CCMX
Competence Centre for
Materials Science and Technology

Annual Activity Report 2012

Annual Activity Report 2012

Contents

CCMX and Materials Science in Switzerland:

2012 has seen CCMX's continued success in creating new opportunities for collaboration between Swiss industry and academic research institutions—with the appointment of new professors, negotiations for industry involvement in the Materials Challenges research initiative, course offerings and outreach events.

PHOTO NATHALIE JONGEN

CCMX's OMNY project scientists meet with the engineering team.

PHOTO TONY KUNZ

Participation at the CCMX Annual Meeting 2012, Bern.

CCMX was formed to create new opportunities to link the research capabilities of Swiss academic institutions and to build strong industrial partnerships in the field of materials science. Following seven years of productive Public-Private partnerships (PPP), industry and academia have reached an unprecedented level of cooperation and understanding. Within its network of ETH Domain research institutions and CSEM, CCMX catalyses collaboration across a wide range of multilateral research programmes.

CCMX's continuing focus is to consolidate and extend these kinds of collaborations through its strategy of 'New Professor Chairs' and 'Materials Challenges', with the ultimate goal of enduring sustainability. This tandem approach co-funds new professors at EPFL and ETH Zurich in priority research areas identified by industry, and launches research platforms, co-funded by industry, to tackle critical scientific issues.

In early 2013, two professors were appointed, one each at EPFL and ETH Zurich. Recruitment of two additional professors to start in 2014 is well advanced. Negotiations to launch two Materials Challenges—Functional Coatings and Nanoparticles Safety Assessment—are in the process of being finalised in 2013.

In addition to 28 ongoing research projects, 2012 included a dynamic programme of courses and events that attracted both academic and industrial researchers. Industry partners confirm that training by research is essential, and that hiring former PhD students is a valued form of knowledge and technology transfer. The solid scientific background of such new recruits better equips them to translate technical issues into scientific questions and then resolve them. Companies identify this as a critical competency for remaining innovative and competitive over the long term.

Changing the way research is funded changes the way research is conducted. CCMX offers a unique mechanism for supporting fundamental research that has been disregarded by the SNFS and the applied, market-driven CTI. The CCMX model is best compared with those of EU FP7 projects, with the significant difference that CCMX operates at the Swiss level, putting Swiss academia in touch with Swiss industry in a much more pragmatic way.

CCMX has created a new paradigm for interfacing academic researchers with industry, going beyond the traditional boundaries that exist for such cooperation. For some academics, this can be quite a radical departure. When asked in their annual reviews what CCMX has brought to their projects, researchers repeatedly emphasise that their projects would not be supported by any other means available to them in Switzerland.

The application of materials science in industry is very diverse. CCMX manages complex interactions within this multi- and inter-disciplinary environment with a variety of tactics. Now that the PPP model has matured, CCMX's Education and Research Units (ERUs) have been phased out in order to establish a more self-sustaining structure

Collaborate to Innovate!

PHOTO NATHALIE JONGEN

Practical session in the X-ray Diffraction Methods for Coatings advanced course.

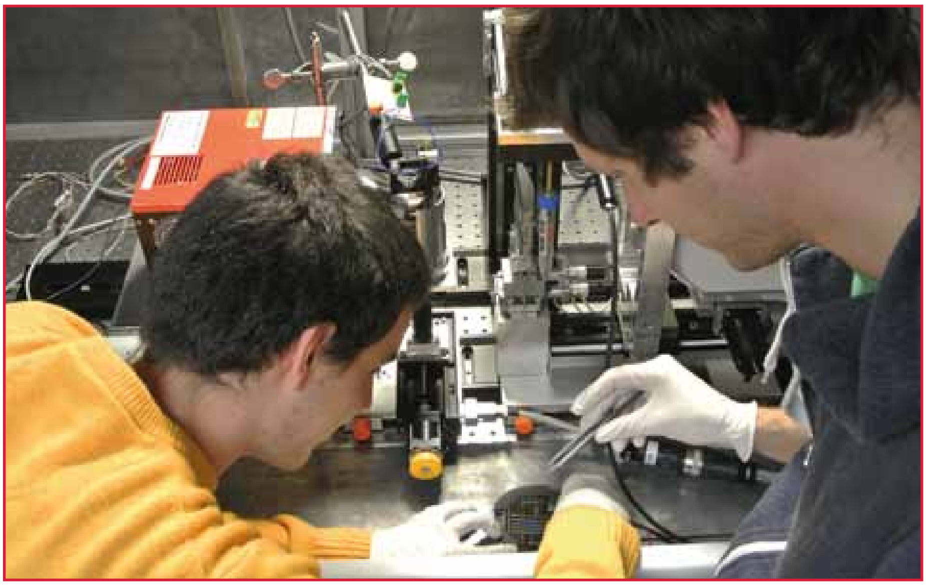


PHOTO COURTESY PSI

PSI researchers preparing a sample to be measured at a Swiss Light Source beamline.

If you do research only from an academic perspective, you may miss the really relevant points, so having interactions with industry keeps you grounded in doing something that's relevant for industry, and more importantly, relevant for society.

Professor Ralph Spolenak, ETH Zurich

Multimedia Complement
See the CCMX film on your smartphone using this QR code, or go to www.ccmx.ch

for future research collaborations. CCMX retains the Analytical Platform (NMMC), with the goal of creating centralised facilities and equipment, accessible to all CCMX partner institutions, which will endure beyond 2016.

Patience and perspective have played a critical role in CCMX's consistent success persuading different groups of stakeholders to communicate effectively and productively. People working in industry sometimes find it difficult to identify issues in scientific terms, while academic researchers sometimes need to be convinced of a project's scientific quality, merit and relevance.

CCMX designs its outreach activities to address these differing concerns by bringing industry and academic researchers together in both structured and informal ways. These events introduce companies to research potential within the ETH Domain, while sensitising academic researchers to industry's current needs.

Since 2007, CCMX advanced courses have established a dynamic brand identity, demonstrated by the way participants anticipate their occurrence with early registration. Courses with recurring themes often have their places filled several months in advance. This contributes to curriculum development for PhD students, as well as to continuing education for post-doctoral and professional researchers.

The familiar adage, "a picture is worth a thousand words" applies to CCMX's accomplishments in all the years leading up to 2012. The short film, "When Industry Meets Materials Research" captures the essence of what CCMX aims for in every sphere of its activity—from funding research, to technology transfer, to organising education and outreach: Collaborate to Innovate!

Education and Outreach Activities

Courses

Because education is a core priority, CCMX organises a variety of advanced training events. With an emphasis on practical application, the advanced courses are limited to a small number of participants to maximise hands-on experience and interaction with subject matter experts. This blend of theory and practice is much valued by course participants.

Over the years, courses on recurring themes have established a brand identity—demonstrated by the way students anticipate their occurrence with early registration. The Powder Characterisation and Dispersion advanced course scheduled for June 2012 had half its seats filled by the preceding February. Besides training, another benefit offered by CCMX courses is the opportunity for PhD students from different projects and research institutions to meet, network with one another, and potentially collaborate.

CCMX courses are also available to industry and institutional researchers, enriching the networking potential of these training events.

Lecture session for CCMX advanced course.

Hands-on experience with a wafer.

Course materials for 2012 Summer School.

Powder Characterisation and Dispersion practical session.

PHOTOS NATHALIE JONGEN

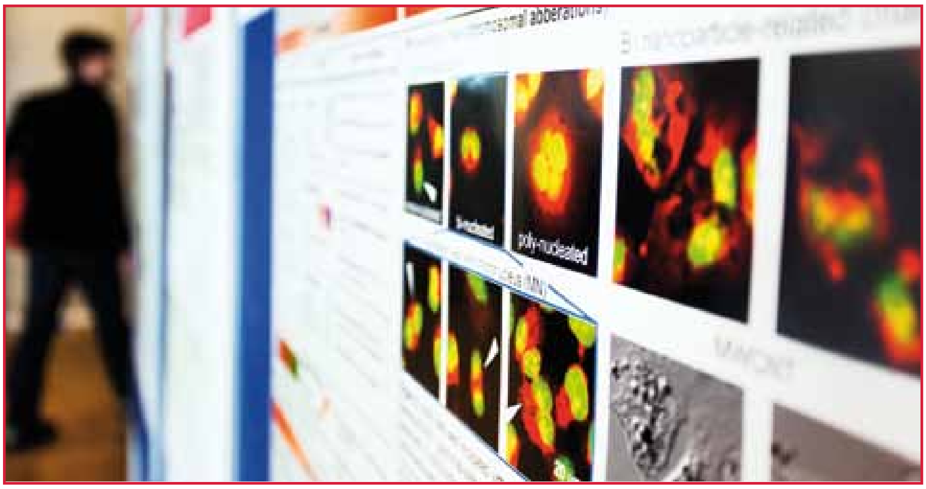
"I found that the balance between theory and practice was very good and it gave me a nice overview of methods, advantages and limitations for different measurements regarding particles characterisation." Powder Characterisation and Dispersion course participant

"I liked that speakers gave almost tutorial courses, explaining their topics from the basics and then illustrating with examples, making it easy to follow." Summer School participant

"I liked the strong practical approach and that immediately on the first day the practical work was a part of the course." X-ray Diffraction Methods for Coatings course participant

"We attended several programmes, and also our production people have been interested in [CCMX courses] so the offering is really broad." Industry partner

Education and Outreach Activities



Poster session, CCMX Annual Meeting 2012 at Kursaal, Bern.

Project presentation, CCMX Annual Meeting 2012.

Industry partners at final MERU meeting.

PHOTOS TONY KUNZ, SUE NIEWIAROWSKI

CCMX project researchers at the CCMX Annual Meeting 2012.

CCMX Education and Outreach Activities in 2012

25	April	Annual Meeting Materials Challenges working session	Kursaal, Bern
4–6	June	Advanced Course, Powder Characterisation and Dispersion	EPFL, Lausanne
28	June	Technology Aperitif, Exploring Materials in 3D Down to the Atomic Scale	Kursaal, Bern
29–31	August	Summer School, Multiscale Modelling of Materials	EPFL, Lausanne
3–5	October	Advanced Course, X-ray Diffraction Methods for Coatings	CSEM, Neuchâtel
6	November	Technology Aperitif, Neutron and X-ray Diffraction in Materials Science	PSI, Villigen

"I really appreciate how the CCMX Annual Meeting brings together academic and industry researchers, especially since they tend to work and think differently." Annual Meeting participant

Events

CCMX has organized six annual meetings since 2007. Bringing active CCMX members together with industry and other institutional representatives, these meetings offer an opportunity for showcasing research activities and achievements. The 2012 programme featured presentations from researchers in current CCMX projects, and from CCMX alumni currently working in industry.

The poster session's animated one-on-one discussions were once again a pivotal part of the programme. Feedback after the meeting revealed that the efficiency and focus of the half-day format was much appreciated, and that more time for the poster session would be well received.

Outreach

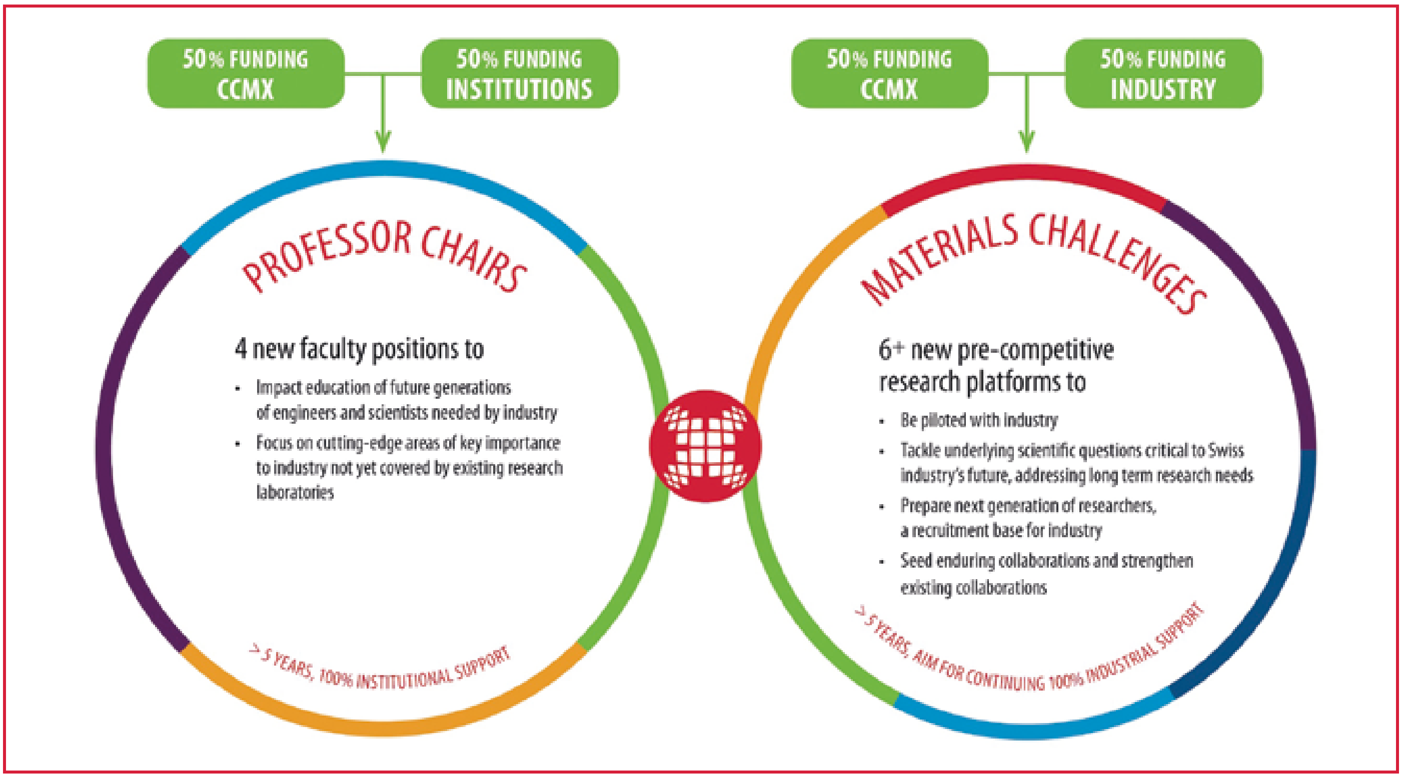
The monthly e-newsletter is distributed to nearly 1'400 subscribers. Besides being a means for promoting CCMX courses and events, the e-newsletter includes briefer versions of news items posted on the website. The newsletter and website are closely linked channels for communicating about the achievements and successes of CCMX project researchers, for profiling PhD students involved in current CCMX projects, and for sharing information about materials science related courses and events at our partner institutions.

"When Industry Meets Materials Research"

This film was inspired by the success stories presented at the final Metallurgy Education and Research Unit (MERU) meeting in Bern on 10 October 2012. In bringing project researchers and stakeholders together, this closure meeting was an excellent opportunity to capture what has made CCMX's Public-Private Partnerships productive and unique.

The film will be used to demonstrate the benefits of industry involvement and support of pre-competititve research, and as a means for promoting Materials Challenge research platforms. (See QR code on page 3)

Research Activities



At the heart of CCMX's current strategy is a tandem approach for supporting new professor chairs in areas of key importance, and creating focused research platforms—Materials Challenges—to ensure the longevity of the interactions between the ETH Domain, CSEM, and industry.

Investing in new professors is a cornerstone of the Materials Challenges initiative. Younger scientists are being recruited to bring their eagerness and dynamism into a leadership role in collaborating with industry partners.

Materials Challenges

The initial phase of the first two Challenges, Functional Coatings and Nanoparticles Safety Assessment, has begun. Discussions between industry stakeholders and ETH Domain research institutions have made excellent progress. Once the new professors at EPFL and ETH Zurich have established themselves, additional Challenge topics can be defined and launched.

The remaining potential Challenge topics—advanced metallic materials, structural coatings, meso-scale mechanics and fracture of metals—will progress as additional professors are appointed and as discussions continue with industry and academic partners.

Use of funding in 2012 (KCHF)

Funding of research	4'402
Education activities, conferences, industrial liaison	68
Management & administration	421
Total	4'891

Metrics for 2012

Running projects	28
Professors involved in projects	22
Senior scientists (FTE)	10
Post docs paid by CCMX (FTE)	18
Post docs not paid by CCMX (FTE)	6
PhD students paid by CCMX (FTE)	20
PhD students not paid by CCMX (FTE)	2
Publications	151*
Patent	1

* Reviewed ISI publications, non ISI publications, conference proceedings, conference talks and posters, PhD theses

38 companies involved in 2012

ABB Turbo Systems
Alstom
Asulab
Attolight
BASF
Bobst
Bruker Optics
Constellium
DECTRIS
HeiQ Materials
IG DHS
ION-TOF Technologies
KonMed
Kugler Bimetal
Lyncée Tec
Matter Aerosol
Meyer Burger Group
NanoScan
Nanosys
Novartis Pharma
Novelis
OC Oerlikon Balzers
Plansee Powertech
RMS Foundation
Rolex
Rolic Technologies
SCANCO Medical
Scientific Visual Sàrl
Sika
Stettler Sapphire AG
Straumann
swissnuclear
Synthes
TSB
TSI
Varinor
Wessling
Zeiss

2 federal offices involved in 2012

Federal Office for Public Health
Federal Office for the Environment

Bold signifies 8 companies newly and/or doubly involved with CCMX projects in 2012

Collaboration is Critical to Success

Final MERU meeting demonstrates the advantages of working together

PHOTO SUE NIEWIAROWSKI

Researchers and industry partners came together for the afternoon “round-table” discussion.

What happens when industry meets materials research? Participants in CCMX projects know very well what advantages collaboration with industrial or academic partners can bring. These gains were highlighted at a gathering of researchers in the Metallurgy Education and Research Unit (MERU) at their final meeting in October 2012.

More than 30 people from participating companies, research institutions and universities met in Bern to share their research, exchange visions for the future and socialise. The meeting, both educational and fun, also gave everyone an opportunity to capture what makes these partnerships productive and unique. The conclusion? Such collaboration not only benefits everyone, it is critical to success.

The participants’ own words demonstrate best what each of them gained from MERU.

Benefits to Industry
“We were able to gain fundamental results that we wouldn’t have gotten through any other cooperation”—Thomas Etter, Alstom Ltd

“A necessary, if not sufficient condition is to have this kind of collaboration with the academy. Otherwise, even if you have good ideas, you’re not going to be able to develop them. Precompetitive research is also very useful because often a single company cannot fund a project it would like to”
—Philippe Jarry, Constellium

“Technology is developing very fast and to really keep track of the assessment methodologies you have to have these kinds of collaborations” —Ingo Kuehn, Alstom Ltd

“We developed new projects thanks to CCMX. Now those projects are part of our R&D programme”—Régis Sanglard, Varinor

“Having good connections with new PhD students is very important for us if we want to develop research activities here in Switzerland”—Cyril Bezençon, Novelis

Benefits to Researchers
“I think a benefit for a PhD student working in such an environment is the fact he already gets a feeling of the interest and the priorities set by the industry. And in most cases that is completely different than what is said in a solely scientific group”—Thomas Etter, Alstom Ltd

“I learnt really well what industry wants and to consider that in what I am doing”
—Thomas Mayer, PhD student, Empa

“As we are achieving our own research goals, we also want to consider industry’s needs. That keeps us grounded as scientists, and as researchers”—Julie Fife, Post-doc researcher, PSI

“From my point of view, the collaboration with industry was really important because I will start a new career in industry. I will use this ability that I got from the collaboration in my future career”—Stéphane Pierret, PhD student, PSI

“We could really do some projects that could not be funded by single companies”
—Michel Rappaz, professor, EPFL

“And if you do it only from an academic perspective, you may miss the really relevant points, so having interactions with industry keeps you grounded in doing something that’s relevant for industry, and more importantly relevant for society”
—Ralph Spolenak, professor, ETH Zurich

“What can I take with me? My skills at collaborating with people and tackling challenging theoretical problems”
—Deniz Kecik, PhD student, PSI

> Precompetitive research is very useful because very often a single company cannot fund a project it would like to.
>
> Philippe Jarry, Constellium

Professor Pietro Gambardella, ETH Zurich

The newly appointed Full Professor of Magnetism and Interface Physics at ETH Zurich, did not want to be a scientist. It was the implicit challenge of a first year physics professor's taunt that less than a quarter of the assembled students would pass the class. Gambardella said, "I heard this and thought 'well, I'll show you.'" And he did.

He went on to graduate with a physics degree from the University of Genoa in 1996 before completing his PhD at EPFL on the growth of nanowires using molecular beam epitaxy, a method of depositing ultrathin crystalline materials. After a stay as a visiting scientist at the Max Planck Institute for Solid State Research in Stuttgart, Gambardella returned to EPFL as a research associate.

By this time, he was most interested in the structural, electronic and magnetic properties of nanostructures and on what can be done with them. Magnetic properties, for instance, depend heavily on the size of the material, especially as it approaches the nanoscale, as well as on the shape—a material's properties vary if it is in the form of a wire, film or a 3D object, for instance.

"What hooked me on this subject was the interface between physics and materials science," he said. "You have a strict interplay between structures–how you make materials and grow them—and function. You can modify a material's electronic properties as well as its chemistry, and then you have a bit of everything."

This focus led him in 2006 to the Catalan Institute of Nanotechnology in Barcelona, which was just being set up. He was head of the Atomic Manipulation and Spectroscopy Group, and also an associate professor at the Autonomous University of Barcelona. The experience of starting something new and being able to contribute from the very beginning put him in a good position for his current job at ETH Zurich, where he is again building up a lab from scratch.

"I have a lot of academic freedom and the resources to put ideas into being . . . there are no real boundaries other than those you set yourself."

Gambardella's work now focuses on the synthesis and characterisation of magnetic systems with novel structural and electronic properties. He is particularly interested in how the interplay between structure, bonding and size effects determine their electrical properties and in controlling the spin, or magnetic orientation, of the materials.

PHOTO TOM KAWARA

The dream of a scientist . . . is to discover something fundamentally new, but also useful for some application.

Potential applications of spin manipulation in nanostructured materials in particular include the replacement of external magnetic fields to control magnetisation and the flow of electric charge in small systems. This use of local electric fields or current rather than external coils to write data on computer memory, for example, would provide advantages in terms of the capabilities, speed, miniaturisation and energy consumption of such devices. Another area of research involves the development of organic magnets. Few organic materials act as magnets at room temperature. It may be possible though to tune the magnetic interactions in molecular systems, potentially resulting in organic magnets that are less expensive to make than inorganic magnets and which have appealing electrical or mechanical properties. Ideally, research could also uncover some new, unexpected phenomenon.

"The dream of a scientist in my position is to discover something fundamentally new, but also useful for some application—I think there are few of these moments where you can say this really happens on an important scale in the lifetime of a scientist."

Professor Fabien Sorin, EPFL

EPFL's New Tenure Track Assistant Professor of Materials Science says the best thing about his field is that materials are and will remain at the heart of scientific and technological challenges. Highly multidisciplinary, it incorporates sciences ranging from physics to chemistry. This allows his work to have far-reaching implications in different areas; it also means that it often makes sense to seek the expertise of others.

So while many people take the first week of a new job to settle into their office, Sorin used the time to kick off joint projects with groups in two completely different academic fields.

"I've always valued collaboration because I'm in a multidisciplinary field and can't be a specialist everywhere," he said. "Collaboration makes my projects advance much faster, and I can help others with my own expertise."

Sorin develops new photonic and fibre materials as well as innovative processes that allow for unique tailoring of structures and properties on length scales spanning from the nanometer to the kilometer.

He studied physics at the Ecole Polytechnique in Palaiseau, France, before finishing a PhD and Post-doc at MIT's Department of Materials Science and Engineering. His experience there led Sorin into industry. He joined St. Gobain, a French maker of building materials, in 2011.

"At both MIT and St. Gobain I was always at the frontier between fundamental research and application and that's really where I like to be," he said. "It's about developing a fundamental understanding of phenomena and advancing knowledge of science, but at the same time being able to transfer it and have an impact on society."

Sorin sees many practical applications for his work. Sophisticated devices integrated into thin and flexible fibres are well suited, for instance, to matching the size and shape of the human body's structures. Such wires could fit into pores or veins and be used to burn out cancer cells. Another potential use is in energy harvesting. It is now very difficult to manufacture devices that require large scale efficiency from nanostructures, which is a big problem for producing photovoltaics.

"If you can integrate the kind of functionality into a multi-material fibre that enables you to harness different forms of energy then you have a way of making simple, flexible, large scale and potentially low-cost energy harvesting devices."

PHOTO ALAIN HERZOG

I've always valued collaboration because I'm in a multidisciplinary field and can't be a specialist everywhere.

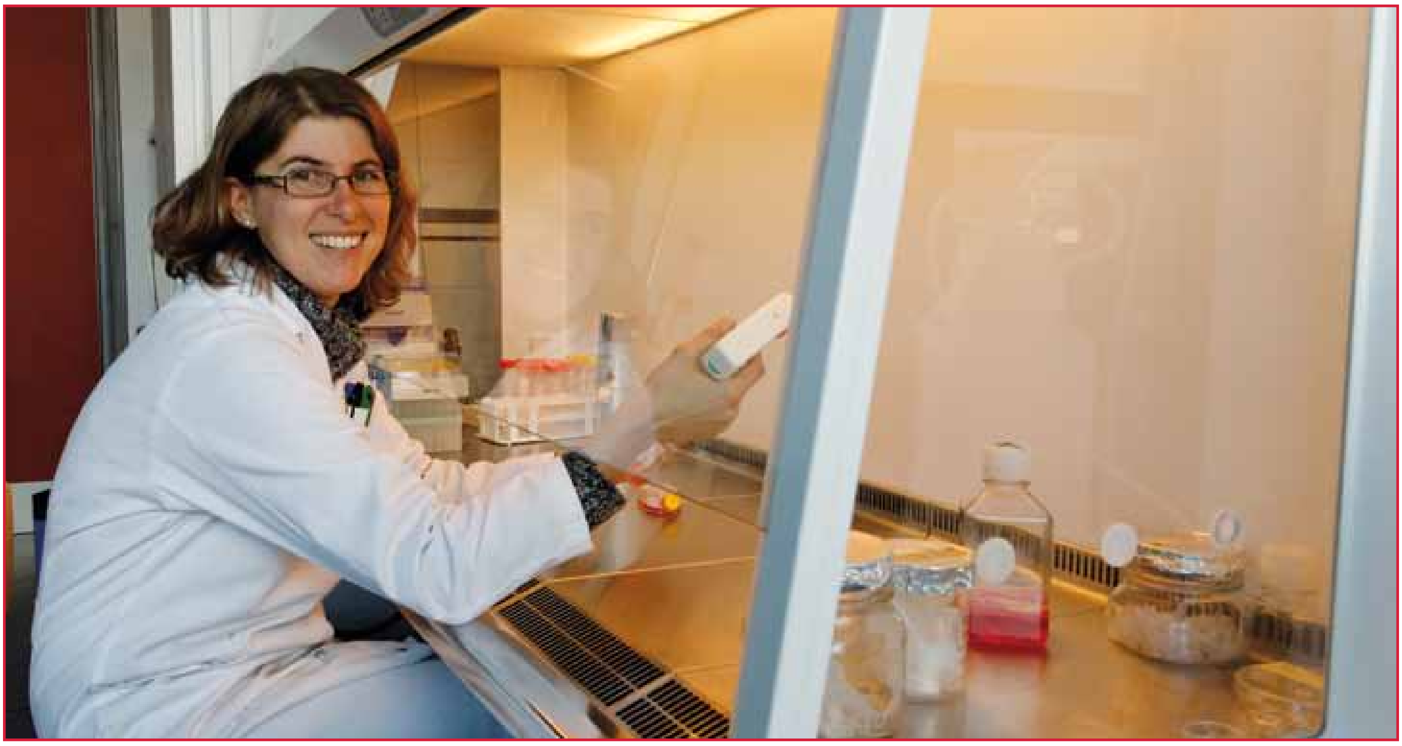
Other potential applications include use in smart buildings to make them more energy efficient, and in smart fabrics that might allow us to charge our mobiles phone while hiking in the mountains. "Discovering some fundamentally new aspect that leads to a practical application in a reasonable timeframe is something I'd like to achieve."

As excited as he is about these future applications and working with industry to achieve them, Sorin nonetheless chose to return to academia because he missed more fundamental research—and students.

They are not only key to ensuring the future success of materials science, they also provide a certain job satisfaction. Sorin cites the case of two students he mentored at MIT. Both master students had decided to go into strategy and finance after graduation but still needed to fulfil the requirements of their degree with four-month internships, which they did with Sorin. After the experience, they both decided to stay in materials science. One will start his PhD with Sorin in May 2013.

"This kind of influence—having students enjoy the work and stick to science—is very gratifying to me."

Sunscreen to Tyres: New Tests to Assess Nano



C. Hirsch working with human cells under sterile conditions. The cells are used to assess nanomaterial toxicity *in vitro*.

As use of these particles spreads, it becomes increasingly important to find out what effects they have on humans.

Human hair is about 80'000 nanometers wide. Red blood cells are between 7'000 and 8'000 nanometers across. The tiny particles increasingly used in products ranging from sunscreens to car tyres are more than 1'000 times smaller.

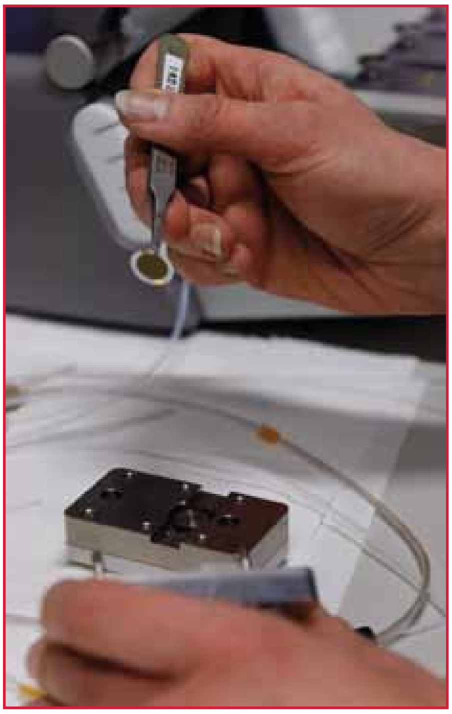
Nanoparticles, particularly those smaller than 100 nanometers, are used in more and more products because they offer characteristics that are distinct from their larger counterparts. They may feature high tensile strength, low weight, high thermal and electrical conductivity and unique optical properties. These properties may lead to new technologies, but might also have unexpected effects on humans and the environment. Nano-sized objects can enter cells much more easily, faster and in higher concentrations than bigger particles and they are also more reactive.

As use of these particles spreads, it becomes increasingly important to find out what effects they have on humans. This is not an easy task because nanoparticles are more challenging to test than bulk materials or classical chemicals. Because they're so reactive, they interact with proteins and other small molecules commonly used in testing and this interaction may ultimately result in false positive or false negative results.

"Nanomaterials always seem to be different and to react unexpectedly, at least from a biologist's point of view," said Cordula Hirsch, the scientist running the project at Empa. "Controlling every step of an assay is crucial to figuring out where and how interference reactions may take place."

Although there are studies on the biological effects of engineered nanoparticles, there is little standardised testing—results are difficult to compare and can be inconclusive or even contradictory. Researchers at Empa and EPFL want to fill that gap by developing an evaluation system based on International Standards Organization and OECD guidelines, eventually offering a standardised tool to both regulators and industry to evaluate four critical aspects of toxicity to cells: viability, inflammation, genotoxicity and oxidative stress.

particle Safety in Products



PHOTOS NATHALIE JONGEN

G. Coullerez demonstrating the sensor used in the microbalance that allows for the determination of nanoparticle transport properties.

There is a lot of discussion about whether nanomaterials are new materials or not– if we say nanomaterials are only new if we really have a change in properties, than we can say, for example, that the titanium used in sunscreen still has bulk properties

Professor Heinrich Hofmann, EPFL

"Common assays may be good for chemicals, but they're not always usable when you want to test nanomaterials," said Harald Krug, head of Empa's Department "Materials meet Life." The original aim of the project, dubbed VIGO, was to develop at least two different assays looking at each element and to deliver standardised tests. The researchers plan to modify existing tests to make them suitable for nanoparticles, or develop and standardise new ones. They quickly ran into a stumbling block though—finding the appropriate controls.

That is, they need particles that are known to provoke inflammation, damage to DNA and oxidative stress to use as benchmarks for evaluating whether the assays they are developing actually work. That way, they would know how, for instance, a particle that damages DNA reacts in a given test. They have not been able to find the right ones yet.

"We expected to find a nanomaterial that can be used as a control to see if the system really responds to them," Krug said. "I've been working more than 10 years in this field and so far we have no materials that are really toxic in these assays."

The Empa research team, which also includes Peter Wick, co-Head of the Laboratory for Materials–Biology Interactions, is developing new tests around chemical controls while trying to develop the appropriate nanomaterial benchmarks. They have, for instance, started investigating the use of a new test that measures DNA strand breaks in human cells—an indicator of genotoxicity—in zinc oxide nanoparticles to see how the method could be used to test nanoparticles.

At the same time, colleagues Heinrich Hofmann, head of the Powder Technology Laboratory at EPFL and scientist Géraldine Coullerez have been tackling another stumbling block to nanoparticle testing—characterisation of the materials being used. The scientists are looking specifically at three key points: the size at which nanomaterials change their physical and chemical properties; to what extent particles come into contact with cells in the testing media and, finally, how quickly particles dissolve in it.

"We're really looking at the physical and chemical characterisation and trying to figure out the biological identity of the particle during bioassays," Coullerez said. "We want to know what the nanoparticles are when we start and understand what happens to them as they're modified during testing."

"The question of how small nanoparticles have to be to show different properties is particularly critical to both science and policy," Hofmann said. If the nanoparticles still exhibit bulk behaviour at a given size, it could be argued that there is no reason to put them through a full cycle of new testing. Most commercially interesting particles change their chemical properties below 10 nanometers. The titanium dioxide used in sunscreen has a diameter of about 25 nanometers.

"There is a lot of discussion about whether nanomaterials are new materials or not," he said. "If we say nanomaterials are only new if we really have a change in properties, than we can say, for example, that the titanium used in sunscreen still has bulk properties."

Longer Lives for Cutting Tools Thanks to New

M. Böttger explaining a simulation being done to understand the effect of ellipsoidal droplets on the temperature distribution of multilayer coatings.

A multilayer coating test sample for X-ray photoelectron spectroscopy analysis.

PHOTOS NATHALIE JONGEN

A team of researchers from ETH Zurich and Empa want to develop an alternative solution based on protective coatings that disperse heat and protect tools.

Modern titanium and nickel alloys have changed the way we make aircraft, gas turbines and even medical implants. They make airplanes lighter, reduce corrosion in motors and produce stronger artificial hips and knees.

These innovative metals have solved many problems—and have created others. They don't, for instance, conduct heat very well. Heat generated by cutting concentrates around the tip of the tool, so machining the materials is difficult and expensive. Temperatures can be as high as 1'000 degrees Celsius, and cutting tools need to be replaced as frequently as every few minutes. Lubricants can extend the life of these parts and keep tips from welding themselves to alloy surfaces, but the liquids can be dangerous for machinists, contaminate final products and harm the environment.

A team of researchers from ETH Zurich and Empa want to develop an alternative solution based on protective coatings that disperse heat and protect tools. Working with industrial partner OC Oerlikon Balzers, the team, led by Valery Shklover, group leader at the Laboratory of Crystallography at ETH Zurich and Joerg Patscheider, head of the Thin Films group at Empa, is developing anisotropic coatings made of chromium nitride, titanium nitride and combinations of these materials with oxygen.

"The aim is to apply coatings to protect cutting tools, to extend their lifetimes and maybe also to make the cutting process faster and to avoid using lubricants," said Shklover. "If we're successful, we'll help industry to machine so-called difficult-to-cut materials. This will be huge progress because it has been a big problem up until now."

The first steps involved figuring out what material systems to explore the best way to calculate thermal conductivity both in compound materials and in thin layers attached to massive substrates. Finding the answer to this last question, preparing samples and getting reliable thermal conductivity data took post-doc Michael Böttger the better part of a year and a visit to the University of Illinois to work with scientist David Cahill, who pioneered an approach to such measurements.

Protective Coatings

J. Patscheider checking the sample inside the X-ray photoelectron spectroscopy instrument.

Determining these influences has been a matter of trial and error, but now we're linking it to something that can be measured and explained—and having measured it, we can make use of it.

Valery Shklover, ETH Zurich

Cahill's technique involves introducing a very thin layer of metal that acts as a thermometer by changing reflectivity with temperature. Researchers can introduce heat into the system with a laser and then measure how it dissipates over given intervals of time. This generates datasets that can be fit to a three-layer model of the system, allowing for measurement of thermal conductivity within a shallow depth of about 200 nanometres. This in turn allows Böttger, who splits his time between Empa and ETH Zurich, to analyse the effects of different variables on thermal conductivity. For now, the focus is on oxygen content.

"People have always been adding oxygen to these kinds of coatings, but no one was looking at what this does to thermal conductivity," Böttger said. "It turns out that it changes a lot, almost on an order of magnitude."

Oxygen affects thermal conductivity by changing the mean free-path, or the average distance travelled by phonons, particles that describe heat transport. Adding oxygen is not the only way of influencing thermal conductivity though, and the researchers are looking at other approaches, including the introduction of aluminium.

"Determining these influences has been a matter of trial and error, but now we're linking it to something that can be measured and explained," Shklover said. "And having measured it, we can make use of it."

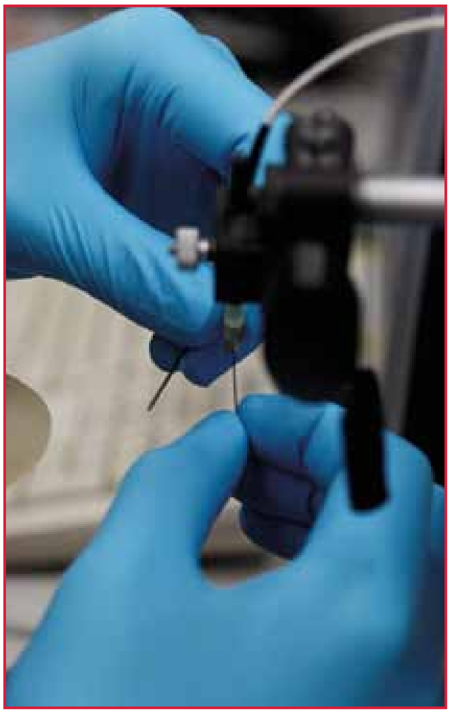
Making use of it involves designing microstructured coatings of about 5-micron thickness with targeted thermal conductivity and uniform heat dissipation along the tool surface. Böttger has proposed several coating concepts, asking partner OC Oerlikon Balzers to produce some, but also taking advantage of Empa's advanced magnetron sputtering technology to produce his own versions.

"There is always a trade-off when you do coatings on an industrial scale and when time and money's less of an issue," Patscheider said. "When we make model materials here, they have very good microstructures, they're almost free of flaws. We have to make sure that we can distinguish between microstructural flaws and the intrinsic properties of the material; we can separate those two effects by making a clean material here in our machines."

Böttger carried out thermal conductivity measurements and surface and chemical analysis of the materials using various methods, including X-ray photoelectron spectroscopy at Empa. The results were as his models predicted, and the coatings will soon be tested under real cutting conditions in collaboration with another ETH Zurich department, the Institute of Machine Tools and Manufacturing. The measurements are complex because the researchers want to selectively examine the impact of thermal conductivity exclusively—they must be sure that all other parameters are constant.

"People have been using the same coatings for 20 or 30 years now and many things are very little understood," Böttger said. "It's interesting to bring some physics into it and move from trial and error to a more systematic approach—this is where I'm hoping to make an impact."

Thin Alloys Contribute to First New Circuit Bre


PHOTOS NATHALIE JONGEN

F. Vüllers preparing an electric arc discharge experiment by exchanging the tip shaped electrode in the in-house built arc erosion testing device (left and middle). Inserting the AFM cantilever holder with installed cantilever for AFM surface reconstructions of an arcing crater (right).

> We've already made a lot of progress—figuring out how to simulate the arc in the lab was critical. You'd otherwise need a power plant to test these things—we obviously don't have one, so we had to focus on the essentials
>
> Professor Ralph Spolenak, ETH Zurich

In the world of high-voltage circuit breakers, "state of the art" refers to technology some 20 years old.

While existing units do what they are supposed to—carry current and extinguish arcs—they are not ideal. The metal contacts are eroded by high temperatures; the sulphur hexafluoride often used to quench the arc is deemed 20'000 times more damaging to the environment than carbon dioxide; and components may be heavier than necessary. Ralph Spolenak at the Department of Material Science at ETH Zurich, his PhD students André Röthlisberger and Franz Vüllers and industrial partner Plansee Powertech AG, are looking to solve a number of these problems with innovative contact coatings made from metal alloys.

"We are looking at materials resistant to the arcing experienced by switches used at the limits of possible performance," Spolenak said. "That means we have to go to materials that have two or three properties that are usually not found in a single material."

Contacts are already made from a copper and tungsten alloy. Copper provides high thermal and electrical conductivity, while tungsten features good heat resistance. A downside, however, is density. The breaker needs to be heavy enough to resist the mechanical forces generated during operation, but excess weight also limits how quickly mechanical switches can open and interrupt the circuit. Speed is critical for protecting equipment and avoiding explosions and fires. A lightweight substrate and a functional surface layer could be better. Ideally, it would provide improved thermal properties, reducing erosion, while optimising density. Understanding what happens when the arc meets the metal and how materials mechanically deform is, however, a critical first step to developing the new alloy.

"What is really happening at the interplay between the arc and the material is something that hasn't been researched," said Röthlisberger, who is also a student of Edoardo Mazza, head of Empa's Laboratory of Mechanics for Modelling and Simulation. "The focus has just been on taking tungsten, making it heavy and thick enough and then dealing with geometry to make it as reliable and cost-efficient as possible."

The group is taking two approaches to figuring out what is going on at that interface. Röthlisberger is focusing on using finite element modelling to produce numerical simulations of arc erosion, while Vüllers is taking on experimental investigation of the materials themselves. Methods include focused ion beam tomography and a new

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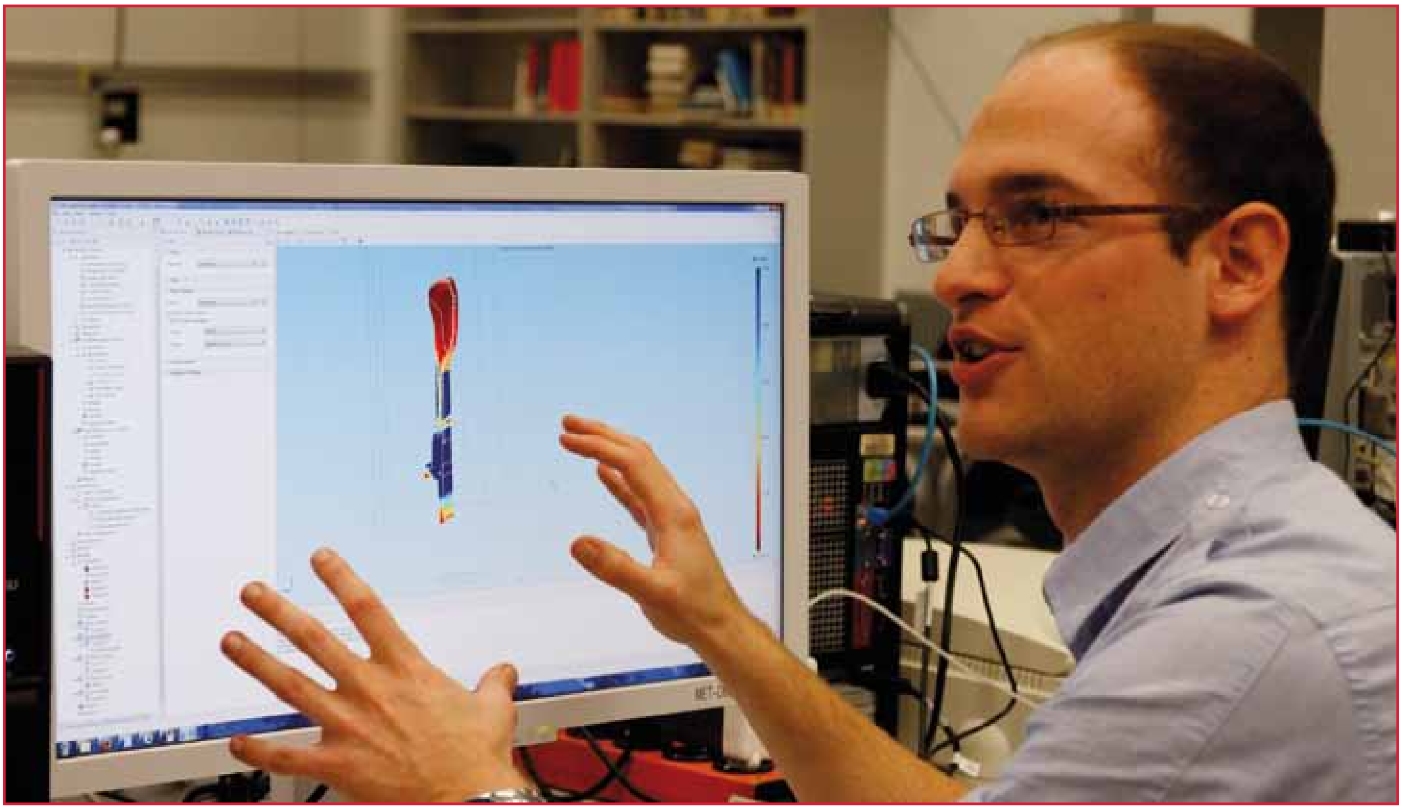


A. Röthlisberger explaining the finite element simulation results, showing the strain distribution in an arcing electrode.

arc erosion testing device developed in Spolenak's lab.

"We've already made a lot of progress," Spolenak said. "Figuring out how to simulate the arc in the lab was critical. You'd otherwise need a power plant to test these things—we obviously don't have one, so we had to focus on the essentials."

The ultimate aim of the research is to figure out the best length scale for making a material as resistant as possible to high local temperatures. Shorter diffusion distances improve thermal conductivity, but making things smaller and smaller eventually results in an increase in electrical resistivity and a corresponding drop in conductivity. Working out the ideal scale may then open the door to designing circuit breaker components that are not based on bulk materials, but on coatings that are just 100s or 10s of microns thick. Röthlisberger and Vüllers have already produced thin tungsten-copper films of various compositions and thicknesses with magnetron sputter deposition.

The next steps involve using simulations to find out what temperatures and mechanical loads are generated during arc erosion. The team will then run high temperature testing in those ranges and see if results differ from predictions. They also want to improve controls of the testing environment—all work is now done in lab air, which may affect results—and improve the distancing precision of their device.

The PhD students are also continuing to look at devices made by partner Plansee to analyse the microstructures of devices being used now. The company's assistance is critical in that regard, and also in terms of helping researchers focus on an essential eventual benefit—safety. It is critical for power plant operators to protect the personnel and equipment and to avoid explosions and fires.

"They don't want to change anything that's working, but they see that there's a lot of potential to reduce weight and to reduce costs," Vüllers said. "There's also a lot of interest in moving to more decentralised energy networks and to do this you need everything to be smaller. The understanding we're working on is necessary for adapting to a new and changing grid."

There's also a lot of interest in moving to more decentralised energy networks and to do this you need everything to be smaller. The understanding we're working on is necessary for adapting to a new and changing grid

Franz Vüllers, PhD student, ETH Zurich

New Scanner Promises Medical Progress, Materi

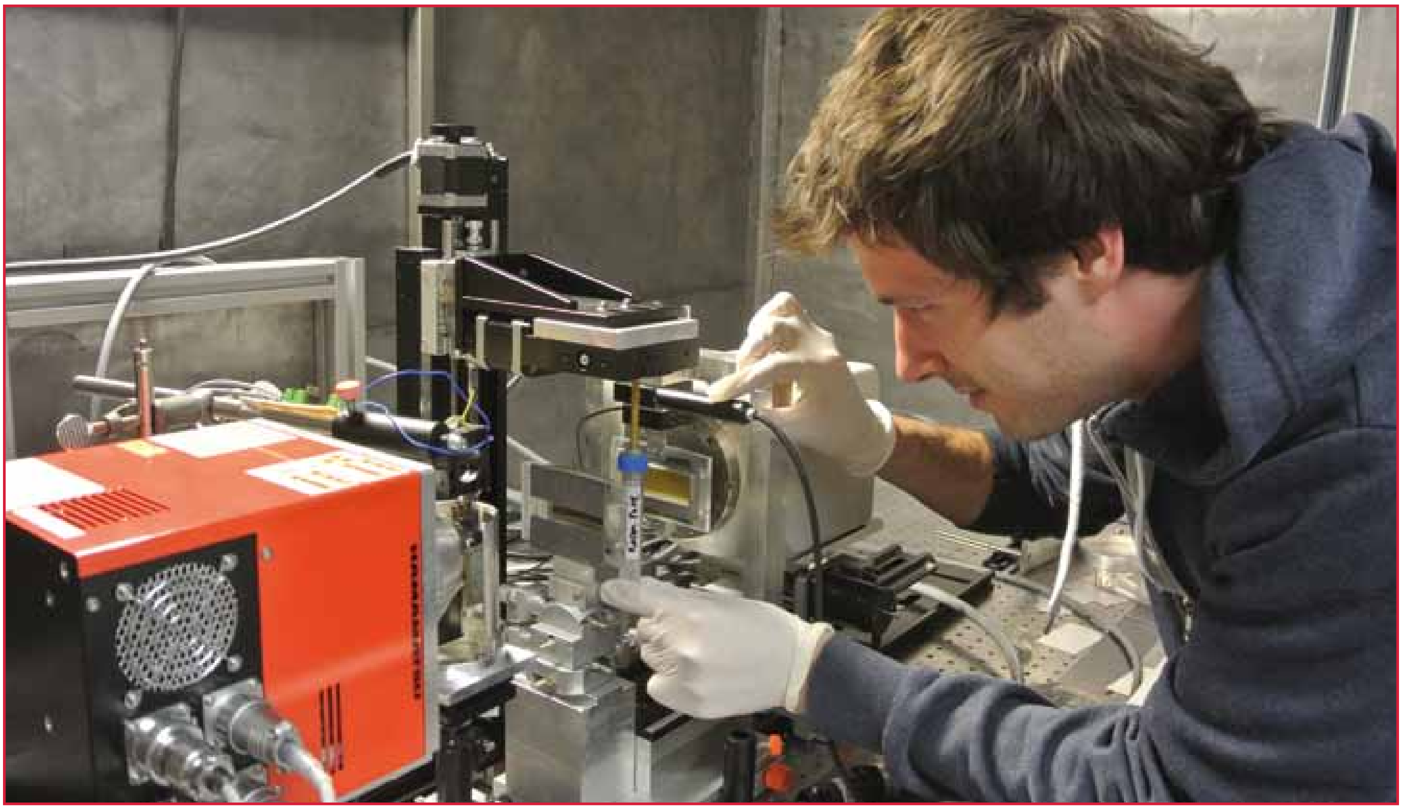


PHOTO COURTESY PSI

T. Thuering mounting a sample on a demonstrator X-ray phase contrast CT system in the laboratory.

Semtex is a plastic explosive. Gruyère is a slightly salty cheese originally from the canton of Fribourg. While the difference in physical properties is considerable, they appear exactly the same under X-ray security systems used in airports.

"So if you want to board an airplane with either a kilogram of Gruyère or a kilogram of Semtex and there are no dogs that can detect the difference, you could probably make it," said Marco Stampanoni, head of the X-ray Tomography Group at PSI and Professor for X-ray Microscopy at the Institute of Biomedical Engineering at ETH Zurich. "But if airports used our system, it's clear you couldn't."

The two substances look identical under conventional X-rays because they have the same absorption properties—X-rays passing through them are attenuated in the same way. They differ in the way they refract and scatter the beam. A team of scientists from the Paul Scherrer Institute and CSEM along with partners from SCANCO Medical AG are designing equipment that will use this data to help distinguish substances from one another, examine weakly absorbing samples such as soft tissue, and investigate the micro-structures of new composite materials. This "table-top, gantry-based X-ray phase contrast microCT scanner," also being designed for use with high-energy beams, could be the first of its kind.

"Refraction and scattering were considered noise and systematically removed from data because they were somehow affecting the quality of the final images," Stampanoni said. "We want to exploit those two physical signals to increase the contrast and provide better images at the end."

The signals have always been there, but it is only in the last decade or so that researchers have figured out how to acquire images that capture them in a meaningful way. The approach pioneered at PSI is based on X-ray interferometry. The method uses gratings—optical components with varying periodic structures—to analyse waves that have passed through a sample. This in turn gives researchers information about material properties such as electron density or small-angle scattering power, as well as standard attenuation characteristics.
Though the method has been used for years, its application has been restricted because of limitations on spatial resolution and working energy, and a need to rotate the sample. The team intends to offer an alternative that overcomes these issues.

Meeting the first goal of high spatial resolution is linked to grating fabrication. These optical components are formed by very fine lamella with a depth of up to 100 microns periodically arranged with trenches of only a few microns in between them. This involves precision micro-fabrication work that few laboratories can accomplish. Luckily, PSI and CSEM are among them. The ultimate spatial resolution is reached only with the most demanding specifications in terms of the shape and quality of the gratings.

"The challenge in achieving the best images is to find a design that guarantees the optimum trade-off between spatial resolution and sensitivity," said Christian Kottler, a physicist at CSEM. "We have a plan A and a plan B for

als Advances and Safer Skies

PHOTO NATHALIE JONGEN

V. Revol explains the phase contrast X-ray setup at CSEM.

the design of the system in order to approach the optimum solution."
Kottler and CSEM colleagues have tested some elements of the system by looking at specimens of animal soft tissue, such as the leg of a mouse. It turned out that compared with existing methods the phase contrast images allow for the discrimination between different kinds of soft tissue, such as muscles, ligaments or fat.

"Researchers are interested in visualisation of soft tissue as it can be seen with our method," Kottler said. "This is something that is hardly possible today."

The team also plans to integrate the X-ray source, image detector and interferometer—the device that measures the phase shifts—onto a gantry that will allow researchers to rotate the device around the sample rather than rotating the specimen. This will benefit medical applications because the patient cannot be rotated, Kottler says, but also other uses such as in the inspection of cables or wires that move out of the beam when rotated. While gantry-based microCT systems exist, they do not incorporate the critical phase-contrast element.

The final aspect of the project involves increasing the working energy of the system. While refraction occurs at varying energies, higher-energy X-ray beams are less likely to be absorbed by the samples being examined. This means that high-energy techniques using refraction data to increase the contrast would give better images while exposing the sample to a lower dose of radiation. This element of the project involves a number of challenges including new curved grating structures, improved manufacturing techniques for these components and more efficient detectors.

"Reducing the dose in X-ray investigations such as radiography or computed tomography is a crucial issue," Stampanoni said. "Phase contrast imaging relies on refraction rather than absorption and therefore it is a highly promising technique when addressing these aspects."

Reducing the dose in X-ray investigations such as radiography or computed tomography is a crucial issue—phase contrast imaging relies on refraction rather than absorption and therefore it is a highly promising technique

Professor Marco Stampanoni, ETH Zurich

New Tool Reveals a World of Exciting Images fr

PHOTO NATHALIE JONGEN

J. Raabe, T. Lachat, M. Vitins, and H. Walther discuss the sample stages' cryogenic connection.

OMNY is a high-resolution system enabling tomographic 3D imaging at a resolution down to 10 nanometers, the thickness of a cell membrane.

Modern imaging has led to scientific advances because researchers can now examine precious samples without destroying them. We have gained a better understanding of how cement hardens. Studying fossilized embryos has changed what we know about the origins of species.

Available methods are not very good at measuring thick samples at high resolution though. Improved imaging techniques may reveal much more.

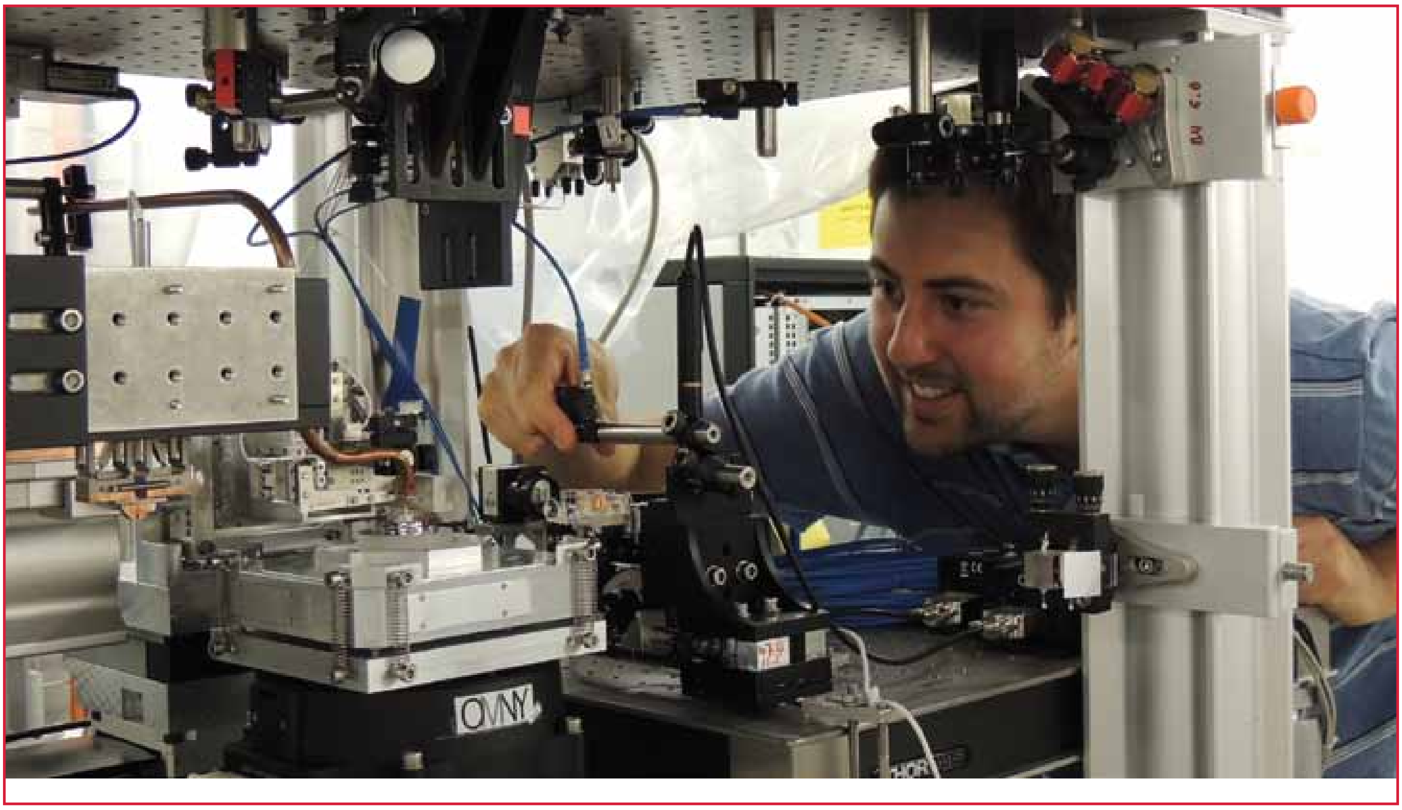
Researchers and engineers at the Swiss Light Source of the Paul Scherrer Institute (PSI) along with industrial partner Dectris Ltd. are working on a novel instrument that will overcome these restrictions. The tool, OMNY, is a high-resolution system based on scanning X-ray microscopy for tomographic 3D imaging at a resolution down to 10 nanometers, the thickness of a cell membrane. When complete, OMNY will image biomaterial, materials science and physics samples at cryogenic temperatures in a vacuum environment. A test set up has already been used to examine cement and bone.

"This is not only leading instrumentation, this is actually being used right away for something," said Oliver Bunk, Head of the Laboratory for Macromolecules and Bio-imaging at the Swiss Light Source. "There is strong user interest and people want to use it for their scientific questions that can really only be answered by this machine. It's a really nice situation."

The project targets 3D nanometric imaging. In classical tomographic imaging, the object is illuminated and imaged from different sample orientations to a detector, which records the transmission of the beam through the material. Instead, OMNY incorporates scanning microscopy, which involves focusing a beam on an object and detecting transmitted light, one spot at a time. The object is moved and, step-by-step and point-by-point, a two-dimensional projection of the object is created. With this technique, resolution depends on both the accuracy of the object's positioning in the beam—researchers need to know exactly where the light hits the sample—and, done in the traditional way, on the size of the beam.

Hard X-rays are needed to penetrate thick samples, but are tricky to use in such applications because of the lack of appropriate X-ray optical elements. One of the key techniques

om the Heart of Materials



PHOTOS COURTESY PSI

M. Holler adjusting the optics of the laser interferometry system of the OMNY test setup.

the researchers are using to get around this problem is called ptychography. Rather than only detecting the transmitted light in a scan, the method involves using X-rays and 2D detectors to measure diffraction patterns at successive, overlapping regions of the sample. This creates a redundant dataset, allowing them to reconstruct the object and the illuminating beam using phase retrieval algorithms. Applied in 3D, the method is quantitative and provides a 3D dataset of the electron density in the sample.

"With OMNY, we have a technique where the resolution is not determined by the spot size of the X-ray," said Mirko Holler, the PSI researcher leading the project. "We can use it with hard X-rays to measure thick specimens to high resolution. It is a lens-less method without any optical elements between the object and the detector that could limit the resolution. This also allows us to reduce the dose on the samples."

The next challenges include perfecting their sample positioning system, developing a sufficiently fast scanner and integrating cold storage and a vacuum chamber to protect sensitive samples—such as biological material—from radiation damage.

Much of the on-going engineering and machining is being done at PSI. This has been critical to the project's success.

"We have three mechanical engineers working 100% on this project," said Joerg Raabe, group leader of Microspectroscopy at PSI. "Mirko meets with them once or twice a week and this close interaction is extremely important." In addition to other PSI departments, the team is also working with industrial partner Dectris Ltd. Stimulated by the needs of the OMNY project Dectris developed and now sells X-ray detectors that can operate in a vacuum.

While the fully functional OMNY is not likely to be running before 2014, in the meantime researchers have access to a test set-up operating at room temperature and atmospheric pressure. It is now being used regularly by scientists attracted by its improved resolution and quantitative data. Research on cement and bone will be published thanks to novel data generated by OMNY.

"We definitely have a leading position pursuing this technique," Holler said. "We're doing things that no one has done before."

We definitely have a leading position pursuing this technique. We're doing things that no one has done before

Dr. Mirko Holler, PSI

Map of Switzerland interpreted as a word cloud.

2012 Peer Reviewed Publications

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Projects Ongoing in 2012

PROJECT TITLE	PRINCIPAL INVESTIGATOR (PI)	PI'S INSTITUTION	OTHER INSTITUTIONS	ERU/PLATFORM
Evolution of microstructure and mechanical response due to cyclic deformation at elevated temperatures*	Stuart Holdsworth	Empa	ETHZ, PSI	MERU
In-situ mechanical testing*	Helena Van Swygenhoven	PSI	Empa	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 modelling of optical properties of gold alloys*	Ralph Spolenak	ETH Zurich	PSI	MERU
Microtome4SIMS: Chemical tomography of biological material with 100 nm resolution	Beat Keller	Empa	Unispital Basel	NMMC
Colored ceramic surfaces for metallic dental implants and prosthetic appliances	Ralph Spolenak	ETH Zurich	Empa, UZH	MatLife
Structural evolution and rheological properties in gel carrier	Christopher Plummer	EPFL	ETH Zurich	MatLife
Low wear articulating implants employing DLC coatings on CoCrMo and TiAlNb with predictable, long-lasting coating adhesion lifetime	Roland Hauert	Empa	ETH Zurich	MatLife
Fibroblast growth factor 2 delivery for tissue repair: From natural concepts to engineered systems	Viola Vogel	ETH Zurich	PSI	MatLife
Liquid repellent wear resistant coatings (LIRE-WERE-CO)	Patrik Hoffmann	Empa	EPFL	SPERU
Serrulatane-based antimicrobial surface platforms	Harm-Anton Klok	EPFL	ETH Zurich, Unispital Basel	MatLife
VIGO: A new evaluation tool for determination, description, and comparison of the biological effects of nanoparticles / nanomaterials	Harald Krug	Empa	EPFL	MatLife
Synchrotron phase-contrast nanotomography of fresh and hardened cementitious materials	Pietro Lura	Empa	EPFL, PSI	NMMC
Development of computational tools for molecular modelling and X-ray spectroscopy, with application to the understanding and design of molecular alignment technology in commercial LCDs*	Daniele Passerone	Empa	PSI, UZH	NMMC
Equipment for *in-situ* mechanical testing of nanostructured alloys under service-type loading	Helena van Swygenhoven	PSI	EPFL, Empa	NMMC
Measurements and modelling of residual stresses in aluminium components in relation to their microstructure	Jean-Marie Drezet	EPFL	PSI	MERU
Arc erosion processes in contact materials: modelling and model experiments	Ralph Spolenak	ETH Zurich	Empa	MERU
Protective coatings with managed thermal conductivity for machining difficult-to-cut materials	Valery Shklover	ETH Zurich	Empa	SPERU
Quantitative Magnetic Force Microscopy platform (qMFM)	Miguel Marioni	Empa	ETH Zurich	NMMC
OMNY (tOMography, Nano, crYo stage)	Mirko Holler	PSI	CSEM	NMMC
Development of a He-Ion Beam Induced Charge scanning system (He-IBIC)	Urs Sennhauser	Empa	ETH Zurich	NMMC
Ultrasensitive sensing transducer based on Fano interferences in plasmonic metamaterials—FANOSENSE	Olivier Martin	EPFL	CSEM	NMMC
Gantry-based X-ray phase contrast scanner for microCT applications	Marco Stampanoni	PSI	ETH Zurich, CSEM	NMMC
Study of biological processes in cell membranes at nanoscale by near field digital holographic microscopy*	Pierre Magistretti	EPFL	CSEM	NMMC
NanoAir – Online coupling of a scanning mobility particle sizer SMPS to an inductively coupled plasma mass spectrometer ICP-MS for size fractionated, elemental analysis of nanoparticles in aerosols	Andrea Ulrich	Empa	EPFL, PSI, FHNW	NMMC
Failure and defect analysis of fibre composite materials by means of X-ray interferometry	Rolf Kaufmann	CSEM		NMMC
Structure-activity relationships of metal oxide nanoparticles-based gas sensors for non-invasive medical diagnosis by time- and surface-resolved XAS-IR	Davide Ferri	Empa	PSI	NMMC
Optical detection and investigation of subsurface features and defects in unpolished transparent materials and films	Patrik Hoffmann, Yury Kuzminykh	Empa		NMMC

* Projects that finished in 2012. All other projects continue in 2013.

CCMX Team 2012

Management Team

Prof. Karen Scrivener, Chair
karen.scrivener@epfl.ch

Dr. Nathalie Jongen
Managing Director
nathalie.jongen@epfl.ch

Kathleen Collins
Website/Events/Courses
kathleen.collins@epfl.ch

Maria Delaloye
Administration/Accounting
maria.delaloye@epfl.ch

Sue Niewiarowski
Publications/Promotion
susan.niewiarowski@epfl.ch

CCMX Management Board

Prof. Karen Scrivener, Chair (EPFL)

Dr. Nathalie Jongen
Managing Director

Prof. Heinrich Hofmann
EPFL – Director, SPERU

Dr. Katharina Maniura
Empa – Director, MatLife

Prof. Michel Rappaz
EPFL – Director, MERU

Paolo Di Napoli
EPFL – Scientific and Industrial Liaison Officer, MERU

Prof. Hans Josef Hug
Empa – Director, Analytical Platform/NMMC

Chiara Corticelli
Empa – Scientific and Industrial Liaison Officer, Analytical Platform/NMMC

Analytical Platform/NMMC

Nano- and Microscale Materials Characterisation for Industry and Academia

Prof. Hans Josef Hug
Empa – Director

Chiara Corticelli
Empa – Scientific and Industrial Liaison Officer

CCMX Steering Committee

Prof. Karen Scrivener, Chair (EPFL)
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Prof. Ralph Spolenak (ETH Zurich)
Prof. Friso van der Veen (PSI)

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Texts: Carey Sargent, Nathalie Jongen, Sue Niewiarowski
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ECOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE
ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich
EMPA Materials Science & Technology
PAUL SCHERRER INSTITUT PSI
csem

CCMX
Competence Centre for
Materials Science and Technology
EPFL STI
Batiment MX
Station 12
CH-1015 Lausanne
+41 21 693 4656
www.ccmx.ch