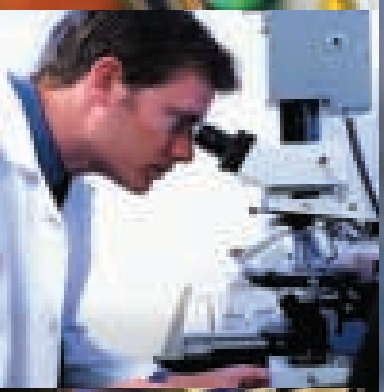
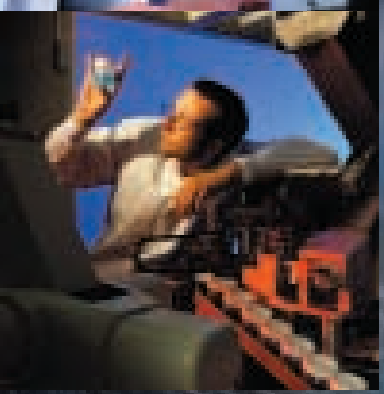
MESA+

University of Twente
The Netherlands

Materials, technologies and systems for the information society





Annual Report 2000


MESA+ SCHRIJFT
MET NANODEELTJES
'LABORATORIUM OP
CHIP' KOMT DICH
Achter de spiegel
klotst
Leading the way in microsystems
'ALS ER EEN

Preface

The year 2000 marked the start of a century that promises increasing technological progress. With Information and Communication Technology providing the thrust for profound societal changes and new economical chances in the past 30 years, the increasing capabilities of Bio Technology and Nano Technology invite us to contemplate on the unseen and possibly astounding new horizons of our technological journey.

Microtechnology, Nanotechnology, Self-assembly and Materials Science are the areas in which MESA+ travels. Powered by an excellent staff and fine infrastructure, the institute completed a new organization structure in 2000, which enables it to optimize its direction.

Being the first year in which the institute was fully operational, the year 2000 also provided us with a test. We concluded that we have the right attitude and gear. Already, a number of impressive results can be presented in this annual report over 2000.

The matrix organization with program directors and group leaders provides us with a challenge that is unique for a university setting. The first results encourage us to proceed with the ambitious challenges for fundamental changes in academic institutions.

The (inter)national visibility of our institute has increased considerably. In this report, some proof of that should be visible.

With the start of MESA+, the University Board allocated considerable additional funds, which enable the institute to reach for its ambitious goals. The courage and vision behind that already pays back in scientific quality and success.

We look ahead with confidence.

Prof.dr.ir. D.N. Reinhoudt
scientific director

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Sketch of the institute

Field and mission

MESA+ focuses on the materials, technologies and systems of the information society ('the hardware of ICT'). Its mission is

+ to excel in its field of science and technology
+ to educate researchers and designers in its field;
+ to build up fruitful national and international cooperation with industry and fellow institutes.

MESA+ is an 'onderzoekschool', designated by the Royal Dutch Academy of Science.

Key words are: nanotechnology, materials science, microsystem technology and engineering, micro-optics and self assembly.

MESA+ has defined the following indicators for achieving its mission:

+ scientific papers at the level of Science, Nature, or journals of comparable stature;
+ 1:1 balance between university funding and externally acquired funds;
+ sizable spin-off activities.

Organisational structure and programmes

MESA+ has a matrix structure, in which scientific disciplines, led by a responsible professor, are combined with strong and ambitious multidisciplinary programs, the Strategic Research Orientations (SROs) which one aimed at the various aspects of Nanotechnology. This structure is depicted below.

The creation of SROs ensures a strong multidisciplinary activity within the institute and is a basis for realization of its goals. An SRO is a large scientific program (in the order of 30-50 full-time researchers), which satisfies the following criteria:

+ combining high-quality research of at least 5 groups within the institute into a genuine multidisciplinary program;
+ providing excellent opportunities for international top-level research;
+ attractive for external funding (which is a quality indicator in its own).

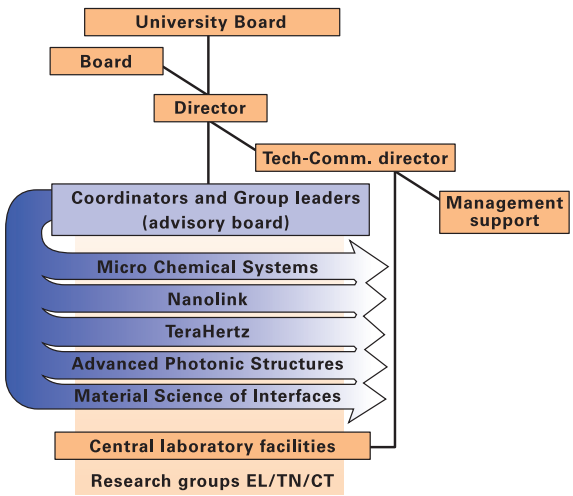
For each SRO, a Program Director is responsible for the scientific coordination. The Program Director is directly responsible to the Scientific Director of the institute.

The SROs will be evaluated after two years, based on the criteria mentioned above. MESA+ will use its external reviewers (e.g. Scientific Advisory Board, STW, or others) for this evaluation, which can result in (dis)continuation of the program. In case of discontinuation, MESA+ will only fund salaries of existing Ph.D.'s and post docs for the remainder of their appointment.

The SROs and their Program Directors should achieve a strong presence and exposure in the (inter)national scientific world. The Program Directors are appointed (at least) at the level of associate professor.

The current MESA+ SROs are:

+ Micro Chemical Systems (MiCS) , prof.dr.ir. Albert van den Berg (Lab-on-a-chip)
+ NanoLink, dr. Jürgen P. Brugger (Tying top-down to bottom-up micro-, nano- and molecular engineering)
+ TeraHertz Signal Processing (TeraHertz), dr.ir. Gerrit J. Gerritsma (Acquisition, transportation and manipulation of information at very high speed)



Advanced Photonic Structure (APS), dr. Laurens (Kobus) Kuipers (Novel optical devices based on low-dimensional photonic crystals and microcavities) Materials Sciences of Interfaces (MASIF), dr.ing. Dave H.A. Blank (Material growth on an atomic scale for the realization of different kinds of junctions for advanced nanometer-scale devices)

The SROs cover approximately 70% of MESA+ research. This activity is completed by disciplinary research, which has an important role in the further development of the research group's disciplinary activities (founding research), in the exploration of new fields (potentials), etc.. This research is referred to as Complementary Research.

MESA+ is the largest research institute of the University of Twente. It employs approximately 400 people, almost 300 of which are scientists including over 200 Ph.D.'s, post docs, etc.. MESA+ has a turnover of approximately Mf 55, of which 50% is acquired in competition from external sources (National Science Foundation, European Union, industry etc.).

MESA+ has extensive laboratory facilities at its disposal:

+ a 1000 m2 fully equipped clean room, with a focus on Micro Systems Technology (MST), 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.

MESA+ has a strong relationship with industry, both through joint research projects with the larger multinational companies, and through a cooperation policy focused on small and medium-sized enterprises.

Participating research groups

Within MESA+, 4 faculties combine their strengths within the field of expertise: Applied Mathematics (TW), Applied Physics (TN), Chemical Engineering (CT) and Electrical Engineering (EL). From these faculties, the following research groups participate:

+ CT-MTP:
  Materials Science and Technology of Polymers, prof.dr. G.J. Vancso
+ CT-SMCT:
  SupraMolecular Chemistry and Technology, prof.dr.ir. D.N. Reinhoudt
+ CT-CA:
  Chemical Analysis, vacant
+ CT-IMS:
  Inorganic Materials Science, vacant
+ EL-BIOS:
  Biosensor Technology, prof.dr.ir. P. Bergveld
+ EL-ICD:
  Integrated Circuit Design, prof.dr.ir. B. Nauta
+ EL-IDR:
  IC-Technology, Devices and Reliability, prof.dr. H. Wallinga
+ EL-SMI:
  Systems and Materials for Information storage, prof.dr. J.C. Lodder
+ EL-LDG:
  Lightwave Devices Group, dr. A. Driessen, dr. P.V. Lambeck
+ EL-TDT:
  Testable Design and Testing of Microsystems, dr.ir. H.G. Kerkhoff
+ EL-TT:
  Micromechanical Transducers, prof.dr. M.C. Elwenspoek
+ TN-BFT:
  Biophysical Techniques, prof.dr. J. Greve
+ TN-CMS:
  Computational Materials Science, prof.dr. P.J. Kelly
+ TN-LT:
  Low Temperature Division, prof.dr. H. Rogalla
+ TN-OT:
  Optical Techniques, prof.dr. N.F. van Hulst
+ TN-VSF:
  Solid State Physics, prof.dr.ir. B. Poelsema
+ TW-AAMP:
  Applied Analysis and Mathematical Physics, prof.dr. E.W.C. van Groesen

MESA+ Annual Report 2000, general part

The year 2000 was the year in which MESA+ started its Scientific Program 2000-2004. With its organization in place and five ambitious scientific programs starting at January 1st, the MESA+ community aims for achieving its mission.

Although MESA+ is more than an institute for Nanotechnology, it is clear that many of the scientific challenges in the 5 SROs are moving into the realm of the nanodimension.

The organization, established in 1999, proved to be a strong basis for scientific progress and interaction. The multidisciplinary programs strongly support the scientific communication, and prove to be an excellent stimulus for top-level research. This can be seen from the excellent score in external funds that the SROs attracted in competition in 2000. In total, the sum of these external grants approached M*f* 15. In addition many of the individual groups were highly succesful.

Internal communication is focused towards scientific progress, and is supported by SRO meetings, colloquia, the internal MESA+ symposium, and interpersonal discussions. The Advisory Board, consisting of all group leaders and program directors, met monthly, mainly focusing on internal affairs, evolving policies and new activities.

The MESA+ management is continuously evaluating the progress of the institute, looking for optimization of the strategy and policy, in close communication with the MESA+ Board.

Results

MESA+ produced 228 papers in refereed journals in 2000. The institute is pleased with the high level of quality achieved in the different fields in the institute. Two excellent papers in Nature were published. This, on the other hand, shows that MESA+ has some distance to travel, still, in achieving its goal. These Nature papers are covered among others in the scientific highlights on the following pages.

The excellent results in achieving external funding by the National Science Foundation, Industry and the European Commission led to a financial planning for 2001 that showed for the first time an external funding of more than 50%. With this, MESA+ is on course. For a healthy 'home base' also the direct support by the University of Twente should keep grace.

The year 2000 also saw the realization of two industrial spin-offs. MESA+ now participates in Avantium, a high-tech company focusing at developing methods and equipment for high-throughput screening techniques for the chemical and pharmaceutical industry. This ambitious start-up, based in Amsterdam, cooperates with MESA+ in next-generation technologies, based on the lab-on-chip technologies offered by MESA+.

The second activity is Micronit, a start-up firm that focuses on rapid prototyping for lab-on-chip applications, on glass and silicon microfluidic chips.

Next to Avantium and Micronit, some 7 start-up plans are in progress. These plans are expected to lead to a number of realized start-ups in 2001, with participation of MESA+. Accompanying measures have been taken to support the growth of these companies: a cleanroom for facility sharing with industry, further improvement of the research cleanrooms for use by companies, realization of office facilities, a strong relation with a network of micro- and nano-technology companies in the Netherlands (MINAC) and with a growing network of venture capital players.

The visibility of MESA+ for the outside world is growing. MESA+ supports an active PR-policy, not in the least for gaining more interest from potential students, since the numbers of students in technical sciences are dropping rapidly. Within this annual report several references to press releases covering MESA+ are made.

Highlights

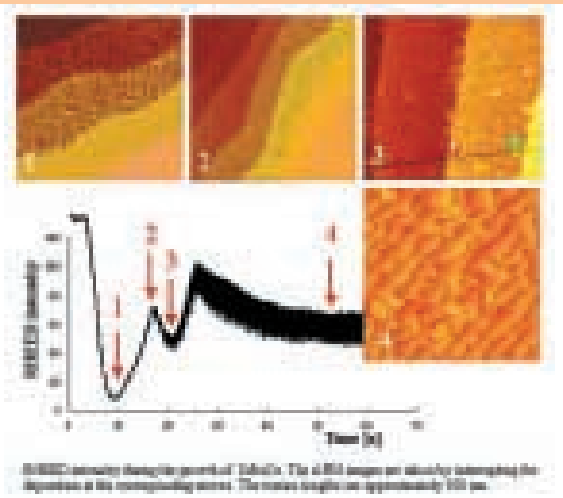
Traditionally, MESA+ shows its scientific achievements by putting forward a number of highlights, indicating the progress made in the past year. These highlights can be found on the following pages.

We would like to add two other successes of a more personal nature: two considerable grants from the Netherlands Organization for Scientific Research (NWO) for MESA+ colleagues Dr. Holger Schönherr and Dr. Leon Abelmann. These personal grants ('innovation impulse') were awarded for the stimulating and innovative proposals submitted.

Holger Schönherr, who finished his PhD-work in the group of prof. Julius Vancso in 1999, gets the 'innovation impulse' for his research proposal about combinatorial chemistry on a nanoscale. Holger wants to develop nanolaboratories: arrays of domains with nanometer size. In individual domains, formed by self-organization, he will use scanning probe microscopes to alter the chemical structure. By letting them react with external molecules, the results of the changes can be measured. Holger considers this new type of chemistry as a future way for better understanding complex reactions, like protein interactions. Currently Holger, who says to be 'still in an excited state' about the NWO-reward, works at Stanford University in California. In 2001 he will start his NWO-research, for which he will cooperate with the Max-Planck-Institute für Polymerforschung in Mainz.

Leon Abelmann is full of ideas for the follow-up of the computer hard-disc. This information-carrier will reach limits in some years time. The speed at which a disc has to turn, for example, is at present already at 15000 rpm to get an acceptable access time. For alternatives, revolutionary ideas are more than welcome. Innovative ideas are not at all strange for the researchers of the Information Storage Technology Group, who already developed the famous spin valve transistor, a very sensitive magnetic sensor. For new read/write systems, Leon considers scanning a magnetic surface with an array of moving magnetic sensors. Therefore the 'MicroWalker', a miniature linear engine developed by the colleagues of the Micromechanical Transducers group, is a good option for movement on a small scale. Scanning the magnetic surface with small silicon arms and without any physical contact: that's an idea Leon wants to work out in his NWO-research.

Induced step-flow growth of $SrRuO_3$ caused by switching of surface termination



Using a unique growth monitoring system, we were able to study the growth of $SrRuO_3$ by Reflection High Energy Electron Diffraction (RHEED) and observed in real-time a switch in surface termination at the initial growth stage, accompanied by a change in growth mode. The monitoring system, high pressure RHEED during pulsed laser deposition (PLD), enables us to study the growth at relative high pressures. RHEED monitoring is indispensable because a number of oxides, including materials suitable for spin-electronics, like $SrRuO_3$, have their best properties if they are grown at higher (oxygen) deposition pressures. Furthermore, since their application is mostly in trilayer junction configurations, control of the growth mechanism and domain structures of the individual layers as well as the interfaces and defects in the barrier layer is required: they have to be grown on an atomic accuracy, making an in situ diagnostic tool indispensable.

The figure shows the observed specular RHEED intensity of SrRuO3 grown on TiO_2-terminated $SrTiO_3$ with a miscut angle of 0.2 degree at a deposition temperature of 600 °C. At the initial stage a decrease of the intensity is observed, due to the formation of very small islands on the smooth $SrTiO_3$ surface. At the minimum intensity value, the step density is maximal and further deposition will lead to the formation of larger island and thus less scattering of the electrons and an increase of the RHEED intensity, see also the corresponding AFM images. This phenomenon is typical for 2-D island growth. Only two oscillations can be observed. After the second oscillation the RHEED intensity stays almost constant. The absence of oscillations interprets on an increased roughness or on a step-flow growth mode. The first option is in our case not evident because of the high RHEED intensity, the latter option is more likely and is supported by the increased effect of the mobility of the deposited material as shown by RHEED relaxations.

From the figure another remarkable feature can be observed. The number of pulses to complete the first RHEED intensity oscillation is approximately 34, whereas for the second oscillation 20 pulses are needed. The latter is the correct number as determined from thickness measurements.

The observed phenomena, change from 2D to step-flow growth, a longer period of the first oscillation, and the asymmetric first oscillation, can be explained by a termination switch from B-site (TiO_2 terminated $SrTiO_3$) to A-site (SrO terminated $SrRuO_3$) in the first unit-cell layers. This is in contradiction to what one should expect; preserving perovskite stacking and stoichiometric deposition should lead to RuO_2 termination. Most likely, this terminating layer is not stable at these deposition conditions. It is expected that the first unit cell layer decomposes in highly volatile Ru_xO_y and SrO. This decomposition stops after the terminating layer is completely switched from TiO_2 to SrO. The temperature has a large influence on the evaporation of the Ru_xO_y, causing the distributed transition in the oscillation period, observed at lower temperatures. The switch in termination precedes the growth mode transition.

References:

1 This work was presented at the 7th international Workshop on Oxide Electronics October 2000, Switzerland and MRS Fall meeting December 2000, Boston, USA.

2 The work is accepted for publication in Applied Physics Letters: Growth mode transition from layer-by-layer to step-flow during the growth of heteroepitaxial SrRuO3 on (001) SrTiO3 by J.H. Choi and C.B. Eom, G. Rijnders, H. Rogalla and D.H.A. Blank.

Cross strip interferometry: Explicitly simple and robust integrated optical devices

While searching for technologically simplified integrated optical device concepts, we have discovered the promising properties of a specific class of waveguide interferometers. A typical structure consists of nothing more than a single strip, etched from a bimodal dielectric film. Guided light is launched perpendicularly to the strip. Provided that specific conditions for the film thickness and etching depth are observed, the strip acts as an interferometer of surprisingly good quality. Avoiding the necessity for bend or laterally precisely dimensioned waveguides, the geometry offers an attractive alternative to common integrated interferometric devices like Mach-Zehnder structures or directional couplers.

Figure 1 sketches the basic structure. Understanding its behaviour starts with a division into three homogenous waveguide sections. The light enters from the thinner single mode waveguide outside the strip into the thick strip segment, which is configured to support two guided modes. At the end of the strip, the amount of power that is guided in the following lower output region depends on the local phases of these two fields. For a properly adjusted geometry there are two extreme scenarios. In the first one, the superposition of the two strip modes matches the output profile well. Most of the input power passes the device; the modes interfere constructively. In the opposite scenario the field that arrives at the output junction is orthogonal to the mode of the subsequent segment. The power is scattered into the substrate and cover regions; consequently we call this destructive interference.
In both cases the achievable levels of transmission respectively suppression are remarkable:
Our numerical calculations predict insertion losses below 0.1 dB and extinction ratios well Above 30 dB for realistic device designs.

The concepts originated from semianalytic mode expansion simulations in the Applied Analysis and Mathematical Physics Group (UT, TW). Until now, the modeling and design activities have led to concrete proposals for polarizing strips, illustrated in Figure 2, and for experiments on magneto–optic isolator devices.

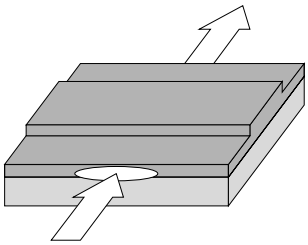


Figure 1: The interferometer configuration. A vertically guided, laterally unguided beam of light traverses a wide, deeply etched strip.

Realizations are under way in both cases, in the Lightwave Devices Group (UT, EL/TN), and at the Department of Physics, University of Osnabrück, Germany, respectively. Further prospective applications include electro–optic modulators, and in particular the field of optical sensors.

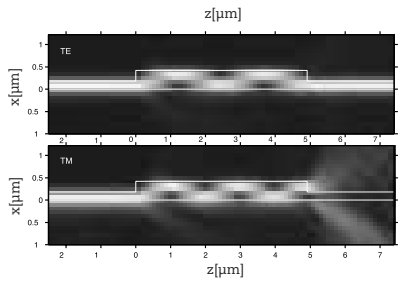


Figure 2: Simulation of the light propagation through an interferometric polarizer device. Intensity levels are plotted on a strip cross section along the light path. If the electrical field oscillates in the direction perpendicular to the figure plane, the inserted optical power passes the device (TE polarization, top). Orthogonally polarized light waves are scattered into the surrounding (TM polarization, bottom). Being easily adaptable to a variety of material systems and to TE suppression, the cross strip can implement polarizer functionality into an integrated optics chip on a total length of less than m, without the requirement of exotic materials or complicated processing steps.

References:

1 "Integrated optical cross stip polarizer concept", Optical and Quantum Electronics, M. Lohmeyer and R. Stoffer, accepted for publication, to appear in 2001.

2 "Integrated magnetooptic cross strip isolator", Optics Communications, M. Lohmeyer, L. Wilkens, O. Zhuromskyy, H. Dötsch, and P. Hertel, accepted for publication, to appear in 2001.

Singular patterns in propagating light waves

Figure 1: Measured height image of a conventional channel waveguide (all image size 10 mm x 9 mm). The ridge (height 4 nm) that confines the light is easily resolved.

Figure 2: The optical amplitude distribution measured with the new interferometric PSTM. Three waveguide modes propagate simultaneously through the waveguide, giving rise to a clear beating of the optical amplitude (beat distance ~4 μm).

Figure 3: The measured cosine of the optical phase. On the whole horizontal stripes can be seen, associated with the propagation of plane waves. The unexpected phase singularities show up as fork-like shapes in the stripy pattern.

While the complexity of geometrical structures with which light is manipulated increase, the size of the structures decrease. As a result, scientists gain a tremendous control over light. Not only the propagation of the light is controlled on a scale approaching the wavelength of the light itself, but also the light emission of, for example, molecules can be either stimulated or inhibited. The investigation of how light actually behaves inside such structures is one of the key topics of the Applied Optics group.

Conventionally, a somewhat counter-intuitive scheme is used to investigate the propagation of light *inside* structures: the structures are investigated by 'looking' at them from the outside. In other words, one shines light on the structures and the transmitted and/or reflected light is measured. The results are then compared to a model. The only insight into what actually occurred inside the structure comes from the confrontation between experiment and theory. And while a good agreement may give a satisfying sense of understanding, lack of agreement will result in very little understanding.

In a recent breakthrough the Applied Optics Group has built a novel instrument that circumvents this counter-intuitive scheme. A conventional photon scanning tunneling microscope (PSTM) maps the intensity distribution of light *inside* a photonic structure. The topography of the structure is simultaneously measured. By introducing an entire PSTM together with the photonic sample in one branch of a Mach-Zehnder interferometer, the evolution of the optical phase inside the structure has become accessible for the first time ever, all this with a sub-wavelength resolution.

Surprisingly, visualizing the optical phase even in a geometrically simple structure like a channel waveguide reveals unexpected phenomena. When several so-called waveguide modes, each with its own wavevector, are simultaneously excited, interference between the modes leads to an expected beating of the optical amplitude. Totally unexpected however is the formation of *phase singularities* associated with the beating pattern. These singularities are points in space where, if you travel around them while exactly ending up at your starting position, you have acquired a phase shift of N times 2π (in this case $\pm 2\pi$). The phase singularities are formed at those positions where the amplitude is zero (actually rendering the notion of phase useless).

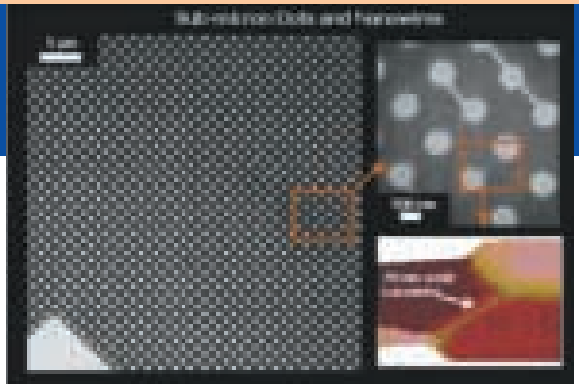
The new instrument opens avenues for new research on more advanced photonic structures, like photonic crystals or microresonators, of which the optical properties arise from subtle interference effects. In such structures the interplay between geometry and light propagation is very strong. With its ability to measure both the topography and all the relevant optical parameters the interferometric PSTM will be able to unravel all the exciting phenomena in these advanced structures.

This work was published in:

1 Local observation of phase singularities in optical fields in waveguide structures,
M.L.M. Balistreri, J.P. Korterik, L. Kuipers and N.F. van Hulst,
Phys. Rev. Lett. 85, 294-297 (2000).

Nanostencil

Low-cost nanopatterning on large surfaces



Constructing well-defined sub-100-nm structures is of great importance to the fabrication of advanced integrated electronic devices, including molecular electronics. Lithography, besides advanced thin film deposition and pattern transfer techniques, represents *the* key step. Continous miniaturization of advanced electronic devices induce dramatic cost increases for lithography-related infrastructure to maintain a cost-effective combination of *high resolution and high throughput* pattern definition.
It is therefore widely envisioned that future electronic chips will be built by a synthesis of so-called *top-down* and bottom-up fabrication methods. The top-down approach is a continuation of state-of-the-art miniaturization techniques and will be used to define solid-state devices and template structures at a scale that is still accessible to lithography. It also allows to provide links to larger dimension. The templates will then be used to direct the (self)-assembly of nanoparticles and (supra)molecular structures and to refine the man-made patterns down to the molecular precision, preferably at very low processing costs.
When aiming at the use of individual nanoparticles and molecules for future devices, ultra-clean surface conditions are required to provide good contact properties. Therefore, among other issues, the nanofabrication ahead of us will most probably face two major challenges:

a) How to define a high-density template with structures having <100-nm precision on a large surface area (wafer scale) having links to the 'outside world'?
b) How to avoid contamination of the surfaces, contacts and interfaces at molecular scale?

In view of this we demonstrated already a new area-selective material deposition technique that is capable to construct structures at the sub-100-nm scale, on large area, without lithography-steps, in clean vacuum conditions (UHV compatible) and at low cost. It relies on the area-selective material deposition through the openings of a 100-nm thick silicon nitride shadow mask (nanostencil) directly onto the surface[1].

To explore its limits a focused ion beam (FIB) was used to drill tiny apertures (150 nm wide) in the membrane. Tilt angle evaporation resulted in well defined 70-nm wide metallic nanostructures. The Figure shows high resolution images of an array of multi-millions of sub-micron metal dots that cover an area of several milimeters (left), as well as close-ups of a nanowire that is bridging two dots.

By moving the surface below the bundle[2] it is possible to write arbitrary patterns, and to vary the thickness of the layers. In ATOMS (an EU funded project) we aim, together with our partners, to further develop direct deposition techniques by combining a 'smart' nanostencil fabricated by MEMS technologies, with ultra-high vacuum deposition and surface- and bio-chemistry. By specifying the movements in the x and y directions, nanopatterns could be defined within minutes, instead of days. This would speed up the cycle of trial and error, which is important to further advance the science and technology of nanoscale and molecular electronics.

This work was published in:

1 Resistless patterning of sub-micron structures by evaporation through nanostencils, J. Brugger, J.W. Berenschot, S. Kuiper, W. Nijdam, B. Otter, M. Elwenspoek, Microelectronic Engineering 53 (2000) 403-405
2 Parallel Nanodevice Fabrication Using a Combination of Shadow Mask and Scanning Probe Methods; R. Luthi, R.R. Schlittler, J. Brugger, P. Vettiger, M.E. Welland and J.K. Gimzewski Applied Physics Letters, v. 75, n. 9, Aug. 30, 1999, p. 1314-1316

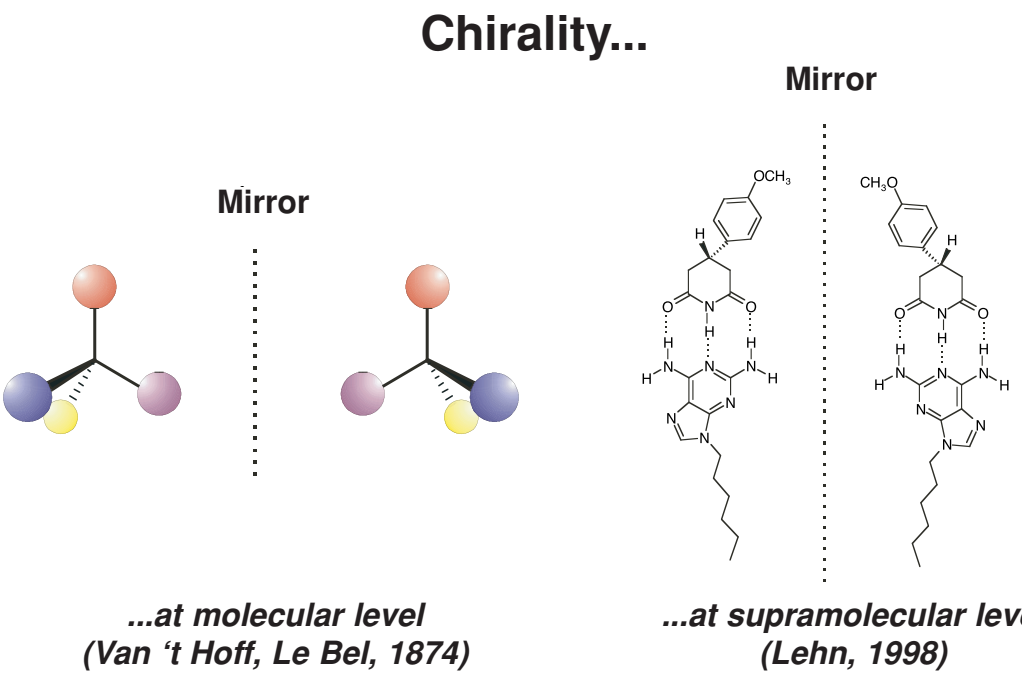
Supramolecular structures remember what happened yesterday

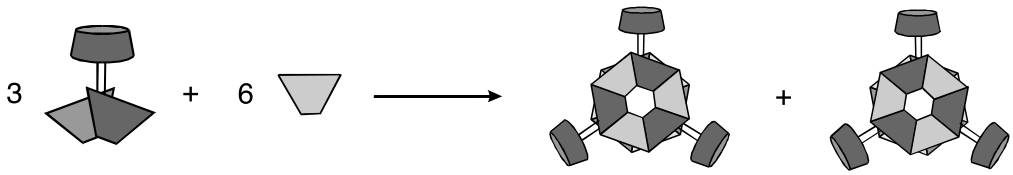
Nano-clusters with a 'long-term-memory'

Large molecules are in! Chemists have long strived to build molecular boxes, containers, tennis balls, machines and so on. However, armed only with the building kit of the traditional organic scientist, this has proven a difficult task. This is why supramolecular chemists are now seeking alternatives, inspired by Mother Nature which, in a stunningly simple way, manages to continually create complex structures. Non-covalent interaction is the magic word here - and the more of it the better. In recent years, David Reinhoudt and his team have been active with the non-covalent synthesis of supramolecular clusters via hydrogen bonding. And they have had considerable success. Last year the researchers demonstrated that the supramolecular chirality in these clusters can be fully controlled. In an article recently published in Nature magazine, they describe supramolecular structures with a memory. These structures retain the chiral information for a few days, even when the chiral building blocks have been removed.

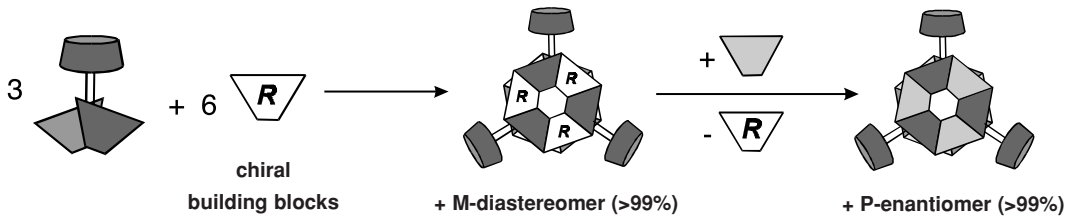
Chirality is a well-known concept that we all remember from our first organic chemistry lessons. The brilliant idea of a tetrahedrally encircled carbon atom, with four different substituents as the source for chirality, was used by Van 't Hoff and Le Bel in 1874 as an explanation for the mysterious phenomena of chemical substances such as camphor and oil of turpentine oil rotating polarized light. More than 125 years later, chirality is still in the spotlight. Chemists daily invent new methods to lay their hands on enantiomerically pure chiral links.

The fact that chirality exists on more levels than just the covalent level has been known for a long time. After all, each of us has heard of the x-helix structure in DNA or protein chains, two examples of supramolecular chirality. However, the same chiral forms also manifest themselves in synthetic clusters. Research into the self-organisation of calyx[4] arenes that have been functionalised with melamine units has proven that these molecules, while creating 36





When the assembly is created from archiral building blocks, a racemic compound is created of two enantiomer shapes, the M- and P- enantiomer, available in a 50:50 ratio.



With the help of chiral building blocks, the M- or P- diastereomer is created. Exchange of chiral with achiral building blocks only gives one of the two enantiomers, in an optically pure form. This cluster has, so to speak, a 'memory' for chirality because it is refained in the absence of the chiral building blocks. Racemisation of the pure enantiomer dissolved in benzene takes appoximately four days at room temperature.

hydrogen bonds, arrange themselves in a 'double rosette' shape, a kind of double-flat disc made up of nine independent components. The separate units are arranged in the cluster in such a way that it becomes chiral, i.e. the mirror image cannot be fitted onto the original. This form of chirality is so special because none of the independent components are chiral themselves in the sense of containing an asymmetrically encircled carbon atom.

Last year, researchers at Twente University revealed in an article in Nature magazine that they could completely control the chirality in these hydrogen-bonded clusters by using chiral building blocks. While the non-chiral building blocks are creating a racemic compound of the left and right rotating (M- and P-) helix, the chiral carbon centres situated in the building blocks are steering the assembly process entirely in the direction of either the left or the right helix (see figure 3). Their latest discovery sees the Twente scientists using this control of chirality and taking it a step further. Once created in the pure helix form (M- or P-), the chiral building blocks are removed and replaced by non-chiral building blocks. What remains is a cluster that is firmly fixed in the same chiral shape as before the exchange. This shape is retained for a few days at room temperature. When is cluster is heated up to 70°C, the memory vanishes within the hour.

What is actually the news value of this discovery? It is important because it proves that, with the help of non-covalent interactions such as hydrogen-bonding, characteristics such as chirality can be created that, until recently, were exclusive to covalent structures. The availability of supramolecular chirality in hydrogen-bonded clusters has been known for a long time but it had never been proven that the life-span of chiral supramolecular clusters is comparative or even longer than those of covalent structures. As a result, non-covalent structures can no longer be dismissed as being 'ultra-weak and extremely fragile'. Moreover, it has been proven that they can compete with covalent structures in terms of stability.

This work was published in:

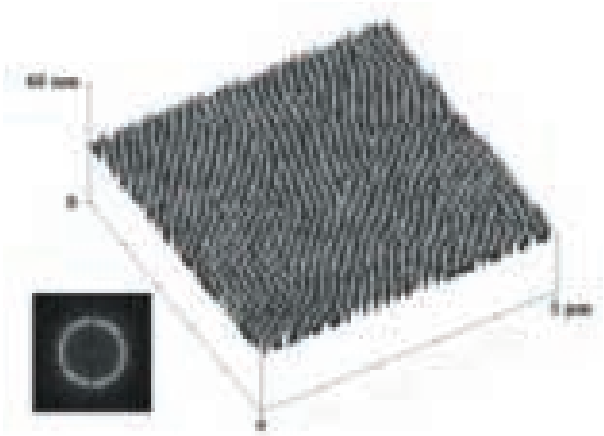
1 Prins, L.J.; Huskens, J.; De Jong, F.; Timmerman, P.; Reinhoudt, D.N.. Nature (London), 1999, 398, 498-502.

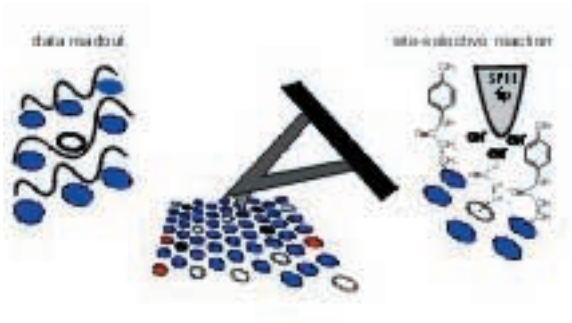
2 Prins, L.J.; De Jong, F.; Timmerman, P.; Reinhoudt, D.N.. Nature (London), 2000, 408, 498-502.

Functional block copolymers for nanotechnology

In block copolymers, macromolecular chains are composed of two or more distinct sequences of different monomers joined in a single polymer chain. Blocks consisting of organic and organometallic segments, such as poly(isoprene-block-ferrocenylsilane) possess distinct properties that are not commonly found in organic systems. Thin films of these polymers can form frustrated, phase-separated nanostructures by self-assembly, which consist of organometallic domains embedded in the matrix of the organic component. Upon treatment of these films with oxygen plasma under reactive ion etching conditions, the organic phase can be selectively removed [1]. The AFM image shown in the top figure exhibits a typical surface topology of such an etched, nanostructured film. These films can serve as lithography masks e.g. to etch multilayer structures, which eventually yield patterned surfaces exhibiting magnetic Co nanodomains [2]. The discovery of this form of nanolitography is described in the Ph. D. Thesis of R.G.H. Lammertink, which was defended in 2000 (ICI 2000 Student Prize Award Finalist, American Chemical Society, Washington, D.C., 2000).

Block copolymers can also be used in functionalized, two-dimensional periodic arrays on the nanoscale for exploring new chemistries. The block copolymer nanodomains can be individually chemically modified, addressed, and analyzed by atomic force microscopy (see the bottom figure). Using block copolymer nanostructures, high throughput combinatorial chemistry can be extended to the nanometer scale to explore massive parallel screening of chemical reactivity of synthetic, as well as natural molecules (H. Schönherr, prize winning proposal, Dutch Scientific Organization (NWO), 'Vernieuwingsimpuls', also described at page 8 of this report).





This work was published in:

1 R.G.H. Lammertink, M.A. Hempenius, J.E. van den Enk, V.Z.H. Chan, E.L. Thomas, G.J. Vancso, Adv. Mater. 2000, vol. 12, pp. 98-103.

2 Fabrication of nanopatterned thin films using self-assembled block copolymer lithography, announced at the MRS 2000 Boston meeting, J.Y. Cheng, C.A. Ross, V.Z.H. Chan, E.L. Thomas, R.G.H. Lammertink, G.J. Vancso, submitted to Adv. Mater.

Cryogenic Microcooling

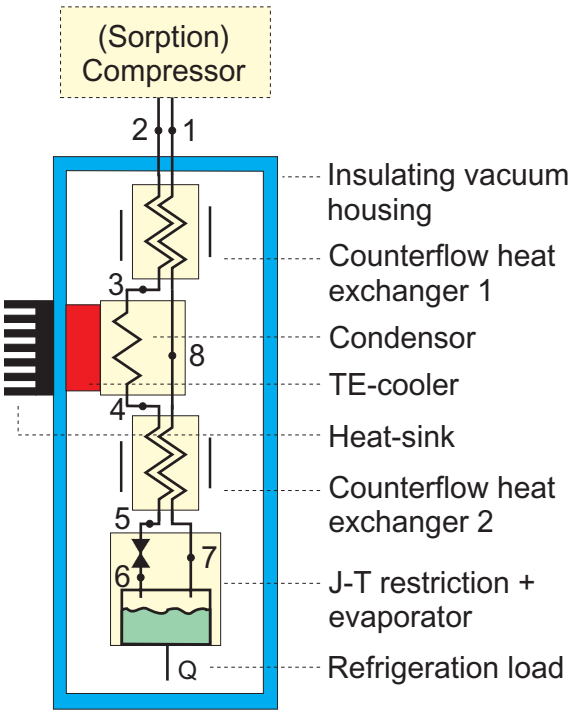


Figure 1. Schematic cooler diagram.

Knowledge of the Low Temperature Group and the Micromechanical Transducers Group, both part of MESA+, was combined in a co-operative project to develop the first closed-cycle microcooler. Low-temperature electronic applications requiring very little cooling power, such as a single chip with a low-noise amplifier or a superconducting magnetometer, will benefit from the development of such miniature cryocoolers.

After investigating different options for miniature cryocoolers, a micromachined vapor compression cold stage was developed that is driven by a sorption compressor. This precision engineered stainless steel compressor is able to produce the required gas pressures (20 bar) without the use of moving components, except for some micromachined high pressure check valves. The absence of moving parts in the cooler facilitates scaling down to small sizes, it eliminates interferences, and it contributes to achieving a long life time.

Figure 1 shows a schematic diagram of the cooler. The fluid cycle is similar to that used in a household refrigerator. After compression (1-2), the high pressure gas is precooled (2-3) by the returning low-pressure gas (8-1) in the first counterflow heat exchanger. In the condenser, the high pressure vapor is condensed (3-4) using a miniature thermoelectric cooler (which cannot be used to cool directly to temperatures below about 210 K due to a dramatic reduction in performance). The condenser is not essential for operation of the cycle, but it increases the available cooling power per unit mass flow with a factor of ten. Further cooling (4-5) occurs in the second counterflow heat exchanger by the returning low pressure vapor (7-8). The low temperature is reached by a pressure reduction through Joule-Thomson expansion (5-6). Evaporation of the low pressure liquid in the boiler (6-7) produces the cooling power, which can be used by some thermal load connected to the silicon evaporator.

The cold stage is shown in figure 2, and consists of three micromachined silicon components that are interfaced by two coaxial glass-tube counterflow heat exchangers. The glass-tube heat exchangers are visible as the two thick tubes and consist of two tubes that are placed concentrically around each other; the orange color is caused by a coating. The two thin glass tubes that are visible are included to add mechanical stability to the system. Thin-film heaters with a gold layer on top of it are located on the three silicon parts. The left part combines the high and low pressure gas lines in the first counterflow heat exchanger, the middle part is a condenser where a vapor-liquid transition occurs, and the right part contains a flow restriction and an evaporator. This is the actual cold part. The interior of these three components is visible in figure 3, which shows part of a processed silicon wafer. By application of ethylene gas, 200 mW of cooling power was obtained at 169 K, as is illustrated in the measurements of figure 5.

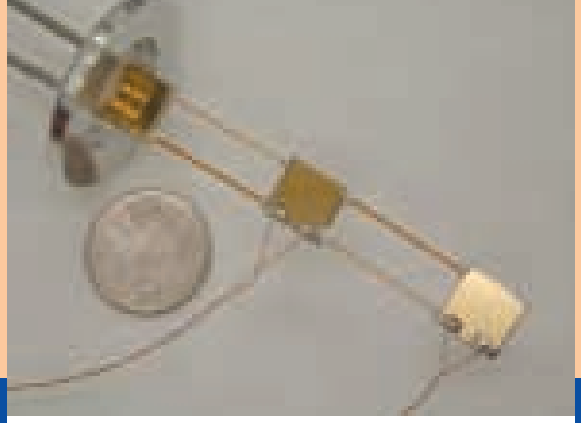


Figure 2. Integrated cold stage that is connected to a vacuum flange with gas supply tubes.

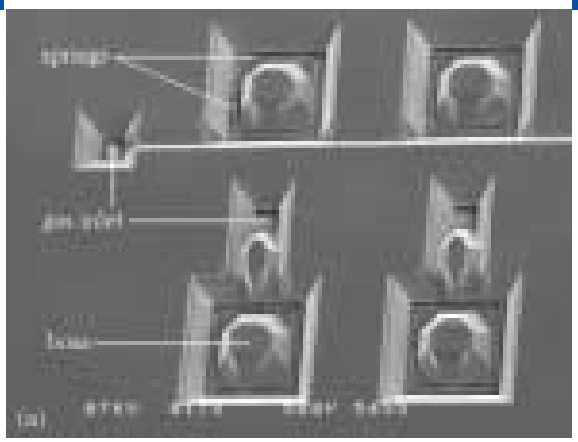


Figure 3. Part of a silicon wafer with 12 etched components for the cold stage.

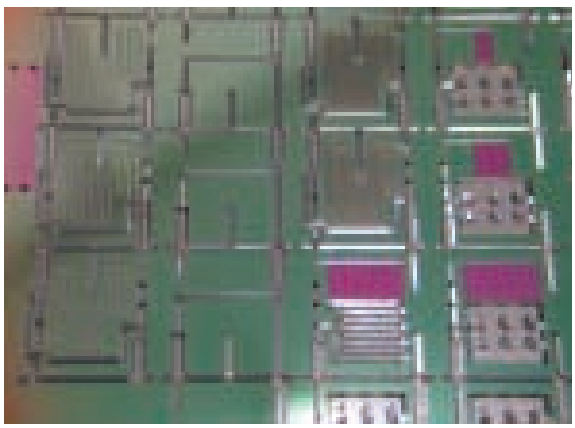


Figure 4. Micromachined high-pressure check valves, required to rectify the slowly pulsating pressure wave from the sorption compressor cells.

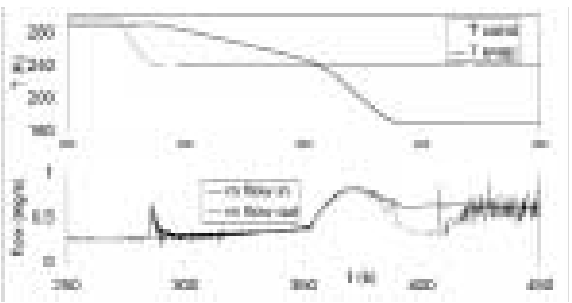


Figure 5. Typical measurement of temperature and massflow during start-up of the cold stage.

Operation of a sorption compressor is based on the principle that large amounts of gas can be adsorbed on certain solids such as highly porous carbon.
If a pressure container is filled with a sorber material and gas is adsorbed at a low temperature and pressure, then a high pressure can be created inside the closed vessel by an increase of the temperature of the sorber material. Next, a controlled gas flow out of the vessel can be maintained at a high pressure by further increase of the temperature until most of the gas is desorbed from the adsorption material.

In a project funded by the European Space Agency, the developed cooler is currently being explored for application in the future space telescope DARWIN.

This work was published in:

1 169 kelvin cryogenic microcooler employing a condenser, evaporator, flow restriction and counterflow heat exchangers, J.F. Burger, H.J. Holland, E. Berenschot, J.H. Seppenwoolde, H.J.M. ter Brake, J.G.E. Gardeniers and M. Elwenspoek, Proc. of the 12th IEEE MEMS Conf. (2001).

2 Cryogenic microcooling - A micromachined cold stage operating with a sorption compressor in a vapor compression cycle, J.F. Burger, PhD Thesis, University of Twente (2001).

Defect-oriented testing of electronic-fluidic microsystems

The 'lab-on-a-chip' concept is rapidly gaining importance. Essential is the integration of the fluidic parts together with the required vast amount of analogue-digital microelectronics for signal conditioning, control and signal processing.
For microelectronics, many testing concepts have been developed, one of which is the defect-oriented testing approach. Here, likely physical defects are modelled and subsequently tested for.

For a microsystem designer and test engineer the world of fluidics is alien. As far as we know, we are the first in the world to join these two worlds by using the physical defects in the microsystem as common basis. We have developed circuit network representations for several defects, which can be simulated and evaluated in a microelectronics CAD environment. It forms the basis of an overall design verification of electronic-fluidic microsystems and opens the road to structural testing and guaranteeing the quality of these systems based on hard metrics.

The combination of microelectronics and structures in which fluids flow, such as in 'lab–on-a-chip' implementations, are extremely difficult to test. Usually separate microelectronic tests and functional testing of the combined system are carried out. The problem with functional testing is its manual generation and, even worse, the absence of any metrics to guarantee the quality of the complete system. In this research, physical defects in the total system have been taken as a common measuring stick.

As a benchmark to show the concept, a simple fluidic flow sensor has been used. Figure 1 shows a flow sensor having three resistors Rh (heater) and Rd and Ru (temperature dependent sensors) on top of a membrane in the middle of a sealed (water)channel. A lot of defects can occur in such a simple structure, like e.g. obstructing particles in the channel (1, 6), leakage of the channel (5), cracks and additional/lack of material on the membrane (2, 7, 3). It is clear that such defects can influence the behaviour of the whole sensor.

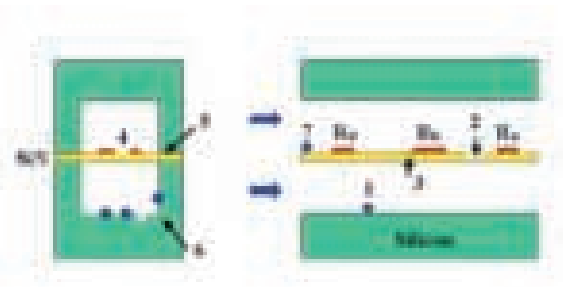


Figure 1: A flow sensor and several possible physical defects in its different parts.

Figure 2 shows the temperature distribution in the case a large particle is in front of the membrane. The red part illustrates the heated membrane (by Rh), the blue parts along the channel perimeter are at ambient temperature. A FEM simulator for fluidics has been used for the simulations. As can be seen, an asymmetric temperature profile results, which will cause errors in the flow measurement. At low flow velocity or in the case of no defects, a symmetrical profile results.

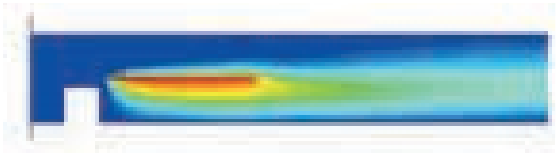


*Figure 2: Temperature distribution in the flow sensor. The heater temperature is 320K. A 30 mm/s flow of water. Particle size is 200*200mm. Membrane length: 800mm. Distance particle-membrane: 50mm. (ANSYS FEM simulation).*

A large number of simulations under different conditions have been simulated to obtain temperature profiles, in order to develop a fault-free and faulty channel networks. In our case we required a circuit network, as fluidics and temperatures can be readily modeled as resistors, capacitances and sources. Defects are modeled as additional components or components of which the parameters have been changed. Figure 3 shows the model of the central part of the flow sensor. The voltages at the nodes are a measure of the temperature. Note that only the static situation has been modeled (no capacitances).

Comparing simulations of the temperatures along the membrane in the case simulated with a FEM simulator and the commonly used circuit simulator Spice are given in figure 4. It shows a good match of illustrating the effect of a jamming particle in the channel on the local temperatures. This modelling can be used to model defects in the overall fault simulation of a microelectronic fluidics system and can help to find the proper signals to detect these faults and investigate the influence on the system.

The research has been carried out within the Strategic Research Orientation **MiCS** and is a cooperation between the Testable Design & Testing of Microsystems group and the Micromechanical Transducer group.

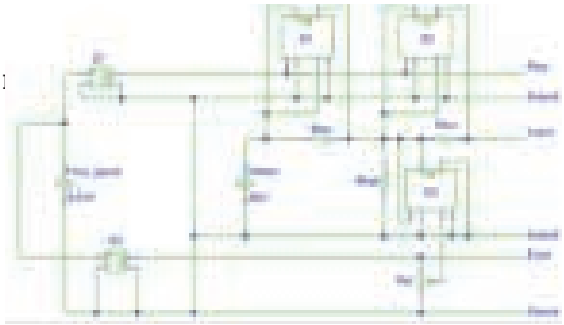


Figure 3: The basic combination of flow-speed, heater and (lumped) channel element.

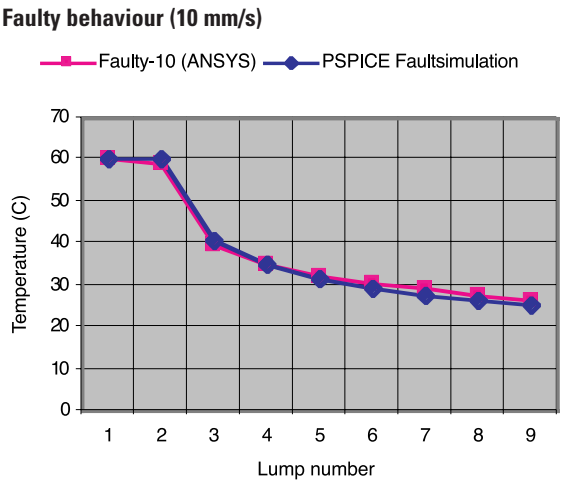


Figure 4: Simulated ANSYS and PSPICE behaviour of the faulty micro channel with a jamming 200µm particle in the channel near the heater (50µm). Flow speed is 10mm/s.

This work was published in:

1 'Defect-Oriented Testing of Microelectronic Fluidic Systems', H.G. Kerkhoff and E. Oosterbroek, Proceedings Microtas 2000, May 2000, Enschede, pp. 315 – 318.

2 'Analogue Fault Modelling and Simulation Techniques in Electronic/Fluidic Microsystems', H.G. Kerkhoff and H.P. A. Hendriks, Proceedings of the IEEE International Mixed-Signal Test Workshop, June 2000, Montpellier, France, pp. 7 – 13.

Lab-on-a-chip technology for biomedicine

In the framework of a FOM Rolling Grant program a completely new concept has been developed for continuous monitoring of a patients blood chemistry in intensive care situations. In order to face haemocompatibility problems, the microdialysis sampling technique has been chosen as the basic starting point. Therefore a microdialysis double-lumen probe has been integrated with a monolithic lab-on-a-chip system, applying a generic technology for all distinguishable components.

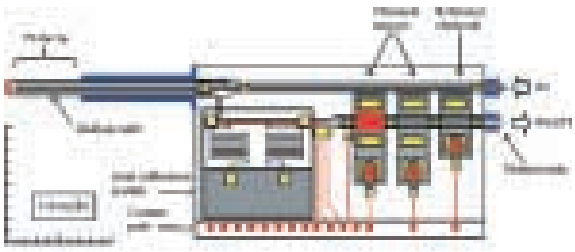


Fig.1 Design of microdialysis probe, connected to a lab-on-a-chip system. The externally applied micropump should be integrated in a later version.

More or less as a reaction on the biocompatibility and calibration problems of single electrochemical sensors for biomedical applications, microdialysis probes have been introduced in the seventies. However, the present available microdialysis probes have to be connected via tubes to adequate miniaturized chemical analysis equipment, which is still a serious drawback for a real application, especially in the case of patient monitoring in intensive care units. To solve this problem the MESA+ Biosensor research group started a project for the comprehensive integration of microdialysis probes and a measurement system made in silicon. In fact the plastic connector of a microdialysis probe is replaced by a silicon connector, containing an integrated peristaltic pump for transport of the perfusion liquid. Moreover this piece of silicon contains the relevant sensors as well as facilities to calibrate the sensors just before the dialysate sample plug is transported over the sensors. In order to reach this goal a monolithic technology has been developed, which needs completely new designs for pump facilities and sensors.
All components have been designed for processing in one generic technology, being an etch technology for dimensioning the double lumen tube connections, meander-shaped cavities which contain calibration solutions, connected to a dosing pump chamber, microcavities for potentiometric and amperometric ion- and enzyme sensors, as well as a channel with flexible valves for the peristaltic pump. At the present moment the connector as such, the calibration system and some ion sensors (Na, K, Li and pH) as well as enzyme sensors for glucose, lactate and glutamate have been realised, whereas the peristaltic pump is under development.

The sensor array is of the flowthrough type and consists of a microdialysis tube, led through an etched channel, which is widened at regular distances. The cavities formed in this way contain specific ionophores, in contact with a KCl solution and a Ag/AgCl electrode for the potentiometric ion sensors. Replacing the ionophores by a specific enzyme solution and adding a Pt electrode results in amperometric sensors for several metabolytes. In case the cavity is only filled with a KCl solution a reference electrode is formed. In principle the array design is unlimited with respect to the number of sensors placed in series. As such this type of flowthrough sensor array drew the attention of the horticulture industry (Van Vliet-Pijnacker BV) which received a license from FOM with respect to the related patent.

Because any sensor can exhibit drift and variable sensitivity, a calibration facility is required. In the case of the lab-on-a-chip concept, calibration liquids are stored in meander-shaped cavities which can be dosed in small plugs into the dialysate channel by the electrochemical production of gas bubbles at two noble metal electrodes in a cavity formed at the end of the meanders.

All channels and cavities are etched in a single piece of silicon (1.5cm x 2.7cm), which is covered with a piece of glass containing the necessary electrodes. Figure 1 shows the basic design of the microdialysis probe with a silicon/glass lab-on-a-chip system and figure 2 shows a realised chip. The company Roche Diagnostics GmbH in Mannheim received the license rights of the international patent owned by FOM.

This work was published in:

1 The comprehensive integration of microdialysis membranes and silicon sensors, PhD Thesis S. Böhm, University of Twente, 2000, ISBN:90-365-1462-2.

2 Microdialysis probe integrated with Si-chip, P.Bergveld, S.Böhm, W.Olthuis, international patent application PCT/NL99/00057.

3 Analyse –inrichting voor het detecteren van in water opgeloste bestanddelen, S.Böhm, P.Bergveld, W.Olthuis, Dutch patent application 1013072.

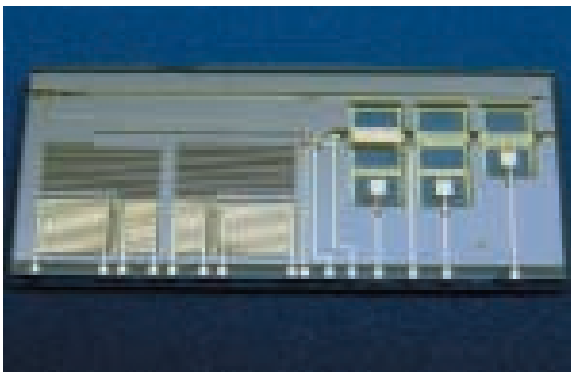


Fig.2 Realised lab-on-a-chip system for connection to a microdialysis probe. The components as indicated in figure 1 can clearly be distinguished.

The power of probes and MEMS for future memories (or µSPAM)

The Nobel price winning invention of the Scanning Tunneling Microscope by Binnig and Rohrer in 1981 has triggered a completely new branch in science and engineering called Scanning Probe Microscopy (SPM). In the last decade SPM has become an indispensable tool in scientific research, for instance in the form of the Magnetic Force Microscope (MFM) which is used for imaging magnetic structures, such as written bits in a hard disc.

The scanning probe technique does however not limit itself to the field of microscopy; one can envision that it will also be used for applications such as nano-manufacturing or recording. SPM's are quite slow and cover only small areas. If scanning probe techniques are to be used for application, arrays will be needed to increase the throughput and active area of the device. Since the total device should be kept within the cm range, this implies that each probe occupies a cell of a few tens of µm square. Therefore MEMS technology is needed to develop such a device, which might be called a Scanning Probe Array (µSPA).

Within the MESA+ Scientific Research Orientation NanoLink, the Systems and Materials for Information storage (SMI) group is working together with, amongst others, the Micromechanical Transducers group on a scanning probe array system for memory applications: µSPAM. It consists of an array of approximately 1x1 cm of active (magnetic) read/write probes, positioned above an array of xy-positioners. The total thickness of the device will only be 2-3 mm.

The medium used in the system is a patterned magnetic medium prepared by Laser Interference Lithography, a technique which is developed in a joint project of the SROs NanoLink and Advanced Photonic Structures in cooperation with the Micromechanical Transducers Group and the Lightwave Devices Group. We are now able to realise 70 nm single-domain magnetic dots spaced at a distance of 200 nm over an area of at least 1 cm^2. The main emphasis of the research is high density storage. The read/write probes are based on an architecture similar to either probes used for MFM or those found in tape drives. Several configurations for reading and writing are under consideration. For the positioning system an array of µ Walkers will be used, each capable of moving a small medium sled over 100 µm. Special attention is paid to access times, for which we cooperate within an STW project with the Control Systems group of the Faculty of Electrical Engineering. The use of a patterned medium and a huge number of probes imposes new questions on data channel design as well. Special attention is paid to read/write synchronisation and scheduling.

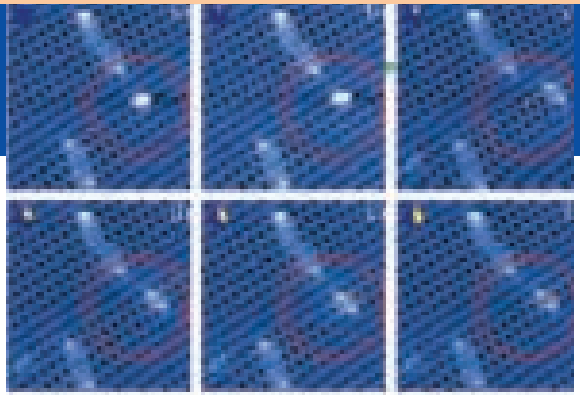
Because of the small form factor of the µSPAM system, its first application could be in portable computing systems such as palmtops, camera's or mp3 players. The µSPAM combines the high capacity of the hard-disk with the low power consumption of the FlashRAM. Next to this, the huge parallelism in read/write and the micromechanical x-y positioning allow for very high data rates and low access times, and it can be expected that the probe recording system will also find a place in the storage pyramid, in between the hard disc and the RAM.

This work was published in:

1 Abelmann et al. 'Micromagnetic simulation of a flux guide for a read head with sub-100 nm resolution'
Journal of Applied Physics, 87 (2000), no 9, Page 5538-5540

2 Carley et al. 'Single-chip computers with microelectromechanical systems-based magnetic memory'
Journal of Applied Physics, 87 (2000), no 9, Page 6680-6685

Diffusion driven concerted motion of surface atoms



Successive Scanning Tunneling Microscopy (STM) scans of the same area (10 nm x 10 nm) of a germanium (001) surface after the deposition of a small amount of germanium (~ 1% of a monolayer). The time lapse between the images, which are taken at room temperature, is 276 seconds. The white blob in the red circle is a germanium dimer (=cluster of 2 atoms). The red and yellow points mark the position that has been visited by the dimer. Initially the dimer diffuses over one of the germanium substrate rows (the dimer bond is aligned in the substrate row direction). In image (c) the dimer rotates by 90 degrees and subsequently hops to a position between two substrate rows (trough position). The most striking observation is that during diffusion in the trough the local environment of the diffusing dimer changes significantly (note for example the conversion of the two substrate rows in the red circle of images (d)-(e)-(f) from a zigzag to a non zigzag appearance and vice versa). In image (c) a similar conversion (green arrow) can be observed. Finally, the blue arrow in image (c) refers to the adsorption of a single hydrogen atom.

A detailed understanding of how an atom or small cluster diffuses over a surface is of great fundamental and technological interest. The development of the Scanning Tunneling Microscope has brought about a unique opportunity to study various surface processes, such as example diffusion, with atomic resolution. It is common wisdom that during diffusion of an atom or a cluster over a substrate the surface remains unaltered. Here we show, however, that this simple atomistic view on surface diffusion needs revision (see Figure). For the system we studied (germanium dimer on a germanium surface) we observe occasionally that *more* than 30-50 substrate atoms (!) change their position due to a single diffusion event. This observation has important implications for the development of microscopic models for crystal growth and etching.

This work was published in:

1 Diffusion driven concerted motion of surface atoms:
Ge on Ge(001),
H.J.W. Zandvliet, T. Galea, E. Zoethout and B. Poelsema,
Physical Review Letters 84, 1523 (2000).
(A full video presentation can be found at:
www.omicron-instruments.com/pom/montho4.html)

MESA+ Scientific Publications 2000

Ph.D. Theses

- Balistreri, Dr.ir. M.L.M. (2000, October 13). Coherent imaging of guided optical fields. Universiteit Twente, 135 pp. Promotor(en): Prof.dr. N.F. van Hulst. Assistent promotor(en): Dr. L. Kuipers. ISBN 90-365-14924.
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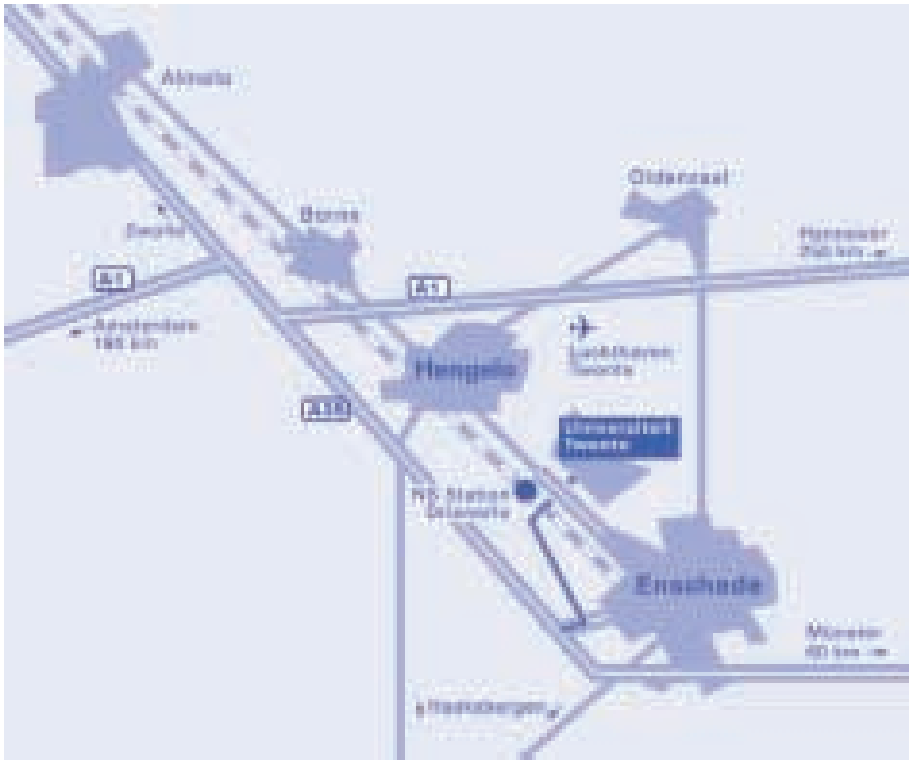

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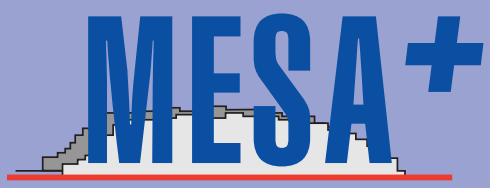

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