GENERAL

Preface.................................................................5
About MESA+, in a nutshell........................................6
MESA+ Strategic Research Orientations...................8
Commercialization..............................................16
The Dutch Nano-landscape....................................18
National NanoLab facilities...................................20
International Networks.......................................22
Education..........................................................25
Awards, honours and appointments......................26

HIGHLIGHTS

BES Biomolecular Electronic Structure.......................32
BIOS Bios Lab-on-a-Chip........................................33
BNT BioMolecular Nanotechnology..........................34
CBP Computational BioPhysics................................35
CMS Computational Materials Science......................36
COPS Complex Photonic Systems............................37
CPM Catalytic Processes and Materials.....................38
ICE Interfaces and Correlated Electron systems........39
IHNC Inorganic & Hybrid Nanomaterials Chemistry......40
IM Inorganic Membranes.......................................41
IMS Inorganic Materials Science............................42
IOMS Integrated Optical MicroSystems....................43
LPNO Laser Physics and Nonlinear Optics.................44
MCS Mesoscale Chemical Systems..........................45
MnF Molecular nanoFabrication..............................46
MSM Multi Scale Mechanics..................................47
MST Membrane Science and Technology...................48
MTF Materials Science and Technology of Polymers.....49
MaCS Mathematics of Computational Science............50
NBP Nanobiophysics..........................................51
NE NanoElectronics............................................52
NEM NanoElectronic Materials...............................53
NI Nanofonics..................................................54
NLCA Nanofluidics for Lab on a Chip Applications......55
OS Optical Sciences...........................................56
PSP Philosophy of Science in Practice......................57
PCF Physics of Complex Fluids................................58
PCS Photocatalytic Synthesis..................................59
PIN Physics of Interfaces and Nanomaterials...............60
PNS Programmable NanoSystems............................61
PoF Physics of Fluids..........................................62
PGMF Physics of Granular Matter and Interstitial Fluids..63
QTM Quantum Transport in Matter...........................64
SC Semiconductor Components.............................65
SPI Soft Matter, Fluidics and Interfaces.....................66
StaPS Science, Technology and Policy Studies............67
TST Transducer Science and Technology....................68

PUBLICATIONS

MESA+ Scientific Publications 2012..............................70

ABOUT MESA+

MESA+ Governance Structure..................................78
Contact details..................................................78
Nanotechnology settles in society

In 2012 the national programs NanoNed and NanoNextNL got off the ground. MESA+ is, as one of the lead partners, strongly involved in both initiatives. The programs have a strong focus on valorization and are performed in close collaboration with industry. This is in line with the new innovation approach by the Dutch government, called ‘topsectors’, being strong industrial areas strengthened by joint research and development at Dutch industries, research institutes, universities, and science foundations. In the coming years we will learn if this strategy will be an alternative to the successful programs NanoNed and NanoNextNL.

MESA+ NanoLab, part of the national NanoLabNL facilities, is used extensively by research groups and companies. In 2012 new investments in the BioNanoLab have been realized, and the first research projects using this equipment started. MESA+ and its NanoLab facilities attract a lot of visitors, excited to learn more about nanotechnology, its products and its promises.

Since a few years MESA+ stimulates and facilitates its spin-off companies increasingly in developing towards high-volume production. High Tech Factory, located in the redeveloped former MESA+ labs, provides production facilities to SMEs, and gives access to an operational lease fund where companies with growth ambitions can apply for the investment and use of production equipment. In 2012 High Tech Factory was fully realized, with the redevelopment of the building coming to an end, and the first twelve companies moving in.

To stimulate and support PhDs and postdocs who are interested in developing their research results towards a product MESA+ started to offer a workshop in early business development. In 2012 MESA+ launched its Young Business Award that will be granted biennially to promising young entrepreneurs and their business ideas.

Besides the above activities to encourage nanotechnology in business development, outstanding research and education remain vital. After all, new developments often depend on advances in science. Consequently, we want to remain attractive for international students and researchers. Recognition of MESA+ as research institute and graduate school provides the basis for ongoing internationalization activities that fit into the comprehensive integration of nanotechnology in our society.

Ir. Miriam Luizink, Technical Commercial Director, MESA+ Institute for Nanotechnology
Prof. dr. ing. Dave H.A. Blank, Scientific Director, MESA+ Institute for Nanotechnology
“MESA+ Institute for Nanotechnology is one of the largest nanotechnology research institutes in the world”

About MESA+, in a nut shell

MESA+ Institute for Nanotechnology is one of the largest nanotechnology research institutes in the world, delivering competitive and successful high quality research. MESA+ is part of the University of Twente, and cooperates closely with various research groups within the university. The institute employs 525 people of whom 300 are PhD candidates or postdocs. With its NanoLab facilities the institute holds 1250 m² of cleanroom space and state of the art research equipment. MESA+ has an integral turnover of approximately 50 million euros per year of which 60% is acquired in competition from external sources (National Science Foundation, European Union, industry, etc.).

MESA+ supports and facilitates researchers and actively stimulates cooperation. MESA+ combines the disciplines of physics, electrical engineering, chemistry and mathematics. Currently 37 research groups participate in MESA+. MESA+ introduced Strategic Research Orientations, headed by a scientific researcher, that bridge the research topics of a number of research groups working in common interest fields. The SROs’ research topics are an addition to the research topics of the chairs. Their task is to develop these interdisciplinary research areas which could result in new independent chairs. Internationally attractive research is achieved through this multidisciplinary approach. MESA+ uses a unique structure, which unites scientific disciplines, and builds fruitful international cooperation to excel in science and education.

MESA+ has been the breeding ground for more than 50 MESA+ high-tech start-ups to date. A targeted program for cooperation with small and medium-sized enterprises has been specially created for start-ups. MESA+ offers the use of its extensive NanoLab facilities and cleanroom space under hospitable conditions. Start-ups and MESA+ work together intensively to promote the transfer of knowledge. MESA+ has created a perfect habitat for start-ups in the micro and nano-industry to establish and to mature.

MESA+ is a Research School, designated by the Royal Dutch Academy of Science. All MESA+ PhD’s are member of the MESA+ School for Nanotechnology, part of the Twente Graduate School.
Mission and strategy
MESA+ conducts research in the strongly multidisciplinary field of nanotechnology and nanoscience.

The mission of MESA+ is:
- to excel in its research field;
- to explore (new) research themes;
- to educate researchers and engineers in its field;
- to commercialize research results;
- to initiate and participate in fruitful (inter)national cooperation.

MESA+ has defined the following key performance indicators for achieving its mission:
- scientific papers in high ranked journals like Science or Nature;
- 1:1 balance between university funding and externally acquired funds;
- sizable spin-off activities.

MESA+ focuses on three issues to pursue its mission:
- to create a top environment for international scientific talent;
- to create strong multidisciplinary cohesion within the institute;
- to be a national leader and international key player in nanotechnology.

Organizational structure

MESA+ is an institute of the University of Twente and falls under the responsibility of the board of the university. The scientific advisory board assists the MESA+ management in matters concerning the research conducted at the institute and gives feedback on the scientific results of MESA+.

The governing board advises the MESA+ management in organizational matters.

The scientific director accepts responsibility for the institute and the scientific output.

The managing director is responsible for commercialization, central laboratories, finance, communications and the internal organization.

The participating research groups and SRO program directors form the MESA+ advisory board.
Dr. Pepijn W.H. Pinkse:
"Applied NanoPhotonics: there's more to light than meets the eye"

Applied NanoPhotonics

Optics has revolutionized fields as various as data storage and long-distance communication. Optical systems have a chance to become even more ubiquitous in other areas, like today's smart devices, but this step requires further miniaturization. The example of electronics shows us that miniaturization will sooner or later hit physical limitations. In the case of optics this will be in the nanodomain. Working with optics on this scale requires new concepts to be developed and many questions to be answered:

How can we shrink the dimensions of optical structures to or even below the wavelength limit? To what extend can we build so called "meta-materials" that have specially engineered optical properties by nanostructuring? How can we miniaturize lasers, reduce their threshold and increase their yield? How can one make high-sensitivity optical detectors, e.g. for medical applications, and integrate them in low-cost labs on a chip? Can we use nanophotonics to study complex (molecular) systems and can we tailor light to efficiently steer their behavior? And on the more fundamental side: Can single emitters be controlled efficiently and embedded into nanophotonic structures? How can we exploit the quantum character of light for new functionality?

The goal of our SRO is to address these questions exploiting the expertise in MESA+ groups. Building adaptivity into nanophotonic systems is becoming a common paradigm in answering these questions. Adaptivity allows optimizing properties or processes with clever learning algorithms. Adaptive systems can react on external stimulus, can compensate for fluctuations and inevitable randomness in nanophotonic structures. Adaptive Quantum Optics goes one step further and merges this adaptive control in random systems with quantum optical tools such as single-photon detectors and non-classical light sources. The example of a beam splitter made from a multiple scattering medium is illustrated in the figure on the right. We are currently exploring other intriguing applications in, e.g., cryptography.
Applied Nanophotonics (ANP) started in October 2009 and has become a very active Strategic Research Orientation. ANP fosters new research and develops new expertise in a few key areas. ANP scientists meet on a monthly basis in ANP meetings to lively debate the latest nanophotonic developments. By means of these ANP group meetings, ANP colloquia and workshops, ANP stimulates cooperation between the research groups at MESA+ that have a strong optics focus including COPS, IOMS, LPNO, NBP, and OS. In 2013 the mathematics group MaCS joined ANP in the understanding that mathematics is indispensable for the understanding of optics and that at the same time optics offers an ideal testbed for new mathematical tools, in particular efficient and reliable numerical methods.

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A sugar cube illuminated with 2 red laser beams illustrates a beam splitter that can be made from a multiple-scattering medium. Incident light on a multiple-scattering medium generates speckles. By wavefront shaping, a revolutionary technique developed in Twente to control the propagation of light in complex media, the equivalent of a normal beam splitter is created. In Adaptive Quantum Optics we use this technique to program quantum interference of single incident photons or other quantum states with opaque scattering media.

"What makes Nanotechnology possible? There are many important driving forces to mention, but for sure one of the most influential was the development of scanning probe microscopies’’

Enabling Technologies

The Strategic Research Orientation (SRO) Enabling Technologies is a multidisciplinary program aiming at bundling the research activities of MESA+ in a very important enabling area in nanotechnology, that is Scanning Probe Microscopy. In particular, Enabling Technologies aims to foster research and expertise in the field of nanoscale electrochemistry and electrical probing. For instance by means of group meetings and workshops, the strategic research orientation Enabling Technologies aims to stimulate cooperation between the research groups at MESA+ that have a strong interest in nanoscale electrochemistry and electrical probing.

AFM cantilever with in-situ renewable mercury microelectrode

The mercury electrode is an exceptional landmark in electroanalytical chemistry because of its outstanding electrochemical performance which provided the basis for fundamental electrochemical techniques like polarography and voltammetry.

In a collaboration between the MESA+ groups MTP and TST and spin-off company SmartTip an entirely novel type of mercury electrode based on a fountain pen probe was introduced recently. In proof of principle experiments chronoamperometry and cyclic voltammetry measurements were done in electrolyte testing the principle usability for electrochemical studies [1,2]. Our results enable to further integrate the in-situ renewable mercury electrode into the AFM setup, in particular to enable combined AFM electrochemical measurements to simultaneously probe forces and electrical/electrochemical signals. This might open novel avenues in areas where mechanics is coupled to electrochemical or electrical properties, for instance in biological membrane research.

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Schematics of the AFM cantilever integrated mercury electrode and amperometric signal recorded upon mercury dropping and stop of dropping [1, 2].

Joint workshop on ‘SPM for Life Sciences and Soft Matter Research’ 2013

The joint workshop on ‘SPM for Life Sciences and Soft Matter Research’ 2013 was shared between the MESA+ SRO ‘Enabling Technologies’ and the EU-COST action TD 1002, a European network on applications of Atomic Force Microscopy to NanoMedicine and Life Sciences providing excellent opportunities for discussions and exchanging ideas.

Nanomedicine

While populations are generally ageing and life expectancy continues to increase especially in developed countries, healthcare faces new challenges in the 21st century. For instance, new classes of diseases related to ageing must be addressed, and tissue/organ failure is becoming more and more recurrent. Subsequently, a new paradigm of “healthy ageing” has been identified as a priority by the EU. This paradigm includes the development of policies towards more effective disease prevention as well as fundamental studies to understand biological factors playing a key role in ageing and disease onset. Next, novel and more appropriate approaches must be developed for early disease detection and personalized treatment, as well as for tissue repair. Finally, the healthcare system must become more competitive, and drastically reduce its overall expenses.

Nanotechnology is undoubtedly to play a decisive role in this revolution in the field of medicine. For instance, targeted and localized treatment and imaging are made possible using nanodrugs and nanoparticles. Nanosensors hold great promises for early disease detection, and for the development of miniaturized point-of-care and home therapy monitoring devices. Nanostructured materials are drawing much interest in the field of regenerative medicine. Finally, nanometer-sized tools are taking ever more prominent places in the investigation of molecular processes, allowing for more insightful understanding of what causes a disease.

The SRO Nanomedicine was taken over in 2012 by Dr. ir. Séverine Le Gac. In the year that followed, an inventory was made on nanomedicine-related research at MESA+. Promising research topics have been identified and continue to be fostered, such as intracellular delivery using physical or chemical means and membrane protein studies in artificial membranes. The SRO Nanomedicine further works to strengthen collaborations within MESA+, as well as with research groups at MIRA and IGS Institutes at the University of Twente, through the organization of monthly meetings.
Microfluidic platform for experimentation on membrane proteins

Membrane proteins represent > 60% targets for the development of new drugs: they are involved in a great variety of diseases (e.g., cystic fibrosis, cardiovascular diseases, etc.), they are easily accessible due to their position in the cell membrane, and they regulate various intracellular signaling pathways. Furthermore, abnormal protein-membrane interactions seem to be central in neurodegenerative diseases, although these mechanisms are not fully understood yet. In this context, new experimental platforms are needed to conduct drug screening assays on ion channels or to elucidate membrane-associated molecular processes involved in diseases.

Researchers in the BIOS group have developed a microfluidic platform where planar lipid bilayers are formed in an automated way, and which are compatible with both electrical and optical detection, including confocal microscopy. Pore-forming species, widely used as models for ion channels, have been successfully inserted in the lipid bilayer and their activity monitored to validate the capability of the platform for experimentation on individual membrane proteins. These promising results have been published as the cover article in Small (April 2013).

This platform will be applied for experimentation on biologically relevant ion channels, and in collaboration with NBP, for examining interactions between α-synuclein with cell membrane models.

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NanoMaterials for Energy

The worldwide energy demand is continuously growing and it becomes clear that future energy supply can only be guaranteed through increased use of renewable energy sources. With energy recovery through renewable sources like sun, wind, water, tides, geothermal or biomass the global energy demand could be met many times over; currently however it is still inefficient and too expensive in many cases to take over significant parts of the energy supply. Innovation and increases in efficiency in conjunction with a general reduction of energy consumption are urgently needed. Nanotechnology exhibits the unique potential for decisive technological breakthroughs in the energy sector, thus making substantial contributions to sustainable energy supply.

The goal of the Strategic Research Orientation (SRO) NanoMaterials for Energy is to exploit and expand the present expertise of the MESA+ groups in the field of nano-related energy research. Through multidisciplinary collaboration between various research groups new materials with novel advanced properties will be developed in which the functionality is controlled by the nanoscale structures leading to improved energy applications. The range of new research projects for nano-applications in the energy sector comprises gradual short and medium-term improvements for a more efficient use of conventional and renewable energy sources as well as completely new long-term approaches for energy recovery and utilization.

**Micro- and nanoscale patterning of functional oxides for energy applications**

Yttria-stabilized zirconia (YSZ) is a technologically important ceramic due to its outstanding properties, i.e. mechanical strength, chemical resistance, and high ion conductivity. It is used as electrolyte in solid oxide fuel cells (SOFC) and oxygen sensors, and in thermal barrier coatings. Patterning of YSZ films on micro and nanoscale would enable the fabrication of electrolyte monoliths for micro-SOFCs. Moreover, patterning the electrolyte increases the interfacial surface area between electrodes and electrolyte, which may facilitate oxygen ion transport through the interface and, thus, improve cell performance. It was demonstrated how YSZ patterns
can be formed by a combination of micromolding and sol−gel solution processing. The shape and size of the resulting features are critically dependent on the concentration of the YSZ precursor, varying between micronscale ceramic structures and nanoscale ring structures. Similar patterning techniques can also be employed to form other microstructures on arbitrary substrates. An example are zinc oxide (ZnO) nanowire rosettes on polyethylene terephthalate (PET) plastics. ZnO is a semiconductor that is employed in organic photovoltaics (OPV), but it may also find applications in photocatalytic processes for solar fuel (hydrogen), for which very high surface areas are required. The wires shown in the figure are single-crystalline, and they were grown on a substrate onto which a prepattern was deposited by a soft lithographic process.

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Commercialization

Nanotechnology offers chances for new business. Around knowledge institutions, stimulated by a dynamic entrepreneurial environment, nuclei of spin-off companies arise. The number of new businesses based on nanotechnology is growing rapidly. MESA+ plays an important role nationwide, being at the start of more than 50 spin-offs. Access to state-of-the-art nanotech infrastructure, shared facilities functioning in an open innovation model, is of crucial importance for both creation and further development of spin-off companies. These spin-off companies are important for the national and regional economy; SMEs will become increasingly important for employment and turnover. MESA+ intensifies and strengthens its commercialization activities to further increase the number of patents, the number and size of spin-offs and, consequently, its national and international reputation.

High Tech Factory
MESA+ has established High Tech Factory, a shared production facility for products based on micro- and nanotechnology. High Tech Factory is designed to ensure that the companies involved can concentrate on business operations and focus their energies on growth rather than on realizing the basic production infrastructure required for achieving that growth. In 2012 the full production area of cleanrooms, labs and offices has become available and ready to use. At the start 13 parties of which 11 companies are located here.

High Tech Fund
The technical infrastructure fund High Tech Fund offers an operational lease facility for companies in micro- and nanotechnology. Equipment is located in the production facility High Tech Factory. The 9 M€ fund, supported by the ministry of Economic Affairs, the province of Overijssel and the region of Twente, was launched successfully in June 2010. In 2012 investments have been realized for the companies SmartTip and SolMateS.

MESA+ Technology Accelerator
With the MESA+ Technology Accelerator, organized in UT international ventures (UTIV), MESA+ invests in early stage scouting of knowledge and expertise with a potential interest from the market. The first phase of technology and market development is organized in so-called stealth projects. A successful stealth project is continued as a spin-off or license. Through the initiative Kennispark, the UT is applying the UTIV model more widely at the University.

Kennispark Twente
Commercialization of nanotechnology research is one of the very strong drivers of MESA+. As illustrated in the topics above, key aspects of the MESA+ agenda encompass business development, facility sharing, area development, and growth towards a production facility. With these key commercialization projects MESA+ contributes strongly to the Kennispark agenda and the provincial and regional innovation systems.
The Dutch Nano-landscape

Netherlands Nano Initiative
The nanotechnology research area is comprehensive and still extending. The Netherlands continually makes choices based on existing strengths supplemented with arising opportunities, as is described in the NNI business plan 'Towards a Sustainable Open InnovationEcosystem' (2009) in micro and nanotechnology. Generic themes in which the Netherlands excel are beyond Moore and nanoelectronics, nanomaterials, bionanotechnology and instrumentation, while application lies within the areas of water, energy, food, and health and nanomedicine. These generic and application areas are, when applicable, covered by risk analyses and technology assessment of nanotechnology. NanoLabNL provides the infrastructure for the implementation of the NNI strategic research agenda.

Topsector High Tech Systems & Materials
Since 2012 the Nanotechnology roadmap is hosted by the topsector HTSM, part of the innovation policy of the Dutch government. Each year there will be an update of this roadmap. The roadmap forms the basis for additional grants based on cash industrial investments.

NanoNextNL
NanoNextNL, the 250 M€ innovation program has started in 2011. NanoNextNL, a collaboration of 120 partners, proposes to apply micro- and nanotechnologies to strengthen both the technology base and competitiveness of the high tech and materials industry and to apply them in support of a variety of societal needs in food, energy, healthcare, clean water and the societal risk of certain nanotechnologies. The main economic and societal issues addressed in this initiative are:
- the societal need for risk analysis of nanotechnology;
- the need for new materials;
- ageing society and healthcare cost;
- more healthy foods;
- need for clean tech to reduce energy consumption, waste production and provide clean water;
- advanced equipment to process and manufacture products that address these issues.

NanoNextNL covers all relevant generic, application and social themes.
National NanoLab facilities

NanoLabNL

NanoLabNL is listed on the ‘The Netherlands’ Roadmap for Large-Scale Research Facilities’ as one of 29 large-scale research facilities whose construction or operation is important for the robustness and innovativeness of the Dutch science system. NanoLabNL provides access to a coherent, high-level, state-of-the-art infrastructure for nanotechnology research and innovation in the Netherlands. The NanoLab facilities are open to researchers from universities as well as employees from companies. NanoLabNL seeks to bring about coherence in national infrastructure, access, and tariff structure. Since its establishment in 2004 the NanoLabNL partners invested about 110 M€ in nanotech facilities through their own funding and additional public funding.

The partners in NanoLabNL are:
- Twente: MESA+ Institute of Nanotechnology at University of Twente;
- Delft: Kavli Institute of Nanoscience at Delft University of Technology and TNO Science & Industry;
- Groningen: Zernike Institute for Advanced Materials at Groningen University;

Together, these four locations cover most of the country and offer the widest possible spectrum of nanotechnology facilities for researchers in the Netherlands to use.

MESA+ NanoLab

MESA+ NanoLab has extensive laboratory facilities at its disposal, offering a wide spectrum of opportunities for researchers in the Netherlands and abroad:
- a 1250 m² fully equipped cleanroom, with a focus on microsystems technology, nanotechnology, CMOS and materials and process engineering;
- a fully equipped central materials analysis laboratory;
- a number of specialized laboratories for chemical synthesis and analysis, materials research and analysis, and device characterization.

In 2012 MESA+ has invested largely in realizing its new BioNanoLab, part of the MESA+ NanoLab, for research in bionanotechnology, nanomedicine and risk analysis.

The MESA+ NanoLab facilities play a crucial role in the research programs and in collaborations with industry. MESA+ has a strong relationship with industry, both through joint research projects with the larger multinational companies, and through a commercialization policy focused on small and medium sized enterprises.
International Networks

(Inter)national position and collaborations
MESA+ has a strong international position, several strategic collaborations and is active in international networks and platforms. MESA+ has strategic collaborations with: NINT (Canada), Ohio State, Materials Science Nano Lab (US), Stanford, Geballe Lab of Advanced Materials (US), Berkeley, nanoscience lab Ramesh group (US), California NanoSystems Institute at UCLA (US), INCASR (India), NIMS (Japan), University of Singapore, and the Chinese Academy of Science CAS, and in Europe with: Cambridge, IMEC, Karlsruhe, Munster, Aarhus and Chalmers University.

EICoon
EICoon is the FP7 Euro-Indo forum for nano-materials research coordination & cooperation of researchers in sustainable energy technologies. The consortium addresses the strategic assessment including synergy analysis of nano-materials research needs in the EU and India. It establishes and communicates the mutual interests and topics for future coordinated calls to enable decision and policy makers to make better informed decisions. Besides the assessment, the project also addresses the dissemination of the “nano-materials research acquis” in the field by organization of events. Finally, it brings together researchers to exchange ideas for joint projects for future research collaboration.
Visit the EICoon website for more information: www.eicoon.eu.
Education

Twente Graduate School/ MESA+ School for Nanotechnology
MESA+ is a research school, designated by the Royal Dutch Academy of Science. All PhD students are member of the MESA+ School for Nanotechnology which is part of the University of Twente’s Twente Graduate School. The Graduate School is aiming to strengthen education and improve the skills of PhD students.

Master of Science Nanotechnology
Access to the best research students worldwide is critical to the success of MESA+. In 2005 a master track nanotechnology was started as the first accredited master’s training at the University of Twente. MESA+ invests in information to students of appropriate bachelor’s courses, and brings the master’s nanotechnology to the attention of its international cooperation partners. The master Nanotechnology is incorporated into the MESA+ School for Nanotechnology.

Fundamentals of Nanotechnology
Nanotechnology is a multidisciplinary research field, and requires expertise from the field of electrical engineering, applied physics, chemical technology and life sciences. The course ‘Fundamentals of Nanotechnology’ is annually organized by MESA+ and provides an initial introduction to the complete scope of what nanotechnology is about. The course is set up for graduate students and postdoctoral fellows that are starting to work or are currently working in the field of nanotechnology. The workshop is given in an intensive one-week format; participants attend about 20 lectures and labtours on different subfields of nanotechnology. Each year about 25 students participate.
Awards, honours and appointments

**ERC Starting Grant**
Prof. dr. ir. Rob Lammertink has been awarded with an ERC Starting Grant of € 1.5 million for his study of membrane interfaces. Lammertink is head of the Soft Matter, Fluidics & Interfaces department, which was established just two years ago. Dr. Nathalie Katsonis has been awarded with an ERC Starting Grant of € 1.5 million for her research on Photo-engineered helices in chiral liquid crystals. Katsonis is member of the Bio-Molecular Nanotechnology group.

**ERC Proof of Concept Grant**
Dr. Pascal Jonkheijm has received the Proof of Concept Grant worth € 150,000. Jonkheijm will research the marketability of a chip that enables printing of proteins (and even viruses) onto various surface types. Jonkheijm is member of the research group Molecular nanoFabrication.

**STW Valorisation Grants phase 2**
The Dutch Technology Foundation STW established the Valorization Grants in 2004. The Phase 2 award of € 200,000 is intended to enable the receiver to build up a viable business. Dr. Michel Versluis received the STW valorisation grant phase 2 for his proposal ‘A monodisperse microbubble generator for the production of ultrasound contrast agents’. Versluis is member of the Physics of Fluids group.

**VIDI Grant**
Prof. dr. Devaraj van der Meer has been awarded a VIDI grant of € 800,000. The aim of the grant is to give talented researchers the opportunity to develop their own line of research and to build their own research group. He will use the grant to study how raindrops behave as they fall on a layer of sand. Van der Meer heads the Physics of Granular Matter and Interstitial Fluids group.

**VENI Grant**
The VENI grant is a prestigious grant for young scientists who have recently gained their PhD. Dr. ir. Wiebe de Vos has been awarded with the VENI grant of € 250,000 to develop polymeric thin layers as protein switches. De Vos is member of the Membrane Science and Technology group. Dr. ir. Maarten Smulders has been awarded with the VENI grant of € 250,000 for his research on responsive self-assembled materials. Smulders is member of the BioMolecular Nanotechnology group.

**George K. Batchelor Prize**
Prof. dr. Detlef Lohse of the MESA+ Physics of Fluids group has been awarded the George K. Batchelor Prize. This global prize in the field of fluid dynamics is awarded once every four years by the Journal of Fluid Mechanics (Cambridge University Press) and the International Union of Theoretical and Applied Mechanics (IUTAM). The George K. Batchelor Prize is worth $ 25,000 and is intended for excellent scientists who have made a substantial contribution to fluid dynamics over the past ten years.

**YES! Fellow FOM**
The Foundation for Fundamental Research on Matter has awarded a Young Energy Scientist (YES!) Fellowship to Dr. MSc. Richard Stevens of the Physics of Fluids group. He will carry out his research into the interaction between wind turbines at the Johns Hopkins University in Baltimore, USA. YES! is aimed at young, highly promising researchers with a PhD who have innovative ideas in the area of energy, generation, storage and transport and who aspire to a scientific career in fundamental energy research.

**Simon Stevin Gezel award**
Dr. Loes Segerink of the BIOS Lab-on-a-chip group received the Simon Stevin Gezel award for her research on a fertility chip for semen analysis. Last year she was already awarded with the Simon Stevin Student jury and audience award.
Rubicon Grant

The Rubicon program allows recently graduated scientists to gain experience at a foreign top institute. This is an important step up in a scientific career. Dr. Antony George, former PhD student of the Inorganic Materials Science group, and Dr. Menno Veldhorst, former PhD at the Interfaces and Correlated Electron Systems group both were awarded a prestigious Rubicon Scholarship by the Netherlands Organization for Scientific Research (NWO). The granted research proposal of Dr. George is concerned with the fabrication of nanoscale graphene devices by soft patterning and related approaches. The proposal of Dr. Veldhorst relates to the storage and transfer of quantum information in silicon chips, making use of such phenomena as quantum-teleportation.

Akzo Nobel Science Award 2012

Prof. dr. Detlef Lohse of the Physics of Fluids group received the 2012 AkzoNobel Science Award, in recognition of his groundbreaking research in the field of fluid dynamics. The AkzoNobel Science Awards are presented in recognition of outstanding scientific contributions by individuals in the fields of chemistry and materials science.

IBM Faculty Award

Prof. dr. Jeroen Cornelissen of the BioMolecular Nanotechnology group has received an IBM Faculty Award of $20k. The IBM Faculty Awards is a competitive worldwide program intended to foster collaboration between researchers at leading universities worldwide and those in IBM research, development and services organizations; and promote courseware and curriculum innovation to stimulate growth in disciplines and geographies that are strategic to IBM.

Aspasia Premium

Aspasia is an NWO (Dutch Science Foundation) program and aims to facilitate the promotion of female scientist to associate professor or professor. Prof. dr. ir. Kitty Nijmeijer of the Membrane Science and Technology group received an Aspasia grant. She will use the grant of €200,000 to further expand her research on polymer-molecular organic framework (MOF) architectures for gas separation. Nathalie Katsonis of the BioMolecular Nanotechnology group received an Aspasia premium of €50,000 to support her research on photo-engineered helices in chiral liquid crystals.

Overijssel PhD award

During the 51st Dies Natalis the Overijssel PhD award for the best University of Twente thesis was rewarded to Dr. MSc. Richard Stevens, former PhD of the Physics of Fluids group. He received this award of €5,000 for his thesis ‘Rayleigh-Bénard Turbulence’.

‘De Winter Prijs’ 2012

During the celebration of the Dies Natalis, Dr. Nathalie Katsonis of the BioMolecular Nanotechnology group received the University of Twente ‘De Winter Prijs’ 2012. The Professor de Winter Prize is named after Prof. Herman de Winter who was Professor of Applied Physics at the University of Twente. The prize is intended for the best publication written by a female academic of the University of Twente and was awarded to Dr. Katsonis for her publication in the Journal of Materials Chemistry, entitled “Controlling chirality with macroscopic helix inversion in cholesteric liquid crystals”. This paper was also highlighted as a ‘hot feature article’ by the Journal of Materials Chemistry, earlier this year.

EUROTHERM Young Scientist Prize

Dr. Richard Stevens, post-doc researcher in the Physics of Fluids group, has won the EUROTHERM Young Scientist Prize 2012. This prize, which is awarded every four years, is given to the European researcher who writes the best thesis in the field of Thermal Science. The young MESA+ researcher received an amount of €2,500.

Nottingham Prize

Dr. Daniël Schwarz of the Physics of Interfaces and Nanomaterials group obtained the 2012 Nottingham Prize at the Physical Electronics Conference in Dallas (USA). This is a very important achievement as this prize actually is the most prestigious one in the area of physics and chemistry of surfaces and interfaces.

Marcel Mulder Award for David Vermaas

MSc. David Vermaas, PhD Student of the Membrane Science and Technology Group of the University of Twente and Wetsus, Centre of Excellence for Sustainable Water Technology in Leeuwarden, has won the Marcel Mulder Award of 2012. The award of €5,000 is a remembrance to Prof. Marcel Mulder, who was next to professor in Membrane Process Technology at the University of Twente, the originator of Wetsus.
Springer Thesis

The thesis ‘Orthogonal supramolecular interaction motifs for functional monolayer architectures’ of Mahmut Deniz Yilmaz of the Molecular nanoFabrication group has been published as Springer Thesis, in the ‘best of the best’ series. Besides the honor Yilmaz received a prize of € 500.

MESA+ meeting 2012

During the MESA+ meeting in Cinestar on September 18, 2012, Dieter ’t Mannetje of the Physics Complex Fluids group won the 1st prize for the best poster. The 2nd prize was won by Remko Dijkstra of the Nanobiophysics group, and the 3rd prize was for Chris Hellingen of the Physics Interfaces and Nanomaterials group.

MESA+ Young Business Award 2012

At the annual MESA+ meeting, the Young Business Award 2012 was awarded to David Fernandez Rivas and Bram Verhaagen, respectively PhD-students at the Mesoscale Chemical Systems and the Physics of Fluids group. During a 3 minute pitch, they presented their business idea ‘ByBCLEAN’ for cleaning root canals and other spaces around teeth that are difficult to clean, using a novel technique that can generate microbubbles in a controlled way. A three-experts jury considered this idea the most promising one in terms of applicability, scalability and ease of entering the market.

Cum Laude distinctions

In 2012 five PhD students received cum laude distinctions for their work:

- Daniel Schwarz of the Physics of Interfaces and Nanomaterials group with his thesis ‘Visualization of nucleation and growth of BDA-films on Cu(001) and Au(111)’.
- Xiaofeng Sui of the Materials Science and Technology of Polymers group with his thesis ‘Chameleon’ Macromolecules: Synthesis, Structures and Applications of Stimulus Responsive Polymers’.
- Menno Veldhorst of the Interfaces and Correlated Electron systems group with his thesis ‘Superconducting and topological hybrids’.

Appointments

On April 20, 2012, Prof. dr. ing. Dave Blank has been appointed as member of the ‘Advisory Council for Science and Technology Policy (AWT)’.

On September 1, 2012, Prof. dr. ir. Kitty Nijmeijer, head of the Membrane Science and Technology group was appointed professor Membrane Science and Technology.

On October 1, 2012, Prof. Erik Roesink was appointed part-time professor Advanced membranes for aqueous applications. His research focuses on the design of membranes for e.g. water purification, water treatment and for food and beverage applications. The research is part of the strategic research program of the research group Membrane Science and Technology.

On October 26, 2012, Prof. dr. ir. Albert van den Berg received an honorary professorship from the SCNU in Guangzhou, China.

On October 29, 2012, Prof. dr. ir. David Reinhoudt, former scientific director of MESA+, has received the gold medal of honor of the University of Pécs.

The entire nanolayer Surface & Interface physics (nSI) department, headed by Prof. dr. Fred Bijkerk, which is currently located at FOM’s DIFFER institute in Nieuwegein, is to become part of the University of Twente/MESA+. The nSI department is among the top groups in the field of nanotechnology. It excels in gearing fundamental research to the specific questions and needs of science and industry. The department’s move to Twente will take place gradually. The entire department will be settled in its new home by mid 2014.
HIGHLIGHTS
MESA+ ANNUAL REPORT 2012
Biomolecular Electronic Structure

Gas-phase retinal spectroscopy: Temperature effects are but a mirage

Vision begins with the photo-induced isomerization of the retinal chromophore in rhodopsin, the photoreceptor in the vertebrate eye. Retinal represents a fascinating archetype of a photosensitive biological component since it functions as light detector over a remarkably wide range of absorption energies in visual and archaeal rhodopsins. To understand how the protein tunes absorption over so many wavelengths, it is important to establish the spectral behavior of retinal in the gas phase to discern intrinsic geometric and electronic features from the response of the chromophore to the biological environment. While photo-induced dissociation spectroscopy represents in principle an ideal experimental technique to probe retinal in the gas phase, rather distinct dissociation spectra have been recently obtained for retinal, which have in turn motivated many theoretical attempts to reproduce them. In particular, the unusual features of the dissociation spectrum were explained in terms of the multiple conformations which the flexible chromophore can visit at room temperature. With the use of state-of-the-art first-principle approaches, we investigate the complex dynamics of gas-phase retinal and, at variance with previous studies, provide compelling evidence that temperature effects cannot be responsible for the anomalous shape of the spectrum. Furthermore, our findings raise serious concerns on the interpretation of these model experiments, and call for further experimental investigations and careful characterization of the dissociation spectra.
In the BIOS Lab-on-a Chip group fundamental and applied aspects of miniaturized laboratories are studied. With the use of advanced and newly developed micro- and nanotechnologies, enabled by our Nanolab facilities, micro- and nanodevices for biomedical and environmental applications are studied and realized, such as chips for monitoring medication, counting sperm cells, mimicking organs on chip, discovery of new biomarkers and ultrasensitive detection thereof. To realize this, we work closely together with (bio)medical experts from our sister-institute MIRA, academic hospitals in the Netherlands and colleagues from the Wyss institute at Harvard.

**BIOS Lab-on-a-Chip**

**High-yield single cell encapsulation in droplets**

Recently, droplet microfluidics has evolved as a powerful platform for cell-based assays. Using microfluidic devices, droplets can be generated, merged, and sorted at kilohertz rates, enabling high-throughput single cell screening. However, the method suffers from one fundamental limitation, the variability in the number of cells per droplet. We overcome this drawback and present a new approach to deterministically encapsulate single cells in droplets using inertial ordering in a curved microchannel. The curvature introduces a second force, the Dean force, which causes particles to focus faster to a single equilibrium position. Matching the droplet generation frequency with the cell passing frequency leads to more than 100% increase in single cell encapsulation, at a speed of around 1000 droplets/s. Future work is focused on increasing the functionality of our device by implementing a droplet pairing, droplet fusion and droplet shrinkage module, making this platform attractive for a variety of biomedical applications.

BioMolecular Nanotechnology

Time-programmed helix inversion in phototunable liquid crystals

Cholesteric liquid crystals are a topic of intense interest due to their potential use in helix-based materials such as smart windows, actuators and sensors. These types of liquid crystals are of particular interest, since their helical nature induces the selective reflection of light of a certain polarization over a narrow range of wavelengths. This range can be controlled by the inclusion of photo-responsive chiral dopants.

In our studies we use overcrowded alkenes as dopants, which undergo a stable to unstable (cis-trans) isomerization upon irradiation with UV light. This results in an unwinding and eventual inversion of the supramolecular helix structure of the liquid crystals. Furthermore, in the absence of UV light the system relaxes back to its initial state. The modifications of the cholesteric helix during these processes are accompanied by changes of the selective reflection which we monitored using UV/Vis spectroscopy and Circular Dichroism spectroscopy.

An important parameter for all liquid crystals is the relaxation time of the cholesteric helix, i.e. the time needed to go from one helical state to the other, which needs to be suitable for the envisioned application. We have studied cholesteric liquid crystals doped with overcrowded alkenes in an effort to find a general paradigm correlating relaxation kinetics of the dopants with the rate of helix modification. We have shown that the helix relaxation kinetics are fully determined by the kinetics of the light-sensitive dopants. The relaxation of the dopants from unstable to stable is unperturbed by the liquid crystalline environment.

On the other hand, exchanging a dopant with a relatively slow relaxation rate against a faster relaxing dopant can dramatically accelerate helix inversion. Therefore the inversion can be time-programmed by a judicious choice of the dopant. These findings have great potential for the fine tuning of cholesteric liquid crystals for smart materials with sophisticated functions.
Prof. dr. Wim J. Briels

“There’s plenty of room in the middle.”

Computational BioPhysics

Controlled assembly of colloids by external stimuli

Entanglements of dissolved long flexible polymers endow simple liquids with visco-elastic flow properties. Colloids suspended in such visco-elastic solutions behave markedly different from colloids in Newtonian fluids. The in-house developed technique of Responsive Particle Dynamics (RaPiD) has made it possible to simulate and understand the dynamics of hundreds of colloids in large amounts of visco-elastic solutions. In agreement with experiments, the colloids are seen to align under shear in some visco-elastic solvent but not in others, nor in Newtonian liquids. The simulations indicate that flow reduces the polymeric concentration between adjacent colloids, thereby creating an attraction between the colloids. This flow induced depletion attraction varies with the size of the dissolved colloids, sometimes resulting in the segregation of colloids under shear.

The work is part of a large international program aiming at controlled organization of mesoscopic systems by external agents and in micro-channels.

The Computational BioPhysics (CBP) group investigates how the thermodynamic and rheological properties of a complex fluid emerge from its molecular constitution. Our computational studies focus on the mesoscopic level, i.e. the time and length scales of the macro-molecules determining the macroscopic behaviour, while the atomic details of these molecules are reduced to their bare essentials. By developing equations of motions and force fields that capture only the crucial molecular features, a complex molecule like a polymer or a protein can be modeled as a single particle. This approach proves very successful in studying the emerging macroscopic properties of biological and non-biological soft condensed matter.

Computational Materials Science

A new twist to an old problem

A magnet can point up or down in a magnetic field. In magnetic materials, information is stored digitally by using two such “states” to represent ones and zeros. A proposal to store information in high-density “racetrack” memories has focussed attention on how electric currents in a magnetic material are affected by twisting of the magnetism in between regions - “domains” - where the magnetism is either all “up” or all “down”. By performing extensive quantum mechanical calculations on a supercomputer, we find that a twist in the magnetism - a “domain wall” (Fig. 1) - makes a finite contribution to the resistance of a material no matter how slowly the twisting occurs, when a relativistic effect, the spin-orbit coupling, is taken into account. Our finding for domain walls in the technologically important Ni$_{80}$Fe$_{20}$ magnetic alloy, Permalloy, contradicts received wisdom for disordered materials and suggests that it should be possible to detect the number of domain walls in a nanowire with just electrical transport measurements.

In this work, we investigated diffusive transport through a number of domain wall (DW) profiles (Fig. 1) of Permalloy taking into account simultaneously noncollinearity, alloy disorder, and spin-orbit-coupling fully quantum mechanically, from first principles. In addition to observing the known effects of magnetization mistracking and anisotropic magnetoresistance, we discovered a not-previously identified contribution to the resistance of a DW that comes from spin-orbit-coupling-mediated spin-flip scattering in a textured diffusive ferromagnet. This adiabatic DW resistance, which should exist in all diffusive DWs, can be observed by varying the DW width in a systematic fashion in suitably designed nanowires.

Understanding the magnetic, optical, electrical and structural properties of solids in terms of their chemical composition and atomic structure by numerically solving the quantum mechanical equations describing the motion of the electrons is the central research activity of the group Computational Materials Science (CMS). These equations contain no input from experiment other than the fundamental physical constants, making it possible to analyze the properties of systems which are difficult to characterize experimentally or to predict the physical properties of materials which have not yet been made. This is especially important when experimentalists attempt to make hybrid structures approaching the nanoscale.
Looking through an opaque material

The COPS group, in collaboration with NPB, AMOLF Amsterdam and the University of Florence, has succeeded in making sharp pictures of objects hidden behind an opaque screen. This breakthrough in research has been published in the world-leading research journal *Nature*.

Materials such as skin, paper and ground glass appear opaque because they scatter light. In such materials light does not move in a straight line, but travels along an unpredictable and erratic path. As a result, it is impossible to get a clear view of objects hidden behind such media. Powerful methods have been developed to retrieve images through materials in which a small fraction of the light follows a straight path. To date, however, it has not been possible to resolve an image when all light has been completely scattered.

The COPS team has now succeeded in doing just this. They hid a fluorescent test object behind an opaque diffuser (Fig. 1). Then they scanned the angle of a laser beam that illuminated the diffuser. At the same time, a computer recorded the amount of fluorescent light that was returned by the hidden object. While the measured intensity cannot be used to form an image of the object, the information needed to do so is in there, yet in a scrambled form.

A computer program initially guesses the missing information, and then tests and refines the guess (Fig. 2). The team succeeded in making an image of a hidden fluorescent object just 50 micrometers across – the size of a typical cell. It is easy to guess from this high-resolution image that the work may lead to new microscopy methods capable of forming razor sharp images in a strongly scattering environment.

The Complex Photonic Systems (COPS) group studies light propagation in ordered and disordered nanophotonic materials. We investigate photonic bandgap materials, random lasers, diffusion and Anderson localization of light. We have recently pioneered the control of spontaneous emission in photonic bandgaps and the active control of the propagation of light in disordered photonic materials. Novel photonic nanostructures are fabricated and characterized in the MESA+ cleanroom. Optical experiments are an essential aspect of our research, which COPS combines with a theoretical understanding of the properties of light. Our curiosity driven research is of interest to various industrial partners, and to applications in medical and biophysical imaging.
Prof. dr. ir. Leon Lefferts

“One of the most high impact applications of nanotechnology is in the area of heterogeneous catalysis. The challenges are to improve the level of control over the active nanoparticles as well as the local conditions at those particles, and to understand the molecular mechanism at the surface.”

The aim of the Catalytic Processes and Materials group (CPM) is to understand heterogeneous catalysis by investigation of catalytic reactions and materials on a fundamental level in combination with their application in practical processes. Our research focuses on three themes:

1. Sustainable processes for fuels and chemicals, like catalytic conversion of biomass to fuels.
2. Heterogeneous catalysis in liquid phase.
3. High yield selective oxidation.

The fundamental study of surface reactions in liquid phase requires the development of new analysis techniques for which CPM is in the forefront of leading catalysis groups in the world. Moreover, we explore preparation and application of new highly porous, micro-structured support materials as well as micro-reactors and micro-fluidic devices, using the information obtained from in-situ spectroscopy studies.

Catalytic Processes and Materials

Stable Ru nano-particles on carbon-nano-tubes: promising catalyst for hydrogen production from biomass

Catalytic reforming of biomass derived waste streams in sub- and supercritical water is a promising process for the production of sustainable hydrogen. This type of process is called ‘aqueous-phase-reforming’ and is very interesting from a point of view of energy efficiency because evaporation of water, and the consequent energy penalty, is circumvented. Acetic acid is a major component in many anticipated feed streams (e.g. the aqueous fraction of pyrolysis oil) and is therefore used as a model compound. Conventional supported (e.g. alumina) catalysts deactivate in presence of acetic acid rapidly due to conversion of alumina to boehmite and hence other catalytic systems must be developed to make this process industrially feasible. Carbon nanotubes (CNT) are very resistant to deactivation during acetic acid reforming in supercritical water and are therefore very suitable as catalyst support. Supported Ru nanoparticles are very active for acetic acid reforming in sub- (195-340 °C, 225 bar) and supercritical water (400 °C, 250 bar). Even more important is the fact that Ru nanoparticles supported on CNT perform remarkably stable in acetic acid reforming in supercritical water.

Figure: Highly dispersed Ru nanoparticles supported on carbon-nano-tubes; stable in hot compressed water even at 400°C and 250 bar.
Conducting interfaces between oxide insulators

Transition metal oxides in the perovskite crystal configuration display a variety of remarkable properties. These range from high-$T_c$ superconductivity to colossal magnetoresistance, and from piezo-electricity to high-K dielectric behavior. Remarkably, interfaces between such perovskites can show even further effects, different from the abutting crystals. A prominent example is the conducting interface between the band insulators SrTiO$_3$ and LaAlO$_3$.

In the past years, a research program has been conducted at MESA+ involving the CMS, IMS, NE, NEM, PIN, QTM and ICE chairs, in the frame of the national FOM research program ‘InterPhase’, coordinated by Prof. Hilgenkamp. In 2012, the research in Twente has focused on a further understanding of the properties of these interfaces, and their improvement toward applications. The latter especially involves the increase of the electron mobility by enhanced oxygenation techniques and the development of high-quality top-gating for the local application of electric fields (see figure).

Materials with exceptional, well-tailored properties are at the heart of many new applications. In the electronic/magnetic domains, powerful means to create such properties are nanostructuring as well as the use of compounds in which the intrinsic physics involves ‘special effects’. These can arise from intricate interactions of the mobile charge carriers mutually and/or with the crystal lattice.

In the ICE group, the fabrication and basic properties of such (nano-structured) novel materials are studied, and their potential for applications is explored. Current research involves superconductors, p- and n-doped Mott compounds, topological insulators, electronically active interfaces between oxide insulators and novel electronic materials and device concepts for low power electronics and neuromorphic circuitry.

Interfaces and Correlated Electron systems

Prof. dr. ir. Hans Hilgenkamp

“The Interfaces and Correlated Electron systems group (ICE) focuses on materials and interfaces with unconventional electronic properties, especially related to interactions between the mobile charge carriers.”

Prof. dr. ir. Hans Hilgenkamp


Research in the Inorganic & Hybrid Nanomaterials Chemistry (IHNC) group focuses on the development and understanding of novel processing routes for hybrid and inorganic nanomaterials, with emphasis on thin films, micro/nanopatterns and low-dimensional nanostructures, for energy, electronic and biomedical applications. Starting from colloidal solutions of nanoparticles, complexes, nanowires or nanosheets, new functional nanomaterials are assembled. The use of low temperature, energy and resource efficient processing routes is central to our strategy.

Inorganic & Hybrid Nanomaterials Chemistry

Elucidating the structural evolution on nanoscale in drying thin films

Sol-gel derived ferroelectric thin films such as barium titanate BaTiO$_3$ and lead zirconate titanate Pb(Zr,Ti)O$_3$ are known for their good ferroelectric properties. These films are typically prepared by a wet-chemical coating process using precursor solutions that contain 2 or more metals in the form of metal-organic complexes. Upon drying, these complexes must somehow transform into an as-dried precipitate that is subsequently annealed at high temperature to form a dense perovskite-type oxide film with desired properties. While the initial state of precursor solutions has been studied in detail by many researchers, and the microstructure of the final oxide films is also well known, the structural transformations that take place between the initial and final states remained a mystery.

We used time-resolved small angle x-ray scattering to study nucleation and growth in drying sol-gel thin films at the European Synchotron Radiation Facility in France, focusing on nanostructures that evolve on the 1-10 nm length scale. Our studies showed that Zr and Ti precursors have a strong tendency to form polynuclear clusters, thereby inhibiting the mixing of metal centers on atomic scale. Detailed TEM-EELS studies on dried films at the MESA+ CMA lab showed that the resulting spatial separation between Ba and Ti-rich domains in as-dried films also depends on the water concentration in the film. These studies demonstrate that as-dried sol-gel films are not necessarily uniform on the nanoscopic and mesoscopic level.

Figure 1: Time-resolved small-angle x-ray scattering curves, showing the structural changes that take place in a drying thin film of a BaTiO$_3$ precursor solution. The evolving correlation peak at high q indicates the formation of agglomerates of polynuclear titanium oxo complexes.

Figure 2: Electron energy loss spectra (EELS) mappings of the distribution of Ba (red) and Ti (green) in as-dried films. The differences between the mappings show the influence of increasing water concentration on the distribution of elements.
Inorganic Membranes

Ultra-Thin Hybrid Polyhedral Silsesquioxane-Polyamide Films with Potentially Unlimited 2D Dimensions

The group Inorganic Membranes aspires to make membranes for molecular separation under harsh conditions, such as high temperature, elevated pressure, and the presence of aggressive chemical components. Under such conditions organic membranes, based on polymers, cannot show prolonged high separation performance, due to swelling, plasticization, and degradation. Inorganic membranes have superior stability, but their fabrication is challenging and costly. Hybrid inorganic-organic materials potentially allow combination of the beneficial properties of organic and inorganic membranes.

Recently, we have developed a facile method for formation of hybrid polyamides - polyhedral silsesquioxane (POSS), in the form of self-supporting or supported ultra-thin (~100 nm) films (see Fig. 1). The method is based on the principle of interfacial polymerization, in which thin film formation and polymerization are combined in a single step by dissolving two monomers in two different immiscible solvents. Film formation occurs at the interface between these two immiscible solvents where the monomers react. The formed interfacial thin film separates the two reactants causing the reaction to be self-terminating, innately avoiding the formation of thicker films, and promoting the self-healing of defects such as pinholes. The thin hybrid films combine intrinsic local ordering of inorganic and organic constituents on the molecular scale with potentially infinite lateral macroscopic dimensions, are robust and flexible, and exhibit molecular selectivity in gas and liquid permeation experiments.

The developed method allows for macromolecular network design of ultrathin hybrid films, with high loading of POSS molecules, covalently linked to a variety of organic groups, distributed homogeneously on a molecular level. Future research activities within our group are aimed at such design, tuning independently the chemistry and network dynamics of these films for use as high-performance membranes, and the detailed in-situ characterization of the thin film properties under relevant conditions (see Fig. 2).
Enhanced Electrical Conductivity in Vortex Cores of Ferroelectric Domains

Topological defects in condensed matter offer a powerful paradigm for nanoscale-device engineering owing to the combination of unique physical properties and the capability for their manipulation by external magnetic, electric, or strain fields without disruption of the host lattice. Examples include vortices in superconductors, defects in topological insulators, and domain walls in ferroics. The numerous examples of novel functionalities at the domain walls enabled by stabilization of a high-symmetry phase and order-parameter coupling include domain wall ferroelectricity in paraelectric materials, enhanced electronic conductivity, magnetoelectric coupling, magnetic phase transitions, and ionic phenomena. This potentially facilitates a broad spectrum of reconfigurable magnetoelectric, optoelectonic, and strain-coupled memory and logic devices through domain engineering.

We have controllably created and probed the electronic properties of 1D topological defects. Specifically, we explored the physical properties of artificially engineered domain junctions forming vortex or antivortex states in 50 nm (001)-oriented multiferroic BiFeO$_3$ thin films by local current detection using scanning probe microscopy, and deciphered the associated mesoscopic and atomistic conduction mechanisms to establish the origins of vortex conduction.

The Integrated Optical MicroSystems (IOMS) group performs research on highly compact, potentially low-cost and mass-producible optical waveguide devices with novel functionalities. After careful design using dedicated computational tools, optical chips are realized in the MESA+ cleanroom facilities by standard lithographic tools as well as high-resolution techniques for nano-structuring, such as focused ion beam milling and laser interference lithography. Integrated optical devices, including on-chip integrated light sources and amplifiers, optically resonant structures, micro-mechanically or thermo-optically actuated switches, spectrometers, and novel light generation, manipulation, and detection schemes based on these devices are developed for a variety of applications in the fields of optical sensing, bio-medical diagnostics, and optical communication.

Intra-laser-cavity nano-particle sensor

Masers and lasers were invented in the 1950s and 1960s, because they provide by far the most monochromatic, narrowest-linewidth, hence highest-quality optical light generated in our universe and, therefore, can be used as the most sensitive spectrometers.

We deposited rare-earth-ion activated Al2O3 layers on thermally oxidized silicon microchips by reactive co-sputtering and microstructured channel waveguides by chlorine-based reactive ion etching. Bragg gratings were inscribed to the SiO2 top cladding by laser interference lithography and subsequent reactive ion etching. Adiabatic widening of the waveguide close to the center of the Bragg grating creates a phase shift, resulting in an optical resonance, which allowed us to demonstrate distributed-feedback (DFB) lasers at 1.5 µm in Al2O3:Er3+ and 1 µm in Al2O3:Yb3+ with free-running linewidths of a few kHz, equaling optical coherence lengths of tens of km [1].

The implementation of two such adiabatic phase shifts results in the simultaneous oscillation of two frequencies whose longitudinal optical modes are distributed unevenly over both phase-shift regions (Fig. 1A). Since the two phase-shift regions are close to each other on the same chip and pumped optically by the same pump laser, the two emitted laser lines react similarly on environmental changes, e.g. in temperature or pump power. Hence the electrical 15-GHz microwave beat signal generated by the two laser lines at a detector is highly stable in frequency (Fig. 1B) [2].

This dual-wavelength DFB laser can be used as a highly sensitive nano-particle sensor (Fig. 2A), e.g. in microfluidic environments. When disturbing the evanescent laser field in either of the two phase-shift regions by a borosilicate microsphere attached to the cantilever of an atomic force microscope, we observed a tiny frequency shift in the according laser line by reading out the electrical beat signal with the second, unperturbed laser line. Even at its current state of infancy, this intra-laser-cavity optical sensor is capable of detecting objects down to a diameter of 500 nm (Fig. 2B). We anticipate that further improvement of our device will enable the detection of particles down to a size of a few tens of nm [3].

Figure 1: Self-heterodyne beat spectrum of the WECSL. The black dots show the measured RF-beat spectrum and the red line shows a Lorentzian fit with a 3 dB bandwidth of 50 kHz. This corresponds to a laser bandwidth of 25 kHz.

Figure 2: Schematic of the waveguide chip. (a) The complete waveguide chip. The waveguides are depicted in white, electrical contacts are in yellow, and heaters are in gray. The heaters are placed on top of the MRRs (for thermal tuning of the MRRs’ resonance frequencies), and on the straight waveguides after the MRR mirror (for changing the refractive index of the straight waveguides after the MRRs, such that a maximum output power can be achieved after the two straight waveguides are combined). (b) The waveguide chip without heaters and electrical contacts. (c) Zoom-in on the two MRRs, having radii $R_1$ and $R_2$, and the coupler C.

**Laser Physics and Nonlinear Optics**

**Novel approach to on-chip spectral control of lasers**

Tunable diode lasers with narrow bandwidths well below 1 MHz are of interest for many applications, e.g., in coherent optical communications, where frequency tunability and narrow bandwidths can be used to increase data transfer density. The spectral bandwidth of free-running diode lasers without frequency selective feedback is on the order of GHz. We have applied spectral narrowing methods in order to reach bandwidths significantly below this value. Using a novel type of laser, which is a semiconductor laser coupled to a waveguide circuit based external cavity (WECSL), we have reached a record low spectral bandwidth of 25 kHz [1], see Fig. 1. The waveguide chip incorporates a double micro-ring resonator (MRR) structure, as depicted in Fig. 2, referred to as an MRR mirror. The resonance frequencies of both MRRs can be tuned by heating the MRRs, resulting in faster tunability than possible for mechanically tuning a free-space external cavity. Since the external cavity is integrated on a waveguide chip, mechanical stability is significantly increased compared to free-space external cavities. Also, entire arrays of such lasers might be integrated and phase locked, while the general concept can be applied to semiconductor lasers over a large wavelength range, from the visible to the mid-infrared range.
Taming acoustic cavitation

In a collaboration with the Physics of Fluids group and the team of profs. Keurentjes and Schouten at the TU Eindhoven, research was performed with the goal to improve the efficiency of sonochemical reactors. The work done in the MCS group by PhD student David Fernandez Rivas has focused on the control of the nucleation sites of streams of bubbles in aqueous solutions, by using microfabrication techniques. It was demonstrated that one order of magnitude improvement in sonochemical yield, compared to a conventional sonoreaction system, is possible. The characteristics of the sonoluminescence and the sonochemiluminescence arising from the collapsing bubbles in the reactor have given useful information on the type of bubbles generated, and the sonochemical results could be coupled quite well to theoretical computational results.

The bubble streams, originating from micromachined pits in a silicon substrates after the application of ultrasound, demonstrated a characteristic pattern, which depends on ultrasound power. Due to specific forces between the bubbles in combination with acoustic streaming, after a certain power threshold has been passed, the trajectories of the bubbles switch to paths close to the substrate, as is shown in Fig. 1. In this mode, enhanced erosion of the substrate surface is observed (Fig. 2), a topic that was studied in detail for different types of silicon, leading to important insights useful for future reactor design strategies. The positive side of this is that the bubble streamers can be used for local surface cleaning, which effect will be exploited in a new spin-off company ‘Bubclean’, founded by Bram Verhaagen and David Fernandez Rivas.

Mesoscale Chemical Systems

The research focuses on the themes:

- Alternative activation mechanisms for chemical process control and process intensification: Examples are: electrostatic control of surface processes and reactions in liquids, photochemical microreactors for solar-to-fuel conversion, sonochemical microreactors and microreactors with integrated work-up functionality;
- Miniaturization of chemical analysis systems: Examples are: liquid chromatography on a chip, microscale NMR, nanostructured gas sensors, micro optical absorption cells (UV, IR);
- Micro and nanostructured surfaces for biological studies: Chip-based array of bioreactors with integrated electronic and microfluidic functionality are developed for the study of neurophysiologic responses of neuronal tissue.

Molecular nanoFabrication

A Supramolecular System for the Electrochemically Controlled Release of Cells

Our approach to design supramolecular coupling chemistry for binding proteins to surfaces works selectively and specifically. [1] We have recently extended this approach to the use of a specially designed supramolecular glue to electrically switch the behaviour of individual cells. [2] This occurs under the same physiological conditions as those found in the body. The latter finding is enormously important in terms of the highly specific and local administration of medication, at the molecular level. The success or failure of this approach is not simply a question of pure chemistry. It also depends on the, occasionally indefinable, “watery” conditions around the cell. The new method is exciting because it enables ligands to be presented dynamically to cells in contrast to many existing methods, but practically as Nature does herself. An external electric pulse determines whether the cells bind to the ligands or unbind from them. On a specially prepared surface, a “wound” inflicted on a cell-covered substrate healed significantly faster than it would under normal conditions in a healthy body. The key player in this supramolecular approach is a pumpkin-shaped macromolecule that can accommodate two guest molecules in its skeleton. One binds to a specially prepared gold surface, the other stretches its feelers out to a specific body cell. The links appear to be reversible. Reversing the electrical signal causes cells to bind or to unbind. This research opens the way to studies of fundamental aspects of cell biology as well as applications, together with researchers from the MIRA Institute and our partners in the BioMedical Materials programme. In the case of regeneration, for example, natural factors often play a decisive part. For instance, in the worst case, any infections that develop during treatment can lead to rejection. In such situations, the ability to control events at the cellular level is a pivotal tool.

Simulations of fluids confined in narrow slit nano-pores

The properties of fluids confined to nanometer-sized geometries are known to deviate from classical bulk fluid properties. The atoms close to the walls arrange in layers, turning the fluid density and various other thermodynamic and hydrodynamic fields into (anisotropic) functions of the distance from the wall. Understanding and finding relations between these local fluid quantities near walls are still open research themes. Over the last decades, especially molecular dynamics simulations have advanced our understanding of strongly confined inhomogeneous fluids. These studies usually focused on one-dimensional profiles across a channel, assuming homogeneity in the two remaining directions. The figure shows a two-dimensional density distribution of a strongly confined fluid, flowing to the right under a large body force. Very close to the wall, the distribution of atoms displays inhomogeneities in the directions parallel and perpendicular to the wall. Our recent two- and three-dimensional analysis might provide the key to finding quantitative relations between the local state variables close to the walls with the goal to predict flow in nano-channels, -reactors, underground reservoirs, membranes, or biological, cellular and vascular systems.

The research group Membrane Science & Technology (MST) focuses on the multidisciplinary topic of membrane science and technology for the separation of molecular mixtures and selective mass transport. We aim at designing polymer membrane chemistry, morphology and structure on a molecular level to control mass transport phenomena in macroscopic applications. We consider our expertise as a multidisciplinary knowledge chain ranging from molecule to process. The research program is divided into three application clusters: Energy, Water and Life Sciences. The group consists of two separate entities: the academic research group Membrane Science and Technology (MST) and the European Membrane Institute Twente (EMI), which performs confidential contract research directly with the industry.

Membrane Science and Technology

Tailor-made anion exchange membranes for salinity gradient power generation using reverse electrodialysis

Reverse electrodialysis (RED) or blue energy is a non-polluting, sustainable technology to generate power from the mixing of solutions with different salinity, i.e. seawater and river water. A concentrated salt solution (e.g. seawater) and a diluted salt solution (e.g. river water) are brought into contact through an alternating series of polymeric anion exchange membranes (AEM) and cation exchange membranes (CEM), which are either selective for anions or cations. Currently available ion exchange membranes are not optimized for RED, while successful RED operation notably depends on the used ion exchange membranes. In the current work, we designed such ion exchange membranes and for the first time, we show the performance of tailor-made membranes in RED. More specifically we focus on the development of anion exchange membranes (AEMs) as these are much more complex to prepare. Here we propose a safe and more environmentally friendly method and used halogenated polyethers such as polyepichlorohydrin (PECH) as starting material. A tertiary diamine (1,4-diazabicyclo[2.2.2]octane, DABCO) was used to introduce the ion exchange groups by amination and for simultaneous cross-linking of the polymer membrane (Fig. 1). Area resistances of the series of membranes ranged from 0.82 to 2.05 \( \Omega \cdot \text{cm}^2 \) and permselectivities from 87 to 90%. For the first time we showed that tailor-made ion exchange membranes can be applied in RED. Depending on the properties, application of these membranes in RED resulted in a high power density of 1.27 W/m\(^2\), which exceeds the power output obtained with the commercially available anion exchange membranes (Fig. 2). This shows the potential of the development of ion exchange membranes especially designed for Blue Energy.
Materials Science and Technology of Polymers

Smart polyionic liquids for controlled molecular release

Polyionic liquids (PILs) consist of charged macromolecules and small-molecular counterions, have low melting temperatures, and can exhibit good water solubility. PILs provide new functions and enable numerous applications as dispersants, absorbents, surface-active agents, and precursors for other advanced materials. We synthesized novel water-soluble PILs based on a redox responsive, smart, organometallic backbone chain that consists of ferrocenylsilane (PFS) repeat units featuring charged vinyl imidazole side group, which also includes a reactive carbon-carbon double bond for cross-linking (Fig. 1). Using PFS-PILs, PFS microgel particles were obtained by a microfluidic system coupled with UV photopolymerization (Fig. 2). The microgel particles were loaded with fluorophores as model molecular guests, which could be released by oxidizing the PFS backbone chain. These redox responsive PFS microgel particles are very promising materials in controlled molecular release and catalysis.

Mathematics of Computational Science

Efficient Multigrid Methods for Advection Dominated Flows

Higher order accurate discontinuous Galerkin (DG) finite element methods are well suited to obtain very accurate numerical solutions of advection-dominated flow problems. Unfortunately, when thin boundary layers or singularities require highly stretched meshes the numerical efficiency of higher order DG algorithms is rather poor. This severely limits their application to complex flow problems. Recently, we significantly improved the computational performance of higher order DG methods for advection-dominated flow problems by developing the hp-Multigrid as Smoother (hp-MGS) algorithm. This algorithm combines several multigrid techniques (h- and p-multigrid). In particular, the h-multigrid acts as smoother in the p-multigrid and efficiently removes the high frequency part of the numerical error. Using this approach a significantly better convergence rate can be obtained than with standard multigrid techniques. The key to the success of this novel multigrid algorithm is the use of a detailed multi-level analysis. Using this mathematical analysis technique it is possible to accurately predict the theoretical performance of the multigrid algorithm. The multilevel technique also allows the determination of optimal values of free parameters in the algorithm, such as the smoother coefficients. This makes it possible to develop optimized algorithms for specific classes of problems, such as the Navier-Stokes equations, which show a fast convergence rate. The hp-MGS algorithm was tested on a fourth order accurate space–time discontinuous Galerkin finite element discretization of the advection–diffusion equation for a number of model problems, which include thin boundary layers and highly stretched meshes, and a non-constant advection velocity. For all test cases excellent multigrid convergence was obtained.

Getting a grip on α-Synuclein oligomers

Aggregation of the human α-Synuclein protein is implicated in the onset and progression of Parkinson’s disease. There is compelling evidence that small oligomeric aggregates of the protein play a role in neurotoxicity, but very little is known about the molecular details of these species. We have developed a method that uses sub-stoichiometric fluorescent labeling of a fraction of monomers in combination with single-molecule photobleaching to determine the aggregation number, that is, the number of monomers per oligomer (1). Using this method, we can determine the composition, probe the distribution in the aggregation number, and investigate the influence of the fluorescent label on the aggregation process. This work was featured on the cover of Angewandte Chemie.

How to control the energy transfer between molecules

In a collaboration with the MESA+ Complex Photonic Systems (COPS) group, AMOLF, and Technical University of Denmark we have resolved a long-standing debate about whether one can influence the rate at which energy is transferred between a pair of two closely spaced molecules by changing the nanophotonic environment (2). We used a well-defined system constructed by attaching energy donor and acceptor molecules to both ends of a piece of DNA of exactly defined length, and controlled the nanophotonic environment by positioning the molecular pair with nanometer precision very close to a metallic mirror. We found a surprising outcome: the energy transfer rate is not at all influenced by changing the nanophotonic environment. Simultaneously, the efficiency of energy transfer can be quantitatively and predictively increased or decreased by purely changing the nanophotonic environment without changing the energy transfer system itself. This work was featured on the cover of Physical Review Letters.
NanoElectronics

Ultrahigh-Frequency Surface Acoustic Wave Generation for Acoustic Charge Transport in Silicon

Surface acoustic waves (SAWs) are propagating elastic deformations confined to the surface. This elastic waves can be electrically excited at GHz frequencies on a piezoelectric material by using interdigital transducers (IDTs). On semiconductors, SAWs can be used to modulate the optical and electronic properties by means of the associated lattice deformation and the respective piezoelectric fields. For piezoelectric semiconductors, the SAW-induced piezoelectric field leads to a periodic type II modulation of the conduction and valence band edges. Electrons and holes can be captured in the minima and maxima of the CB and VB edges. In this way, they can be stored, transported and intentionally forced to recombine at a remote position along the SAW’s path. Moving potential wells are also a good candidate for metrology as they allow for controllable charge pumping in the GHz regime. Recently, there have been some attempts to develop SAW-driven single-photon sources. Acousto-electric transport is mostly limited to III-V semiconductors (particularly GaAs). Group IV semiconductors such as silicon lack piezoelectricity and have a lower carrier mobility. In addition, the IDT operation frequencies usually do not exceed a few GHz due to the lithographical limitations of conventional fabrication methods.

We have developed a novel CMOS-compatible approach to generate SAWs at ultrahigh frequencies on a silicon-based multilayer system, which consists of a thin ZnO layer sandwiched between SiO$_2$ layers on a Si wafer (Fig. 1). We have used UV-based nanoimprint lithography (NIL) for the IDT fabrication. Finger electrodes with width and spacing down to 65 nm were realized with very high critical dimension control. SAW frequencies up to 23.5 GHz were reached, the highest ever reported for silicon systems. The excited SAW modes were compared with numerical simulations and showed excellent agreement (Fig. 2). The acoustic and electric field distributions show that the electron and hole mobility in silicon are sufficiently large to realize efficient acousto-electric transport.
New Physical Phenomena in Oxide Multilayers by controlled Interface Engineering

Perovskite oxides are well known for their wide range of properties and the possibilities of materials engineering to enhance these properties. Next to strain engineering, recently, research has focused on the engineering of the oxygen octahedra rotation patterns at the interfaces between perovskite thin films. It is shown that the specific oxygen octahedra pattern, which controls the film properties, depends on the strain in the layer and, especially at interfaces, also on the rotation pattern of the substrate. We have found a critical thickness of 10 unit cells below which the conductivity of La_{0.67}Sr_{0.33}MnO_3 films disappeared and simultaneously the Curie temperature increased to 560 K, indicating a magnetic insulating phase at room temperature. The canted antiferromagnetic insulating phase in ultra thin films coincides with the occurrence of a higher symmetry structural phase with a different oxygen octahedra rotation pattern. Such a strain engineered phase is an interesting candidate for an insulating tunneling barrier in room temperature spin polarized tunneling devices.

Perovskite oxide heteroepitaxy receives much attention because of the possibility to combine the diverse functionalities of perovskite oxide building blocks. A general boundary condition for the epitaxy is the presence of polar discontinuities at heterointerfaces. These polar discontinuities result in reconstructions, often creating new functionalities at the interface. However, for a significant number of materials these reconstructions are unwanted as they alter the intrinsic materials properties at the interface. Therefore, a strategy to eliminate this reconstruction of the polar discontinuity at the interfaces is required. We show that the use of compositional interface engineering can prevent the reconstruction at the La_{0.67}Sr_{0.33}MnO_3/SrTiO_3 (LSMO/STO) interface. The polar discontinuity at this interface can be removed by the insertion of a single La_{0.33}Sr_{0.67}O layer, resulting in improved interface magnetization and electrical conductivity.

The aim of the NanoElectronic Materials (NEM) group is to advance the field of materials science, with a focus on nanomaterials for applications in electronic devices. The research is based on current trends in nanomaterials science and developments within MESA+, such as the controlled growth of materials, control of their structure, and understanding of the structure-property relations. The research is focused on three areas: Artificial Materials, Functional and Smart Materials for Devices, as well as In-situ Characterization of Film Growth and Interface Processes. These areas have in common that they find their basis in materials science, bridging major disciplines within MESA+, i.e., Chemical Engineering, Applied Physics, and Nanotechnology.
Prof. dr. Serge J.G. Lemay

“The physics of ions in liquid are directly relevant to a surprisingly wide array of research areas of current scientific and societal interest. These include nanoscience (the ‘natural’ length scale for ions), energy (fuel cells, supercapacitors), neuroscience (signal transduction, new experimental tools), and health and environment monitoring (new and better sensors).”

NanoIonics

The goals of the group Nanoionics (NI) are to add to fundamental understanding of electrostatics and electron transfer in liquid, and to explore new concepts for fluidic devices based on this new understanding. Our experimental tools, which are largely dictated by the intrinsic nanometer scale of the systems that we study, include scanning probes, sensitive electronics, and lithography-based microfabrication. Through its focus on nanoscience and its multidisciplinary nature, this research is a natural fit for MESA+.

Nanolonics

Measuring the smallest trickle

We have developed a method for electrically measuring record-low flow rates of picoliters per minute in nanochannels, corresponding to one 30-microliter drop of water every few years. Our approach is based on a pair of nanogap electrochemical sensors located downstream from each other inside a nanochannel. When liquid is driven through this device, small statistical fluctuations in the local density of molecules are transported along the channel. We perform time-of-flight measurements of these fluctuations by comparing the current-time traces at the two sensors, from which it is straightforward to extract the fluid velocity. More generally, we envision a broad range of uses for this electrochemical cross-correlation spectroscopy approach: similar to its direct optical analogue, fluorescence correlation spectroscopy, it can be used to investigate local concentration, adsorptivity and reaction kinetics in fluidic devices. All-electrical detection without the need for a microscope further facilitates integration in microfluidic lab-on-a-chip systems, where multiple detectors in more complex nanochannel networks can also be realized.

Nanofluidics for Lab on a Chip Applications

Extreme nanofluidics: DNA movement through nanopores

One of the hot new methods that is in development for DNA sequencing is nanopore sequencing. For this purpose the DNA is drawn through a membrane nanopore by the application of an electrical field. The pore has a diameter of just a few nanometers and a typical length of a few tens of nanometers. The signal in this method will be the time-varying electrical current through the pore or across the pore, which is expected to be slightly different depending on the specific base pairs moving through the pore. This method has the potential to revolutionize DNA sequencing, since just one DNA molecule would be needed and the data could be rapidly obtained, like from an old-fashioned tape recorder. The method however at the same time poses very heavy requirements on the precision of current measurements and needs an exquisite control of the passage of the DNA through the nanopore. At present the fingerprint during DNA passage is not well understood and may contain a number of unknown contributions. Current overshoots after DNA passage are for example often observed. We decided to study this process on the basis of our experience with DNA electrophoresis in nanochannels.

We showed by a theoretical analysis of the ionic transport during such translocation events, that concentration polarization will occur at the start and end of the DNA passage. Figure 1A and 1B illustrate this process. Ions are sucked away in the front of the entering DNA and enriched at the tail of the exiting DNA. Both processes will induce strong variations in local conductivity which will then affect the current signature during DNA passage. The processes thus have to be controlled or to be accounted for in the course of future nanopore sequencing. Recently, the group of Rohit Karnik in MIT has indeed reported current signatures during DNA translocation through nanochannels that show both phases. (Sen and Karnik, Proc. 25th IEEE MEMS, Paris (2012) 812-814).

Figure 1: Schematic of a DNA molecule (in blue) and its surrounding electrical double layer (in red) entering [A] and leaving [B] a nanopore as occurring in nanopore DNA sequencing. The diameter of the DNA is about 2 nanometer and the diameter of a typical nanopore about 5 nanometer. We derived that at the front of the entering DNA (A; between planes 1 and 2) ion depletion will occur and at the back of the exiting DNA (B; between planes 3 and 4) ion-enrichment will occur. The ion depletion and enrichment will modify the transpore electrical conductance, which will influence the current fingerprint of the DNA base sequence during translocation in a manner as schematically shown in figure 2.

Figure 2: Current fingerprint of a DNA translocation event influenced by the processes shown in figure 1 (schematic). The fingerprint is altered at A and B by the concentration polarization occurring in translocation phases A and B (figure 1).
Optical Sciences (OS) is a dynamic and multidisciplinary research group, whose infrastructure and expertise ranges from near-field probing of (single) molecules and materials through nonlinear spectroscopy and imaging to nanostructure fabrication and ultrafast laser spectroscopy. The integration of phase-shaped femtosecond laser pulses and adaptive learning algorithms within these themes is leading to exciting new research at the interface of chemistry, physics and nanomaterials science. Applications include improving the efficiency of photovoltaic and photocatalytic devices, chemically-selective imaging in biology and pharmacology, and studying wave propagation and nonlinear phenomena in nanostructured materials.

Active and passive shaping of the light-matter interaction

Two approaches are used in the group: active control via pulse shaping and passive control via strategic manipulation in the periphery of the molecular structure. The objective of both of these control experiments is the same: to enhance the yield of the functional pathway and to minimize loss channels. In [1] the aim of the active control experiments is to increase the intersystem crossing yield in zinc phthalocyanine (ZnPc), which is important for application in photodynamic therapy (PDT). Pulse shaping allowed an improvement in triplet to singlet ratio of 15% as compared to a transform-limited pulse. This effect is ascribed to a control mechanism that utilizes multiphoton pathways to higher-lying states from where intersystem crossing is more likely to occur. The passive control experiments are performed on ZnPc derivatives deposited onto TiO$_2$, serving as a model system of a dye-sensitized solar cell (DSSC). Modification of the anchoring ligand of the molecular structure resulted in an increased rate for electron injection into TiO$_2$ and slower back electron transfer, improving the DSSC efficiency.
Philosophy of Science in Practice

Scientific concepts as epistemic tools

Nanotechnology and other techno-sciences aim at producing phenomena (materials, properties and processes) for specific technological functions. In a traditional view, science aims at explaining phenomena that exist in Nature. But how is it possible to generate knowledge for technologically changing, controlling or even creating phenomena that do not exist as yet? This raises the question of how knowledge is related to the world. In a commonly accepted view, knowledge describes ‘matters of fact’ – it presents true descriptions or adequate pictures of how the world is. Yet, how we attain descriptions of the unobservable world is a controversial epistemological issue. ‘Believers in science’ assume that this is just a matter of successful conjecturing what ‘the world behind the observable phenomena’ is like. One of the key-ideas of the alternative view presented here is that scientific explanations of phenomena are constructed in light of epistemic purposes – as epistemic tools for reasoning about the world. Furthermore, the construction of scientific knowledge is constrained and enabled by both empirical and theoretical knowledge, as well as technological devices and measurement instruments, and mathematical tools. As an alternative to the metaphor in which scientists discover the world behind the phenomena, the construction of scientific concepts such as ‘oxygen’, ‘temperature’ and ‘electro-magnetic field’ could be understood metaphorically as a design process, which aims at fitting-together ideas, knowledge of technologies and materials, etc. Scientific concepts resulting from this process are epistemic tools which allow for epistemic activities such as creatively thinking up empirically testable hypotheses. Techno-scientific practices could advance from paying attention to how scientific concepts were constructed, instead of presenting them as if they are descriptions of ‘unobservable objects’ independent of technological instruments used to produce or investigate them.

The group Philosophy of Science in Practice (PSP) aims at an integrated and workable account of how techno-scientific research produces technology and scientific knowledge that facilitates critical reflection on methodological issues. Textbooks by scientists usually repeat an inappropriate traditional picture of science that concurs with a traditional philosophical view of science. A more refined philosophical understanding is crucial for dealing with methodological difficulties that result from increasing scientific fragmentation and technological complexity, and for coping with the societal importance of techno-scientific research.
Manipulating fluids and interfaces from the nano- to the microscale
The goal of the Physics of Complex Fluids (PCF) group is to understand and control the physical properties of liquids and solid-liquid interfaces from molecular scales up to the micrometer meter range. We are particularly interested in i) (electro) wetting & microfluidics, ii) nanoscale properties of confined fluids, and iii) soft matter mechanics. Our research connects fundamental physical and physico-chemical phenomena in interface science, nanofluidics, microfluidic two-phase flow, static and dynamic wetting, superhydrophobicity, drop impact, drop evaporation to practically relevant applications including inkjet printing, immersion lithography, lab-on-a-chip systems, optofluidics, as well as advanced methods of enhanced oil recovery.

Physics of Complex Fluids

High resolution atomic force spectroscopy and molecular simulations reveal origins of confinement-induced excess dissipation on the nanoscale

On macroscopic scales the relevant material properties characterizing a liquid are its density and its viscosity. If confined between solid surfaces at a distance of a few nanometers, however, a simple description based on continuum fluid dynamics is no longer appropriate and molecular properties of the liquid start to matter. Geometric packing constraints induce a layered average arrangement of the molecules and simultaneously hinder diffusion and site exchange of the molecules. The fluid becomes structured – and more ‘viscous’. To elucidate the properties of such ultra-confined liquids we have been performing high resolution Atomic Force Microscopy for several years. Recently, we developed a new technique that allows for extracting conservative and dissipative forces from the fluctuation spectrum of thermally driven AFM cantilevers in the vicinity of solid surfaces. With this ‘excitation-free’ method we impose minimal perturbations on the system and managed to improve the resolution of conventional driven AFM dissipation measurements by more than one order of magnitude revealing confinement-induced excess dissipation with unprecedented resolution. The results are consistent with Molecular Dynamics simulations of the same system carried out in collaboration with the Computational Biophysics group of Prof. Briels.

The new AFM spectroscopy method was developed in the context of the FOM program ‘Fundamental Aspects of Friction’ coordinated by Prof. Frenken (Leiden).

Photocatalytic Synthesis

Characterization of optically excited silicon by Attenuated Total Reflection InfraRed spectroscopy

Photocatalysis is based on the use of light activated catalysts in chemical conversion. Practical application is limited because of problems in light management, such as mismatch in catalyst sensitivity and solar spectrum, the limited ability of photo-excited states to induce electron transfer reactions, and lack of efficient light exposure of catalysts in reactors. Using advanced (infrared) spectroscopies, the Photocatalytic Synthesis (PCS) group aim at understanding the role of both the physical and chemical properties of innovative materials in establishing photocatalytic transformations. We also study the effect of process conditions and reactor geometry on performance, to determine optimized operation conditions. Finally, we evaluate (photo)electrochemical methods for chemical conversion. Potential fields of application are: 1) conversion of CO₂ and H₂O to hydrocarbons, 2) alkane activation, and 3) purification of waste streams (air and water).
Direct visualization of one-dimensional electronic states

The physical realization of two-dimensional electron systems has revealed a cornucopia of novel and intriguing physics. It has been predicted that one-dimensional electron systems should also open a new realm of exotic physical phenomena, driven by the appearance of spin and charge collective modes. Until now, however, the exploration of this realm has barely begun, its promises have not yet been materialized, and the extent of its potential for new physics and devices has remained largely untapped. In a recent Nature Physics article [1] we have shown that one-dimensional electronic states can be mapped out in real space using dual imaging of topographic (STM) and spectroscopic (dI/dV) information (see Fig. 1).

Direction observation of critical nuclei during crystallization

One of the highlights of the PIN group’s experimental work of the year 2012 is the direct observation of critical nuclei during the crystallization of 4,4’-biphenyldicarboxylic acid (BDA) molecules into two-dimensional (2D) crystals with our low-energy electron microscope (LEEM) [2]. The figure shows how condensed molecular islands (solid arrows) form as coverage the BDA increases (see inset). The energetics of the films is however such that the critical nucleus size is very large and we were able to directly visualize the appearance and disappearance (open arrows) right around the critical nucleus size. Because our LEEM also offers to measure the dilute density of molecules around the molecular islands, we were able to visualize and quantify the entire nucleation and growth process that normally occurs on atomic length scales.

Prof. dr. ir. Hajo Broersma

“We have entered a new era in which we are not always able to build devices by first designing them on the drawing table. But nature itself has offered us a powerful solution concept: evolution.”

Programmable NanoSystems

NASCENCE

In the FP7 project “NASCENCE: Nanoscale Engineering for Novel Computation using Evolution” that started on November 1, 2012, the aim is to model, understand and exploit the behaviour of evolving nanosystems (e.g. networks of nanoparticles, carbon nanotubes or films of graphene) with the long term goal to build information processing devices exploiting these architectures without reproducing individual components. With an interface to a conventional digital computer we will use computer controlled manipulation of physical systems to evolve them towards doing useful computation. See www.nascence.eu for more details on progress.

During the project our target is to lay the technological and theoretical foundations for this new kind of information processing technology, inspired by the success of natural evolution and the advancement of nanotechnology, and the expectation that we soon reach the limits of miniaturisation in digital circuitry (Moore’s Law). The mathematical modelling of the configuration of networks of nanoscale particles combined with the embodied realisation of such systems through computer controlled stochastic search can strengthen the theoretical foundations of the field while keeping a strong focus on their potential application in future devices.

Members of the consortium have already demonstrated proof of principle by the evolution of liquid crystal computational processors for simple tasks, but these earlier studies have only scraped the surface of what such systems may be capable of achieving. With this project we want to develop alternative approaches for situations or problems that are challenging or impossible to solve with conventional methods and models of computation. Achieving our objectives fully would provide not only a major disruptive technology for the electronics industry but probably the foundations of the next industrial revolution.

Overall, we consider that this is to be a highly adventurous, high risk project with an enormous potential impact on society and the quality of life in general. Apart from the Programmable NanoSystems group, other UT groups involved are NanoElectronics, Multiscale Modeling and Simulation, Formal Methods and Tools, and Computer Architectures for Embedded Systems. The other EU consortium partners involved in the NASCENCE project are located in Durham, Lugano, Trondheim and York.
Two drops become one

The coalescence of liquid drops is a fundamental process relevant for the formation of clouds, foams and emulsions. We have investigated coalescence for drops in contact with a substrate, as for example encountered during condensation or inkjet printing. After an initial phase where the drops spread over the surface (Fig. 1), two drops meet and start to merge (Fig. 2). Once coalescence is initiated at a first, singular point of contact, the two drops rapidly merge by the action of surface tension. We have found that the dynamics of the contact region exhibits scale-invariance and is characterized by power-law growth. The growth exponents subtly depend on the properties of the liquid and the wetting properties of the substrate. A theoretical analysis based on similarity solutions very accurately predicts the coalescence dynamics and reveals how two drops become one.

Physics of Fluids

The Physics of Fluids (PoF) group is studying various flow phenomena, both on a micro- and macro-scale. We use both experimental, theoretical, and numerical techniques and we do both fundamental and applied research. Our main research areas are:

- Turbulence and Two-Phase Flow
- Granular Flow
- Biomedical Application of Bubbles
- Micro- and Nanofluidics

Two drops become one

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Granular materials, like sand, flour or iron ore, are among the most frequent materials in nature and are the most processed substance in industry, second only to water. Their often-counterintuitive behavior however is distinctly different from that of molecular matter and remains far from understood. The Physics of Granular Matter and Interstitial Fluids (PGMF) group employs a combination of experiments, analysis and numerical techniques to attain to a profound understanding of the physics of granular flow. Special attention is given to unraveling the intricate role of the interstitial fluid, the gas or liquid that resides within the pores between the grains. The group is embedded into the Physics of Fluids group.

**Physics of Granular Matter and Interstitial Fluids**

**Oscillations and stop-go cycles in a cornstarch suspension**

When an object is dropped into a container with an ordinary (so-called Newtonian) liquid, it slowly decelerates to a terminal velocity and continues until it comes to a full stop at the bottom of the container. This rather dull, continuously decreasing trajectory in velocity space changes radically when the liquid is replaced by a cornstarch suspension.

Cornstarch consists of non-spherical particles that all have roughly the same size (20 μm). When mixed with water it turns into a suspension with remarkable properties: when stirred gently it flows like a liquid, but as soon as one tries to move through it in a more violent manner, it strongly resists, up to the point that it appears to fracture much like a solid material would do. As a result you can hit it with a hammer without splashing and you may even walk on it. That is, as long as you move fast enough: slowing down will inevitably make you sink in.

To investigate the origin of this behavior we measure the velocity of a sphere while it settles into a cornstarch suspension and make two surprising observations: First, in the bulk of the liquid the velocity of the sphere oscillates around a terminal value, without damping. Secondly, near the bottom the sphere comes to a full stop, but then accelerates again towards a second stop. This stop-go cycle is repeated several times before the object reaches the bottom. We explain these stop-go cycles using a minimal model based on the jamming of the cornstarch particles in the suspension: The particles are squeezed in between the sphere and the bottom and in this way are able to exert a force exceeding that of gravity by an order of magnitude. This instantly stops the sphere. Subsequently the particles rearrange and unjam, as a result of which the sphere starts reaccelerating.

Quantum Transport in Matter

Topological Superconducting Quantum Interference Devices

Topological insulators and superconductors are two very special electronic materials. Topological insulators are electrical insulators in the bulk but conduct at the surface. The surfaces conduction has the special property that the spin of the electrons is coupled to the direction in which they move. A superconductor conducts electricity without resistance.

After having realized a sandwich Josephson nanostructure of a Bi$_2$Te$_3$ topological insulator in between two Nb superconductors, MESA+ researchers have now made superconducting rings interrupted by two of those topological Josephson junctions, a so-called topological SQUID (see Fig. 1). Even when the ring consists of a trivial superconductor (see Fig. 2), we have calculated that the non-trivial Majorana-type current-phase relation of the topological Josephson junctions can become visible in the magnetic field modulation of the critical current of the SQUID.

These topological SQUIDs form an important step towards the detection of Majorana fermions in topological insulators. We hope to explore the feasibility of using Majorana fermions as non-Abelian anyons for topological quantum computation in the near future.
Towards long-lifetime power transistors

Solid-state lighting is a booming market. Rapid advances in the light-emitting diode of such light sources are accompanied by advances in the embedded electronics. LED lamps require ac-dc transformation and additional signal manipulation to optimize color, power efficiency and reliability. The long lifetime of the LED, about 30 years, leads to the requirement that the electronic parts last at least equally long.

In a study conducted in close collaboration with NXP, we investigated the degradation phenomena of power transistors applied in LED lighting under long-term electrical stress. These power transistors have a unique dedicated design leading to an almost uniform internal electric field distribution at the most stressing operating condition. However, during electrical stress charges build up in certain positions, thus distorting the electric field distribution, and leading to changing transistor performance.

The main physical mechanism responsible for degradation in these transistors under different stress conditions was identified, as well as the location in the transistor where physical and chemical changes take place. A diagnostic technique and an analytical model were subsequently developed to allow the prediction of the transistor’s performance as a function of temperature and time, under given stress conditions. This work allows the prediction of the lifetime of the transistor and the lighting system, as well as a further improvement of the power transistor itself towards longer guaranteed lifetimes.

Prof. dr. ir. Rob G.H. Lammertink

“Many transport phenomena are very rich at the microscale, offering great opportunities to exploit them.”

Soft matter, Fluidics and Interfaces

Contacting on the micron scale

Numerous processes involve contacting of a gas and liquid phase for the purpose of exchanging species. These include the oxygenation of blood, the dehydration of bioethanol, and the carbonation of soft drinks. The interfacial transport is greatly determined by the near interface fluid dynamics. To overcome transport limitations normally the fluid velocity near the interface is increased, obviously at the expense of increased energy input. Alternatively, we have attempted to modify the near surface fluid dynamics by using structured membranes. The structure of these porous membranes is such that they result in superhydrophobic surface properties. A microfluidic device was designed and fabricated that includes a porous, superhydrophobic, membrane. This membrane functions as an interface stabilizer between gas and liquid, while allowing facile passage of gas. At the same time, the microstructures on the membrane surface effectively incorporating gas micro bubbles that the interface. The presence of these interface bubbles generates partial slip conditions at the gas exchanging interface. The size of the interface bubbles determines the absolute amount of slip that can be obtained at the interface. As the convective transport is enhanced by this partial slip condition, the mass transport increases as well. Combined this results in drag reduction and mass uptake improvement.

Figure 1: Microstructured porous membrane for enhanced interfacial transport.

Figure 2: Exploded view of the microfluidic device containing a superhydrophobic porous layer.
Science, Technology and Policy Studies

Context matters: the domain-specific uptake of nanotechnologies’ promises and concerns

While the general promise of nanotechnologies is acknowledged in many application domains, domain-specific features play a key role for the way how nanotechnologies are actually taken up - both in promises and concerns and in innovation strategies responding to them. Promises and concerns around novel technologies affect their development and uptake. Analyzing scientific journals, we compared the promises and concerns and the linkages between both, related to nanotechnologies in food and water (Te Kulve et al. 2013). We observed clear differences. In water, nanotechnologies are essentially portrayed as contributing to sustainable innovation; concerns about health, environmental and safety risks are treated, but rarely linked to the promise-oriented discussion. In contrast, in the food domain concerns about risks are related to the promises, and - in contrast to water - concerns about possible user concerns are a major issue. We suggest that these differences cannot simply be explained by differences in the technologies, but result from domain characteristics, such as prior experiences with emerging technologies, or different user-producer relationships. We conclude that domain-specific discourses may lead to undesirable lock-ins; but lock-in may be mitigated by opening up the discursive repertoires drawing on other domains or technology fields.

Furthermore, we have investigated for organic large area electronics and drug delivery how nanotechnologies’ promises are taken up in the strategies of industry actors (Parandian et al. 2012). We found that despite a broad acknowledgement of the general promise of nanotechnologies not much is actually happening, but that actors are rather caught in a waiting game, expecting others to make the first step. This could be attributed to the particular characteristics and dynamics of open-ended ‘umbrella promises’, as well as to particular characteristics of the domains. Possible directions to overcome the waiting game in each domain were identified.
Figure 1: Fabrication scheme of a nano-wire trapping device. 

Figure 2. Primary bovine chondrocyte after 2 hours of culturing. Chondrocytes can be seen adhering to the ribs of the pyramid shaped nanowires while maintaining their rounded morphology. The onset of protein formation between the neighboring cells can be observed.

Prof. dr. ir. Gijs Krijnen

“The fabrication of complex 3D micro- and nano-systems is a main challenge for the near future. A combination of photo-lithography based technologies with self-assembly is a potential solution to this challenge.”

Transducer Science and Technology

Fabrication of 3D fluidic components by corner lithography

Corner lithography is an emerging 3D nanofabrication technique which has been developed in the TST group in recent years. It basically uses the residues of material that remain in sharp concave corners after conformal deposition and isotropic thinning, either as structural material or as mask material in subsequent steps. We used this technique to fabricate nano-apertures at or near the apex of a pyramidal tip and to create micro pyramids comprising nanowires. Microarrays of these pyramids have been integrated into a cell-seeding device for entrapment of single cells (Fig. 1). Polystyrene microspheres could be efficiently captured from a suspension of homogeneously shaped spheres. The same procedure was done with a suspension of primary bovine chondrocytes (in collaboration with the Tissue Regeneration Department), after which their phenotype was studied over 48 h. The electron micrograph (Fig. 2) shows the efficient entrapment of 1 cell per pyramid after 2 h of cell culture. Cells maintain their native round morphology during entrapment, while the onset of protein formation between these confined cells can be observed. These results, as well as the fact that corner-lithography is scalable to much smaller structures, holds potential for future bio-medical applications.
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