



CCMX

Competence Centre for
Materials Science and Technology

ANNUAL ACTIVITY REPORT 2009



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Message from the Chair



In 2009 CCMX has advanced well with its core mission of linking materials research in the ETH Domain and CSEM to industrial needs. The flagship projects launched in 2006 have now finished, producing more than 36 new PhDs in Materials Science and a host of publications. Several have led to follow on projects at a European level bringing more than CHF 15 million to fund the Swiss research groups.

We are now focusing on projects funded by public private partnerships (PPP) with funds from industry being double matched by funding from CCMX. This has promoted intense discussion between academic and industrial researchers to identify pre-competitive materials research needs of the different industrial sectors. Across the ERUs and the analytical platform 12 such projects are running or starting with 23 companies involved. It is intended that one more call for such PPP projects will be launched before the summer taking us to the end of the current funding period.

In addition to research, the education and outreach programme of CCMX is flourishing with 9 courses, events and technology aperitifs held in 2009. These events have proved to be an excellent forum for informal exchanges between researchers and feedback has been very positive.

Sincerely,



Professor Karen Scrivener
Chair CCMX

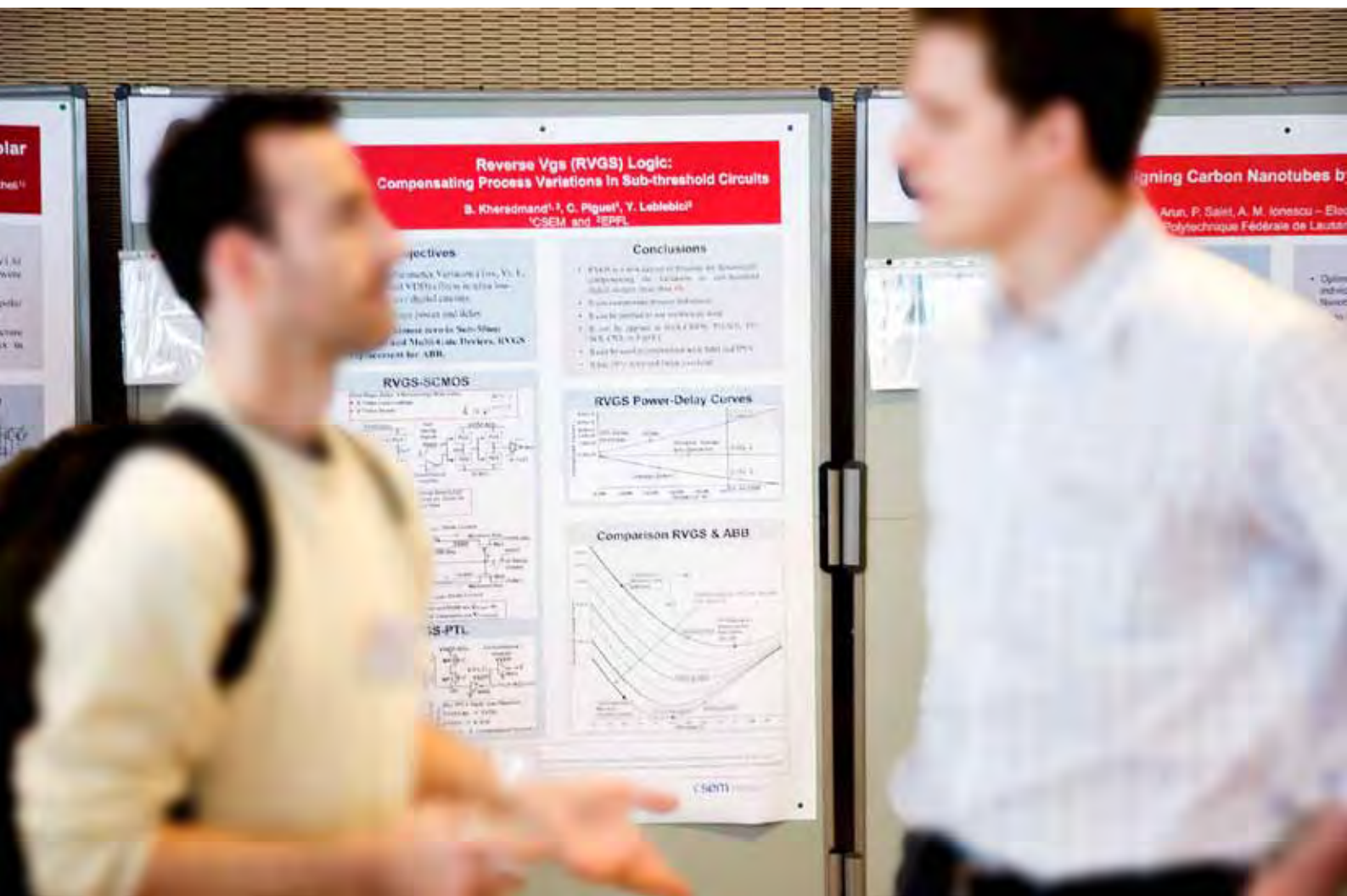


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How to be involved with CCMX

With the ambitious goal of being a link between academia and industry in the world of Materials Science in Switzerland, CCMX offers several entry points to its various programmes.



Education & training


CCMX offers several different types of courses. Summer and winter schools are geared mainly towards doctoral students. The courses and workshops are more oriented for engineers and scientists from industry who are looking for on-going education and hands-on workshops where participants can visit labs and actually experience some of the theory that is taught. Please see page 7 for a summary of the training provided in 2009.

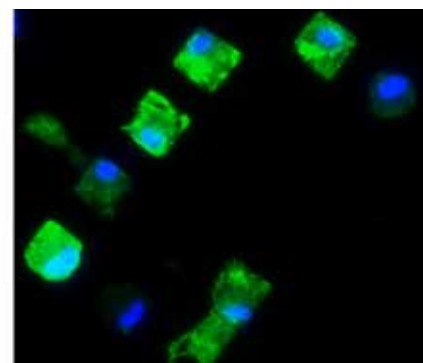
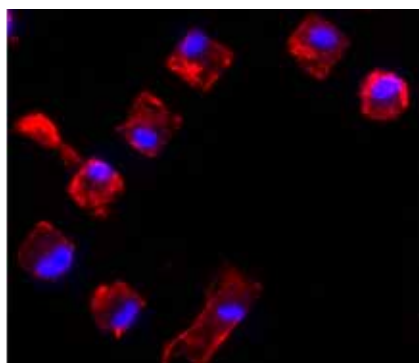
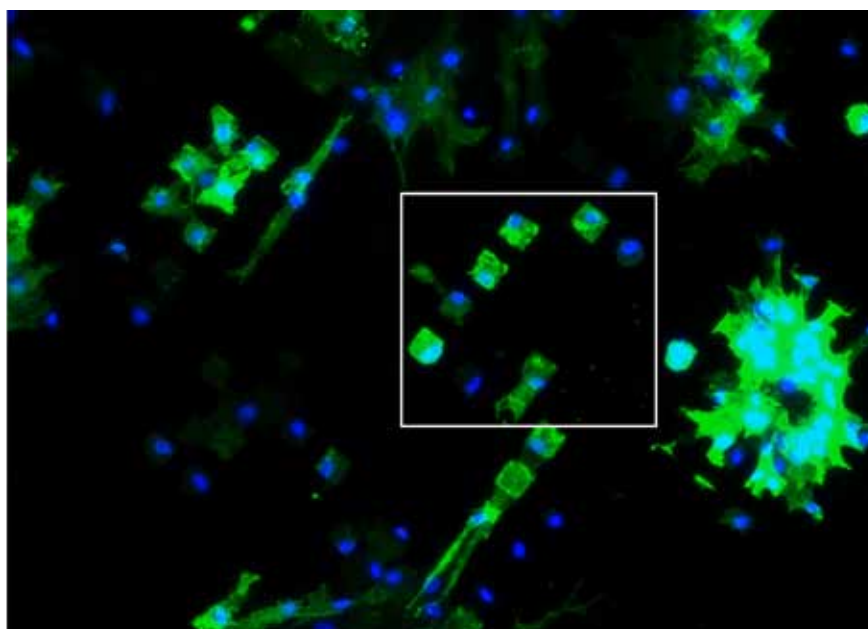
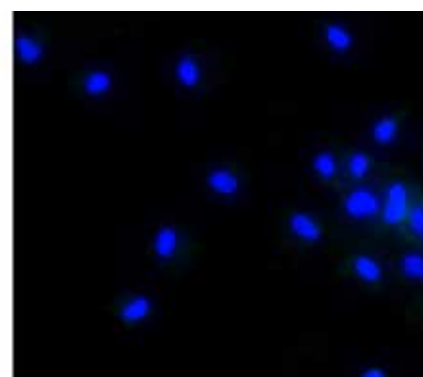
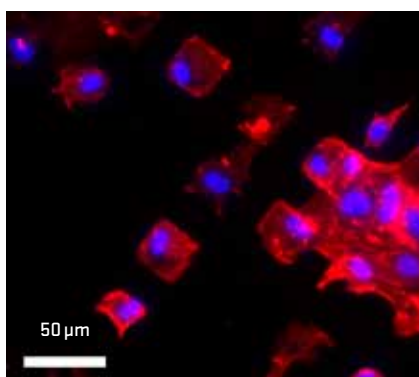
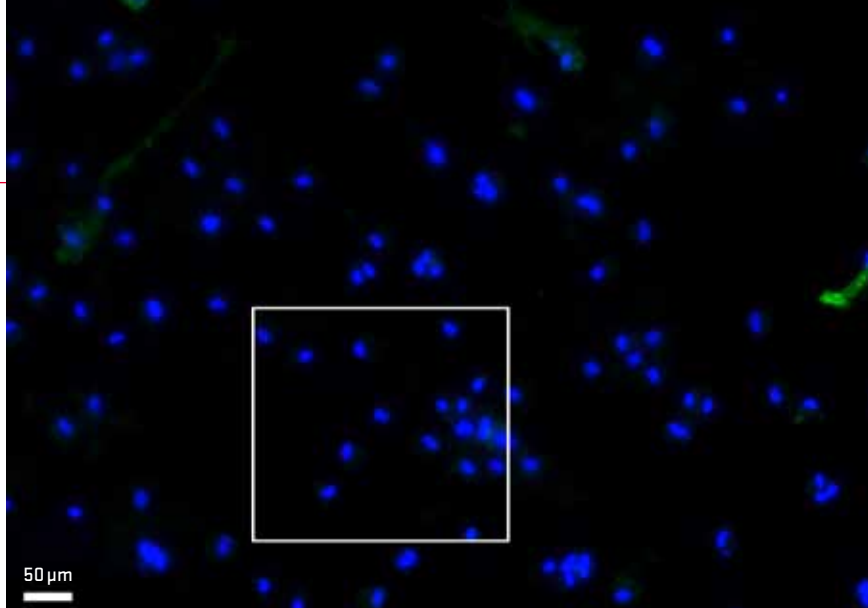
Outreach activities

Several events are organized by CCMX. The main aims of these events are knowledge transfer and networking by allowing participants to meet and discuss materials science in all its different aspects. The principal networking events organized by CCMX are called "Technology Aperitifs". These are end of afternoon/early evening events that consist of scientific presentations on a particular topic followed by an informal aperitif where

people can meet and talk. Please see page 9 to learn about the outreach activities in 2009.

Research

Many research projects are funded by CCMX in several thematic areas. Please see page 35 to find a list of all the funded projects. The research funded by CCMX is described as “pre-competitive” meaning that it is a middle ground of research that lies between fundamental basic research conducted mainly in universities and the ETH domain and proprietary research performed in corporate laboratories. In addition, the CCMX analytical platform funds projects aimed at the development of new analytical tools, methods and instrumentation for characterization on the scale below 100nm. 



Learning with CCMX

2009 was a fruitful year in terms of education. More than 200 persons participated in the different courses that were organized by CCMX. PhD students, engineers and scientists from academia and from industry mixed together in very different settings ranging from the Swiss Alps to the benches of EPFL.



CCMX Winter School

The CCMX Winter School took place from 25 to 30 January 2009 in Les Diablerets, a fun ski resort in the Swiss Alps. The 19 PhD students who participated in this course were thrilled with their experience. At first, they partly admitted that they had mainly registered for the Winter School because of the very attractive mixture of snow and surface science. But they did add that the impressive line-up of invited speakers had been the principal motivation. The daily programme was organized in such a way that the courses covered the mornings and the evenings, leaving the afternoons free for skiing. The whole idea of these “free” afternoons was to allow

the students to network and get to know each other.

The scientific programme was split between fundamentals of surface science, analytical tools for surface characterization, surface modification, materials in contact with biological environments and surfaces in energy and catalysis applications. Several instructors joined the course for a couple of days and shared their knowledge on surface science from their own perspective. Each theme of interest was complemented with an exercise session in the evening, consisting of presentations by a group of students in accordance with pre-assigned questions. 🇨🇭

Some comments from the students:

“Teaching surface science to students with backgrounds as diverse as Materials Science, Physics, Chemistry and Biology, whom in addition work on topics that are fundamentally different, must have been a big challenge! However this was a very positive feature which showed us how important and sometimes uneasy communication is between colleagues.”

“If one must quickly sum up this experience I would say that it was a week one will not forget that brought a breath of fresh air with new insights and ideas for our research activities.” Nikola Castillo



“The high impact surface science week was well balanced between scientific information and free time for the participants to interact with each other. On the whole, it was an enriching week for all of us, both on the professional level and personal level.” Prabitha Urwyler

2009 Programme of CCMX courses

Date	Course	Title
25-30 January 2009	CCMX Winter School	Surface Science : Fundamentals, Properties & Selected Applications
01-02 April 2009	CCMX Continuing Education Course	Powder Characterisation : from nanometers to millimeters and from theory to practice
29 June-03 July 2009	CCMX Summer School	Nano-Bio-Sensing
26-28 August 2009	CCMX Summer School	Modelling in Materials Science
09 September 2009	CCMX Workshop at the ESB2009	Design of Interfaces for Directing Biological Response

Outreach and Networking activities

Outreach and networking activities were numerous in 2009. Several “Technology Aperitifs” were organized along side the regular Annual Meeting, a CCMX stand at NanoEurope and a conference on “the state of the art and future of coating technologies”. All these events were attended by more than 200 researchers, scientists, engineers and students.

MaCH²

MaCH², Materials CHaracterisation in Switzerland (CH), is the analytical equipment database that was created and launched in 2009.



This database was set-up following a request made by the industry. Its access is free and accessible to anybody who needs to find analytical instrumentation available to them in the ETH Domain and CSEM. Each instrument is listed with its contact person and with application examples including properties that can be measured and materials that can be analysed. MaCH² is growing constantly and is available at: www.ccmx.ch/mach2





Technology Aperitifs

A survey was carried out among the participants of the different Technology Aperitifs to obtain the satisfaction rate.

Please see below some of the comments :

"Many useful contacts."

"Very good information (concentrated) to get an overview."

"The presentations were short and relevant and stimulating."

"The short-time seminars are of interest to me as consultant. I can see and speak to representatives of industry and academia, I am informed quickly and the late afternoon offers the opportunity not to waste too much time." 🇫🇷

2009 CCMX outreach and networking activities

Date	Activity
26 March 2009	Technology Aperitif "Optical Effects at Surfaces"
22 April 2009	CCMX Annual Meeting
25 August 2009	Technology Aperitif "Materials for the Life Sciences"
01 October 2009	Conference "Stand und Zukunft des Beschichtungstechnologien"
28 October 2009	Science Day "Surface, Coatings & Particles Engineering"
25 November 2009	Technology Aperitif "Nanocoatings and Ultrathin Films"
25-26 November 2009	Stand at NanoEurope 2009

The research we focus on

Fostering public-private partnerships

The Research Ticket Programme is designed to foster public-private partnerships in materials science in order to ensure the longevity of the interactions between industry and the CCMX institutions. Instead of engaging in research on a project-by-project basis as it has been done in the past, industrial partners collaborate with academic groups in a consortium focusing on a selected "Thematic Research Area". The creation of multilateral partnerships for medium term pre-competitive research is mutually beneficial and is a good approach to bridge the funding gap between the fundamental research supported by SNSF and the applied, "close to market" projects supported by CTI.

What is pre-competitive research?

Pre-competitive research is a middle ground of focused cutting-edge research that lies between fundamental basic research conducted mainly in universities/ETH domain and proprietary research performed in corporate laboratories.

Members from industry identify priority research topics with CCMX

The Research Ticket Programme allows flexibility for companies of different sizes to participate in the research activities of the Centre. Companies take a lead in identifying the priority research topics and may influence the choice of research projects to be carried out within a thematic research area. Not only is research funding more than doubled since funding comes from both CCMX and two or more industrial partners, but companies also share the risk of funding long term strategic research. In 2009, CCMX significantly increased the involvement of industrial stakeholders: 8 new projects involving 14 new entities are scheduled to start in 2010.



Thematic research areas in 2009

- Neo-metallurgy: new alloys, new processes and new investigation techniques
- Multi-scale, multi-phenomena modelling of metallic systems
- Surface modification by coating and structuring
- Functional foams
- Functional particles in contact with biological fluids
- Medical device technology and innovation
- Biosensing and diagnostic strategies

Keeping materials characterisation in the loop

In addition to this research programme, CCMX's Analytical Platform brings together expertise in the development of analytical methods and broad analytical resources from different institutions within the ETH domain, industrial partners and other universities. On one hand, the analytical platform funds projects aimed at the

development of new analytical tools, methods or instrumentation for the analysis of physical, biological or chemical properties on the scale below 100nm. On the other hand, the projects funded concern the exploitation of existing analytical techniques for nanoscale analysis in new fields of application. Co-funding from industrial partners and/or other institutions is a key aspect of these projects. ■



Photo: PSI

Why should industry participate ?

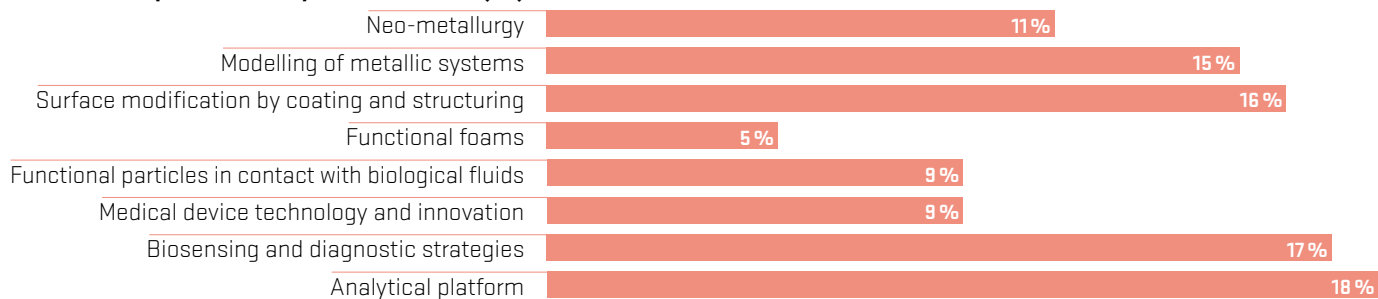
- Increased expertise in topics relevant to industry
- Access to hiring well-trained scientists
- Access to new knowledge, data and tools
- Access to multiple Swiss research institutions and equipment
- Directing research on industry's medium and long term needs
- Option to negotiate IP Rights
- Vote on allowing other companies to join

Companies involved in 2009 in projects (21)

Alphabetic order

- ABB Turbo Systems
- Alstom
- Alcan
- Asulab
- Attolight
- AO Foundation
- Arrayon Biotechnology SA
- Ayanda Biosystems SA
- Biotronik AG
- ION-TOF Technologies
- Kugler Bimetal
- Lovalite
- Lyncee Tec
- Metalor
- Novelis
- OPEA
- Rolex
- Sanofi Pasteur
- SurfaceSolutionsS AG
- swissnuclear
- YXLON International X-Ray GmbH

Research expenditures by research area (%)



NanoXAS: a closer look into materials

— NMMC —

The *Paul Scherrer Institut (PSI)* is not only the biggest research laboratory in Switzerland, but it has also been home to a world-wide unique experiment aimed at revealing some of the ultimate mysteries in materials science since November 2009. Up until recently, the *Scanning Probe Microscopes (SPM)* were available to assist in resolving surface topography, electronic and mechanical properties down to the atomic scale. Although these are powerful tools in areas as diverse as semiconductors, magnetic memory, polymers, and surface coating, they do not provide any chemical information. On the other hand, there were also *Scanning Transmission X-ray Microscopes (STXM)* measuring the x-rays transmitted through a thin sample and thus providing chemical information for such materials. Unfortunately, the spatial resolution of STXM analysis is limited to about 20 nm due to the difficulty of focussing x-rays to finer spots.

Scientists from PSI and Empa, the Swiss Federal Laboratory for Materials Testing and Research, have combined these two techniques in a fundamentally new instrument. In their new *NanoXAS* instrument, located at PSI in Villigen, they join their experience of synchrotron radiation spectroscopy and scanning probe microscopy. The NanoXAS instrument uses x-rays produced by the Swiss Light Source (SLS). These x-rays are many orders of magnitude more intense and better focused than x-rays from a laboratory source. In addition, their energy can be adjusted to match the absorption of different chemical elements, each of which has a unique fingerprint in the x-ray absorption. A change in polarization even makes it possible to study the orientation of magnetic fields in materials.

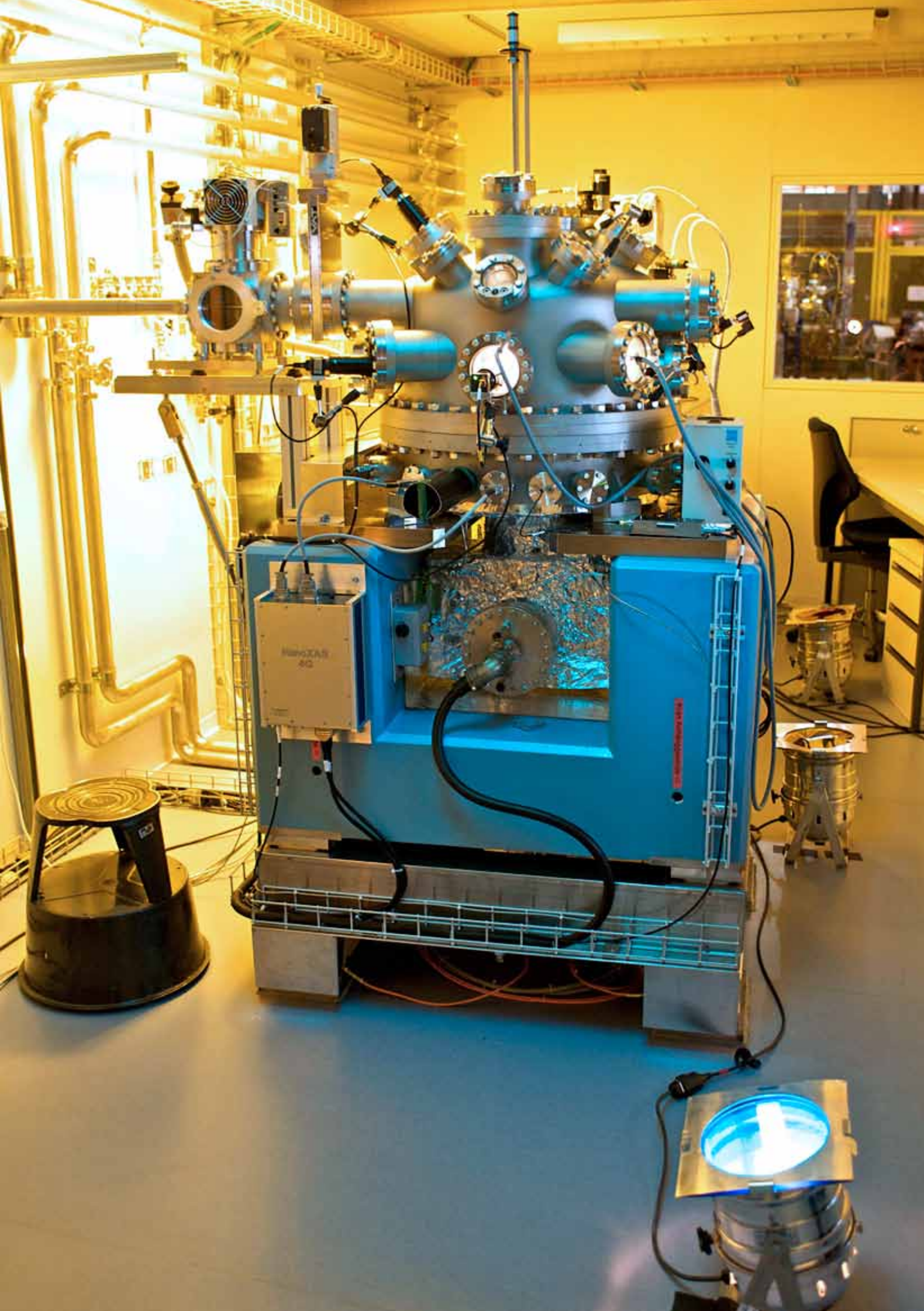
In the new instrument, x-rays of adjustable energy and polarization illuminate the sample. The tip of a specially designed scanning probe microscope is used to detect photoelectrons which are produced upon absorption of the x-rays by selected chemical elements. This not only greatly enhances the spatial resolution, but the combination of SPM and x-ray techniques also provides new contrast modes and thus allows a closer look into materials.



As one of its first applications the NanoXAS instrument is presently being used to shed light onto the function of novel electronic devices and magnetic storage media. “In the case of many semiconductor or magnetic materials for storage media we do not know exactly how they work as the relevant structures are too small to be looked at with methods available up to now”, says Dr Joerg Raabe, a scientist in charge of the project. “By using the NanoXAS instrument we can observe the orientation of nano-sized regions in materials for computer hard disks or the distribution of doping atoms in novel semiconductors.” Small quantities of doping atoms are introduced into semiconductor materials to modify their electrical conductivity. The boundary between regions of different doping are what makes elements like a transistor

work. Although they are very small, they are what needs to be studied.

With such insight, scientists can now understand the details of present-day materials and use this understanding to optimize future materials for electronic components or magnetic storage media. “There is a heavy demand for investigations with the NanoXAS from companies and research institutes from all over the world”, comments Dr. Iris Schmid, physicist at PSI and responsible for the precious instrument. Such demand is a good sign of this unique microscope’s success. It was created thanks to a cooperation between PSI and Empa with the University of Basel and German institutions, and partially funded by CCMX. It will provide researchers from these institutions and many other partners with a better insight into materials. 卐



A deep look into the nano cosmos: Time

— NMMC —

Time-resolved cathodoluminescence (TRCL) is the ideal tool to measure dynamics at the nanoscale. “With this spectroscopy technique you select an excitation point, send an electron pulse, collect the outgoing light and resolve it spectrally and temporally”, explains Dr. Samuel Sonderegger.

The CEO of Attolight Sàrl, the specialist for ultrafast spectroscopy for NanoPhotonics, is involved in a CCMX project under the aegis of Dr. Jean-Daniel Ganière at the EPFL Laboratory of Quantum Optoelectronics. His aim was to produce a new measurement tool for semiconductor nanostructures that combines both high spatial and high temporal resolution. The tool is based on ultrafast TRCL and integrates the advantage of electron microscopy (high spatial resolution) and ultrafast optics (high temporal resolution). An optically generated ultrafast pulsed electron beam is focused onto a specimen and information on the electron dynamics is obtained by resolving spectrally and temporally the outgoing cathodoluminescence signal.

With industrial applications in mind, the EPFL scientists wanted to achieve a cost effective solution with a compact magnetic/electrostatic SEM (Scanning Electron Microscope) column equipped with an optically driven electron source. For the gun of their electron microscope they used ultra-high-vacuum technology and immersed the cathode tip in the magnetic field of the gun lens. Two electrostatic octopoles are located in the pole-piece of the gun lens for measuring the virtual source size of the photocathode. Three movable apertures serve for the virtual source measurement and to control the final spatial resolution of the system. The body of the objective lens contains a linear

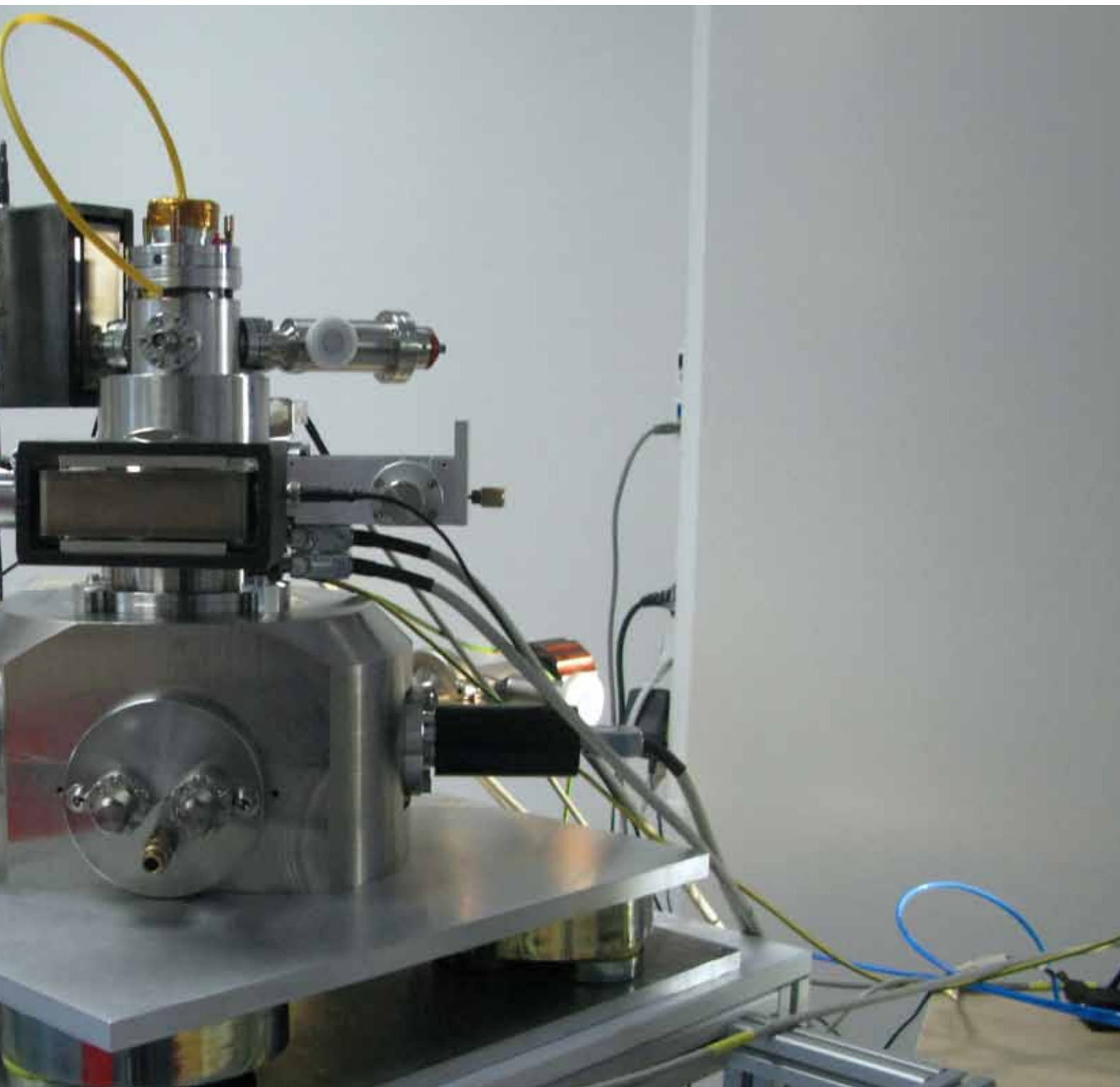
tube creating a vacuum along the optical axis and keeping the electromagnetic coils outside. The coils, located in the upper part of the objective, serve as stigmator and deflector to shape the electron beam, those which are in the lower part of the objective act as scanning coils. The main chamber made of massive iron protects the sample stage and the beam from mechanical vibrations and electromagnetic interferences. The detection is carried out on one hand by a secondary electron detector located on one of the side walls of the chamber, and on the other hand by a simple solid state detector located inside the gap of the objective lens working with backscattered electrons. During the whole project there was a close collaboration with the industrial partner. Attolight's crew produced the fiber based pointed photocathode for the generation of photoelectrons and provided the UV laser necessary to test the device.

At the end of 2009, Dr. Jean-Daniel Ganière gives a positive summary. “Actually we had planned to reach 100 nm using electrostatic lenses”, he comments. “But during the design phase, it turned out that magnetic lenses would be more suitable than electrostatic ones. We optimized them and this yielded a 7 nm resolution. Then the electron optics were built and a spatial resolution of 10 nm was achieved.” For production cost reasons, the researchers had planned to work at a fixed acceleration voltage of 5 kV. In the



course of their studies they realized that with magnetic lenses they could get a tuneable acceleration voltage between 1-5 kV. That was good news for Jean-Daniel Ganière: “Low acceleration voltages are crucial for applications on polymers and

-Resolved Cathodoluminescence TRCL



biological samples.” The results of the CCMX project open up new horizons for the semiconductor industry and Attolight is going to launch the product on the market. Concrete applications are for instance the defect analysis in Gallium nitride. Local

lifetime measurements bring the temporal dimension to defect analysis, providing further insight into defect optical activities. Another example are wide band gap semiconductors, as TRCL is the perfect tool for time-resolved measurement of materials

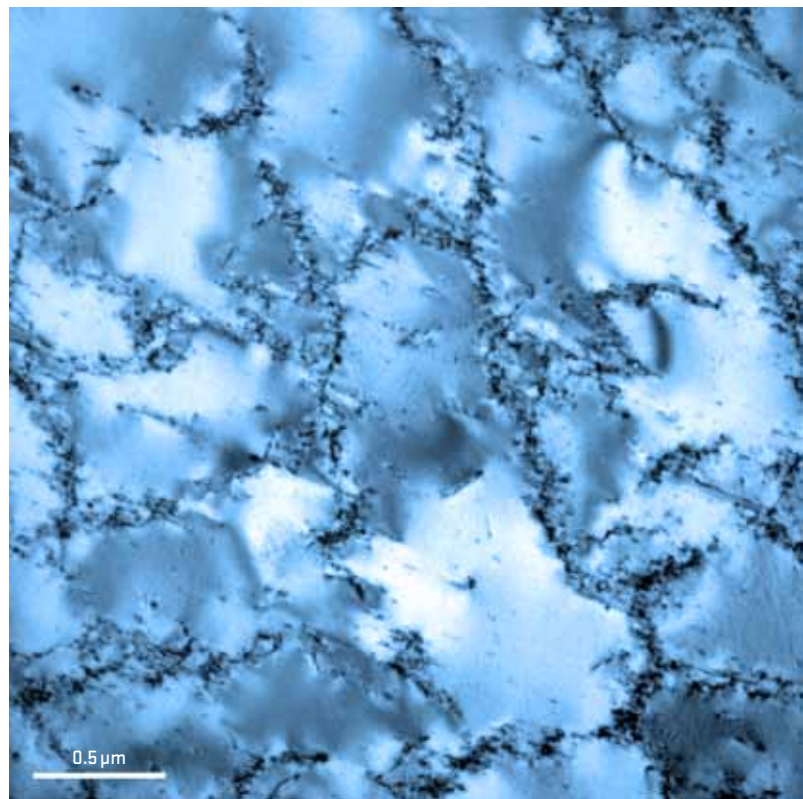
such as Boron Nitride, Aluminium, Nitride, with emission energies up to 6.88 eV. TRCL proves to be more versatile than laser excitation spectroscopy and ensures a rapid measurement of different samples in spectral ranges from ultraviolet to near infrared. 𐄂

Opening up new markets with ingenious

— MERU —

Today, there is a high demand for new sophisticated metallic alloys to meet the evolving requirements of the power generation, petrochemical and aerospace industrial sectors.

To tailor them for specific structural or functional applications, insight into the phenomena defining their thermo-mechanical behaviour needs to be gained.



In a co-operation between Empa, ETH Zurich and PSI, researchers are establishing relationships between micro-structural condition and the mechanical response of two types of steel to cyclic deformation at elevated temperatures. Two PhD students are examining an austenitic steel which softens and a bainitic steel which hardens as a consequence of constant strain amplitude low cycle fatigue (LCF). Their task is to quantify the variations in dislocation, sub-grain and glide band conditions as a function of temperature, cyclic strain and strain rate, and to create the basis of evolutionary equations for the internal state variables

which characterise the history dependence of cyclic deformation behaviour of the steels.

The PhD students first reviewed the existing knowledge. Then, by means of mechanical testing they determined the LCF endurance characteristics for both steels, each at two temperatures, using the resulting data lines to form the basis of test interruption campaigns to provide samples for micro-structural characterisation. The scientists used their new expertise to characterise the microstructure in samples taken from interrupted fatigue specimens. For this purpose,


they had recourse to TEM (Transmission Electron Microscopy), EBSD (Electron Back Scatter Diffraction) and SEM-BSE (Scanning Electron Microscopy in Backscattered Electron Mode). A complementary contribution was made by the Nuclear Physics Institute of the Academy of Sciences of the Czech Republic (CNPI) which accomplished the dislocation density measurements in interrupted fatigue specimens. A master student project examined the applicability of a number of cyclic plasticity models to both of the two steel varieties. The research activities are very complex and involve



the study of dynamic recovery, recrystallization, crack growth, dislocations density and subgrain formation. Characterisation of the thermo-mechanical behaviour of the steels will give the power generation industry in particular, a greater knowledge about the materials they are working with and it will allow both PhD students to prepare a thesis of high academic value in a pre-competitive environment between in-depth fundamental research and purely applied research.

Two other PhD students are working on a project involving PSI and Empa which

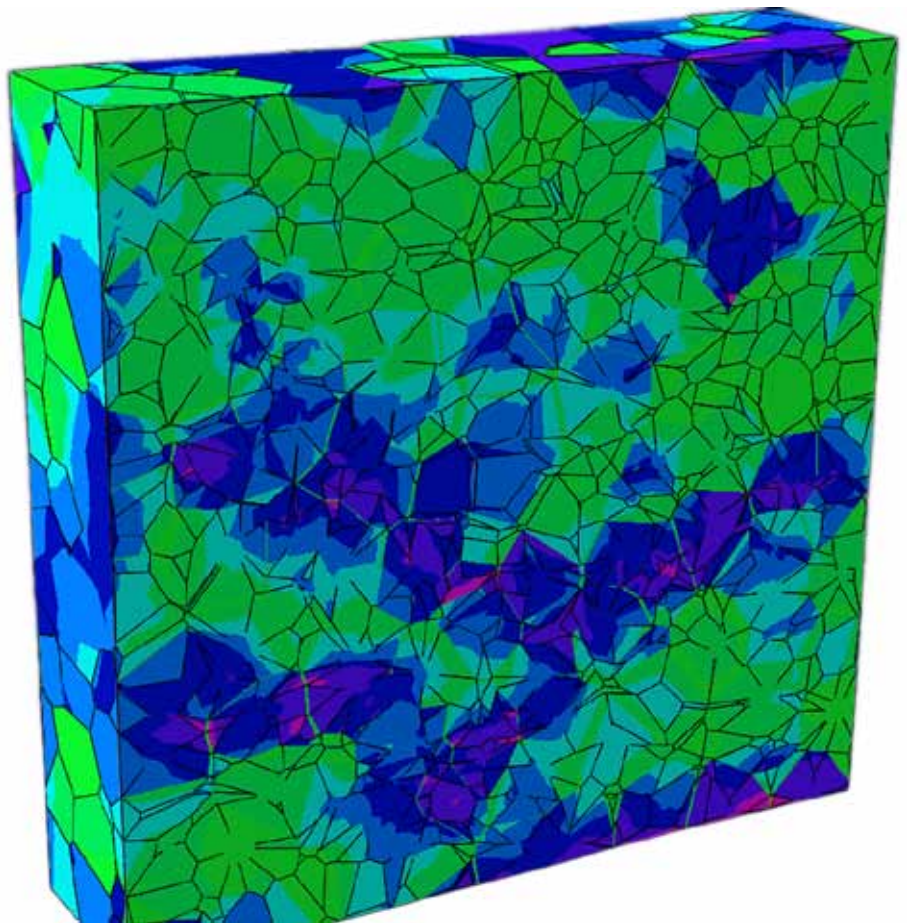
aims to understand the mechanisms which determine the relationship between the microstructures in advanced alloys and their deformation behaviour. While performing mechanical testing during neutron and/or X-ray diffraction, the scientists want to demonstrate the potential of in-situ techniques for understanding the dynamical behaviour of the microstructure during loading. The project focuses on two types of alloys. The first type are Ni-based single crystal superalloys used in turbine blades: this two-phase sub-micron structured material is known to coarsen during the application of stress

and temperature, a process that alters the material's performance. The second type are creep resistant steels where the repartition of stresses and strains over the different constituent phases is studied. The understanding of the load partitioning in relation to the microstructure should provide valuable input for predictive modelling of the materials behaviour in service type conditions. 

How to make use of modelling techniques

MERU

Computer simulation is a very helpful tool in metallurgy as it makes it possible to model, understand and optimize processes to obtain the best material properties with specific characteristics. Especially multi-scale modelling which allows different aspects of materials science and engineering to be linked from the atomistic to the process scale. Professor Michel Rappaz, who leads the Computational Materials Laboratory at EPFL and the CCMX Education & Research Unit on Metallurgy (MERU) agreed to answer a few questions.



1. Are numerical modelling techniques the ideal tools for materials research and development ?

MR: Materials are at the intersection point of different disciplines from basic research to applied technology. As such, they comprise multiple scales of length and time from the atomic structure to processes or component dimensions. The modelling tools for materials, developed in the last three decades by mathematicians, physicists, chemists and engineers are increasingly more comprehensive, important and helpful for scientists and engineers.

2. Can you name some running projects funded by CCMX in which such techniques play a role ?

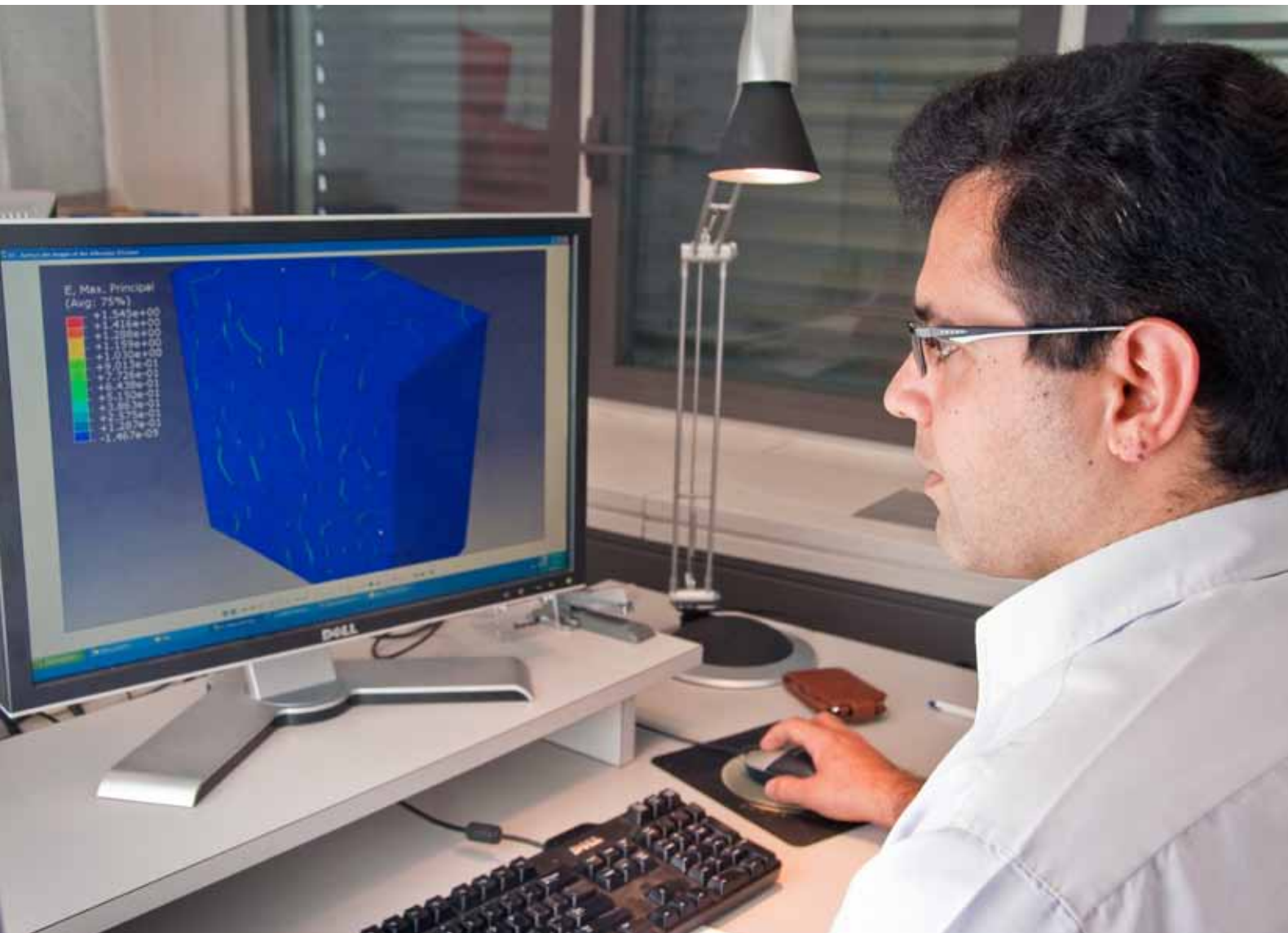
MR: In one project with several academic and industrial partners granular dynamics and phase field approaches are developed to study the formation of defects in solidification processes, namely micro-porosity and hot tearing. These two major defects occur during solidification of metallic alloys as a result of a lack of liquid feeding to compensate shrinkage and deformations. Another co-operation with industry deals with a combinatory study

and the modelling of optical properties of gold alloys as they are applied in the jewellery and watch industry. Two other projects dealing with mechanical properties of metallic alloys have an important simulation aspect as well.

3. Where do you locate the challenge in using modelling for materials in an efficient way ?

MR: On one hand it is essential to choose the appropriate tool for solving a specific problem. On the other hand it is important to manage the exchange of information

ques for metallic systems



between models developed on different scales – atom, grain, object – in an adequate way.


4. Is that where the CCMX network provides expert services ?

MR: Our task is to carry out research and continuing education in advanced technologies. On the occasion of a Technology Aperitif – an event we organize on a regular basis as a meeting place for researchers, developers and marketing people – visitors asked us to provide information on the possibilities of

modelling for the development of materials. In August 2009, in answer to this request, we organised a three day Summer School on Modelling in Materials Science with specialists from all over Europe and the USA. The high attendance confirmed the great interest for such topics.

5. Can you give interested parties from industry any advice ?

MR: The first thing is to consider precisely what you expect from modelling software before you get involved in this domain. Secondly, allow some time to build up an

expertise and a certain ‘culture’ of modelling in your company. A good example in this respect is the modelling of solidification processes of turbine blades, for which the EPFL – together with European and American industries – has developed sophisticated tools for many years. Within CCMX and MERU in particular, industrial partners can find specialists who can give them advice on how to make optimal use of these modelling tools. 

Flame Spray Deposition at low tem

Surface treatment by coating and

— SPERU —

They may revolutionise technological devices and open up multibillion dollar markets. “They” are the electroceramic thin films that show great potential for entirely new generations of advanced micro-devices as they offer huge functionalities which traditional semiconductor materials such as Silicon (Si) or Gallium Arsenide (GaAs) cannot provide.

Electroceramics present high capacity density, magneto-resistive properties, piezoelectric actuator or sensor functions, supraconductivity or electro-optical activity. If such electroceramics are incorporated in integrated semiconductor circuits the function of micro-electronics and micro-mechanics may even be combined. An example is the integration of ferro-electric ceramics on Si-CMOS circuits resulting in non-volatile, ferro-electric memories.

Scientists from ETH Zurich, Paul Scherrer Institute and Empa teamed up in the CCMX project NANCER in order to study these promising possibilities and to then hand them over to industrial partners for exploitation of results. They compared the properties of electro-ceramic thin films deposited with different methods and integrated them into micro-solid oxide fuel cells and gas sensor devices mounted on MEMS-based Si-chips. For this purpose they processed amorphous to nano-crystalline zirconia, ceria, perovskite and tin oxide-based thin films making use of five different thin film manufacturing methods and they examined their microstructure and electric conductivity evolution with respect to temperature and time. It was possible to establish laws for crystallization and grain growth of oxide thin films, results which the researchers published in high ranked journals. Micro-strain, defects and residual amorphous phases play an important role for the electric conduction properties of nano-crystalline thin films. The NANCER researchers found that the

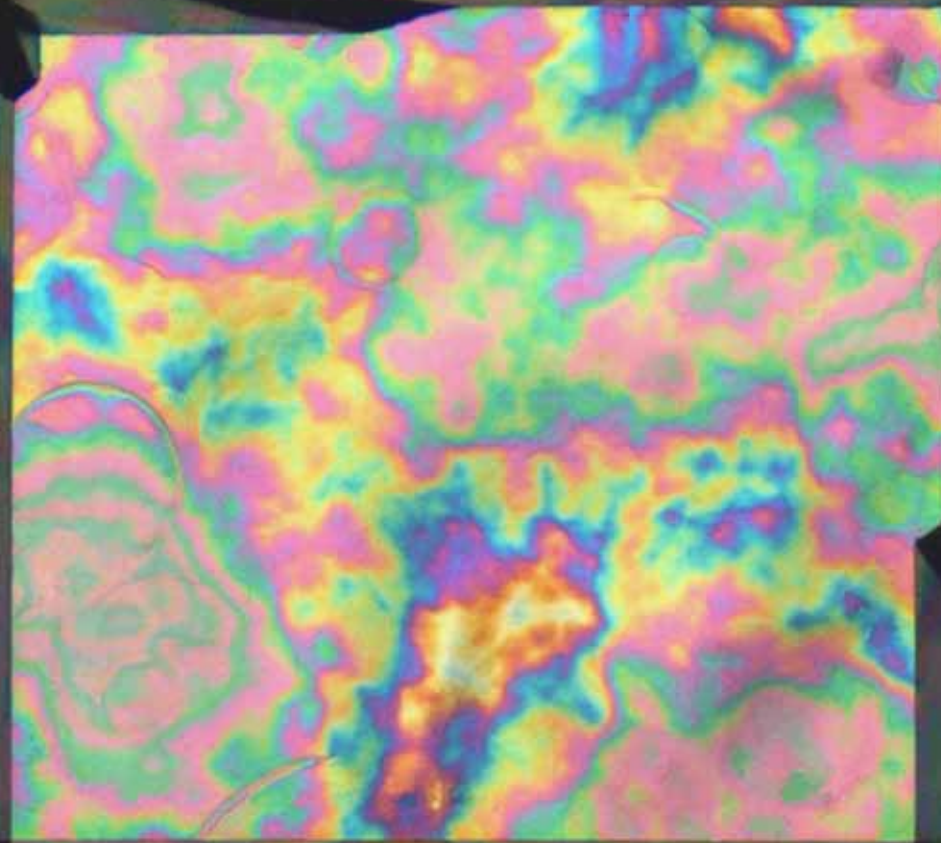


original thin film processing strongly affects the level of actual disorder in the oxide thin films and influences the crystallization process and grain growth as well as the electronic transport properties.

Nikolaos Karageorgakis, PhD student at Empa had the challenging task to investigate if it was possible to create sub-micron thick functional coatings using Flame Spray Deposition at low deposition temperatures. Flame-based processes are well-known for being a quick and inexpensive way to produce composite nanoparticles, but

would it be possible to deposit dense thin films at about 200°C? “In the first year I almost despaired as we did not succeed in achieving a thin coating by flame for specific ceramic materials”, remembers the mechanical engineer who previously worked at the ETH Zurich group of turbo-machinery. “But in early 2009, we succeeded in characterising the flame deposition process and began to understand its mechanism.” This was a real breakthrough! With their new findings they can now deposit different materials such as dense sub-micron films at tempe-

perature structuring



ratures as low as 200°C. “The process can potentially be used for thin film deposition on polymer substrates. This was not possible three years ago”, states Nikolaos Karageorgakis. “This allows for the first time the deposition of coatings on temperature sensitive substrate materials such as polymers, which have the ability to bend and create flexible products, but also melt when heated over 150°C - 200°C.”

These results open up a range of new possibilities to companies active in the coating business. They could now exploit

all the advantages of the Flame Spray Deposition process such as high production rates, low cost for raw materials, easy to scale up and relatively straightforward to operate. The scientist, who moved to Empa to prepare his PhD in nanotechnology, sees a bright future for surface modification. “We select a material and functionalize its surface, providing it with enhanced characteristics such as high electrical conductivity, reflectivity, or mechanical stability.” Although building a micro-Solid Oxide Fuel Cell was a main focus of the NANCER project and while

this target is extremely demanding in terms of materials and processing, the results developed so far are not limited to SOFC. “Surface treatment is very important in various applications in everyday life, for instance coatings inside plastic bags for food preservation, in automotive industry for paints, in energy-related devices such as touch screens for mobile phones, in glass industry to create reflecting coatings.” The coating industry can really benefit from the new knowledge generated during the NANCER project to innovate and break into new markets. 𐄂

From ice cream to foams and micro-capsules

— SPERU —

What do whipped cream and ice cream have in common?

They are so called Pickering emulsions, in the former case stabilized by fat particles, the latter one stabilized by ice crystals.

This principle is the basis for the development of novel foams with tailor-made porosity, pore size distribution and pore connectivity by materials specialists at ETH Zurich and EPFL within the CCMX funded project *Smart Functional Foams*. The scientists use surface modified colloidal particles as foam stabilizers. The resulting wet foams are stable for long periods of time which allows for an improved control of the inner foam micro-structure. This is a prerequisite for a well-controlled fabrication of porous structure with defined porosity and pore sizes and exceptional properties.

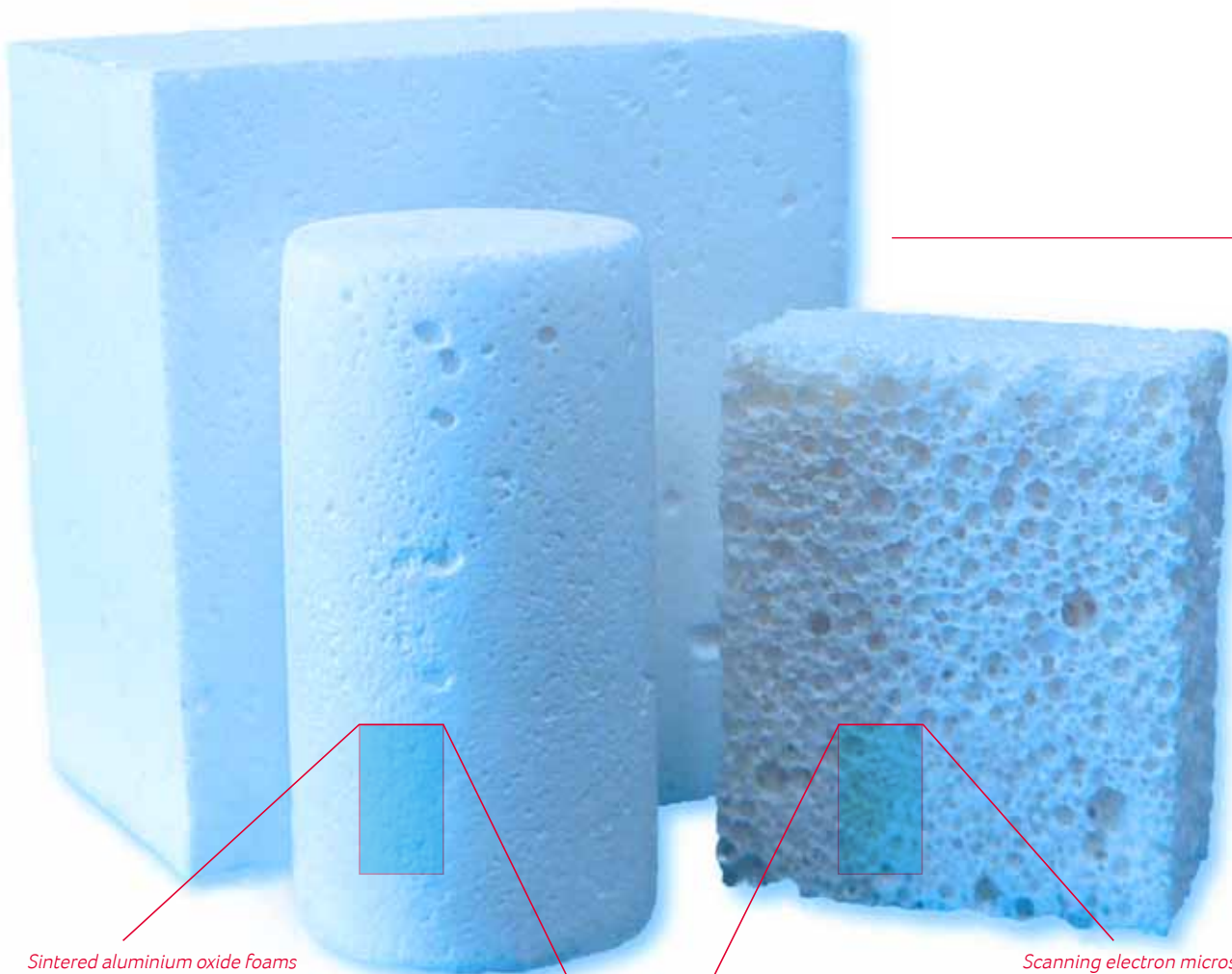
On the basis of these Pickering emulsions the researchers produce porous materials from any powders, may it be polymers, metals or ceramics. The micro-structure of these foams after consolidation can be tailored in a broad range concerning the porosity and the size of the pores. Porosity can range from anything around 30% up to 95% and the average pore sizes can range from 5 μm to 1 mm. Even the permeability of gas or liquids can be adjusted in a wide range. Therefore the foams are promising candidates for novel bone grafts and efficient insulation materials for temperatures up to 1700°C.

“We produced solid foams out of ceramics, metals, polymers and composite materials. It was in fact possible to obtain robust foams from highly inflammable metal particles, a real challenge”, comments Dr Urs Gonzenbach, scientist in the team of Professor Ludwig Gauckler of Non-metallic Inorganic Materials at ETH Zurich. “We developed a procedure to achieve open pores of 100 μm in ceramic foams with controlled pore sizes and apertures and at the same time high mechanic stability.” In the course of their work the engineers also came up with a processing chain for stiff foams made from Ti and Ni/Ti nano particles in an oxygen-free atmosphere. “The oxygen content of less than 2 mass percent in dry, porous material and the average pore size of less than 50 μm look very promising”, proudly says the ETH Zurich researcher.

To bring the patented results to market, Urs Gonzenbach, co-inventor of the technology, established his own company with the help of his colleagues; an ETH spin-off *de Cavis AG*. Based on the ETH Zurich platform, *de Cavis AG* develops and markets inorganic porous materials, suitable wherever there is a demand for saving heat loss and cost-cutting. Areas of

application are industrial plants and furnaces where the temperature exceeds 1400°C. One of his trump cards is the controlled formation of wet foams and emulsions with different compositions and micro-structures. “As the foams and emulsions show high stability in their wet state, we can process them to porous, fibre-free materials or solid-coated micro-capsules with particular characteristics”, explains Urs Gonzenbach. He sees applications as thermal insulation and light-weight construction materials, but also as micro-capsules with a special structure for the encapsulation and release of chemical components, for instance in cosmetics and bio-medicine and catalysis.

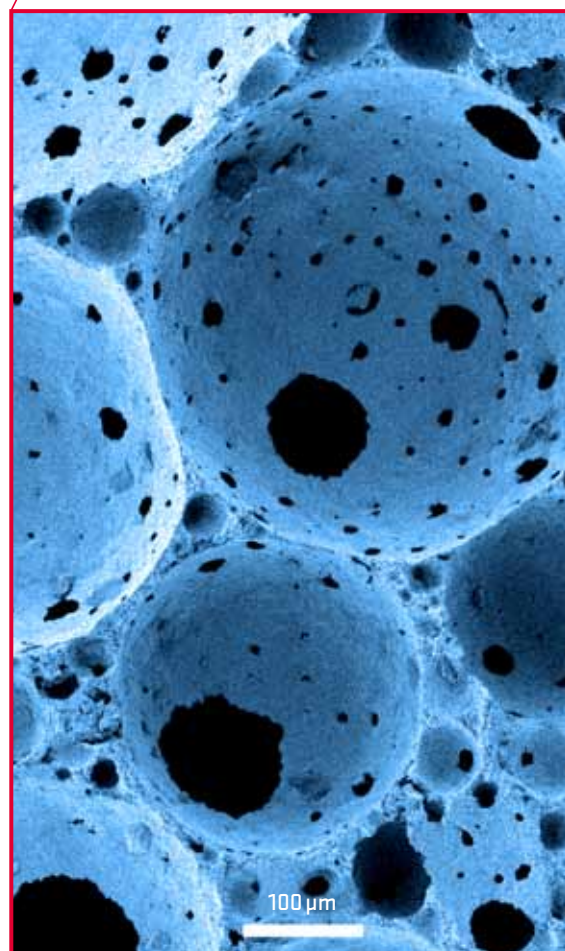
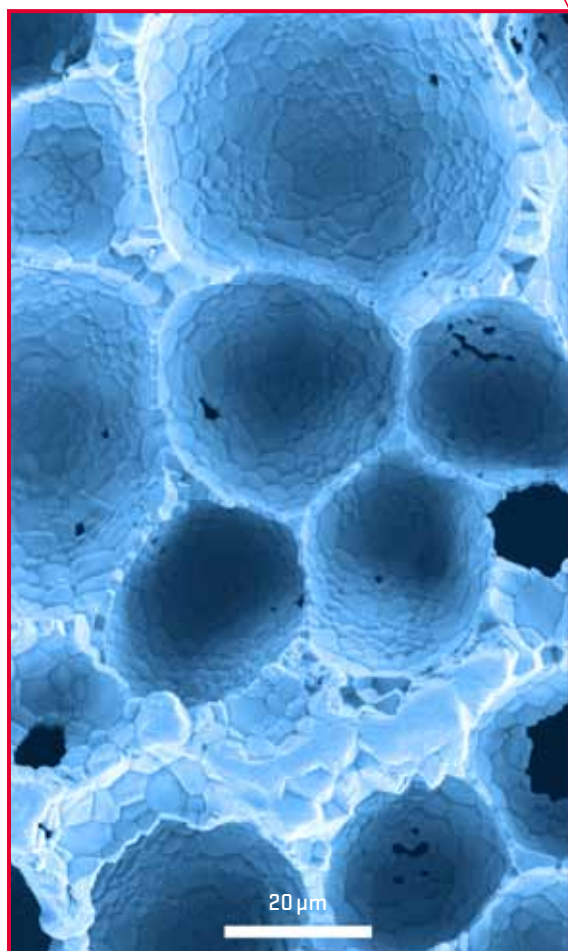
The micro-capsules can be made from different raw materials and customized by size and permeability. “Inorganic, solid-coated micro-capsules are more advantageous than polymer and tensile based systems because of their very good chemical and heat stability”, the young entrepreneur explains. With their smart functional foams, invented at ETH Zurich and further developed within the CCMX programme, the scientists set a new standard in the promising domain of materials technology. 𐄂



Sintered aluminium oxide foams with pores of different sizes. Even though they consist of 87% air, they are of high mechanical stability. (Picture: de Cavis)

1 cm

Scanning electron microscope picture of thin aluminium oxide walls separating each single pore of the ceramic material. (Picture: de Cavis)



Our little helpers : Nanoparticles as Functional particles in contact with

— MatLife —

Nanoparticles have the potential to create drugs of a new kind, as they enhance their bioavailability toward targeted diseased cells, and improve tissue penetration and distribution while minimizing side-effects. The work of Jeffrey Alan Hubbell, Professor at EPFL's Merck Serono Chair in Drug Delivery, focuses on nanoparticles. In collaboration with EPFL Professor Melody Ann Swartz at the Laboratory for Lymphatic and Cancer Bioengineering, he has implemented a nanoparticle-based vaccine platform to produce novel immunotherapies based on materials with bio-functional and immunofunctional capabilities.

CCMX: *Your novel polymer nanoparticle formulations specifically target the draining lymph nodes, the 'filter stations' for tissue fluid in the human body. What is your intention ?*

JAH: As recent studies have proven, the best way to achieve sustained immunity is to deliver an antigen directly to antigen-presenting cells - the dendritic cells (DC). The problem is that DC can only be found in low concentrations in peripheral tissues – the target area of vaccines – unlike lymph nodes. It thus makes sense to deliver an antigen to DC in lymph nodes. In order to activate DC, we need an adjuvant that matures DC and initiates the subsequent immune response. Adjuvants are vital, as most protein and peptide antigens do not show sufficient immunogenicity.

CCMX: *Did you succeed in solving the problem ?*

JAH: Yes, thanks to the self-assembly of polymer material Poly(ethylene glycol)/Poly(propylene sulphide), we obtained



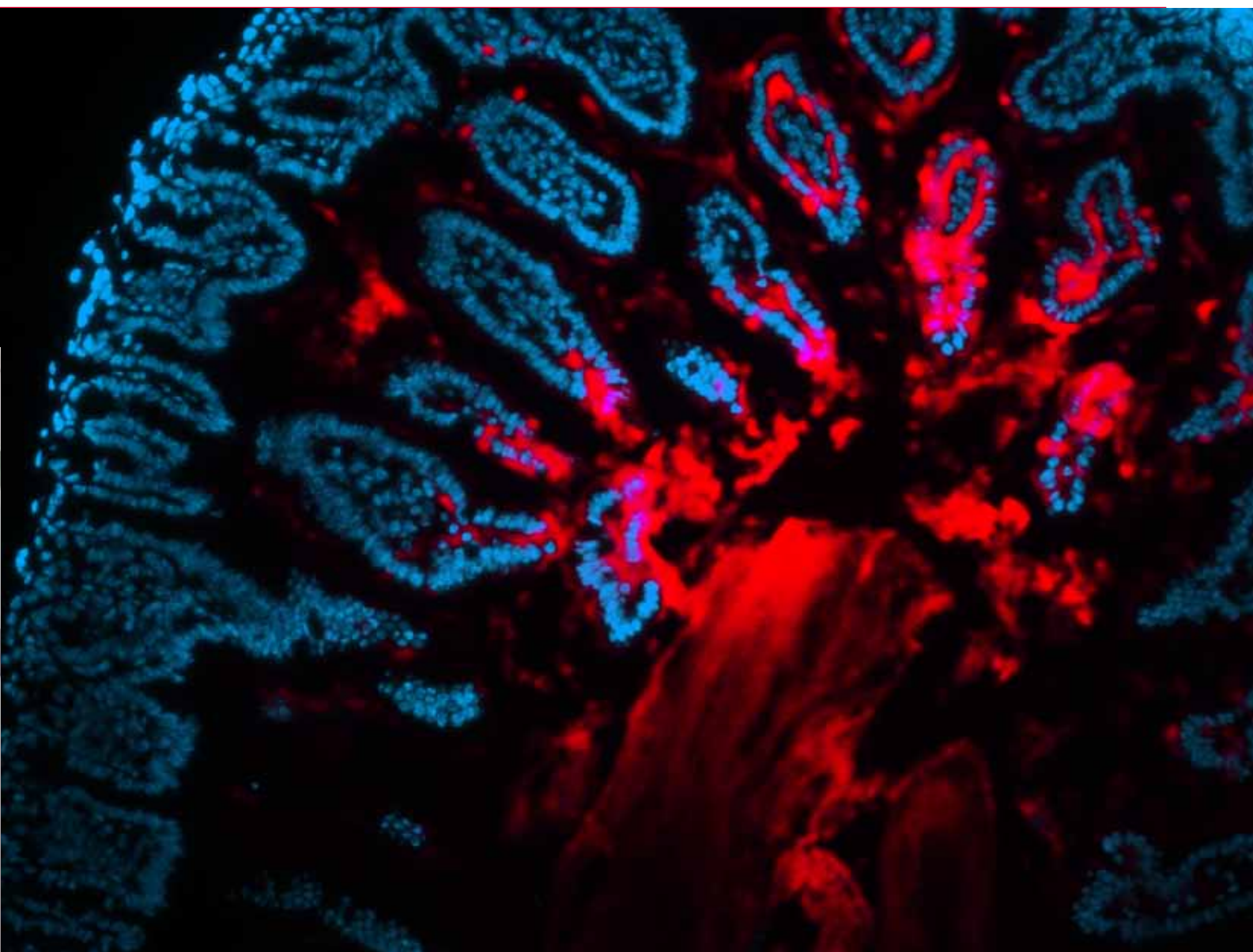
nanoparticles of about 10 - 20 nm in size. By means of intradermal injection, the colloidal objects were readily transported by interstitial flows into lymphatic capillaries, leading to their accumulation in the draining lymph nodes. We designed the nanoparticle surface chemistry for DC activation and were able to trigger an adaptive immune response. Our nanoparticles are thus able to carry hydrophobic drugs and degrade within oxidative environments. With ovalbumin as a model antigen conjugated to the nanoparticles, we have succeeded in proving humoral and cellular immunity in tests with mice.

Our current work with a tuberculosis antigen looks remarkably promising.

CCMX: *Nanoparticles as drug carriers fuel ambitious expectations, and researchers around the globe are working eagerly on the topic. What is so special about your research at the EPFL ?*

JAH: There is indeed a lot of research being carried out in the domain of novel vaccines, but what makes our development so special is that our nanoparticles are smaller than most viruses. This is the result of our cooperation with Melody A. Swartz. While she focuses on the physiology and

a drug carrier biological fluids



biology of lymphatic vessels and lymphatic transport, we study self-assembly and drug delivery in the tissue.

CCMX: *How did the international vaccine community and possible future industrial partners react towards your results?*

JAH: If you can show laboratory disease models, the industry will show interest in your development. We were successful in obtaining funding from the European Commission to lead a project and have also been approached by the Bill & Melinda Gates Foundation, which supports us in the domain of infectious diseases,

a priority area of focus of the foundation. A focal point is a tuberculosis vaccine.

CCMX: *Legend has it that there are fears over unknown consequences of nanotechnology.*

JAH: Most individuals are exposed to particles in the ambient atmosphere, especially from diesel fumes. Any combustion process produces nanoparticles. But nanoparticles – designed to be biocompatible and produced in a responsible way – open up fantastic possibilities for improving human health and healing or preventing diseases incurable at the

present day. Just think of influenza, which spreads around the world in seasonal epidemics, costing the lives of up to half a million people each year. As flu evolves so rapidly, a vaccine formulated one year can be ineffective the next year. Here, we need better and faster methods for developing new active agents on a chemical basis. It is also worth remembering that today's biological vaccines must be stored at low temperatures, which is problematic in developing countries. With our approach, the vaccines are stable and refrigerators may no longer be needed. 🏠

New healing opportunities foreseen Medical device technology and innovation

— MatLife —

The aim to repair or replace lost or damaged tissue and organs by creating living, functional substitutes from autologous cells stimulates researchers all over the world. A promising clinical methodology to reconstruct tissues for transplantation is *cell sheet engineering*.

For this purpose culture surfaces are grafted with temperature-responsive polymer that makes it possible to attach and detach living cells in a controlled way via simple temperature changes from 37°C to below 32°C. The cultured cell sheets can be harvested from the surfaces to create functional tissue sheets for the treatment of diseases like corneal dysfunction, oesophageal ulcerations, cardiomyopathy or type 1 diabetes. Up until now, the thickness of the cell sheets was limited to thin structures - up to five cell layers - because neither oxygen nor nutrition could be supplied to the cells in a sufficient quantity. A new approach is pursued by a group of scientists at ETH Zurich and University Hospital Zurich conducted by Professor János Vörös from the Institute for Biomedical Engineering of ETH Zurich. They develop 3D designed composite materials consisting of cell sheets and polymer hydrogel films. The 3D cell/polymer multilayers serve as a platform to spatially pattern different cell types for *in vitro* analysis and for drug screening. "The fascinating novelty in this project is the interdisciplinary approach", states PhD student Orane Guillaume-Gentil. "While our strong point is cell sheet technology, the obstetricians of University Hospital Zurich contribute by providing their know-how in human stem/progenitor cell biology in 3D culture, and the Department of Cranio-Maxillofacial Surgery focuses on tissue engineering of bone and cartilage and is specialized on *in situ* tissue engineering by using newly developed synthetic and biomimetic materials."

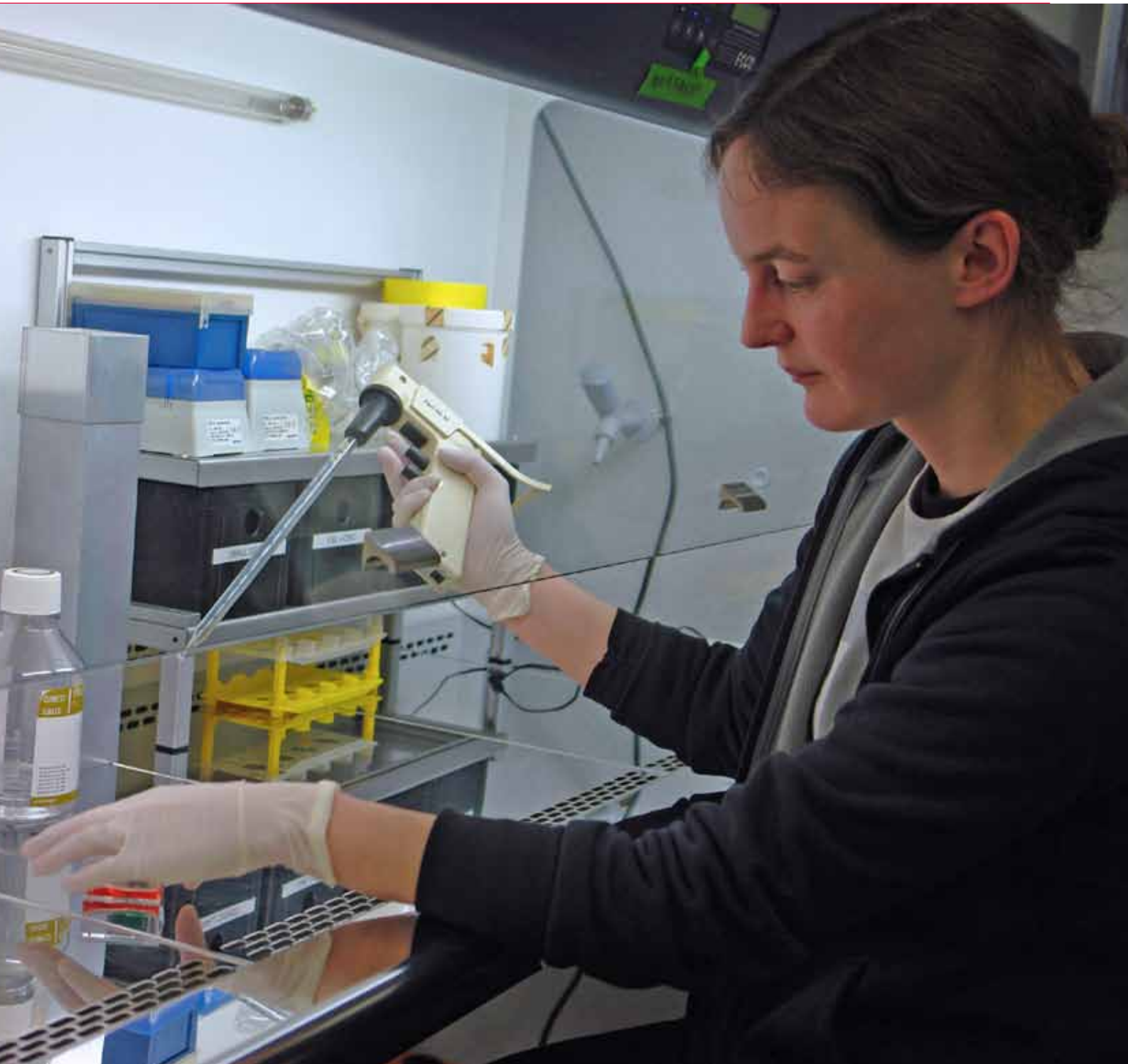
The innovative approach of the ETH Zurich scientists is to harvest the cell sheets by electrochemical means. This procedure, combined with micro-patterning techniques, allows the control of the spatial organization of the cells in 2D. "We develop a 3D composite material consisting of alternating layers of 2D engineered, heterotypic cell sheets and micro-structured biodegradable polymeric hydrogels, containing cells, proteins and growth factors", explains the cell sheet specialist." The main achievement of the CCMX project is the development of the procedure to tailor the dissolution speed using cross-linked coatings. Right at the start the polymer multilayer films were too soft for anchoring the mesenchymal stem cells on the surface. Thanks to the cross-linking polymer, the scientists increased the stiffness which supports the stable adhesion of the mesenchymal stem cells, a prerequisite for the preparation of viable cell sheets.

"We are now in a position to produce thicker tissues thanks to more uniform oxygen and nutrition supply to the cells inside the materials through engineered porosities and to obtain a platform for cell sheet engineering with electronically switchable micro-structured surfaces." With this platform the researchers can tune the mechanical properties of the composite material by selecting the polymer layers and processing it easily into different shapes and sizes. Based on these results it was possible to establish optimal cell density and cell culture time and successfully harvest stem-cell sheets.



"The challenge is to provide the cells with a 'feel good' ambiance to grow, that is to say, the same conditions as they will find in their future environment after they are grafted." Using the new method developed at ETH Zurich, cells are organised in a well-defined multilayered

with innovative cellsheet engineering vation



3D environment of designed polymer substrates presenting specific and variable cues for cell growth.

“Regenerative medicine has the potential to open up healing opportunities that were unimaginable up to now”, states

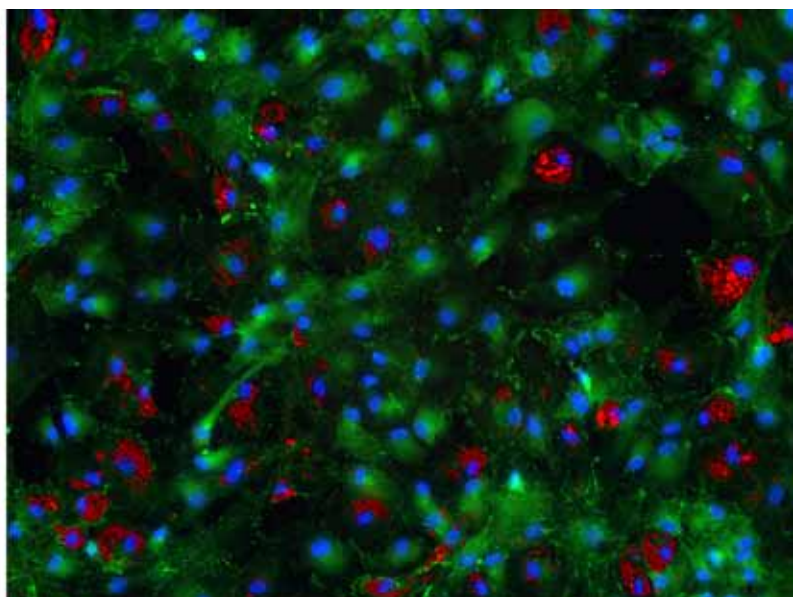
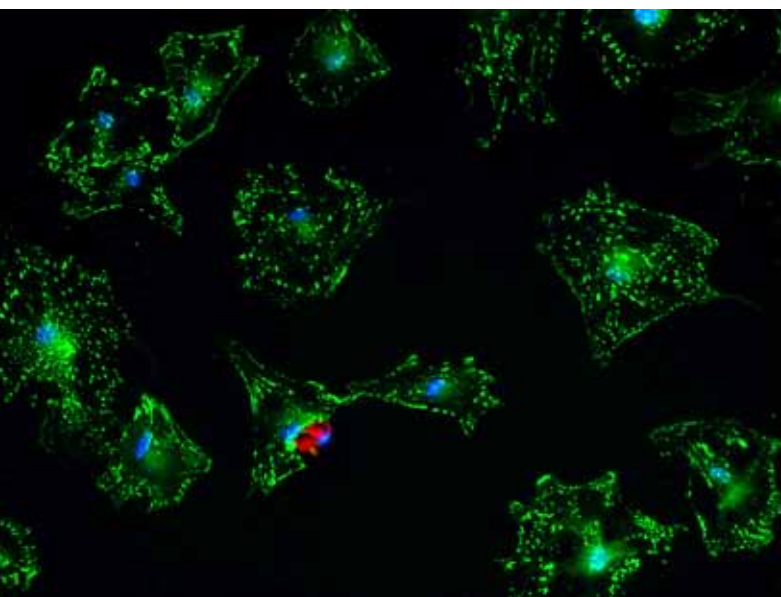
Orane Guillaume-Gentil. “But to make the necessary technology take off, we have to leave the beaten track, link different scientific domains and exploit synergies, as the really innovative new things emerge at the interface of disciplines.” The international research community is

closely following the Swiss activities in this domain : part of this work was awarded the best abstract prize at TERMIS EU 2008, the European section of the Tissue Engineering & Regenerative Medicine Society, and the project results were published in the renowned *Tissue Engineering Journal*. 🇨🇭

How to create the perfect environment Biosensing and diagnostic strategies

— MatLife —

For basic biological questions as well as drug screening, single cells or cells in 3D scaffolds are currently a focal interest of scientists. Cell responses are influenced by cues such as pH, temperature, growth factors and nutrients, but also through the binding to matrix components, other cells or the mechanical properties of the environment. With artificial, engineered environments, these different parameters can be independently controlled, thereby enabling the investigation of the relationship between relevant stimuli and cell response.



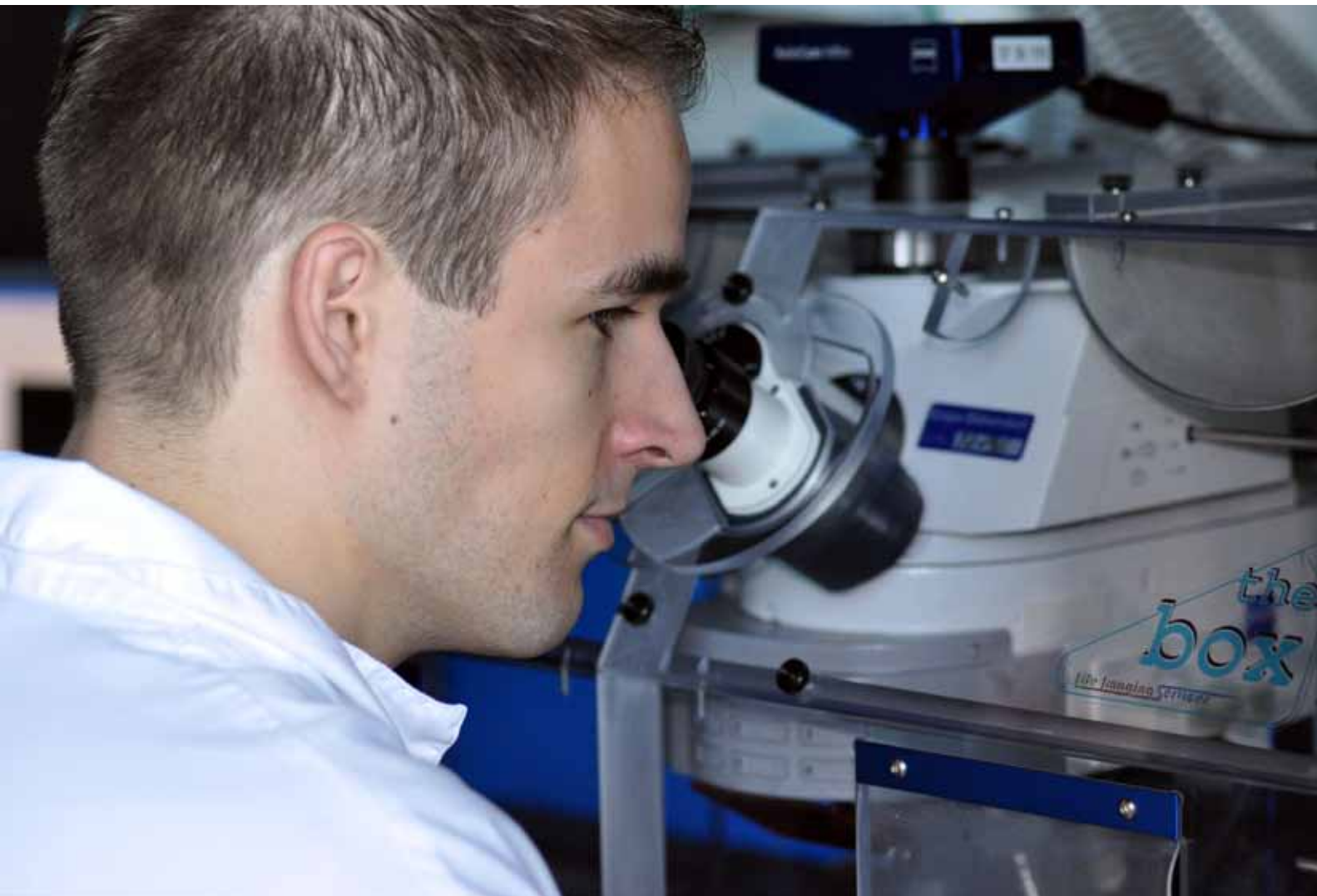
Researchers from ETH Zurich, Empa and AO Foundation Davos were joined by industrial partner F. Hoffmann–La Roche Ltd. to develop a platform technology that allows investigation of the cell behaviour in specially engineered 3D micro-environments. This technology consisting of adhesive micro-wells, which gives control over dimensionality and cell shape, was developed a few years ago by the team of Professor Marcus Textor at ETH Zurich. Up until recently it was only possible to entrap cells in micro-wells for up to 24 hours and the relevance of the experiments for stem cell studies was limited. A major task of the

CCMX project was to modify the existing technology to allow experiments with stem cells over a period of several days, enabling the investigation of biological questions which could not be answered up to now. In order to perform the stem cell differentiation experiments, the researchers developed a method to functionalize the micro-wells with an adhesive protein (fibronectin) followed by passivation of the plateau surface. They first coated the micro-fabricated PDMS (Polydimethylsiloxane) sample with fibronectin, stripped off this layer only from the plateau surface with a glutaraldehyde-coated PDMS stamp

which was then followed by backfilling the plateau with Pluronic®, a block co-polymer based on ethylene oxide and propylene oxide. “It took a while to get it working”, says Markus Rottmar, PhD student at Empa, who is writing his thesis on this topic.

Also, to study the cells in their 3D environment, the scientists introduced genes into the cells which code for specific proteins of interest fused to fluorescent proteins. The fluorescence can then be followed in the living cells in real-time for several days to determine, for instance, how the cell architecture changes in the course of the

for single cells



cultivation. “But the statistical evaluation of the experiments requires a great number of pictures of single cells which leads to an enormous amount of data and complicates the analysis with conventional software and algorithms”, explains the young scientist, who used to work at the Institute of Molecular Systems Biology at ETH Zurich. “For my diploma thesis I had the opportunity to work on a basic research subject in the field of bacterial physiology. But for my dissertation I looked for a new challenge and was immediately interested in the interdisciplinary problem area of this project.”

A specific application of the micro-well arrays could be the study of anti-cancer drugs on cancer cell clusters grown in a 3D environment. The arrayed format of the micro-wells ensures that this platform is suitable for an automated imaging, making it appropriate for high throughput screening. It also offers the advantage of a controlled 3D environment in which different extrinsic parameters can be varied independently. Therewith it is a promising tool for the observation and quantification of biological phenomena in highly controlled 3D environments. F. Hoffmann-La Roche shows great

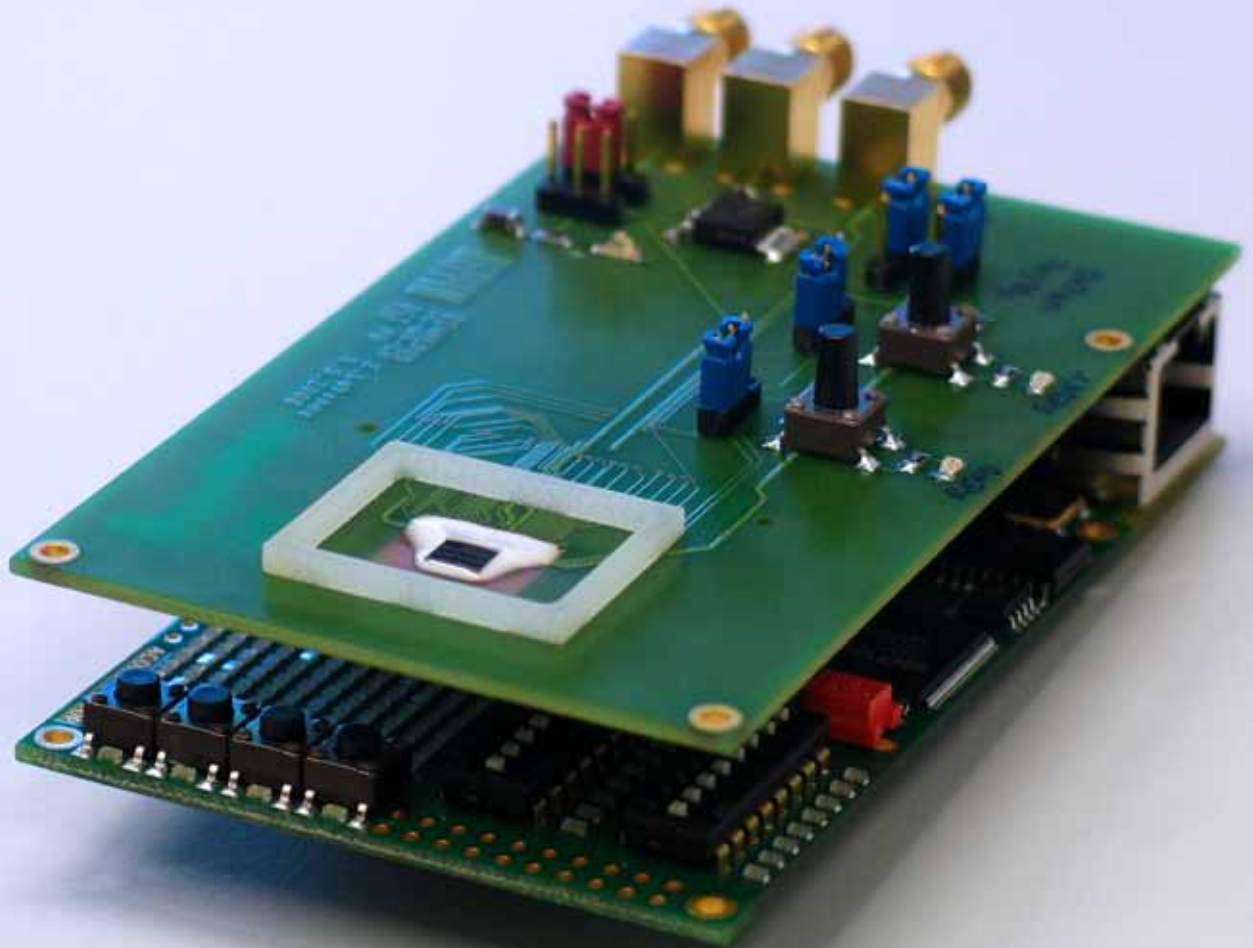
interest in the CCMX project results. “The micro-well platform could be exploited for fundamental biological studies as well as cell-based assay for drug development and screening”, comments Markus Rottmar, who is moving ahead step by step. In November 2009 he published a paper in the *Journal of Material Science – Materials in Medicine* on ‘Stem cell plasticity, osteogenic differentiation and the third dimension’ together with ETH Zurich scientists and Michael Smith, today at the Department of Biomedical Engineering at the Boston University, with whom he keeps in touch. 卐

Materials for micro- and nano systems

The Lab-on-a-chip – a reliable way to

— MMNS —

“What a huge relief! The whole technical team is delighted that it works so well.” The ‘thing’ Norman Wainwright of the Charles River Laboratories was so happy about on this spring day of 2007 was a miniature biological laboratory tested for the first time onboard the International Space Station. The Lab-on-a-Chip detected the presence of bacteria or fungi on the surfaces of a spacecraft far more rapidly than standard methods of culturing.



There is a revolutionary potential in these mini-labs because of their low cost and their moderate substrate consumption, the rapid and efficient blending and heat-up, the better process control and the high degree of automation. In pharmaceutical and genetic research scientists can make thousands of parallel experiments, allowing a more rapid and reliable development of new drugs and a quicker identification

of genes. Lab-on-a-Chip Technology helps to control food quality, to monitor environment parameters and medical devices, for instance regarding the automatic insulin supply.

An innovative approach to Lab-on-a-Chip technology was chosen by a team of scientists under the aegis of Professor Martin Gijs of the EPFL Microsystems Laboratory. The

team is working on a CMOS micro system for magnetic particle actuation with integrated optical detection to move and detect magnetic micro particles in fluids. Since the principles of actuation and detection are not coupled, it is possible to use the particles as mobile substrate to transport bio-materials and to perform on-chip analysis without interference between actuation and detection. The

detect antibodies in a substance

researchers modify magnetic particles with a thin polymer layer. On one hand this prevents the particles from aggregation in aqueous solution and on the other hand it allows functionalization with antibodies that enable binding of specific bio molecules.

“The innovative content of our systems resides in the integration of sensitive optical detectors and magnetic manipulations structures in one single, monolithic CMOS chip”, comments Emile Dupont who is working on his Ph.D. in the frame of this project. Magnetic bead-based immunoassays in the LOC format using optical or fluorescent detection already exist, however, they all need a high-end microscope detection platform to show a satisfying system performance and high sensitivity. This can limit the application scope of the device, particularly for point-of-care testing. Moreover it increases analysis costs and impedes a comfortable use. “With our LOC we perform complete immunoassay quantification directly on-chip”, states the Doctoral Assistant. “In this way we obtain microscope-less fluorescence detection with high sensitivity.”

Emile Dupont was born in the bilingual Aosta Valley in Italy. He received his B.S. from the Politecnico di Torino and a joint M.S. from the Politecnico di Torino, the Institut Polytechnique de Grenoble and the EPFL with maximum grades. During a stay at Cambridge University he experimented with ANSYS simulation and he then worked at the CERN on his Master Thesis ‘From Macro to Micro Computational Fluid Dynamics’. What was the big



challenge of the CCMX project? “The magnetic manipulation of single micro beads”, he admits. “But even trickier was the integration of a micro fluidic chip on top of the CMOS system.” For this purpose the scientists created a custom Poly-dimethylsiloxane (PDMS) micro fluidic cartridge in two separate steps, because they needed the beads in the channel to be as close as possible to the micro actuation coils and to the integrated detectors in the chip. “We thus had to design a channel with a bottom wall as thin as possible – about 20 to 25 microns – and to integrate it on top of the chip geometry.” As a first impressive

result the researchers can detect selectively the cancer biomarker 5D10 mAb, directed against the human breast cancer cell line MCF-7, down to a detection limit of 1 ng/mL, without the use of a bulky and expensive fluorescent microscope setup. During the whole development, the EPFL scientists worked closely together with Microsens SA in Neuchâtel, a specialist of integrated sensor technology. “The interest from the industrial side is very encouraging”, explains Emile Dupont. “But we are still pretty much at academia level and many questions have to be solved before we can think about industrialization.”

2009 Data

Use of funding in 2009 (KCHF)

Funding of projects	4'188
Education activities, conferences	183
Industrial liaison	180
Management & administration	449
Total	5'000

Metrics for 2009

26	Running projects	5	PhD students not paid by CCMX (FTE)
51	Professors involved in projects	48	Publications (peer reviewed)
10	Senior scientists (FTE)	1	Invention disclosure
3	Post docs paid by CCMX (FTE)	3	Patents
3	Post docs not paid by CCMX (FTE)		
32	PhD students paid by CCMX (FTE)		

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Projects funded in 2009

Title of project	Principal Investigator (PI)	PI's Institution	Others Institutions	ERU/ Platform
Development of novel methods for surface modification and investigation of cell-particles interaction for superparamagnetic nanoparticles (PAPAMOD)	Philippe Renaud	EPFL	EPFL (2), PSI	SPERU
Nanocrystalline ceramic thin film coating without sintering (NANCER)	Jennifer Rupp	ETH Zurich	ETH Zurich, Empa, PSI (2)	SPERU
Smart functional foams	Ludwig Gauckler	ETH Zurich	EPFL, ETH Zurich (2)	SPERU
Zero order nano optical pigments (ZONOP)	Alexander Stuck	CSEM	EPFL	SPERU
Photochemically functionalizable scaffolds for Tissue Engineering and Nerve Regeneration	Christian Hinderling & Matha Liley	CSEM	ETH Zurich (2)	MatLife
Immunofunctional Nanoparticles	Jeffrey Hubbell	EPFL	EPFL, ETH Zurich	MatLife
Multivalent Lectin Array: A Combinatorial Approach	Peter Seeberger	ETH Zurich	ETH Zurich	MatLife
Bio-functionalized, biodegradable nanostructured magnesium implant for biomedical applications	Samuele Tosatti	ETH Zurich	ETH Zurich (4), Empa	MatLife
Three-Dimensionally Designed Cell Cultures Consisting of Microstructured Cell-Sheets and Polymer Layers for Tissue Engineering	Janos Vörös	ETH Zurich	EPFL, Unispital Zurich	MatLife
Platform for high-density parallel screening of membrane receptor function	Horst Vogel	EPFL	ETH Zurich (2), CSEM	MatLife
Studying Single Cells in Engineered 3D Microenvironments	Viola Vogel	ETH Zurich	ETH Zurich, Empa	MatLife
Lab-on-a-chip for analysis and diagnostics	Martin Gijs	EPFL	EPFL (6), CSEM	MMNS
Materials, devices and design technologies for nanoelectronic systems beyond ultimately scaled CMOS	Yusuf Leblebici	EPFL	EPFL (4), CSEM, ETH Zurich	MMNS
Development and characterization of nanowires for applications in bio-electronics	Janos Vörös	ETH Zurich	ETH Zurich, PSI	MMNS
Evolution of microstructure and mechanical response due to cyclic deformation at elevated temperatures	Stuart Holdsworth	Empa	ETH Zurich, PSI	MERU
In-situ mechanical testing	Helena Van Swygenhoven	PSI	Empa (2)	MERU
Modelling of defect formation in solidification processes using granular dynamics and phase field approaches	Michel Rappaz & Alain Jacot	EPFL	Empa, PSI	MERU
Combinatorial study and modeling of optical properties of gold alloys	Ralph Spolenak	ETH Zurich	PSI	MERU
Label free imaging of molecular adsorption on in-situ surface-functional patterns	Nicholas Spencer	ETH Zurich	Empa	NNMC
Nanoscale resolution optical microscopy for material imaging and spectroscopy	Christian Depeursinge	EPFL	EPFL, CSEM	NNMC
Vibrational spectroscopy of nanostructured surface systems	Davide Ferri	Empa	ETH Zurich, Empa	NNMC
Time-resolved cathodoluminescence (TRCL)	Jean-Daniel Ganière	EPFL	ETH Zurich	NNMC
Microtome4SIMS: Chemical Tomography of Biological Material with 100 nm Resolution	Beat Keller	Empa	UniSpital Basel	NNMC
Nano-Xas	Iris Schmid	Empa	PSI	NNMC
Development of a X-ray phase contrast instrument for the characterization of materials with low atomic mass	Claus Urban	CSEM	Empa	NNMC
MaCH ² – The Analytical Equipment Database	Susan Meuwly	EPFL	–	NNMC

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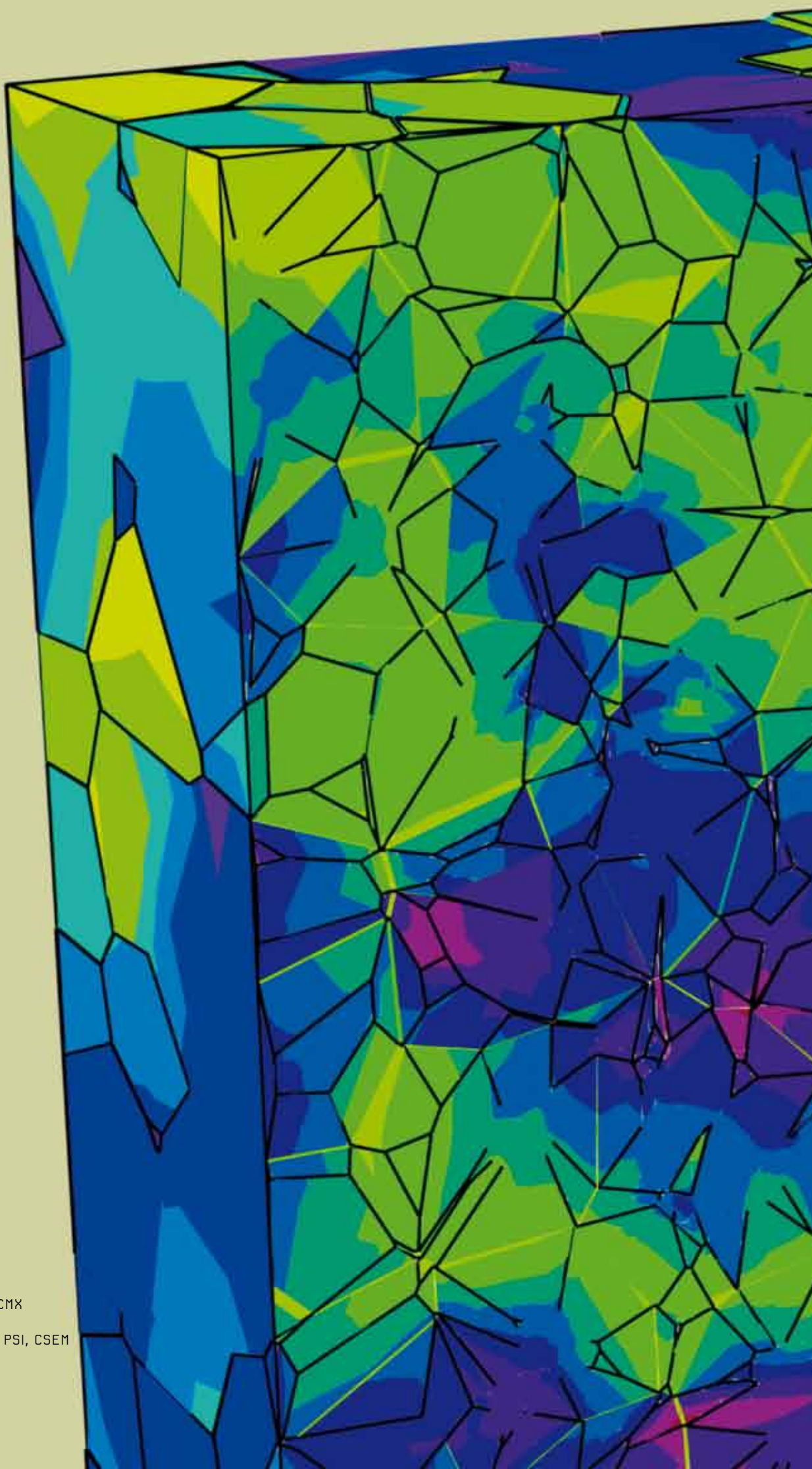
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