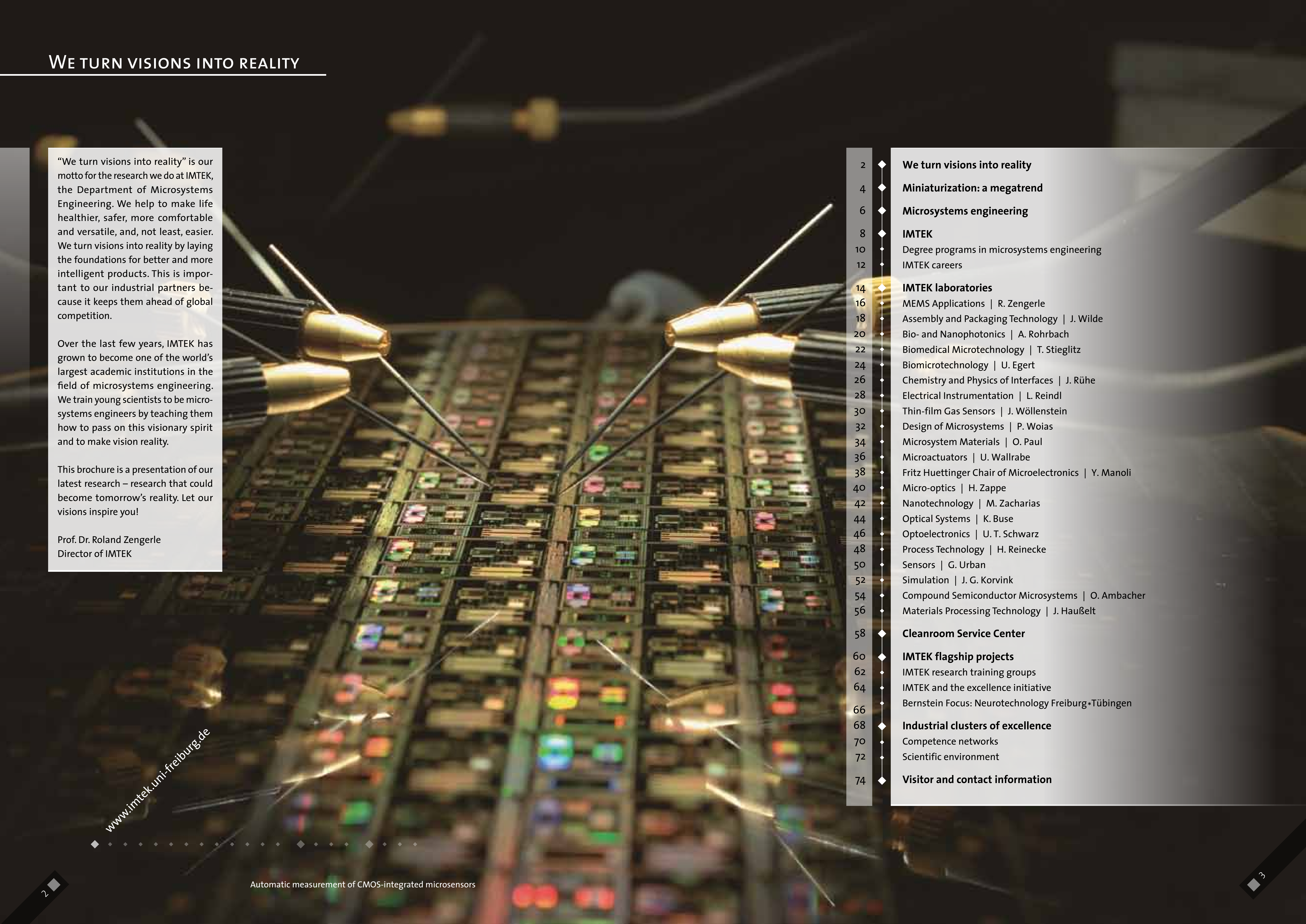
IMTEK

Department of Microsystems Engineering

„Visions become reality“

UNI FREIBURG



"We turn visions into reality" is our motto for the research we do at IMTEK, the Department of Microsystems Engineering. We help to make life healthier, safer, more comfortable and versatile, and, not least, easier. We turn visions into reality by laying the foundations for better and more intelligent products. This is important to our industrial partners because it keeps them ahead of global competition.

Over the last few years, IMTEK has grown to become one of the world's largest academic institutions in the field of microsystems engineering. We train young scientists to be microsystems engineers by teaching them how to pass on this visionary spirit and to make vision reality.

This brochure is a presentation of our latest research – research that could become tomorrow's reality. Let our visions inspire you!

Prof. Dr. Roland Zengerle
Director of IMTEK

www.imtek.uni-freiburg.de

Automatic measurement of CMOS-integrated microsensors

Miniaturization: a megatrend

The products we use in everyday life are becoming smaller, more robust, more intelligent, more networked, and more independent. The sensors and systems inside these everyday objects are often so small that we do not even notice them as users. This is exactly why they are used in most industries today.

Many product specifications in the automotive, medical, computer, telecommunications, and consumer goods industries are no longer conceivable without microsystems engineering. When we play a game on the Wii console from Nintendo, for example, the tiny sensors in the Wii Remote register our every move, no matter how small, and transfer these into realistic movements on the computer.

Sony VAIO P-Series notebook

Source: Sony

Nintendo Wii console

Source: Nintendo

Miss IFA with a LUMIX from Panasonic

Source: Messe Berlin

Portable inkjet printer

Source: Canon

Tire pressure sensor

Source: Bosch

iPhone: the all-in-one phone

Source: Apple

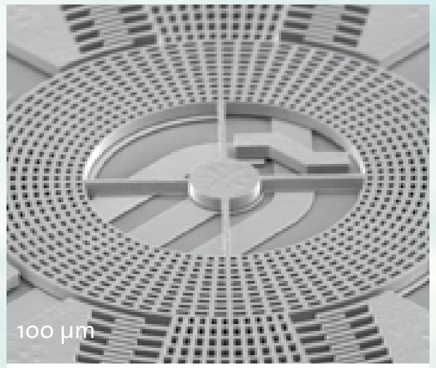
Microsystems engineering: Small technology with huge potential

What is microsystems engineering? We interact with microsystems almost daily – we even have them in our bodies and are not even aware of them. Microsystems engineering is a technology that allows us to build microscopic components that are 100 times finer than a human hair. We use these components to create microsensors and microactuators, which we can combine with electronics to make intelligent microchips that can sense things, make decisions, and perform actions. These components are only a few millimeters in size. They are so small that they are barely noticeable, which is why they can be found in so many devices and in so many industries.

The automotive industry is one of the broadest fields of application for microsystems. Tiny accelerator sensors can detect an impact and trigger an airbag in the event of a collision. Miniature turning-rate sensors can register when a car begins to swerve and help it stay on the road in rainy, snowy, or icy weather. Pressure and flow sensors ensure that an engine is using the right mixture of fuel, thereby reducing the emission of exhaust fumes. Every year, more than 150 million of these sensors are produced by the Bosch company in Reutlingen alone, securing jobs for 2,000 employees.

Microsystems engineering is by no means limited to cars. Acceleration sensors are also used in digital cameras to detect and correct shaking. When we transfer digital photos to a computer, we activate tiny writing and reading heads which save data on the hard drive. When we print photos with an inkjet printer, thousands of microactors shoot miniature drops of ink on the paper with amazing precision and speed. Tens to hundreds of billions of euros are generated in sales all over the world today with classic microsystems engineering products, such as inkjets and writing and reading heads for hard drives and CD, DVD, and Blu-Ray drives.

And the list goes on. In the future, remote controls will contain smarter sensors that register our movements and will therefore become intelligent input devices. We only have to look at the Nintendo Wii gaming console, which is a financial success story thanks to such intelligent sensors. These examples show that microsystems engineering is a vital part of a great number of products across different industries all over the globe. The only limits to realizing its potential seem to be in our imagination. This is how we understand our motto at IMTEK – Department of Microsystems Engineering: We create visions and turn them into tomorrow's reality.



Turning-rate sensor
Source: HSG-IMIT

Automotive industry
Mechanical engineering
Inkjet printing
Communication
Medicine
Pharmaceutical research and biology

"Microsystems engineering – a versatile technology that industries can no longer do without."

Respimat® Soft Mist™ Inhaler
Source: Boehringer Ingelheim microParts GmbH

Source: AUDI AG

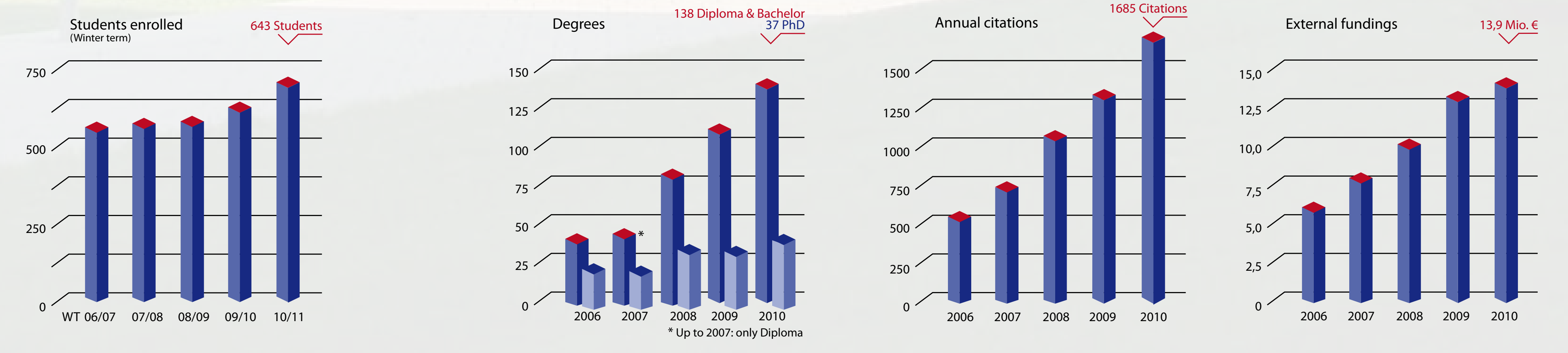
IMTEK

The University of Freiburg was founded in 1457 and has 11 colleges. It was officially named a “University of Excellence” in 2007. The Department of Microsystems Engineering (IMTEK) and the Department of Computer Science are the Faculty of Engineering, which is the youngest of the University’s faculties and was founded in 1995.

Science stands or falls with the people who research, develop, discuss, learn, teach, test, and apply it. IMTEK currently has 21 professors, over 300 research, teaching, and technical staff, and 550 microsystems engineering students. We are one of the world’s largest academic institutions in our field today, and this is reflected in our uniquely broad scope of research and courses.

Microsystems engineering is an interdisciplinary field and not an end in itself. Its relevance comes from the opportunities it creates for other fields, such as engineering sciences, medicine, biology, pharmaceutical research, materials research, and optics. Here at IMTEK, our work is interdisciplinary, and we have years of experience striking new paths with researchers and developers from other fields.

In 2010, we received € 13,9 million in external funding, making us the largest of the University of Freiburg’s 100 departments. We compete with other institutions for third-party research funding. How much funding an institution receives is generally a sign of how successfully its researchers presented projects and ideas to external review committees or sponsors. Because the amount of funding only says something about what goes into our research, we feel it is also important to say something about what comes out of our research. Our output can be measured in the many high-quality scientific publications, patents, innovative products, and successful start-ups coming from IMTEK. Our research publications were cited an estimated 1,700 times in 2010. This means that roughly five scientific publications published every day refer to an IMTEK research publication. With numbers like these, it is easy to see why IMTEK has made a name for itself in Germany and the world.



Degree programs in microsystems engineering

Microsystems engineering is one of engineering's broadest fields. It combines chemistry, physics, mathematics, electrical engineering, and materials science, all of which are also the cornerstones of nanoengineering. Students at IMTEK profit from the practice-oriented courses, the close work with teachers, and the depth and breadth of our degree programs. Regardless of whether they are attending the three-year undergraduate program, the continuing graduate program, or are in a research training group that is part of the postgraduate degree program, students are taught the latest findings which are relevant to research and industry. IMTEK also offers the opportunity to study abroad in Europe, North America, and Asia.

The Bachelor of Science in Microsystems Engineering (courses offered in German) provides students with a solid scientific foundation in chemistry, physics, mathematics, electrical engineering, materials science, and microsystems engineering. Students also gain foundational professional skills, such as project management. This undergraduate degree program is a well-established first step toward a microsystems engineering career.

The Master of Science in Microsystems Engineering (courses taught in German) allows students to continue their microsystems engineering studies at IMTEK. Graduate students pursue their areas of interest in further depth according to their personal preferences and scientific trends.

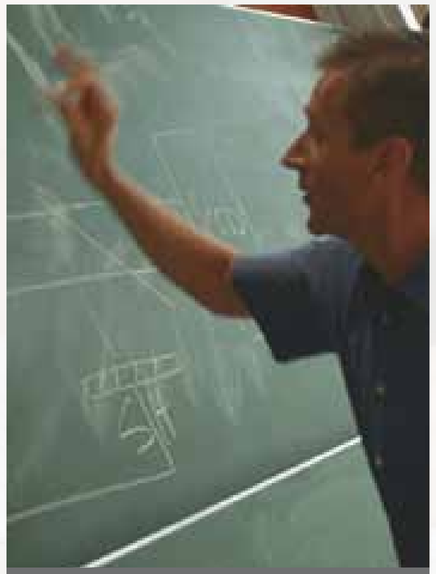
The Master of Science in Microsystems Engineering is also taught as an English-language course that is open to German and international students who do not have a previous degree in microsystems engineering or relevant work experience. This program is designed for students with undergraduate degrees generally in electrical engineering, mechanical engineering, or physics.

The Bachelor of Science in Embedded Systems Engineering (ESE) (courses taught in German) combines microsystems engineering and computer science to give students the training they need for the development of so-called embedded systems, which are intelligent products with virtually invisible integrated computing power.

The Master Online Intelligent Embedded Microsystems master's degree program is a part-time distance learning course designed for working professionals (courses taught in German). It is jointly offered by IMTEK, the Department of Computer Science of the University of Freiburg, and the Baden-Württemberg Cooperative State University in Lörrach. Depending on their previous qualifying degree, students can complete the program in 3 to 7 semesters. The degree program provides the scientific methods and skills needed to develop intelligent embedded microsystems. It is designed for students who have an undergraduate degree in microsystems engineering, computer science, or a related field and at least two years of relevant work experience.

As of the summer term 2010, the University of Freiburg offers the new distance learning program Master Online Photovoltaics in close cooperation with the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg. This innovative blended learning program has been designed to meet the intense demand for highly qualified professionals in the areas of photovoltaic research, development and marketing. It combines an advanced e-learning environment with enjoyable on-site learning courses in Freiburg to ensure maximum benefit for professionals at all levels of management and their companies. For further information, please visit the homepage www.pv-master.com.

For all our programs here at IMTEK, we have state-of-the-art equipment, spacious classrooms, and a high number of laboratories. Most lectures are also recorded by video camera and can be downloaded together with the slides used in class on the internet.



Teaching at IMTEK

Close student-teacher relationship

Prof. Dr. Svetlana Santer

"IMTEK was an important station in my career. It is where I learned how to successfully organize my own research projects and work group and where I completed my teacher training. Learning how to conduct academic research with the goal of generating applications as quickly as possible has helped me to optimize my own science management. IMTEK has a special way of doing things. IMTEK promotes effective, structured, and creative thinking."

Svetlana Santer is a professor at the Institute of Experimental Physics of the University of Potsdam.

After completing her Diplom degree at the University of St. Petersburg, she received her PhD from the University of Ulm. She completed her postdoctoral qualification (Habilitation) at IMTEK Laboratory for Chemistry and Physics of Interfaces on the impact of thin polymer films on nanomotion. In 2009, she was awarded a junior research fellowship at the Freiburg Institute for Advanced Studies (FRIAS).

Prof. Dr. Jens Ducrée

"IMTEK is now one of the major global players in the field of microsystems engineering. Few other institutions have been able to combine a solid education with top international research like IMTEK. I especially enjoyed having the freedom to establish my own lab-on-a-chip research group."

Jens Ducrée is an Associate Professor of Microsystems and Principal Investigator of Microfluidic Platforms at the Biomedical Diagnostics Institute of the Dublin City University in Ireland.

He has a degree in physics and a PhD in new methods of nanostructuring surfaces. In 1999, he worked as a postdoctorate research and teaching assistant at IMTEK's new Laboratory for MEMS Applications, where he also founded the Lab-on-a-Chip research group. After completing his postdoctorate qualification (Habilitation) in microsystems engineering at the University of Freiburg, he joined HSG-IMIT in 2005 before moving to Dublin City University in 2008.

Dipl.-Ing. Sarah Pausch

"IMTEK offered me a very interdisciplinary and multifaceted degree program in a field that is now both in great demand internationally and opens doors within other technical fields. The theory taught in classes was always balanced with internships and research assistant work. The approachability of professors and their close cooperation was an extra bonus for my education."

Sarah Pausch is a project leader in the Tracking Technologies Department of the medical technology company Stryker Navigation in Freiburg.

She already became familiar with the most important companies in her field through her internships as an undergraduate. After completing her Diplom degree at IMTEK, she worked as a postdoctoral research and teaching assistant at HSG-IMIT before completing an internship in the Swedish company XAAR Jet AB in Jarfälla.

Dr. Julian Bartholomeyczik

"IMTEK provided me with an excellent environment to develop my skills. The professors and the research and teaching assistants were always ready to help, and there were wonderful opportunities to take part in interesting projects already as an undergraduate. I now have contact to designers and engineers working in the most important companies in microsystems engineering, because more microsystems engineers are trained here at IMTEK than anywhere else in the world."

Julian Bartholomeyczik is a designing engineer for systems engineering at Bosch Sensortec, a new start-up company that provides sensor expertise for mobile phones and other high-tech devices.

He was a student at IMTEK from 1997 to 2002, after which he received his PhD in advanced CMOS-based stress sensing. From 2005 to 2009, he worked as a designing engineer at Northrop Grumman LITEF GmbH in Freiburg, a company which produces sensors for aviation navigation.

Dr. Sadik Hafizovic

"IMTEK was a great place for me to study for many reasons.
Not only were the teachers excellent, but I had the opportunity to actively participate in research early on. I was also able to take part in international conferences as an undergraduate. I could therefore later build on IMTEK's international reputation and large network when I completed my Diplom degree in Japan and my PhD at ETH in Zurich."

Sadik Hafizovic is a specialist in digital signal processing and CEO of the technology start-up Zurich Instruments, which he also helped found. He still has close contact to IMTEK through his company.

After completing his Diplom undergraduate degree in microsystems engineering in 2002, he completed his PhD at the Physical Electronics Laboratory (PEL) at ETH Zurich, where he also worked as a postdoctorate fellow for two years.

Dr. Stefan Häberle

"IMTEK stands for interdisciplinary high-tech research with an emphasis on real world applications.
As an undergraduate, I was given the opportunity to participate in prestigious groups working on the latest issues of microsystems engineering research. IMTEK has an excellent reputation in the global MEMS community. I am proud to be an IMTEK alumnus!"

Stefan Häberle is a consultant at the Boston Consulting Group in Stuttgart.

After completing an internship in a Swedish company, he acquired his Diplom degree in microsystems engineering in 2004. He was a postgraduate research and teaching assistant at IMTEK's Laboratory for MEMS Applications and HSG-IMIT. He completed his PhD with honors in February 2008. He started working as the leader of the Microdosage Systems group at HSG-IMIT and headed one of IMTEK's lab-on-a-chip groups in 2008.

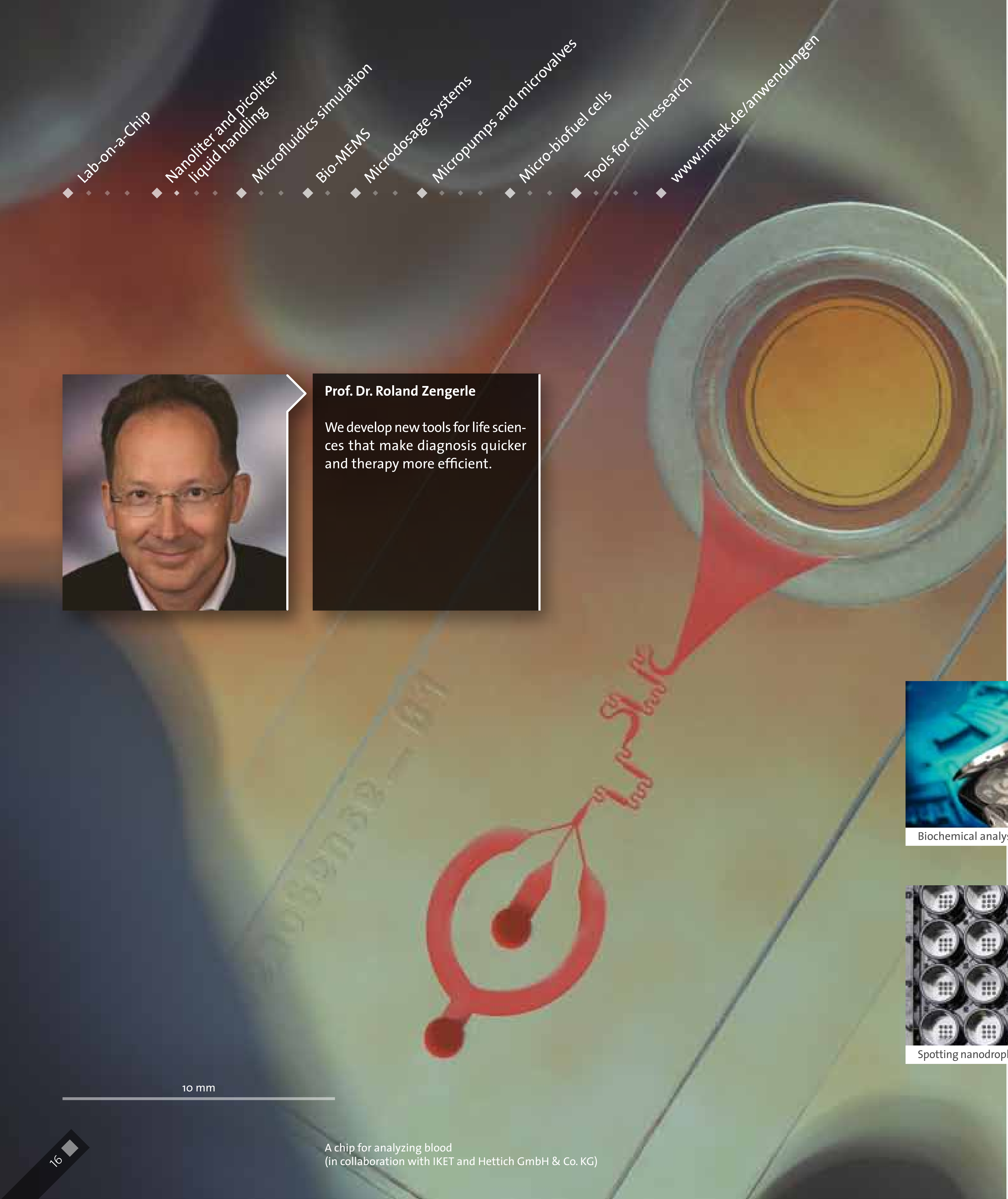
With 21 professors and more than 300 employees, IMTEK has the perfect basis for covering the entire spectrum of microsystems engineering research and education.

On the following pages, we will introduce you to our main areas of research. We hope you find the wide range of themes inspiring. If you would like more information about our projects, please contact us.

"We turn visions into reality"

- MEMS Applications – Prof. Dr. Zengerle
- Assembly and Packaging Technolgy – Prof. Dr. Wilde
- Bio- and Nanophotonics – Prof. Dr. Rohrbach
- Biomedical Microtechnology – Prof. Dr. Stieglitz
- Biomicrotechnology – Prof. Dr. Egert
- Chemistry and Physics of Interfaces – Prof. Dr. Rühe
- Electrical Instrumentation – Prof. Dr. Reindl
- Thin-film Gas Sensors – Prof. Dr. Wöllenstein
- Design of Microsystems – Prof. Dr. Woias
- Microsystem Materials – Prof. Dr. Paul
- Microactuators – Prof. Dr. Wallrabe
- Fritz Huettinger Chair of Microelectronics – Prof. Dr. Manoli
- Micro-optics – Prof. Dr. Zappe
- Nanotechnology – Prof. Dr. Zacharias
- Optical Systems – Prof. Dr. Buse
- Optoelectronics – Prof. Dr. Schwarz
- Process Technology – Prof. Dr. Reinecke
- Sensors – Prof. Dr. Urban
- Simulation – Prof. Dr. Korvink
- Compound Semiconductor Microsystems – Prof. Dr. Ambacher
- Materials Processing Technology – Prof. Dr. Haußelt

Electrode arrays developed by microsystems engineering complement established measuring methods of brain research



Prof. Dr. Roland Zengerle

We develop new tools for life sciences that make diagnosis quicker and therapy more efficient.

A chip for analyzing blood
(in collaboration with IKET and Hettich GmbH & Co. KG)

Laboratory for MEMS Applications

Experts in microfluidics and Bio-MEMS

Our research focus is on microfluidics, meaning the handling of liquids and gases characterized by at least one of the following features:

- Small volumes
- Miniaturized systems
- Minimal energy consumption
- Utilization of effects and phenomena specific for microdimensions, such as capillary forces, laminar flow, controlled diffusion, etc.

In close cooperation with the Institut für Mikro- und Informationstechnik of the Hahn-Schickard-Gesellschaft (HSG-IMIT), we focus on solutions that meet the needs of society as well as the market. Our main areas of operation are:

- **Nanoliter and picoliter liquid handling:** With our contact-free dispensing technologies we can dispense fluids in very small doses with high precision. Our technologies are even able to cope with delicate media such as dissolved particles or living cells and guarantee high throughput. The applications are manifold and range from pharmaceutical research analysis to printing metallic conductors for fabrication of solar cells.

- **Lab-on-a-Chip:** We integrate the entire process of biochemical analysis into chips which are the size of credit cards. A single drop of blood from the patient is enough to conduct a detailed diagnosis that is fast, reliable, and can be done anywhere.

- **Tools for cell research:** We investigate methods for the chemical stimulation of single cells with high spatial and temporal resolution. As a member of the Cluster of Excellence BIOSS Centre for Biological Signalling Studies, funded by the German Research Foundation (DFG), we are currently developing a platform for analyzing enzymatic activity easily and at low cost. This platform will take the knowledge of biochemical processes and pathways within cells a major step forward.

- **Bio-MEMS:** We build dosage systems that emit medication at precisely defined times. The systems are pain-free because the medication is dispensed via microneedles or implants.

- **Biofuel cells:** Biofuel cells extract the energy for operating medical implants from blood sugar, rendering surgical operations for recharging power sources unnecessary. Biofuel cells are simply applied as an additional coating on implants such as cardiac pacemakers.

- **Direct methanol fuel cells (DMFCs):** Our DMFCs are purely passive, easy to handle, and enable the reliable operation of devices such as mobile phones, notebooks, and emergency diagnostic testing devices. There is no need for an additional power supply system. We develop our DMFCs together with our partner, the Fraunhofer Institute for Solar Energy Systems ISE.

Biochemical analysis in a CD player

Spotting nanodroplets into microwell plates

Laboratory for Assembly and Packaging Technology

Experts in reliable microsystems

Assembly and packaging technology (A&P) focuses on the integration of microchips into complex multifunctional systems. Maximum reliability and life span are two of our most important criteria. We also strive to achieve a miniaturized design without impairing the performance of microsystems. In A&P, it is imperative to develop modern fabrication technologies that save costs, materials, and resources.

Simulation is an efficient technique for fulfilling this complex task at the design stage. Unfortunately, in many cases, the fundamental data for a physical modeling are not available, for example materials properties or degradation data. In other cases, the data for verifying simulations are available only if highly-sophisticated analysis techniques are used. The focus of our research is on generating basic data and physical models which are fundamental for the development of improved technologies.

◆ Sensors: The accuracy and long-term stability of MEMS sensors are limited in many cases by mechanical stresses which are induced by their integration into a complete system. The operational conditions can also have considerable detrimental effects on the precision of MEMS because of cross-sensitivities. In our laboratory, we explore the application of simulation methods for hardware-based functional analysis. Our goal is to develop simulation methods which can be used to predict the effect of A&P on the performance and robustness of sensors.

◆ Green electronics: In the future, electronic systems will have to be manufactured from environmentally friendly, non-hazardous materials. In several of our projects, we investigate various options for eliminating lead from solder materials for electronic assemblies without compromising their reliability. We rely on testing and analysis as essential tools for this purpose. Specific physics of failure concepts require a materials characterization as a basis for reliability prognoses utilising simulations. One of the most promising technologies for producing "green" microsystems is adhesive bonding using electrically conductive materials.

◆ Mechatronics is microsystems technology on a large scale. Our activities in this field are primarily focused on power electronics, which deal with high power, large currents, and elevated temperatures. We develop cost-efficient, robust systems which are suitable for mass applications, such as electro-vehicles or photovoltaic systems. We do research on novel materials and processes, for example bonding wires made of novel composite materials, new metallization schemes for high-current power substrates, and new housing technologies.

◆ Design for reliability: Our key tools are models we develop to predict failure probability and lifetime of components and assemblies. Knowledge of the applications' real operating conditions and stress factors is therefore indispensable. For such analyses IMTEK has developed stress sensors which are applied in situ in the manufacturing and during the operation phase for the condition monitoring of technical systems.

Prof. Dr. Jürgen Wilde

We investigate the failure mechanism of microsystems and improve the life span and reliability of electronic systems.

Press-fit interconnections

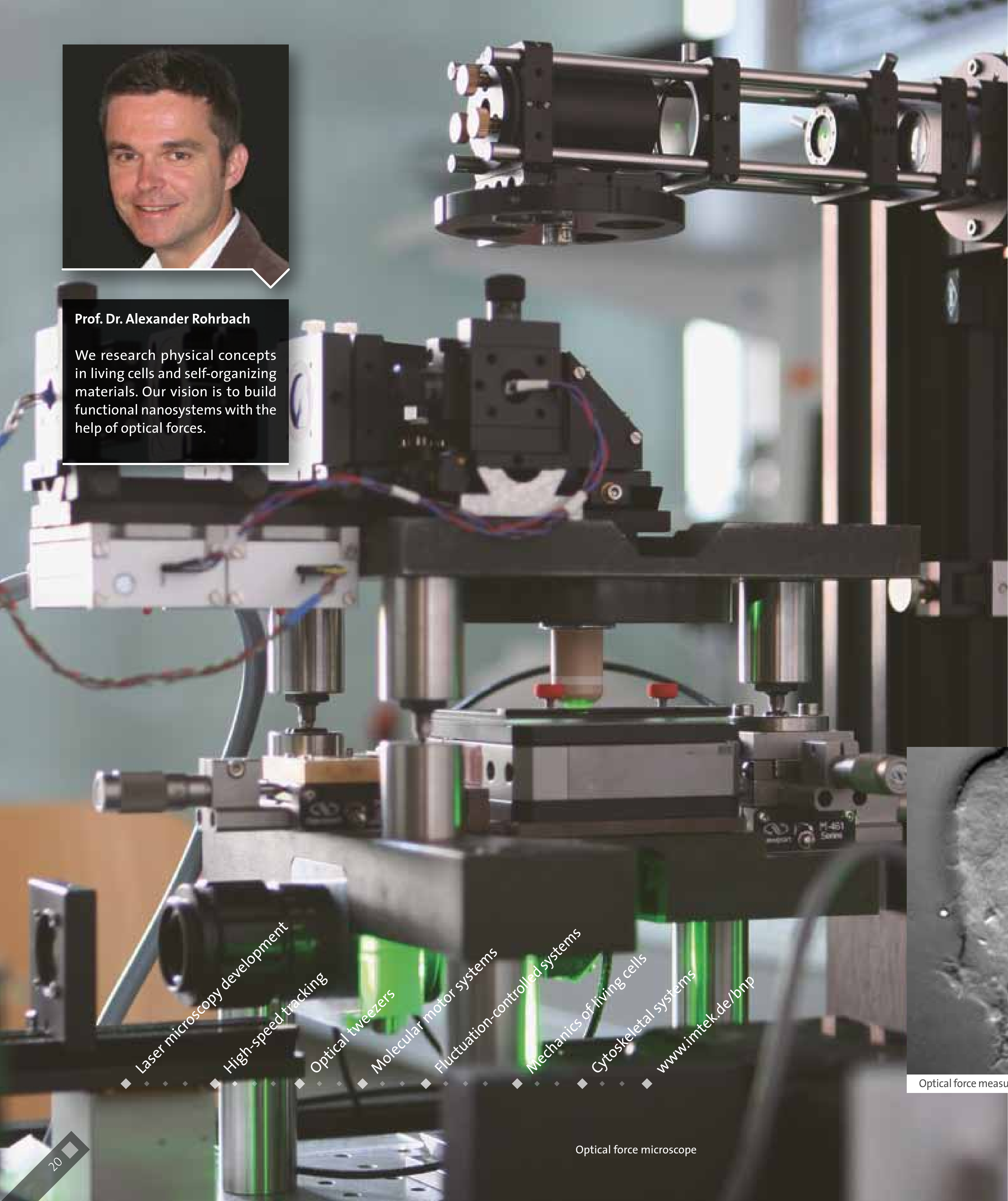
Design for reliability
Influence of A&P on sensor performance
Environmental conditions
Robust electronic hardware for harsh environments
Green microsystems
www.imtek.de/avt

Press-fit interconnections: both the simultaneous fixture of and electrical interconnection between components on circuit carriers

Laboratory for Bio- and Nanophotonics

Prof. Dr. Alexander Rohrbach

We research physical concepts in living cells and self-organizing materials. Our vision is to build functional nanosystems with the help of optical forces.



Optical force microscope

Our goal is to understand the structure, dynamics, and mechanics of cells and biomaterials on the scale of the wavelength of light and below. We investigate measuring and manipulating techniques, such as

- New laser scanning microscopy methods for optimizing the interaction between light and matter
- Optical tweezers, including 3-D particle tracking at microsecond-rate with nanometer precision
- Computer controlled holographic illumination systems

We use these methods to investigate

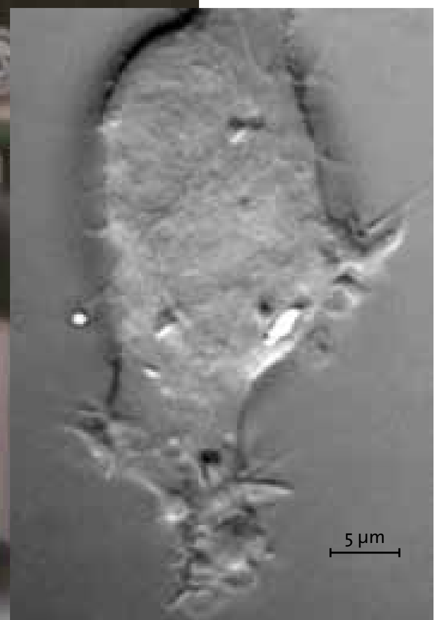
- Thermally fluctuating systems and phenomena in soft materials (cells and complex liquids)
- The nanomechanics of molecular motors and the cytoskeleton

Our basic physical research serves as a platform for developing new technologies for the following fields of application.

- **High-resolution microscopy** for researching versatile cell, polymer, and surface structures: We improve optical resolution and contrast of 3-D images through intelligent combinations of diffraction-limited illumination of very small structures (0.1 – 1 µm) and light scattered at the object to be studied. Light carrying relevant object information is distinguished from light carrying no or wrong information.

- **Measuring and structuring nanotechnology:** How do you build something that is so small that you cannot even see it under a microscope? Using laser optical tweezers (optical traps), we try to assemble very small structures of spherical or rod-shaped building blocks. These are smaller than 0.1 µm and are typically metals or semi-conductors, meaning they have multiple functional properties. We utilize new measuring techniques, such as optically trapped and guided probes or holographic interference, to optically measure and "see" the assembled systems quickly and precisely.

- **Biophysics and biotechnology:** Processes occurring in cells or at their membranes are not only determined by biochemical laws, but also by purely physical laws which regulate reaction kinetics or cell mechanics through diffusion, fluctuation, and molecular motors. This affects the generation and propagation of cellular signals and is one of the subjects of research in the Excellence Cluster BIOSS Centre for Biological Signalling Studies. The fluctuation-controlled absorption of bacteria, viruses, and drugs through still unknown diffusion properties of nearby cell membranes plays an important role in medicine and pharmaceutical research. We strive to understand these physical laws by investigating isolated cellular subsystems to find out how they react to specific changes in their environmental conditions.



Optical force measurement on a scavenger cell

Laboratory for Biomedical Microtechnology

Experts in neurotechnical interfaces

Our expertise is the research area of neural prostheses. We focus on interfacing technical systems with the central or peripheral nervous system to record bioelectrical signals or to electrically stimulate nerves. We are specialists in the following aspects of the development of so-called brain-machine interfaces:

- Development of flexible implantable electrode arrays
- Computer-aided manufacturing of electrode arrays according to patient data in compliance with relevant directives (ISO 13485)
- Biocompatible assembling and packaging
- System development of miniaturized implants

Together with our neuroscientific and clinical partners, we develop the following application-specific solutions ranging from design concepts to clinical trials in humans:

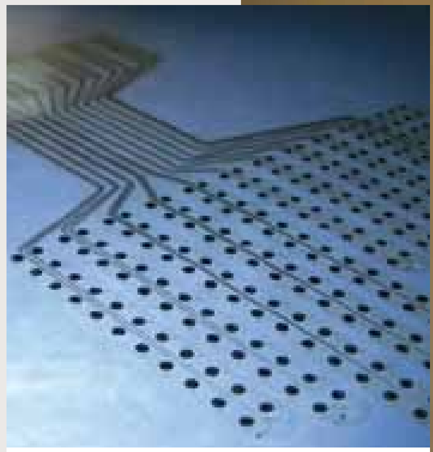
- Micromachined electrode arrays for the neurosciences made of thin, flexible materials enable the recording of local field potentials and electrocorticograms. We have developed a 15 micrometer thick foil made of polyimide with 252 electrode sites and a surface area of 35 x 60 mm² that covers a large portion of one hemisphere of the brain.

- Epilepsy monitoring and brain-computer interfaces: We develop high-resolution electrode arrays for monitoring and stimulation in clinical studies.

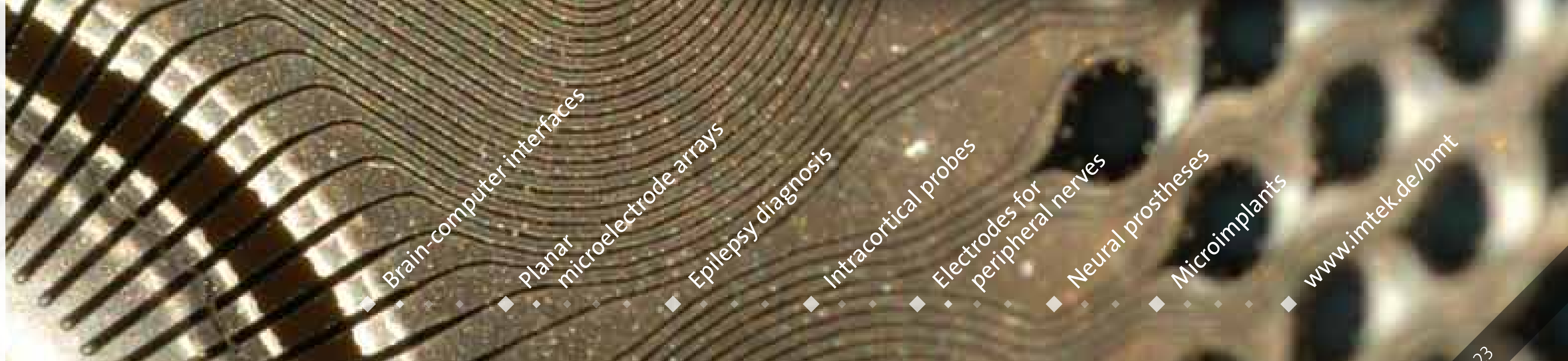
- Flexible intracortical probes: We explore the use of highly flexible probes to measure neural activity inside the brain. These match the mechanical properties of brain tissue better than conventional stiff probes. We develop appropriate implantation tools as well as integrated cables and connectors to interface with established electrophysiological measurement systems.

- Electrodes for peripheral nerves: We develop bidirectional interfaces to record electroneurograms and electrically stimulate peripheral nerves. We select the best device based on the level of invasiveness. Devices range from multipolar cuff, to interfascicular, and sieve electrodes. Our expertise in recording and stimulation paradigms enables us to incorporate spatial and fiber selectivity requirements into the design process already during interface development.

- Packaging and encapsulation of microimplants: The packaging of implants requires the application of various materials and technologies. Our developments in the area of hermetic and non-hermetic packaging aim at minimizing device volume and material-tissue reactions.


Micromachined electrode array


Microflex stud ball bond assembly



Laser-structured implantable micro electrode array

Prof. Dr. Thomas Stieglitz

We explore the coupling of technical systems with the central and peripheral nervous system. Our vision is the restoration of lost body functions and the development of novel diagnostics for neurological disorders and trauma.

Laboratory for Biomicrotechnology

Our research investigates the foundations of the patterns of activity in neuronal networks, their role in diseases of the nervous system as well as in their treatment. A range of techniques is used to explore these patterns, primarily new microelectrode arrays and optical methods to monitor the activity of nerve cells at high spatial and temporal resolution. In the course of this, we further develop neurotechnological tools to interact with neuronal networks and modulate their activity. We compare the properties of these networks with those of computational model networks to help interpret our observations. Our research contributes to the development of new microsystems tools for neurotechnological, biomedical, clinical, and pharmaceutical research.

Within the Bernstein Center for Computational Neuroscience Freiburg and the Bernstein Focus: Neurotechnology Freiburg • Tübingen – Hybrid Brain we investigate various topics in the following fields of research:

◆ We combine single neuron with simultaneous network analysis to explore how individual neurons are embedded in their networks and how they contribute to the networks activity. This is important, for example, to understand how newborn neurons are integrated into the existing networks of the brain.

◆ How does the architecture and composition of a biological network contribute to its function? We build networks with predefined structures, using, e.g., micropatterned chemical surfaces to analyze the relation between structure and function in the nervous system. We investigate how the architecture of neuronal networks influences their capacity to store and process information.

◆ The ever-changing activity of neuronal networks continuously modifies the properties of individual cells. The transfer of results from laboratory studies in vitro to the intact organism must take this into account. We develop new tools to measure and analyze electrical activity, for example to improve the predictive power of pharmaceutical drug discovery studies and to reduce the extent of animal experimentation needed.

◆ Neuroprostheses require an interface between biological and technical materials and components. To develop such devices, we need to understand this link across several levels of complexity and spatial and temporal resolution. We analyze the interaction of artificial stimuli with the spatio-temporal structure of network activity to induce desired network dynamics and interfere with undesirable patterns of activity. In the long run, this has the potential to contribute to techniques used to prevent or interrupt pathological neuronal activity, for example during an epileptic seizure.

◆ New devices developed by microsystems engineers are used to perform the measurements and analyses regularly needed for our biomedical research. In exchange, our research is a test environment for the optimization of individual components. Core elements of our research are the identification of new areas of application, the definition of desired product specifications, and the testing of prototypes. We collaborate closely with academic and industrial partners to optimize new technical solutions for biomedical applications and the development of applications into products.

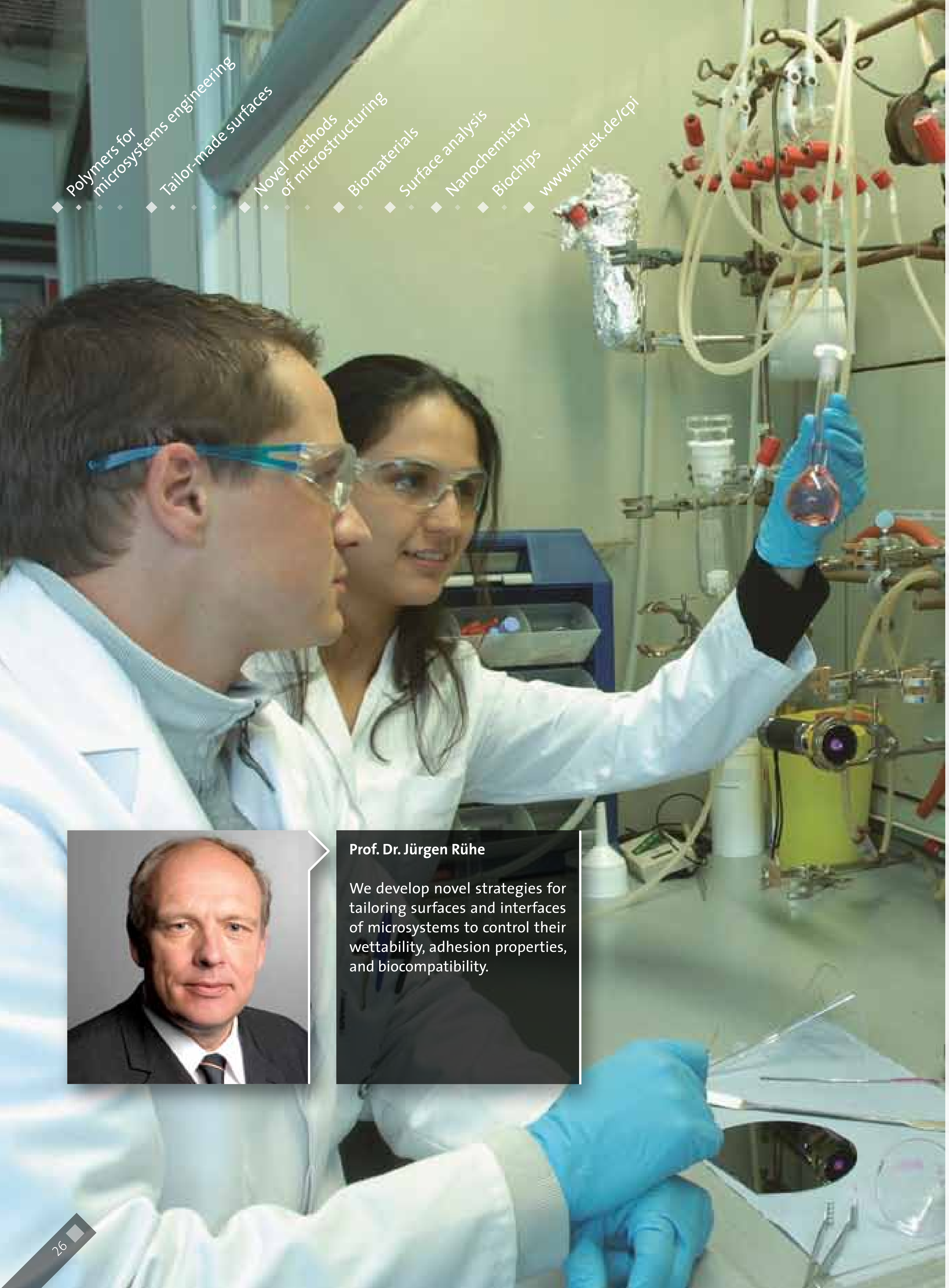
Electrophysiological measuring station

Prof. Dr. Ulrich Egert

We develop neurotechnological tools to analyze and interact with activity patterns in neuronal networks. These tools allow us to better investigate fundamental properties of nervous systems and their dysfunction.

Neuronal networks
Neurotechnological interfaces
Feedback systems
Microelectrode arrays
Electrophysiology
www.imtek.de/biomikrotechnik

Nerve cells connecting into networks through synapses (green)



Prof. Dr. Jürgen Rühe

We develop novel strategies for tailoring surfaces and interfaces of microsystems to control their wettability, adhesion properties, and biocompatibility.

Laboratory for the Chemistry and Physics of Interfaces

The interaction of materials with their environment is largely dominated by only a few layers of molecules on the surface. The influence of surfaces and interfaces on the performance of systems increases dramatically the more miniaturized these systems are. We develop chemical strategies for tailoring surfaces, enabling the necessary precise control of interfacial parameters. We frequently use polymer layers for this purpose; usually a film only a few nanometers thick is sufficient to completely hide the properties of the underlying substrates. For many applications, it is of utmost importance to chemically anchor the polymer molecules to the surface to ensure that the layers are sufficiently stable.

◆ Synthesis of covalently attached polymer layers: We develop novel synthetic strategies for the generation of covalently attached polymer layers. In some cases we use monolayers of polymerization initiators to grow a "lawn" of macromolecules on the surface. This creates so-called polymer brushes which show interesting physical properties and interact with (bio)molecules in very special ways. Details often depend on the precise architecture of the layers. Other systems utilize photochemical or thermal methods to generate surface-attached polymer networks. Such systems are especially interesting if they swell in aqueous environments (hydrogels).

◆ Micro- and nanostructuring of surfaces is made possible through photolithography, microprinting, and other novel techniques.

◆ Surfaces with controlled wetting properties: We combine polymeric layers with methods of microengineering to create a surface with precisely controlled wetting properties that can be set anywhere from superhydrophilic to ultrahydrophobic. Such systems allow us to conduct a detailed investigation of the physicochemical influences on the wetting of micro- and nanosystems.

◆ Controlling the adhesion of cells on surfaces: We use microstructured polymer coatings to influence the interaction between materials and biological cells and materials and to determine which surface areas cells should adhere to and which they should not. Such systems are important for our projects exploring biofouling resistant surfaces, chip systems for researching neuronal networks, and methods for highly parallelized electrophysiological cell experiments.

◆ DNA and protein analysis using biochips: The quantitative analysis of DNA sequences or proteins in small chip devices is a well developed field of research today. Our systems use surface-attached hydrogels as carriers for probe molecules. This architecture presents the probes in a more three-dimensional, skyscraper-like way which is easier for analyte molecules to access. These arrays are often characterized by a large increase in sensitivity and reliability, thus paving the way for routine clinical use as currently shown in relevant studies.

Drop of water on an ultrahydrophobic surface

Neuronal cells on a structured surface

Laboratory for Electrical Instrumentation

Experts in autonomous microsystems

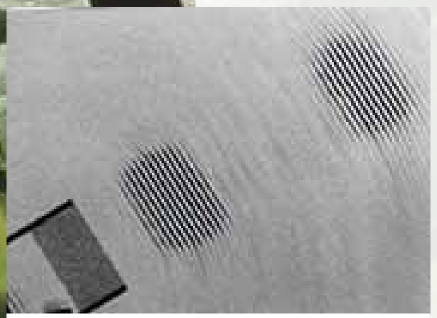
Our aim is to develop the measurement technology of the future. Our expertise includes energy harvesting solutions for the autonomous power supply of sensor networks, wireless readouts of microacoustic sensors, and computers embedded in technical systems for their monitoring and control. We develop new methods and technologies to provide fail-safe systems, particularly for civil protection in cases of disaster.

◆ Energy-autonomous embedded wireless microsystems: The decentralization of data acquisition will continue to become more important in the future. Examples range from environmental monitoring to data acquisition for the efficient administration and management of buildings, installations, and equipment. There are still unresolved issues, however, including the energy supply of sensor nodes and the efficient communication between the nodes and control systems. We focus on wireless energy transmission for the power supply, modeling, and characterization of new energy harvesting converters. We also develop communication protocols and topologies for complex sensor and actuator networks.

◆ Microacoustic sensors: How can we measure the weight of a small group of molecules adhered to a surface? The resonant frequency of microacoustic sensors changes with the deposition of molecules and can be detected very accurately. We develop tools for the simulation and design of surface acoustic wave components and the identification of model parameters for this sensor application. We also investigate sensitive layers and design film bulk acoustic resonator devices.

◆ Safety and rescue: A variety of microsystems applications are possible within this field. We develop systems for delivering important information in case of disaster and systems for aiding the rapid rescue and recovery of buried victims. Regarding prevention, we also develop sensor networks for critical infrastructures, such as tunnels and skyscrapers. When disaster has struck, the robots we have developed can explore and recognize their environment intelligently, and our systems can locate people buried under rubble. Inertial sensors, GSM, and radar- and laser-based position systems can also be used for localization.

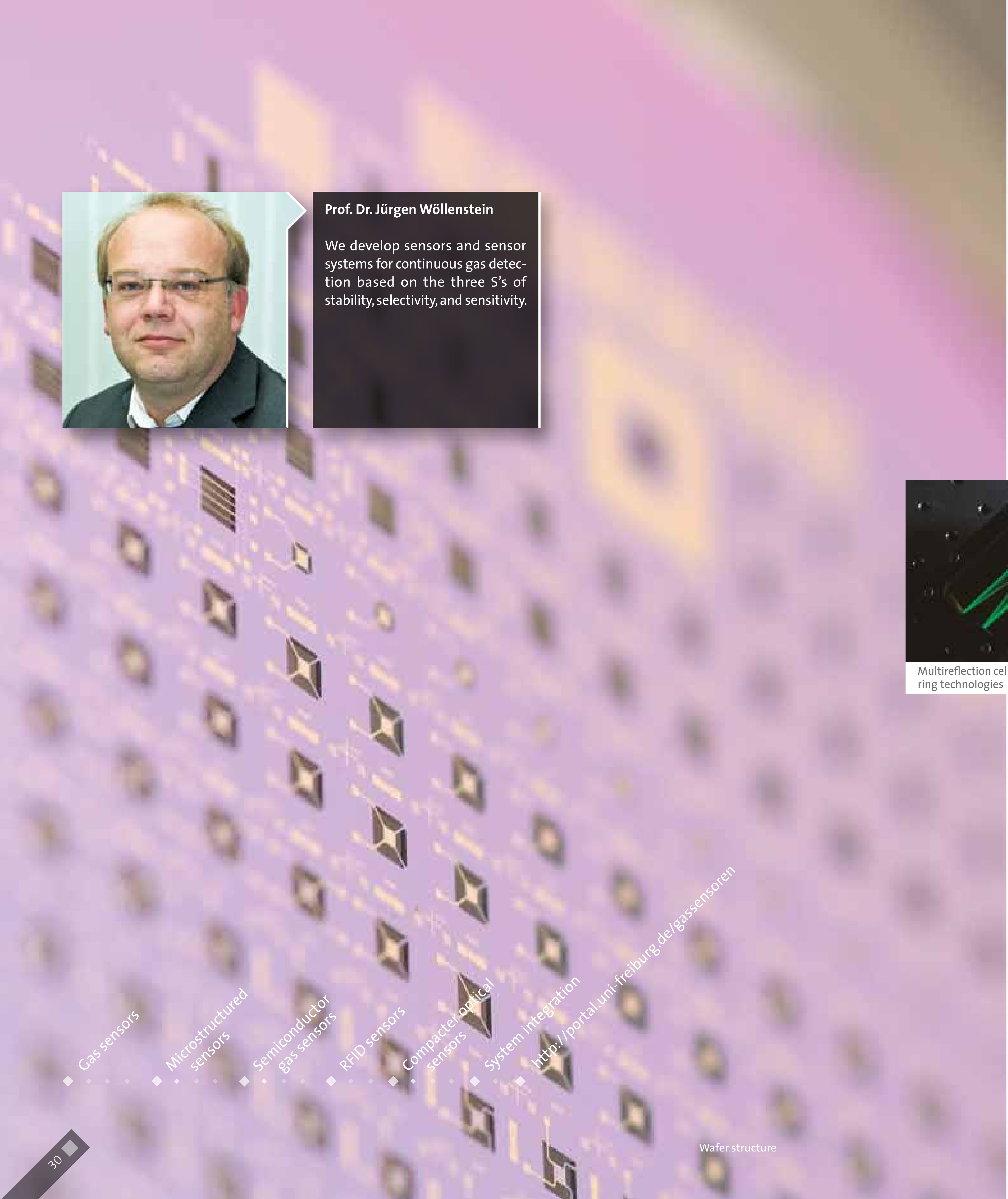

Searching for buried victims using radar detection (Cologne City Archives)


Visualized surface wave

Wireless nodes

Prof. Dr. Leo Reindl

Perceiving the environment may be a common task for human beings, but it is a challenge for electrical machines. We research new technologies and methods for machines to be able to understand their environment and act autonomously.



Prof. Dr. Jürgen Wöllenstein

We develop sensors and sensor systems for continuous gas detection based on the three S's of stability, selectivity, and sensitivity.

Gas sensors

Microstructured sensors

Semiconductor gas sensors

RFID sensors

Compacter optical sensors

System integration

http://portal.uni-freiburg.de/gassensoren

Wafer structure

Laboratory for Thin-Film Gas Sensors

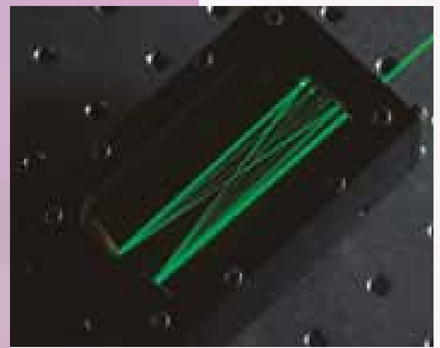
Experts in gas measurement techniques

We utilize a broad range of methods of gas detection to develop tailored gas sensors that can be integrated in complex microsystems. We especially focus on the development of low-cost sensor principles with low-power consumption to be integrated into RFID tags for wireless readouts.

In close cooperation with the Fraunhofer Institute for Physical Measurement Techniques IPM, we focus our research on the following applications:

- **Semiconductor gas sensors:** We develop gas-sensitive films based on nanoscale, semiconducting metal oxides based on the three S's of stability, selectivity, and sensitivity.

- **Optical gas sensors:** The composition of gas mixtures can be reliably determined by their spectral transmission. One possible low-cost solution for this is to use filter photometers. The wavelength range between 8µm and 12µm is of special importance because this is where "characteristic fingerprints" of many gases can be found. We develop IR sources for this spectral range.

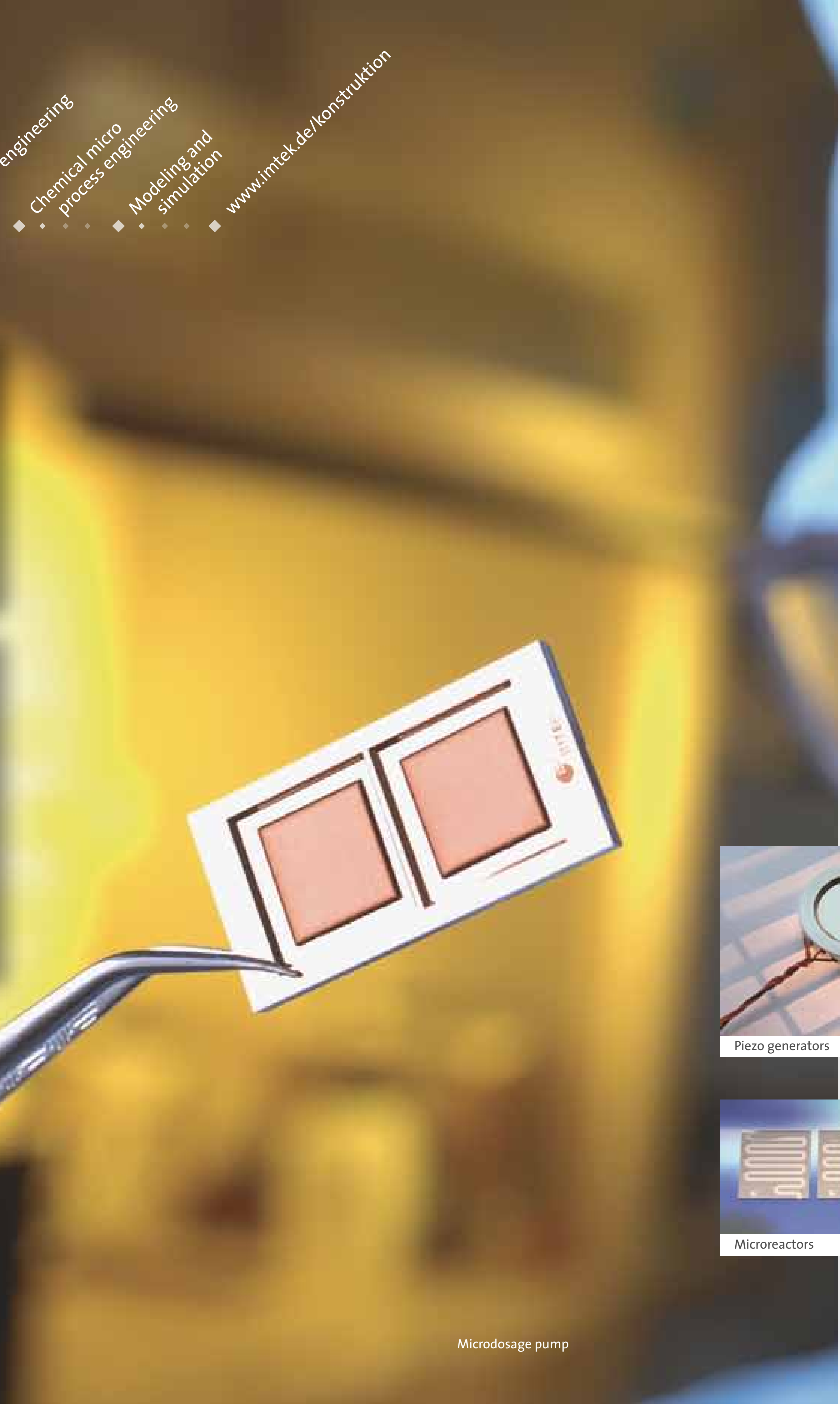


Multireflection cell for optical gas measuring technologies

- **Low-cost gas chromatography:** Gas chromatography allows us to separate gas mixtures into their constituents. The detection limit for volatile organic compounds lies in the ppm to ppb range. We apply this method to the continuous monitoring of processes in the food industry. For sensors, we use specially designed gas sensor arrays that detect all gases simultaneously while also determining non-separable gases by their characteristic fingerprint.

- **Colorimetric materials for gas detection:** Gases can also be detected through a colorimetric change of pH indicators. We develop colorimetric polymers for application on a waveguide substrate and in evanescent field detection. If a color change takes place, it can be read out using simple optical sensors.

- **Wireless sensors (RFID):** We integrate sensors on RFID labels to open up the possibility for tracking and tracing logistic chains, for example in pharmaceutical, automotive, or air-freight applications. RFID technology poses high demands on sensors: they must be very small, flexible, and require very little energy. We have developed sensors for humidity, light, temperature, and integrity.



Microdosage pump

Prof. Dr. Peter Woias

Nature has created energy-autonomous biological microsystems with superior properties by combining materials in the micro and nano range with highly efficient principles for sensing, actuation, and energy supply. This inspires us to develop highly efficient technological microsystems which can produce their own energy and to work with sophisticated materials and concepts for sensors and actuators.

Laboratory for The Design of Microsystems

Experts in design engineering of microsystems

Biological microsystems are energy-autonomous. They use highly efficient, closely interwoven physical and chemical principles of sensing, actuation, and signal processing. Many of these effects are the result of a combination of micro- and nanostructured materials. We use this as a source of inspiration for innovative design in the fields of micromechanics and microfluidics.

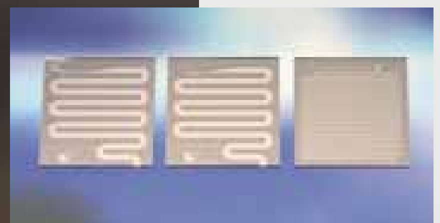
Our application areas include micro energy technologies, medical engineering, and chemical microprocess engineering.

◆ Micro energy harvesting: Small amounts of energy can be directly harvested from the environment with the help of special microgenerators, enabling us to operate distributed embedded systems carrying sensors, actuators, and electronic components. This new idea enables distributed embedded microsystems to function without cables or batteries. The harvested energy is collected in a storage device and supplied through an intelligent energy management, ensuring that the system does its job reliably. We work with piezoelectric generators that harvest energy from the vibrations or sound of motorized vehicles or machines, or within tunnels. We also develop thermoelectric generators and micro heat engines that harvest energy from the temperature gradients present at combustion-type or electric engines, within the walls of buildings, or within manufacturing processes. These concepts help to generate energy for sensor systems in building services engineering, engine control, and biomedicine.

◆ Medical engineering: We develop micromechanical and microfluidic systems for medical implants. These include peristaltic micro pumps for treating urinary incontinence with an implantable, hydraulic muscle. We also develop high precision microdosage pumps for medications and implantable strain gauges for continuous pulse and blood pressure measurement. The scope of our research ranges from innovative concepts and designs to the realization and application of complete systems. In the process, we have gained many years of experience with microsensors and actuators as well as with power-efficient electronics and optimized manufacturing technologies.

◆ Micro process engineering: We take the advantages of microfluidics and microsystems engineering, such as minimal interior volumes, high heat conductivity, and brief mixing times, and combine them to design specific micromixers and reactors. This has a promising outlook for the chemical synthesis of new materials.
Our research includes convective micromixers with short mixing times and a high flow rate, nanoparticle manufacturing through precipitation in microreactors, and multiple phase systems for high exothermic direct fluorination reactions.


Piezo generators


Microreactors

Laboratory for Microsystem Materials

Experts in IC-compatible microsystems engineering

We excel in silicon microsystems engineering, especially in CMOS-based microsensors.

We are experts in
- CMOS-based smart microsystems
- Microstructured needles and cannulas for intracortical, transdermal, and intracellular measurements
- Microsensors for mechanical and magnetic parameters
- Automated determination of material properties of micromaterials

- **Mechanical microsensor systems:** With our innovative piezoresistive sensors produced using CMOS technology, we are able to measure mechanical stress components in all spatial directions with unprecedented resolution. We apply this method to the tactile detection of three-dimensional surfaces, the measurement of forces and torques, and the detection of stress distributions in packaged microchips.

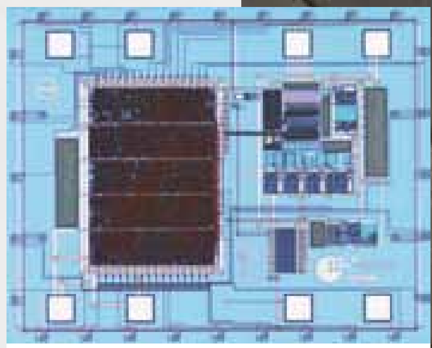
- **Non-mechanical physical microsensor systems:** We use vertical CMOS Hall plates to measure the magnitude and orientation of magnetic fields in the chip plane. We also combine silicon structures with selected materials, such as electrets and amorphous magnetic layers, to develop, for example, vibrating microsystems that can harvest energy from their environment or measure magnetic fields. In addition to these developments, we perform fundamental research for measuring the galvanomagnetic transport properties of thin films.

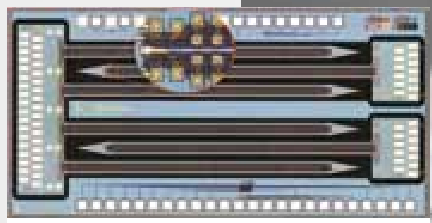
- **Probes for the life sciences:** We develop minimally invasive needle arrays with electric, fluidic, and electrochemical functionality for the following areas of application:

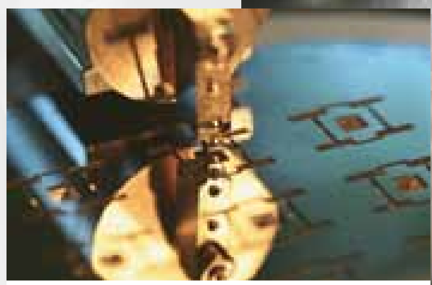
- Nanoneedles and nanocannulas only a few micrometers long enable cell membranes to be penetrated, allowing us to measure intracellular potentials.
- Microneedles roughly 100 µm long enable doctors to administer pain-free allergy tests, perform the spatially resolved detection of muscle activities, or administer medication transdermally.
- Probes that are several millimeters long can be implanted in the brain, making it possible to measure neural signals with three-dimensional resolution combined with electrical and chemical stimulation.

We add platinum, silver, and iridium electrodes to these structures and connect them to external measuring instruments by applying optimal assembly and packaging methods.

- **Mechanical characterization:** We are proud to say we have a unique portfolio of methods and measuring equipment for the automated determination of the elastic, plastic, fracture mechanical, and piezoresistive material constants of micromaterials. We also determine the response of mechanical sensors and sensor systems to axial strains and shear stress and determine the three-dimensional dynamic behavior of microstructures. We calibrate miniaturized force and torque sensors and conduct cyclic load tests on microstructures.


CMOS stress sensor systems


Intracortical CMOS microprobes


Wafer-level microtensile test

Prof. Dr. Oliver Paul

We integrate silicon microstructures and circuits into the smallest of spaces, providing solutions for measurement challenges in biology, medicine, and industry that could not be previously addressed.

Mechanical calibration setup for orthodontic microsensors

Laboratory for Microactuators

Experts in forces and displacement

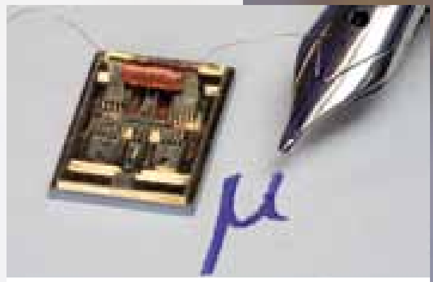
The list of demands made on a driving mechanism for microsystems are manifold and often contradictory. The perfect microactuator which meets all requirements does not exist. This is why we develop miniaturized actuation mechanisms which are tailored to specific applications.

Our expertise lies in electrostatic, magnetic, piezoelectric, and hydraulic microactuators. We focus on lean processes to ensure cost-effective manufacturing. We also evaluate respective materials. We not only work with the materials which are typical for microsystems technology but also with magnetic materials and silicone. By modifying production machines used in semiconductor industries, we are able to produce three-dimensional microcoils with so far unsurpassed efficiency.

◆ Adaptive micro-optics: We develop membrane lenses with apertures ranging from 2 to 10 mm and a controllable focal range from 30 to 1000 mm. The lenses are made from silicone (PDMS) and are actuated by a hydraulic pump with a built-in piezo actuator.

◆ Magnetic reluctance actuators provide large displacements and feature robust designs. They can be operated in normal laboratory conditions without the need for encapsulation. Our actuators are applied in interferometers, spectrometers, and positioning tables.

◆ Microcoils: The applications of microcoils are manifold and are not restricted to microactuators. Small air coils with diameters of 200 µm are used as sensors for the magnetic resonance imaging of cells or very small tissue samples. Coils on magnetic cores in the millimeter range are applied in energy harvesting, actuation, sensors, or actuators. Thanks to our refined technology, we are able to incorporate coils on microelectronic chips to provide high on-chip inductances.


Magnetic actuator


Piezo actuator in measuring device


Adaptive lens with piezo actuator

Magnetic microactuators
Elastic MEMS
Optical MEMS
Materials for actuators
Processes for actuators
www.imtek.de/mikroaktorik

Prof. Dr. Ulrike Wallrabe

We develop precise, reliable, and energy-efficient driving mechanisms for microsystems that can be integrated into micro-optics and life science applications.


Array of microcoils

Fritz Huettinger Chair of Microelectronics

Experts in CMOS circuits

The design of mixed-signal CMOS circuits is our expertise. New system solutions, innovative circuit concepts, and clever implementations of low-power and low-voltage circuits lead to a dramatic reduction in power dissipation.

In a strategic alliance with the Institut für Mikro- und Informationstechnik of the Hahn-Schickard-Gesellschaft (HSG-IMIT), we develop application-oriented solutions in the following areas:

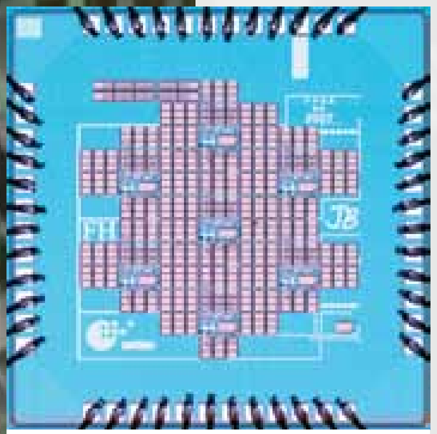
◆ Energy harvesting: The harvesting of kinetic energy in vibrations can be used to power remote sensor systems in cars or industrial machines. We develop harvesters based on inductive, capacitive, and piezoelectric concepts that cover a wide range of vibration frequencies and magnitudes. Our highly efficient, ultra low power circuits operate at supplies below 1V and at a power of a few μW. In order to improve their output power and efficiency, we apply adaptive control methods.

◆ Low-voltage circuits: Circuits for energy harvesting systems have special requirements because they need to work at very low and unstable supply voltages and under extremely tight energy budgets. The effect of large process variations on circuit performance under these conditions makes our research on subthreshold circuits an exciting and challenging task.

◆ Low-power mixed-signal circuits: Reconfigurable analog circuits are still far from offering the same flexibility that digital field programmable gate arrays (FPGAs) provide. However, adaptable filters are a must when the signal bandwidth or data rate of the input signal is variable, as in the case of wireless communication or read-channels of hard disk drives. The goal of our research on field programmable analog arrays (FPAAs) is to provide digitally adjustable analog circuits which allow reconfiguration on all levels, beginning at the level of filter architecture and going all the way down to its analog properties.

◆ Analog-to-digital conversion: An important building block of every mixed-signal system is the analog-to-digital converter. Delta-Sigma modulators are an outstanding option because they take full advantage of modern technologies with high-speed but low-precision capabilities. We combine our expertise in continuous time analog circuits with low-power digital design to deliver architectures which are especially suited for low-power requirements in sensor systems as well as high-speed conversions in communication systems.

◆ Sensor readout: We use our extensive knowledge in low-power electronics, high performance analog circuits, and continuous-time Delta-Sigma modulators to create cutting-edge sensor designs. These employ closed-loop concepts in magnetic sensors and micromachined gyroscopes to improve performance and power efficiency in highly integrated sensor systems.

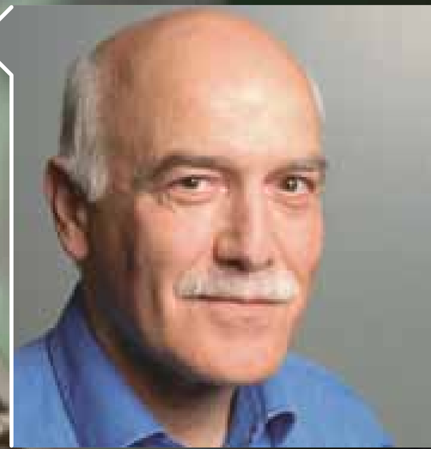


High-speed field-programmable analog array

14-bit analog-to-digital converter

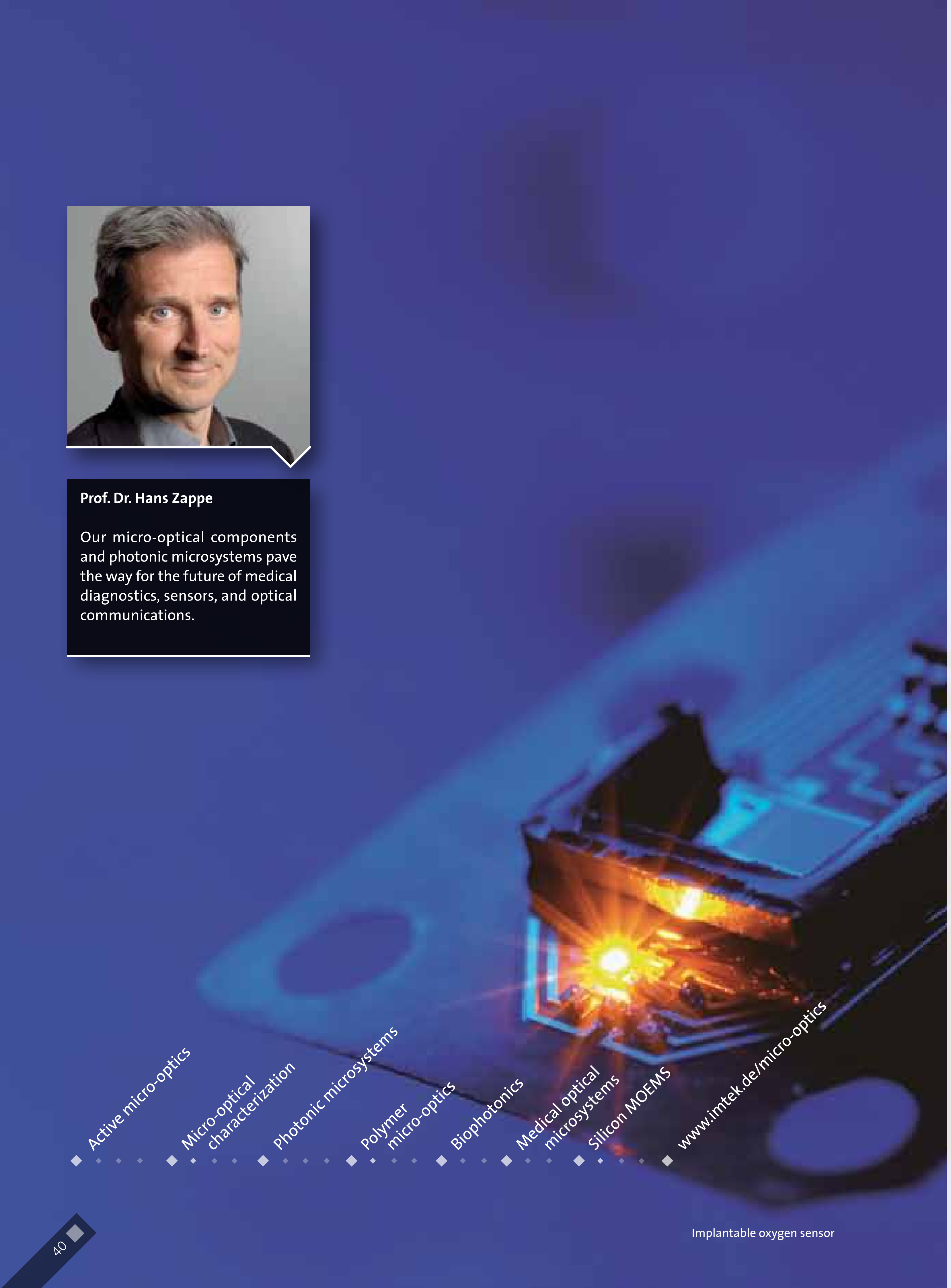
Prof. Dr.-Ing. Yiannos Manoli

We push the power dissipation of integrated circuits towards zero.



- Low-power CMOS-integrated circuits
- Low-voltage mixed signal systems
- Adaptive circuits for energy harvesting
- Subthreshold design techniques
- High precision sensor readout circuits
- Power efficient analog-to-digital-converters
- www.imtek.de/mikroelektronik

Adaptive low-power circuit for electromagnetic vibration harvesters



Implantable oxygen sensor

Prof. Dr. Hans Zappe

Our micro-optical components and photonic microsystems pave the way for the future of medical diagnostics, sensors, and optical communications.

Laboratory for Micro-optics

Experts in optical microsystems

Our expertise is in active micro-optics. We develop tunable microlenses, micromirrors, and other micro-opto-mechanical components and assemble these into complex optical microsystems, predominantly for use in medical applications. We specialize in optical design and modeling, fabrication, and assembly technologies. Because we are also experts in micro-optical characterization, we are an established leading research group in tunable micro-optics, biophotonics, and micro-optics for medical diagnostics.

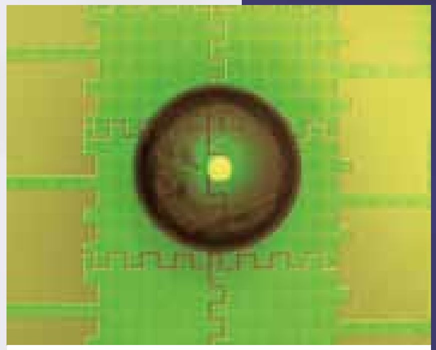
We use a broad palette of microsystem fabrication technologies, semiconductors, polymers, glasses, and liquids to realize advanced and novel optical systems. Soft matter technologies, particularly opto-fluidic techniques, play a major role in our activities. We also focus on micro-optical characterization and develop new measurement approaches using imaging and interferometric techniques. The end-products of our research and development work are, typically, implantable or endoscopic optical microsystems.

- Endoscopic OCT: Optical coherence tomography (OCT) is a non-invasive imaging technique which allows non-destructive imaging below the surface of tissue. We have developed an ultra-miniaturized OCT system suitable for use in an endoscope that enables non-invasive medical diagnostics in the gastro-intestinal system, for example, or during keyhole surgery. We use two-dimensional scanning micromirrors and tunable microlenses to attain very high lateral resolution despite the system's compact, 3-mm-diameter dimensions.

- Implantable oxygen sensor: The continuous in vivo monitoring of blood oxygenation, pressure, pulse, and concentration of trace gasses in blood or perfusion in tissue is of considerable clinical importance. We have developed a number of implantable micro-optical sensors for these measurements and have demonstrated their utility and performance in experimental clinical trials. These biocompatible sensors measure numerous physiological parameters simultaneously, using techniques such as multi-wavelength absorption spectroscopy and new approaches for continuous blood pressure measurement.

- Tunable photonic crystals: Photonic crystals are novel periodic structures which exhibit an optical bandgap and are thus of considerable relevance for guiding and switching light in new-generation optical systems. We advance the capabilities of these devices by making photonic crystals tunable, combining our expertise in soft matter micro-optics with new developments in optical polymers and novel actuation mechanisms.

Optical characterization system

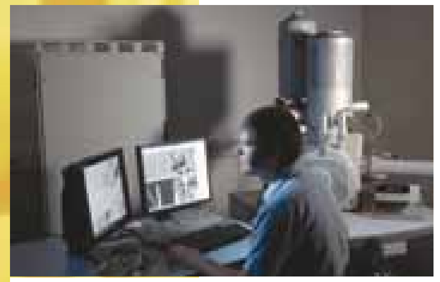


Liquid lens

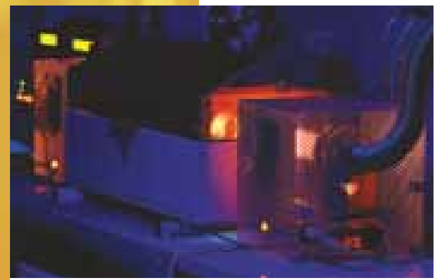
Spatial arranged ZnO nanowire arrays

Prof. Dr. Margit Zacharias

We research new materials and processes to enable the fabrication of nanostructures with atomic precision and to provide innovative material properties.



Working with a high-resolution SEM



Growth of nanowires

Laboratory for Nanotechnology

Experts in nanomaterials

Nanostructures are only visible under an electron microscope and have characteristic dimensions in the range of 1-100 nm. In nanotechnology, the properties of a material depend strongly on its structural size. We study new growth and structuring methods to realize such nanogeometries in a controlled and precise way.

- Nanowires and nanotubes: We realize the growth of nanowires and nanotubes for photonics, sensor technology, and other applications. These nanosystems are characterized by an extremely high surface-to-volume ratio which influences and controls physical and sensor properties, allowing new three-dimensional structures and devices to be designed with customized characteristics.

- Silicon nanocrystals: We research quantum structures on the basis of nanocrystals and optimize their high absorption, light emission, and charge storage. We use PECVD and evaporation processes which are compatible with microelectronic technology. Our vision is to develop highly efficient solar cells, new light emitting structures, and semiconductor devices with higher storage capacity or new efficient functionalities.

- Nanolithography: We develop unconventional nanolithographic methods such as nanosphere, phase shift, and UV interference lithography. This allows us to generate periodic nanostructures with dimensions down to the range of a few nanometers which we use to create templates for the controlled growth of semiconductor nanowires.

- Controlled bottom-up growth: We grow self-organized nanostructures with high accuracy at desired positions. Our methods are based on catalytic or self-catalytic vapor deposition and work without the necessary etching of the top-down processes. One advantage of this is the reduced surface effect density resulting from the higher quality of the grown nanostructure. We concentrate on zinc oxide but we also have experience with other materials.

- Nanodoping: When doping a semiconductor material, small amounts of foreign atoms are inserted to systematically change the properties of the material. We develop new procedures for the selective doping of nanostructures with very sharp doping profiles.

- Atomic layer deposition enables us to deposit various kinds of materials atom layer by atom layer over 3 dimensional nanostructures or plane surfaces. This can be done even at rather low temperatures enabling the coating of polymers or biologic samples. We study the reactions on nanosurfaces to change surface properties, and to generate extremely thin interfaces and protective layers.

Nonlinear optical materials
Microstructuring
Optical parametric oscillators
Whispering gallery resonators
Generation of terahertz waves
www.imtek.de/optical-systems

Prof. Karsten Buse

We develop micro-optical systems which enable the full manipulation and control of light and all its properties

Optical parametric oscillator

Laboratory for Optical Systems

Experts in frequency conversion

Nonlinear optical systems are at the core of our research activities. With the help of these systems, we can change the color of incident monochromatic laser beams. The scope of our work spans from optimizing and microstructuring various materials (crystals and polymers) to engineering and realizing new resonator designs. We also miniaturize these designs in order to study fundamental physical effects. In this, we cover the entire spectral range between ultraviolet light and terahertz radiation.

We are particularly active in the following areas of research:

- Nonlinear optical materials: Devices based on the second-order nonlinear optical response require crystalline materials without inversion symmetry. We use various spectroscopic and interferometric methods to identify crystal impurities with concentrations at sub-ppm level. In order to reduce their negative influence on the frequency conversion process, we apply optimized thermo-optical and thermo-electrical material treatments.

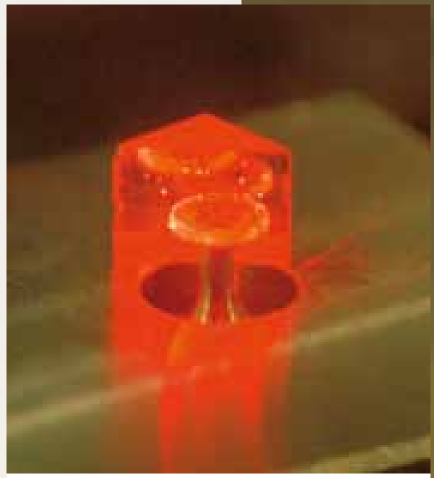
- Microstructuring a nonlinear optical material can greatly enhance the efficiency of frequency conversion. In order to achieve the desired pattern in ferroelectrics, we apply an electric field to the crystal using structured electrodes. Alternatively, we “write” ferroelectric domains by using an ultraviolet laser beam like a pen, which considerably expands the flexibility of domain engineering.

- Optical parametric oscillators (OPOs) are nonlinear optical systems that can outperform state-of-the-art lasers in terms of tuning range. We develop continuous-wave OPOs with tailored characteristics, including small linewidth, wavelength tunability over several octaves, and high output power. Such devices are ideally suited for spectroscopic applications in physics, biology, and medicine.

- Whispering gallery resonators: Standard frequency-conversion setups comprise mirror cavities for efficiency enhancement. Instead of using these bulky devices, we employ whispering gallery resonators based on total internal reflection. These combine an ultrahigh quality factor with intrinsically perfect alignment and compactness. They can easily be tuned by applying an electric field, and it is possible to fabricate them out of any solid material. This makes them a promising platform not only for nonlinear optics, but also for sensing applications.

- Generation of terahertz waves: We expand the tuning range of continuous-wave optical parametric oscillators into the terahertz range by applying cascaded nonlinear optical processes or employing advanced resonator designs. Tunable single-frequency radiation around 300 μm wavelength is generated from monochromatic laser light at 1 μm wavelength.

Technology transfer of innovations achieved by this research team is ensured through close collaboration with the Fraunhofer Institute of Physical Measurement Techniques IPM.



Whispering gallery resonator

Microstructured lithium niobate crystal

Prof. Dr. Ulrich T. Schwarz

We develop new light sources for the green to UV spectral region. These are based on light-emitting diodes and laser diodes and will eventually replace expensive, bulky, and inefficient light sources in many applications.

Pre-characterization of blue LEDs on a wafer

Laboratory for Optoelectronics

Experts in group-III-nitrides

We are experts in the development of optoelectronic components based on group-III nitrides, such as semiconductor laser diodes and light-emitting diodes (LED). Our focus is on the characterization and simulation of optoelectronic devices and the spectroscopy of semiconductor heterostructures on the sub-micrometer length scale (micro-photoluminescence).

We collaborate with the Fraunhofer Institute for Applied Solid State Physics IAF in the following areas of research:

- Efficient light-emitting diodes (LEDs): We optimize high efficiency LEDs for automotive applications and solid state lighting. This is a major contribution to energy conservation and climate protection. We combine blue LEDs with phosphor converters to produce white light, or we combine red, green, and blue LEDs in RGB-LEDs. We also use group-III-nitrides to access the ultraviolet (UV) spectral region and develop UV-LEDs for applications, such as water purification, spectroscopy, and material processing.

- Short wavelength laser diodes (LDs): Green and blue LDs enable us to realize technologies for flying spot micro-projectors the size of mobile phones. These systems are expected to have a high market penetration within the next few years. We characterize these LDs and develop new LDs with special functionality, such as high output power, narrow linewidth, ultrashort pulses, and special wavelengths. Such LDs are much compacter compared to conventional lasers and are expected to replace these in applications in physics, biology, and medicine. An example of such an LD is a picosecond (AlGaIn)N LD, which fits into a match box and replaces a Ti-sapphire laser system that occupies a whole table top. Completely new applications like these will soon become feasible in time-resolved spectroscopy.

- Basics of the (AlGaIn)N material system: We study epitaxial growth and optical properties of indium-free and indium-rich Ga(In)N layers to extend the spectral range of LED and LD towards UV and green. We use micro-photoluminescence and micro-electroluminescence spectroscopy and topography to correlate optical and electronic properties with the morphology of materials. In our research, particular emphasis is put on semi- and non-polar group-III-nitride layers, which is where the piezoelectric field in the materials can be minimized through crystal orientation. Our method of using spatially, spectrally, and temporally resolved spectroscopy for investigating wide bandgap materials can also be applied to other material systems and problems in micro- and nano-optics.

Wafer with InGaN quantum well

Laboratory for Process Technology

Experts in innovative manufacturing technology

We focus our research on the processes of manufacturing and testing of micro- and nanostructures. Our broad engineering portfolio includes ultra-precision machining, microwire and spark erosion, electrochemical machining, polymer replication through injection molding, hot embossing, thermoforming and nanoimprinting, and related In-Process and Statistical-Process control and measurement methods and strategies. We also optimize product-specific production processes and implement quality improvements in collaboration with our strategic partner, the Institut für Mikro- und Informationstechnik of the Hahn-Schickard-Gesellschaft (HSG-IMIT).

◆ Precision manufacturing: Our research is focused on various methods of ultra-high-precision machining of metals and polymers and the processing of non-conductive ceramics through spark erosion processes.

◆ Micromolds: We use high-precision micromechanical and lithographical methods to enable the manufacturing of micromolds for the replication of components for optics, fluidics, and mechanics. These include nanotiter plates, diagnostic platforms, and free-form surfaces for complex optical lens systems.

◆ Polymer replication: We research on hot embossing, nanoimprinting and injection molding technology and the thermoforming of composites and polymer components. One of our main areas is the monolithic integration of nano-structured surfaces and elements, microstructured functional elements, and macroscopic interfaces into a single component.

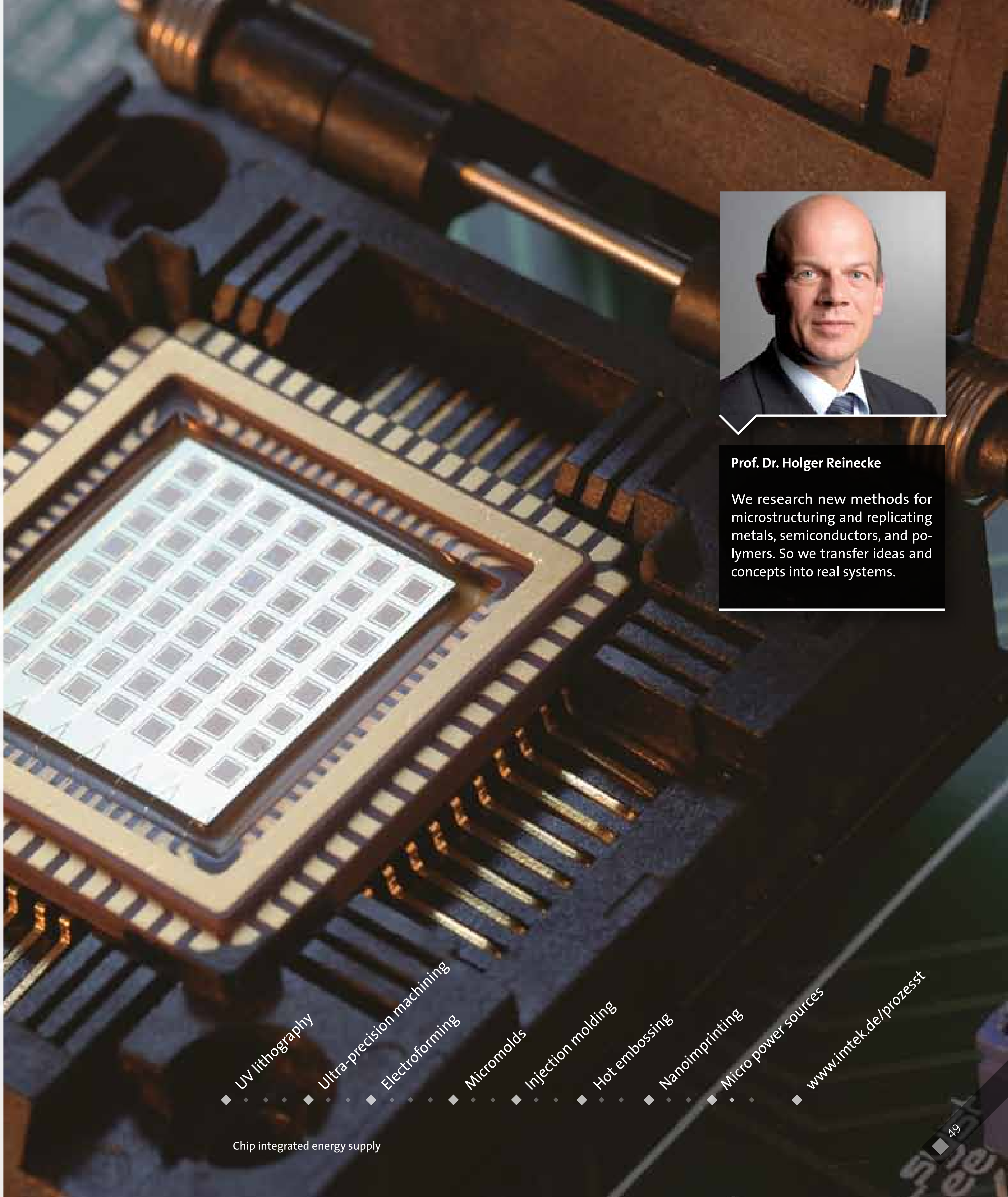
◆ Measuring systems: We develop specific, needs-based measuring systems for qualifying and monitoring our manufacturing processes. These include modifying and verifying algorithms on 3-D coordinate measuring machines and developing a 3-D laser tracker system to determine the tool center point of automated production equipment like roboters.

◆ Minimally invasive instruments: We develop forceps, grippers, scissors, and scalpels out of plastic, metals, and ceramics for microsurgical instruments.

◆ Micro power sources: We have successfully created microfuel cells using the same CMOS procedure used to produce common chips. This basic technology allows us to combine electronics with power supply in a single component that we can manufacture in one step. We are therefore able to create energy-autonomous sensor-actuator systems that are completely new. This technology is also useful as a basis for storing energy.

Prof. Dr. Holger Reinecke

We research new methods for microstructuring and replicating metals, semiconductors, and polymers. So we transfer ideas and concepts into real systems.



Chip integrated energy supply

Laboratory for Sensors

Experts in Lab-on-a-Chip technology

Our area of expertise lies in the development of miniaturized and integrated sensor systems for biomedical analysis systems and process technology. We functionalize sensor arrays through the localized immobilization of macro- and biomolecules, thus defining their biochemical specificity. We create complete miniaturized analysis systems, so-called Lab-on-a-Chip systems, by integrating microfluidics. We use cost-effective, modularly constructed microtechnologies, such as polymer- and foil-based procedures.

Another field of study is nanotechnology procedures, such as the synthesis of nanoparticles and the development of nanocomposites – in particular out of quantum dots –, metallic nanoparticles, and carbon nanotubes. These are used for nanosensorical analytics in the life sciences and for the production of fuel cells and photovoltaic devices. We also do research on the deposition of nanofilms by means of magnetron-supported plasma polymerization for microsystemic and sensoric fields of application.

- On-chip analytics: We develop biomicrosystems for fast, highly sensitive, on-site diagnostics, where it is most needed by the patient (point-of-care diagnostics). Our Lab-on-a-Chip system consists of a combined biomolecular sensor for the detection of bacteria and viruses. This system joins the accumulation of organisms and digestion of cells with the purification of the molecules to be isolated and the detection of biomolecules, in particular small RNAs.

- Metabolomics: We combined microsensors with microfluidics to create integrated multianalyt bio- and chemosensor arrays for the measurement of oxygen, pH, temperature, flow, glucose, lactate, and glutamate, and we developed these until they reached the production stage for clinical applications. We also developed our microbiosensor arrays into highly sensitive microcapillar immunotests for protein analytics in body fluids. In addition to our in vivo applications, we use comparable systems with integrated sensors for oxygen, nitrogen monoxide, pH, and neurotransmitters in the field of cell culture monitoring.

- Nanotechnology: We synthesize and characterize nanoparticles from metals and semiconductors and apply them in photovoltaics, fuel cell electrodes, and bioanalytics.

- Tumor and stem cell monitoring: We are developing a screening platform for the analysis and monitoring of stem and tumor cells. The system can be applied in the future for cancer research, for cancer treatments and for systematic and controlled tissue engineering based on metabolic monitoring.

- Plasma coating processes: We deposit nanofilms and different compositions of nanofilm multilayers on sensors and implants (for example, stents, artificial heart parts, and contact lenses). These layers are protective coats that increase biocompatibility through a non-inflammatory and antimicrobial behavior.

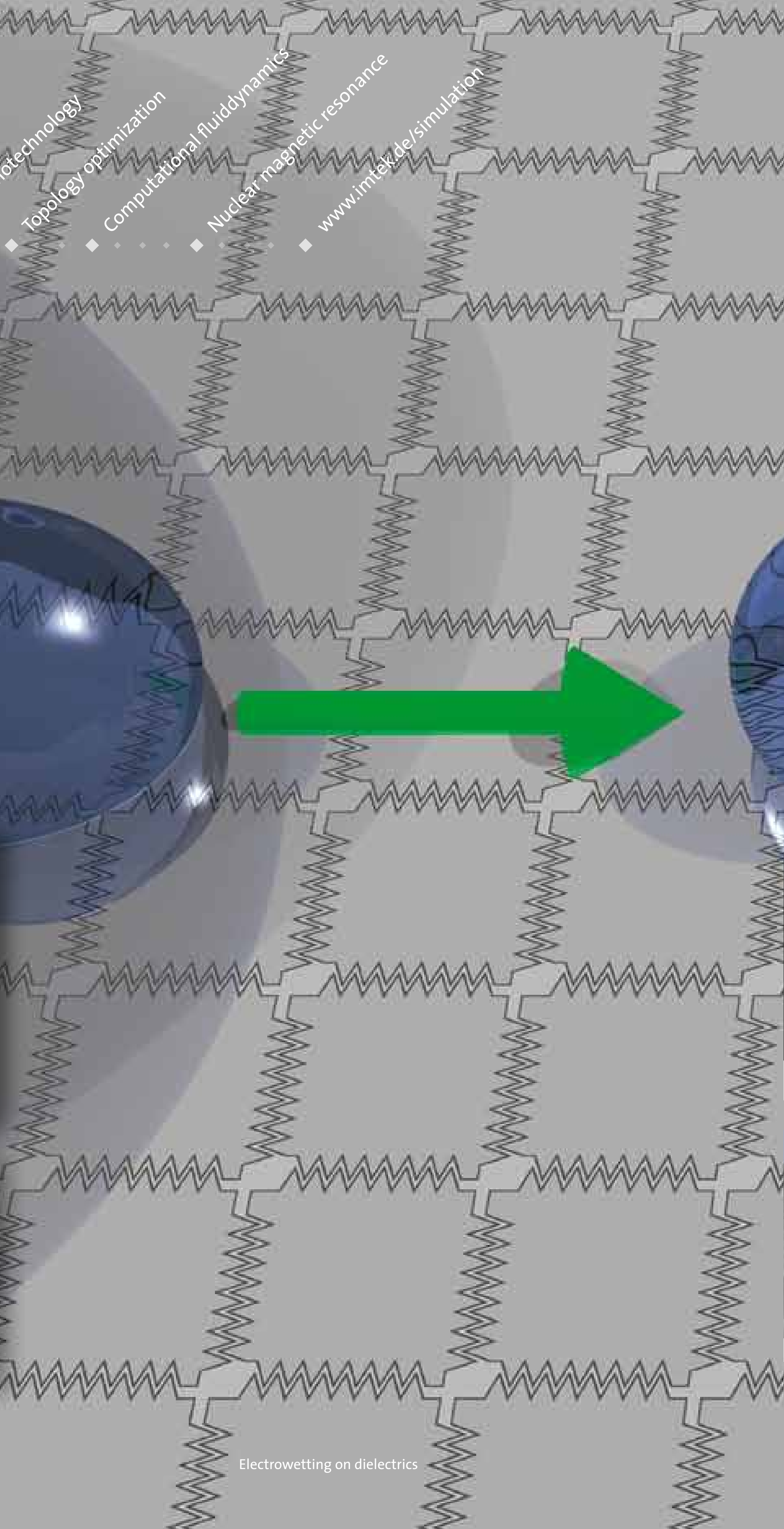
Virus detection chip

Biochip fabrication

Prof. Dr. Gerald Urban

We develop new diagnostic tools for medicine and the life sciences.

Chip for tumor cell analysis



Electrowetting on dielectrics

Prof. Dr. Jan G. Korvink

We perform research for the advancement of computational design and low-cost manufacturing paths for MEMS. Our applications include high resolution magnetic resonance spectroscopy and imaging as well as energy harvesting.

Laboratory for Simulation

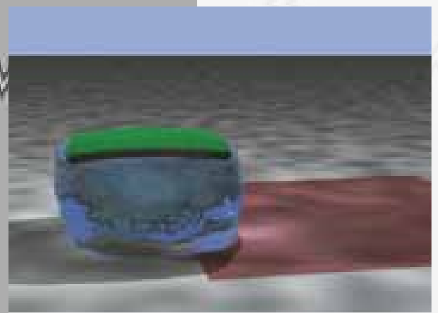
Experts in the design and simulation of microsystems

We are experts in developing application-specific simulation tools. Automation in design is highly developed in electrical and mechanical engineering. It allows even small-sized companies to place sophisticated products on the market. Design automation is not as developed in MEMS, and available computation tools for mechanical and electrical engineering are only partially suitable. We alleviate this gap in computational technology by targeting topology optimization, automatic compact modeling, and multiscale simulation, which covers mesoscopic and continuum models in an efficient manner. A key prerequisite is that the tools be able to run on office computers (PCs and laptops) instead of expensive supercomputers.

We develop manufacturing methods for low-cost fabrication. Low volume applications require alternatives to CMOS-based MEMS and the merging of packaging and functional layers to simplify construction. Inkjetting as a manufacturing technology is inspired by recent advances in the production of polymer electronic displays entirely through small-scale dispensing. POEMS® (polymer MEMS, an IMTEK simulation trademark) can be produced on arbitrary substrates (paper, plastic, PCB, or glass) and can be flexibly introduced into existing products.

New MEMS structures are produced with a backend automatic wire bonder. Perfect solenoids are produced in minimal time (a few milliseconds) on wafers, chips, or PCBs and are wired and ready for a range of applications. In combination with other low-cost technologies, this opens the door to a range of new applications that would be too costly if based on lithographic processing.

Inkjet print of nuclear magnetic resonance sensors



Fluidic transport of microcomponents

◆ Moldyn: The particle-based simulation program is currently being used for the simulation of microPIM (micro powder injection molding), a low-cost, high-volume manufacturing process, in the production of 3D microparts. The code is tremendously flexible and naturally handles a range of microfluidic effects important to the practitioner, such as free surfaces, powder migration, thermal gradients, and convection. Moldyn is currently also being used to predict the dynamics of carbon nanotubes during synthesis.

◆ fMRI coil arrays and gradients: In cooperation with the University Medical Center in Freiburg, we are developing a next generation massively parallel head coil array for high resolution (space and time) functional brain cortex imaging. This approach focuses on a new optimized PATLOC gradient field for the spatial encoding of the head; low noise GaAs amplifiers in cooperation with Fraunhofer IAF; and decoupled, matched, and tuned sensor arrays that conform to the patient's head. Metal coils are produced using a variety of technologies, including inkjetting. Design via simulation plays a decidedly central role.

◆ Micro-magnetic resonance imaging: Together with the Laboratory for Microactuators and the University Medical Center we develop magnetic resonance imaging solutions for microscale imaging and spectroscopy for scanning very small tissue areas and organisms with dimensions under half a millimeter. We join wire-bonded coils, polymer lithography, and fluidic sample handling to produce next generation analysis equipment for research and analysis in biology and chemistry.

Prof. Dr. Oliver Ambacher

We rely on optimized compound semiconductor heterostructures to develop energy-efficient electronics, compact bright light sources, flexible mobile communication systems, and novel sensors for medical applications.

Module with eight coupled quantum cascade lasers

Laboratory for Compound Semiconductor Microsystems

Experts in semiconductor-based micro- and nanostructures

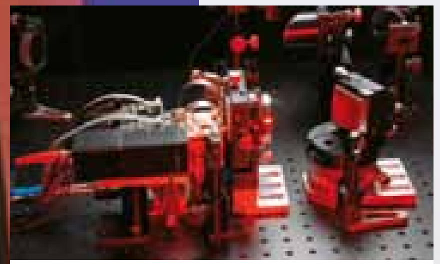
We focus on the realization of micro- and nanostructures based on III-V compound semiconductors (GaN, GaAs, GaSb), metal oxides (In_2O_3, Ga_2O_3), and diamond. These materials are outstanding in terms of electron mobility, band gap, mechanical stability, piezoelectric properties, and biocompatibility.

We cooperate closely with the Fraunhofer Institute for Applied Solid State Physics IAF in the following fields:

- High brightness light-emitting diodes and lasers: We develop optical systems such as high-power infrared light sources which make blood "transparent". These endoscope-integrated systems are used to generate images and movies of blood vessels and cells with improved spatial resolution compared to existing methods. The systems can be applied in non-invasive surgical intervention during operations on cardiac valves. They enable the surgeon to see the heart valve surrounded by blood without x-ray exposure or injecting contrast liquid.

- Safety and communication systems: Passengers passing security checkpoints in the gate areas of international airports are required to remove their shoes for inspection reasons. This inconvenient and time-consuming procedure is necessary for x-ray machines to look for voids which might be filled with explosives. Like x-rays, electromagnetic waves with frequencies above 100 GHz can penetrate dry materials such as leather and plastic, but without creating a health risk for humans. High frequency electromagnetic waves can also be used to examine shoes, clothes, and medical bandages without them needing to be removed. We develop high frequency transistors, circuits, and modules which operate in frequency ranges from 1 to 500 GHz and use these to generate, amplify, and detect micro- and millimeter waves. These devices can also be used for multiplexer and demultiplexer circuits which are necessary for optical data communication at rates above 100 Gbit/s.

- Energy-efficient micro- and nanoelectronics: Roughly 63,000 stationary base stations are needed to operate the German mobile communication network for 100,000,000 mobile phones. Each base station consumes an average of 2 kW in electrical power every 24 hours to be able to generate microwaves for information transfer. As a consequence, 3,000 gigawatt hours of power are required for operating the communication network, resulting in the emission of 320,000 tons of carbon dioxide. We have developed compound semiconductor-based microelectronic power amplifiers to generate microwaves in a very energy-efficient way, saving 50 percent in comparison to conventional base stations. We increased the electronic bandwidth of the amplifiers to achieve a higher number of frequencies which can be used for information transfer at improved data rates.



Infrared laser module

Background: Infrared image of a test structure in blood

Laboratory for Materials Processing Technology

Experts in the microengineering of ceramics

Our expertise in ceramics covers two main areas. One is the manufacture and processing of polymer ceramic composites and the ability to precisely influence their properties. We use polymerized reaction resins and technical thermoplastics as a basis and we develop the appropriate microcomponent processing and forming procedures.

Our second area of research is ceramic processing. We investigate the synthesis of inorganic materials for the production of oxide powders, thick-films, and thin-films. We also deposit such films using solvent based (metal-organic) and powder-based (traditional) ceramic methods. We dope these oxide ceramic materials, improve their performance, and investigate innovative deposition methods such as inkjet printing and electrophoretic deposition. This allows us to create microwave components based on doped barium strontium titanate films. We control electronic transmission properties at GHz frequencies through the application of an electrical DC voltage.

We cooperate with other IMTEK colleagues and our strategic partners in materials research: the Karlsruhe Institute of Technology (KIT) and the Institute of Microwave Engineering of Technische Universität Darmstadt.

◆ Functional composites based on polymers: We add nanoscale ceramics or organic dopants to make intentional changes to the refraction index of polymers (reaction resins and thermoplastics). By adding inorganic dopants, we can also adjust the relative dielectric constants of these polymers. They can be layered to create buried capacitors. We also dope polymers with carbon nanotubes to increase their electrical conductivity.

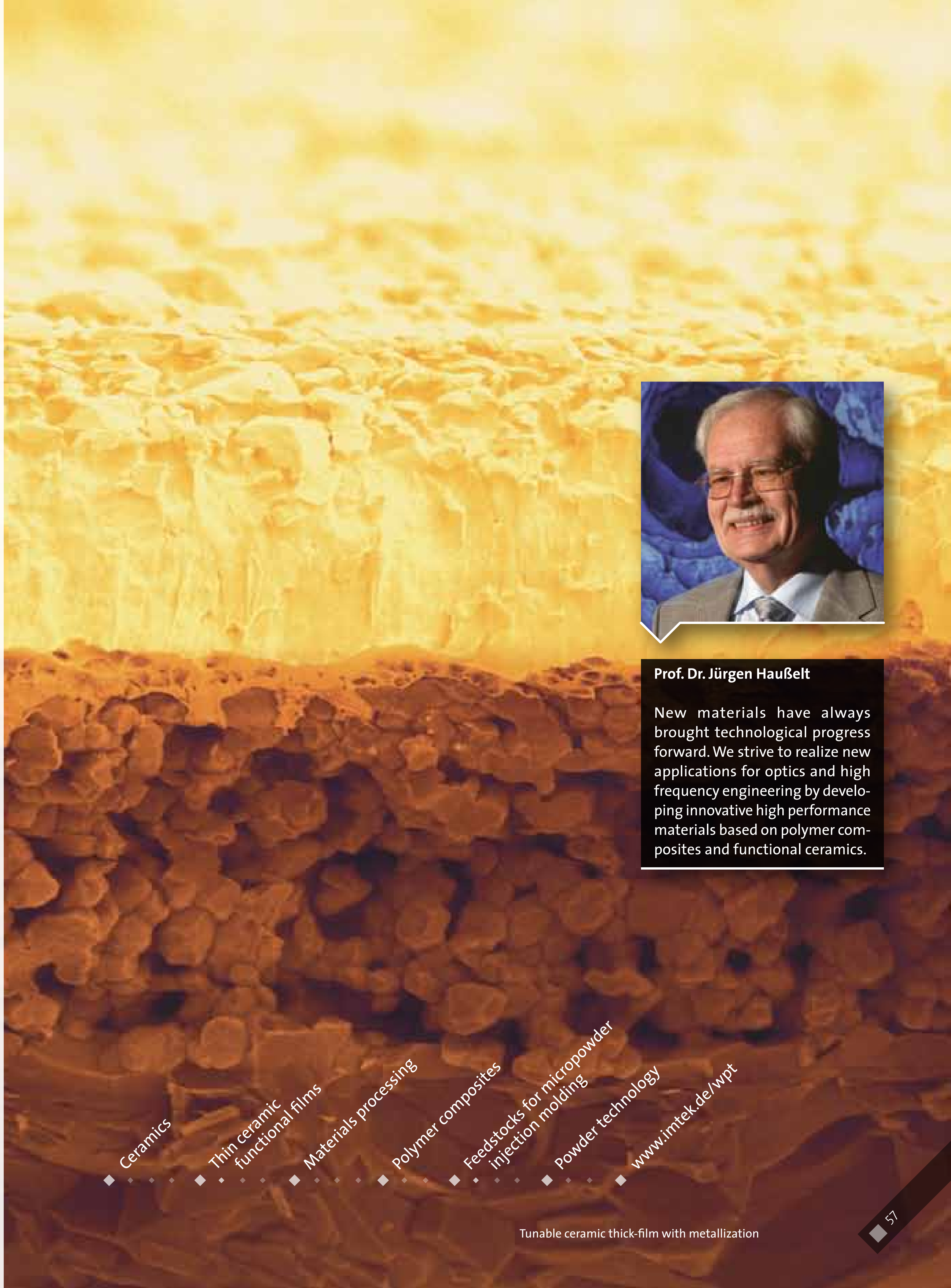
◆ Electronically tunable microwave components: We develop electronically tunable capacitors (varactors) that allow us to realize new applications for mobile communications and wireless sensors.

◆ Materials for micropowder injection molding: We use carefully selected ceramic powder, organic binders, and dispersants to develop so-called feedstocks with maximum powder filling grades and optimized rheological and mechanical properties for the powder injection molding of ceramic microcomponents.

Gravimetric determination of density

Prof. Dr. Jürgen Haußelt

New materials have always brought technological progress forward. We strive to realize new applications for optics and high frequency engineering by developing innovative high performance materials based on polymer composites and functional ceramics.

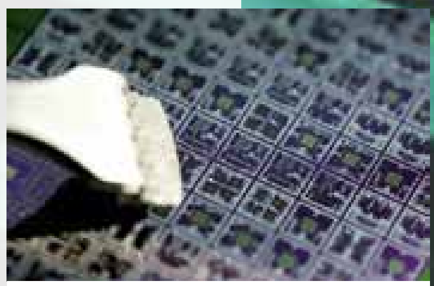


Tunable ceramic thick-film with metallization

Cleanroom Service Center

The Cleanroom Service Center (RSC) coordinates the operation and use of IMTEK's 600 m² cleanroom and its more than 240 registered users. The RSC team is in charge of the professional training of users and its semiconductor standard processes and ensures that IMTEK's process expertise is maintained in the long term. RSC is excellently equipped for processing internal and external projects with high proficiency and reliability, thanks to its 8 dry etchers, modern equipment for the deposition of CVD and PVD layers, and state-of-the-art metrology equipment.

Photoresist spin coating



Chips on wafer

- 100/150 mm wafer
- Chemical vapor deposition (CVD)
- Sputtering and evaporation
- Photolithography
- (Anisotropic) Deep reactive ion etching (DRIE)
- Packaging
- Wet and dry etching
- www.imtek.de/rsc

Wafers in boat in oxidation furnace

Dr. Michael Wandt

As one of IMTEK's main service departments, we provide an excellent infrastructure for internal and external users to develop their microengineering products.

Our society may be more high-tech and advanced than ever before, but there are still many questions that have not yet been answered:

- How can we provide enough energy to meet our growing needs in the future?
- How do we tackle the demographic change in our society?
- How does the brain function?
- How can we relieve the effects of chronic illness?
- What signals regulate the function and regeneration of cells in the body?

Being able to meet these complex challenges not only requires excellent researchers with vision, but more importantly, it also requires interdisciplinary teams of experts in different fields and sufficient time and financial resources. These basic conditions are satisfied in flagship projects. IMTEK researchers have the privilege of working in five such projects, either as leaders or partners.

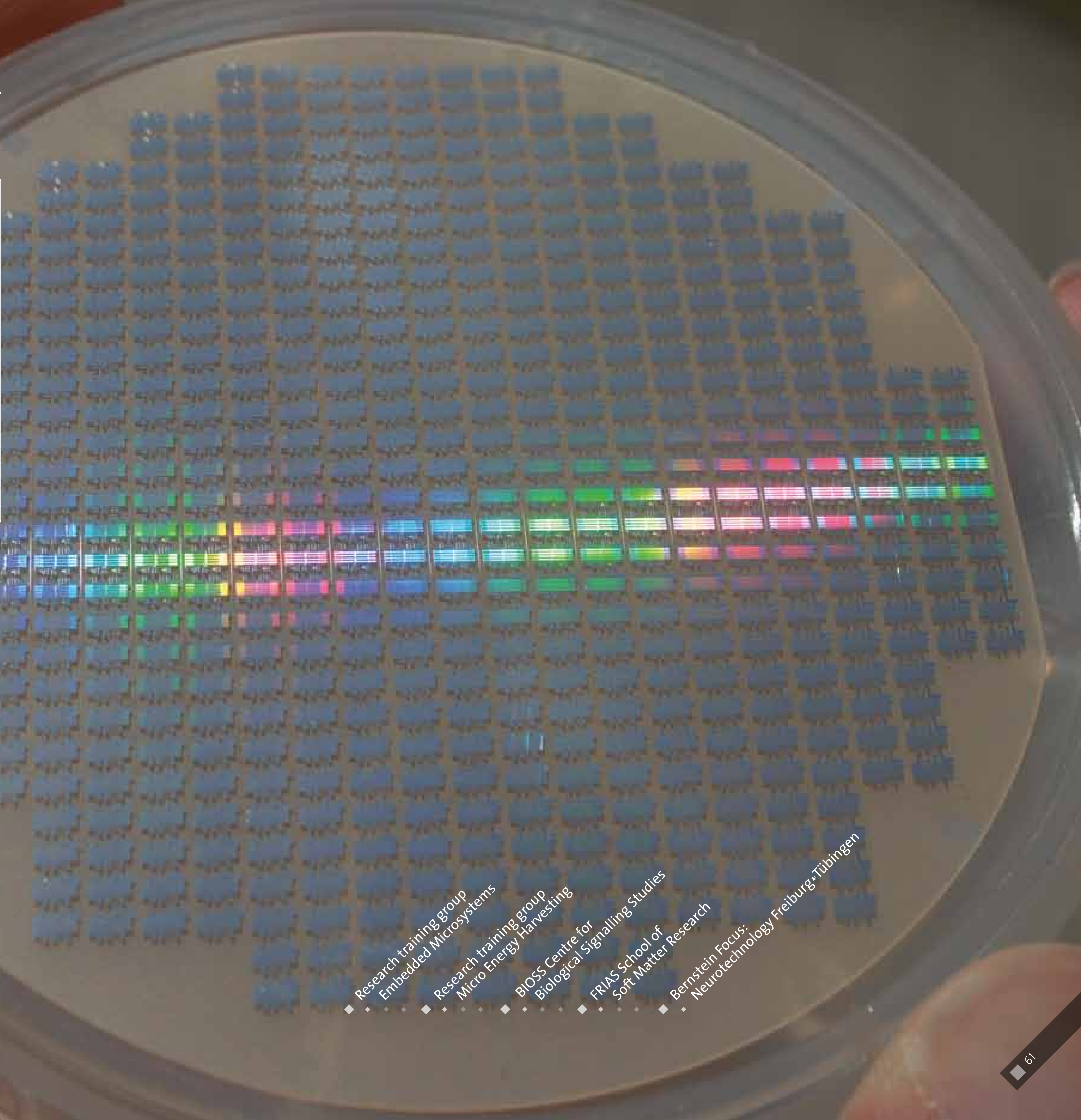
The research training group Embedded Microsystems provides doctorate students of microsystems engineering and computer science the opportunity to cooperate in networked systems research.

Young researchers in the research training group Micro Energy Harvesting develop solutions for sensors and actuators to harvest energy from their environment.

IMTEK researchers develop new technical tools that help us to understand in detail how single cells interact with materials in their environment and how they internally process these signals in the Cluster of Excellence BIOSS Centre for Biological Signalling Studies.

The international research center Freiburg Institute for Advanced Studies (FRIAS) of the University of Freiburg awards one-year fellowships to top international researchers. This exchange generates new ideas and approaches and brings people together on an international level.

Human-machine interfaces are studied in the Bernstein Focus: Neurotechnology. The long-term goal of this project is to enable the human brain to directly interact with technical prostheses.



IMTEK research training groups

Embedded Microsystems

Embedded microsystems are created using a combination of sensors, microelectronics, and computer science. This makes it possible to integrate intelligent and communication-enabled units into everyday objects that are so small they are virtually invisible. Embedded microsystems can be found in medical diagnostics, the control systems of motorized vehicles, and in safety engineering.

The research training group Embedded Microsystems offers postgraduate scholarships to 20 young researchers who are passionate about a field of research that is currently important in science and relevant to industry. The research training group combines the fields of computer science and microsystems engineering. Routine workshops stimulate continuous interdisciplinary exchange and bring people together, providing future graduates with an academic profile that is unique in all of Germany.

The German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) will support the Research Training Group with over € 4 million until 2014. The Group also receives financial support from several local companies, such as SICK AG from Waldkirch, Endress+Hauser from Weil am Rhein, Micronas AG from Freiburg, and HSG-IMIT from Villingen-Schwenningen.

Please contact:
Prof. Dr. Oliver Paul
www.imtek.de/content/ems

Micro Energy Harvesting

The applicability of distributed and embedded microsystems is directly dependent on the reliable and long-term supply of energy to nodes in decentralized systems. New technologies are developed in the research training group Micro Energy Harvesting that enable sensor nodes to operate autonomously without batteries or cables. The 21 scholarship students in the research training group work to develop new strategies of converting, storing, and managing energy. Their research includes the development of generators which harvest light, heat, movement, or chemical energy in the local environment of sensor nodes and convert this into electrical energy. The research training group also focuses on new materials for converting and storing energy and on microelectronic solutions for energy conversion.

The Fraunhofer Institute for Solar Energy Systems ISE, the Freiburg Materials Research Center (FMF), the Institut für Mikro- und Informationstechnik of the Hahn-Schickard-Gesellschaft (HSG-IMIT), and IMTEK have joined their research competence in the fields of decentralized energy engineering, microsystems engineering, and materials science to pursue comprehensive research in this ambitious field in this network unique in all of Germany.

The research training group also works together with regional and national partners, such as Endress+Hauser, SICK AG, Siemens AG, Weidmüller Interface GmbH & Co. KG, HSG-IMIT, and Enocean GmbH.

Please contact:
Prof. Dr. Peter Woias
www.imtek.de/meh

Wireless node

bioss
CENTRE FOR BIOLOGICAL SIGNALLING STUDIES

How do biological cells recognize single molecules or entire pathogens in their environment? How do the biochemical processes with which they handle this information function? How do they communicate with neighboring cells? How do cells organize themselves into large clusters, complex organs, or even entire organisms? These are only a few of the many questions still to be explored in the BIOSS Centre for Biological Signalling Studies.

Many human diseases are caused by defective or irregular cell signaling. Understanding this process is therefore an important step in the advancement of biological and medical research.

Thanks to the Excellence Initiative of the German government, BIOSS receives € 32 million in funding from the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG). Researchers from the fields of biology, medicine, and chemistry work together with engineers in microsystems engineering and computer science. Their cooperation is the basis for creating new tools and methods used for the analysis of biochemical processes in single cells, clusters of cells, and entire organisms.

Please contact:
Prof. Dr. Michael Reth
Coordinator of BIOSS
Prof. Dr. Roland Zengerle
Vice-coordinator of BIOSS
www.bioss.uni-freiburg.de

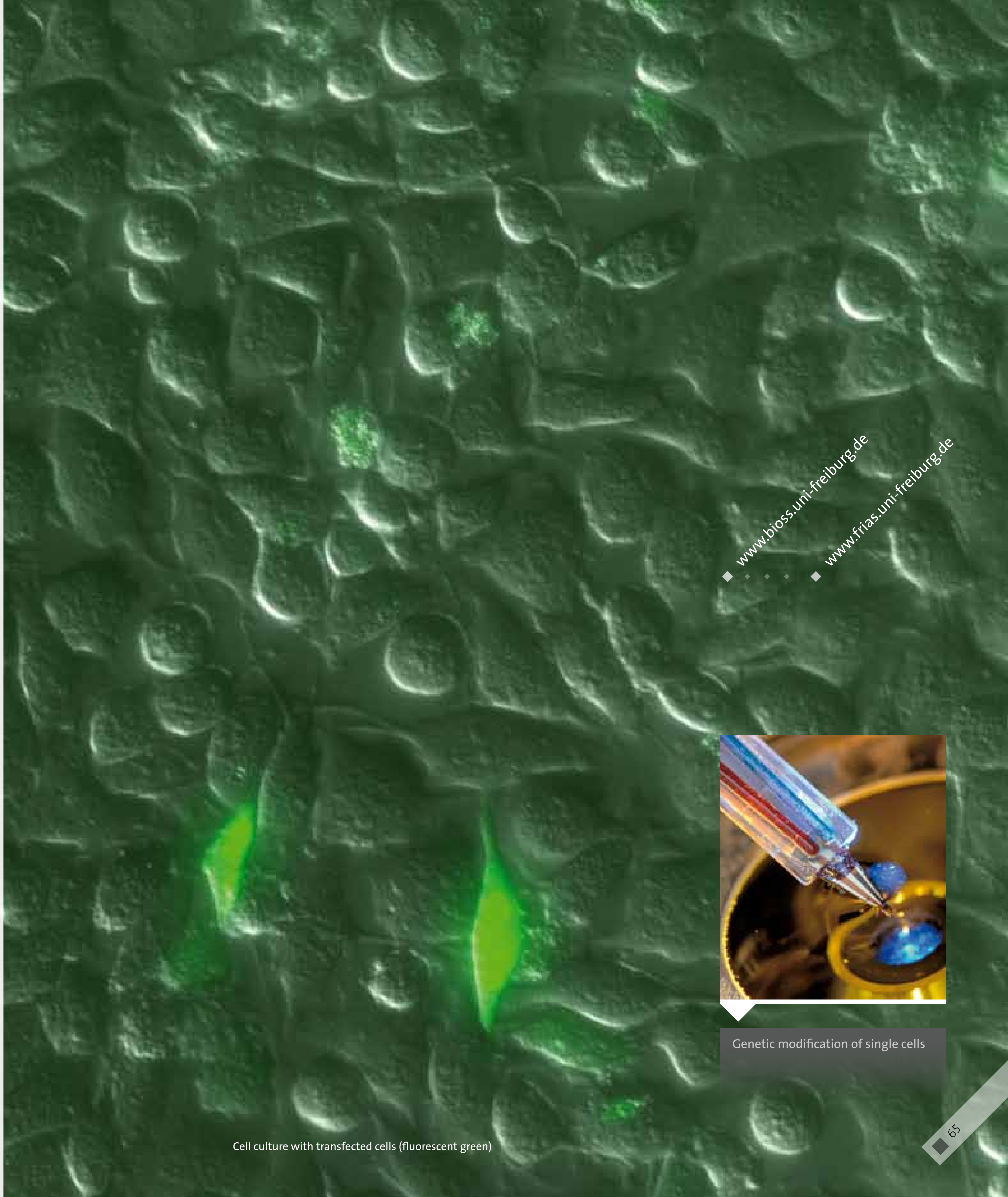
FRIAS
FREIBURG INSTITUTE FOR ADVANCED STUDIES
ALBERT-LUDWIGS-UNIVERSITÄT FREIBURG

Researchers from around the world come to the international research center Freiburg Institute for Advanced Studies (FRIAS) at the University of Freiburg to work together with researchers from Freiburg to generate completely new ideas and approaches in research. FRIAS consists of four schools:

- School of History
- School of Language and Literature
- School of Life Sciences – LIFENET
- School of Soft Matter Research

The School of Soft Matter Research is organized by the College of Chemistry, the College of Physics, IMTEK, and the Freiburg Materials Research Center (FMF). The School focuses on producing functional materials with sensory characteristics and improving the precision of simulation and manipulation methods at the molecular and macroscopic level.

Please contact:
Prof. Dr. Werner Frick
Spokesman for the FRIAS Board of Directors
Prof. Dr. Jan G. Korvink
Director of the School of Soft Matter Research
www.frias.uni-freiburg.de



Genetic modification of single cells

Cell culture with transfected cells (fluorescent green)

Bernstein Focus: Neurotechnology Freiburg * Tübingen

Bernstein Focus: Neurotechnology Freiburg * Tübingen

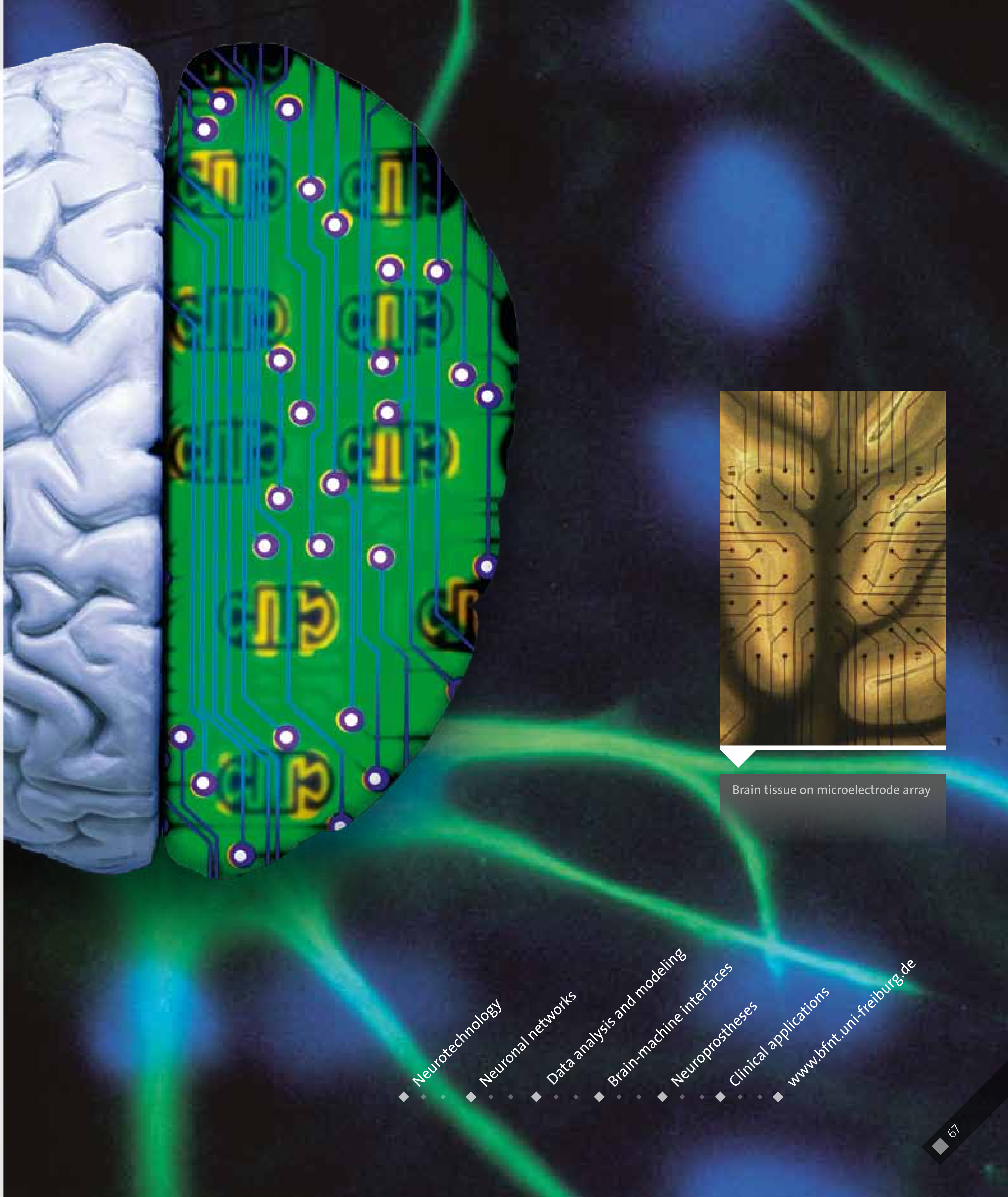
Neurotechnology is a burgeoning new field of research that focuses on the development and application of technologies for the treatment, restoration, or enhancement of brain functions that have been damaged by disease of the nervous system or by an accident.

Specific signals, primarily electrical, are measured within and outside of the brain before they are analyzed and utilized to operate prostheses or computers. Conversely, direct electrical or chemical stimuli can be used to modulate brain activity for therapeutic purposes. In combined approaches, recorded brain activity controls the stimuli, thus improving their efficacy and reducing their side effects.

In the Bernstein Focus: Neurotechnology Freiburg * Tübingen (BFNT-FT) – Hybrid-Brain, scientists from the Universities and neurological University Medical Centers in Freiburg and Tübingen as well as the Max Planck Institute for Biological Cybernetics in Tübingen investigate these electrical signals, their sources, and their information content. Their ultimate goal is to use such signals and stimuli in the treatment of certain forms of paralysis, epilepsy, stroke, and migraine. In terms of technology, the BFNT-FT's more immediate goal is to improve the recording and analysis of neuron signals, enhance the stability of long-term implants, and optimize the harvesting of information.

Industrial partners, such as Multi Channel Systems, Inomed, and the Honda Research Institute, contribute to research at the BFNT-FT. Thanks to the BFNT-FT's interdisciplinary approach and these industrial partners young scientists receive valuable experience in practice-oriented research early in their training. Ulrich Egert, Professor for Biomicrotechnology at IMTEK, is the coordinator of the BFNT-FT. IMTEK's Laboratories for Biomedical Microtechnology, Sensors, and Chemistry and Physics of Interfaces constitute the technological branch of this collective project. The BFNT-FT is part of the National Network Computational Neuroscience (NNCN), funded by the German Federal Ministry of Education and Research (BMBF) through its "Understanding Thought Processes" initiative. As an application-oriented project, the BFNT-FT complements the Bernstein Center for Computational Neuroscience, to which IMTEK's Laboratory for Biomicrotechnology and Laboratory for Chemistry and Physics of Interfaces also contribute.

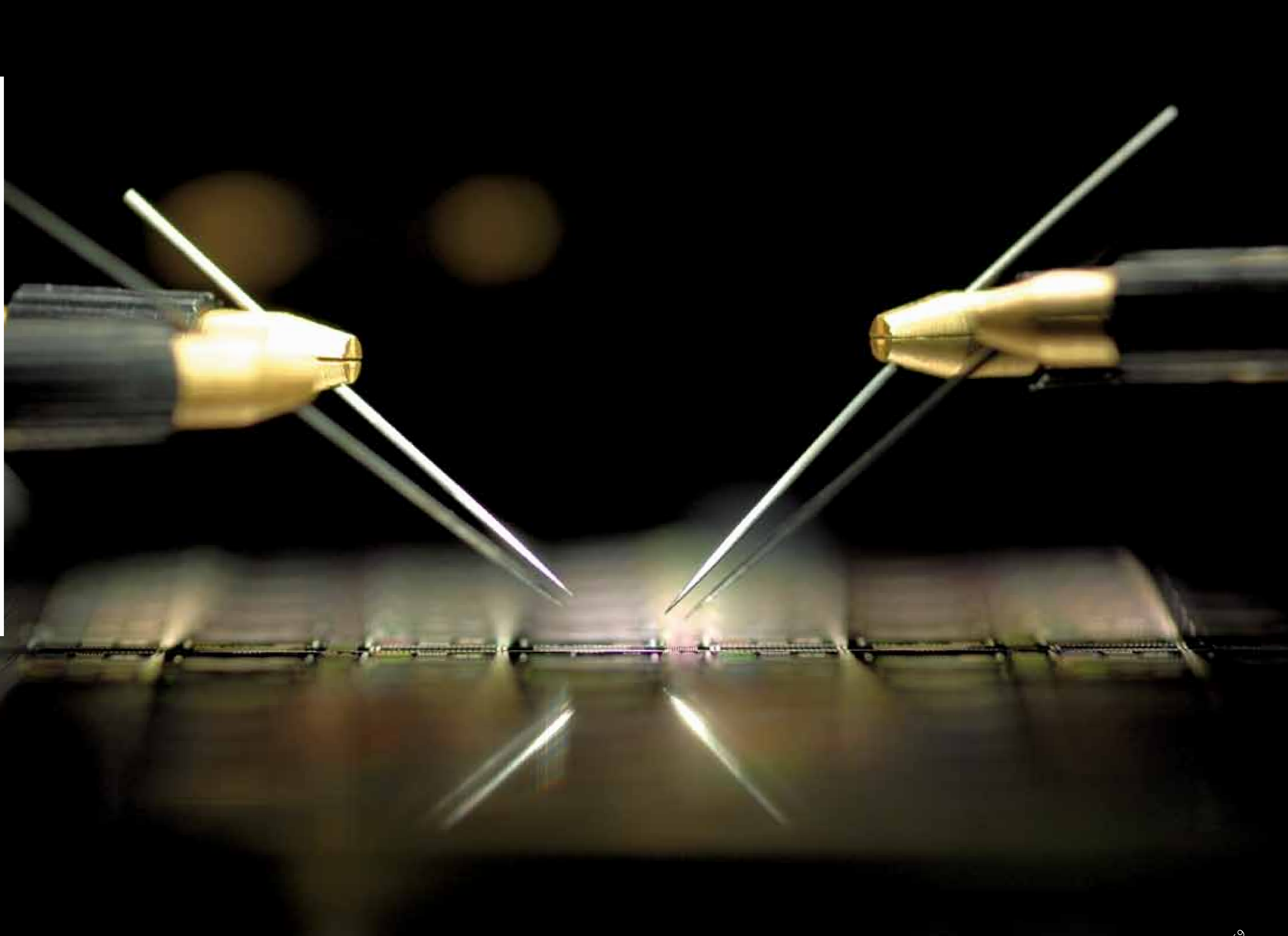
Please contact: Prof. Dr. Ulrich Egert
www.bfnt.uni-freiburg.de



Brain tissue on microelectrode array

In January 2010, the Federal Ministry of Education and Research (BMBF) pronounced five new clusters of excellence as winners of the second round of its Leading Edge Cluster Competition. All winning clusters focus on industrial issues of the highest priority for the future development of German industry. The cross-industry technology cluster MicroTEC Südwest (Southwest) was one of the five winners of this highly prestigious competition. A total of € 80 million in grant monies for MicroTEC Südwest's R&D budget will be coordinated by MST BW, a microsystems technology association commissioned with managing the cluster and whose main offices are located next to IMTEK. This important award is a clear sign of the enormous impact that microsystems technology is expected to have on Germany's economy.

Members of MicroTEC Südwest include more than 340 universities, universities of applied sciences, research institutes, and companies. The excellence cluster competition is based on the Excellence Initiative of German universities but has a much stronger focus on the applicability of research.



Automatic measurement of CMOS-integrated microsensors

The Forum Applied Microsystems Engineering (FAM) provides hands-on experience to engineering students at the University of Freiburg and promotes the cooperation between IMTEK and industry, the public sector, and society. Many companies are members of FAM, which is managed by a Board of six companies and universities led by the Chairman of the Board Wolfgang Bay, SICK. FAM provides the following key services:

- Conceptual and material support for defining and completing innovative and forward-looking research projects
- Assistance and support in education, for example through lecture series on topics such as patent policy, technology management, and starting and managing your own company
- Lectures at IMTEK held by key representatives from industry (flagship lectures)
- Assistance with student exchanges and placements for student internships
- Implementing microsystems engineering in industry

www.imtek.de/fam

MicroMountains Applications AG is based in Villingen-Schwenningen and is a development services provider for microengineering and microsystems engineering. MicroMountains Applications AG helps companies with implementing forward-looking research and development results into new products and methods by providing industrial services ranging from coordinating projects, to market, customer and technology analysis, IP management, and the transfer of technology and expertise.

www.mm-applications.com

MST BW – Mikrosystemtechnik Baden-Württemberg e.V. is a key association of all organizations who are active in microengineering in Baden-Württemberg. It represents the interests of its members in politics and institutions. Its services include the following:

- Networking and partnering in Baden-Württemberg, Germany and beyod its borders
- Workshops and interdisciplinary work groups
- Initiating strategic network Projects and supported research projects
- Training and continuing education programs
- Information services providing the latest news on important issues
- Overviews of available providers for consulting, R&D and production
- Support for start-up companies Co-marketing: internet portals, media, trade fairs and events

MST BW is commissioned by the Department of Trade and Industry of Baden-Württemberg for the Management of the Spitzencluster MicroTEC Südwest, winner of the Spitzencluster-Wettbewerb (Leading-Edge Cluster Competition) launched by the German Federal Ministry of Education and Research.

www.mstbw.de

IMTEK, HSG-IMIT, five Fraunhofer institutes, KIT, and VIM put Freiburg on the map as the best in microsystems engineering and related sciences in all of Europe. These institutes are members of the MicroTEC Südwest cluster and have made it standard practice to share experiences with one another and therefore complement one another's competencies.

HSG-IMIT

The Institut für Mikro- und Informationstechnik of the Hahn-Schickard-Gesellschaft (HSG-IMIT) has roughly 100 employees in Villingen-Schwenningen and Freiburg and is one of Germany's leading research and development services providers of micro-engineering components and systems. Its main fields include microfluidics, sensors and systems, and microengineering. HSG-IMIT not only provides prototyping and small-scale production, it also does serial production in a certified cleanroom.

Fraunhofer EMI

The Fraunhofer Institute for High-Speed Dynamics (Ernst Mach Institute, Fraunhofer EMI), deals with physical-technical aspects of high-speed, mechanical, and fluid-dynamic processes. Fraunhofer EMI is the coordinator for the innovation cluster Future Security BW in which it works together with IMTEK and other partners to create new technologies to counteract terrorism and organized crime.

Fraunhofer IAF

The Fraunhofer Institute for Applied Solid State Physics (Fraunhofer IAF) is a research center in the field of micro- and nano-structured compound semiconductors and synthetic diamond. Its research and development focuses on micro- and opto-electronic circuits, modules, and systems. It focuses on solutions for applications in safety engineering, communication systems, medical engineering and environmental protection.

Fraunhofer IPM

The Fraunhofer Institute for Physical Measurement Techniques (Fraunhofer IPM) develops and realizes turnkey optical sensor and imaging systems. Fraunhofer IPM is also a leader in the field of thermoelectricity and provides materials research, simulation, and the development of systems. Fraunhofer IPM also provides thin-film technology research with a focus on materials, production processes, and systems and research on semiconductor gas sensors.

Fraunhofer ISE

The Fraunhofer Institute for Solar Energy Systems (Fraunhofer ISE) is a global pioneer in efficient and environmentally friendly energy supply. Faunhofer ISE develops materials, components, systems, and methods for energy-efficient buildings. It also develops solutions in applied optics and functional surfaces, solar thermal energy, silicon photovoltaics, alternative photovoltaic technologies, renewable power supply, and hydrogen technology.

Fraunhofer IWM

The Fraunhofer Institute for Mechanics of Materials (Fraunhofer IWM) characterizes, simulates, and asseses the behavior of materials, components, and systems under the influence of external forces in different environments. Fraunhofer IWM develops solutions to improve the safety, dependability, life and functionality of technical components and systems.

KIT

The Karlsruhe Institute of Technology (KIT) was founded by a merger of the Helmholtz Association's Forschungszentrum Karlsruhe and the University of Karlsruhe in 2009. KIT bundles the goals of the state University and the national research center, which conducts program-oriented research within the Helmholtz Association. With approximately 8,000 employees, 20,000 students and an annual budget of € 700 million, KIT is one of the largest research and teaching institutions worldwide.

VIM Virtuelles Institut Mikrosystemtechnik

The Virtual Institute of Microsystems Engineering (VIM) is one of the biggest international R+D alliances in the field of microsystems engineering and nanotechnology, bringing together IMTEK and KIT. In joint projects ranging from materials research to silicon technology, LIGA and mechanical microsystems, VIM creates research and teaching synergies by merging complementary technologies and by sharing top-of-the-line equipment.

HSG-IMIT, Villingen-Schwenningen
Source: HSG-IMIT

Fraunhofer EMI, Freiburg
Source: Fraunhofer EMI

Fraunhofer IAF, Freiburg
Source: Fraunhofer IAF

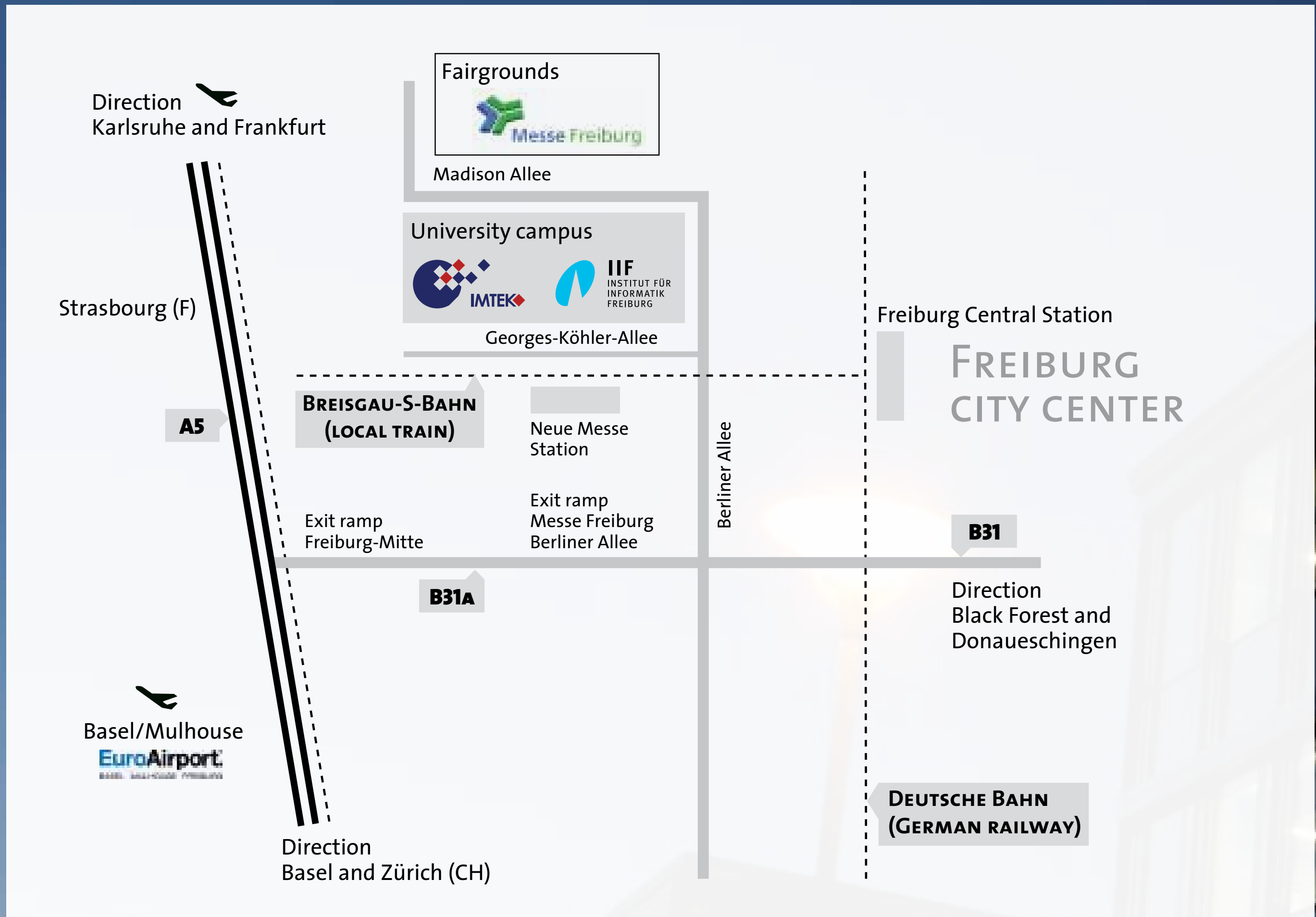
Fraunhofer IPM, Freiburg
Source: Fraunhofer IPM

Fraunhofer ISE, Freiburg
Source: Guido Kirsch

Fraunhofer IWM, Freiburg
Source: Fraunhofer IWM

KIT Campus North, ANKA Building
Source: KIT

KIT Campus North, INT Building
Source: KIT



Getting here

By car
From outside Freiburg: Take the Autobahn A5 north or south toward Basel or Karlsruhe, exit at Freiburg-Mitte, follow signs for Messe. When you reach the Messe (Trade Fair Hall), you will see the Technische Fakultät (College of Engineering) building, where IMTEK is housed, across the street.

In Freiburg: Take the road Freiburg-Nord approaching the Autobahn A5, follow signs for Messe. When you reach the Messe (Trade Fair Hall), you will see the Technische Fakultät (College of Engineering) building, where IMTEK is housed, across the street.

By train
ICE and InterCity trains run hourly on the railway line BASEL – FREIBURG – OFFENBURG – KARLSRUHE – MANNHEIM – FRANKFURT to Hauptbahnhof Freiburg. At Hauptbahnhof Freiburg, take the Breisgau S-Bahn local train in direction of Gottenheim/Breisach to Neue Messe/Universität

From the airport
From EuroAirport BASEL-MULHOUSE-FREIBURG: Take airport bus to Hauptbahnhof Freiburg.
From other airports in the region (which are further away), such as KARLSRUHE/BADEN-BADEN, STUTTGART, FRANKFURT, STRASBOURG (France), or ZURICH (Switzerland): Please ask visitor information on arrival.

By city transit
By local train: Take Breisgau S-Bahn from Hauptbahnhof Freiburg toward Gottenheim/Breisach to Neue Messe/Universität.

By bus
Take bus 10 from city center (Siegesdenkmal or Fahnenbergplatz) toward Paduaallee to Bärenweg.

For further information about public transportation services in Freiburg, please visit the Freiburger Verkehrs AG's website: www.vag-freiburg.de. For information about hotels and tourism, please see the City of Freiburg's website: www.freiburg.de.

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„Visions become
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