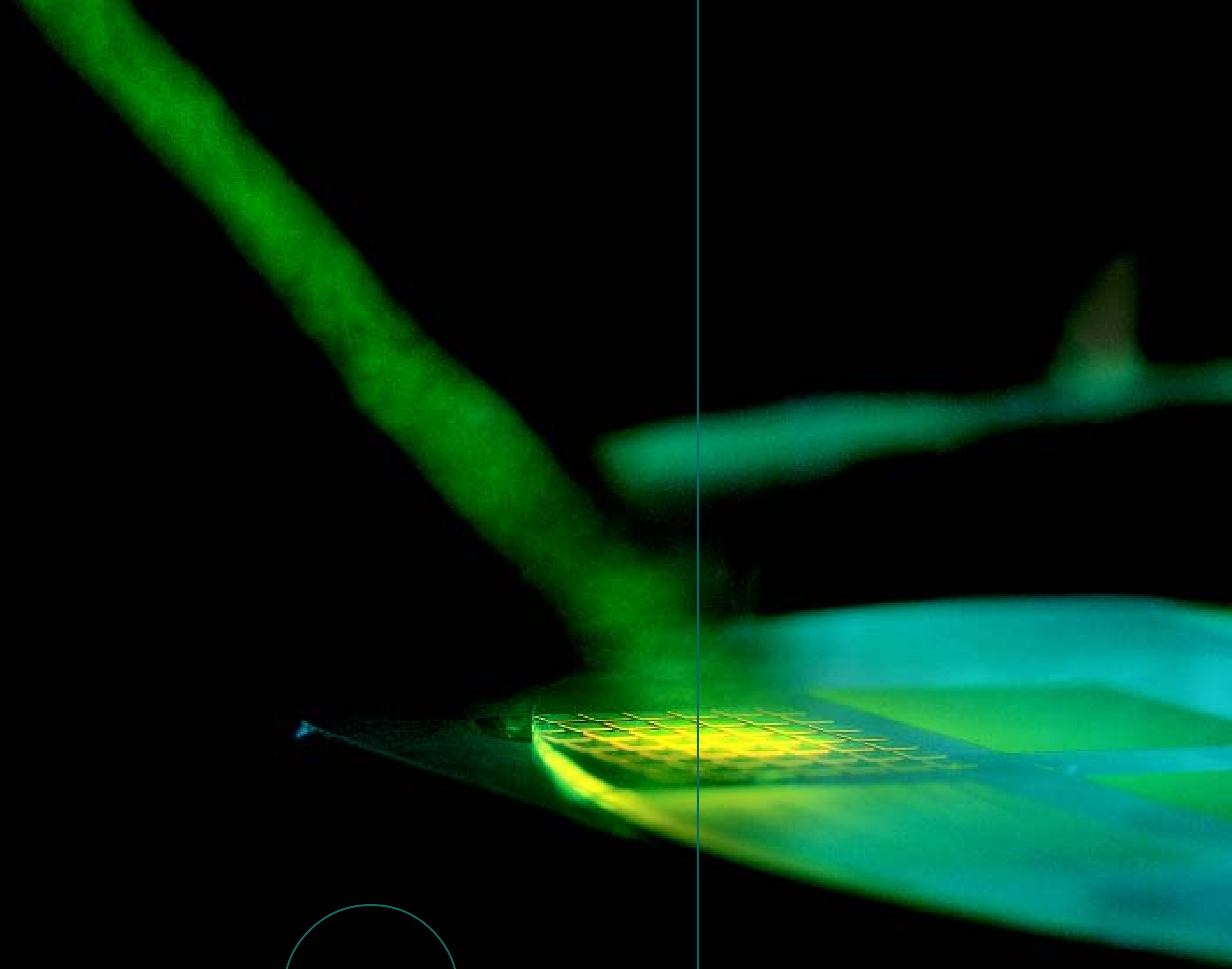
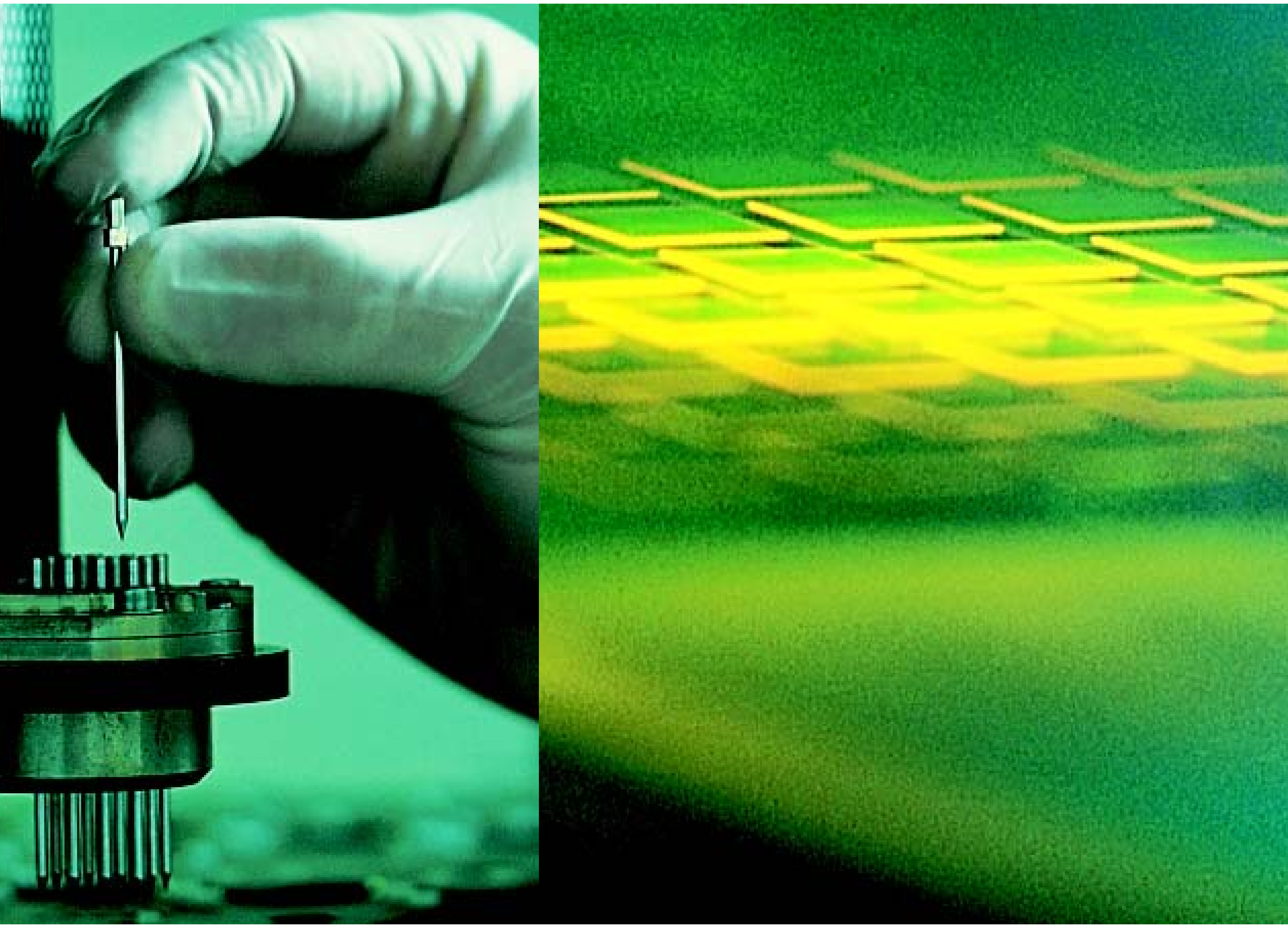
MIC
Annual Report



2002

Contents



Annual Report 2002
MIC (Mikroelektronik Centret)
September 2003

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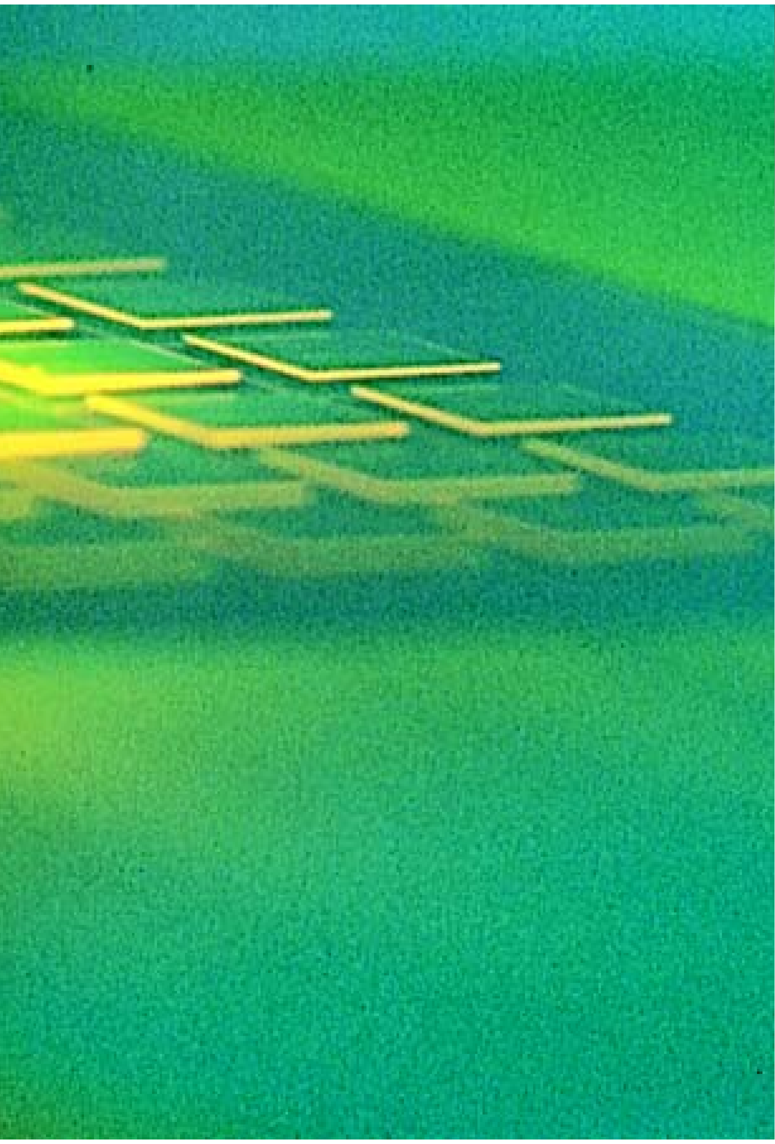


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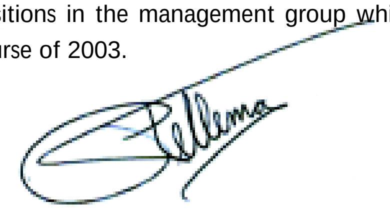
New winds blowing

After celebrating the Mikroelektronik Centret's (MIC) tenth anniversary in 2001, 2002 presented itself as a year of change. Jon Wulff Petersen, director of MIC for over 6 years, announced his departure from MIC in the summer of 2002. He accepted new challenges in the role of vice-director at Risø National Laboratory. Jon leaves a strong organisation with a reputation for research and innovation in micro- and nanotechnologies. Under his guidance, microtechnology firmly established itself in Denmark in the form of a string of commercial activities. In the fall of 2002, following the birth of his daugther, vice-director Francois Grey opted for reunification with his family in Switzerland. He has since accepted a position at CERN. Francois has been with MIC for 8 years and fulfilled the role of vice-director since 1996.

We wish both Jon and Francois the best of luck in their new positions. At the time that this year report goes to print I have accepted the position of director. The excellent infrastructure and unique atmosphere at MIC which were important factors for me in acquiring a position at MIC in 1997, prompted me to accept the position of director of the centre. To warrant continuity from the previous management to the new management, I asked Ejner Mose Hansen to become vice-director at MIC. Ejner has been with MIC ever since the establishment of MIC in 1991 and managed MIC's most important asset, the clean room, since its inauguration in 1993. The changes in management in 2002 leave us with two open positions in the management group which we aim to fill in the course of 2003.



Message from the Director

The entire staff at MIC is dedicated to pursuing education, research, and innovation in micro- and nanotechnology as set forth in the Result Contract with the Technical University of Denmark (DTU).

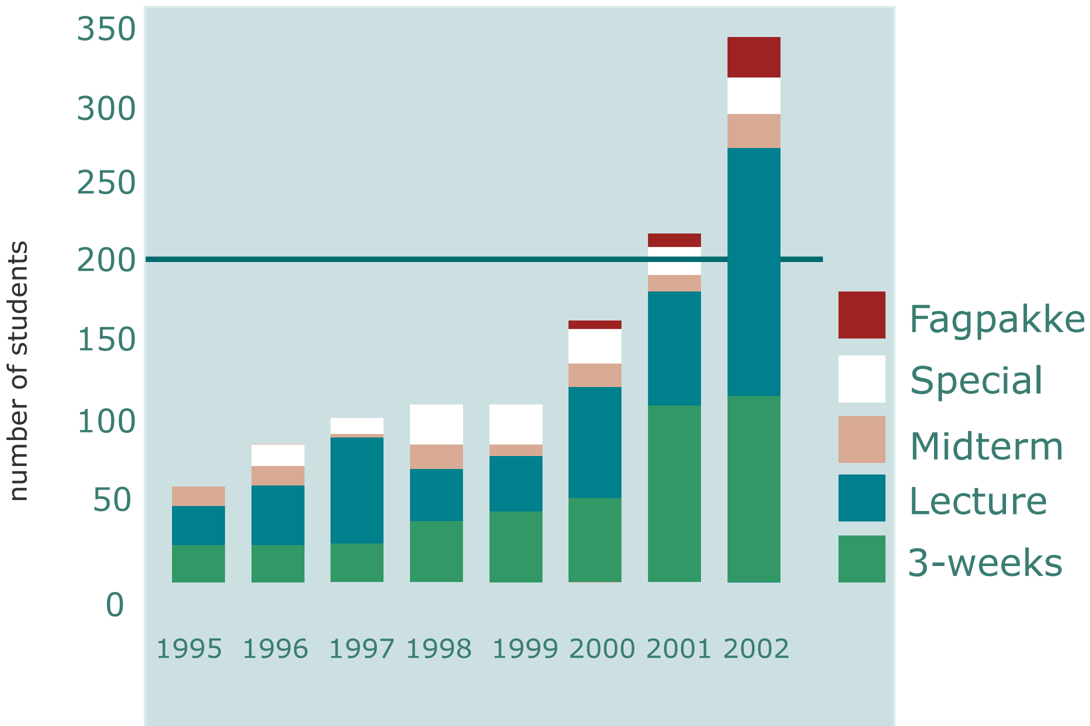
MIC´s goals

In 2002 important results were obtained towards reaching our goals. In our aim to double the number of M.Sc. and Ph.D. candidates we have expanded and modernized our teaching. These efforts have resulted in a further increase of the number of students that attended courses at MIC in 2002 compared to the previous year. This increased exposure to MIC's exciting research projects entices more and more students to stay at MIC and engage in a M.Sc. or Ph.D. project at MIC. In research we witnessed a doubling of the number of peer-reviewed conference proceedings as well as an increase in peer-reviewed papers. Never satisfied with scientific publications as the only outcome of research, 2002 has been a succeful year for MIC's collaboration with industry. The highly succesful SUM 'center kontrakt' which contributed significantly in bringing microtechnology closer to commercialization in Denmark came to an end and efforts are underway to find means to continue this fruitful collaboration between Danish institutes and industry.
In 2002 MIC started collaboration with a number of Danish institutes and companies in a new 'center kontrakt': Micro Chemical Analysis in Polymers (μKAP). The aim here is to fabricate microstructures for chemical and biochemical analysis in polymers.
In 2002, DTU finalized its plans to expand the clean room facilities to further enhance micro- and nanotechnology related activities at DTU. The existing clean room combined with the newly build facilities will be known under the name Danish Advanced Nanotechnology Center for Highly Integrated Production (DANCHIP).
DANCHIP will allow small scale commercial production thereby bridging the wide gap between research and foundry.
As one of the first equipment purchases, DTU acquired a state-of-the-art e-beam lithography set-up. This e-beam facility opens up the possibility to fabricate and explore components and systems at a scale well below our current capabilities. The system will come on-line soon after DANCHIP is inaugurated in the begining of 2004.
The bridge across the sound between Sweden and Denmark which was completed in 2000 not only improved the infrastructure of the region but also increased regional collaborations in the form of joined teaching and research programs. To further stimulate collaboration between MIC and LTH, Prof. Lars Samuelson from the Nanometer Consortium at LTH accepted a part-time position as vice-director at MIC. MIC and the Nanometer Consortium will constitute a strong axis in an international context not the least when applying for funds from EU's 6th framework programme. Closer cooperation between the two institutions will strengthen MIC's national position within nanotechnology, and help MIC in attracting well-qualified senior researchers as well as gifted students from all over the world. The cooperation will likewise contribute to a broader contact with the Swedish academic environment and the Swedish industry and thereby lead to a greater Scandinavian engagement in the new extended processing facility DANCHIP.
MIC has witnessed many changes over the years and will continue to do so in the coming years. We view these changes as precursors to new acitivities and improvements that will allow MIC to stay at the forefront of education, research, and innovation in micro- and nanotechnology.

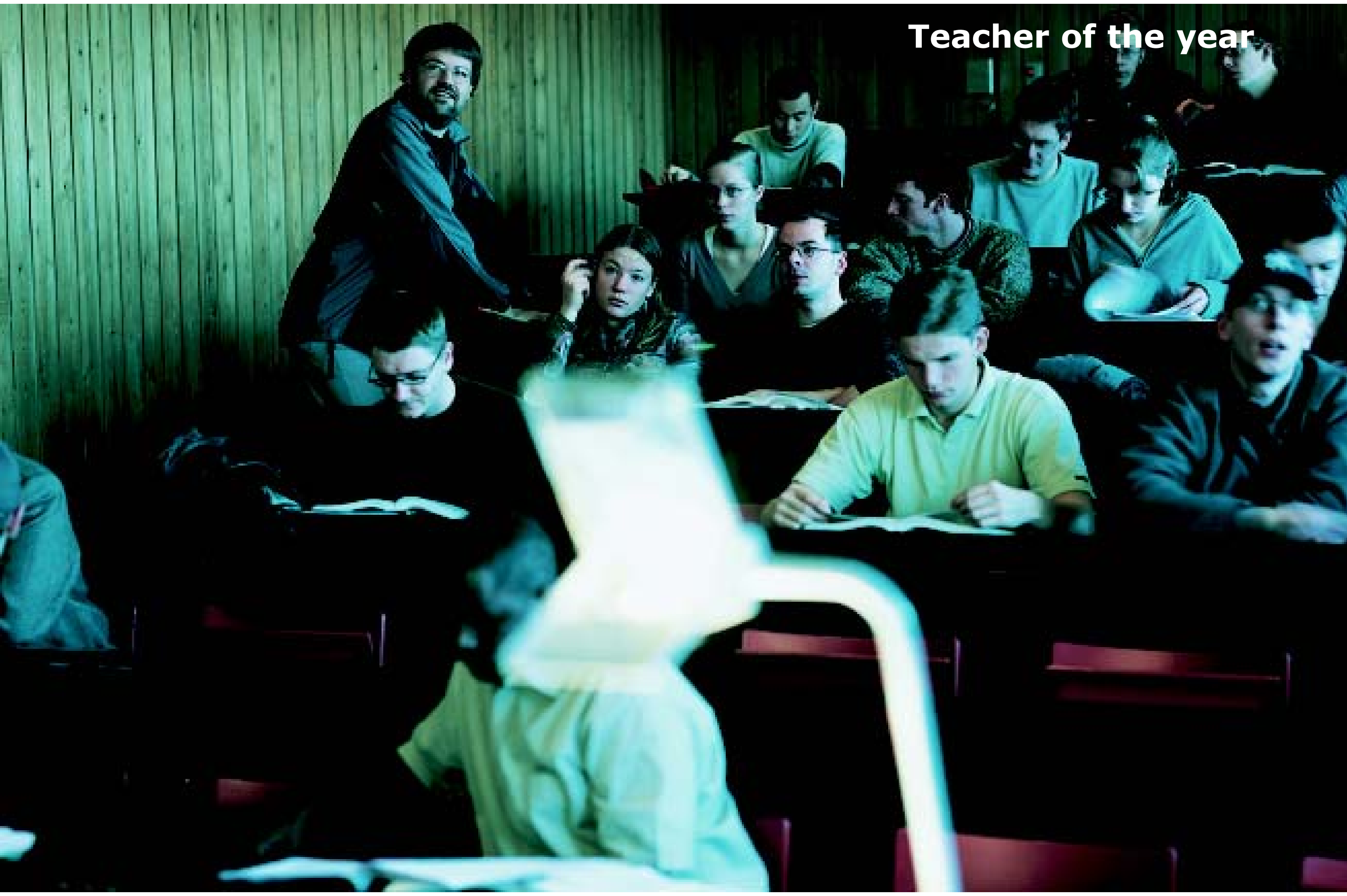
Record breaking year for education

Year 2002 was a record breaking year for education at MIC with 330 students following the courses given by teachers at MIC. This is the highest number in the history of MIC as evidenced by the evolution in student numbers shown in the figure. In short, 150 students followed the lecture courses, 110 students participated in experimental 3-week courses and around 60 students carried out other types of experimental courses based on project work.

Year 2002 was also in another manner an epoch-making year. In autumn 2001 DTU launched a new course schedule where lessons are given in blocks of four hours, and at the same time many courses were rescheduled from five to ten ECTS points in accordance with the new guidelines provided by DTU. At MIC this meant a major change in curriculum and a considerable didactic challenge for the three introductory courses in nano-, micro- and bio-technology. For example, in the course Solid State Electronics and Micro Technology several new teaching methods were introduced to activate the students during the lessons with the goal of increasing learning. Conventional lectures are supplemented with interactive sessions where the students are challenged with questions and exercises. There are also two poster sessions, an exercise where a multi-layered cake is used to illustrate the planar process used for silicon wafer processing, and a final project work. This course was so well received by the students that they recommended one of the teachers, Erik V. Thomsen, for DTU "Teacher of the Year 2002" award which he received later that year.



Teacher of the year

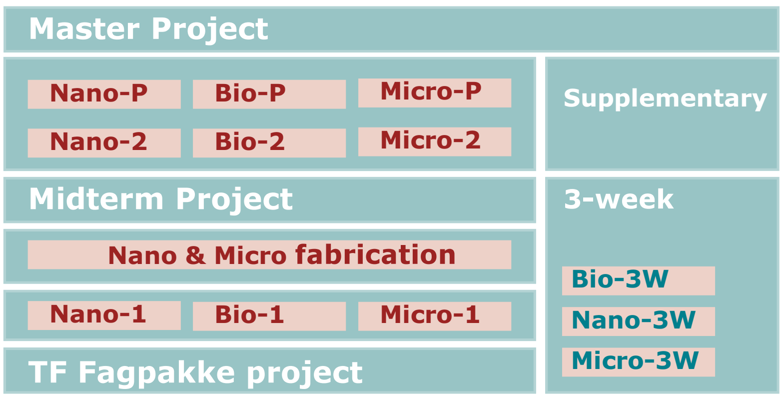


During 2002 MIC restructured its course program under the heading nanosystems engineering and as a result of this several new courses will be introduced in the next two years.

The course program consists of three blocks of courses arranged within the fields of nano-technology, micro-technology and bio-chemical microsystems. There are three introductory courses aimed at the fourth semester (Nano-1, Bio-1, Micro-1) each having a related experimental 3-week course.

A new course in nano-and micro fabrication will be launched in autumn 2003. This course, aimed at the sixth semester, provides a good background for doing a midterm project within the research fields at MIC.

The graduate level core of the education consists of three advanced courses (Nano-2, Bio-2, Micro-2), each having a related experimental project course (Nano-P, Bio-P, Micro-P), and a package of supplementary courses at an advanced level. The advanced micro-technology course, the Micro-2 course, was launched already in 2001, the advanced nano technology course (Nano-2) will start in autumn 2003 followed by the advanced course in bio-chemical microsystems (Bio-2) which will begin in autumn 2004.



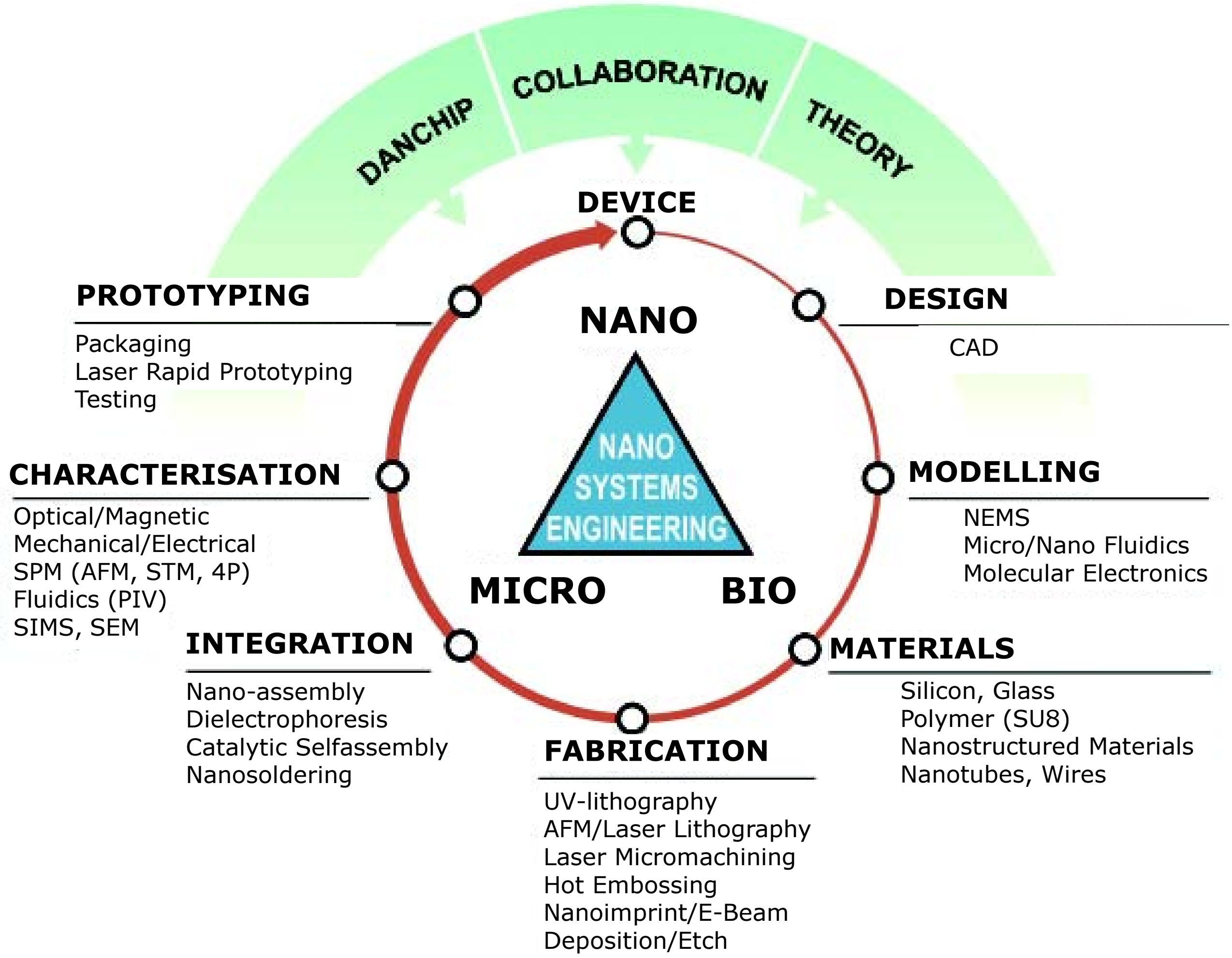
The final part of the education is a master project within the fields of research at MIC. With this education in place MIC is well prepared to continue to educate a growing number of engineers and researchers within the fields of nano-technology, micro-technology and bio-chemical micro-systems.

Nanosystems engineering

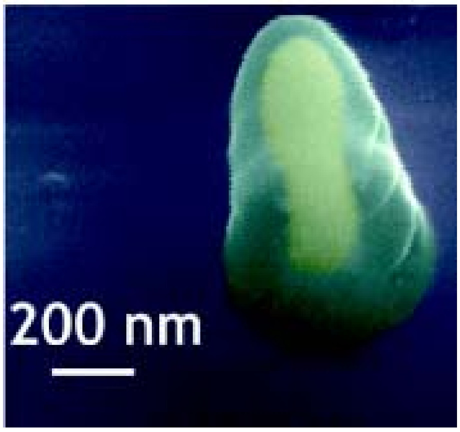
One of the unique aspects of the research at MIC is the systems level emphasis on the applications, which has enabled the results to be translated into commercial products.

Hence at MIC the research and education of nanoscience and technology is addressed in a systems context as well. Nanosystems engineering focuses the device level applications of nanotechnology and its interface to micro and bio systems. The proven MIC model of close industry collaboration together with world-class research utilizing the state of the art fabrication facilities will again be utilized to achieve expediated commercialisation of nanotechnology. With the recent establishment of the DANCHIP facility at DTU we are uniquely positioned to accomplish this goal. We will also continue our close collaborations with national and international partners in this endeavour.

„ nanotechnology research areas at MIC"



An electron microscope image of a gold core inside a carbon coating. The diameter of the gold core relative to the coating can be adjusted by controlling the growth conditions.



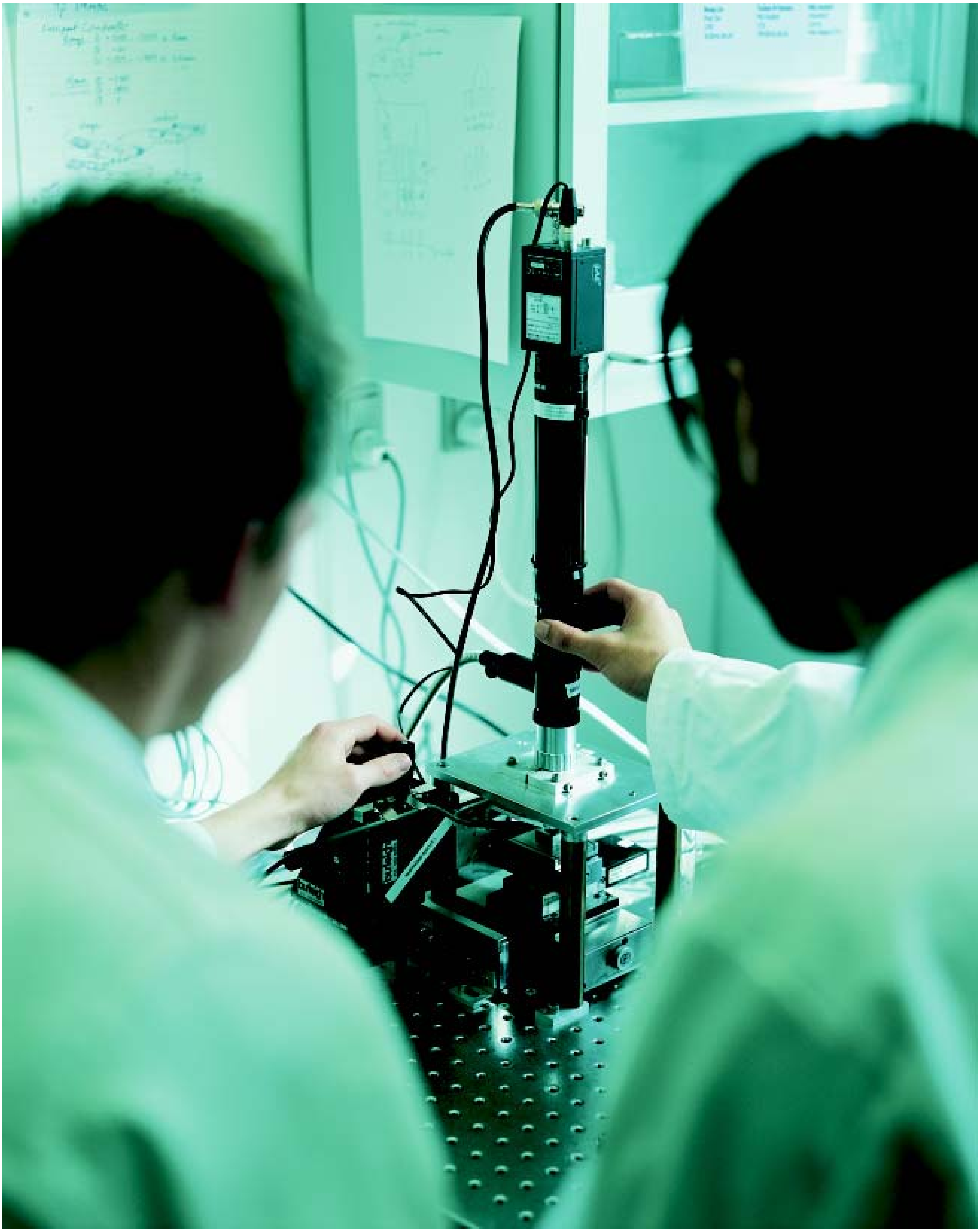
Scientific highlight: soldering on the nanoscale

As nanotechnology steadily progresses in discovering and developing new small objects that have outstanding properties, one can only dream of how these could be used as compact, fast transistors and ultra-sensitive sensors in microscale circuitry. For instance, carbon nanotubes have been investigated with an amazing intensity throughout the past decades; these small rolls of carbon atoms are expected to revolutionize electronics and materials science. All that is needed are methods to connect these - just like a soldering iron does it with macroscale components.

At MIC a considerable effort is devoted to finding solutions to the problem of integrating nanoscale components.
In 2000 a microfabricated nanotweezer was developed providing smaller hands to hold and move nanoscale components.
MIC has developed a novel method that aims to solve the problem by "soldering" the carbon nanotube to the electrode using a tiny metallic "solder bump". The soldering material is a gas of organic molecules containing gold, and the solder iron is a beam of electrons that frees the gold at exactly the right spot; where the connection is to be made. Tiny 50 nm diameter carbon nanotubes were soldered to tiny micro-fingers.

The combination of low contact resistance and a high mechanical strength of the connections - of the "solder bumps", holds great promise for the future of this method. The researchers are now learning to control the gold content and the composition of the solder material, and to automatise the soldering process.
In combination with nanotweezers for grasping and moving nanocomponents, a powerful method for integration of nanocomponents in nanosystems is at hand.

Students in nanolab



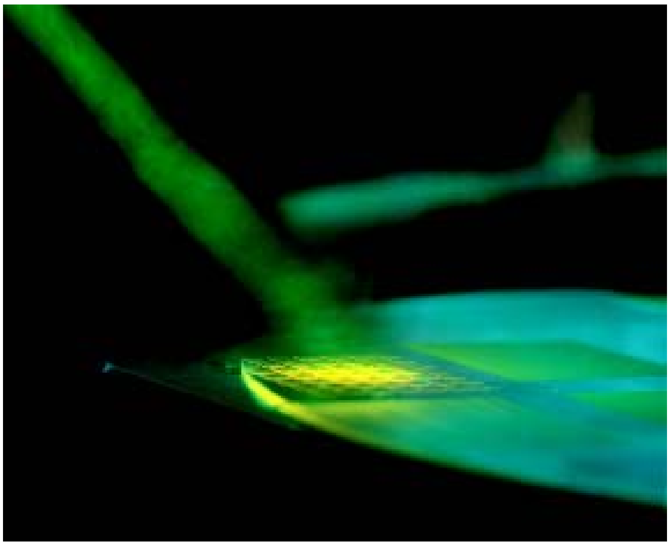
Visions for nanoscience & nano-technology for MIC and Øresund

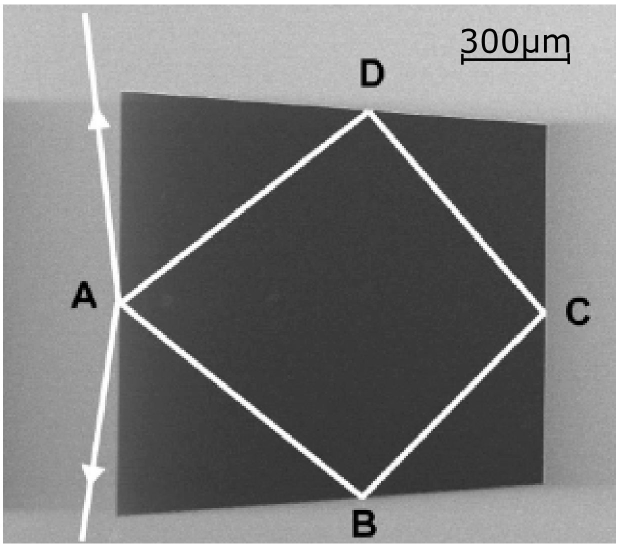
By Lars Samuleson, Vice-director at MIC and Head of the Nanometer Consortium in Lund (Sweden).

The recent inauguration of the Øresund bridge between Copenhagen and Malmö has made it possible to commute between the Technical University of Denmark (DTU) and the Lund Institute of Technology (LTH) at opposite ends of the region in less than one hour. Sharing of laboratory facilities and exchange of staff are therefore realistic. Substantial regional investments in nanoscience and technology research and education present an opportunity right now to optimize these investments and gain a sharper profiling of our research centres. In this way we can allow each of the universities to reach international excellence in their respective primary areas of strengths. These specializations will become accessible to researchers and students in the whole region. In principle, all research sites need access and activities in the areas of silicon microfabrication, compound semiconductor materials technology, quantum transport physics, quantum devices and systems, photonic devices and systems, macro-molecular systems and bioanalytical systems, to a varying degree. There is little doubt however that an optimization and coordination would be beneficial to all research sites and have important consequences for attracting top-level scientists and students to the region as well as attract and generate more high-tech companies.

In the traditional mode of operation, each university would make sure to have all resources in-house with the consequence that the effort at each site and in the region as a whole gets under-critical.

In the new vision, each of the sites focuses on its primary strength areas and guarantees full access to researchers and students from the other sites.





Brick by brick - building the optical lab on a chip

2002 has been an year of new initiatives for the MEMS research at MIC, building on our strengths in silicon based microsystems as well as bridging MEMS and µTAS to provide additional functionalities in a lab on a chip. Some of these new initiatives are highlighted in the following.

Optical techniques - like spectroscopy, fluorescence detection and evanescent wave sensing - are widely used for chemical and biological analysis. This motivates for integrating optical and micro-fluidic components on lab-on-a-chip microsystems.

MIC has a series of research activities on integration of optical transducers - lasers and photodetectors – on polymer based lab-on-a-chip microsystems. During 2002 the building blocks for a fully integrated optical analysis system – lasers, waveguides and photodectors - were demonstrated at MIC.
The picture shows a scanning electron microscope picture of a solid polymer dye micro-cavity laser, fabricated at MIC by Søren Kragh during his master thesis project. The active material is a commercial laser dye cast into a matrix of solid polymer.

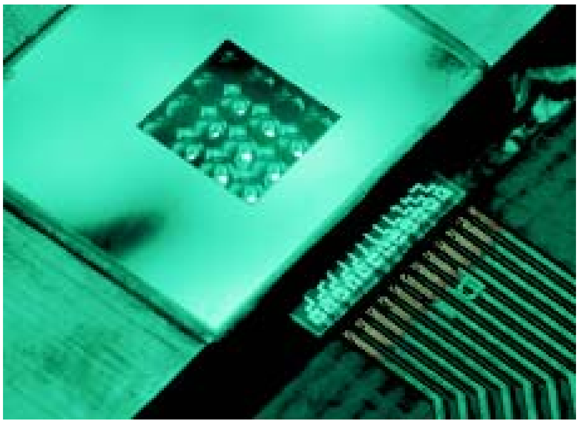
In the present device, the laser dye Rhodamine 6G was dissolved into SU-8 photo-resist. The dye doped photo-resist is spun onto a Pyrex glass substrate, and the laser micro-cavities are formed by standard photo-lithography. The solid polymer dye lasers are pumped optically by an external laser. The 1.6 µm high solid polymer cavity has a lateral shape of a trapez. In the present form, the optically pumped solid-state polymer micro-cavity lasers rely on total internal reflections at the polymer-air interfaces, as illustrated in the figure above. The lasing wavelength is controlled by the lateral dimensions of the polymer cavity. The present device is optically pumped by a laser at a wavelength of 532 nm, and emits at a wavelength of 598 nm.

Optical MEMS for controlling light

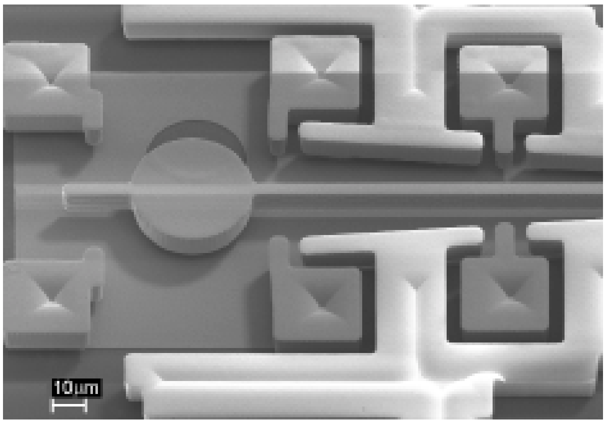
In this project, a new technology for fabrication of an integrated optical MEMS system for controlling light is developed in collaboration with the Danish company Dicon A/S.

By combining MEMS and optical components such as mirrors, switches and microlenses on the micro-scale, very cost attractive, compact and advanced systems can be made. Such systems have an increasing number of applications within areas like telecommunication, displays, scanning, data storage, signal processing and sensing.

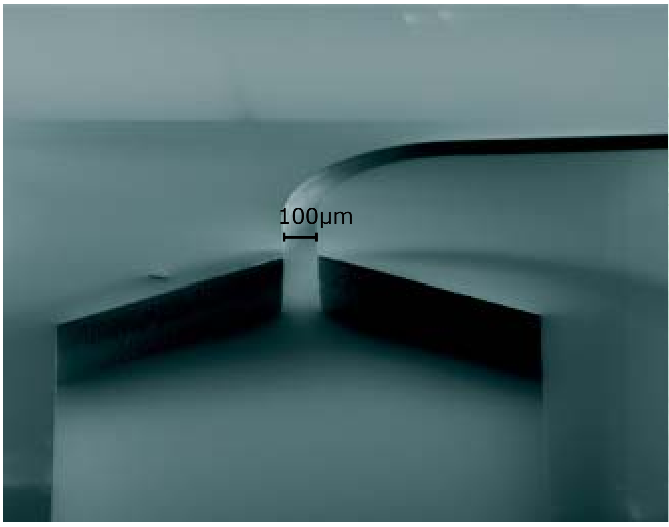
By focusing light on the surface of a microchip consisting of a large amount of individually addressable microshutters, it is possible to control the spatial transmission of light. Such a system is called a Spatial Light Modulator (SLM). One possible application for such an SLM is in advanced fibre optical light distribution systems, where the SLM is used for switching on and off or modulate light in a number of optical fibres.
The goal for this project at MIC is to develop cost optimized fabrication processes for very compact SLM's with on-chip packaging.

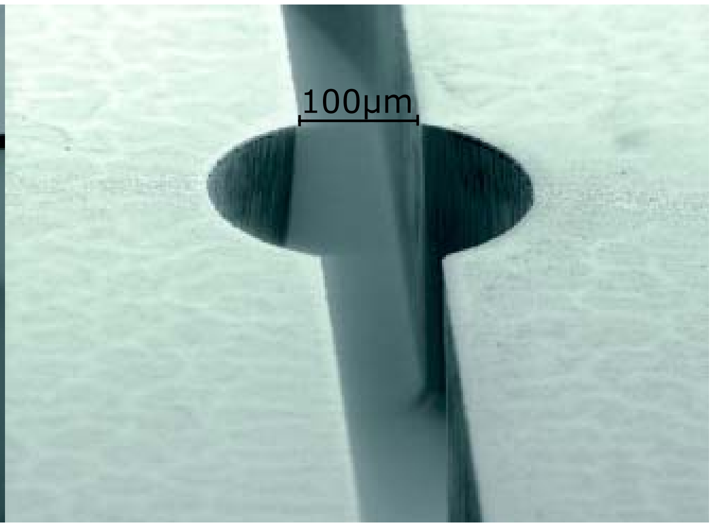


A micro-optical stack containing a 4x4 array of a microlens chip on top of a micro-shutter chip. Control signals for the shutters are fed through the electrical connections seen at the front of the image.



SEM picture of a microshutter with control electrodes.





Microreactors for studies of catalytic reactions

Last year's acquisition of a high performance silicon plasma etcher (STS-ASE) has allowed us to move into new fields of microchemical systems. We are now able to fabricate channel networks with high aspect ratios in silicon, making higher temperature reactions like for instance catalysis reactions possible in the channels. To investigate this application space, a collaboration between ICAT (Interdisciplinary Research Center for Catalysis) and MIC has been established concerning fabrication and application of silicon microreactors.

Microreactors are catalytic chemical reactors with at least one linear dimension in the micrometer range. Compared to ordinary macroscopic chemical reactors, they exhibit enhanced heat dissipation and laminar flow characteristics, and due to these physical differences a whole new parameter space for chemical reactions can be investigated.

For example, chemical reactions that are difficult or impossible to control in macroscopic reactors have been demonstrated in microreactors, and even explosive reactions can be carried out safely.

With the variety of microfabrication methods available, it is possible to integrate different sensors and actuators into the microreactor, giving the technology very interesting scientific and technological perspectives.

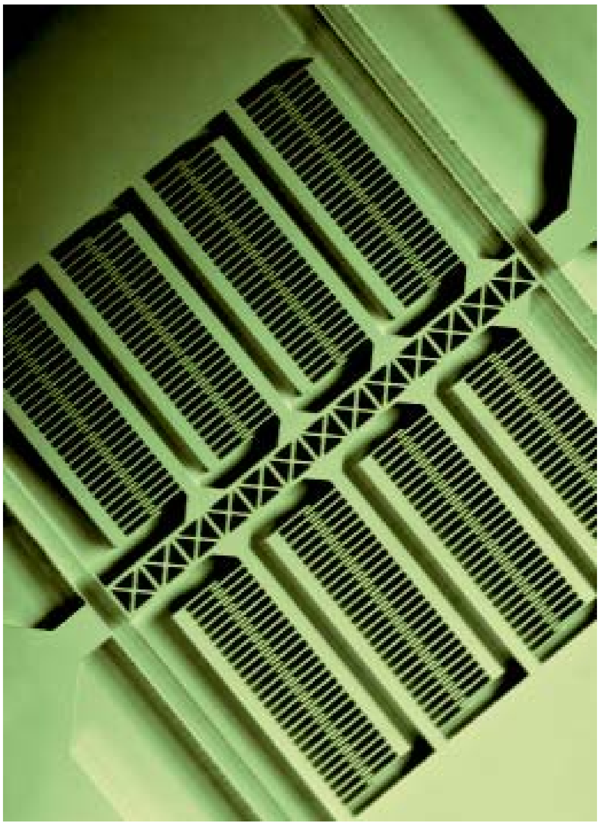
At ICAT, the use of microreactors serves two purposes. One is to use microreactors to demonstrate fast catalyst characterization and optimization as compared to slow conventional testing. The other is to use the unique physical properties of microreactors to study catalytic reactions far away from steady state. Examples include extreme temperature gradients or fast oscillating temperatures and flows.

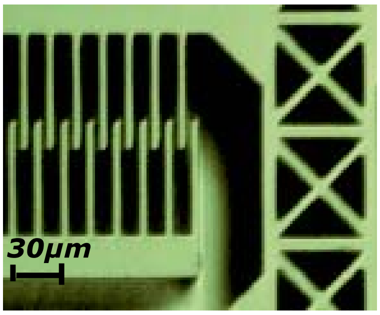
The primary tool in the development of silicon microreactors is the new plasma etcher capable of etching trenches with aspect ratios exceeding 20 at etch rates ten times higher than traditional systems. Combining this tool with MIC's wide range of other microfabrication methods, we are able to make backside feedthroughs for in- and outlet channels and also high aspect ratio through-holes in the outlet channel for real-time studies of the catalytic reaction using gas chromathography and mass spectroscopy.

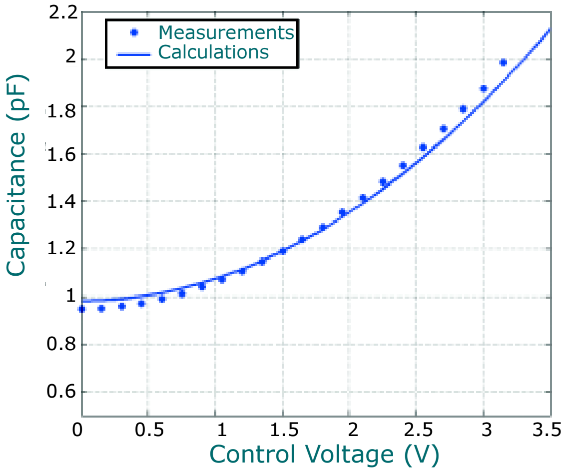
RF MEMS for mobile communicationsystems

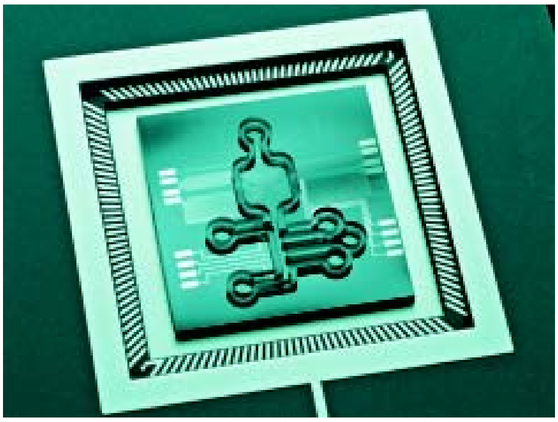
Applications of tunable capacitors in integrated circuits spread in a wide segment, several of which can be named as voltage controlled oscillators, tunable filters and resonators. In the implementation of channel selecting filters with center frequencies ranging from 455 kHz to 254 MHz in radio-frequency (RF) communication systems, band pass filters with high quality factors in heterodyne receivers are used. Conventionally, RF blocks have used electronic varactors implemented through diodes or transistors. Recently, micro electromechanical varactors have been a common interest of the RF community as an alternative technology to be used in the aforementioned applications.

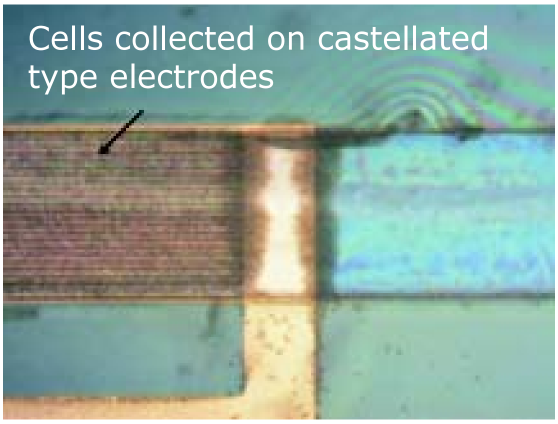
At MIC, we have fabricated different versions of in-plane, high-aspect ratio novel tunable capacitors on silicon-on-insulator (SOI) substrates, which can offer a wide tunability range with state of the art electronics compatible low actuation voltages. The device was fabricated using deep reactive ion etching (DRIE) with parameter tuning, allowing a gap aspect ratio of 1:20 and a feature aspect ratio of 1:60. With a static capacitance of 1 pF, the tuning ratio was found to be 2:1 with 3 V of excitation which is an order of magnitude better than the current semiconductor varactors. Characterizations at microwave frequencies showed a self-resonance frequency exceeding 3.4 GHz permitting RF regime operation without frequency range restrictions.











Bugs on a chip

An integrated microsystem for detecting and analysing microorganisms.

The polymerase chain reaction (PCR) is an enzymatic, synthetic method used to amplify specific DNA sequences from organisms. PCR is widely used for detecting microorganisems in clinical, biological, agricultural, and environmental samples as well as in food and food products. However, when doing PCR on complex biological samples such as blood, milk, soil, meat, cheese, faeces etc., inhibitory substances in the sample may reduce the efficiency of the PCR process severely. It is therefore often necessary to "clean" the sample for inhibitors prior to the PCR reaction. Such sample pre-treatment is labour-intensive, time consuming and cannot easily be automated.

In the Cell Particle Handling Project we have developed an integrated Microsystem that combines structures for PCR reaction and for sample pre-treatment (picture left). The cells are captured on the sample pre-treatment structure and inhibitors in the sample are washed away (picture right). Then the cells are released and led into the PCR chamber where the DNA of the cells is amplified.

Such a system can e.g. be used in medical diagnostics or for detecting microorganisms in food and food products. As an example we are currently developing this as a system for rapid detecting of the pathogen bacteria *Campylobacter* in chicken in close collaboration with Dr. Bang from the Danish Veterinary Institute, Århus.

Polymer microfludic systems

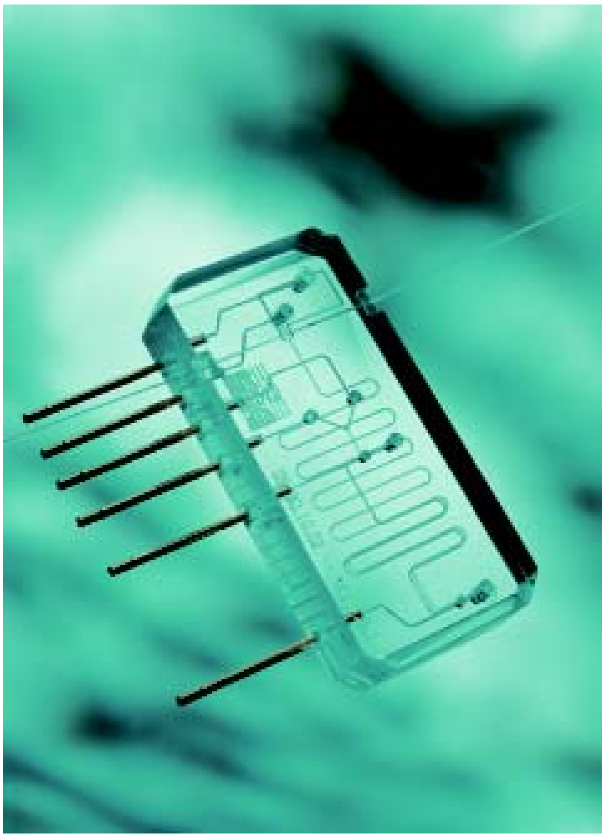
Silicon micromachining has traditionally been the prominent technology platform at MIC. Taking advantage of the unique material properties of silicon an array of interesting components and systems can be realized as highlighted in this and previous MIC year reports. However, more recently, micro- and nanotechnology has attracted a strong interest from the chemistry, biotechnology, medicine, and pharmacology communities as well. The unfavorable material properties of silicon with respect to exposure to chemical and biological samples and reagents have triggered a research program at MIC where we are transferring our extensive micro- and nanomachining knowledge from silicon to polymers.

Polymers represent a large group of materials with a wide variety of properties, which make them ideally suited for micro- and nanosystems with applications in chemical and biochemical analysis. Furthermore, the ability to mass-produce polymer structures inexpensively by microinjection moulding enables the realization of single use devices as required in medical applications.

Berthie Liquid Handling chip

(see picture, right)

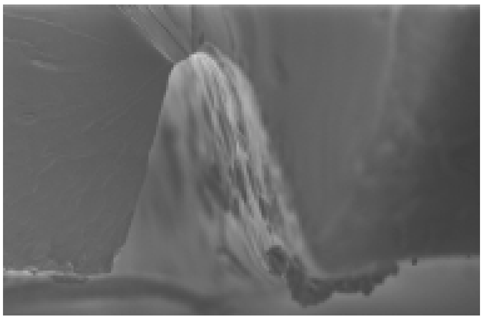
One example of a polymer chip, which was recently designed and fabricated at MIC, is the 'Berthie' microliquid handling chip for the on-line analysis of ammonia in waste water. This project is the continuation of a succesful collaboration with Danfoss A/S and other European partners in a former European project on waste water analysers: MicroChem. For this polymer chip a channel network was fabricated by means of laser ablation on 6 individual sheets of the polymer PMMA. These 6 sheets were thermally bonded to form a cube where sample and reagents were transported, mixed and reacted in three dimensions. During the bonding process other functional elements, such as optical fibers and membranes, can be incorporated into the microfluidic system, thus allowing for optimized optical detection on the one hand and the possibilities of filtering liquids or the connection of actuators for pumping or valving on the other hand. Exploring these possibilities is now just in its beginning phase and leaves room for exciting new discoveries.

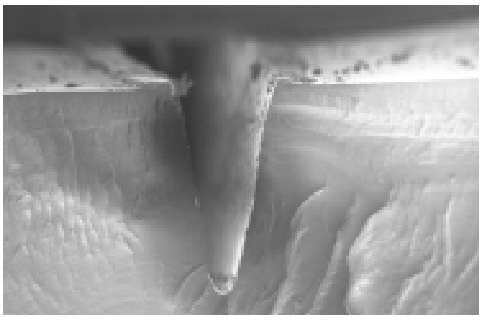


μKAP

Signalling the strong interest from industry for microliquid handling structures in polymers, an extensive collaborative effort was started under the title "Centre for Microsystems for Chemical and Biochemical Analyses Based on Polymers (μKAP)". This centre contract has been established in the summer of 2002 as a research collaboration between the following partners: Radiometer A/S, Danfoss A/S, Nunc A/S, Scandinavian Micro Biodevices (SMB A/S), Vir A/S, Delta, Sensor Technology Centre (STC), Teknologisk Institut, Institut for Produktion og Ledelse (IPL) and MIC. Within the centre methods for the fabrication of micro- and nano-structures in different polymers by micro-milling, laser ablation, hot embossing, and microinjection moulding will be developed. The partners will also investigate bonding methods and surface treatment of polymers. Manufacturers of polymer parts, research institutes, service institutes and end users work closely together in this consortium on several demonstrator projects such as an on-line wastewater sensor, a miniaturized blood analyser and a surface plasmon resonance biochip. Total funding for this project is almost 41 million DKK where industry contributes almost 24 million DKK and the Ministry for Science and Technology provides 16.7 million DKK funding.

For more information please visit the website: mikrokap.teknologisk.dk





Two SEM pictures of laser ablated microfluidic structures

DANCHIP

Establishing DANCHIP (Danish Advanced Nanotechnology Center for Highly Integrated Production) is a national investment in a new cleanroom facility for micro- and nanotechnology, based at the existing process facility shared by MIC and COM.

DANCHIP is a professionally run organization based on knowledge- and cost sharing which form a reliable bridge between education, research and industrial production supporting clusters of new modern industry in Denmark. A staff of service- and maintenance technicians and process engineers maintains the facility and the process equipment.

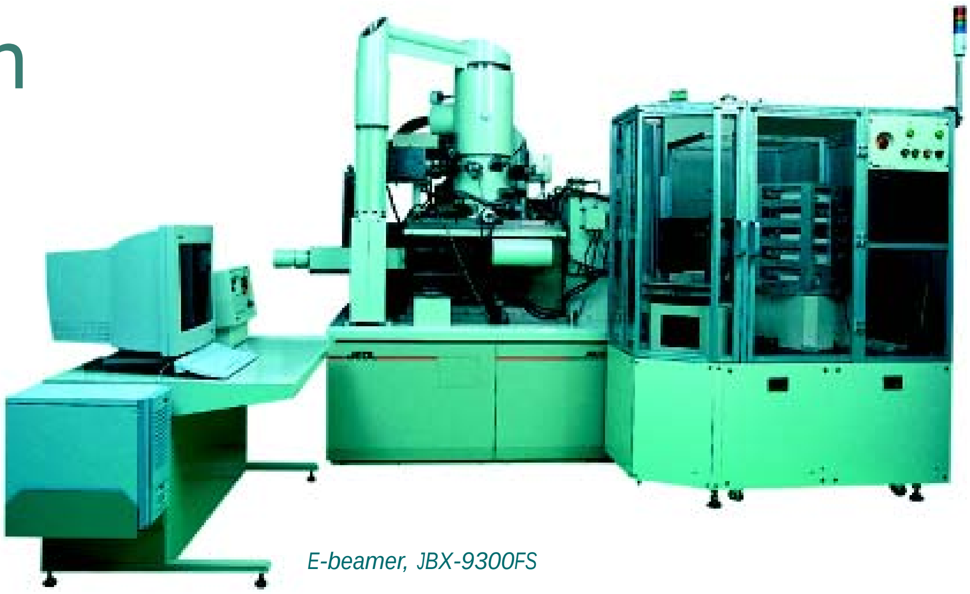
The goal in establishing the new facility is to support world-class research and development within the broad range of micro- and nanotechnologies with state-of-the-art process equipment. The doubling of the cleanroom space will make DANCHIP able to develop process steps, process sequences, as well as components and to have the capability to commercially manufacture these in small quantities. One of the new technological focus areas is nanotechnology where lithography is very crucial. The highlight is the new electron beam lithography system (EBLS) model JBX 9300FS from Jeol with a spot diameter of 4 nm and a minimum feature size of around 10 nm.

The users of DANCHIP will be companies, start-ups, MIC and COM, other departments at DTU, and universities in Denmark and abroad. The users of DANCHIP will get access to advanced equipment for research and development within micro- and nanotechnology. The excellent facilities provided combined with knowledge sharing will enable a fast development of new areas and thus provide a technological lead.

DANCHIP will be the ideal platform for cooperation between companies, MIC, COM and other universities within micro- and nanotechnology.

During 2002 MIC, COM and the industrial partners have conducted the detailed planning of the new facilities. The construction of the new building started in the spring 2002 and will be finished primo 2004.

Equipment in MIC´s cleanroom



E-beamer, JBX-9300FS

Photolithography:

- Süss RC 8 single wafer spinner
- SSI 150 dual track spinner with thick (25 µm) photoresist facility.•
- Electronic Visions AL6-2 doublesided mask aligner.
- SÜSS MA/BA6 doublesided mask aligner.
- STAR 2000 photoresist adhesion primer.

Furnaces:

- Wet and dry oxidation
- LPCVD of doped SiO_2,Si_3N_4, as well as doped polysilicon
- Annealing

Deposition:

- Three STS PECVD cluster systems for depositing SiO_2, PSG, BSG, BPSG, Si_3N_4, and SiO_xN_y with rare earth doping facility.

Evaporation and sputtering:

- Alcatel SCM600 e-gun evaporation and sputter deposition
- Leybold LAB500 e-gun evaporation
- Varian 3180 cassette-to-cassette sputterer
- DCA UHV dual sputterer

Etching:

- Dry etch of Si, SiO_2, and Si_3N_4, by RIE in the STS clusters using F-based plasmas
- Deep anisotropic dry etch of Si by „Advanced Silicon Etch" (ASE™)
- KOH based anisotropic etching
- Deep glass etch
- Isotropic etching
- Plasma Processor 300 barrel asher from Technics Plasma

Ion implantation:

- Varian extrion 200keV cassette-to-cassette ion implanter

Characterisation equipment:

- Leo 1550 Field Emission SEM with EDX (X-ray analysis)
- Atomika Secondary Ion Mass Spectrometer (SIMS)
- Scanning Probe Microscopes (STM, AFM from DME)
- Wolllam Vase Scanning Ellipsometer
- Tencor Profiler

Packaging:

- Dicing
- Wire Bonding
- Solder bump bonding
- Anodic glass bonding (bulk)
- Thin film glass anodic bonding
- Silicon direct bonding
- Polishing

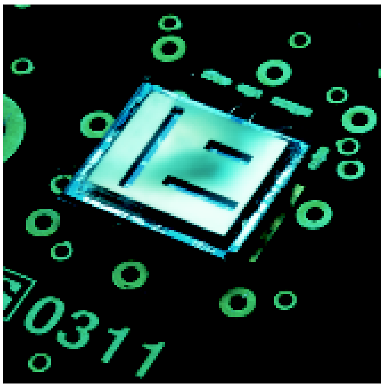
Satellite facts

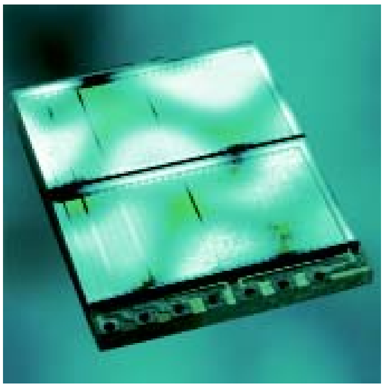
Sun-sensor:

Weight	~3.5 gr. including electronics
Dimensions	7.7 x 8.8 mm (sensor alone)
Field of View.	+/- 70 º
Predicted res.	0.07 º (to be verified)

E-emitter:

Weight:	~2.5 gr ex. elec.
Dimensions	10 x 20 mm
Number of tips	~1.67 millions
Expected current	~1 mA





MEMS in space

In April 2001 a number of students at DTU decided to build a small satellite. They contacted one of the designers of the Danish Ørsted satellite, Prof. Mogens Blanke. By adapting the CubeSat concept originally proposed by Prof. Robert Twiggs of Stanford University, a number of parameters are predetermined i.e. size, mass, and maximum energy consumption. The payload of the satellite consists of a new mechanism to wilfully remove a satellite from orbit by letting an electro dynamic thether interact with the earth's magnetic field. By slowing down the satellite it looses altitude and eventually burns up in the atmosphere.

Small and light

With a size of only 10 cm by 10 cm by 10 cm, ca. 1 Watt power and a total mass of 1 kg the students needed to be very creative in order to make a fully functional satellite. Micro Electro Mechanical Systems (MEMS) solutions present an excellent choice when size, weight and power consumption must be limited. Therefore two of the sub-systems of the satellite the sun sensor and the electron emitter, were MEMS-based.

The sun-sensor (see picture above, left)

A Micro Opto Electro Mechanical System (MOEMS) was chosen to realize a sextant for space applications. The device was developed by two students, Jan Hales and Martin Pedersen, during their midterm project. After this course finished two succesive special courses at MIC provided the possibility to realize the device in MIC's clean room. The sun sensor consists of an optical slit constricting the light and a set of photo-diodes measuring the light intensity. As the angle of the sun varies the current generated by the photodiodes changes as well.By designing the photo diodes with triangular shapes the angle sensitivity can be enhanced. The fully finished sensor was tested and shown to perform according to specifications and accurately measure the sun's angle.

The electron emitter (see picture above, right)

The electron emitter is a crucial part of the payload. The electro-dynamic thether (an aluminium wire) collects electrons in the plasma surrounding the satellite in orbit. In order to keep a current running in the tether electrons need to be emitted from the satellite. To meet the requirements of low power consumption a MEMS based device consisting of millions of gated tips for electron emission was chosen. The device was fabricated with the Atomic Force Microscopy (AFM) tip process developed at MIC. By changing the number of emitting tips the current in the tether can be regulated thereby controlling the electro-dynamic force on the satellite. The students Anders Torp and Philip Ralhan Bidstrup from the Physics Department of the University of Copenhagen designed and fabricated the electron emitter during a special course at MIC.

This project not only demonstrates the excellent advantages of MEMS and MOEMS in applications where size, weight and power consumption are limited, e.g. space applications, but also shows how far initiative, ambition and ingenuity can go. This project has been made possible by financial support from the Danish Space research committee and private industry. The satellite is to be launched into space by the Russian company Eurockot in June 2003.

From the lab to the fab

Three recent examples:

1) Establishment of a MEMS production line

Starting with a Ph.D.project in 1993, SonionMEMS developed its process and design competenc within MEMS technology through national and international research collaborations at MIC.

One of the major hurdles was to transfer this know-how to a production environment. Production facilities and business concepts were still under development and most end users were not aware of this new technology.

SonionMEMS started dedicated collaboration projects with MEMS manufacturing houses in order to establish this expertise, realizing very soon that there was not any one single MEMS manufacturing house or foundry capable of and/or interested in implementing all desired processes.

In a major redesign and concept change, the component was divided into modules, which could be connected to each other by advanced packaging processes without sacrificing automization and standardization. The modular concept added flexibility and the possibility to outsource standard tasks, allowing for a shorter time to market and reduced up-front costs, as well as the utilization of the general technology trends.

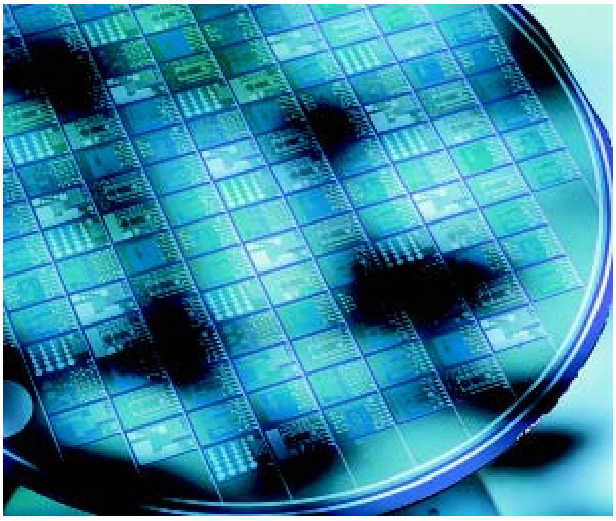
Today, SonionMEMS is constructing a cleanroom facility for an in-house assembly line in Roskilde, which will be used for all backend processing such as dicing, flip-chip assembly, and underfill application – processes, which have been developed and tested within MIC (SUM and PackLab), and which SonionMEMS regards as a new core competence. All front-end processes have been developed at MIC/ DTU and were outsourced to foundries.

SonionMEMS intends to continue its research and development activities at DANCHIP and PackLab, respectively, and hopes to be able to bridge the gap between R&D and production environments by improved process control and uptime of critical equipment at these two facilities.

2) From Research to Industrial Production

Grundfos has been an industrial partner of MIC right from its inception in 1991. This longstanding collaboration has enabled the company to start its own MEMS production of pressure sensors two years ago in a facility based in Farum near Copenhagen. The sensor is based on a traditional design of the element with piezoresistors positioned on an anisotropically etched membrane of silicon. A unique feature of this sensor is its ability to operate in harsh environments due to very corrosion resistant protective coating. The launch of the new production facility has been very successful and the first sensors are now being tested.

The company has also started a follow-up project at MIC on a „multi-sensor for pump control". This new industrial PhD project will involve a new sensor design at MIC, which will be processed at the new DANCHIP facility. The sensors will be packged at the company head quarter in Bjerringbro and evaluated in pumps.



3) SUM *(by Jens Branebjerg,Delta & Erik V. Thomsen, MIC)*

In 2002 the SUM center contract project went into its final year. The SUM project is a collaboration on microsystem development between MIC, the service provider Delta and the Danish companies Capres, Danfoss, Grundfos and SonionMEMS.
The project began in 1999 with an overall goal of bringing microsystems into production. The main results obtained are:

- The partners have built a packaging laboratory (packlab) located in the CAT building next to MIC.
- The partners have established connections to production networks and microsystem devices have been fabricated at foundries using Multi Project Wafer processes and engineering runs.
- MIC has established a prototyping process for fabrication of piezo-resistive devices and a database driven knowledge based process-composing and registration system.
- Delta has built up new services within the field of micro system packaging.
- Capres has realised packaging of micro four-point probes.
- Grundfos is starting up mass production of pressure sensors in Denmark.
- Danfoss has set pressure sensors in field test.
- SonionMEMS has developed packaging for micro mechanical microphones and are setting up mass production in Denmark.

To ensure a highly efficient collaboration with low communication barriers the partners established a set of common values governing the collaboration and defined a vision for the SUM project: "All participants feel and work like a team. We use all available means of communication in a team oriented method of work. Our method of collaboration is widely known and sets an example because it has yielded better results: Professional, practical and commercial". Throughout the project the focus on collaboration helped to fulfil the mission of SUM.

The SUM project has placed high focus on microsystem production and the transfer process between research and production environments. The results obtained from the SUM project has strengthed the position of Denmark within the area of microsystem production. Mass production of MEMS sensors in Denmark is now a reality and the road is paved for newcomers to profit from this pioneering work. *The SUM project was supported by the Ministry for Science and Technology.*

Partners

Brüel and Kjær
Development of high performance accelerometers and microphones

Cantion
Development of cantilever based biosensors

Capres
High-quality systems for accurate electrical characterization of materials on the microscale

Chempaq
Development of new sensor technologies for medical diagnostics

Cohaesio
Advanced software for tracking cleanroom prototyping activities

Danfoss
Development of total chemical analysis systems and industrial sensors

Danish Technological Institute
Polymer-based oxygen sensors

Danish Veterinary and Food Administration
DNA mutation analysis on a chip (Fødevaredirektoratet)

Dantec
Particle image velocimetry and computer simulations

DELTA
Test and packaging of microsystems

DFM
Danish institute for Fundermental Metrologi

Dicon
Microsystems for the graphics industry

DME
Probes for scanning probe microscopy

Exiqon
DNA chip design and fabrication

Foss
Food quality analysis using micromechanical sensors

Grundfos
Development of sensors for water circulation systems

Haldor Topsøe
Catalyst and technology company

Hymite
Optical telecommunications equipment manufacturer: decreasing cost/performance ratio

Ibsen Photonics
Industrialization of holographic elements, phase masks and integrated optical sensors

NKT Research Center
Micro optoelectromechanical systems

Novo Nordisk
Microliquid handling systems for biochemical analysis

NUNC
Collaboration on development of plastic-based microsystems for rapid screening

Oticon
Microtechnology for hearing aid applications

SonionMEMS
Intelligent silicon-based transducers for hearing instruments

Radiometer
Medical instruments manufacturer

SMB
Development and manufacture of biochips

Sophion
Development of equipment for ion-channel high through-put screening of drug candidates for the pharmaceutical industry

Topsil
Fabrication of high-purity silicon crystals and wafer structures

Vir
Prototyping of polymer-based flow cells for surface plasmon resonance (SPR) measurements

CFM
Microinstrument center supporting Ph.D. students, funded by Thomas B. Thrige foundation.

DABIC
National competence center developing advanced instrumentation platform for biotechnology.

EU scientific networks
MIC is part of the European networks NANOFAB (nanofabrication) ATOMS (nanolithography) NanoMass (cantilever-based mass sensor) and Saneme (molecular electronics).

Framework program
MIC is involved in three nationally-funded collaborative framework programmes in nanoscale electrochemistry, micro total analysis systems and silicon wafer bonding.

FREJA
National program for Female Researchers in Joint Action, supporting Bioprobes project.

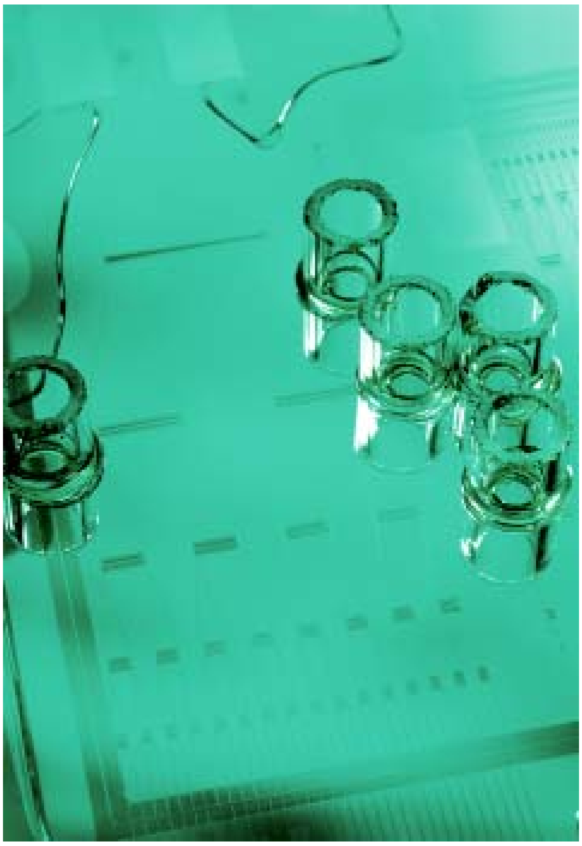
HISTACK
Industrialisation of microsystems, in particular silicon microphones for hearing aids, in collaboration with Danish company Microtronic (EU funded).

IMMUNALYZE
Microsystems for groundwater analysis, in collaboration with biotech company Exiqon and other Danish research institutes.

NORMIC
Network including Norwegian company SensoNor and other other European partners, offering services for prototyping, testing and qualification of microsystems (EU funded).

Rapid Screening
Development of detection for Campylobacteria in poultry, in collaboration with Danish Poultry Meat Association

SeSiBon
Consortium focussed on silicon wafer bonding for sensor encapsulation, including Danish company Danfoss as well as Norwegian firm SensoNor and Finnish firm Okmetic (EU funded)



SUM
Consortium of three Danish companies
and the technology service institute Delta, collaborating on prototype fabrication at MIC

Talent Projects
Four national Talent Projects have been awarded to MIC researchers in molecular electronics, integration of optical detection with microliquid systems, cell sorting, and nanoscale tweezers

µKAP
Mirosystems for chemical and biochemical analyses based on polymers

Theses

26

Ph.D. theses

Jensenius, H. "Microcantilever-based studies of bio/chemical systems" (MIC, Lyngby 2002) 153 pages ISBN: 87-89935-44-6

Mogensen, K. B. "Integration of Planar Waveguides for Optical Detection in Microfabricated Analytical Devices" (MIC, Lyngby 2002) 90 pages

Petersen, N. J. "Electrophoretic Separations on Microchips: Performance and Possibilities" (MIC, Lyngby 2002) 116 pages

Rehder, J. "Micromachined Loudspeaker for Hearing Instrument Application" (MIC, Lyngby 2002) 130 pages

Lisby, T. "Interconnect Substrates in Silicon with Flexible Regions for Multi Chip Microsystems" (MIC, Lyngby 2002) 123 pages

Master theses – co-supervisors from MIC

Alkauskas, A. "Coulomb drag in lateral superlattices" (Vilnius University, Vilnius, Lithuania 2002) Supervisors: **Jauho, A.P.**, Flensberg, K.

Gjelstrup, H. "Strømninger i mikrosystemer" (DTU, Lyngby 2002) Co supervisors: Larsen, P.S., Michelsen, J.A., **Kutter, J.P.**

Master theses

Andersen, L. H. "Soft Magnetic Actuator membranes - Development and Fabrication of a Stepped Membrane" (MIC, Lyngby 2002) 145 pages

Bitsch, L. "Blood flow in micro channels" (MIC, Lyngby 2002) 111 pages ISBN: 87-89935-29-2

Brask, A. "Principles of electroosmotic pumps" (MIC, Lyngby 2002) 156 pages ISBN: 87-89935-31-4

Eriksen, S. C. "DNA detection on cantilever-based sensors" (MIC, Lyngby 2002) 52 pages

Han, A. „Development and Characterization of a colorimetric Microarray Immunoassay for detection of Pesticides in Water" (MIC, Lyngby 2002) 69 pages

Hansen, F. R. "Dispersion in electrokinetically and pressure driven microflows" (MIC, Lyngby 2002) 121 pages ISBN: 87-89935-33-0

He, J. "Micro-controller for Micro-analysis-system" (MIC, Lyngby 2002) 84 pages

Helbo, B. "Micro-Cavity Fluidic Dye Lasers" (MIC, Lyngby 2002) 143 pages

Jensen, M. J. "Bubbles in microchannels" (MIC, Lyngby 2002) 155 pages ISBN: 87-89935-35-7

Johansen, W. J. "Modelling of a MEMS Actuator Array" (MIC, Lyngby 2002) 138 pages

Mateiu, R. "Fabrication and Assembly of Carbon Nanotubes on Microelectrodes" (MIC, Lyngby 2002) 105 pages

Meelby, T. "Miniaturized Polymer-flow-cell for SPR-setup" (MIC, Lyngby 2002) 87 pages

Ruseng, H. "Fremstilling og karakterisering af biokompatible multipunkts prober til måling af ionkanal aktivitet i nerveceller" (MIC, Lyngby 2002) 110 pages

Stangegaard, M. "Qualitative analysis of Campylobacter sp. by use of DNA micro arrays" (MIC, Lyngby 2002) 92 pages

Awards

Nielsen, T. Master thesis stipend from the Oticon Foundation. The award consists of a grant of DKK 100.000 (2002)

Thomsen, E. V. "DTU Teacher of the Year". The DTU Teacher of the Year award is given to a teacher who has showed outstanding performance. The award consists of a grant of 3.600 Euro and a work of art (2002)

Patents

9 Patent discloseres filed with DTU
2 US patent applications filed
1 International patent application (PCT) filed

Journal articles

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Brandbyge, M., Mozos, J. L., Ordejon, P., **Taylor, J.** and **Stokbro, K.**, "Density functional method for nonequilibrium electron transport", Physical Review B **65** pp. 165401-165417 (2002)

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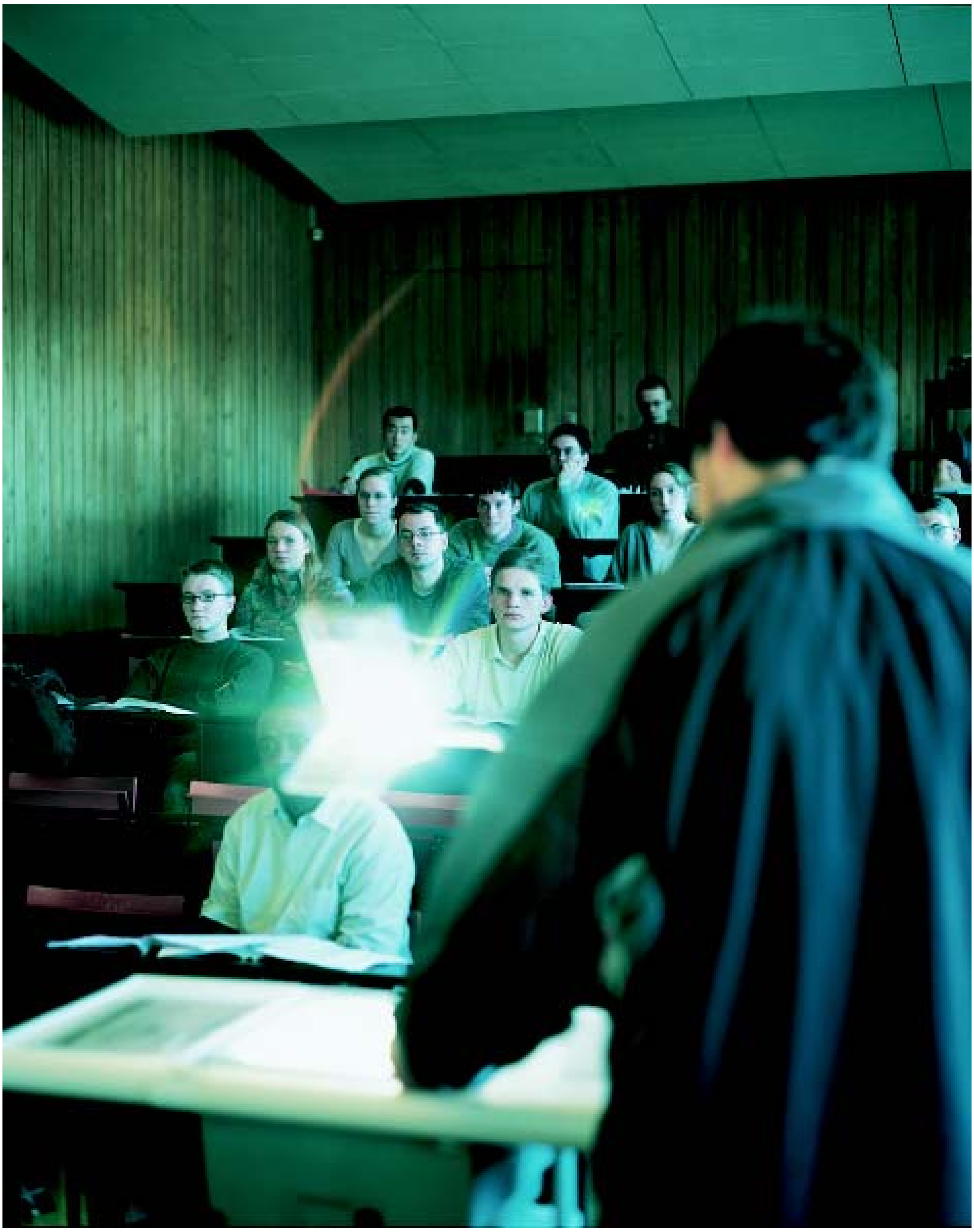

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Mikroelektronik Centret (MIC) at the Technical University of Denmark (DTU), is a national research and development centre for micro- and nanotechnologies.

Within this field, MIC is committed to educating scientists and engineers, conducting research on an internationally competitive level, and transferring new technologies to Danish industry through joint programmes.