empa News

Empa, an Institution of the ETH Domain for Materials Science and Technology

EMPA Materials Science & Technology

Interview with Dr Arthur Vayloyan, Credit Suisse

Science in Dialog

Events such as the NanoConvention are important

The first NanoConvention held in 2006 was such a success that this year's event has been extended to cover two days, to allow participants more time for interaction, discussion and debate. One new side to the convention is that more emphasis is being placed on the economic and financial aspects of nanoscience. This is not least due to the fact that this year the principal sponsor is Credit Suisse, an organization which for some time now has been involved in a large number of events and publications in the field of nanotechnology. In the following interview with Dr Arthur Vayloyan, you will learn why Empa is the ideal partner for Credit Suisse.

MICHAEL HAGMANN

Credit Suisse is the main sponsor of the Swiss NanoConvention, which Empa is organizing for the second time this year. Mr. Vayloyan, why is a bank interested in nanotechnology?

The connection might not actually be evident at first sight. But as a financial services enterprise that expects itself to assume a leading role in terms of innovation and advice, Credit Suisse aims to identify new markets and corresponding investment trends at an early stage. We want to offer our clients comprehensive, first-hand information about the opportunities – and, just as important – the risks arising from developments of this sort. This will enable them to reach sound, broad-based investment decisions. We're building bridges between scientists and investors, as it were. Especially when a key subject of the future such as nanotechnology is involved, it's essential for researchers, developers and investors to come together so as to pinpoint the potential more precisely. We took this subject up back in 2002, and since then we have organized events and published research on this topic.

Not long ago, you described the NanoConvention as a «knowledge mart». What precisely does Credit Suisse want to «buy» at this mart?

We would like to expand our existing network of researchers, developers and investors by bringing all the key interest groups together. This will create a unique platform – a kind of marketplace, in fact – where representatives of scientific, political and social circles can meet, exchange views and offer ideas to others who are interested. Financial aspects are involved too, as they are on any marketplace, and it is precisely here that we can be of assistance with solutions. Numerous interesting discussions will allow an interdisciplinary exchange of ideas that will continue to advance this pioneering technology. For interested clients, this will also provide an opportunity to gain insights into nanotechnology from various angles. Our commitment is intended to emphasize this, and to show that we are not merely paying lip service to these ideals.

Dr Arthur Vayloyan, Member of the Private Banking Management Committee of Credit Suisse (Picture Hans Schürmann)

A partnership between a financial institution and a research organization that is supported by public funds is not (yet) an everyday occurrence, at least in Switzerland.

Partnerships of this sort are not at all unusual, in fact. For a long time now, interesting partnership models have been in existence between universities or colleges and the business sector. For example, Credit Suisse was one of the first banks in Switzerland to cooperate with Zurich University of Applied Sciences, Winterthur so as to set up a joint Bachelor of Banking program.

Why did you specifically decide on Empa as your partner in the nanotechnology sector?

It wasn't difficult for us to make this choice. Credit Suisse is a globally oriented company with strong Swiss roots; in a similar vein, Empa is globally integrated into the scientific and academic network. Moreover, Empa is highly involved in the nanotechnology sector, and plays a key role in the Swiss education, research and innovation scene. It has acquired a very good reputation and it fosters cooperation with industry and public institutions – making it

continued on page 2

Editorial

Safe Nanotechnology as a Motor for Innovation

Nanotechnology is already in use in a wide variety of applications – from IT and electronics via materials with enhanced properties, ranging all the way to novel medicinal applications.

Underpinning these developments is the interdisciplinary research into the basic principles, which is leading to an *improved understanding of nanometer scale phenomena*. For only when we understand the behavior of materials can we modify them to suit a certain particular application.

However, to be able to implement this hard-won knowledge in practice also requires *problem- and product-oriented research*. The latter takes place primarily in industry and an innovation-based national economy is therefore very dependent on close cooperation between publicly funded R&D institutions and industry.

Ultimately the development of new technologies always carries a certain degree of *corporate risk*. To encourage and strengthen the entrepreneurial spirit in Switzerland, the country's industry and financial sector need to work together significantly more efficiently than has been the case to date.

On the other hand, questions regarding the *safety of nanoproducts* are becoming ever more important. A great deal of work is currently in progress in this very field – in particular Empa's intensive, interdisciplinary research. Science and society have learnt the lessons of the past; an evaluation of its possible effects and consequences is a critical part of the process of developing and implementing a new technology. The Swiss NanoConvention 2007 is devoted to this very topic, the aim being to extend the dialog on the opportunities and risks involved in using the new technology and thereby paving the way for a secure, sustainable nanotechnology.

Prof. Dr Hans Josef Hug
Head of Empa's «Nanotechnology» Research Program
Head of Empa's Nanoscale Materials Science Laboratory
Professor of Physics, University of Basel

Inside pages

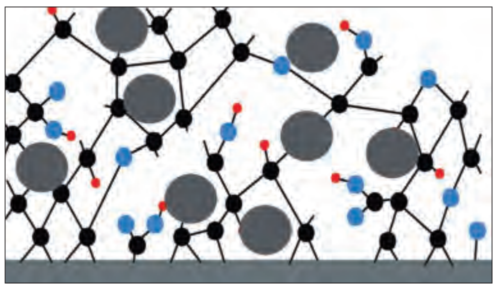
2 2007

Using plasma against bacteria, odors and wounds

Imagine: your favorite cuddly pullover with the woven-in silvers highlights is not just incredibly trendy, but it keeps you warm, absorbs the sweat when you do anything sporty, kills harmful germs and in addition it very handily suppresses embarrassing body odors. Of course it goes without saying that this all-singing, all-dancing garment is water resistant and dirt repellant, and even after a very social «Jass» evening at the local bar it doesn't smell like an old ash tray. You don't even actually have to wash it, though you can if you want since, on top of everything else, it is of course color fast and wear resistant.

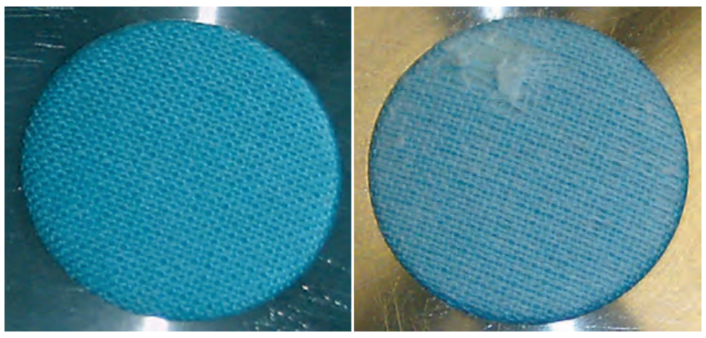
SABINE BORNGRÄBER

This is not fantasy; it is applications oriented science as practiced by Empa's Advanced Fibers Laboratory. Such innovative textiles are made possible by a process known as Low Pressure Plasma Technology, a snatch of jargon which refers to a textile finishing method of enormous potential. It allows fibers to be given a nanometer-fine surface coating without changing the feel of the woven material. The trick is in using a plasma, an ionized gas throughout which the nanoparticles are extremely finely distributed. In addition, the layers which are grown out of the gas phase contain so-called functional groups which anchor the nanoparticles firmly to the textile fibers. This enables researchers to give the fibers the required specific characteristics, which can range from color, conductivity, and water and dirt repellent properties all the way to antibacterial and even wound-healing capabilities. «The fibers we are now producing are for the first time really multi-functional, and yet they retain all the characteristic properties of textiles,» says Dirk Hegemann, head of the Plasma and Coatings Group. «And best of all, no chemical additives at all are necessary during the process, so that there are no negative effects on man or the environment.»



Schematic diagram of a nanoporous plasma layer (black) which contains functional groups (blue & red) and in which the silver nanoparticles (gray) are firmly embedded.

To date we have had to pay the price of having functional clothing by making concessions in terms of wearability and comfort – outdoor clothing which has the feel of tarpaulin, or a sweat shirt which, though fresh as a washing-powder advertisement when first worn, smells like an old sock after you have been jogging in it. These, according to Hegemann, are now problems of a bygone era. He and his co-workers have developed various plasma-based methods to render textiles multifunctional – that is, to lend them several additional desirable characteristics. For example plasma polymerization can be used to give a material a silicone coating which renders it not only completely water repellent but also wash and wear resistant. A «sputtering» process can be used to spray metal particles such as copper or silver onto textiles to enhance their electrical conductivity and give them an antistatic finish.



An abrasion test conducted on the nanoporous plasma-coatings, left, which have been coloured with acid dye, demonstrates the resistance of the surfaces until the woven material is worn through, right. Standard test material: polyester.

Further possibilities open up when both methods are combined to give the so-called plasma co-sputtering technique. In this process silicone and metallic particles float together in the plasma, giving the treated fibers all those additional functions which will in future make conventional textiles look old fashioned. The Empa team has notched up one particular success with the combination method – they have used it to develop nanoporous layers in which the finest silver particles are embedded. The silver layer puts an immediate stop to any kind of bacterial or fungal growth, and in addition the nanopores create the perfect matrix in which to deposit other medically active substances, such as for example agents which encourage healing. This is of particular interest in cases where patients suffer from skin conditions which cover large areas of the body. Neurodermitis sufferers could, for example, be given continuous doses of medication to sooth itching and inflamed skin directly from the garments they are wearing, a welcome alternative to having to rub in ointment at regular intervals.

In comparison to conventional silver coating methods based on electrolytic techniques, the Empa plasma process uses significantly less material, and so is more economic. A further advantage is that the Empa process generates no waste water containing environmentally damaging heavy metals and other noxious chemicals, unlike the conventional techniques where these drawbacks are unavoidable. Currently the silver coating process is being given the final touches to make it ready for use in industrial applications. Negotiations with sports garment manufacturers and producers of medicinal textile products are at an advanced stage. ■

Dr. Dirk Hegemann, dirk.hegemann@empa.ch

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continued from page 1

an ideal partner for us. Cooperation is therefore an obvious step for these two institutions, both of them very important to Switzerland and both of them with leading roles in their sectors.

Switzerland could be called the cradle of nanotechnology, with the invention of the scanning tunneling microscope by Heinrich Rohrer and Gerd Binnig at the IBM Research Laboratory in Rüschlikon, which won them the Nobel Prize. But on more than one occasion, this country has missed the chance to put its advanced knowledge into practice by converting it into new technologies. Is there a risk that history will repeat itself?

In recent years, Switzerland has produced a series of spin-offs in the nanotech sector and some of them have already become global market leaders in their core businesses. Switzerland also has a wide range of different companies that have come into being and are now active in many different areas of this sector. The TOP Nano 21 research program aroused industry's interest and promoted cooperation between science and business. We should utilize nanotechnology to strengthen Switzerland as a research and business location. I think that the political world has also seen the signs of the times: We ought to look forwards, and I'm very optimistic about the prospects.

Financial analysts regularly outdo one another in their estimates of the economic potential for nanotechnology. People talk of annual sales of one trillion Euros or more. Scientists are more cautious about what they say. What should we make of these figures? Hype by the financial sector to entice investors, or a likely scenario for the future?

It's very difficult to arrive at an accurate estimate of the market size. There are very wide divergences between some of the estimates because nanotechnology is embedded in products. Estimates in the range of trillions refer to the market for products that contain nanotechnology. For nanomaterials on their own, such as carbon nanotubes or quantum dots, the estimates are in the range of billions of US dollars. Quantum dots can be used as minuscule markers to highlight individual genes, nucleic acids, proteins or even small molecules and trace them in cells. They could lead to rapid progress in medicine. Carbon nanotubes could be interesting to the electronics industry because of their thermal conductivity and current carrying capacity. However, it's relatively difficult to give a reliable estimate. Figures differ widely in the financial sector too, but I believe that the potential really is very high.

Whether new technologies ultimately become established on the market – or among the consumers – depends not least on social acceptance of the technology in question. This is why things have not always worked out ideally for a number of other novel technologies. In the case of nanotechnology, how do you assess the interaction between technology and society – which, incidentally, is one of the main themes of this year's NanoConvention?

This is exactly why it is very important to seek dialog with society at an early stage. The general public should join in the discussion and be able to understand it. The problem with technologies in the past was that the public were often involved too late in the day. It is important that both the potential and the risks are clearly stated and explained. To enable a real dialog to take place, you also need a language that can be understood – which means that events such as the NanoConvention must enable the transfer from the world of science into society.

Your colleague Giles Keating, Head of Global Research, has compared nanotechnology – regardless of its market potential – to the introduction of computer and information technology or electricity, probably two of the most important technological achievements of all time. Will nanotechnology entail similarly far-reaching consequences?

Yes, but nanotechnology is also an «enabling» technology, in other words, one that makes other technologies possible. It's a technology that can be used everywhere, across all business sectors. You have to conclude, therefore, that this technology will have an extremely important role to play. ■

Virus-fishing with nano in drinking water

More than a billion people have only limited or even no access to clean drinking water that is free of disease-causing pathogens. Several million die each year from drinking contaminated water. Empa is working together with an industrial partner to develop a new type of virus filter based on the high-tech ceramics that are already in use for bacteria filters.

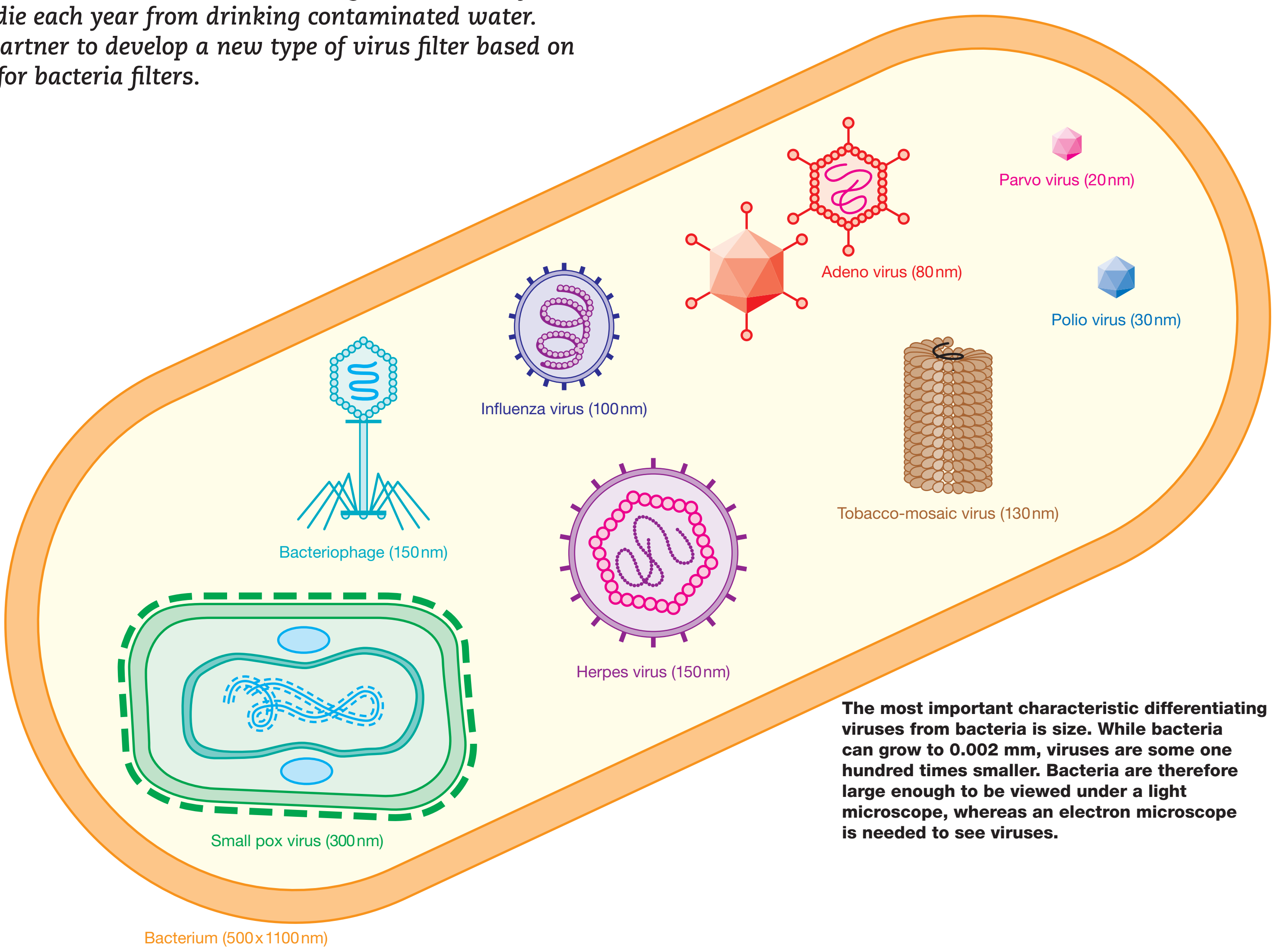
MICHAEL HAGMANN

Viruses are generally considered to be the smallest micro-organisms living on our planet. Over the course of evolution, they have thrown all genetic «ballast» over board and grown steadily smaller. Whereas micro-organisms such as the coli bacteria in our digestive tract measure approximately one micrometer in size, viruses are some 10 to 100 times smaller. Indeed, this is the crux of the matter: efficient ceramic filter systems capable of removing pathegenic bacteria from drinking water – giants, compared to viruses – were already developed quite some time ago. Not so for viruses. These minute, infectious germs slip through even the finest filter.

New type of manufacturing process for ceramic microbe filters

For several years now, Empa researchers under the direction of Thomas Graule and Frank Clemens have been working with Katadyn Produkte AG, a Swiss company specializing in water purification technology, to develop effective microbe filters. «The world leader in the field of portable water treatment systems is an ideal SME development partner», says Graule, head of the High Performance Ceramics Laboratory. Initial work proved successful, as the jointly developed new production process demonstrates: the so-called extrusion process lowers material consumption and production costs by more than half while at the same time increasing the reliability of the high-tech ceramic filters. Then, in a project funded by the Swiss Promotion Agency for Innovation (CTI), Empa researchers endeavoured to modify their high-tech ceramic bacteria filter in such a way that it could also efficiently retain viral pathogens.

Ceramic filters made from diatomaceous earth, a natural raw material composed mainly of silicon oxide, possess highly promising characteristics. They can be manufactured simply and economically and regenerated for repeated use. On the other hand, the specifications for effective virus filters – such as those prescribed by the US Environmental Protection Agency (EPA) – are extremely strict. They must be capable of retaining at least 99.99 percent of all viruses in contaminated water – or in other words, no more than one virus in 10 000 may pass through the filter. In addition, virus filters must have a processing capacity of some 60 liters per hour and in portable deployment – i.e. to process highly contaminated water – must possess a minimum «service life» of 500 liters. Furthermore, such microporous ceramic filters must naturally still remain effective against bacteria.



The most important characteristic differentiating viruses from bacteria is size. While bacteria can grow to 0.002 mm, viruses are some one hundred times smaller. Bacteria are therefore large enough to be viewed under a light microscope, whereas an electron microscope is needed to see viruses.

Virus filter for clean drinking water

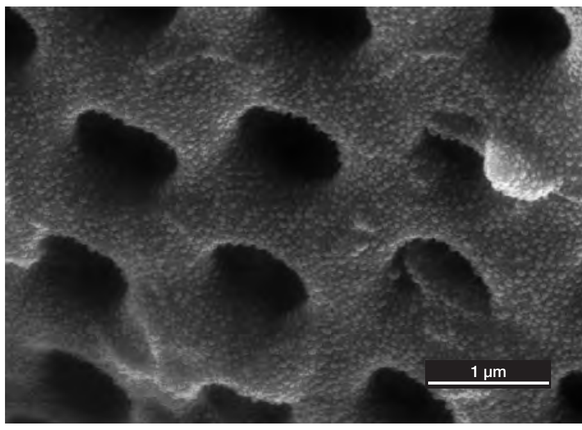
Empa researchers have now come up with the idea that if the filter surface were coated with nanoparticles, the modified surface should be capable of retaining viruses. A patent for this idea has been applied for. Initial tests with nanoparticle coatings indicated its potential – which is why the project is named NANOVIR. However, in order to determine virus filter efficiency, Empa researchers and their colleagues at Katadyn first had to establish a (safe) filter test. After evaluating the properties of various substances, fluorescent latex particles were found to be most similar to viruses by virtue of their diameter of 36 nanometers and their surface characteristics. Researchers also developed a real virus test using MS2 bacteriophages – viruses which infect bacteria but are harmless to humans.

Early results are very promising. Under laboratory conditions, the nano filter successfully retained 99.9999 percent of the MS2 phages at a filter throughput of 60 liters per hour. In addition, bacteria were also filtered out in the usual way, as required. However, filter efficiency diminished over time, as the nanoparticles lose their effectiveness with increasing use.

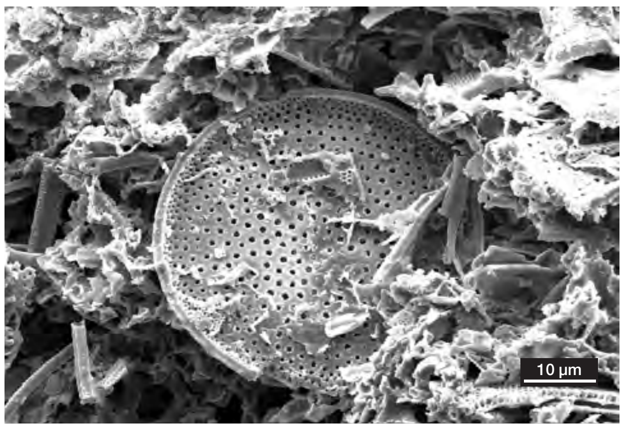
Influence of suspended contaminants

Empa researchers are currently testing various nanocoatings and production conditions to achieve irreversible bonding of the nanoparticles to the ceramic filter. A recently begun PhD thesis is additionally investigating the influence of contaminants such as organic substances suspended in river water that would adversely impact virus filter effectiveness. A first possible use for these filters would therefore be for the household treatment of tap water in developing countries where such filtering is necessary and makes good sense. ■

Dr Thomas Graule, thomas.graule@empa.ch



Fracture surface of a coated virus filter with adsorbed latex nanoparticles (particle size: 50 nm).



Electron microscope imaging shows the pore structure of diatomaceous earth, the raw material used to fabricate the virus filters.

Preparing the ground for safe nanotechnology

The safety and reliability of new materials have always played an important role at Empa. The same holds true for nanomaterials. Nano safety research at Empa is focusing particularly on free nanoparticles and their impact on health and the environment. Empa researchers are investigating not only how nanoparticles affect human cells and the environment, but also how we as a society are reacting to this new technology and what we judge its value to be.

MARTINA PETER

Whenever new materials or technologies are introduced, questions quickly arise regarding their safety. Those who speak of the «risks of nanotechnology» are thinking particularly of the risks associated with synthetically manufactured nanoparticles. If these tiny particles are firmly embedded in a material – in a polymer, for example – they do not, according to current research, pose any hazard. Minute salt crystals blown from the oceans onto land, for example, are likewise considered harmless to health. However, under certain circumstances many other nanoparticles may adversely affect our health. When and how do they become a health hazard? Is it their chemical composition, their size or their surface characteristics? Or is the decisive factor the number of particles to which a person is exposed? Furthermore, what happens when nanoparticles are released into the environment? Empa is studying all of these questions because – according to Harald Krug, head of Empa's Material-Biology Interactions Laboratory – «The institute has a very high level of expertise in the production, analysis and science of the biological effects.»

Nanotoxicity: when are these very small units toxic?

To date, very few meaningful studies of nanoparticle release mechanisms and nanotoxicology, the study of the toxicity of nanoparticles, have been performed. Biologists and material scientists at Empa, in cooperation with biochemists at ETH Zurich, have developed cell tests which enable an approximate measurement of particle toxicity. Initial results demonstrate that while some metallic oxide particles have a considerable adverse effect on human pulmonary cells, substances such as tricalcium phosphate (used in medical implants) proved as innocuous in cellular experiments as silicon oxide, a substance that has long been approved as a foodstuff additive and used, for example, to improve the pouring properties of salt.

Nanologue: social dialogue on nanotechnology

Empa scientists are also concentrating efforts on determining the current attitudes of society towards new technologies. There is still little public awareness of the opportunities and hazards posed by nanotechnological applications. However, this situation will undoubtedly change as more «nano products» appear on the market. The goal of the «Nanologue» project was to prepare the way for the broadest possible, best informed public dialogue on nanotechnology. This EU project drafted three possible scenarios depicting how nanotechnology might develop in the future. Numerous examples are used to illustrate how society might benefit from this new technology (for example, if nanomaterials enable the creation of new, environmentally friendly forms of energy), but also how neglected questions (such as those concerning risks) foster mistrust and fear. Furthermore, the internet-based «NanoMeter» uses a type of questionnaire to help research communities and companies to identify socially relevant topics associated with «their products» and to understand what reservations or objections the public may have to the use of such products. The aim is provide impetus for thought at an early stage in the product development phase with the aim of initiating an open dialogue. «For example the fact that the particles are invisible causes users a degree of unease. They would therefore like to see clear product descriptions which include details of the particles used in manufacture», says Krug, based on what he has learnt during such dialog-based events.

Nanoparticles and society: are new rules needed?

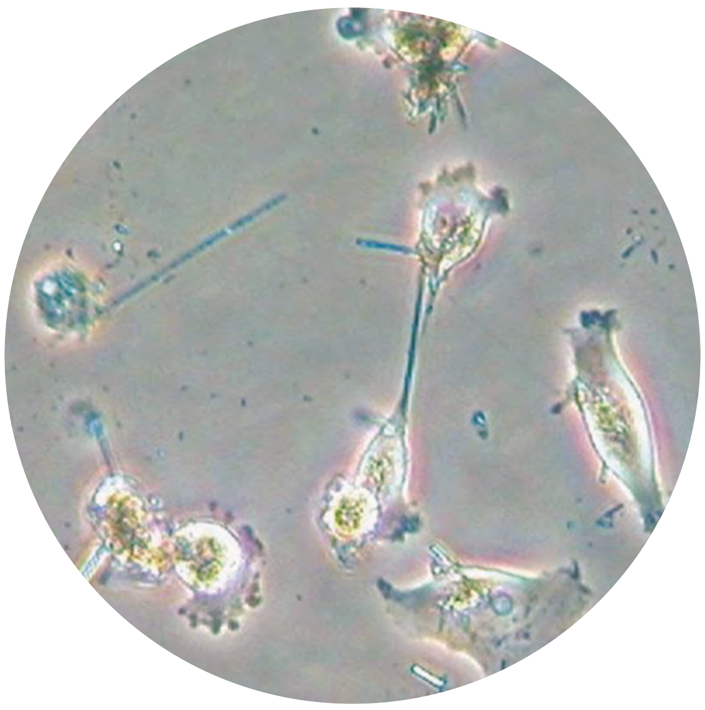
Much in the field of nanotechnology is new and seems futuristic. Do we therefore also need new laws to regulate these new materials? To date, no European state has taken this step and nanoparticles are subject to the same legislation as "conventional" chemicals. Of the European decision-makers from science, industry, the health authorities, the EU and non-governmental organizations (NGOs) surveyed by Empa researchers, none of them – with the exception of NGOs – expressed any desire to push for new, more stringent laws, not to mention outright prohibition. The basic tenor is that today's sketchy, incomplete knowledge is insufficient to formulate any legislative framework. However, all those interviewed voiced the belief that more safety research is needed along with open communication of the results yielded by such research.

Looking ahead to the future

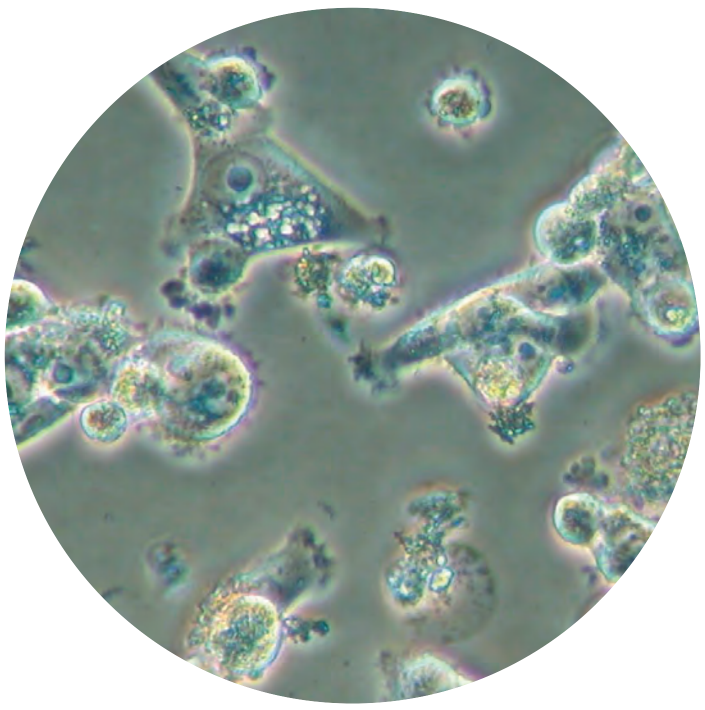
Empa, in collaboration with national and international research institutions, conducts research into the safety of nanotechnology and communicates its results openly. One of its many interdisciplinary projects focuses on lifecycle analysis of nanomaterials and nanoproducts. Another project is investigating the question of how nanomaterials behave in the environment, i.e. in various ecological systems such as bodies of water and soils. The answers to these questions will undoubtedly stimulate further debate and thereby fuel society's imperative dialogue on this new technology. ■

Prof. Dr Harald Krug, harald.krug@empa.ch
Dr Bernd Nowack, bernd.nowack@empa.ch

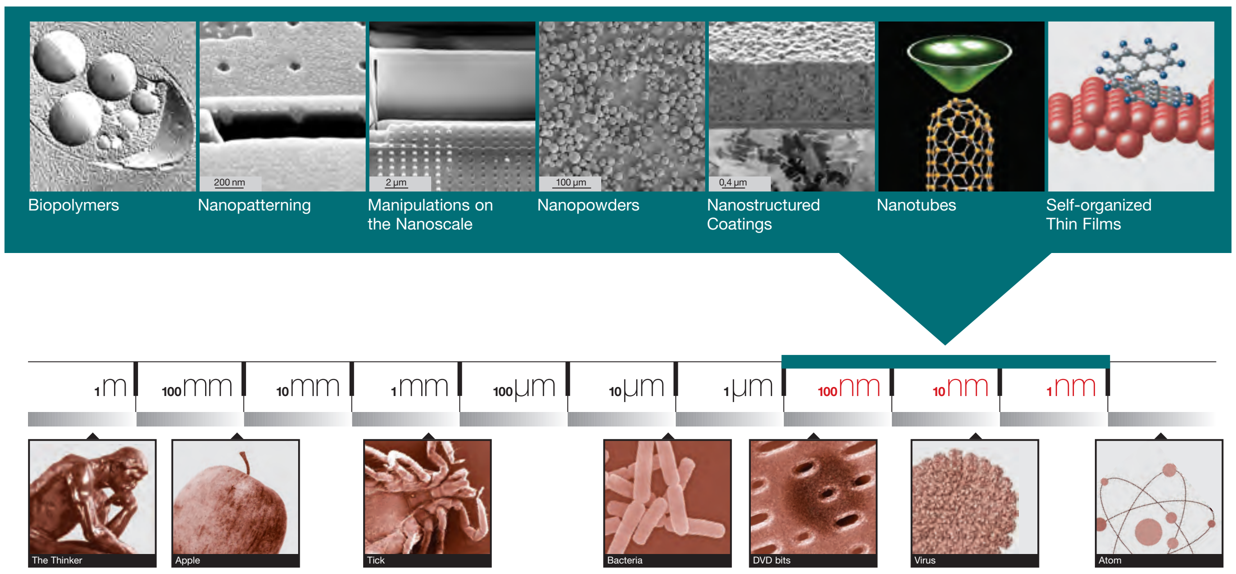
Human pulmonary cells which have been exposed for three days to harmless silicon dioxide (SiO_2) nanoparticles. The cells are firmly attached to the substrate and have a spindle-like form. This is how a healthy cell culture should appear.



Human pulmonary cells which have been exposed for three days to toxic asbestos fibers. Instead of being attached to the substrate and elongated, as normally the case, these cells have begun to develop a rounded shape and to detach from the substrate, signs of stress.



Human pulmonary cells which have been exposed for three days to iron oxide (Fe_2O_3) nanoparticles. Here too the cells are already beginning to develop a rounded shape and to detach from the substrate, initial signs that the iron oxide particles are cytotoxic too.



An illustration of the size relationship between one meter and atomic dimensions. Several examples form current Empa projects in the nanometer range are marked in blue-green, the largest of which is as large as 100 nanometers.

Empa is contributing to «NanoDialog» and «NanoAmbassador»

Nanotechnology stands for progress and innovation. In order to avoid repeating the mistakes made in the past with biotechnology and gene technology, those working within this new field are taking great pains to ensure that a philosophy of open communication and information exchange with all concerned prevails from the very earliest opportunity. The aim is to foster trustworthiness and confidence in nanotechnology and those associated with it to ensure the acceptance of this new technology in society in general.

Harald Krug, head of Empa's Materials-Biology Interactions Laboratory as of January 2007, was appointed to the «NanoDialog» Action by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) at the end of 2006. Until the end of 2008 sixty experts drawn from politics, industry, the economy, science and society, divided into three working groups, will regularly collate their experiences, opinions, and know how, and share information to generate an annual nanoscience balance sheet as well as making interim and final recommendations. The flow of information will not only take place within and between working groups but also be directed toward the general public through enhanced communication about the work and the results of «NanoDialog». The aim is to integrate the general public into the communication loop and to make known to a wide audience both the opportunities presented by nanotechnology and the risks involved. Harald Krug's experience and enthusiasm is contributing to the success of the «Risks and Safety Research» working group (see ***www.bmu.de/nanotechnologie***).

As a further vehicle to encourage open, factual dialog about nanotechnology the Deutsche Museum in Munich has established the «NanoAmbassador» Initiative. On 23rd April 2007 six selected ambassadors were presented to the public, among them Harald Krug. A «NanoAmbassador» is a scientist who has taken on the task of informing the general public about nanotechnology and encouraging public dialog on this topic by engaging in open discussion, conducting expert exchanges of opinion and participating in other such events (see ***www.nanobotschafter.de***).

Until the end of 2006, Harald Krug was Head of the Molecular Environmental Toxicology Laboratory at the Institute of Toxicology and Genetics, Forschungs-zentrum Karlsruhe, Germany. He completed his professorial qualifications («Habilitation») in Environmental Toxicology at the University of Karlsruhe, where he continues to hold a Professor-ship. On behalf of the German Federal Ministry of Education and Research (BMBF) he has, since the beginning of 2006, headed the NanoCare Consortium. One important research topic (among others) for Krug is the molecular interaction between very fine dust or nanoparticles and cultured human cells. The motivation for his passionate engagement in nano research and in nanodialog has its origins in his belief in science's social responsibility. «New technologies carry the risk of bringing with them dangers to human health and to the environment. Facing up to our responsibilities towards society and individuals means that the development of new technologies must be accompanied by research into their effects on man and the environment.»

Events

Empa Academy

September 5 through 6, 2007

CEM 2007 – 8th International Conference on Emissions Monitoring

CEM 2007 is a major international confer-ence specifically designed to cover the subject of source emissions monitoring in its entirety. It will consider the latest developments in measurement techniques, environmental legislation and standardization.
Venue: AKADEMIE, Empa, Dübendorf

September 10, 2007 9 am – 4 pm

Cement Research at Large-Scale Facilities

3rd CEMNET Workshop, in collaboration with Swiss Light Source (SLS) and Swiss Neutron Source (SINQ).
The goal of the workshop is to map out the increasing role played by synchrotron light sources and neutron sources in cement research, with special reference to structural and process-oriented investigations
Venue: Paul Scherrer Institut, Villigen

July 22 through 24, 2008

CICE 2008 – 4th International Conference on FRP Composites in Civil engineering

CICE 2008 is an official conference of the International Institute for FRP in Construction (IIFC). It will provide a forum for discussions of the state-of-the-art, state-of-practice, recent advances and future trends in the application of FRP composites in civil engineering.
Venue: ETH Zürich

Details and further events see at www.empa-akademie.ch

Notes

Empa blimp puts in convincing performance at Berlin regatta

Empa's EAP blimp achieved the fifth best time at the regatta held during Berlin's «Lange Nacht der Wissenschaften» («long night of science») on 9 June 2007. For Silvain Michel and his team of Empa scientists, however, more important than the result was the fact that they were able to control the blimp perfectly with the electroactive polymer (EAP) hinges in its fin assembly. EAPs are able to convert electric energy directly into mechanical work by expanding their surface area when an electrical voltage is applied. This occurs noiselessly and in an extremely energy-efficient manner. Thus the technology is also suitable for providing propulsion. The Empa team's ultimate goal is to build a blimp in which the EAPs are fused with the hull, enabling the airship to «swim» through the air like a trout. The team established interesting leads on this subject with the Institute of Bionics at the Technical University of Berlin. Furthermore, Michel does not rule out further races!

Empa's EAP blimp at the regatta during Berlin's «Lange Nacht der Wissenschaften» («long night of science»).

Manipulation with unheard of precision

We expect them as a matter of course, as self-evident as sunshine in summer – more powerful computers, cell phones with yet more functions, even smaller MP3 players, and so on. At the heart of each of these high tech devices sits a silicon chip bearing minute electronic circuits. To monitor the quality of such chips, optical methods such as Raman spectroscopy are used. Empa materials expert Johann Michler and his team have now managed to make significant improvements to this spectroscopic technique. With colleagues from the Max Planck Institute for Microstructure Physics in Halle, Germany, the Empa researchers constructed probe tips out of silicon nanowires which improve the precision of the Raman method by a factor of up to a hundred. This allows changes at the molecular level – such as those on a microchip - to be observed.

SABINE BORNGRÄBER

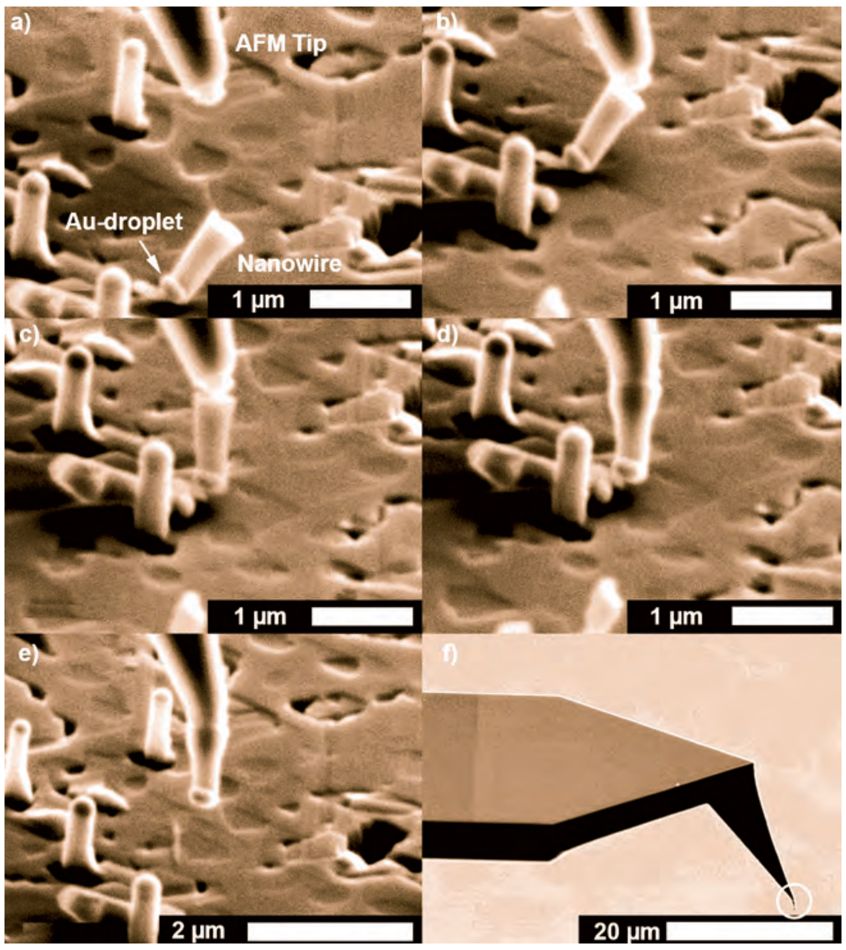
Studying the properties of materials at the nanometer level is a speciality of the new Empa Mechanics of Materials and Nanostructures Laboratory in Thun. Johann Michler and his team are conducting research into the inner structure of solids with the help of so-called tip enhanced Raman spectroscopy (TERS). A laser beam scans the surface of the sample and causes the molecules to oscillate. In doing so, they absorb some of the light, reradiating it later in a phenomenon known as «Raman scattering». This effect is unique for many substances, a sort of optical fingerprint, and it allows scientists to infer not just the composition of a sample, but also whether it contains crystal faults or internal stresses.

Locally enhanced laser spot makes molecules visible

Until recently researchers such as Michler and his colleague Silke Christiansen of the Max Planck Institute in Halle were, however, confronted with a problem. In order to use the spectroscopic technique to detect mechanical stresses in minute components the laser spot needed to be locally enhanced. This required a metallic tip, ideally manufactured to exactly the right size and shape with nanometer accuracy, something which to date was not possible technically. The technique was therefore not sensitive enough to allow quality control of materials on the nanometer scale and to uncover minute structural faults.

For decades, scientists have faced the problem of how to make molecules visible with the help of laser beams. The wavelengths of the light emitted by lasers are still much longer than the nanometer scale dimensions of molecules, which therefore cannot be «seen» – resolved, in scientific jargon – by the laser light. One way to «trick» the visible light waves was discovered in 1974 by the American chemist Martin Fleischmann, the same scientist who, fifteen years later, would claim to have discovered cold fusion in the laboratory. While his cold fusion experiments could not be reproduced by other researchers (and are today considered to be erroneous), his optical experiments have revolutionized several scientific fields including Raman spectroscopy.

Fleischmann discovered that a rounded tip coated with gold or silver can be used to efficiently couple laser light into molecules or crystals. Doing so makes the Raman technique significantly more sensitive, theoretically enabling individual molecules to be identified. In practice, to date the factor limiting the resolution of the method has been the fineness of the tip which can be achieved. The sputtered gold surface of the tips tip takes on randomly different shapes, so that each one is slightly different in shape and size. «These tips look like the Matterhorn under the microscope», says Michler. To be able to follow surface features with a spatial resolution in the nanometer range – such as for example how microelectronic components change over time – requires that the tips must be identical to the nanometer. Only then the measurements are comparable.



A sequence of images showing the steps necessary to create a nanotip for Raman spectroscopy applications:

a) **a nanowire is broken off from the silicon «lawn» and turned on its head**
b) **the still-unfinished tip of the spectroscope contacts the nanowires**
c) **the tip maneuvers the nanowire into a vertical position**
d) **he tip and nanowire are welded together by an electron beam**
e) **the finished nanotip is removed from the microscope**
f) **the holder with the finished tip, ready to be used for Raman spectroscopy measurements.**

Silicon nanowires with identical gold heads

Now Michler and Christiansen have developed a new method of creating even finer Raman tips. They grow silicon nanowires with gold heads on a silicon substrate, the nanowires growing like blades of grass on a lawn. In contrast to grass, however, they are just a few micrometers long, with diameters selectable between 25 to 500 nanometers. The most important feature is that all the nanowires have identical, perfectly round gold tips. No trace of the Matterhorn now, more a case of the cupola on the Federal Parliament building in Bern.

The nanowires are then welded onto a holder in an electron microscope. «This allows us to see the wires and we can guide them precisely to where we want to locate them, and then fix them in place», explains Stephan Fahlbusch, the nanotools specialist in Michler's team. He and his colleague Samuel Hoffmann use a joystick to move the holder to the vicinity of one of the nanowires. A quick twitch of the joystick and the wire adheres to the tip, where it is welded in place using the electron beam. Now Fahlbusch can use the tip for nano-Raman spectroscopy experiments. The sensitivity of the new method is demonstrated by the colleagues in Halle, where the tip was scanned over a layer of malachite green. Although only single molecules of the dye were present on the substrate, the equipment produced a definite Raman signal. This means that the resolution of the technique is high enough to measure changes in the internal mechanical stresses of semiconductor materials, for example. This is important because it indicates the presence of defects or material fatigue.

Automization – the next step

Michler's method of producing nanotips for Raman spectroscopy applications represents enormous progress, above all for the EU-Project NanoHand, in which Empa researchers, together with partners from France, Germany, and Switzerland, have been involved since 2006. The aim is to construct a nanorobot for the semiconductor industry which will be capable of handling miniaturized samples on the platform of an electron microscope and producing tips without human intervention. Automated production, with its associated cost reductions, will extend the range of applications of the nanotips, for example to the chemical analysis field. This might allow forensic science or hospital hygiene to benefit from the potential offered by nano-manipulation, by allowing for example a conviction to be obtained by the discovery of a single cocaine molecule on the jacket of a suspect or the identification of a single lethal bacterium which triggers a pandemic-avoiding quarantine. ■

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NanoHand: Europe's largest microrobotic project

The name says it all. The NanoHand is intended to assemble, manipulate and transport objects just a few nanometers in size such as carbon nano tubes and nanowires. Leading research institutes in the field of microrobotics and nanohandling (including Empa), six SMEs (as manufacturers) and the largest semiconductor producer in Europe (as the end user) are working on the development of a robotic system which will allow the convenient handling of components with nanometer scale dimensions. This robotic dexterity is of great importance in the semiconductor industry. The aim of the project is to develop nanotools which will allow the automation of both the manufacture of silicon chips and the monitoring of their quality. NanoHand is a successor project to Robosem, which was successfully completed in Summer 2005.

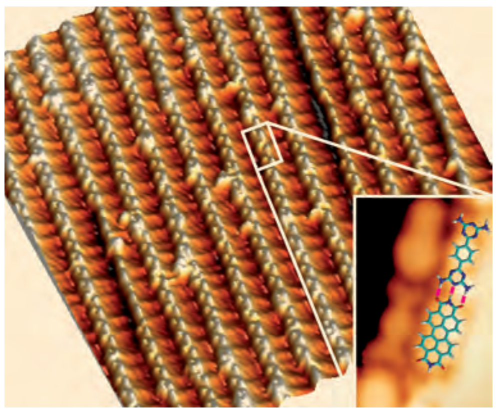
Nanocomponents for tomorrow's computers and electronics

«Smaller, faster and cheaper» – these are the relentless demands made of the components used in future electronic circuits and devices. To actually produce these minute items, and so to complete the transition from today's classical microelectronics to tomorrow's new nanoelectronics, Empa scientists are developing novel manufacturing strategies and technologies. They are, for example, creating nanotransistors by inserting atomic defects into carbon nanotubes, or they are using molecular self assembly techniques to make electronic components such as nanowires create themselves.

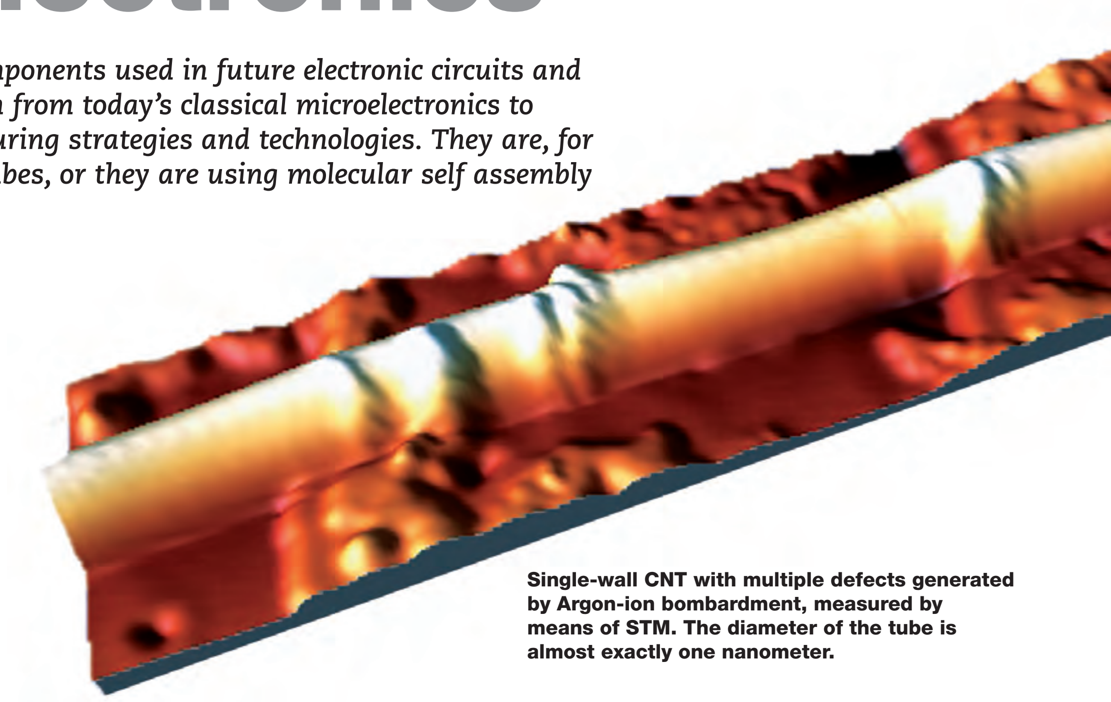
MICHAEL HAGMANN

In addition to the continuing efforts of chip manufacturers to squeeze ever increasing performance out of computer chips of ever decreasing size, there is also growing interest in developing the cheapest possible electronic devices to open new applications, e.g. sensors or displays on packaging. This is easier said than done – to achieve such an aim entirely new solutions and manufacturing processes need to be developed. These are applications for which nanotechnology is predestined, since one of the potential building blocks of future nanoelectronics – carbon nanotubes, or CNTs – can be made to be electrically conductive, like a minute wire, or semiconducting like silicon, depending on its atomic structure and diameter. Silicon is used among other things for making transistors – mini-switches which, when wired into an appropriate electronic circuit, either conduct electricity or not, depending on the applied gate voltage.

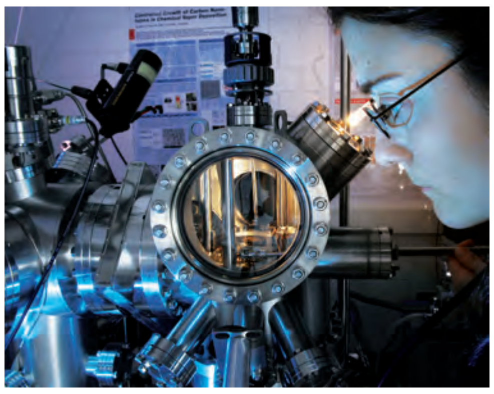
The guiding principle of semiconductor technology is the ability to control the electrical characteristics of semiconductors by intentionally inserting «defects» into the material structure. This is done by doping the material, a process of adding controlled concentrations of foreign atoms. The aim of Empa researcher Oliver Gröning and his team is now to control specific electronic properties of CNTs by making atomic modifications to the substance. To create the required defects in the carbon lattice of the nanotubes the scientists are using a hydrogen plasma under ultra high vacuum conditions. At the point where a carbon atom chemically binds to a hydrogen atom the carbon atom is pulled from the surface of the tube by a small amount. A small bump is formed which can be «seen» (or more accurately scanned) by a scanning tunneling microscope, or STM. The minute atomic-scale distortion now acts as a barrier for electrical charge carriers, as the STM measurements also show. «The electrons are in fact reflected by the defect,» explains Gröning.



STM image of double-row heteromolecular wires (70 nm x 70 nm). Inset: Well-resolved individual molecules within the double-row wires (3 nm x 4 nm), with superimposed model structure of the molecules.



Single-wall CNT with multiple defects generated by Argon-ion bombardment, measured by means of STM. The diameter of the tube is almost exactly one nanometer.



The ultra-high vacuum STM with which the Empa researchers study surface phenomena, such as the self-assembly of supramolecular structures.

On the way to creating the single electron transistor

If two of these defects are located very near to one another – in this context «near» means 10 to 20 nanometers apart – then, according to the STM electron density measurements made by the Empa researchers, a so-called single electron transistor should be formed. This is a kind of transistor which switches on only when certain precisely defines gate voltages are applied. Conventional field-effect transistors, on the other hand, conduct electricity when the gate voltage lies below a certain value. Above this value the device switches off. The properties of a field effect transistor are therefore defined by these two voltage regions only. The great advantage of the single electron nanotube transistor is the fact that, unlike previous prototypes made of classical semiconductor materials such as gallium which can only be used at temperatures below -190°C, it will function at room temperature.

The next step for the Empa team, which is working in collaboration with colleagues from the Swiss Nanoscience Institute at the University of Basel, is to confirm the STM results by conducting electrical measurements on the modified nanotubes.

Electrical circuits that «build themselves»!

Roman Fasel and his team, on the other hand, are taking a completely different approach to tackling the same problem. Instead of making nanocomponents and circuits using classical techniques, the Empa researchers are attempting to let chemistry do the job for them. Their vision: one merely has to mix the chemical ingredients together and without further intervention the required components assemble themselves and arrange themselves into finished electronic circuits. What sounds like alchemy to the layman is known in the scientific jargon as molecular self-assembly, a field in which Fasel and his colleagues have recently been making impressive progress. They have been able to make fullerene molecules (so-called buckyballs) arrange themselves into a two dimensional lattice of «nano islands», and have persuaded two organic molecules to assemble themselves into long parallel nanowires.

For some time now scientists have been able to shape organic molecules so that they bind to each other alternately and under certain circumstances (for example on surfaces) form chains. But not very long ones, because surfaces – even very smooth ones – always have some residual roughness on the atomic scale such as steps a few atoms in height. The latter features represent an insurmountable obstacle to molecular chains, causing them to break. The Empa researchers' method actually takes advantage of the steps, since on a surface with steps that run in parallel the molecular chains (which form preferentially along the edges of the steps) arrange themselves into long, parallel lattices.

And so doctoral student Marta Cañas-Ventura and her Empa colleagues prepared the surface of a gold crystal in a suitable fashion, repeatedly bombarding it with argon ions (a cleaning step which removes microscopic contamination from the surface) and heating it. The gold surface was now covered with countless parallel steps, all separated by exactly 5.8 nanometers and all of the same height – exactly one gold atomic layer, or 0.24 nanometers. All that remained for the scientists to do was to evaporate the components of the nanochains onto the gold surface under ultrahigh vacuum conditions. One of the organic molecules used was specially synthesized for the Empa team by colleagues at the Max Planck Institute for Polymer Research in Mainz.

What the researchers then saw under the STM confirmed their hypothesis. At low concentrations of the two chemical components a single chain formed on each step. At higher concentrations a double chain formed. The double chains, with defect free zones up to 30 nanometers long, actually showed significantly better self organization than the single ones. «The two chains probably mutually stabilize each other,» hypothesizes Fasel. All told, a sort of lattice was formed on the gold surface with countless regularly spaced nanochains running parallel to each other. «Our study shows that it is basically possible to grow supramolecular chains oriented parallel to each other on surfaces, and that over relatively large distances, too» says the Empa researcher.

The self assembling supramolecular chains are, however, not suitable as electrical conductors for molecular electronics applications. For one thing, they are in contact with a metallic substrate – gold – and for another their electrical conductivity is not good enough. The Empa team is therefore working intensively on methods of creating supramolecular chains on insulating substrates, using molecules which are better suited to use as electrical conductors and which can be formed into nanowires. Also of interest are molecular transistors, based on the hexabenzocoronene molecule, which consists of 42 carbon atoms and some day may well find use as a molecular single electron transistor. «Our long term aim is to understand and control molecular self assembly processes so that technically exploitable applications can be developed, not just in the laboratory but also for manufacturing on the industrial scale,» says Fasel, who is also the coordinator of the RADSAS project («Rational Design and Characterization of Supramolecular Architectures on Surfaces»), supported under the auspices of the EU 6th Framework Program. ■

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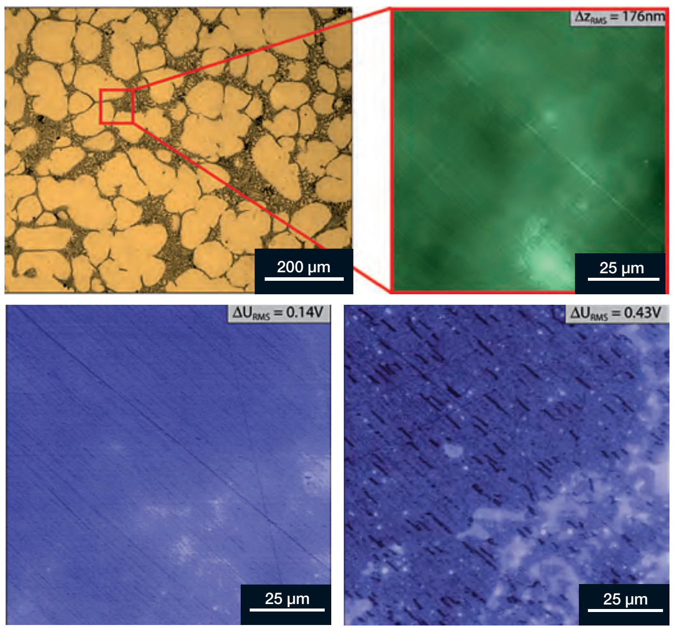
Service lab for «nanometer-accurate» surface analyses

Recently, the Swiss Scanning Probe Microscopy User Laboratory (SUL) has been established at Empa in cooperation with the ETH Domain's Competence Centre for Materials Science and Technology, (CCMX). It offers customers from industry and research institutes a complete infrastructure for precision surface measurements and analysis.

MANUEL MARTIN

Studying surfaces on the nanometer scale

The surface of a material constitutes its interface with the outside world. It is therefore exposed to numerous environmental influences. Moreover, surfaces play an essential role in determining material properties such as reactivity, corrosion resistance, wear behavior and mechanical strength. An understanding of the surface structure and characteristics is therefore of paramount importance to the materials processing industry as well as in materials research. Standard equipment used for surface analysis includes the scanning force microscope (SFM), which has been used to image surfaces, providing «nanometer-accurate» information on specific properties quickly and non-destructively.

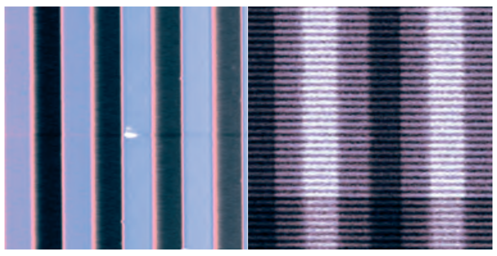


Images top to bottom, left to right: Optical and SFM topography image of a Mg-Al-Zn film. After plasma cleaning, the film shows a homogeneous oxidation of the surface. Following exposure to 70 percent relative humidity, strong surface corrosion (light blue and black features) becomes visible.

Often institutions and enterprises require only a few measurements for such surface analyses, hardly justifying the investment necessary to buy and maintain their own instrument. A central service and user laboratory open to customers from industry and research has now been conceived to meet these needs. In cooperation with the ETH Domain's Competence Centre for Materials Science and Technology, (CCMX), Empa recently established the Swiss Scanning Probe Microscopy User Laboratory (SUL) – once again demonstrating Empa's bridging function between science and industry, between applications oriented research and its practical implementation. In taking on this role the institution is contributing to converting technical innovations into marketable products, thereby strengthening the competitiveness of the Swiss economy.

Empa – THE address for surface analysis

The newly established SUL, coordinated by Empa scientists Sara Romer und Peter Kappenberger, offers its customers a complete infrastructure for precision measurements and analyses of surfaces: five scanning force microscopes are currently available for a wide variety of measurements. These SFMs can determine surface roughness in the micro- or nanometer range, but they are also able also perform demanding measurements of surface electrical resistance, local hardness or magnetic and electrical properties. The measuring environment can be adapted to almost any customer needs; the possibilities ranging from atmospheric pressure and room temperature to high-vacuum conditions and atmospheres of various gases – including corrosive gases – or degrees of humidity, high and very low temperatures. Sara Romer emphasizes the fact that customers can at anytime tap into Empa's extensive research knowledge base right from the experiment planning phase. And she adds, «We will also provide advice and hands-on help with the operation of the equipment or the analysis of measurement results.»



Topography (left) and electrostatic force microscopy (EFM) signal (right) of a microfabricated grating. The EFM image reveals that the vertical bars are differently charged. (Images: 10 µm x 10 µm)

Precision measurement and tailor-made atomic force microscopes

The SUL's broad range of services is truly unique in Switzerland and enables it to satisfy individual wishes of customers and partners. Extensive cooperative arrangements for research and development are possible, too. In such projects, providing infrastructure and performing measurements are just the basis, as these are frequently only partial steps towards solving a general problem in surface science. How are the results, i.e. the material parameters that have been measured, to be interpreted? Do comparable values already exist in the literature? The experts at Empa are available for consultation on such questions at any time. In addition, the SUL offers training and continuing education opportunities. Finally, should none of the existing microscopes prove suitable for the application at hand, the Empa's specialists can use specialized research equipment that offers even greater possibilities for tailor made measuring environments and conditions.

Empa scientists are not just studying structures on the nanometer scale, they are also developing novel instruments for this purpose, such as an SFM which will be connected to a synchrotron beamline at the Swiss Light Source (SLS) to permit chemical analyses at the nanometer range. Another, specialized SFM will be optimized for high-resolution measurements of (biological) samples immersed in liquids. Thus, the SUL can continuously expand the range of possible applications of scanning force microscopy and thereby broaden its service spectrum to meet future customer needs. ■

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SUL

- Provides consulting: SFM experts solve material problems with the aid of surface analyses.
- Performs measurement services: expert Empa researchers conduct SFM measurements for customers.
- Leases SFM workstations to customers: this enables customers to perform their own measurements on an SFM after appropriate introductory training.
- Supports scientific collaborations: research projects for surface analysis or for developing new SFMs or SFM components.
- Holds training courses and continuing education programs.

Opinion

Prof. Dr Hans-Joachim Güntherodt
NCCR Nanoscale Science
University of Basel

«In recent years, Empa has evolved very impressively as Switzerland's most eminent research institution in the «Nano» arena, conducting both nanotechnology in numerous application-oriented areas as well as first-class basic research and risk assessment.»

Impressum

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