nanomaterials productions.
The applications of nanomaterials on a large scale of components could follow two (possibly in part converging) lines: 1) large volume production of nanomaterials powders and development of integrated approaches to consolidation and forming (Integrated Nanomanufacturing Chain for Nanomaterials: Nanochain); 2) micromanufacturing of Engineered Nanomaterials and components.
The two lines will be discussed, with reference to a running reseach background, in view of extending and implementing a large scale Nanomanufacturing of either materials (high volume) or components (micromanufacturing).
The Nanomanufacturing chain (Integrated Nanomanufacturing) for Nanomaterials includes: a) synthesis of the nanomaterials in ordered domain sizes below 10-20 nm either as individual particles or agglomerates of crystals up to the size of microns; b) hierarchical assembly to sizes in the mm scale. Whereas the first issue is variously addressed by a number of processes and companies the second one constitute the actual, main, bottle neck to mass production of semifinished nanomaterials products. The hierarchical assembly of nanomaterials could be classified in the following main steps: 1) particles treatments for controlling stability and processability; 2) consolidation to obtain a fully dense solid, in dimensions in the mm scale or above; 3) shaping the consolidated

material in beneficiated products; 4) net shape consolidation and forming (alternative to 2 and 3).
Materials represents in general combination of properties. The control by the processing routes of such combination of properties is almost negligible, since usually the approach is to look to the existing materials available, merging then the combination of properties closest to the desired application. This produces: 1) the existence of large "holes" in the properties space of materials (for example in density versus elastic limit); 2) a very low level or none of engineering the materials facing the applications. Nanomaterials may constitute the necessary base for micromanufacturing resolved in the micron scale, also thanks to the structure definition allowed by nanomaterials. Micromanufacturing using nanomaterials, for example by Laser sintering, may open the way to large scale micromanufacturing facilities and machines, for production of micromponents. Full engineering of both components, materials structures and gradients could be achieved by proper development of materials design methodologies and tools.
Both the approaches (Integrated Nanomanufacturing and Engineered Nanomaterials), at different scales, constitute a progress toward a more knowledge based production. Life cycle and environmental sustainability analysis can constitute part of the materials design considerations. High precision production equipments and production of microsystems are the purposes addressed in the Engineered Nanomaterials approach.

Software solutions for simulation and interpretation needs at the nanoscale

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Nanotimes is a nanoscience and nanotechnology software solutions and services provider.

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- to help develop nanotechnology research tools and activities
- and become a major industrial actor in nanoscience software development.

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Field Configured Assembly of Functional Mesoscale Devices

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Mesoscale components are an important class of functional objects whose dimensions span a range of length scales intermediate between that of individual molecules (nanometer scale) and that of macroscopic objects (millimeter scale and above). Mesoscale components therefore represent a family of objects that exploit many different materials systems, are synthesised or fabricated using a diverse array of tools and that exhibit a wide range of chemical, biological and physical properties. Typical examples include macromolecular polymers, supramolecular assemblies, nanocrystals, nanowires, micron-scale colloidal particles, biological cells and discrete semiconductor components such as resonant tunnelling diodes, light emitting diodes, vertical cavity surface emitting lasers and micro-opto-electro-mechanical devices with dimensions of up to several hundred microns.

A critical challenge in the development of new integrated systems that exploit mesoscale components as active device elements is the availability of novel substrates and integration tools that enable manipulation and assembly of mesoscale components into dense multifunctional arrays in which components interface with each other and with the macroscopic world.

In addressing the assembly challenge, recent advances have led to the development of many novel "bottom-up" synthetic and "top-down" fabrication strategies capable of creating ordered mesoscale component arrays with a wide variety of tuneable properties. To achieve molecular self-assembly chemists often exploit interaction paradigms observed in biological systems such as shape-complementarity, hydrophobic or hydrogen-bonding effects. Self-assembly of mesoscale component arrays with length scales on the order of several microns or more has also been demonstrated using these principles by tailoring or pre-programming the structure and functions of mesoscale components during synthesis so that under appropriate conditions components self-assemble themselves into ordered 1-, 2- and 3-D architectures. Other alternative types of mesoscopic phenomena, operative on length scales characteristic of the dimensions of larger sub-millimeter components, for example, have also been exploited to assemble ordered mesoscopic architectures. These include electromagnetic, fluidic and capillary effects.

However, for many future applications of mesoscale components, demonstration of organization and self-assembly approaches to ordered 1-, 2-, or 3-D mesoscopic architectures alone will not suffice. **New combined approaches to assembly *and* heterogeneous integration of mesoscopic components are required whereby components may be assembled into multifunctional mesoscopic arrays on active substrates that permit direct connection to each of the components for either selective component addressing or collective read-out of array status.**
To this end, silicon might be considered as the substrate of choice for assembly and electronic addressing of mesoscopic components given the maturity of microelectronic device large-scale integration technologies. The versatility of silicon processing methods enables rapid development and prototyping of a wide range of component assembly substrate options allowing optimization of, e.g., electronic circuit architectures for interfacing of densely integrated component arrays or component- and assembly-compatible chip substrate surfaces, etc.

Examples of functional mesoscale systems successfully integrated on addressable silicon substrates are already available. These include patterned DNA and biological cell arrays for high throughput sensing in genomics and drug discovery, nanocrystals and nanowires assembled as functional elements in nanoelectronic devices and longer length-scale integrated devices such as resonant tunnelling diodes for high speed logic or memory applications, light emitting devices for optical communications and mechanical components for microsystem applications.

To address the future challenges of fabrication of densely integrated mesoscale systems, our work focuses on development of novel programmable self-assembly approaches to parallel heterogeneous integration of functional mesoscale components (with diameters of 1-100 µm and widths of 1-10µm) at technologically relevant interface substrates (e.g., silicon). To this end, we have developed a new "hands free" programmable force field method for component integration whereby electric fields, configured by selective addressing of receptor and counter electrode sites patterned on a chip substrate immersed in an appropriate solvent, drive the electrophoretic transport, positioning and localisation, i.e., self-assembly, of components at each selected receptor site.

To demonstrate the broad applicability and potential of this novel method, a range of mesoscale components including 1 µm diameter carboxylate modified latex spheres, 50 µm diameter GaAs discs and 80 µm diameter GaAs-based LEDs have been successfully manipulated on-chip using programmed electrophoretic force fields. Furthermore, following field configured assembly, active optoelectronic devices such as LEDs have been permanently bonded to each respective receptor site thereby facilitating direct electrical addressing of components either individually or collectively in an array format.

These results constitute the first demonstration of rapid field programmable self-assembly and heterogeneous integration of sub-100 micron size III-V optoelectronic devices at silicon substrates. The potential of the method for further application to the high-throughput manufacture of future hybrid integrated nanoelectronic, photonic and biotech systems is now under investigation.

Atomic Scale Modelling of nanotechnologies : Thin Film Gate Oxide Simulation

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The European network ATOMCAD "Linking Micro and Nano Technology CAD Tools to Conventional Packages"is dedicated to the atomic scale modelling and simulation of NanoTechnology processes. In this paper, we present the case of thin film oxide gates for future MOS transistors.
The reduction in size of microelectronic devices, down to 50 nm in feature size and 1 nm in thickness, necessitates the development of atomistic TCAD tools. At these sizes, the conventional tools based on empirical macroscopic mechanisms are no more valid. They can only be adapted by the use of a large number of adjustable parameters restricted to a small range of experimental conditions and depending on the particular experimental set up.
We have developed atomistic simulation packages by using a series of hierarchical models. Ab initio quantum calculations allow the determination of basic mechanisms involved in the process while the Monte Carlo technique is used to reproduce actual experiments. We will show how basic mechanisms and their related parameters can be found from ab initio calculations, as an alternative to experimental results, where these latter are not easy to obtain. We will then discuss the use of the above parameters in Kinetic Monte Carlo simulations to determine physical properties of materials, such as their structure and the nature and concentration of defects, as a function of experimental conditions.

The New Institute for the New Science

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The Institute of Nanotechnology (see www.nano.org.uk) acts as the focus for nanotechnology Europe-wide, has over 1,500 members, a database of over 10,000 nanotechnologists and a website that receives over 1 million hits per month.

The Institute is a unique source of information on nanotechnology. We hold leading-edge conferences for scientists, investors and business, whilst providing up-to-the minute reports for business, banks and government organisations. As a membership organization, our members benefit from access to extensive nanotechnology briefings and analyses, via password-protected areas of the IoN website.

The Institute is also is currently poised to lead a pan-European nanotechnology 'Network of Networks', Nanoforum, funded by the EU to the tune of 2.7 million euros. Supporting partners will include the VDI-TZ (the futures division of the German Association of Engineers), CEA/Leti (the research arm of the French Atomic Energy Authority), and CMP-Cientifica, co-ordinators of the Phantoms network

The Institute is also assisting with the development of projects eligible for funding through the EU's 6th framework programme. We would be pleased to help organisations develop their proposals for FP6 through identifying appropriate partners.

A further key strength of the Institute is its ability to bridge between the research, industrial and financial communities in order to accelerate technology transfer and the development of new European nano-businesses.

Our recent presence in Australia (see www.nanotechnology.com.au) will act as a spring-board to the far East, as the IoN looks forward to making this an important step in bringing the nanotechnology communities of Europe, the Far East and Australasia closer together.

Activities this year include a hugely successful follow up to the ground-breaking 2001 meeting 'Investing in Nanotechnology', where delegates sought to understand the economic potential of nanotechnology for industry. Such was demand for access to the second Investment conference in March 2002, that the event was webcast in order to satisfy the Institute's growing international membership base.

More recently, a 2-day conference, 'Nanotechnology - The Next Industrial Revolution?' held in Edinburgh, April 2002, created a rare opportunity for delegates to learn how nanotechnologies are already impacting industry today.

For further information, see our website http://www.nano.org.uk or contact Del Stark, del@nano.org.uk

High-resolution imaging and temperature measurement technique in micro-engineering

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Micro-Electro-Mechanical Systems (MEMS) are an emerging, cutting-edge technology, which relies on micro-fabrication of small-scale mechanical components and integration of those components with on-board electronic processing. According to a widespread opinion MEMS and/or NEMS (Nano-Electro-Mechanical Systems) devices are likely to dominate in the future and will be used in such diverse applications as gas and pressure sensors, accelerometers, chemical analytic ``microlaboratories", and airborne ``nanosatellites". MEMS offer tremendous possibilities for volume, mass, and power consumption reductions in spacecraft as well as Earth-bound applications, ranging from simple integrated sensors to micro-pumps to mechanical fibre-optics switches. In spacecraft, miniaturization offers the potential for new levels of redundancy, allowing for more long-term reliability and autonomy.

Multiple approaches for improving MEMS tribological performance are available. Surface coatings can provide both lubrication and hydrophobicity to combat adhesion, and hard coatings may be employed to reduce wear rates. The base material from which the MEMS structures are formed could be potentially modified in order to provide native surfaces with better tribological characteristics. Optimisation of the micro-engineering technology requires a novel method for imaging and temperature control of micro-parts and micro-devices to be fabricated.

Recent achievements in the development of CCD sensors give an opportunity to provide a high spatial resolution (~1 μm) fast (~1 μs) imaging technique for on-line monitoring and temperature control of the MEMS fabrication process. This imaging technique will feature a high readout rate of >20 MHz and will be able to integrate images on the CCD from 1 μs up to 10 minutes with 12-bit digitisation. It will provide a flexible high quality imaging solution where high-speed digital imaging and operational flexibility are required. RS232 (or fireware) digital output will ensure compatibility with a large number of commercially available frame grabber boards and industrial computers. In addition, special high quality lens coupling allows easy connection to optical microscopes. Fast electronic shuttering, fast readout and low noise integration all combine to make this imaging technique suitable both on-line geometry control and temperature mapping. Internal Peltier cooling system (-20 °C), hermetically sealed and dust protected head is cooled too, reducing dark noise and minimizing thermal drift will ensure high accuracy and stability of this camera in various industrial applications.

The idea of application of the CCD sensor for temperature measurement is realised in various types of the so-called Thermo-Vision Systems (TVS). Unfortunately, existing TVS are relatively slow and their spatial resolution is not high enough to be applied for micro-objects monitoring. It is caused by rather sophisticated nature of measured signal – a charge of an individual pixel of a CCD sensor. The value of the charge depends mainly on light intensity and accumulation period. In reality, it depends on several other factors as well :
influence of neighbouring pixels ;
matrix temperature stability ;
depth of electron hole for each pixel ;
geometrical distortion for each pixel, difference in sensitivity ;
charge drippage and noise;
CCD linearity. Typical Charge-Coupled Device is a non-linear unit.

To reach high accuracy in temperature measurements all these problems should be taken into account. The light intensity for a small object (like micro-parts of MEMS) is very low

even for a relatively high temperature. Nevertheless, modern trends in CCD sensor design give a chance to develop a TVS characterised by high sensitivity and spatial resolution. The complete system should be supported by a software to achieve the following metrological goals :
calibration of a CCD matrix : individual pixels sensitivity, noise and geometry distortion, neighbouring pixels influence. Calibration should be done both for static and dynamic measurements;
Choice of a group of pixels to be used for signal averaging. This approach allows to reach required accuracy in charge (light intensity) definition.

The proposed imaging technique will be supported by a special software allowing fast data transfer, recording, image treatment and results presentation (for example, temperature maps for fabricated micro-parts). The software will be created employing the modern technology of software development – LabWindows/CVI from National Instruments. It will include the following main modules:
Micro-processor supporting module for CCD camera control ;
Operators module for process interactive monitoring ;
Module for the grey image analysis and reconstruction of temperature maps.
Pixel-by-pixel 12-bit (or even higher) digitalisation of CCD matrix signals will be applied in diagnostic system. As a result, each frame will be presented by all the pixels intensities recorded in a data file. The grey scale video image will be based on this data file. Micro-parts will be presented in this video image as light regions with different dimensions and intensities. Special algorithm (the so-called sub-pixel resolution) in combination with the fine procedure of calibration of optical distortion and nonuniformity of the CCD matrix allows reaching 1 μm resolution in the object size measurement. The temperature precision of the diagnostic system could be about a few degrees.

Potential fields of application of the proposed imaging system could be really wide – starting from the quality control in MEMS production and up to the nano-tribology. Micro/nano-tribological phenomena are essential to understand wear mechanisms of the microparts friction. Atomic force/friction force microscopes (AFM/FFM) are applied to study surface topography, adhesive force, friction, scratch resistance, wear resistance, lubrication, and mechanical properties applying small scales and light loads. Nevertheless, one of the important factors – temperature within the contact zone – cannot be analysed by these instruments. The proposed imaging technique could be applied to detect both average temperature values and the so-called temperature flashes leading to intensive material wear and destruction.

Another important application field is the temperature control and optimisation of nanostructured coatings deposition. The optimum temperature ranges should be provided both for the substrate (micro-parts to be coated) and for the coating itself (including the cooling stage) to reach the required nano-structure and functional properties.
The improved performance of friction joints may be realised by the development of advanced high-performance Solid Lubricant Coatings (SLC) through materials engineering approach in which required properties will be finely tuned by :
designing an appropriate matrix for the solid lubricant as a high performance material: nanostructured, functionally graded ;
synthesising of nanophased powder materials to be applied for coating fabrication.

Essential for the deposition process to be applied, would be the definition of an appropriate deposition strategy, which would respect the nano-phased structure of powders being used. The discussed above imaging system could be applied to measure particles in-flight temperature, velocity and size in High Velocity Oxygen Fuel spraying that is characterised by high particle velocities (up to 700 m/s) and relatively low temperature, therefore allowing minimising damages to structure of materials due to crystal growth.

Nanoimprint Lithography: an alternative nanofabrication approach

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The need for accessible, flexible and low-cost nanofabrication techniques is becoming increasingly acute as fast developments in the general field of nanotechnology demand smaller and smaller structures in a variety of materials.

Nanoimprint lithography (NIL), with its apparent simplicity and resolution down to 6 nm, has become a preferred technique for one-level nanopatterning of thin films, which themselves act as a mask for further nanofabrication steps, or which can be used as-printed thanks to the functionality of the thin film itself.

We review the progress of NIL and compare it to other alternative nanofabrication techniques. Throughput, resolution and issues affecting critical dimensions will be discussed.

The use of NIL to realise passive optical devices over several cm^2 and organic electronic devices down to 30 nm will be demonstrated. Moreover, progress in the synthesis of novel polymers for photolithography, NIL and electron beam writing, opens the door to mix-and-match lithography giving hope to use NIL in multilevel nanofabrication processes.

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Nanostructured PVD coatings for future applications in tribology

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A major problem of manufacturing processes on a European level in spite of improvements in the last years is the wear and the corrosion of tools and components under tribological and corrosive loads. Wear and corrosion nowadays still cause considerable damage to economies worldwide. Conventional wear-resistant protective coatings on tools and components widely employed in industry today consist of binary or ternary compounds. Using single-layer, single-phase hard coatings such as TiC, TiN, CrN or Al_2O_3 led to a significantly increased lifetime of tools in metal working by a factor of 10 or more in specific applications if compared to uncoated tools. Further improvement was achieved by designing advanced coating materials, e.g. ternary compounds such as TiAlN or Ti(C,N), as well as by developing new coating concepts, e.g. multilayer and gradient coatings, and introducing them in commercial applications. For instance TiAlN coatings have considerably greater high temperature oxidation resistance, compared to TiN coatings. The properties of multilayer coatings benefit from the dramatically increased interface volume caused by periodic layers of different materials on a nanometer sized scale. For example, TiC/TiN, TiN/TiAlN or TiN/NbN multilayer coatings show higher hardness and cracking resistance than either of those materials alone.

On a laboratory scale a great variety of coating concepts for designing innovative, multifunctional nanoscaled PVD thin films with properties tailored to specific applications have been developed, as well as promising advanced coating materials such as nanocomposite coatings, nanostructured multilayer films, nanomodulated superlattice films, nanocrystalline films, nanostabilised single and multilayer films and nanograded films. The interface volume, grain size, single layer thickness, surface and interface energy, texture, and epitaxial stress and strain are principal factors, besides material selection and deposition characteristics, in determining the constitution, properties and performance of such coatings. For example, new nanocomposite coatings based on the incorporation of nanometer-sized inclusions of a dry lubricant phase such as amorphous carbon or MoS_2 into a matrix consisting of a metastable hard material could help to reduce substantially flood lubricants in production processes by providing wear-resistance together with low friction coefficients. Superhard coatings such as diamond-like carbon, cubic boron nitride and new phases within the materials system B-C-N are prevented from being introduced widely into the market by low adhesion on substrate materials caused by high intrinsic stress and different bonding characteristics. Although coating concepts for the stress management of such coatings have been found, the future realization of such coatings could significantly benefit from applying such a new in-situ stress-sensor during PVD deposition to control the coating properties in an engineering manner. In particular the scaling-up of nanostructure coatings for commercial use by special deposition concepts remains a high-skill demanding as well as a high-risk challenge for R&D institutions. Success is needed for further improvement and rationalization of current manufacturing processes, i.e. in high-speed cutting and dry machining.

4th Joint EC/NSF Workshop on Nanotechnology

Tools and Instruments for Research and Manufacturing

Workshop – 12-13 June 2002 – Grenoble (France)

Annex 1: Background Document on nanomanufacturing

June 2002

Introduction

This document is intended as background for the EC-NSF Grenoble conference on nanomanufacturing.

Future nano- manufacturing processes have to be developed and industrialised. Industry needs production methods of a whole range of materials and devices such as nanomaterials, nanoporous systems, corrosion inhibitors, polymers, molecular sieves, ceramics, light absorbers and emitters, magnetic nanomaterials, pigments, colloids, sensors, nano-robots, DNA chips and so on. And these manufacturing processes should be cost-effective. For each of these processes, equipment and tools have to be developed. In addition, for end products, a competitive market position can only be maintained if the analytical equipment necessary for material characterisation on an atomic or molecular level is available.

The goal of the conference is to think about the research infrastructure to be put in place and to prepare projects developing that infrastructure. Also essential are people who are trained to understand the new production methods, tools, analytical and testing techniques.

Hence it was thought to be relevant to give a short (hopefully more or less complete) overview of equipment existing today. Starting with this we can reflect on what still needs to be developed.

This overview of existing equipment[5] will be complemented with the research ideas presented at the conference. Also, at the end of the conference, we might be able to see whether the ideas presented are complete and cover real research priorities. From then on you should be in a good position to prepare future EC-FP6 and NSF proposals, and with this we would have reached some of the objectives of the workshop.

We wish you a nice and fruitful conference[6].

The EC team

[5] This note is extracted from a study by Eurotech Data for the EC and information available on the web.

[6] Please note that conclusions and background documents are put on the GROWTH/NSF websites.

Core concepts of nanotechnology

Today manufacturing methods are very crude at the molecular level. Casting, grinding, milling and even lithography move atoms in great quantities. The word "nanotechnology" is used to describe many types of research where the characteristic dimensions are less than about 100 nanometers. For example, continued improvements in lithography have resulted in line widths that are less than one micron: this work is often called "nanotechnology." If we are to continue the miniaturisation trends we will have to develop a new "post-lithographic" manufacturing technology which will let us inexpensively build systems that are molecular in both size and precision. Nanotechnology will let us do this.

There are several ways that one can approach fabrication of structures with a nano-dimension.
One method involves scaling down integrated-circuit fabrication until one atom at a time is removed. A more sophisticated hypothetical scheme involves the assembly of a chip atom-by-atom like bricklaying. An extension of this is the notion that a chip might assemble itself atom-by-atom using programmable nanomachines. It has been suggested that a so-called biochip might be grown like a plant from a seed; the components would form by a process resembling cell division in living things.

Concepts commonly associated with nanotechnology are positional assembly (to get the right molecular parts in the right places) and self-replication (automatic copying). The need for positional assembly implies an interest in molecular robotics, e.g. robotic devices that are molecular both in their size and precision. These molecular scale positional devices are likely to resemble very small versions of their everyday macroscopic counterparts. Positional assembly is frequently used in normal macroscopic manufacturing today, and provides tremendous advantages.

The requirement for low cost creates an interest in self replicating manufacturing systems, studied since von Neumann in the 1940's. These systems are able both to make copies of themselves and to manufacture useful products. If we can design and build one such system the manufacturing costs for more such systems and the products they make (assuming they can make copies of themselves in reasonably inexpensive environment) will be very low.

Two different approaches processes are to be integrated. The top-down approach uses electron beam lithography for nanotechnology fabrication. The bottom-up method involves self- assembly processes and molecular fabrication. With this nanotechnology becomes a truly multi disciplinary activity integrating physics, chemistry and biology.

The difficulties of exploring the nano world exist in both theoretical and experimental aspects. Theoretically, nano system, or mesoscopic objects are in a size regime about whose fundamental behaviour we have little understanding. They are too large to be described by the first principle, and are too few to be described by a statistical ensemble. Experimentally, the particles are too small for direct measurements. Although two strategies, top-down and bottom-up, for creating nano systems have been presented, there is still very far to go. A better method for enabling nanotechnology may be a combination of these two ways, i.e., firstly to fabricate building blocks through directed self-assembling to generate supramolecules (material goes bottom-up), and then to assemble

them into more complex nano system by smaller and smaller nanomanipulator (tool goes top-down).
Hence, nanomanipulation, or positional control at the nanometer scale, will be a key technology towards molecular nanotechnology. Its long-term purpose is to build novel functional nanometer scale structures and/or mechanisms, which would otherwise be unobtainable, with nanometer scale building blocks. Presently, nanomanipulation would be also helpful for the exploration of nano world. It might find applications in relative simple nano structure fabrication and biology research in near future.

This is then also what researchers are working on to merge top-down technologies such as lithography and patterning with bottom-up approaches such as self-organization of molecules to bridge the gap between silicon structures and single molecules. In addition to this techniques that enable us to probe these molecules, using atomic force microscopy, optical tweezers, confocal and near-field optical microscopy have been developed.

Table Typical nanoprocessing techniques

nanometer scale e-beam lithography
optical near-field lithography
scanning probe techniques (AFM, STM)
atomic layer epitaxyal growth
Langmuir-Blodgett film growth
cluster beam technique
nanoparticle beam technique
cluster size-selection technique
nanoparticle size-selection technique
electric mobility utilisation
molecular recognition
synthesis of mono-dispersed nanoparticles
structure formation by self-organisation
nano-imprint lithography
templating technique
lithography-induced self-organisation

Spectroscopy

Scanning Probe Microscopy (SPM)

Activities for manipulation of atom and molecules at the nanoscale level are dominated by the use of scanning probe microscopes in ultra-high vacuum. Year after year, this instrumentation becomes the more ubiquitous tool for a direct exploration of the atomic scale. Scanning Probe Microscopy (SPM) is a technique that is used to study the properties of surfaces at the atomic level. Unlike conventional microscopy, which uses light waves for imaging, SPM involves scanning the surface of a sample with a very fine probe ("tip") and monitoring the strength of some interaction between the tip and surface. A Scanning Probe Microscope scans an atomically sharp probe over a surface, typically at a distance of a few angstroms or nanometers. The interaction between the sharp probe and surface provides 3-D topographic image of surface at the atomic scale. Compared with other instruments that open a window to a world of molecule-sized spaces, SPMs are relatively simple, inexpensive, and easy to operate. And especially appealing about the proximal probes is their multipurpose nature that offers not only a view of individual atoms but also ways to pick them up, move them around, and position them at will.

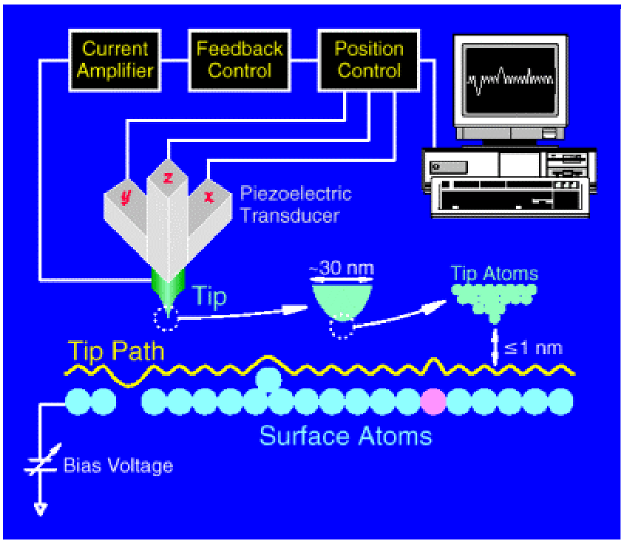
The most popular modes in Scanning Probe Microscopy are Scanning Tunneling Microscopy (STM) and Atomic Force Microscopy (AFM) –see below- The STM, revolutionised the study of solid surfaces, and enabled for the first time tracking images and performing spectroscopy of such systems with atomic resolution. STM is also the only instrument with the ability to rip atoms from the sample surface and relocate or otherwise manipulate them. As the STM is limited to operation with conducting surfaces, an entire family of imaging technologies based on various physical interactions appeared. We then saw the birth of the Atomic Force Microscope (AFM). Success in controlling and imaging tiny bits of matter with STM and AFM have spurred development of other scanning probe procedures.

A key shortcoming of scanning probe procedures is the slow, serial method by which they operate. This characteristic has limited their use mainly to laboratory applications involving atom-at-a-time manoeuvres.

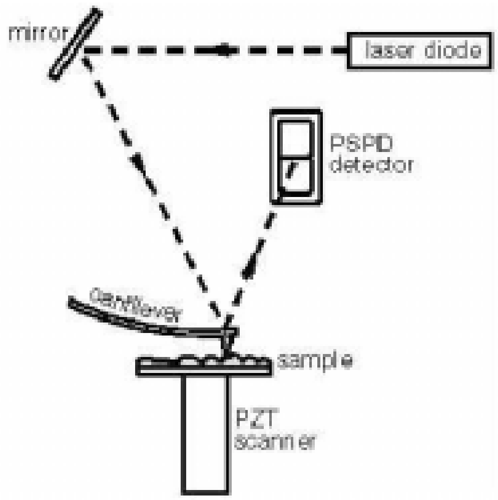
Scanning Tunneling Microscope (STM)

STM is the only device that allows scientists to study both topographical and electrical properties of materials, which are important for understanding the behaviour of microelectronic devices. The Scanning Tunneling Microscope (STM) was invented by Gerd Binnig and Heinrich Rohrer of IBM Zurich around 1982. A very fine wire tip is brought to within a few Angstroms of a conductive surface. Because of the quantum mechanical effect called "tunneling" electrons can hop between the tip and the surface. This effect decreases very rapidly with distance so that very small changes in position can be measured.

The other essential part of the microscope is a way to move the tip across the surface with extreme precision. This is done using piezoelectric ceramics, which expand or contract very slightly when an electric field is applied to them. A feedback circuit moves the tip normal to the surface to minimise current variations. The feedback information is then processed into a picture on the atomic scale. Increasing the voltage enables a researcher to move atoms around, pile them up, or trigger chemical reactions.



STM



AFM

Atomic Force Microscopy (AFM)

The Atomic Force Microscope (AFM) uses various forces that occur when two objects are brought within nanometers of each other. An AFM can work either when the probe is in contact with a surface, causing a repulsive force, or when it is a few nanometers away, where the force is attractive. Scanning works similarly to the STM, and also creates three-dimensional images. AFM is based on scanning a flexible, force-sensing cantilever across a specimen. Attractive and repulsive forces acting on the tiny diving-board-like arm cause deflections that can be measured with laser methods. The newer proximal probe can be used in a number of modes of operation. Included are a contact mode, in which the tip touches the specimen surface and senses internuclear repulsive forces between nuclei in the tip and sample, and a noncontact mode that exploits electrostatic or van der Waals forces. As with STM, a feedback circuit can be used to adjust the tip-to-sample distance to maintain constant force. The tip motions can be recorded and converted into relief maps. The AFM works on most materials. It can image down to atomic dimensions but is best for larger features. Since the tip is in direct contact with the surface, problems can occur if the material is soft, sticky, or has loose particles.

Transmission Electron Microscopy (TEM)

Older techniques have also made their mark on science and technology at the small scale, and new instrumental methods continue to be developed. Transmission electron microscopy, for example, has been used for decades to examine tiny structures and currently can resolve features as small as 1 to 2 Å. Transmission Electron Microscopy (TEM) and X-ray Diffraction (XRD) are often used to determine the morphology and structure of nanomaterials. Electron microscopy can obtain nearly atomic resolution of a material’s atomic arrangement and chemical composition. This technique requires a clean sample that meets ultrahigh-vacuum standards in order to provide surface characterisations such as reconstruction and phase transitions.

Scanning electron microscopy (SEM) is performed by scanning a focused probe across the surface of the material. Secondary electrons emitted from the sample are typically detected by a photomultiplier system, the output of which is used to modulate the brightness of a monitor synchronised with the electron-beam scan. The more electrons a particular region emits, the brighter its image. Scanning transmission electron microscopy (STEM) has made possible new imaging techniques by using inelastically scattered electrons, emitted x-rays, and other forms of an elastically scattered beam.

X-ray absorption spectroscopy

New synchrotron-based X-ray microscopy is emerging. X-ray absorption fine structures (XAFS) spectroscopy, a synchrotron technique, is particularly useful in revealing the local structure.

Lithography, a “top-down” technique for nanofabrication

Lithography is the key technology to realise very small feature size for nano components. Optical lithography, the main technology used today is predicted to be applicable beyond 100 nm and 70 nm with the use of respectively 193 nm wavelength and 157 nm wavelength tools. The reduction of feature sizes down to 50 nm and below will require more advanced lithography tools. As the candidate for the next generation for the microelectronics industry, *Extreme Ultraviolet Lithography* is to be strongly supported. EUV lithography, at the wavelength of 13nm, will achieve feature size at 45 nm and below.

More intensive research efforts are required. To support these developments, nanometrology needs a large effort too.

Photolithography

Photolithography is the selective process that allows the patterning of a desired design onto the material we want to fabricate with (the wafer in the semiconductor industry). Photoresist is applied as the first step in applying a pattern in a uniform film. The mask is a metal sheet that holds the actual pattern that will be etched into the photoresist. The mask is cut so that when a UV light is shined from behind the exposed parts of the photoresist will be the actual pattern. These exposed parts can then be cleaned away (positive resist) or will stay on the to be fabricated device (negative resist). As a result of photolithography being the number one limiting factor on the size of wafer production this is the field where most of the research has gone. Contact printing was the very first form of photolithography. In this form the mask was placed directly on top of the photoresist during the exposure process. This process gave a good resolution but sometimes resulted in slight damage to the wafer and the mask. In order to defeat the problems the next innovation, projection printing, separated the mask from the photoresist.

Electron Beam (e-beam) lithography

Today, electron-beam lithography (EBL) is employed to make the smallest components on silicon substrates and is the most effective method of creating patterns on substrates such as photomasks and x-ray masks. Electrons are used to directly etch onto the resist. Through a series of coils and lenses a computer to expose the correct sections of the photoresist controls the electrons path. Effort for advanced *e-beam lithography* is focused on the elaboration of a matrix of a microfabricated e-gun for e beam masker. The objective is to parallelise electron beam lithography leading to a large increase in throughput (this field is covered by a European project IST named NANOLITH).

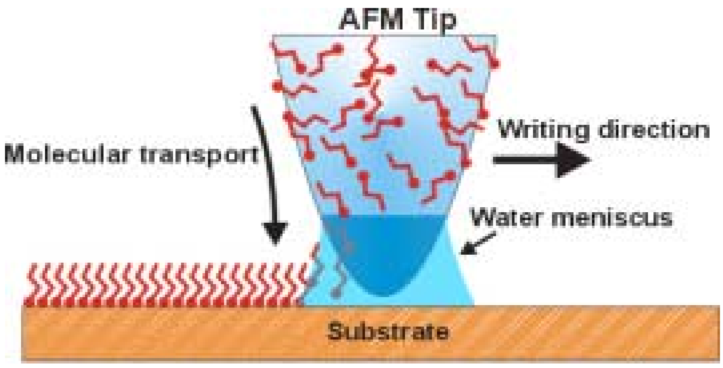
The advantages of this system are that the critical geometry is getting even smaller. The disadvantage is that this system is quite costly.

X-ray lithography

It uses the same procedure as above except that instead of using UV an X-Ray source is used.

Nanolithography

Dip Pen Nanolithography (DPN) is a direct-write soft lithography technique which is used to create nanostructures on a substrate of interest by delivering collections of molecules via capillary transport from an AFM tip to a surface.



Creating nanostructures using DPN is a single step process, which does not require the use of resists. Using a conventional Atomic Force Microscope it is possible to achieve ultra-high resolution features–as small as 15 nm linewidths and ~ 5 nm spatial resolution. For nanotechnology applications, it is not only important to pattern molecules in high resolution, but also to functionalize surfaces with patterns of two or more components. One of the most important attributes of DPN is that because the same device is used to image and write a pattern, patterns of multiple molecular inks can be formed on the same substrate in very high alignment,

Nanoimprint lithography (NIL)

One of the cheapest nanolithography techniques available for laboratories is *nanoimprint*, and the resolution reached can be as low as 10 nanometers. The principle of this technique is the embossing of a patterned mold in a heated resist. A stamp with suitable feature sizes, the adequate polymer material to be printed and equipment for printing with adequate temperature and pressure control are the three pillars of nanoimprint lithography. The first step in nano-imprinting is building a silicon relief mold using direct-write e-beam equipment. That is a slow process wherein each feature is defined by rastering an electron beam across the wafer. But once the imprint mold has been defined, it can be used to stamp out features with the same parallel speed of the mask-based exposure process. As a result, NIL can achieve sub-10 nm structures over large areas with low cost and high throughput—a feat currently unachievable using existing lithographies. Successful development of NIL can remove the main obstacle —cost— to nanostructure commercialisation and will make nanostructures easily accessible for industrial applications (a European program concerning nanoimprint is IST/CHANIL).

UV imprint and EUV Lithography

By utilising UV resist, the imprint forces are reduced to less than 1 bar. During an UV nano-imprint, the resist hardens by means of UV so that long heating and cooling phases become unnecessary. This leads to shorter process times, avoids any undesirable expansion of the material, and facilitates a gentle imprint of pre-structured substrates as well as work in step-and-repeat mode. Because of the transparent stamp, it is possible to make visual adjustments.

The process begins with the production of an UV transparent silica stamp. By means of optical or electron beam lithography, the structures are written and transferred to the stamp material by conventional etching. The stamp imprints the structure into a thin polymer (resist) centrifuged on the substrate. This is then hardened by UV through the transparent stamp. The polymer relief that is created serves as a component i.e. as an etching mask for further structuring of the substrate. The stamp can be used as often as required, without any loss of information.

Both single and combinations of micrometer and nanostructures are imprinted onto surfaces of up to 1 inch in one step. In this way, it is possible to simultaneously print gate and source domains, as well as leads and contact pads and also complete circuits. In order to create desired patterns over a large area, a high degree of plane parallelism between the stamp and the varnish surface has to be achieved, as the same imprint depth is required over the whole surface. The centrifuged resist has an inhomogeneity of less than 2 % over the whole imprint surface. The differences in the imprint depth are less than 5 %. The homogeneous and even etching mask is the prerequisite for a transfer of the structure true to dimensions to the base material.

Soft Lithography

Soft lithography represents an alternative set of techniques for fabricating micro- and nanostructures. The original version of this technology employed an elastomeric stamp (or mold) to pattern a wide variety of materials such as self-assembled monolayers, organic polymers, colloids, inorganic solids, proteins, and cells.

The soft lithography techniques offer advantages over conventional photolithography such as tolerating a wide range of materials needed for chemistry, biochemistry and biology (complex organic function groups, sol-gel materials, colloidal materials, suspension, etc.) and they are compatible with a wide range of substrates including glass, plastics, ceramics, or carbon.

The approach is reminiscent of one of the most famous examples of mass-production, the printing press. Soft lithography is already used to make microfluidic systems, such as those in lab-on-a-chip systems, and it scales readily down to the nanoscale (depending on the variant of the technology used, resolution can get below 10 nanometers). The techniques also promise potential in the creation of optical devices, which may in turn ultimately be used in optical computing. As a replacement for traditional lithography for creating electronic devices, however, there is currently a major obstacle – the technique is not well suited to making the precisely aligned, multi-layered structures currently used in microelectronics, although researchers are working to overcome this limitation.

Stamping in bio- nanofabrication

Microcontact printing is simple. A photolithographically patterned stamp is fabricated with the desired pattern etched to a very shallow depth in the surface. This stamp is then loaded from a protein, polysaccharide or other large molecule bearing surface carrying these molecules in a weakly or unattached form. If hydrophilic proteins or peptides are to be printed then the surface of the stamp needs to be made hydrophilic, for example by a very short-term etch with oxygen plasma. The stamp is then brought into contact with the surface that will carry the print. That surface already bears a cross-linking reagent, such as glutaraldehyde. The stamp is left in contact for about an hour and then removed. The protein is then found to be transferred to the surface, for example an appropriate polymer bearing the aminopropyl triethoxy silane .

Other developments…

AFM tips can also be used to indent a soft polymer surface, each divot "writing" a bit of information no more than 50 nanometers in diameter. The scientists then use the same array of tips to rapidly read the indentations and erase them as needed.

Deposition

Thin Film Processing

There are many techniques for depositing thin. The main techniques that are currently used are Chemical Vapour Deposition and sputtering (PVD). Nanoscale dimensions have long been used in semiconductor devices. The thickness of many of the thin films used is often below 1000 angstroms. The challenge however is in creating devices with spatial resolution below 100 nm. The challenge also exists in developing a process that is scalable to large-scale manufacturing and to cut the cost of processing to reasonable levels.

Ion beam assisted deposition

Two other examples of the use of ion beams as a materials fabrication tool are ion-beam synthesis and ion-assisted growth. Rather than implant ions into a substrate, ion-beam synthesis deposits atoms at or near the surface of a substrate. Because the ions are deposited at relatively high energies, this technique can be used to produce materials with metastable structures. In ion-beam assisted deposition, an ion beam is used to locally deposit energy at the surface of a substrate. Inert ions like argon, for example, can be used to add extra kinetic energy at a substrate while other lower-energy, gas-phase species are simultaneously deposited:

Other techniques for synthesis of nanostructures

Among them are classical chemical and electrochemical approaches. In addition, soft chemistry efforts are underway.

Activities for fabrication of Self-assembled nanostructures

Numerous techniques based on self-assembly have been developed. For a better control of nanostructure growth, these techniques often imply a functionalisation and a specific conditioning of the substrate. They are developed specifically for a given purpose (nanomagnetism, molecular electronics, nanoelectronics, biochemistry). The chemistry of macromolecules for self-organisation purposes is an important aspect of this activity.

Strategies, tools and instruments for nanomanipulation

Nanomanipulation provides a unique pathway to micro and nanomanufacturing that is unobtainable otherwise. There are two main types: contact manipulation and non-contact manipulation (where contact refers to whether the tool contacts to the objects or not).

These manipulations depend on the objects, the environment and observation devices. Mechanical contact, dielectrophoretic attracting, electric or magnetic field and laser trapping have been used for nanomanipulation, while new strategies are emerging. A typical nanomanipulation is composed of a manipulator(s) for positioning the end effector(s), a sensing system and /or a measurement system to facilitate the manipulation and determine the properties of the object. A user-friendly human-machine interface is also desired. Applications of nanomanipulation include many fields such as physics, chemistry, and biotechnology among others. The pick-and-place technology is especially significant for nanomanipulation since the main purpose of nanomanipulation is to assemble pre-fabricated building blocks into structures. The main problem in manipulation of nanometer scale objects is how to achieve control of the interaction between the tool and object and that between the object and substrate.

Nanorobotic Manipulators - Microactuators - nanodevices

Although this field is more related to microsystems (it is not strictly speaking "nano"), it has to be mentioned because its development has greatly contributed to nanotechnology by proving tools (probes, actuators etc..) for nanotechnology. It is necessary to manipulate nano scale objects in 3-D space for constructing nano structures and devices. In order to realise such manipulations, robotic manipulators with multi-degree of freedom and nanometer scale resolutions will be useful tools. The basic requirements for a nanorobotic manipulator for 3D manipulations include: a nano-scale positioning resolution, a relative large working space and usually with multi end-effectors for complex operations. However, such kinds of manipulators need microscopes as the real time observation systems. Selectable microscopes include SEM, TEM or OM. The vacuum chamber of TEM is too narrow to be used for complex operations at present for the relative large sizes of actuators. Today Research on microactuators are carried out for micromechanics but also for numerous other applications (optical switch, RF communications, analysis of nano-quantity of materials, microfluidics). One has to emphasise that they are a great potential for industrial development in that field.

DNA-Directed Assembling

DNA chips or arrays are devices in which different DNA sequences are arrayed in a microscopic format on a solid support (glass, silicon, plastic, etc.). DNA arrays can have anywhere from 100 to 100,000 different DNA sites (pixels) on the chip surface. Depending on the chip, the sites can range in size from 10 microns to over 100 microns (smaller sites are possible). Each DNA site can contain from 10^6 to 10^9 DNA sequences. In a hybridisation assay, the DNA array is contacted with a sample solution that contains the unknown target DNA sequences. If any of the sequences are complementary to those on the array, hybridisation occurs and the unknown sequence is identified by its position on the array.

Present DNA chip devices will have applications in genomic research, pharmacogenetics, drug discovery, gene expression analysis, forensics, cancer detection, and infectious and genetic disease diagnostics. Newer generations of electronically active DNA microarrays that produce controlled electric fields at each site may have potential applications for nanofabrication. These active microelectronic devices are able to transport charged molecules (DNA, RNA, proteins, enzymes), nanostructures, cells and micron-scale structures to and from any test site on the device surface. When DNA hybridisation reactions are carried out, these devices are actually using electric fields to direct the self-assembly of DNA molecules at specified sites on the chip surface. These active devices serve as semiconductor hosts or motherboards for the assembly of DNA molecules into more complex three-dimensional structures. The DNA molecules themselves have programmable and self-assembly properties. DNA molecules can also be attached to larger nanostructures, including metallic and organic particles, nanotubes, microstructures, and silicon surfaces. In principle, active microelectronic arrays and DNA-modified components may allow scientists and engineers to direct self-assembly of two- and three-dimensional molecular electronic circuits and devices within the defined perimeters of larger silicon or semiconductor structures.

Thus, electronically directed DNA self-assembly technology could encompass a broad area of potential applications from nearer term heterogeneous integration processes for photonic and microelectronic device fabrication to the longer term nanofabrication of true molecular electronic circuits and devices.

Manufacturing Infrastructure Requirements

A wide range of production capabilities, training and facilities are required as part of the creation of an infrastructure that will nurture nanotechnology and provide the basis for industrial development. For example, mathematics, computer modelling and simulation skills will be essential as well as an understanding of tools and standards. Technological key issues are the adoption of advanced manufacturing processes, access to specialist tools needed for manufacturing, test, assembly and inspection, and the installation of ultra-clean manufacturing facilities.

Advanced Manufacturing Processes

Manufacturing processes at the nanoscale can involve accretion or removal of material, or changes to the shape or form of material already present. At least two processes provide clear challenges and opportunities; accretion of powders and cutting / milling. New generations of processing equipment will be needed to deal with nanopowders in the manufacture of nanocrystalline materials. On the other hand, only focused ion beam (FIB) techniques provide a means for selective cutting or removal of material with sub-100nm accuracy. Although these techniques were largely pioneered in Europe, the present suppliers of such equipment are almost exclusively American or Japanese companies.

Tools and Instrumentation for Test and Inspection - nanometrology

Nanometrology must be seen as an indispensable part of all kind of nanotechnology. Reference measurements to ensure that quantitative results are comparable and products interchangeable must accompany any activity within science and technology. Nanometrology is understood as the traceable (at least quantitative) measurement of following properties: Dimension, material properties, physical, chemical (amount and kind of substance). As structures become ever smaller, the necessity for on-line quality assurance test systems for certification duties, becomes more important and demanding. In the future, the nanometre scale will be the precision standard for material analysis, control purposes and also for material treatment. Already nano-analytical methods are used routinely for testing in the manufacture of a large range of products and processes such as magnetic storage disks, electronic multilayer systems, industrial polishing processes etc. New magnetoresistive multilayer systems offer drastically better positioning and controlling properties of sensors for application in the automotive industry and as measuring systems for velocity, strain or work piece positioning. Efforts towards a nanometrology infrastructure have to consider the following topics: scientific instruments, measurement and calibration procedures, measurement standards and written standards

Ultra-clean manufacturing facilities

Most aspects of nanoscale manufacturing may require clean room technology - either full scale facilities or 'table top' scale; but this will depend on the particular process or industry.

4th Joint EC / NSF Workshop on Nanotechnology:

Tools and Instruments for Research and Manufacturing

Workshop – 12-13 June 2002 – Grenoble (France)

Annex 2: List of participants

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