Annual Report 2014

Materials Science & Technology

Our Vision.
Materials and Technologies
for a Sustainable Future.

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It takes courage to foster innovation

When it comes to innovation, Switzerland regularly performs brilliantly in international rankings. One superlative after another is rattled off in the media and the country is often dubbed a serial "world champion of innovation," the most competitive economy and much more – quite some track record for such a small country. If nothing else, this shows one thing: innovation and the great minds that spawn it are by far the most important resource for Switzerland now and even more so in the future.

But how exactly do you "produce" innovation? How do you convert a grand new idea or an excellent research result into a ground-breaking product that can hold its own on the market? These are questions that are of particular relevance to a research institute like Empa. We like to think of ourselves as Switzerland's "cradle of innovation," as an integral part of the local innovation scene that helps to ensure the country continues to lead the way in rankings like the Global Innovation Index. According to its own self-image, Empa should be nothing short of "the place where innovation starts." So what does Empa need to do to keep reigniting the Swiss "innovation engine"? Or to put it another way: how much basic research can and how much technology development must there be? The fact that both are absolutely necessary is beyond all questions. But what's the perfect balance?

Top-flight basic research in our core area, materials science, is crucial to keep filling our pipeline with new ideas. This goes hand in hand with a close collaboration with the two ETHs and the Swiss universities, but also an intensive exchange with other materials research institutes around the globe. Only in this way can we convey new impulses to our numerous industrial partners and remain a competent partner on technological matters.

If we want to remain competitive on an international level and stay at the top, we mustn't be afraid to take risks. Bold ideas leading to disruptive innovation are impossible in an environment with increasing amounts of administrative burden and in a spirit of complacency and isolationist tendencies. At best, a no-risk mentality might lead to incremental improvements, but not to real innovation. It is purely thanks to courageous, far-sighted entrepreneurs who allow their employees to join in their success, and in open and liberal framework conditions in a stable environment that we have come so far. The courage to take risks and potentially fail is needed right now – and especially in the future – to successfully create new things in an increasingly complex, competitive global environment. Empa champions this ambitious and forward-looking vision as a research institute, with the start-ups in its incubators and through its commitment to Switzerland's National Innovation Park.

***Prof. Dr Gian-Luca Bona**, CEO*

01

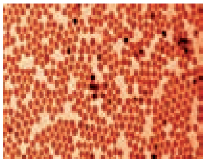
All-clear for nanopaints
After 42 months, the EU-funded research project "NanoHouse" drew to a close with a cautious all-clear: nanoparticles in house paints don't pose any exceptional health hazards.

KIST-Empa collaboration
During an official visit to Switzerland by South Korean President Park Geun-hye, Empa signed a memorandum of understanding with the Korea Institute of Science and Technology (KIST). Meanwhile, several joint projects have been initiated in the energy sector.

02

Concern over research cooperation with EU
After the mass immigration initiative was approved, Swiss universities and research institutes – including Empa – called upon the Federal Council to do everything in its power to enable Switzerland to continue its full participation in EU programs.

Antimony nanocrystals for batteries
For the first time ever, researchers from Empa and ETH Zurich synthesized uniform antimony nanocrystals, which are considered a promising alternative for future electrode materials in batteries with a high charging capacity.



03

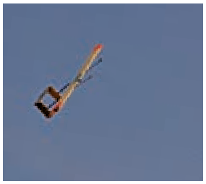
Sheet metal that never rattles
A material that could change the world of mechanics: it is "programmable," can dampen vibrations completely at the touch of a button and is able to specifically conduct certain frequencies further. It was produced by researchers from Empa and ETH Zurich.
Page 31

Sustainability and ICT
Empa researcher Lorenz Hilty, who runs the Chair of Informatics and Sustainability Research at the University of Zurich, was appointed as (the first) Sustainability Delegate of the University's Executive Board.

04

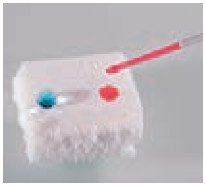
Porous graphene: the ultimate filter
A new, ultra-thin membrane made of graphene is extremely light and breathable. Not only could it make improved functional rainwear possible, but also extremely rapid filtration, as researchers from ETH Zurich and Empa reported in Science.

Victory at "venture kick"
The concept of using high-tech kites to tap into wind power at high altitudes developed by Empa researchers won the final of "venture kick," which carries CHF 130,000 in prize money. The team has already founded a spin-off, TwingTec AG.



05

Using nanocellulose to combat oil spills



A new, absorbent material from Empa's wood research could help with future oil disasters: chemically modified nanocellulose. The light material selectively absorbs oil, floats on the water and can easily be recovered.
Page 28

Empa technology in space
After a ten-year voyage through space, the probe "Rosetta" reached its target comet "67P/Churyumov-Gerasimenko" in May. Among the equipment on board: two mass spectrometers with complex ceramic sensors from Empa to analyze the comet's atmosphere.
Page 25

06

"Expo Nano" at Empa
In July "Expo Nano" visited Empa. The exhibition showcases the opportunities and risks of nanotechnology and points out where nanomaterials are already used. Empa researchers presented medical nanoresearch to the visitors.

Artificial moth eye provides solar power
All over the world, scientists are developing solar cells that imitate plant photosynthesis. Empa researchers came up with one such photoelectrochemical cell modeled on a moth's eye and thus increased the energy yield dramatically.
Page 22

07

Silver textiles in the washing machine
behave when washed: nano-coated textiles release fewer nanoparticles into the wastewater than their conventionally coated counterparts.

Empa Summer Camp
Around 20 children attended the 11th Summer Camp. Besides lab experiments, scientific workshops, and various excursions, the construction of a bridge across the Chriesbach creek was a definite highlight.

Successful Empa researchers
In order to promote precompetitive research more effectively, the Swiss National Science Foundation launched the "precoR" initiative. Of the 27 submitted projects, six are to receive funding, three of which are headed by Empa researchers.

08

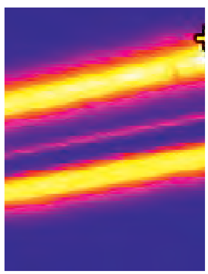
Construction work gets underway for "NEST"
The construction of the modular research and innovation building "NEST" on the Empa campus in Dübendorf began with a ground-breaking ceremony in late August. The building's "backbone" is expected to be finished by the end of 2015, after which the first research modules will follow.

Nanotubes on the cover of "Nature"
Empa researchers succeeded in "growing" carbon nanotubes with a predetermined structure – and therefore identical electronic properties. They could in future be used in ultrasensitive light detectors and mini-transistors.
Page 19

09

Ozone hole has stabilized
Empa researcher Stefan Reimann was one of the lead authors of the most recent international UN expert report on the state of the ozone layer, which was presented at the UN headquarters in New York on 10 September.
Page 38

A form-conscious alloy
Just heat it a bit – and a spectacles frame made of a shape memory alloy will quickly return to its original shape after it has been bent. Empa researchers used these materials to produce prestressed concrete for applications in the building industry.



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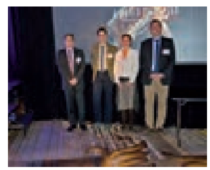
Federal councilor attends kick-off
At the beginning of October, Federal Councilor Johann Schneider-Ammann visited Empa to learn about the work conducted for energy-efficient buildings within the scope of the Swiss Competence Center for Energy Research (SCCER), which is run by Empa researchers.

Gentle caffeine boost for preemies
Empa researchers developed a switchable membrane that gently dispenses drugs via the skin. This could spare premature babies the stress of repeated caffeine injections (in order to prevent respiratory arrest), for instance.
Page 12

GPS from the chemistry lab
Empa scientists teamed up with colleagues from Hungary, Scotland and Japan to develop a chemical "processor" that reliably indicates the shortest route through a labyrinth – even faster than a conventional GPS, too!

11

Empa team honored in the US
Empa researchers Artur Braun, Florent Boudoire, Rita Toth and Jakob Heier figured on the list of the "100 Leading Global Thinkers 2014" in the innovation category published by the US journal "Foreign Policy". They were honored in Washington in the presence of US Secretary of State John Kerry.



The ETH Domain as an energy role model
The ETH Domain, which includes Empa, serves as an energy role model and supports the Confederation in implementing the Energy Strategy 2050 – not just via teaching and research, but also in its infrastructure and facility management.

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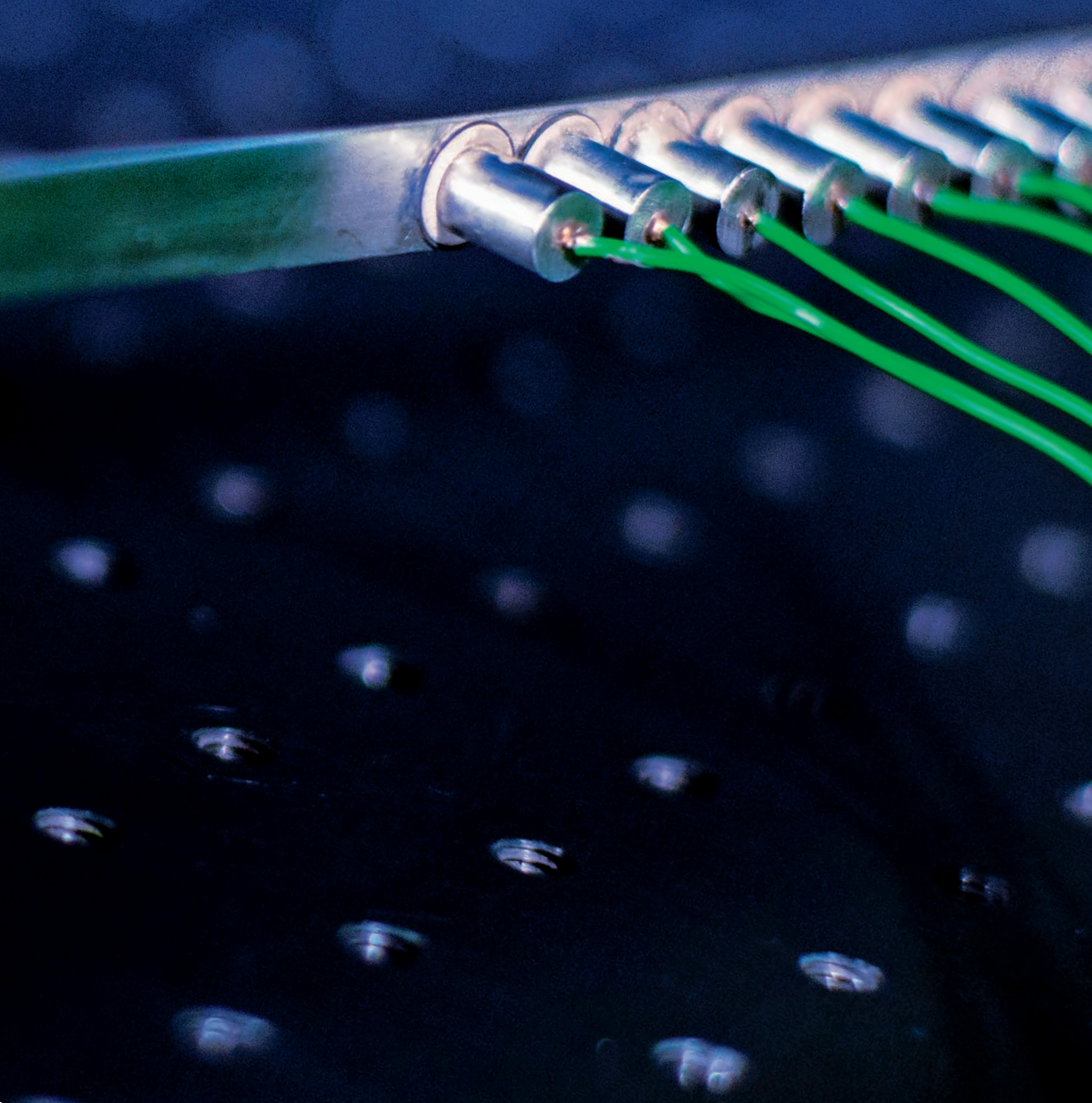
Guidelines on handling nano
The "LICARA" guidelines, which were compiled in an EU project led by Empa scientists, are designed to help SMEs from all walks of industry to weigh up the pros and cons of nanomaterials more effectively and make decisions on their usage.

Flame retardants for business jets
A new coating protects aircraft interiors against fire. Not only is the substance more environmentally friendly than previous flame retardants, it can also be applied more quickly.



Selected projects

Investigating new materials and accelerating the development of innovative technologies; supplying the stimulus for the sustainable development of our society; providing the scientific basis for political and societal decisions – these are Empa's core objectives, which it pursues through research and development, cooperation, networks and partnerships, as well as services, expertise and consulting activities. The following snapshots from the institute's laboratories give an insight into Empa's multifaceted research activities.

Measuring blood sugar through the skin – without taking any blood

3

centimeters is the diameter of the sensor that can gage the blood sugar level through the skin without taking a single drop of blood.

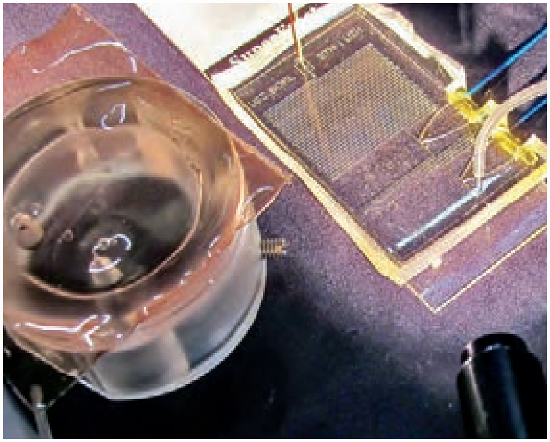
One in twelve children in Switzerland is born prematurely. Monitoring the blood sugar in these premature babies is crucial as the development of the brain can be affected if the baby is hypoglycemic for over an hour. Until now, this monitoring inevitably meant taking blood samples. Drawing blood regularly from the sensitive little ones for hours on end, however, is out of question as the blood loss and stress would be too great. In a project funded by the Swiss National Science Foundation (SNSF), Empa and the University Hospital Zurich thus teamed up for five years to develop the sensor "Glucolight," which gages the blood sugar level through the skin, without the need for any blood samples.

Although skin sensors already exist, they have to be calibrated before use, which means that the skin's permeability value needs to be known. In order to establish this, the blood sugar value has to be determined via a blood sample and the glucose concentration on the skin measured. Based on these two readings, the permeability can then be calculated and the sensor calibrated.

A "smart" membrane and a sensor make it possible

As Glucolight is a non-invasive method to determine the blood sugar level, it spares the premature babies the blood samples that were necessary until now and, at the same time, enables the blood sugar level to be monitored permanently. Glucolight's new measuring technique makes this possible. For the measurement, the sensor, which is roughly three-centimeters in size, is stuck onto the baby's skin and connected to a fluorometer next to the crib, which records and evaluates the readings. The sensor itself consists of a "smart" membrane developed by Empa and ameasuring head and fluorometer, which was developed at the University Hospital Zurich.

The smart membrane produced at Empa contains light-sensitive functional groups, known as spiropyrans, which cause the membrane to open when irradiated with UV light. As a result, considerably more glucose molecules diffuse through the membrane from the skin onto the measuring head on the other side than if irradiated with visible light. Based on these different values, the computer then calculates the premature baby's blood sugar level.



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Research with and on Glucolight continues

The researchers filed a patent application for Glucolight in mid-2014 and the first clinical studies are scheduled at the University Hospital Zurich for 2015. However, it could be years before the use of Glucolight becomes standard. Empa and the University Hospital Zurich are currently in negotiations with partners for the industrial production of the sensor. In the future, the researchers also envisage the use of Glucolight in other fields, such as diabetes.

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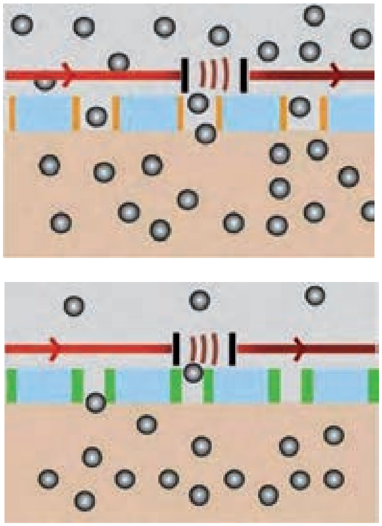
The two hearts of Glucolight: on the left, the measuring head with Empa's "smart" membrane; on the right, the microfluidics chip developed by the University Hospital Zurich.

2
Glucolight's measuring head with the "smart" membrane.

3
Diagram showing the permeability of the "smart" membrane (blue) in visible light (below) and UV light (above).



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Second use of the membrane: caffeine patches for premature babies

In the course of the Glucolight research project, the researchers discovered another potential application for the membrane. Its "switchable" permeability can also be used in the opposite direction: in a drug-loaded plaster. Instead of a measuring head, there is a drug depot behind the membrane. If irradiated with UV light, the membrane becomes more permeable and the drug is gently administered through the skin over several hours. In the absence of irradiation, the membrane keeps the drug in the depot. Consequently, Empa teamed up with the University Hospital Zurich to develop a caffeine plaster to combat respiratory arrest, which is common in premature babies. The plaster is simply stuck onto the baby's skin, upon which it administers a constant supply of caffeine to the tiny patient for several hours, without distressing the sensitive infant with an injection. //

High-end brakes for the Cinquecento?

An ambitious project is taking shape at the Laboratory for High-Performance Ceramics: ceramic brake disks for compact cars. Empa is developing a novel brake disk for mass-produced small cars under the direction of the Politecnico di Torino and in conjunction with Spanish brake manufacturer Fagor Ederlan, Liechtenstein joining specialists Listemann AG and the Fiat research center C.R.F. The Commission for Technology and Innovation (CTI) is funding the Swiss and Liechtenstein portion of the research project.

While today's brake disks are produced from heavy, heat-resistant cast iron, the disks of the future are to be made of light aluminum. This saves weight and thus fuel while improving the vehicle's handling as the unsprung mass in the chassis will be smaller. Before the lightweight brake can succeed, however, a material problem needs to be solved: aluminum, the desirable construction material, is soft and unsuitable for powerful brake calipers. A ceramic layer is therefore needed to protect the aluminum brake disks, which perform the breaking function and remove the heat generated. Empa is developing this crucial component. While ceramic brakes are nothing new in themselves, having long been used in sports and racing cars, they are expensive. Therefore, the technology seems hardly suitable for use in affordable small cars.

15

The number of layers in the ceramic laminate, which is only around two millimeters thick and was developed by Empa for the new brake disks.

Several technical hurdles at once

Consequently, the consortium is taking a different path: the brakes need to be produced quickly and in large quantities, be affordable and last at least as long as existing cast-iron counterparts. Once the Empa team had tested and analyzed numerous ceramic substances, only one base material remained: aluminum oxide. The material is in all kinds of ceramic components – from mixer tap washers to hip joints – and can still be obtained inexpensively. The Empa researchers used it to design a ceramic laminate. Silicon carbide is added to the aluminum oxide layers to increase heat conductivity, along with a cover layer to regulate wear and friction, and an adherent layer to enable the ceramics to be soldered to the aluminum surface. Each of the layers is mixed

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with water to make a slurry before being applied to a synthetic film. Finally, the layers are compressed, the synthetic material in-between burned out, and the different layers joined and condensed at several hundred degrees. An electron microscope then reveals just how well the vertical interconnection process has worked.

Tiles, not disks

The team decided to make small tiles, which are joined to the brake disk side by side – like bathroom tiles. The reason: when exposed to heat, aluminum expands three to four times more than ceramics. A single-piece ceramic brake pad could thus fall off the aluminum carrier due to thermal stresses.

However, the joining process is also easier done with small tiles: as aluminum melts at roughly 700 °C, the joining has to be carried out at lower temperatures. Nonetheless, the join material mustn't go soft during heavy breaking; otherwise, the tiles will fall off at the very moment when they are needed most.

In the meantime, researchers at the Politecnico di Torino are developing special joining technology to join the tiles, which Listemann AG in Vaduz will subsequently make industrially viable. The brake manufacturer Fagor Ederlan is designing the aluminum brake system and the necessary dimensions of the brake disk. The culmination of the project, which is due for completion in April 2015, will be a prototype of the "aluminium ceramic brake," which will be put through its paces before it can be integrated in a test vehicle. //

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Empa ceramics researcher Jakob Kübler developed the crucial component for the new brakes.

Molecular seeds for "single-chirality" carbon nanotubes

Carbon nanotubes (CNT) – tiny tubes with a single-atom thick wall made of carbon atoms arranged like a honeycomb – are regarded as the epitome of a nanomaterial. With a diameter on the order of one nanometer, single-walled CNTs (SWCNT) are classed as quantum structures. The slightest differences in structure, for example in the diameter or the arrangement of the atomic lattice, cause dramatic changes in the electronic properties: one SWCNT can be metallic, while another with a slightly different structure is semiconducting. Because of this the interest in reliable methods to produce SWCNTs that are as similar in structure as possible is extremely high. Although several concepts were already formulated at least 15 years ago, only now have physicists and surface scientists from Empa and chemists from the Max Planck Institute for Solid State Research succeeded in turning one of these ideas into reality in the lab, with financial backing from the Swiss National Science Foundation (SNSF).

As described in the renowned journal "Nature" in the summer of 2014, the scientists succeeded in "growing" structurally identically SWCNTs on a platinum surface and clearly determined their electronic properties.

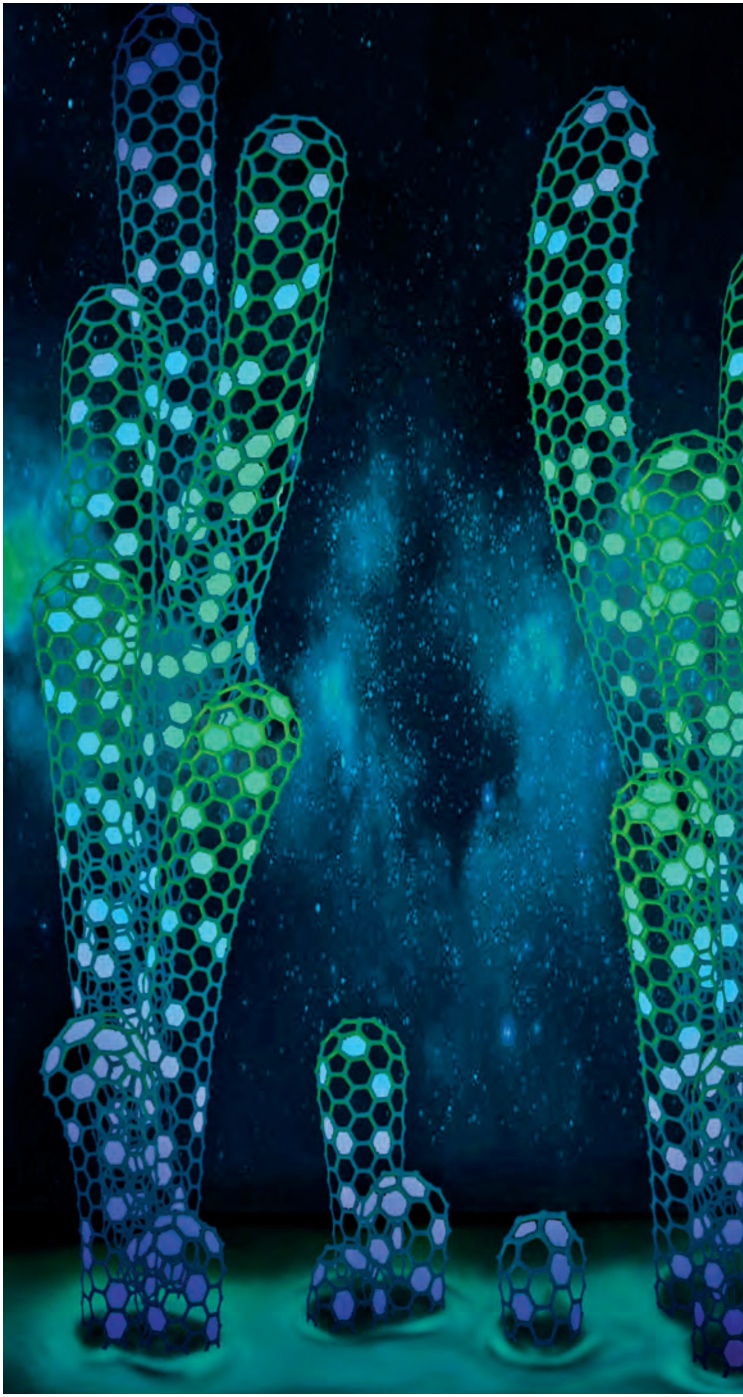
150

The number of atoms that form the hydrocarbon molecule – the "seed" – from which the (6,6) single-walled carbon nanotubes grow.

Empa researchers have been studying how molecules can be transformed or joined into complex nanostructures on a surface for some time. Using so-called "bottom-up synthesis," they had already succeeded in producing specific nanostructures in other cases, such as graphene nanoribbons. The challenge now was to find the suitable starter molecule that actually "seeded" SWCNTs on a smooth surface. Collaborators from the Max Planck Institute in Stuttgart eventually managed to synthesize just the right starter molecule.

Molecular origami

In the first step, the planar starter molecule needs to be transformed into a three-dimensional object (the "seed"), much like in origami. This takes place on a hot platinum surface, Pt (111), via a catalytic reaction, where new carbon-carbon bonds form at very specific places by removal of hydrogen atoms. The seed "folds" out of the flat molecule: a small, dome-like object with an open edge, which sits on the platinum surface. This so-called end cap forms a “lid” for growing SWCNTs. In the second step, other carbon atoms (from the catalytic breakdown of ethylene, C_2H_4, on the platinum surface) accumulate on the open edge between the end cap and the platinum surface, and continue to lift them; the tiny tube gradually grows upwards. In doing so, the seed alone determines the atomic structure of the CNT. The researchers were able demonstrate this by analyzing the Raman spectra of the SWCNTs and taking measurements in the scanning tunneling microscope (STM). Further tests in the new scanning helium ion microscope (SHIM) at Empa also revealed that some of the SWCNTs grow to more than 300 nanometers in length.



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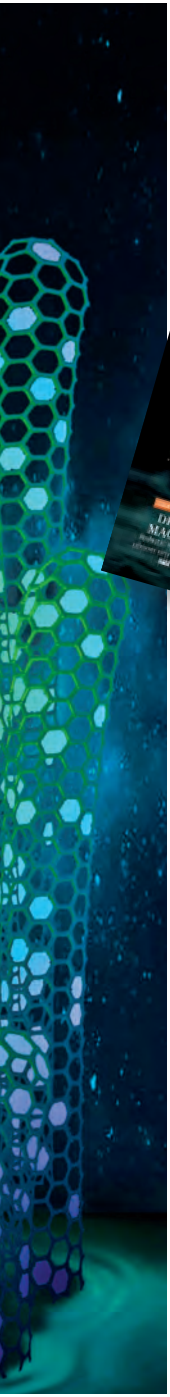

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1
Carbon nanotubes can be produced from molecules in a controlled way for electronic applications: this discovery even made the front cover of the renowned science journal "Nature" in August 2014.

2
The planar hydrocarbon precursor folds into an end cap on a platinum surface. This forms the seed for the selective growth of a (6,6) carbon nanotube.

It works!

The SWCNTs synthesized in this way are mirror-image, symmetrical objects. However, depending on how the honeycomb atomic lattice develops from the starter molecule ("straight" or "diagonally" with regard to the CNT axis), asymmetrical, screw-like tubes, i.e. ones that wind to the right or left, can also be formed. And this very structure also determines the electronic, thermoelectric and optical properties of the material. In other words, the researchers can theoretically produce specific materials with different properties through the choice of starter molecule.

The scientists now want to gain a better understanding of how SWCNTs populate a surface. Although in one square centimeter more than 100 million nanotubes already grow on the platinum, "fully grown" nanotubes only actually form from a comparatively small portion of the seeds. This raises the question as to which processes are responsible and how the yield can be increased. //

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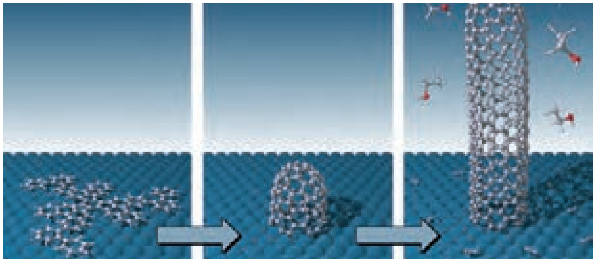

Collecting light with artificial moth eyes

30

nanometers: the thickness of the iron oxide layer covering the fine tungsten oxide microspheres. Light is reflected back and forth in the tungsten oxide spheres and eventually absorbed by the iron oxide.

All over the world, researchers are studying solar cells which mimic photosynthesis in plants using sunlight and water to create synthetic fuels such as hydrogen. In a collaboration with University of Basel, funded by the Swiss National Science Foundation (SNSF) and the Marie Heim Vögtlin Foundation, Empa researchers developed one such photoelectrochemical cell modeled on a moth's eye to radically increase the light efficiency. The cell is made of inexpensive raw materials: iron and tungsten oxide. Iron oxide – rust – could revolutionize solar technology: this extremely inexpensive – and usually unwanted – substance can be used to make photoelectrodes which split water and generate hydrogen. Sunlight is therefore converted directly into valuable fuel as opposed to being used to generate electricity first. Unfortunately, as a raw material iron oxide has its drawbacks: although it absorbs light in exactly the wavelength region where the sun emits most of its light, it conducts electricity very poorly and therefore always needs to be processed in the form of an extremely thin film in order for the water splitting to work. The disadvantage is that these thin films absorb too little of the sunlight shining upon them.

Microspheres collect sunlight

Empa researchers have solved this problem: a unique microstructure on the photoelectrode literally traps all sunlight and does not let it out again. The basis for this innovative structure are tiny particles made of tungsten oxide, which, because of its saturated, yellow color, can also be used for photoelectrodes. The yellow microspheres are applied to an electrode and then covered with an extremely thin, nanoscale layer of iron oxide. When external light falls on the particle, it is reflected back and forth internally until all the light is eventually absorbed. This means that all the energy in the light has been converted and is now available for splitting the water molecules into oxygen and hydrogen. The photocell thus uses water to produce the ecologically beneficial and economically valuable fuel hydrogen.

In principle, the newly conceived microstructure functions like a moth's eye: the eyes of these nocturnal creatures need to collect a lot of light – and reflect as little of it as possible to avoid being detected and killed by predators. The microstructure of their eyes is especially adapted to the wavelength of light. Empa's photocells exploit the same effect.

1 Florent Boudoire testing the yield from a photoelectrode on a sunlight simulator.

1

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In order to recreate artificial moth eyes from metal oxide microspheres, the researchers sprayed a sheet of glass with a suspension of plastic particles, each of which contained a drop of tungsten salt solution. The particles are coated on the glass like a layer of marbles packed close to each other. The researchers then placed the whole assembly in the oven; the plastic material burned away and each drop of salt solution was transformed into the required tungsten oxide microspheres. The next step was to cover the new structure with iron salt and heat it in the oven again.

Along with their experiments, the researchers ran model calculations on the computer and simulated the "capturing of light" in the microspheres. The result of the simulations tallied with the experiments. It is clear just how much the tungsten oxide contributes to the photo current and how much the iron oxide. The researchers are now working on the scale up of the system for practical application. //

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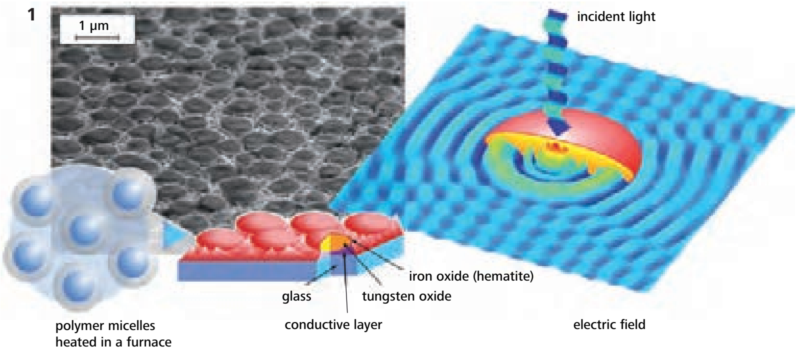


1 How the "moth-eye solar cell" is created, and how it collects light.

To boldly go where no man has gone before

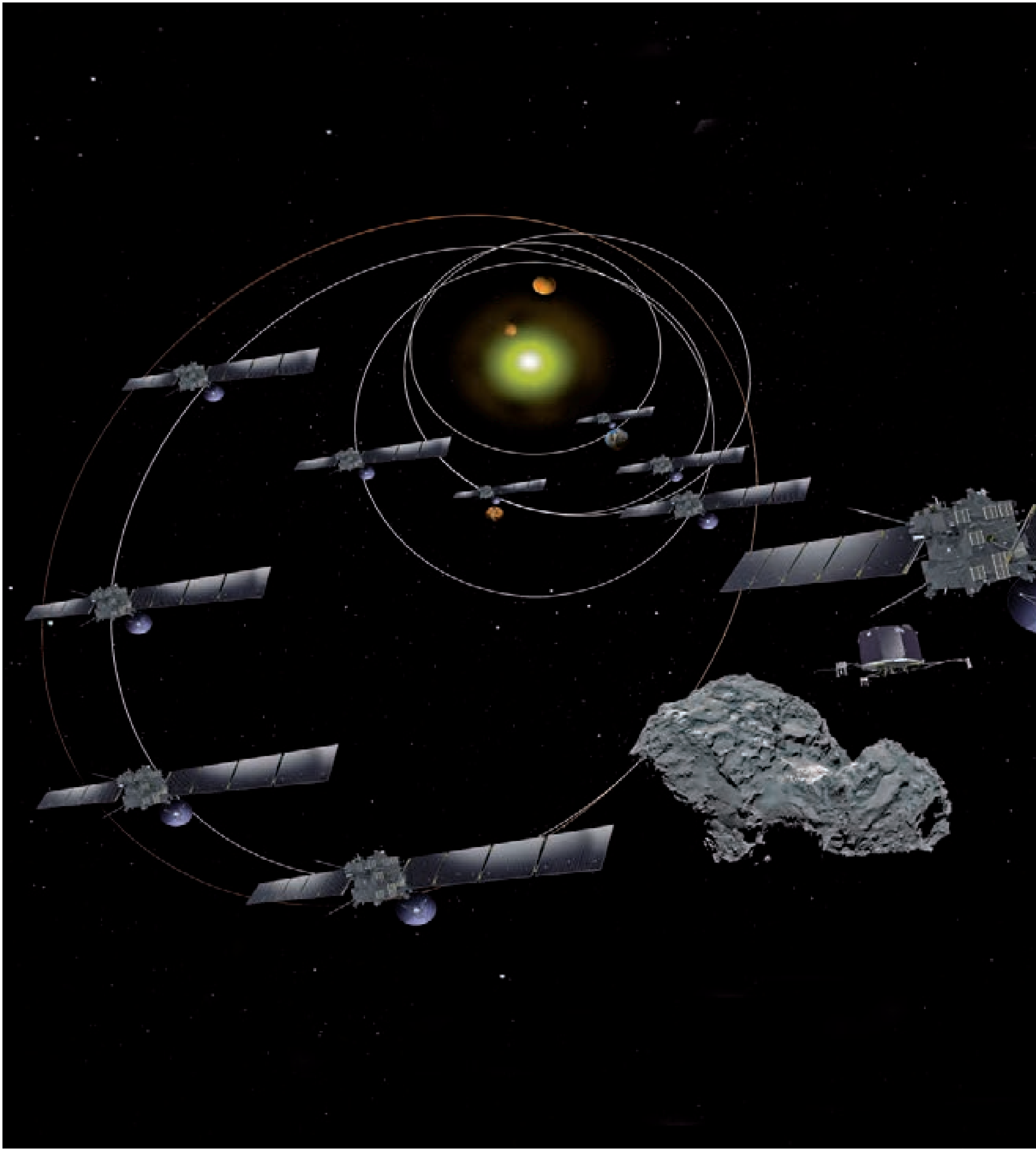
More than ten years ago, the space probe Rosetta embarked on a voyage into space. Its aim was not only to accompany the target comet 67P/Churyumov-Gerasimenko (Tschuri for short) for a year, but also set down a lander (Philae) on the surface of a comet for the first time – a major undertaking and the pride and joy of the European Space Agency (ESA). Highly complex Empa sensors made of metal ceramics, incorporated into two mass spectrometers, are also on board. A few weeks ago, the probe reached the comet and, despite some problems with the anchoring mechanics, the lander successfully touched down on the surface. Comets are regarded as primitive masses in our solar system and – according to one theory – may well have transported water or even simple buildings blocks for life to Earth. However, many fundamental questions concerning these giant lumps made of dust and ice remain open, which is where Rosetta comes in.

26,400,000,000

kilometers long was Rosetta's journey until it reached its final destination, the comet 67P/Churyumov-Gerasimenko.

Empa on board

One of the numerous pieces of equipment on Rosetta was developed with Empa's help. The instrument group ROSINA (Rosetta Orbiter Spectrometer for Ion and Neutral Analysis) was developed under the direction of the University of Bern. It comprises two mass spectrometers, a pressure sensor (which also gages the temperature and velocity of the comet gas) and a data-processing unit. The Bern research group brought in Empa, which took over the development and production of the ion-optic sensors for the two spectrometers. Since Rosetta started orbiting the comet, ROSINA already provided the first data. Based on the composition of the gases measured, for instance, the ESA team was able to determine that the comet's tail smells of rotten eggs, horse urine and bitter almonds. And far more importantly: the water on the comet is considerably heavier than on Earth, which makes it unlikely that a comet like Tschuri brought water to our blue planet.



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1
Voyage to the comet ´67P/Churyumov-Gerasimenko. The comet's two-part shape makes it look like a rubber duck.

2
Rosetta flew past Mars on 25 February, 2007. This "selfie" was snapped from a distance of 1,000 kilometers, shortly before it moved to within 250 kilometers of the planet's surface. It depicts one of Rosetta's solar wings and the northern hemisphere of Mars, where details of the Mawrth Vallis region are visible (Copyright ESA).

3
Compact and lightweight: Rosetta's time-of-flight mass spectrometer with Empa ion sources (right) and reflector (left) is almost a meter long and weighs about 15 kilograms (Image: University of Bern).

Successful process development

In order to develop a measuring device like ROSINA, the Bern-based astrophysicists' ideas had to be translated into a multifunctional, "space-worthy" product that satisfied the highest demands: it needed to be ultra-light, mechanically robust, high-voltage-proof and extremely precise. The methods and technologies developed at Empa were so successful that other space projects soon followed. The Empa team is currently developing a new ion-optic sensor for an even smaller, lighter mass spectrometer for the Russo-Indian moon mission LUNA. And the Empa engineers recently produced equally complex modules and sensors for the joint European and Japanese Mercury mission BepiColombo. //

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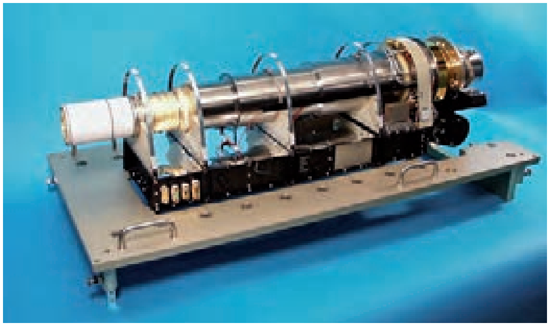

Nanocellulose sponges to combat oil spills

A novel, absorbent material from Empa's Applied Wood Materials department could help with the clean-up operation in future oil disasters: sponges made of chemically modified nanocellulose. The light material, which Empa researchers developed in collaboration with colleagues from the University of Bordeaux, sucks up the oil spill, floats on the water and can easily be scooped back up again. The base material for the sponges, nanofibrillated cellulose (NFC), is obtained from materials that contain cellulose, such as waste straw, waste paper or wood pulp, by mixing them with water and either grinding up the watery paste or squeezing it through small nozzles at high pressure. This produces a gel-like suspension made of long, fine, interconnected cellulose nanofibers and water.

50

times their own weight: the amount the nanocellulose sponges can absorb without losing their shape.

A selective sponge

If you now remove the water from the gel by freeze-drying it, you end up with a nanocellulose sponge. As the untreated material sucks up water and oil in equal measure, it is still unfit for its intended purpose. However, the Empa researchers succeeded in modifying the chemical properties of the nanocellulose in only one procedural step by adding a reactive alkoxysilane to the gel before the freeze-drying process. As a result, the nanocellulose loses its hydrophilic properties, is no longer wetted by water and only combines with oily substances.

Preparing the sponge for market

In the lab, the "silylated" nanocellulose sponge sucked up 50 to 100 times its own weight in different substances in a matter of seconds, including engine oil, silicon oil, ethanol, acetone or chloroform. Nanofibrillated cellulose sponges therefore combine several desirable properties: they are extremely absorbent, still float on water when saturated and are biodegradable. The task now is to refine the sponges so that they can be used in real accidents as well as in the lab. A Swiss industrial partner is already on board, searching for a method to produce the nanocellulose on a larger scale to smooth the way for the industrial production and marketing of the sponge. And as for the users, Empa is already in touch with various partners who have shown a great deal of interest in the product. //


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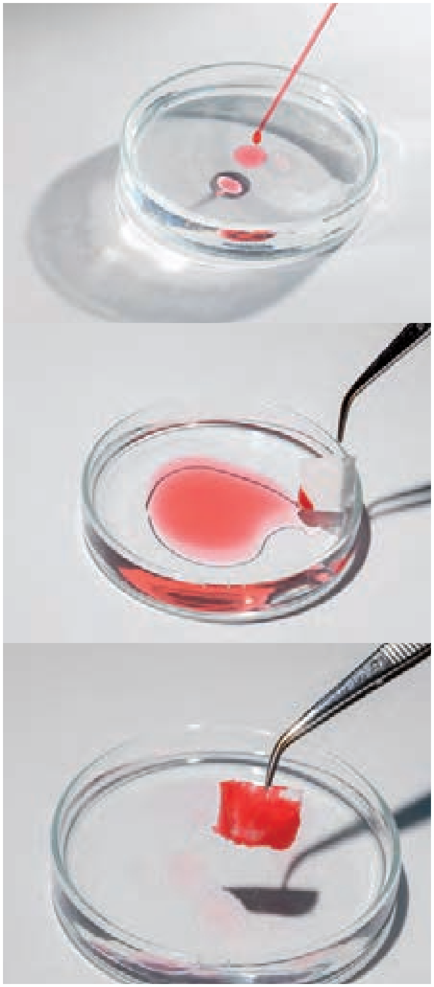
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A piece of nanocellulose sponge during an experiment: thanks to the sponge's new properties, it will only absorb the red oil on the surface of the water.

2
So far, the nanocellulose sponge has only been tested in the lab. In the next phase, however, the sponges are also to be produced on an industrial scale.

Sheet metal that never rattles

Researchers from Empa, ETH Zurich, and Georgia Institute of Technology have succeeded in producing a prototype of a material that enables the propagation of vibrations to be controlled in a targeted manner. This could revolutionize the world of mechanics. The mechanical component with freely programmable properties should make it possible to damp vibrations altogether at the touch of a button or only conduct certain frequencies in future. In the first step, the researchers demonstrated the special capabilities of the "programmable" material with a one-dimensional model construction. The aluminum model is around one meter long, one centimeter wide and one millimeter thick. In order to control the vibration, ten small aluminum cylinders (7 millimeters thick, 1 centimeter high) are attached to the metal. Between the sheet and the cylinders, there are piezo discs, which can be stimulated electronically and change their thickness in a flash. This enables the researchers to control exactly whether and how vibrations propagate in the sheet-metal strip. The aluminum strip thus turns into a so-called adaptive phononic crystal – a material that can change its specific properties.

0.01

millimeter the piezo elements only rise and fall – still enough to eradicate or modulate vibrations in the sheet metal.

Adaptation to momentary vibrations

The piezo controls can be set in such a way that vibrations are able to propagate through the sheet-metal strip completely unimpeded. Or they can be adjusted so that a certain frequency spectrum of the waves is damped. Moreover, this damping is variable as the piezo elements can alter their elastic properties in fractions of a second – from soft to rigid. One attractive aspect of this: if you cut the sheet metal into two, both parts have the same vibration properties. In other words, the waves largely propagate equally in the two halves. Naturally, this method could also be used on three-dimensional components. The "programmable" material could therefore revolutionize mechanical engineering and plant construction. Until now, the vibration properties had to be determined in advance during the construction of the structure. In future, the material could react promptly to any kind of vibrations and immediately adapt its vibration properties accordingly. A system would thus be considerably more stable and easier to construct.

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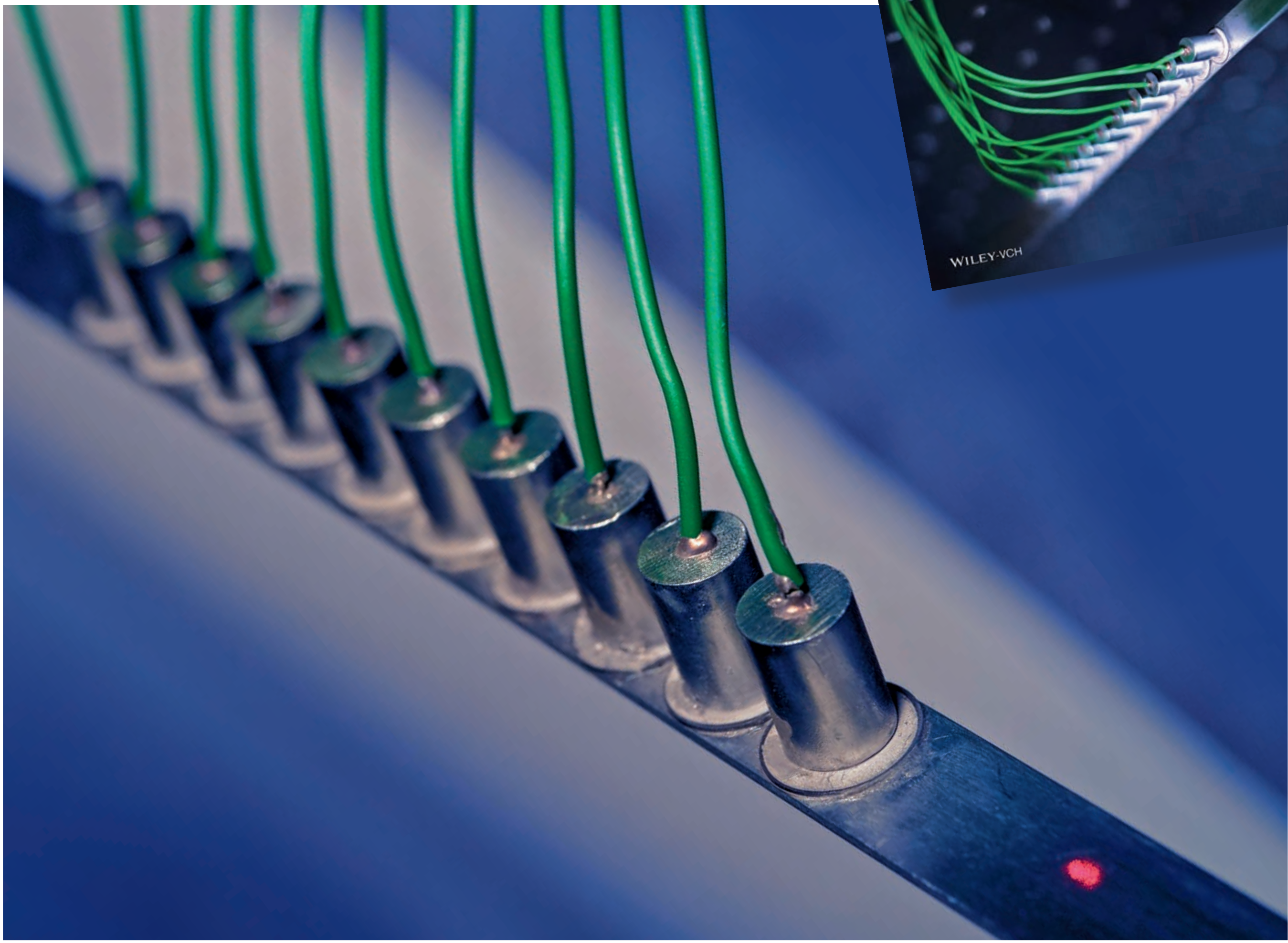

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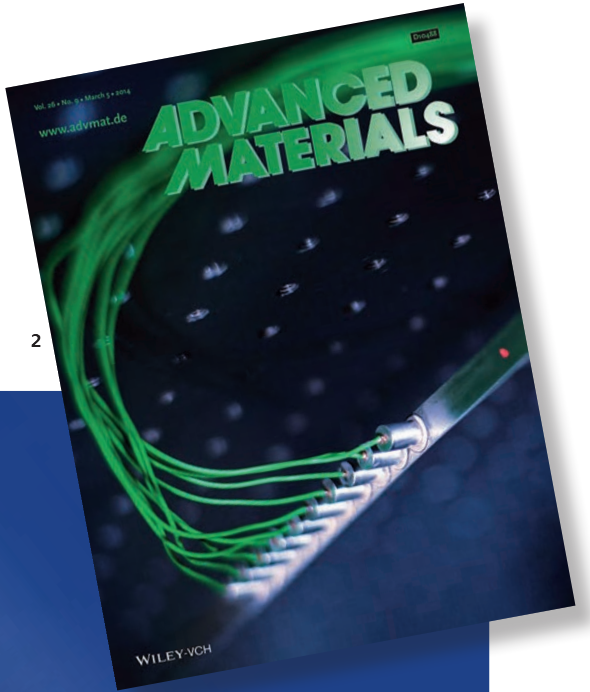

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1
The ten little aluminum cylinders are seven millimeters thick and one centimeter high. Between them and the one-meter-long sheet metal, there are piezo elements, which are able to change their elastic properties at lightning speed.

2
The cover of the international journal Advanced Materials from 5 March 2014, featuring Bergamini's invention.

3
Empa (materials) scientist Andrea Bergamini with the model of a "programmable" material.

Still a long way to go

The programmability of the prototype is now to be expanded in a follow-up project. Until now, every piezo element reacted to vibrations on its own, independent of its neighbor. In the next step, the researchers are looking to interconnect the elements with each other to be able to control them jointly or in a coordinated fashion. //

3

Laser welding for functional textiles

270 °C

is the highest temperature to which the laminated fabric is heated with the diode laser before the engineers determine the melting points and crystallization energy of the textiles.

Although the needles on industrial sewing machines are so fine, they leave holes in the "textile fabric." In order to prevent the stitching on an outdoor coat from letting in moisture, the seams are sealed in a second industrial process. Empa has now honed a method that can be used to weld textiles and make them absolutely impermeable in a single step. The principle stems from the metal and synthetics industry: a diode laser beam heats the textile layers to such an extent that they melt point by point and the polymer chains bind together on a molecular level.

Challenges and solutions

For the perfect fusion to succeed, however, the laser mustn't heat the ultra-thin textiles or membranes too strongly. And another challenge: the laser beam fails on some black materials. What the eye perceives as black – i. e. light-absorbing – is virtually transparent for the laser, which works in the infrared range.

In a project funded by the Commission for Technology and Innovation (CTI), textile engineers from Empa varied all of the process's parameters to find the best combinations and settings for industrial laser welding. They evaluated various thermoplastic polymer fabrics and layer thicknesses and investigated the laser's optimum energy input in each case. As a result, they developed a welding method that binds the fabric tightly and permanently to membranes made of polyester or polyurethane that are up to ten micrometers thick.

The Empa researchers teamed up with their industrial partners Leister Technologies AG in Kägiswil, Unico Swiss Tex GmbH in Alpnachstad, Schips AG in Tübach, Schoeller Textil AG in Sevelen, Serge Ferrari Terrsuisse SA in Emmenbrücke and the Swiss Textile College Zurich to develop two diode-laser welding systems: firstly, a laser sewing machine that can join textiles virtually continuously; and secondly, a system that enables complex structures to be joined in both the X and the Y direction.

New joining technology opens up fresh possibilities

As laser welding is more closely related to computer-based construction than a conventional sewing machine, like with technical construction it can be controlled very precisely. Laser welding can also be used to produce complicated, curvy

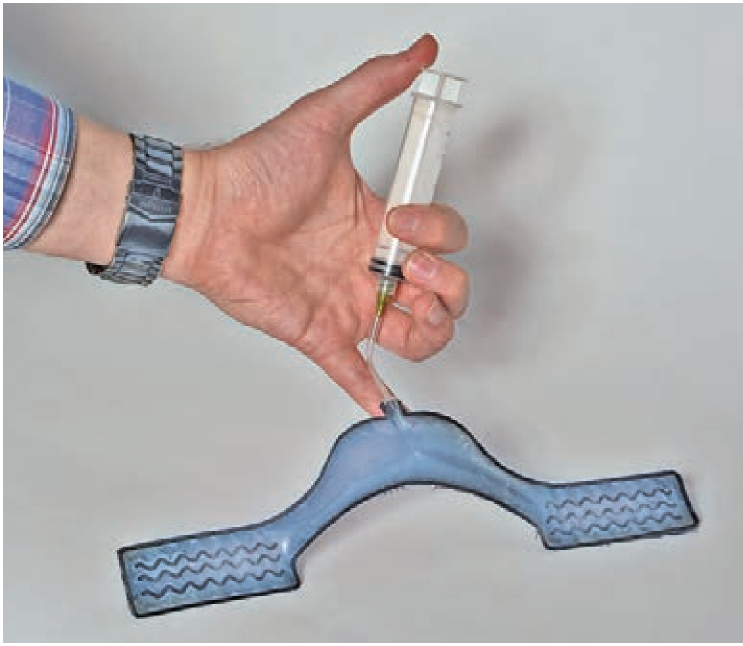
1
Project leader Alexander Haag next to the research laser. The goal is to interconnect ten-micrometer-thick membranes tightly and permanently.

1

weld seams and even 3D structures. These are necessary if valves are planned to let water in between two structures – where cooling pads with water-filled spaces are to be provided, for instance.

Laminates with defined physical properties can now also be created using targeted laser welding: they are capable of absorbing water vapor more heavily or weakly, and can store moisture for a certain period before re-releasing it in doses as and when required – such as cooling plasters. The lamination is so stable that it can withstand several meters of water pressure.

Thanks to this know-how, the researchers from Empa joined forces with the University of Basel and Unico Swiss Tex GmbH in another CTI project to develop an EKG belt with welded-on, wettable elements for the long-term monitoring of cardiovascular patients. It is especially designed with more elderly people in mind as they no longer perspire as much. The skin-friendly EKG belt with a silver-titanium coating can be worn for several days without causing any skin irritations. The textile electrodes can be moistened from the side facing away from the skin using distilled water, which is poured into a small, laser-welded reservoir. The controlled moistening of the skin enables the measuring electronics to record the EKG signals interference-free. //



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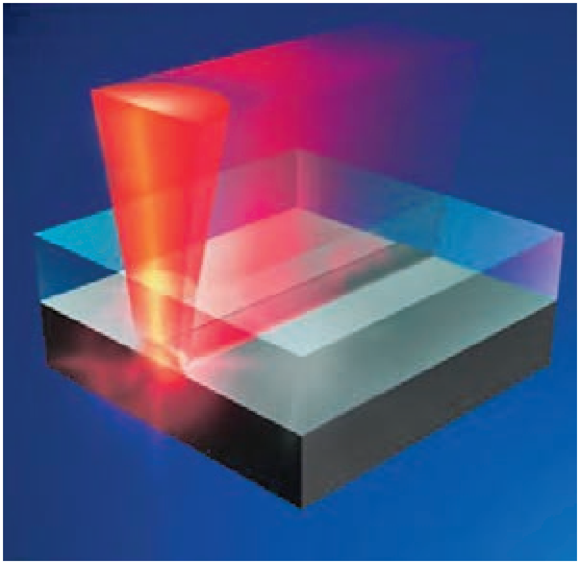

1
The moistening pad on the EKG belt is filled with water via a valve.

2
This is how it works: the top layer of the material must be transparent to the diode laser light, the lower layer must absorb the laser light. This results in precision heating. The simultaneous application of pressure welds the textile layers together.

The hunt for the ozone killers

Chlorofluorocarbons (CFCs) are still destroying the ozone layer. And industrial gases with extremely high global warming potential are heating the earth's atmosphere. Nonetheless, the culprits do not go undiscovered: Atmospheric researchers from Empa use highly sensitive equipment to trace the harmful gases and identify the sources of pollution with the aid of meteorological data.

The save-the-ozone-layer campaign began in 1987. In an international agreement – the Montreal Protocol – 197 nations pledged to ban the worst ozone killers: Greenhouse gases in spray cans and synthetic foams, coolants and fire extinguisher gases. And it worked, as the latest model calculations reveal. By around 2050, the ozone layer over the southern hemisphere should be about as dense as it was in 1980 – provided we continue to keep a watchful eye on the substances that destroy the ozone.

Based on data from the global AGAGE network (Advanced Global Atmospheric Gases Experiment), Empa researchers are studying which substances in particular are currently affecting the ozone layer. The Swiss measuring station is located on the Jungfraujoch at an altitude of 3,580 meters, its Irish counterpart in Mace Head on the Atlantic coast, and the Norwegian station on Ny-Ålesund on the island of Spitsbergen.

Every two hours, the equipment "breathes in" two liters of air from its surroundings and draws it through an activated carbon filter that has been cooled to –170 °C. The filter is then heated and the chemical substances captured enter a gas chromatograph mass spectrometer. This enables every substance to be identified clearly based on its molecular weight.

39,000

The number of tons of the ozone killer tetrachloromethane still released into the atmosphere every year, even though emissions of this substance have been banned all over the world.

An ozone killer that should no longer exist (in such quantities)

The Empa researchers recently found a surprise: Tetrachloromethane, a sweet-smelling liquid with a boiling point of –77 °C that was used in fire extinguishers and as a degreasing agent in workshops and chemical cleaning in the past, decreases in the atmosphere much more slowly than expected. Normally, the


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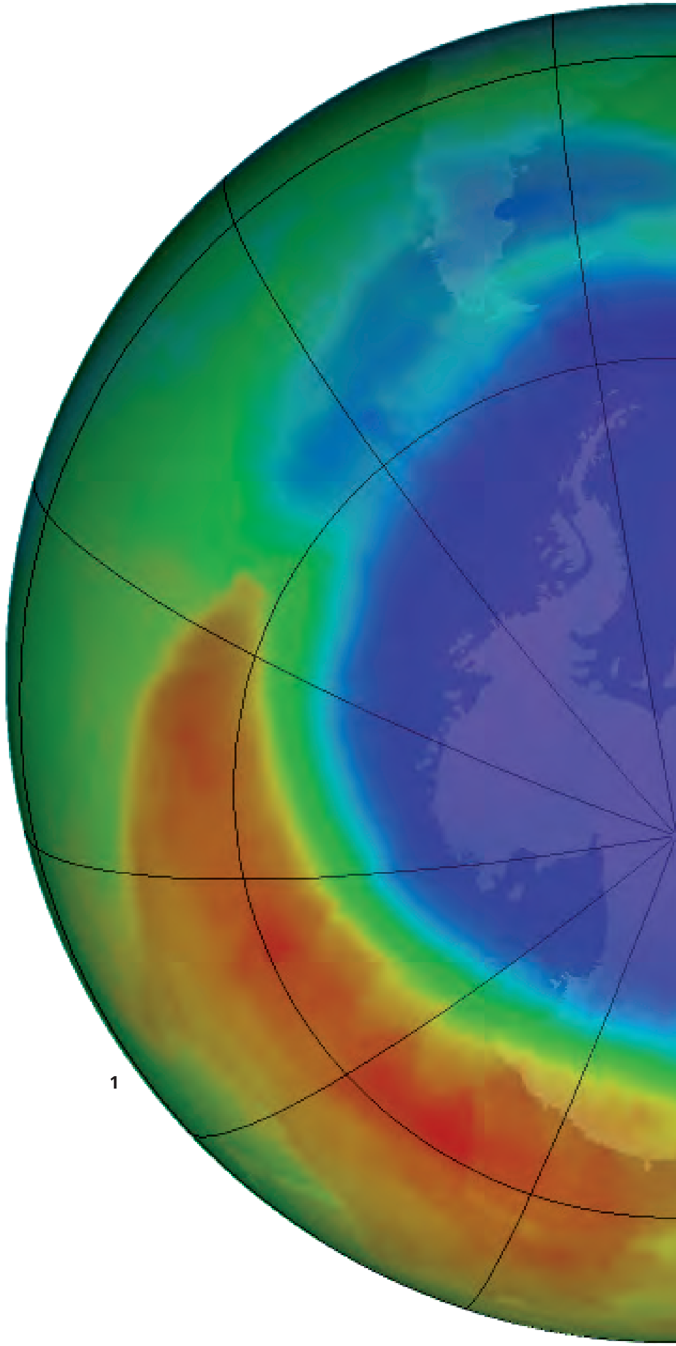
substance should gradually break down in the atmosphere, with the concentration falling by around four percent per year. As the researchers ascertained from their data, however, it is only decreasing by around one percent a year. This means that new tetrachloromethane is still emitted somewhere – around 39,000 tons per year, the researchers estimate.

Searching for the source in the atmosphere

Whenever high concentrations are measured on the Jungfraujoch, the Empa researchers compare the noticeable peaks in the measurements with meteorological data. The wind currents during the measurement period reveal the location of the emissions. It soon became evident that the source for the pollutant tetrachloromethane is not in Europe. The data from the AGAGE measuring network provided a clue: a station in South Korea displayed clear peaks, which makes it highly likely that the majority of the emissions originate in Asia.

Data goes to Federal Office for the Environment

To ensure that the latest findings on the state and chemistry of our atmosphere are also acknowledged in politics and the general public, the Empa experts and their international colleagues regularly write articles in journals and pass on the data to the Federal Office for the Environment (FOEN), which is also a



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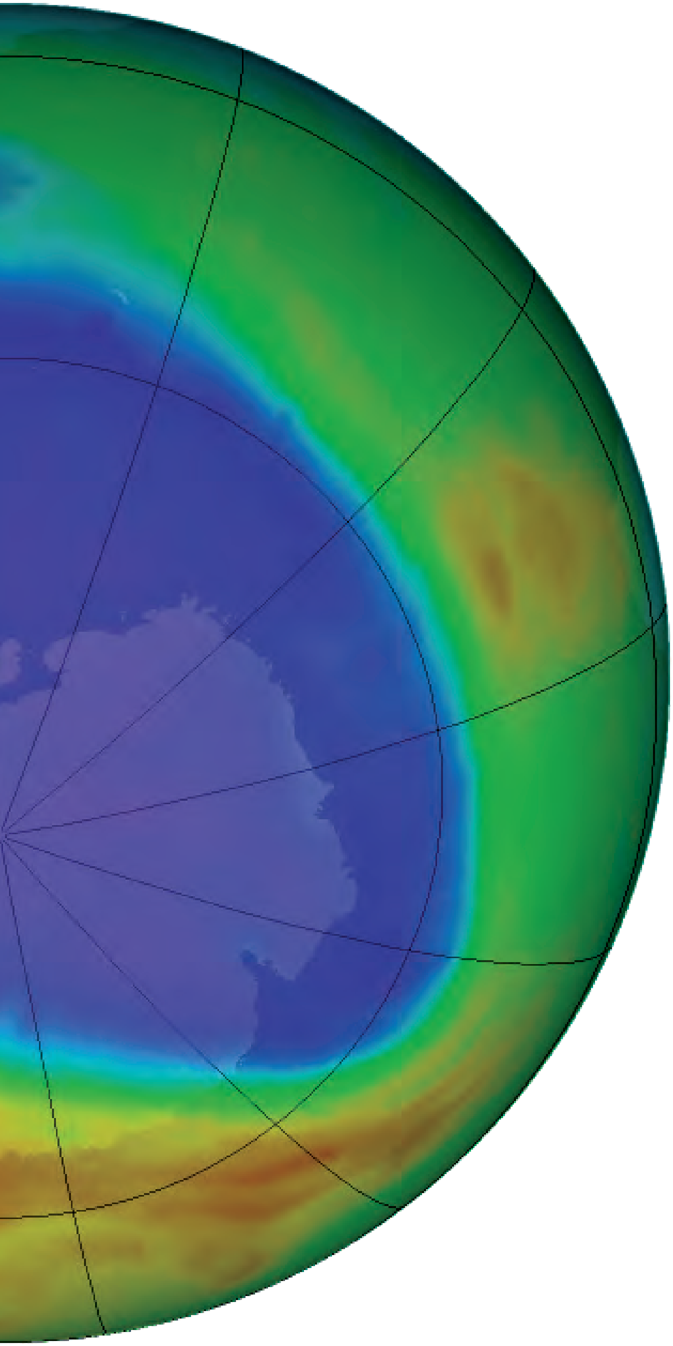

1
The hole in the ozone layer is shrinking – and the monitoring work continues. This was what it looked like on 18 September 2014 (Photo: Nasa).

2
Empa atmospheric researcher Stefan Reimann analyzing data from the Jungfraujoch measuring station and the global AGAGE network.

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financing partner. Empa's observations are then compared with the official emission data submitted by the countries involved. These results can then be channeled into the next round of negotiations concerning amendments to the Montreal Protocol. The researchers also compile regular reports for the World Meteorological Organization (WMO) in Geneva. In the latest article from September 2014, the WMO warns against an increasing indirect impact of the greenhouse gases nitrous oxide, methane and carbon dioxide on the ozone layer. In other words, a definitive solution to the problem has not yet been found. //

2

Empa technology for durable spinal disk implants

100

The number of cycles, i.e. approximately 100 years of movement, that were simulated in a joint simulator constructed especially for the new spinal disk implants. The result: zero wear and tear.

Herniated spinal disks are extremely painful. They are often followed by a surgical intervention, where the spinal column is reinforced at the affected point, which restricts the patient's freedom of movement. While flexible implants have long been used in hips and other joints, they eventually have to be replaced due to mechanical attrition. As bone material is lost every time an implant has to be retrieved, the new joint has to replace more bone and is thus larger than its "predecessor." In the case of spinal disks, this has virtually been impossible until now. On top, they lie too close to the nerve pathways in the spinal cord, which could be damaged by another operation. Researchers from Empa have now succeeded in coating articulating spinal disk implants, so that they do not exhibit any wear and thus last for a lifetime.

What makes artificial joints durable?

Increasing the lifespan of artificial joints was (and still is) one of the aims that various manufacturers looked to achieve using a super-hard coating made of DLC ("diamond-like carbon") – unfortunately with disastrous consequences: approximately 80 percent of all DLC-coated hip joints failed within just eight years. Researchers from Empa investigated the problem and discovered that the failure of the implants did not stem from the DLC coating itself, but was caused by very slow corrosive processes on the bonding agent between the DLC layer and the metal body. So far, this bonding layer contained silicon and corroded in-vivo over the years, which caused the flaking of the layer, enhanced wear and thus aseptic looseing. Thus the goal now was to find a bonding agent that does not corrode and thus will last a lifetime in the body.

Spinal disks: the first step

After extensive efforts with different biocompatible materials as bonding agents, tantalum was chosen. This coating was tested on a so-called "total disk replacement," an articulating disk implant. The artificial disk passed the long-term stress test

1
Empa researcher Kerstin Thorwarth holding the spinal disk implant with a tantalum bonding agent.

1

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and staid fully operational without any wear or corrosion. As tantalum proved successful as a "DLC adherent," the new bonding agent is soon to be used in combination with DLC coatings for other implants. //

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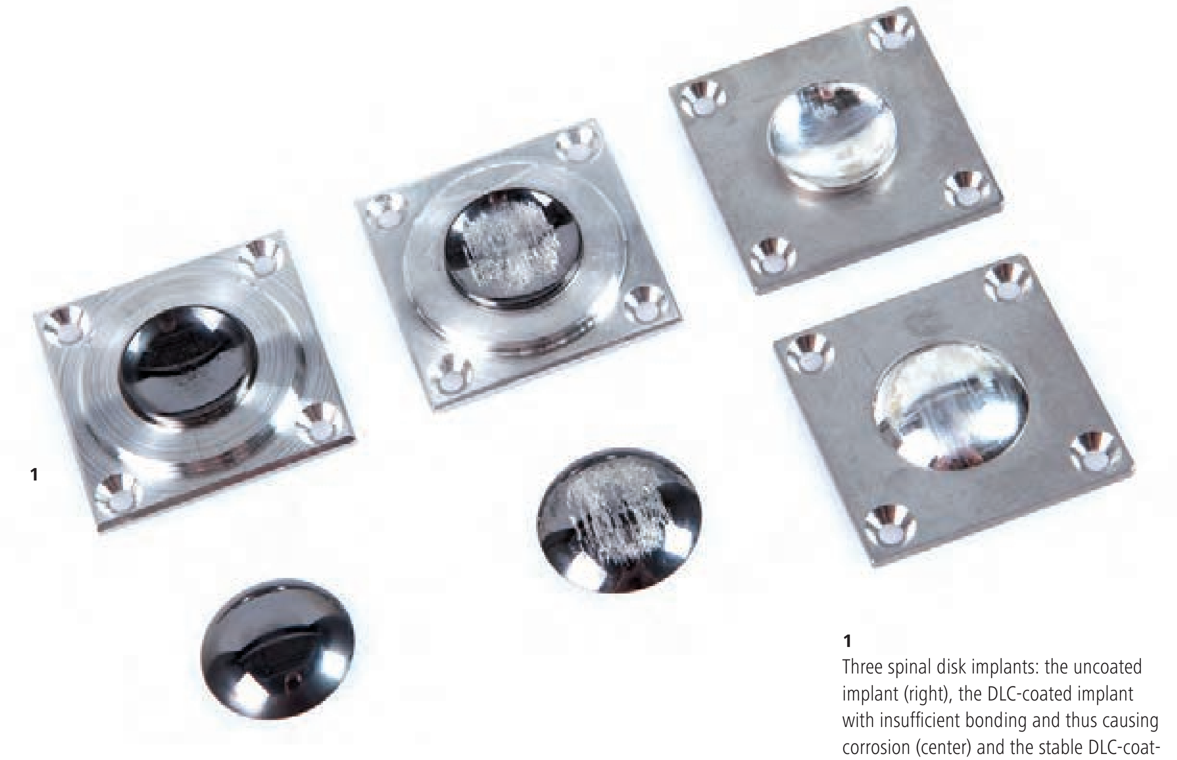

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Three spinal disk implants: the uncoated implant (right), the DLC-coated implant with insufficient bonding and thus causing corrosion (center) and the stable DLC-coated implant optimized by Empa (left).

Printing solar cells like a daily newspaper?

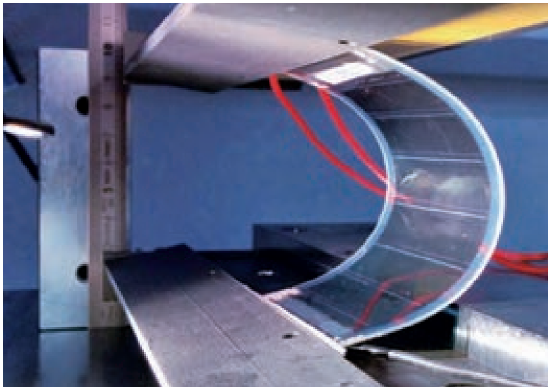
Flexible solar cells are a key technology if we want to convert more solar power into electricity at even lower costs in future. Empa is researching this task with several groups.

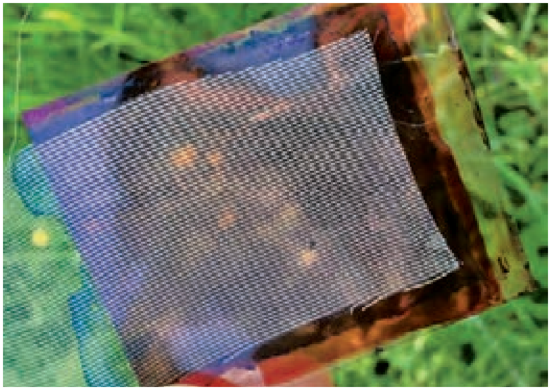
One of these teams is looking into solar cells based on organic dyes and has now – at the halfway mark of its research activities – presented its first functioning prototype. The team is part of the EU project Transparent Electrodes for Large Area Large Scale Production of Organic Optoelectronic Devices (TREASORES), which is coordinated by Empa. TREASORES was launched in 2012 with a budget of more than 14 million Euro and is aimed at producing large solar cells and LED lighting panels (OLEDS) using a roll-to-roll process. The solar cells could thus be printed on large rolls – much like a daily newspaper – which would considerably reduce the production costs and make the use of solar cells more viable on surfaces that have been uneconomical up to now.

50

The number of bend tests the prototype of the flexible, organic-inorganic hybrid solar cell underwent – without compromising its efficiency.

The most important requirement for a flexible solar cell is a supple, transparent electrode that conducts off the electricity while letting sufficient sunlight take effect. The flexlible substrate has to shelter the organic semiconductors of the solar cell from air and water for their whole lifetime. Simultanously it has to be electrically conductive with minimum resistance and must sustain several bends without losing its conductive and protective properties. The researchers developed an ultrathin, transparent silver composite electrode comprising several layers that outperforms the indium tin oxide electrodes (ITO) currently used in terms of efficiency and is also cheaper to produce. On this basis, the TREASORES project managed to produce a prototype of a flexible, organic-inorganic hybrid solar cell that meets the requirements for roll-to-roll mass production: The cell is based on a sublimated layer made of methylammonium lead iodide perovskite sandwiched between two very thin, special organic layers. The newly developed silver composite electrode comprising a layer of silver and two layers of aluminum-doped zinc oxide (AZO) serves as a conductive top electrode.

1 

2 

Prototype with maximum efficiency

Not only did this prototype break the previous record for flexible organic solar cells with an efficiency of seven percent, it also proved to be extremely bendable and durable. In conclusion: although the cell's heart is made of perovskite, an organo-mineral structure; this kind of cell is fit for roll-to-roll processes. Such solar cells could be produced cheaply in large quantities and processed almost as easily as tar paper in future.

The next step in the TREASORES project will be to upscale the most promising manufacturing techniques to industrial level so that transparent barrier-electrodes and entire solar cells can be produced in rolls of more than 100 meters.

In the second half of the project, the researchers will also increasingly focus on other novel electrode materials: transparent electrodes made of nanowires, conductive textiles or carbon nanotubes. //

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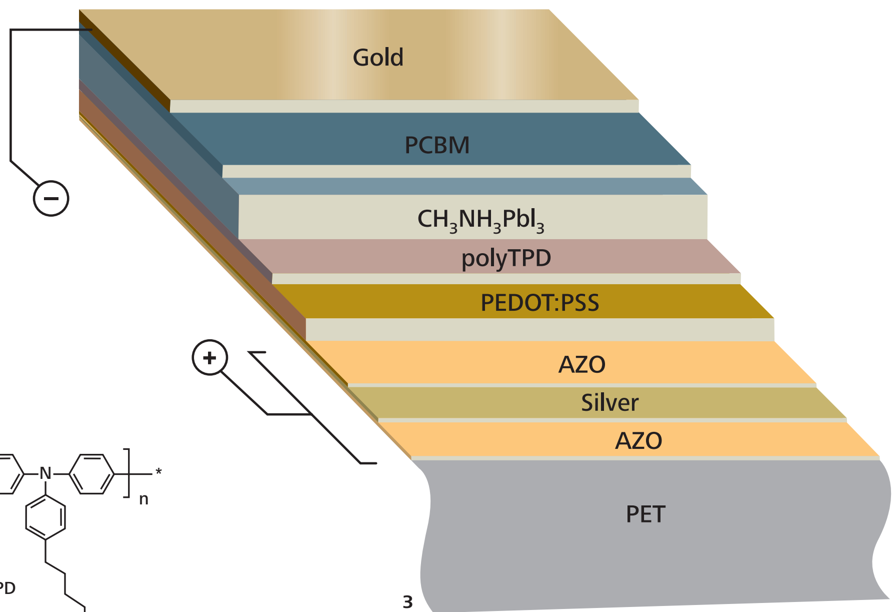
1
Testing the stability of a flexible, organic solar cell from the TREASORES project at the National Physical Laboratory (NPL) in Great Britain: it was bent on a radius of 25 mm more than 50 times while its efficiency was measured. Such prototype cells have already reached lifespans of more than 4,000 hours (Photo: NPL).

2
The new, transparent electrodes for flexible solar cells from the TREASORES project make do without rare metals such as indium. This one here is based on conductive textiles developed jointly by Empa and Sefar AG.

3
Structure of an organic-inorganic hybrid solar cell, which meets the requirements for roll-to-roll mass production.



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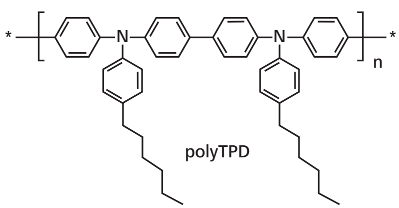
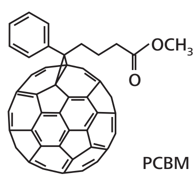
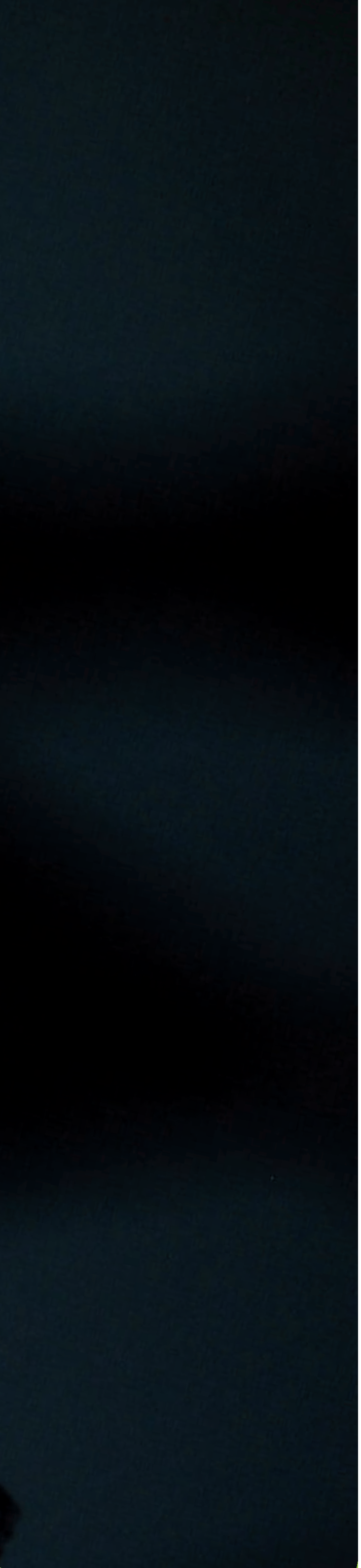






Research focus areas

Where do the major challenges of our time lie? Undoubtedly in the fields of human health and wellbeing, climate and the environment, dwindling raw materials, a safe and sustainable energy supply, and the renovation of our infrastructure. In its five research focus areas, Empa pools the expertise of its 30-plus research labs and centers and develops practical solutions for industry and society.

Engineering on an atomic level

Investigating and developing nanostructured materials means understanding and designing interfaces – sometimes on an atomic level. The nanoscale components of the materials are synchronized via interfaces. Only interface engineering enables nanostructured materials with outstanding, novel properties to be developed.

Improved charge transport

Opto-electronic components such as photodetectors or solar cells are composed of different thin layers – at least one photoactive layer to produce the charge carriers and two electrodes, to collect the charge carriers. As a result, the charge transport at the interfaces is impaired to varying degrees. The efficiency of the entire system is therefore largely determined by the electronic properties of the interfaces. For a number of years, Empa researchers have thus been working intensively on the characterization and optimization of these interfaces, which are usually only one to two nanometers thick.

This has already produced positive results in the development of inorganic thin-film solar cells and organic photodetectors. For instance, Empa researchers were able to demonstrate that the interface between the freshly vacuum-deposited CIGS (Copper Indium Gallium Selenide) absorber layer and the transparent electrodes could be vastly improved by treating it with potassium fluoride. This enabled the efficiency of the CIGS solar cell to be improved from 18.7 percent to 20.4 percent – a new world record for flexible solar cells. (Using the new Empa process, other research groups even managed to increase the efficiency level to 21.7 percent for CIGS solar cells on glass.)

Another Empa team succeeded in developing completely transparent organic photodetectors that detect light selectively in the near infrared range (NIR). A photodetector's sensitivity is primarily determined by what is known as "dark current." Thanks to special, ultra-thin, transparent buffer layers, the Empa researchers were even able to reduce the dark current several times over. As a result, the new organic photodetectors became as swift and sensitive as conventional silicon-based detectors – and carry several advantages: they are very light, inexpensive to produce and can be constructed over large surface areas on flexible substrates. This opens up interesting application possibilities, such as sensors on interactive displays, in quality control or for imaging diagnostic procedures in medical engineering.

Selective catalysis – less happenstance, more control

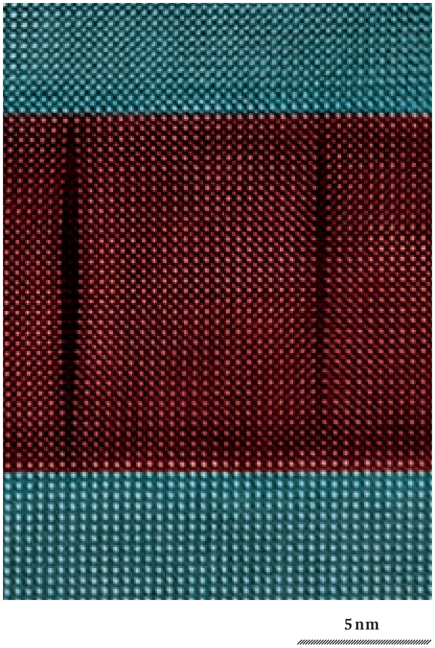
Selectivity, i. e. a preference for one of many possible reactions, is the main challenge in chemical synthesis based on heteroge-

1
Flexible CIGS thin-film solar cell with 20.4 percent efficiency – a world record for flexible solar cells! Round picture: flexible, optically transparent, organic photodetector that displays light in the near infrared range, which is invisible to the human eye, and can be used as an optical switch, for instance.

1

neous catalysis. Undesirable side reactions reduce the efficiency of the process, contaminate the product and can even poison the catalyst. The catalytic process is currently thought to take place at insulated atomic reaction centers on the surface of the catalyst. Noble metal alloys are primarily used as catalysts, where the atoms of the different elements, such as platinum or palladium, are distributed randomly on the crystal lattice's sites, including the surface. In other words, the reaction centers occur by chance.

In order to increase the selectivity of the catalyzed process, it would be advantageous to generate the isolated reaction in a controlled fashion. "Intermetallic compounds" offer one possibility here, where the different metal atoms are not distributed randomly, but rather at defined crystal lattice positions. By alternating between experiments and computer simulations, the Empa researchers studied the catalytic properties of the intermetallic compound PdGa. The results reveal that the catalytically active palladium centers on these surfaces are separated spatially be inert gallium atoms, which considerably improves the catalytic properties compared to pure palladium



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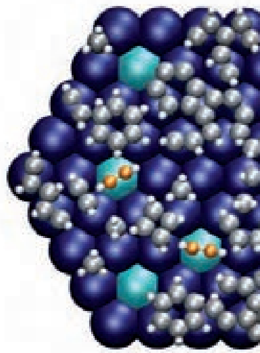

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This scanning transmission electron microscopy image at an atomic resolution displays the composition of a novel magneto-electric layer structure. The displacements (black lines) in the mechanically stressed magneto-electrical layer (red) form through relaxation during the preparation of the extremely thin sample.

2
Different spatial arrangement of the catalytically active centers on a catalyst surface:
carbon is separated on pure palladium (Pd atoms blue and cyan), which releases the isolated active centers for adsorbates (orange and white – left).
The "thinning" of the Pd atoms (blue) with an inert element (brown) in a surface alloy leads to small Pd ensembles as bond centers (middle).
Separation of the active centers on an intermetallic surface, where the adsorption sites (blue) are well defined because of the crystal structure on the entire surface and separated through catalytically inert atom species (brown – right).

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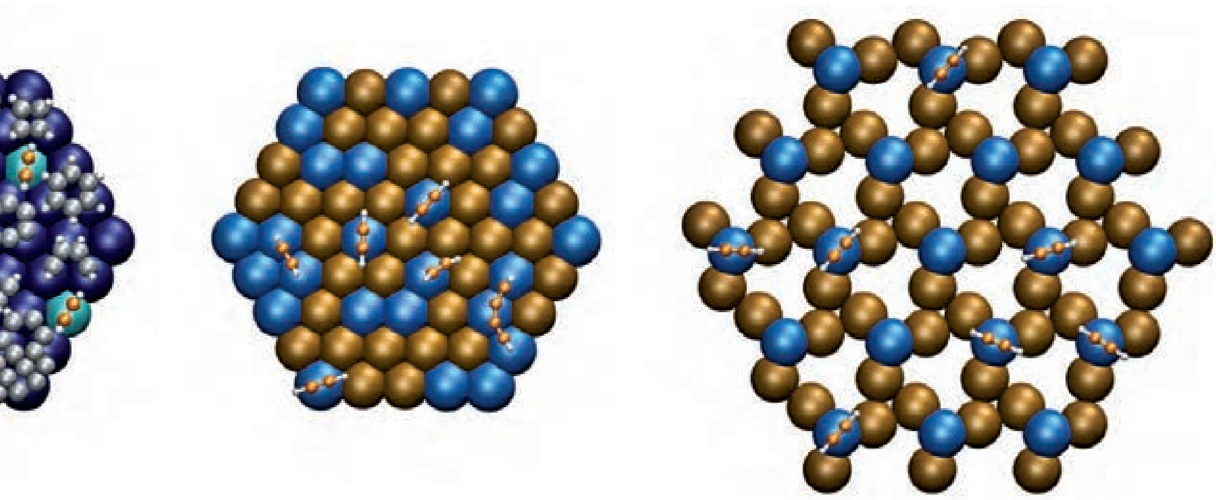
or alloys containing the metal. Moreover, the PdGa crystal structure displays a chirality. PdGa catalysts could thus be suitable for the production of certain pharmaceuticals, where only one of two mirror-image forms is biologically active (and achieves the desired effect). Until now, these had to be painstakingly isolated from a mixture of both forms. //



Practical solutions with an added value for society

The high quality of Switzerland's buildings is a key element for our high quality of life. We take safe and efficient supply and transport infrastructures for granted, not to mention attractive and comfortable living and working space. In order to maintain this level in future, economically, ecologically and socially, attractive solutions need to be developed to preserve and expand the built environment. This includes the economical use of non-renewable resources, especially the most important construction materials concrete and asphalt. It is just as important to maintain the existing structures and adapt them to new requirements so that they can continue to fulfil their function. With its research activities, Empa helps develop practical solutions that create real added value for society.

Asphalt – almost fully recyclable

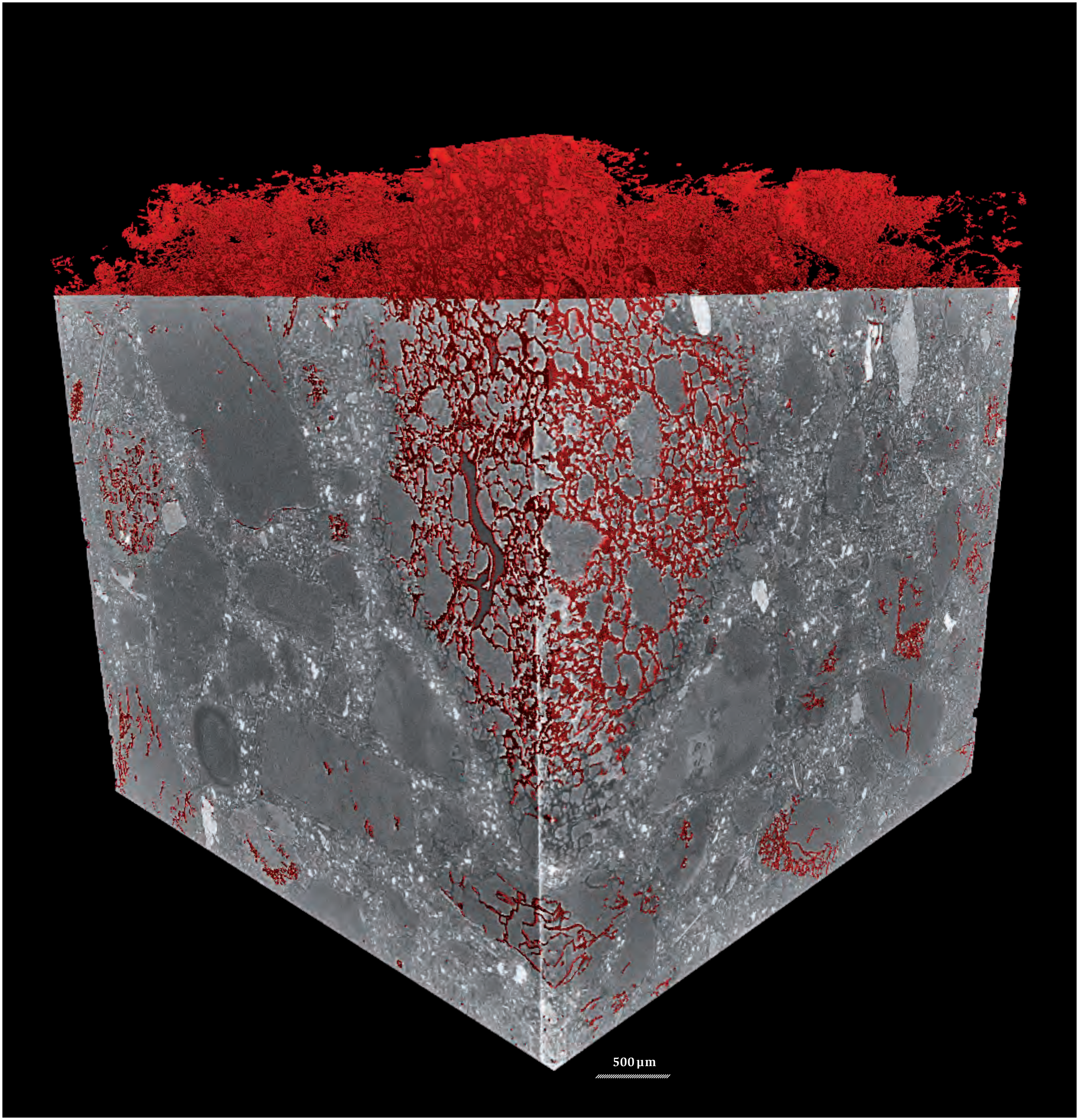
In terms of quantity, asphalt is the main building material after concrete and therefore extremely relevant from both an economic and an ecological perspective. At the same time, itis almost ideal for recycling. In several research projects, Empa researchers demonstrated that it is possible to produce a high-quality hot mix with high recycling proportions of up to 80 percent (in the lab). In other words, full recyclability is within our grasp. As the recycling proportion increases, however, the quality of the recovered asphalt also needs to be guaranteed through early triage, more complex reprocessing and careful storage.

Improvements in high-performance concrete

High-performance concretes facilitate extremely slender structures, especially when combined with a reinforcement made of carbon fibers (CFRP). Unfortunately, the dense structure of high-performance concrete has an adverse effect in the event of a fire as the water vapor released inside the concrete can cause spalling. One solution strategy involves adding polypropylene fibers, which fuse in the event of a fire and open up channels to relieve the pressure. In self-compacting concrete, however, the fibers cannot be added in the necessary quantities. As a result, Empa developed a patented solution, which can be used to produce self-compacting concrete with considerably fewer fibers and superabsorbent polymers (SAP). The SAP particles form macropores, which create a percolating channel system in interaction with the fibers in the event of a fire and therefore considerably reduce the risk of spalling. This was also demonstrated in experiments based on the example of thin-walled t-beams pre-stressed with CFRP wires.

1 X-ray imaging displays cracks in a concrete sample (in red).

1



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1
View of Münchenstein Bridge from below with pre-stressed, transverse reinforcement via CFRP bands.

2
The 120-year-old Münchenstein Bridge was reinforced with CFRP bands.

CFRP makes run-down bridges fit again

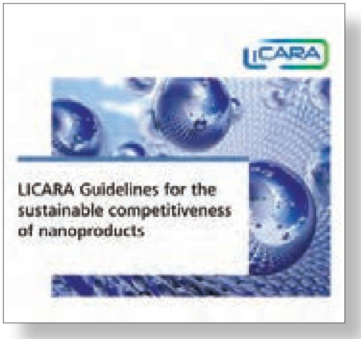
An increasing number of steel bridges need to be replaced or reinforced at a later date due to signs of fatigue. Empa developed a solution in a CTI project where the load-bearing elements are reinforced with pre-stressed CFRP plates. Unlike with conventional solutions, the plates are not stuck onto the structure, which also makes the solution just the ticket for riveted or, due to signs of corrosion, very rough surfaces. The system was already used successfully on the 120-year-old Münchenstein Bridge. The efficiency of the reinforcement could be monitored exactly and demonstrated using a wireless sensor network. This offers bridge operators a far more cost-effective alternative to a replacement, which is also extremely attractive from a cultural heritage perspective on account of the minimal interference with the structure. //

1


2


Using resources efficiently and responsibly

Our society's rising need for consumer goods and growing individual mobility are causing an increasing demand for non-renewable resources. In order to tackle this challenge, new, efficient processes, closed material loops and innovative materials are required to meet our everyday needs. At the same time, our own behavior needs to change to use resources more responsibly. One of Empa's central goals is to promote this development and devise efficient and innovative processes and materials that take the sustainable use of our environment into account.



Guidelines for sustainable products increase competitiveness

Thanks to their specific properties, nanomaterials can significantly improve products and give manufacturing companies a competitive edge. At the same time, however, it is also about avoiding possible negative impacts on humans and the environment through these new classes of substance. As many questions on the benefits and risks of nanomaterials are still open and European legislation is tough in this field, researchers from Empa teamed up with the Dutch research institution TNO, Nano-Cluster Bodensee and partners from industry to compile a set of guidelines within the scope of the EU project LICARA (www.empa.ch/licara). They guide SMEs through a systematic analysis of the pros and cons of nanomaterials in seven steps, help to weigh up decisions on their usage and promote the communication between the various actors along the value chain. The guidelines support industry in estimating the general advantages and risks of these new materials for humans and the environment with a view to developing sustainable, competitive nanoproducts.

Innovative trace gas analysis for emission reductions

Emissions from industrial processes are often a mixture of different gases. Therefore, the assessment of these emissions and the optimization of the corresponding processes usually require several, often expensive measuring devices. An Empa team joined forces with researchers from ETH Zurich to develop an innovative measuring concept based on a quantum cascade laser that can detect several gases in the mid-infrared range at once. The multi-component spectrometer is only realized with

1
Future Mobility, a research and innovation platform for tomorrow's mobility concepts: besides electricity, natural and biogas, hydrogen and a mixture of the latter three are also studied as fuels.

2
Air pollutants and greenhouse gases can be detected with outstanding precision and sensitivity using a measuring device based on quantum cascade lasers. This demonstrator won an award in the "Best Innovation" category at the Photonics Europe exhibition. It is just the ticket for measuring the stable CO_2 isotope, for instance.

1

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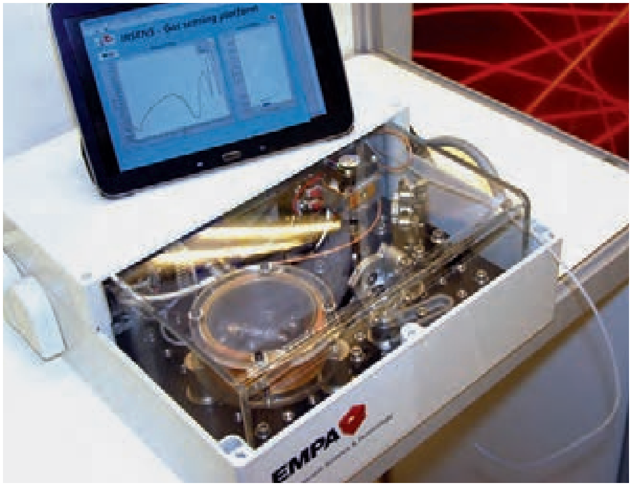
one laser chip optimized for several frequency ranges. This enables a few ppb (“parts per billion,” i.e. the billionth fraction in an air sample) of NO_2 and NO to be detected at the same time and at a high temporal resolution, which is a great advantage for both environmental monitoring and the study of combustion processes.

Renewable energy in the mobility sector curtails CO_2 emissions

Electricity from renewable sources such as solar and wind energy fluctuates greatly over time – and is not always available when needed. If temporary electricity surpluses from wind and solar power plants were to be used as fuel, hundreds of thousands of natural and biogas fuel-cell and electric cars could be powered with local, CO_2-neutral energy. On its Dübendorf campus Empa is constructing the Future Mobility Demonstrator, which uses various technologies to showcase the most economical way to convert surplus electricity into fuel and potentially enable considerable amounts of fossil fuels to be saved. //

2



Supporting Switzerland's energy policy

The research focus area "Energy" was expanded further in 2014. Meanwhile, the "Swiss Competence Centers for Energy Research" (SCCER) launched by the Swiss government within the scope of the Coordinated Energy Research action plan are all up and running. Empa is the leading house of the SCCER "Future Energy Efficient Buildings & Districts" (FEED&D) and makes major contributions towards the competence centers in the fields of storage as well as mobility. The financial scope of these projects for the years 2014–2016 amounts to almost 10 million Swiss francs, a third of which stems from the Commission for Technology and Innovation (CTI), a third from Empa and a third through competitive funding. Hence, Empa, will make a sizeable contribution towards achieving the objectives of the Swiss energy policy and boosting Swiss industry's competitiveness and innovative edge.

Buildings – efficient, intelligent and interconnected

The partners in the SCCER FEEB&D (Empa, ETH Zurich, EPFL, HSLU, FHNW, University of Geneva and their partners from industry) set themselves the goal of developing concepts and technologies that will reduce the energy demand of Switzerland's building stock by a factor of five by the year 2050. This means that buildings need to be efficient, intelligent and interconnected. As far as efficiency is concerned, the research projects involve new high-performance insulation materials that enable the efficient and cost-effective renovation of existing buildings, and new windows that permit maximum solar yields in winter without causing overheating in the summer. If the basic energy needs are reduced to a reasonable extent, intelligent measures are required to ensure that the buildings are also run optimally, i. e. that their efficiency potential is also exhausted. The topics here range from building automation and predictive controls to user integration.

The SCCER's third strategic direction is aimed at integrating buildings in local multi-energy networks that enable heat, cooling, electricity and gas to be distributed among various buildings via a central energy hub. This involves developing a simulation tool that enables the optimum dimensioning of such networks and begs the question as to which technologies should be used for the conversion and storage of energy in the hub. The potential of such integrated networks lies in the optimum use of locally obtained renewable energy and in the reduction of the strain on the grid by avoiding supply and demand peaks. In all of these aspects, socio-economic issues also play a key role, which are dealt with in a separate work package. Finally, a large number of industrial partners are involved in the SCCER as only they are capable of implementing the new solutions on the market.

1

The European FP-7 project COMTES is researching the long-term storage of solar energy using sorption thermal storage systems.


WERAG
Kingspan
Environmental
EMPA
Materials Science & Technology
COMTES

1

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Batteries with an improved storage density – photovoltaics with higher efficiency

In the SCCER "Mobility," Empa continues to conduct research in the field of gas-powered vehicles. And in the SCCER "Storage," Empa focuses on hydrogen and batteries. The latter involves the development of new electrode materials that are based on monodisperse, nanocrystal materials and harbor the potential for higher storage densities. Moreover, Empa has established and activated an infrastructure that enables the reliability and lifespan of larger batteries, such as for e-mobility and photovoltaics, to be studied.

Besides the SCCER-related activities, considerable progress was also made in many other fields, such as the development of photovoltaic tandem cells, which comprise two layers with different bandgaps. This enables a greater proportion of the incoming sunlight to be converted into electricity, which leads to an overall efficiency of more than 30 percent. However, this technology only stands a chance if affordable materials and production processes can be used. Empa is banking on thin-film technology here, where a semi-transparent perovskite layer rests on a CIGS layer. //

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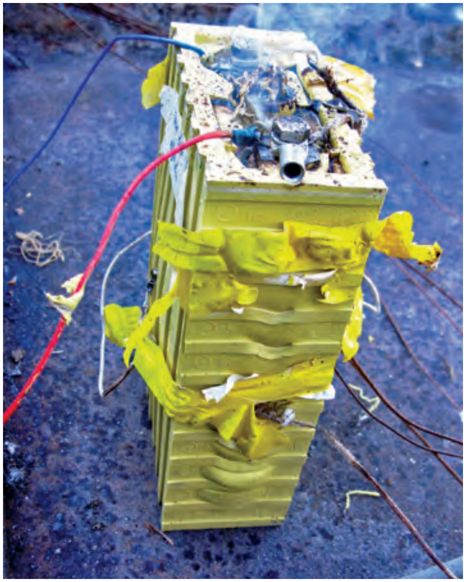


1
Stress test on a lithium iron phosphate battery: the cells themselves do not burn, but the degassing can cause the surrounding combustible substances to ignite.

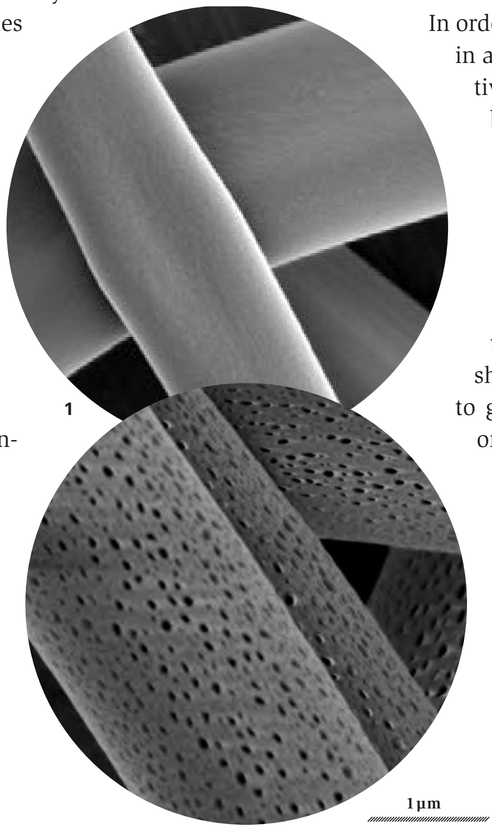
Materials for medical purposes – safety first!

One in two Swiss people will have an artificial hip fitted in their lifetime. And with increasing life expectancy thanks to medical progress, this figure could rise even further in the future. As a result implants need to remain functional for much longer. At the same time, the materials used for implants are being placed under considerably more stress due to increased sporting activities well into old age. The demands on the implants of tomorrow are thus growing permanently.

Interplay between materials and biological systems

Besides improved mechanical properties, however, the interactions between new materials and biological systems – cells, tissue and organs – are also of great importance. These are the focus of the new Empa labs "Biointerfaces" and "Particles-Biology Interactions" established last year. Implanted materials can trigger adverse reactions, for instance, as multi-resistant bacteria increasingly appear on their surfaces. The goal of Empa's research activities is to understand the complex mechanisms on interfaces and surfaces, and develop new therapeutic methods and diagnostic tools thanks to innovative technologies. This interdisciplinary field requires a close collaboration with clinicians at university or cantonal hospitals, and combines competencies from the fields of biotechnology, biochemistry, as well as micro- and cell biology.

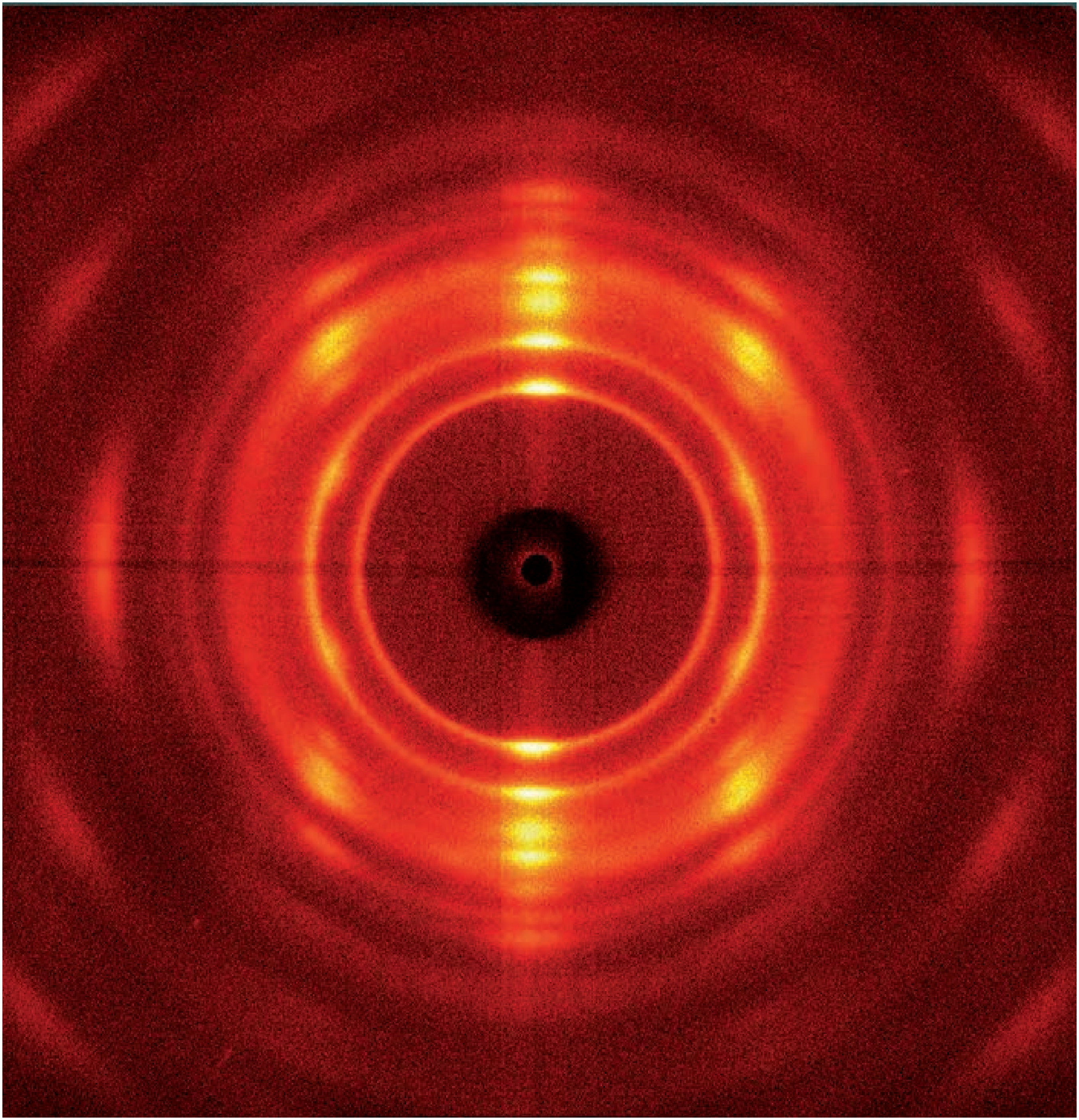
In order to exploit the potential of textiles in and on the human body more effectively in future for sustainable and biologically relevant fields – and use them to develop innovative applications – Empa teamed up with partners from the textile industry and other sectors to launch the research initiative SUBITEX. The development and use of novel materials, fibers, tissues and processes should help Swiss textile companies to gain a long-term competitive edge on the global market. Applications in the field of optical sensor technology, such as optically conductive fibers or novel biosensors, are particularly interesting – but



1

Fibers produced in the electrospinning process exhibit different surfaces depending on the surrounding conditions: low humidity produces smooth fiber surfaces, high humidity provides a porous structure. This can be used to make fibers with a controlled release of substances (drugs, fragrances, etc.).

1



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also polymer multicomponent fibers, such as fluid core fibers or nanofibers with anti-oxidative properties or membranes for the controlled dispensation of drugs through the skin (see also page 10).

Development of an artificial sphincter

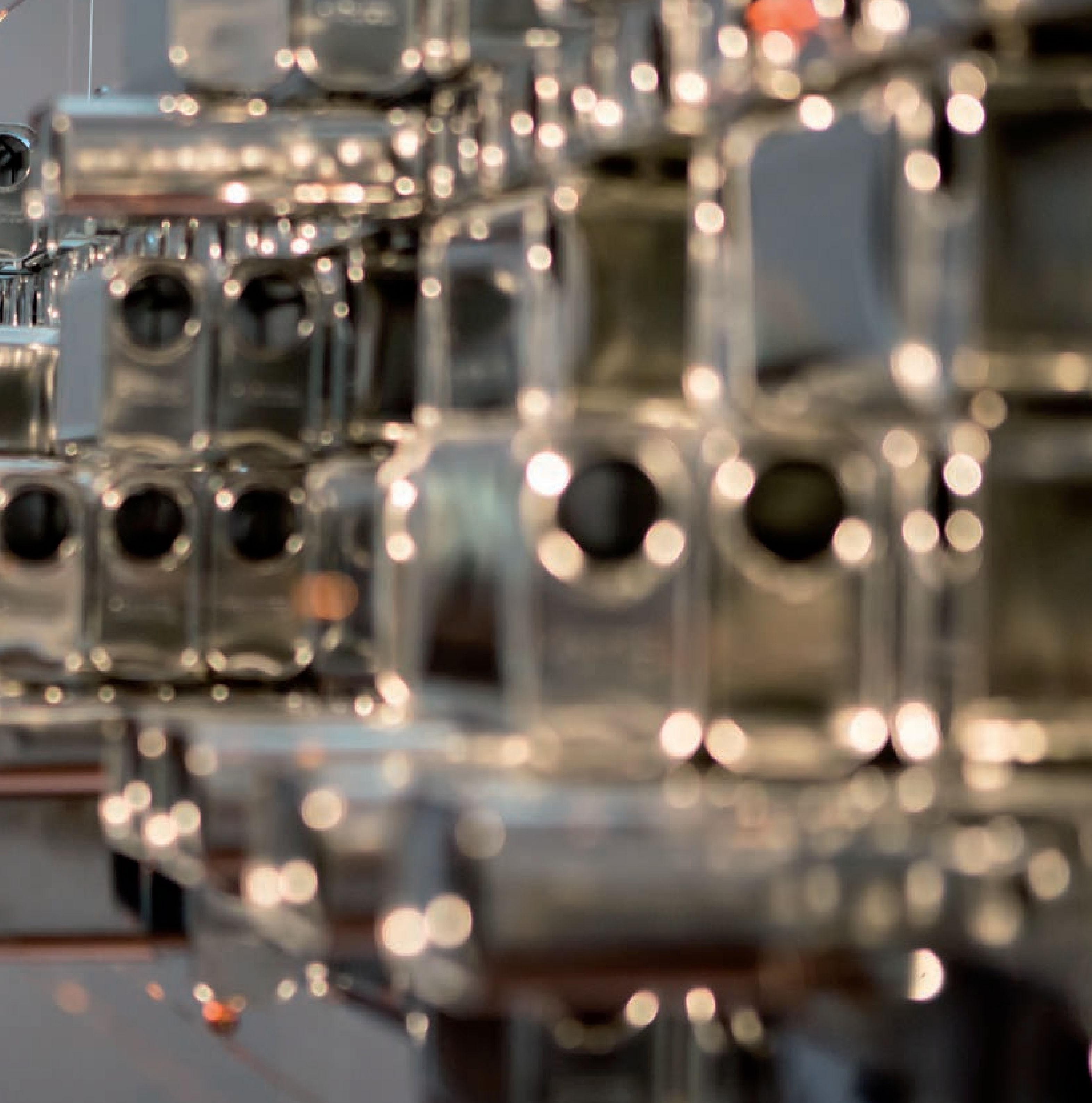
With a prevalence of up to ten percent, incontinence is a common affliction in industrialized countries with drastic physical and especially social consequences. Within the scope of a NanoTera project conducted together with the Biomaterials Science Center at the University of Basel and the Institute for Surgical Technology and Biomechanics at the University of Bern, Empa is developing the control and power electronics for an artificial sphincter and a corresponding battery storage system that can be charged inductively. The sphincter itself comprises an actuator made of electroactive polymers, so-called artificial muscles. The clinical trials are being conducted in the cantonal hospitals of Schaffhausen and St. Gallen, and at Bern University Hospital.

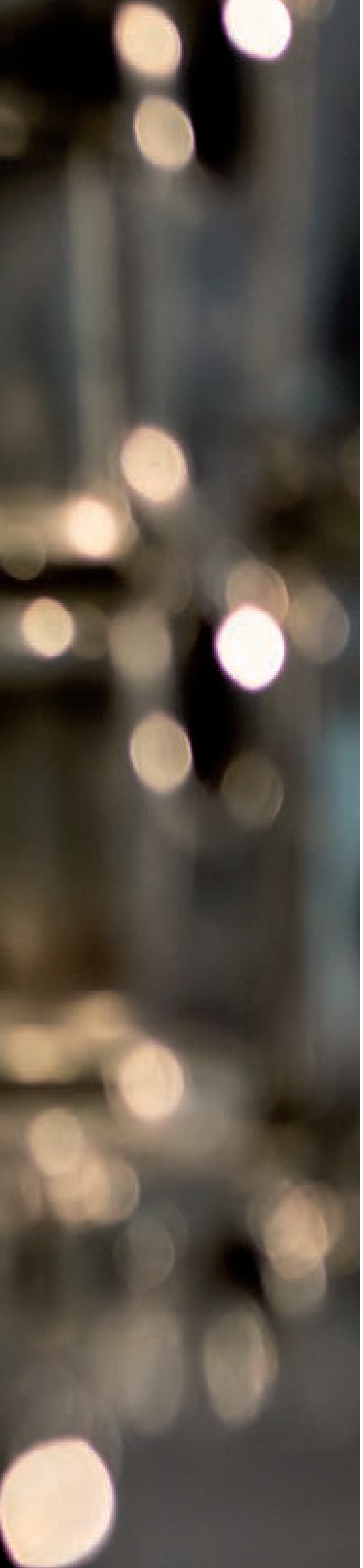
A new center for X-ray analytics

The newly founded Center for X-Ray Analytics also uses analytical methods such as X-ray computer tomography (XCT), X-ray diffractometry (XRD) and small-angle scattering methods (SAXS, XPCI) to characterize biological samples more effectively. Moreover, it is also developing software algorithms for 3D image analysis and computer simulations.

The research focuses on applications in biology and biotechnology, as well as the development of in situ techniques. The Center's new XRD and SAXS instruments in particular are just the ticket for the characterization of materials such as nanoparticles, polymers and fibers. These studies are primarily aimed at an improved understanding and optimization of the mechanical properties of the materials under investigation. Furthermore, the researchers are developing highly efficient X-ray detectors that considerably reduce the radiation dosage in medical examinations and therefore the risks for the patients. //

1
Obtaining X-ray diffraction patterns of a textile fiber through an SAXS analysis:
this allows the molecular structure of the fibers to be determined (Photo: Bruker Corp).





From research to innovation

Top-flight research and a proximity to industry – the two poles between which Empa operates. The institute is able to offer its partners tailored solutions thanks to efficient and individual forms of collaboration and a broad spectrum of services. Whether it be with a view to developing new products and applications, optimizing technologies, solving concrete problems or bringing technical specialists up to the state of the art – with around 550 highly qualified scientists and top-class infrastructure, Empa is the place to be.

A source of innovation for industry

1

The list of companies that cooperate with Empa via joint research and development projects keeps getting longer. Industrial partners use the interdisciplinary expertise of Empa's researchers as a source of innovation for their product developments. With around 130 contracts, the number of new research agreements rose by 14 percent last year compared to 2013. Moreover, Empa registered 18 patents and signed 16 new license and technology transfer contracts with industrial partners.

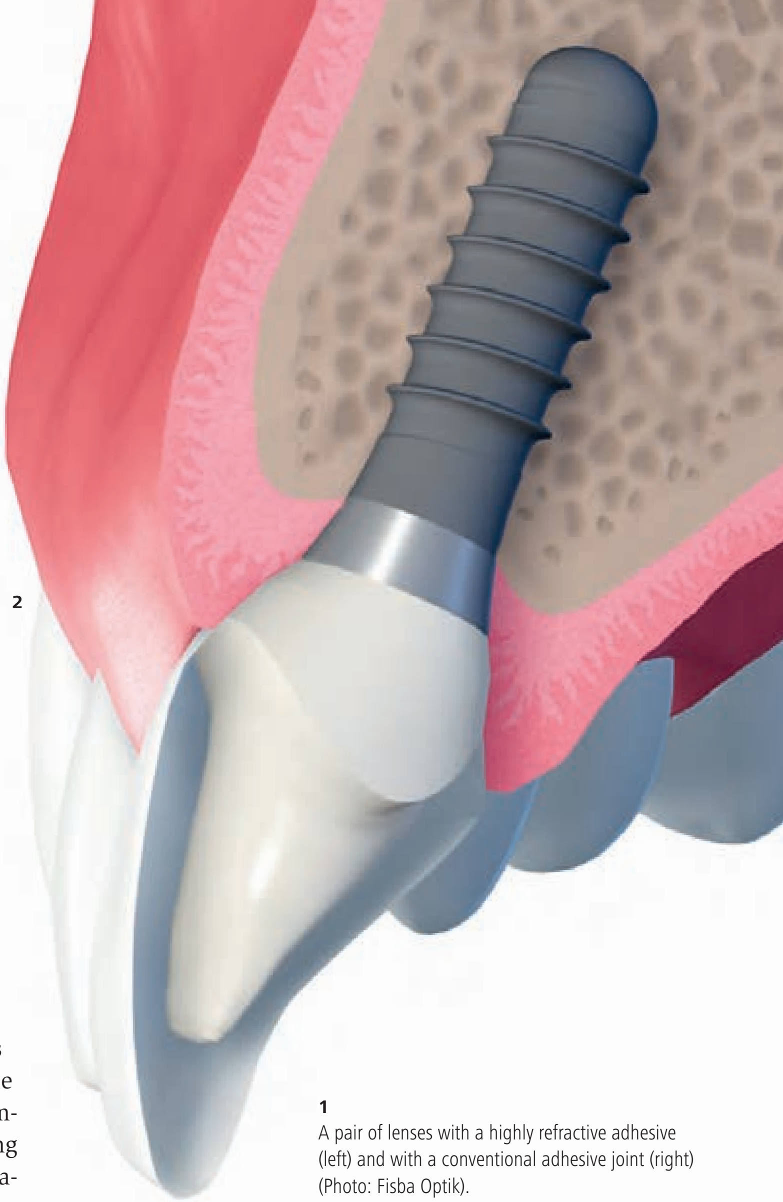
New adhesives made of structured polymers

Researchers from Empa, the Interstaatliche Hochschule für Technik Buchs (NTB) and the Centre Suisse d'Electronique et de Microtechnique (CSEM) developed new, structured, multifunctional polymers as part of a two-year CTI project in collaboration with the companies APM Technica AG, Fisba Optik AG, Baumer Electric AG, Unisensor AG and the UCP Group. These polymers are used as thin adhesive films and casting compounds in "packaging" for optical and opto-electronic systems. Four novel adhesives were developed: two with high optical transparency, one with increased thermal conductivity and one with a very high refraction index and optimum processing and adhesive properties. In future, they will be produced and distributed by APM Technica AG. Fisba Optik AG and Baumer Electric AG already used them to produce the first demonstrators and launch their own product developments.

Optimized ceramic cores for metallic precision casting

Numerous metallic components – such as turbine blades – contain complex cavities in their interiors, which are necessary for the components to work optimally. As such materials are produced using a casting method, so-called precision mould casting, ceramic cores act as a placeholder during the casting process. How these ceramic cores behave at temperatures of up to 1,550 degrees is therefore crucial. The problem: the ceramic cores often consist of silicon dioxide and zircon and can become distorted in excessive heat during the casting process. Consequently, Empa teamed up with the company Engimics SA on a CTI project to develop special ceramic cores with improved thermo-mechanical properties. Important aspects were the improved form stability at high temperatures and the so-called leaching process after the metal casting – the ceramic core is removed from the metal component after casting (in order to make room for the cavity) with the aid of an alkaline solution. By repeatedly varying the raw materials of the ceramic core, the Empa researchers were able to optimize the

2

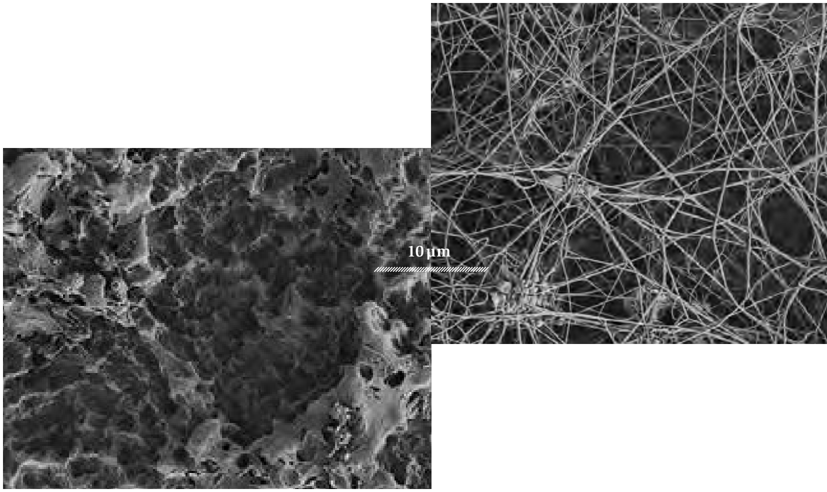


1
A pair of lenses with a highly refractive adhesive (left) and with a conventional adhesive joint (right) (Photo: Fisba Optik).

2
Together with industrial partners, Empa researchers are working on making implants more "bio-compatible" (© Institut Straumann AG 2015).

1
The fibrin network that is important for the healing process builds up more readily on an optimized material (right) more effectively than on a non-functionalized implant surface (left).

2
Ceramic cores optimized for metallic precision casting.



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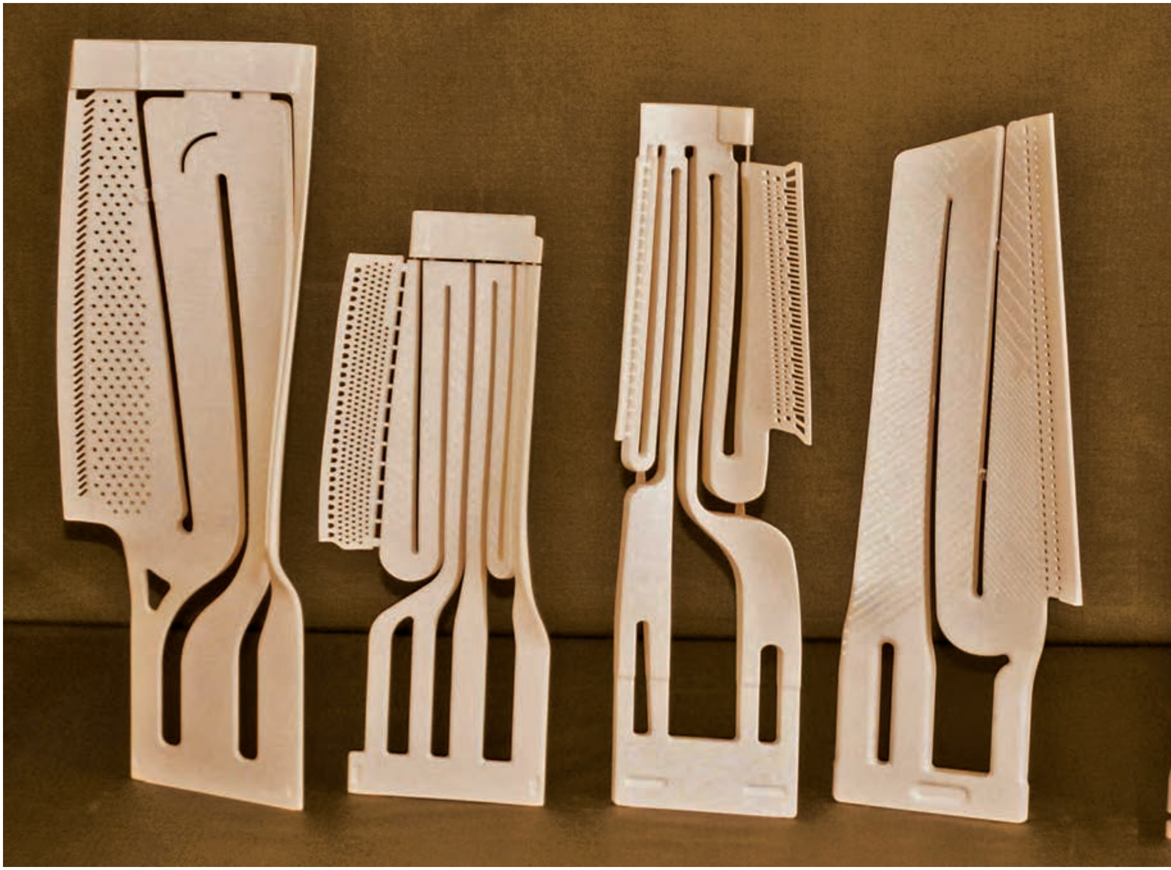

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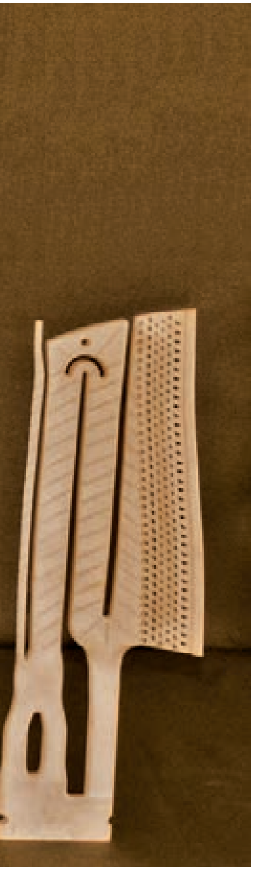


"recipe." The new formula enables ceramic cores to be produced with precisely "set" high-temperature properties for various metal cast components.

Functionality and compatibility of dental implants

In various studies with Institut Straumann AG, including two projects funded by CTI, Empa researchers are examining the biological compatibility and functionality of different implant materials based on in vitro studies. The body's reaction to a "foreign" material directly after implantation governs whether (and how) tissue cells accumulate on the implant surface – i. e. ultimately whether an implant, such as a dental implant or an artificial joint, "grows" firmly into the bone or not. In order to be able to study this crucial implant property more effectively, Empa researchers developed improved in vitro models that enabled them to examine how different tissue types, such as bone cells or fibroblasts, develop on the surface of the implant. //

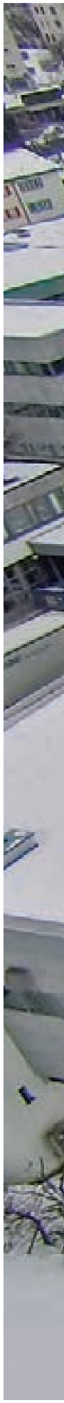
Giving young companies a helping hand

Once again, Empa's two business incubators glaTec and tebo supported numerous young companies during the past year. And the excellent positions of the start-ups in national rankings and competitions just go to show that it pays off. The young glaTec company QualySense, which develops systems for the quality assessment and sorting of cereals and other foods, climbed five places compared to the previous year and finished 5th in Switzerland's top 100 start-ups of 2014. The Empa spin-off TwingTec, which is looking to harvest wind energy with novel kites, won all three rounds of the founder competition VentureKick and was one of the three finalists at last year's Swiss Technology Award in the Inventors category. The former glaTec entrepreneurs from Optotune were also honored with the prestigious Swiss Economic Award 2014.

1

Fit for the market in four years

In 2014 a total of 13 young companies were housed in glaTec on the Empa campus in Dübendorf, including seven Empa spin-offs. Together, the glaTec start-ups employ more than 70 people. After the companies pass the strict, multistage selection process, they can settle in glaTec for three to four years and grow to market maturity with Empa's support. They then move out into the region as young SMEs. For instance, compliant concept AG became the second successful company after Optotune to leave the Empa incubator last year with 15 members of staff and launched the sale of its sensor-based Mobility Monitor care aid to nursing homes and hospitals from its new company headquarters in Fehraltorf.



2

1
Drone belonging to STARTFELD company Meteomatics GmbH, which makes accurate weather forecasts possible for the next 24 hours (Photo: Meteomatics GmbH).

2
Premises with potential: an innovation center in the former Tagblatt building; on the right, the Empa building in St. Gallen (Photo: St.Galler Tagblatt, Ralph Ribi).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Technology and innovation center in former Tagblatt building

In order to create additional space for a technology and innovation center right on Empa's doorstep in St. Gallen, tebo signed a lease for 1,000 square meters in the neighboring ex-Tagblatt building in November 2014. The building will be made accessible from Empa in 2015. The new technology and innovation center is due to open its doors at the end of the year.

Close collaboration with St. Gallen University and University of Applied Sciences

Empa collaborates closely with both the St. Gallen University and the University of Applied Sciences within the scope of the STARTFELD initiative. In 2014 around 100 projects for founding a company were evaluated. Eleven of them received a promotion package in the form of service checks and entrepreneurial coaching. Meteomatics GmbH was also granted a loan of CHF 300,000 for its drone network. Meteomatics was launched in 2012 and specializes in the particular IT needs of the meteorological and energy industries and the raw materials trade. The now seven-strong team developed a drone that enables highly accurate weather forecasts for the next 24 hours. Exact weather predictions are extremely important for energy producers, the insurance sector, aviation, trading companies, and in road and rail transport. The difference between a correct and an incorrect forecast can cost companies in these sectors several billions. In order to record meteorological data throughout Switzerland, Meteomatics is planning a network of around two dozen drones. The young company receives support from MeteoSchweiz and the Federal Office of Civil Aviation (FOCA). However, the sensor network could also be of interest for Empa projects involving air pollutants. //

tebo

Technologiezentrum an der Empa in St. Gallen

glaTec

Technologiezentrum an der Empa in Dübendorf

STARTFELD

Collaborations create successful innovations

1
NEST ground-breaking ceremony on August 26, 2014: Walter Steinmann, Director of the Swiss Federal Office of Energy (SFOE); Empa CEO Gian-Luca Bona; Janet Hering, Director of Eawag; the Mayor of Dübendorf, Lothar Ziörjen; Zurich Government Councillor Markus Kägi, and Fabio Gramazio, the architect who designed NEST.

A close tie to industrial partners was always extremely important for Empa. Besides the intensive collaboration on numerous research projects, Empa concentrated on the development of joint research platforms and demonstrators in 2014 with the aim of preparing new technologies for the market (even) faster and more efficiently.

NEST – construction work gets underway
The construction work on the modular research and innovation building NEST, a joint project between industry, research and the public sector headed by Empa and Eawag, got underway with a ground-breaking ceremony on the Empa campus in Dübendorf at the end of August. The multistory experimental building consists of a core, the so-called "backbone" with three open platforms, upon which several independent research and innovation modules will be installed based on the "plug and play" principle. In these so-called "units," apartments, offices and conference rooms of the future will be developed, tested and refined under everyday conditions. Five teams have already begun with the implementation of their modules.

NEST
exploring the future of buildings


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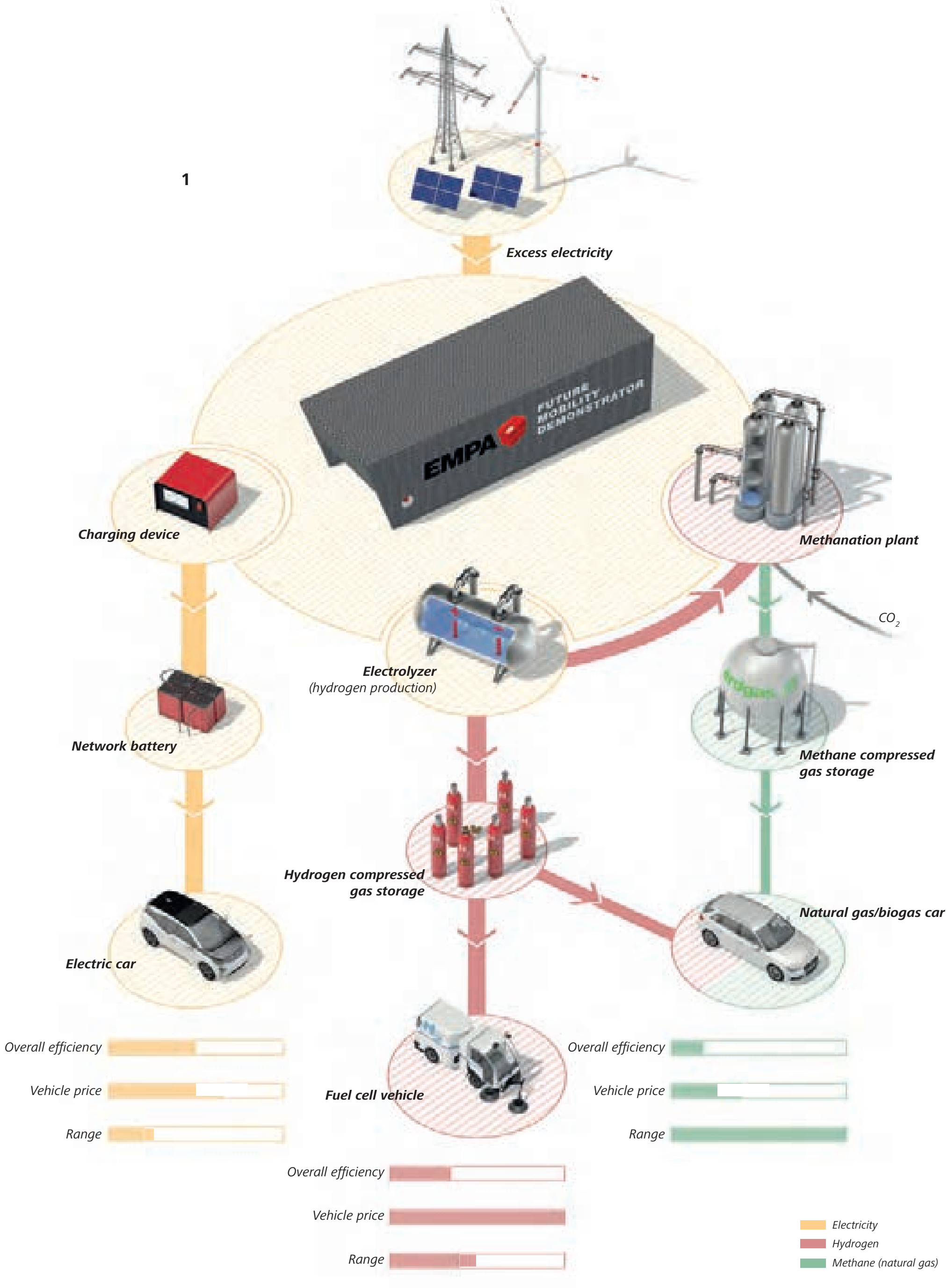
Excess electricity
FUTURE MOBILITY DEMONSTRATOR
EMPA
Charging device
Methanation plant
CO_2
Electrolyzer
(hydrogen production)
Network battery
Methane compressed
gas storage
Hydrogen compressed
gas storage
Natural gas/biogas car
Electric car
Fuel cell vehicle
Overall efficiency
Vehicle price
Range
Overall efficiency
Vehicle price
Range
Overall efficiency
Vehicle price
Range
Electricity
Hydrogen
Methane (natural gas)

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1
"Future Mobility": different technologies should reveal the most sensible way to convert surplus electricity into sustainable fuel.

2
Shape memory alloys can also be used for applications in the building industry: Empa engineers cementing fins made of smart memory steel into a concrete beam.

"Future Mobility" – the sun in the tank

In another large-scale project, "Future Mobility," Empa wants to demonstrate how locally and sustainably produced energy can be used to replace imported fossil fuels. With this in mind, a demonstrator was set up on the Empa campus that enables Empa and its industrial partners to develop pioneering concepts and test their practicality in the interplay with real users. Future Mobility should reveal how such systems have to be dimensioned and operated, and with which applications they need to be combined to be ecologically and economically viable.

Seventh Empa Innovation Award

For the seventh time, Empa awarded a prize to research teams that successfully bridged the gap between science and industry with their applied and market-oriented research. The winning project uses shape memory alloys to pre-stress large concrete frames, which so far has always been far too expensive. The newly developed, iron-based smart memory alloy fundamentally changed this and fulfils all the requirements in terms of phase transition temperature and corrosion behavior for use in concrete structures. The technology is currently being launched onto the market by the Empa spin-off re-Fer AG. //

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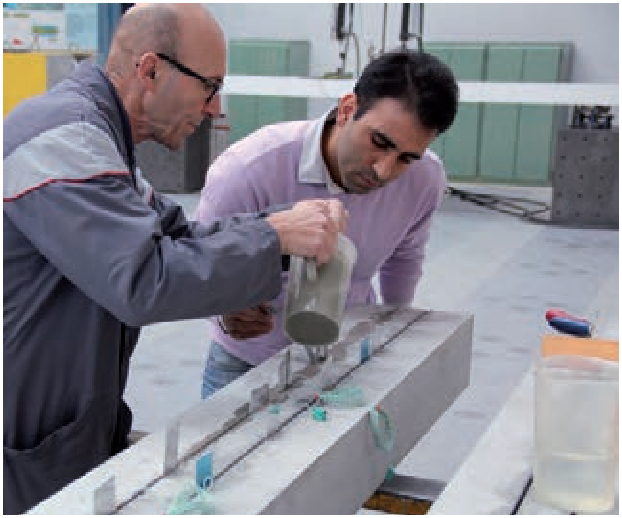


Global networking under the banner of innovation

Knowledge and technical knowhow are global comodities. In order to acquire these and transfer them into practical applications, Empa cooperates with numerous international partners, which is also reflected in the scientific papers published by Empa researchers: way more than half were published with partners from abroad.

A European flagship …

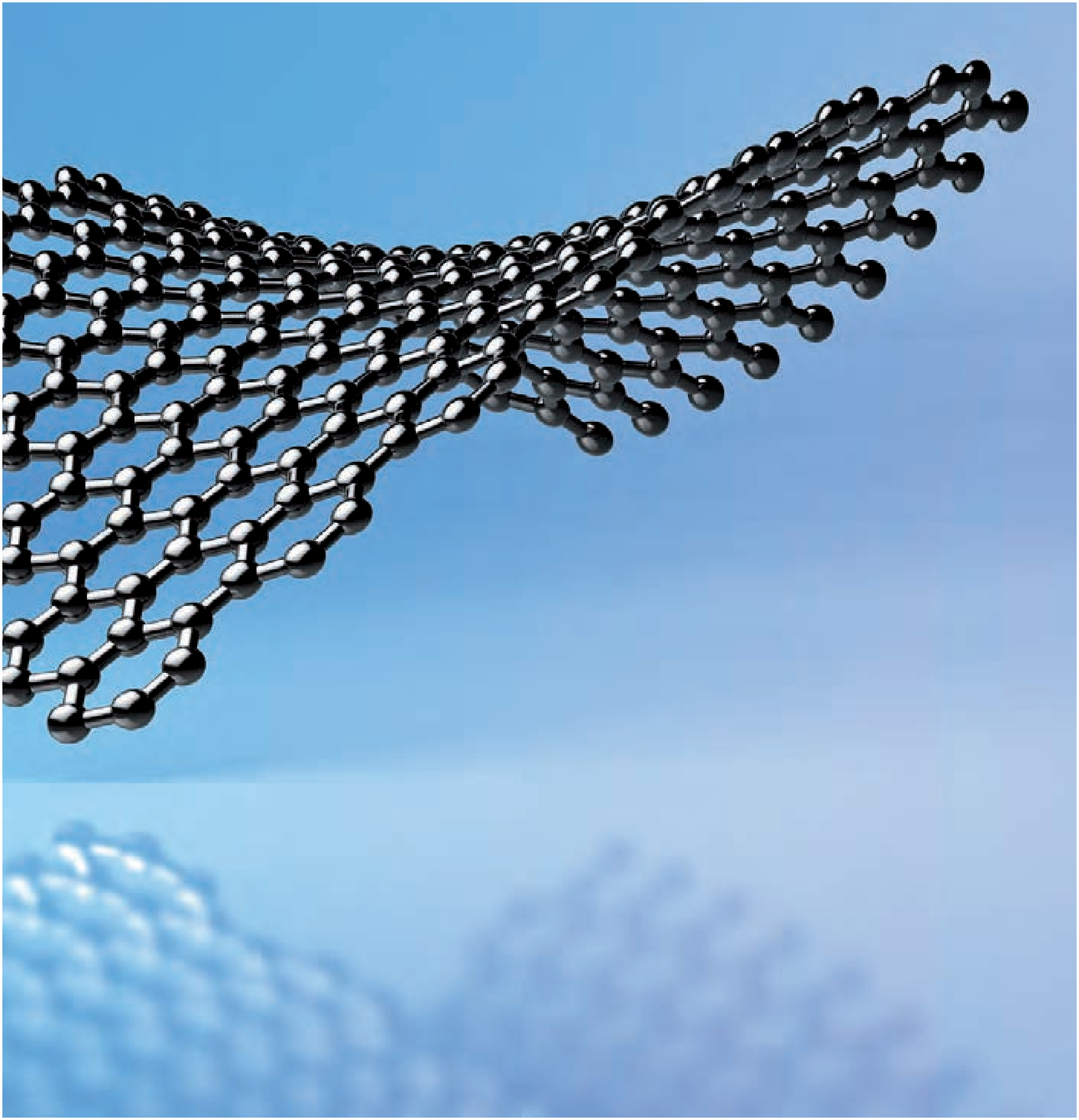
Graphene is regarded as a material with enormous potential for the development of innovative technologies in many different fields, such as electronics, photonics or sensor technology. The EU has therefore been funding graphene research as one of only two flagship projects since last year. Empa is also involved in this large-scale project. In November, scientists from the "Health and Environment" working group from nine European countries convened at their annual meeting at Empa in St. Gallen to discuss possible applications for graphene-based materials in biomedicine and aspects of safety research and toxicology for this new class of materials.

Anne Glover, the Chief Scientific Adviser to the then-President of the European Commission, José Manuel Barroso, became the latest guest "from Brussels" to make a stop at Empa in May 2014. During her tour of various Empa and Eawag labs, the biologist, who holds a chair of molecular and cell biology at the University of Aberdeen, discussed various topics with Empa CEO Gian-Luca Bona, including the internationalization of teaching and research and how the technology transfer between research and industry might be organized more efficiently.

Conversely, Empa CEO Bona attended the annual reception of the Swiss National Science Foundation (SNSF) at Swiss Core, the SNSF liaison office for European research and innovation, and an event organized by the Permanent Mission of Switzerland at the EU in Brussels to discuss with EU partners the conversion of top-flight research into innovations for the market. Primarily thanks to support from the EU, Empa was able to translate various innovative material approaches into new applications, such as flexible thin-film solar cells, the development of which was publicly supported for more than 15 years until they eventually succeeded with a world record efficiency of more than 20 percent.

… and UN report on the ozone layer

In order to shed light on the state and the future of the atmospheric ozone layer, the United Nations Environment Program (UNEP) has been publishing expert reports since 1987 – the signing of the Montreal Protocol, which bans various "ozone



killers." Empa researcher Stefan Reimann was one of the lead authors of the most recent report, which was presented at the UN headquarters in New York on 10 September 2014. The latest conclusion of the international committee: the hole in the ozone layer above the Antarctic has stabilized since the turn of the millennium. Model calculations reveal that the ozone layer may return to its 1980 condition by 2050.

Building bridges to North America

Empa teamed up with swissnex and Eawag to organize the first North American Science Day in October, an event designed to promote an exchange of ideas and experiences between researchers and companies from Canada, the USA and the local research and start-up scene. The Canadian ambassador to Switzerland, Jennifer MacIntyre, representatives of the State Secretariat for Education, Research and Innovation (SERI), and the Swiss Federal Office of Energy (SFOE), and the CEOs of Empa and Eawag – all gave talks on international collaboration, especially for the sustainable use of raw materials and energy resources.

On the other side of the Atlantic, Empa CEO Bona opened a Workshop on Energy for US ivy league universities on the topic of solar energy conversion with a keynote lecture in October – a special honor as Bona was the only non-American to be invited to the conference in Arizona. Topics such as photovoltaics, photocatalysis and new energy storage concepts were discussed and new cooperative projects developed, which are now being supported with seed funding.

Switzerland – Asia: strong ties

For some time now, Empa has been cultivating close relations with various Asian countries. Besides the collaboration with Japan's National Institute for Materials Science (NIMS), with


1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1
Head of Communications Michael Hagmann explaining Empa's research in the field of medical technology to Anne Glover, Chief Scientific Advisor to the EU Commission.

2
Tanja Zimmermann, head of Empa's Applied Wood Research lab (left), explaining how sponges made of modified nanocellulose can suck up oil pollution in water to Canadian ambassador to Switzerland Jennifer MacIntyre (center) and Eawag CEO Janet Hering at the "North American Science Day".

3
"Biosphere 2" in Arizona, where US researchers discussed possibilities of solar energy conversion with Empa CEO Gian-Luca Bona (Bild: iStockphoto).

which Empa has been publishing the scientific open-access journal Science and Technology of Advanced Materials since 2014, contacts with South Korea and China were intensified last year, especially in the field of nanotechnology. For instance, Empa supported the construction of the new Korean Center for Nanosafety Metrology and was represented at several conferences in Seoul, Tokyo and Bangkok. In talks headed by Thai Deputy Prime Minister Yongyuth Yuthavong, who is responsible for technology and research, an international research delegation discussed the further development of nanotechnology in the various regions of the world – together with Empa representative Harald Krug NIMS Director Ikatsu Ushioda, the head of the US National Nanotechnology Initiative, Mihail Roco, the Director of the Korea Research Institute of Bioscience and Biotechnology, Bong Hyun Chung, and the Director of the Thail NANOTEC Institute, Sirirurg Songsivilai were present. //

3


Multifaceted program with numerous highlights

1
Happy faces at the "North American Science Day".

2
"How small actually is a nanoparticle?" – One comparison says it all: a nanoparticle is to a football what a football is to planet Earth (Photo: Exponano).

3
"How do nanoparticles get into the human body?" Another question addressed by the "Expo Nano" exhibition, which visited Empa in St. Gallen in 2014.

The Empa Academy's 2014 program consisted of a successful mixture of conferences, meetings, courses, talks and exhibitions. More than 80 events were attended by well over 4,000 interested visitors.

Nano you can touch

The travelling exhibition "Expo Nano" visited the Empa site in St. Gallen from May to July. It showcases the opportunities and risks of nanotechnology in a comprehensible way and reveals where nanomaterials are already used today. To coincide with the exhibition, Empa organized two public events, where Empa scientists took the visitors off into the fascinating world of nanotechnology. In October, the Empa Academy teamed up with swissnex and Eawag to hold the "North America Science Day," an event for the exchange of ideas between researchers and companies from Canada and the US and the local research and start-up scene. The Canadian ambassador to Switzerland, representatives of the State Secretariat for Education, Research and Innovation (SERI), and researchers from Empa and Eawag – all gave talks.

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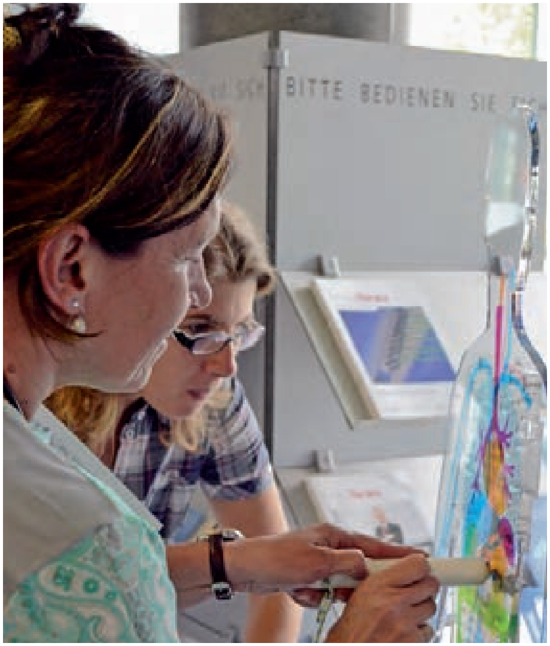


3

Specialist courses for industry

The extensive course program was also well received last year. The course on adhesive technology proved particularly popular and was conducted in partnership with the “Fondation Suisse pour la recherche en microtechnique” (FSRM) – twice to accommodate the great demand. Experts from Swiss industry were given an introduction into the world of adhesive technology, and had the opportunity to bring problems of their own to the table and apply the know-how they gained in hands-on experiments.

50 years of acoustics research at Empa

The Empa lab Acoustics/Noise Control celebrated its 50th anniversary with a large symposium in the summer of 2014. Researchers have been doing their bit to develop innovations in noise control and research since the early 1960s. Although the field of noise control has come on in leaps and bounds in recent years – as the interesting and comprehensive review demonstrated to the more than 150 participants –, there is still plenty of work to be done. An overview of current activities and the future outlook was also provided. //

Communicating research and innovation

The dialog with two of Empa's main stakeholder groups was particularly intensive last year. On the one hand, the number of potential young scientists – i.e. cantonal school classes that visited Empa – steadily increased. On the other hand, "official" delegations from abroad and various levels of the Swiss Administration were (and still are) in frequent contact with their counterparts at Empa.

Arousing a fascination for research

For Empa, the prime goal of its work with high school students – i.e. the researchers of tomorrow – is to make the fascinating world of scientific research accessible to them. And what better way than to visit a lab? Last year, Empa notched up almost 3,000 visitors – more than ever before – including around 400 high school students (another record). Drawing upon their personal experiences, researchers from Empa and from spin-off companies explained how exciting and inspiring it is to be in the front line when innovation is being created.

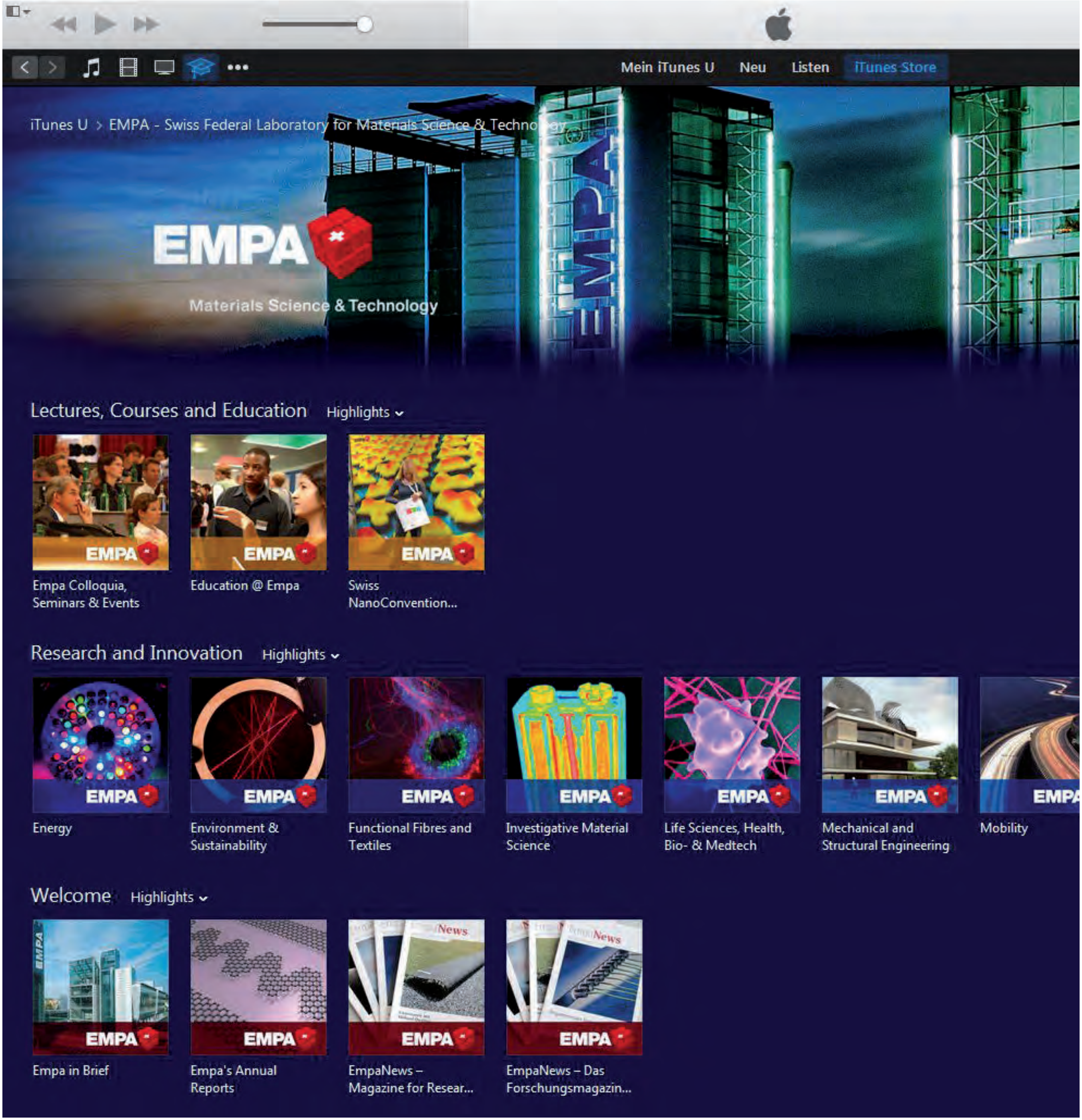
The Empa portal on iTunesU, the iTunes Store's platform for international research institutions which has been active since May, is also all about budding young scientists. Empa is one of the first Swiss research facilities to offer a glimpse into its research activities in the form of podcasts, talks and lectures by Empa researchers and notable guest speakers.

Government and administration delegations from home and abroad

Besides industry, representatives of the government and the administration are Empa's most important partners, with whom it regularly exchanges ideas and experiences. In early October, for instance, Federal Councilor Johann Schneider-Ammann visited Empa in Dübendorf to attend the kick-off meeting of the Swiss Competence Center for Energy Research (SCCER) on the topic of "Future Energy-Efficient Buildings and Districts," which is led by Empa. The Swiss Minister for Economic Affairs, Education and Research – who is also on charge of the ETH Domain and, thus, Empa – was afforded a glimpse into research projects conducted within the action plan "Coordinated Energy Research Switzerland" funded by the Commission for Technology and Innovation (CTI). The focus was on methods for the energy-related renovation of old buildings and wind tunnel research in the field of urban development as well as mobility concepts based on renewable energies.

A visit by Thomas Zwiefelhofer, the Deputy Prime Minister of Liechtenstein, also focused on energy and research topics. The possibility of a closer collaboration between Liechtenstein and Empa was discussed, both in research in general and specifically in the energy sector. Empa already enjoys ties with the country through its cooperation with Liechtenstein-based companies and

1 Empa portal on iTunesU, the iTunes Store's platform for international research institutions.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Investigative Material Science
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Mobility
Welcome
Highlights
Empa in Brief
Empa's Annual Reports
EmpaNews – Magazine for Resear...
EmpaNews – Das Forschungsmagazin...

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as a research partner of the research and innovation center "RhySearch" in Buchs.

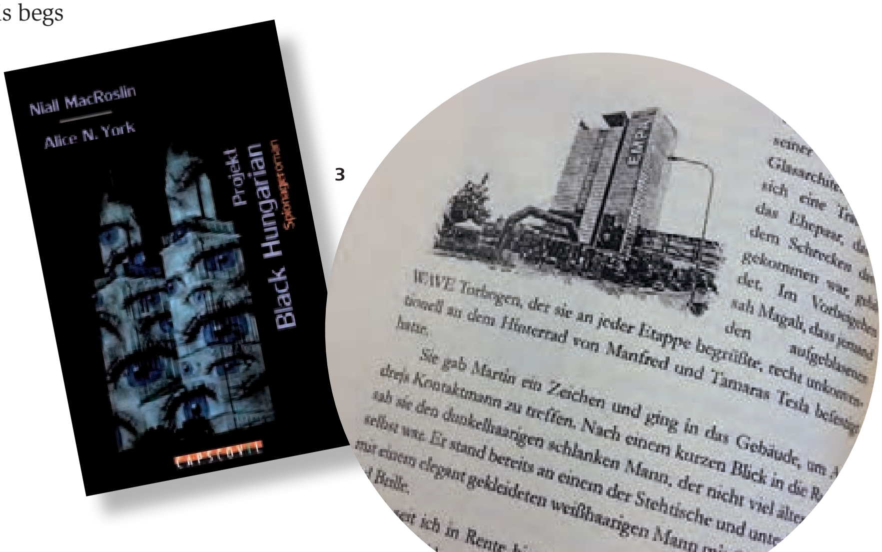
Various federal offices also paid Empa a visit, including the Swiss Federal Office of Energy (SFOE) and the Federal Office for the Environment (FOEN), with which Empa has already been collaborating closely for many years. However, Empa also welcomed around a dozen delegations from abroad to its sites in Dübendorf and St. Gallen in 2014, especially from Russia, China and South Korea.

The stuff novels are made of

Empa (and Empa researcher Marcel Gauch as well as former member of Empa's Board of Directors, Xaver Edelmann) also made their debut in a novel: the spy thriller "Projekt Black Hungarian" was "inspired by actual events during the electric car rally WAVE 2013" and combines current developments in the field of e-mobility and IT security with a fictitious spy story set at the WAVE rally locations, including Empa in St. Gallen. This begs a fundamental question: Who imitates whom – life art or vice versa? //

1
Federal Councilor Johann Schneider-Ammann during his visit to Empa in Dübendorf at the beginning of October.

2
In August, Empa CEO Gian-Luca Bona discussed research and energy matters with Liechtenstein's Deputy Prime Minister Thomas Zwiefelhofer. Member of Empa's Board of Directors Peter Richner and Simon Biedermann, a personal assistant of Thomas Zwiefelhofer, are also depicted (from left).



3
The spy thriller "Projekt Black Hungarian" combines current developments in the field of e-mobility and the IT security with a fictitious spy story set at (among other places) Empa in St. Gallen.

On the right track

Equal opportunities and diversity play a major role at Empa. Numerous activities, such as the Summer Camp and the "Zukunftstag", have practically become "traditional" fixtures on Empa's annual program. Last year, these were joined by some one-off events.

Prix Balance^{ZH} for Empa

The Office for the Equality of Men and Women and the Canton of Zurich's Business and Economic Development Division award the Prix Balance^{ZH} to organizations that make it easier for their staff to reconcile their careers and private lives through special working conditions. Won over by the research institute's broad and flexible services, the judging panel presented this year's Prix Balance^{ZH} to Empa.

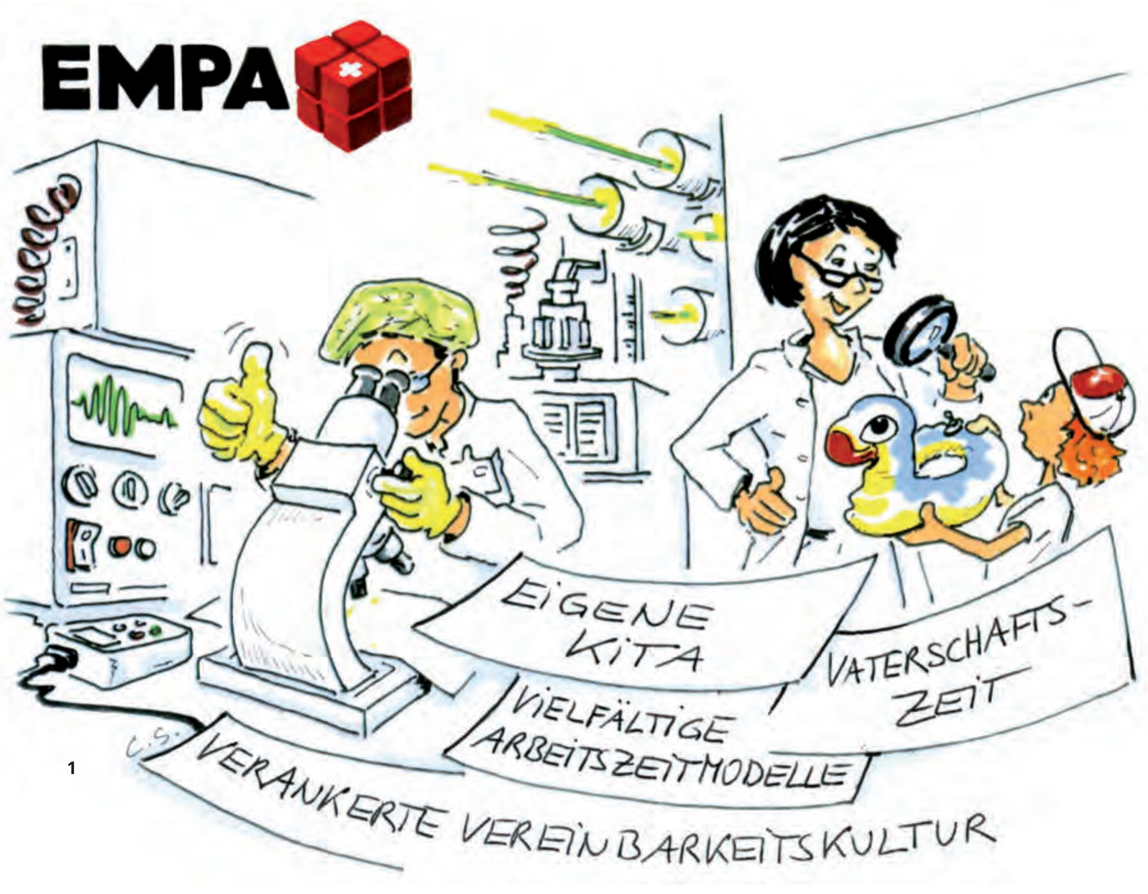
Balancing a career and private life was also the focus of the second network meeting organized by the organization "family AND career," which kicked off with a visit to the joint day nursery of Empa and Eawag in March. The participants were given examples from other organizations and swapped practical tips and ideas on how to juggle a job and a family more effectively and increase equality between men and women.

1

1
André Schmid, head of Empa's "Human Resources", was pleased with the Prix Balance^{ZH} – together with the director of the Zurich Chamber of Commerce, Regine Sauter (right), and Christiane Löwe, Empa.

1
The cartoon on the Prix Balance^ZH award certificate features some of Empa's merits with regard to balancing family and career.

2
Keen interest in the travelling exhibition "Check your Stereotypes," which came to Empa and Eawag at the end of 2014.



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2

In the spring, the first round of “Fix the leaky pipeline,” a careers promotion program for young scientists in the ETH Domain, drew to a successful conclusion. The second round is already underway. 235 participants seized the opportunity to expand their professional network at various information events. As a successful scientist and head of a research lab at Empa, Tanja Zimmermann was also involved in a discussion on the topic of “Female Careers in Academia.”

Travelling exhibition comes to town

In December the travelling exhibition “Check Your Stereotypes” visited Empa and Eawag. It used various examples to illustrate which stereotypes are particularly relevant for the choice of a university degree and a professional career, and how gender-related stereotypes and careers are linked. At the official opening, Monika Keller, one of the exhibition‘s organizers, explained the background and goals of “Check Your Stereotypes,” which was launched in 2013 to coincide with the 20th anniversary of ETH Zurich’s Office of Equal Opportunities. //

Facts and figures

Researchers like to measure things – including their own performance: in 2014 Empa researchers and engineers published around 500 scientific papers and patented around 20 developments. By the end of the year, roughly 120 projects funded by the Swiss National Science Foundation (SNSF), more than 100 projects backed by the Commission for Technology and Innovation (CTI), and over 60 EU projects were underway at Empa – a new record. Empa also attracted over 70 million Swiss francs in third-party funding for the first time last year. And the 21 spin-offs employ a total of around 300 employees together with other start-ups in Empa's two business incubators – and counting.

Key figures

STAFF (AS OF 31 DECEMBER 2014)

	2013	2014
Scientific staff	**516**	**537**
of which professors	25	23
of which Ph. D. students	131	143
of which sci. staff excl. profs. and Ph.D. students	360	371
Technical and administrative staff	**442**	**456**
of which apprentices	38	43
Total	**958**	**993**

PROFIT AND LOSS ACCOUNT (IN MILLIONS OF SWISS FRANCS)

	2013	2014
Revenue		
Federal founding contribution	97,3	106,9
Measures “strong Swiss franc”	0,0	0,0
Third-party funding	61,4	72,6
Of which income from services	14,6	15,3
Miscellaneous income	2,0	2,1
Financial income	0,4	0,2
Total revenues	**161,1**	**181,8**
Expenditure		
Personnel costs	106,5	107,2
Material costs	5,1	5,7
Operational expenses	36,3	35,1
Changes in performance bond	0,0	2,7
Reserve increase for projects	4,6	19,1
Total expenditure for corrent activities	**152,5**	**169,8**
Balance	**8,6**	**12,0**
Investment		
Fixed assets	4,3	5,3
Movable assets	8,3	9,1
Information technology	0,5	0,5
Total investment	**13,1**	**14,9**

SCIENTIFIC OUTPUT

	2013	2014
ISI publications	527	486*
Conference contributions	1134	1222
Doctoral studies completed	26	32
Docoral studies in progress	188	171
Teaching activities (in hours)	3885	3732
Prizes and awards	45	62

* new counting method

MEDIA EXPOSURE

	2013	2014
Radio and TV	100	73
Print	845	1000
Online	1795	2750
Total	**2740**	**3830**
Languages	31	30

EMPA ACADEMY

	2013	2014
Empa events	**88**	**81**
Participants	4500	4100
Scientific conferences	13	15
Events for industry	35	33

KNOWLEDGE DISSEMINATION AND TECHNOLOGY TRANSFER

	2013	2014
New R&D Agreements	111	127
Active exploitation contracts	83	75
New exploitation contracts	19	16
New patent applications	14	18

SPIN-OFFS AND START-UPS (tebo and glaTec)

	2013	2014
Companies total	**32**	**37**
thereof Spin-offs	18	21
Employees total	**250**	**281**
thereof Employees of Spin-offs	94	102

CURRENT PROJECTS

	2013	2014
Swiss National Science Foundation (SNSF)	110	119
Commission for Technology and Innovation (CTI)	108	103
EU-Projects	62	63

Bodies of Empa

ETH Board

The ETH Board has overall responsibility for the management of the ETH Domain, which incorporates the two Federal Institutes of Technology (ETHZ, EPFL) and the four federal research institutes (PSI, WSL, Eawag and Empa).

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Markus Stauffacher Dr, ETH Zurich
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Andreas Schreiner Dr, Novartis, Basel
Eugen Voit Dr, Leica Geosystems, Heerbrugg

Research Commission

The Commission advises Empa's Board of Directors on questions of research, the choice of R&D spectrum and the evaluation of internal R&D projects.

MEMBERS
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Karl Knop Dr, Zurich
Dimos Poulikakos Prof. Dr, ETH Zurich
Heike Riel Prof. Dr, IBM, Rüschlikon
Marcus Textor Prof. Dr, ETH Zurich
Alexander Wokaun Prof. Dr, PSI, Villigen

Organizational chart

Status April 2015

RESEARCH FOCUS AREAS
(Research priorities)

Nanostructured Materials
Dr Pierangelo Gröning

Sustainable Built Environment
Dr Peter Richner
Dr Giovanni Terrasi

Health and Performance
Dr Alex Dommann

Natural Resources and Pollutants
Dr Brigitte Buchmann

Energy
Dr Peter Richner
Urs Elber

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Dr Pierangelo Gröning

Electron Microscopy Center
Dr Rolf Erni

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High Performance Ceramics
Prof. Dr Thomas Graule

Joining Technologies and Corrosion
Dr Lars Jeurgens

Nanoscale Materials Science
Prof. Dr Hans Josef Hug

Advanced Materials Processing
Prof. Dr Patrik Hoffmann

nanotech@surfaces
Prof. Dr Roman Fasel

Mechanics of Materials and Nanostructures
Dr Johann Michler

Thin Films and Photovoltaics
Prof. Dr Ayodhya N. Tiwari

Functional Polymers
Prof. Dr Frank Nüesch

Civil and Mechanical Engineering
Dr Peter Richner

Road Engineering / Sealing Components
Prof. Dr Manfred Partl

Applied Wood Materials
Dr Tanja Zimmermann

Structural Engineering
Prof. Dr Masoud Motavalli

Mechanical Systems Engineering
Dr Giovanni Terrasi

Multiscale Studies in Building Physics
Prof. Dr Jan Carmeliet

Mechanical Integrity of Energy Systems
Prof. Dr Edoardo Mazza

Center for Synergetic Structures
Dr Rolf Luchsinger (PPP Empa – Festo)

Concrete / Contruction Chemistry
Prof. Dr Pietro Lura

Building Energy Materials and Components
Dr Matthias Koebel a. i.

Urban Energy Systems
Viktor Dorer

Materials Meet Life
Dr Alex Dommann

Center for X-ray Analytics
Dr Antonia Neels

Protection and Physiology
Dr René Rossi

Advanced Fibers
Prof. Dr Manfred Heuberger

Particles-Biology Interactions
Dr Peter Wick

Biointerfaces
Dr Katharina Maniura

Reliability Science and Technology
Dr Urs Sennhauser

KNOWLEDGE AND TECHNOLOGY TRANSFER

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Reto Largo

Empa Academy
Anja Pauling

glaTec – Technology Center in Dübendorf
Mario Jenni

tebo – Technology Center in St. Gallen
Peter Frischknecht

Reliability Network
Dr Urs Sennhauser

International Research Cooperations
Prof. Dr Harald Krug

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Materials for Energy Conversion
Dr Corsin Battaglia

Advanced Analytical Technologies
Prof. Dr Davide Bleiner

Air Pollution / Environmental Technology
Dr Lukas Emmenegger

Automotive Powertrain Technologies
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Materials for Renewable Energy
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Kurt Eggenschwiler

Support
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Library (Lib4RI)
Dr Lothar Nunnenmacher

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Stephan Koch

Mechanical Engineering / Workshop
Stefan Hösli

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Heidi Leutwyler

Communication
Dr Michael Hagmann

Facility Management
Peter Wegmann

Human Resources
André Schmid

Marketing, Knowledge and Technology Transfer
Gabriele Dobenecker

Construction 3 RI / Technical Services
Hannes Pichler

Empa – The Place where Innovation Starts

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