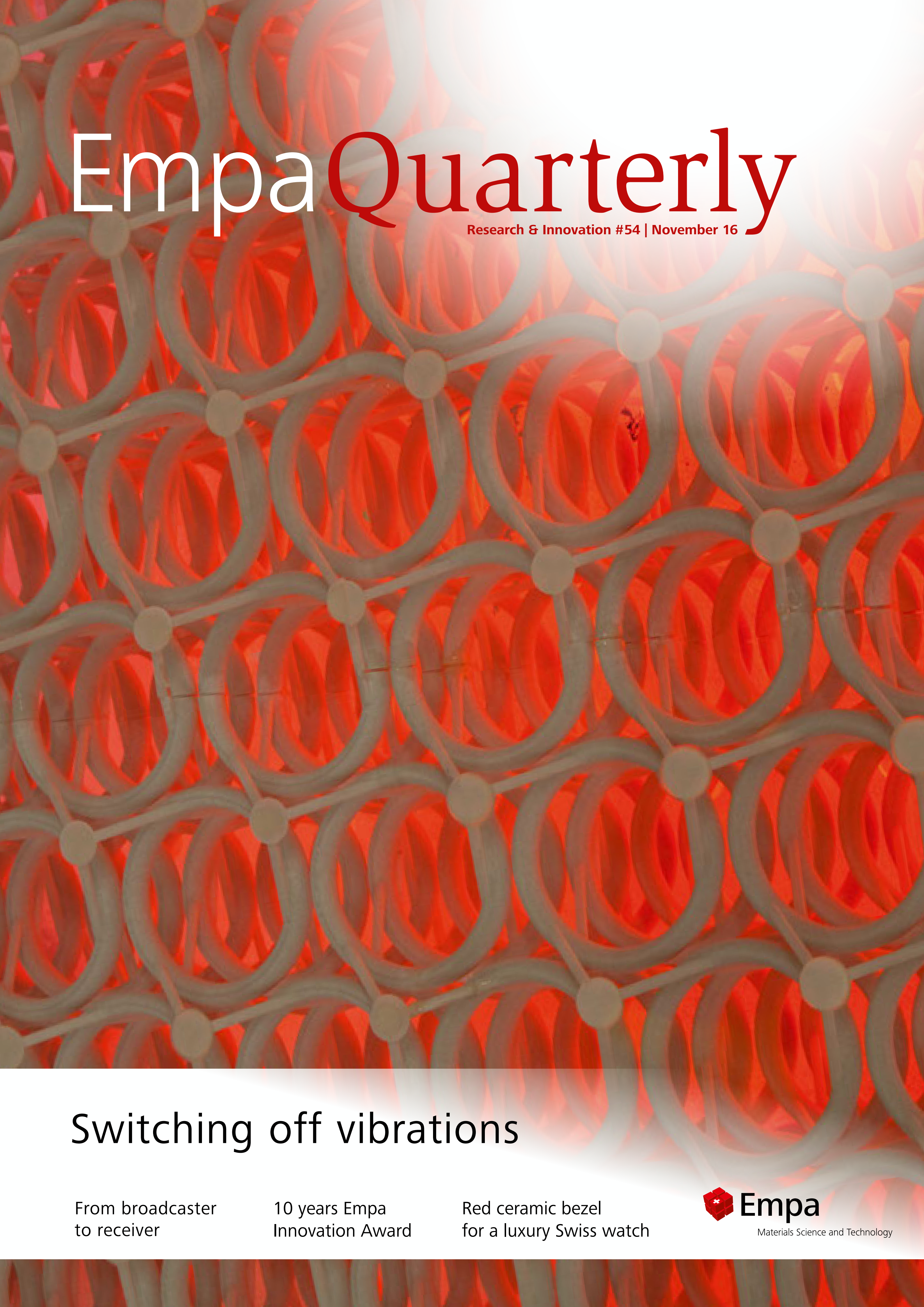


Empa Quarterly

Research & Innovation #54 | November 16

Switching off vibrations

From broadcaster to receiver

10 years Empa Innovation Award

Red ceramic bezel for a luxury Swiss watch

Empa
Materials Science and Technology

MICHAEL HAGMANN Head of Communications

Much more than a catchy phrase

Dear readers

"The Place where Innovation Starts". That's what Empa strives to be. In a way, as a cradle of innovative technologies that help our industrial partners to successfully hold their ground in the face of the ever-stiffening global competition. Together, we ensure that Switzerland fares exceptionally well in various rankings year after year – such as the Global Competitiveness Report 2016/17 published by the World Economic Forum at the end of September, which we are already leading for the eighth time in a row.

Laying it on a bit thick, you think? Indeed, it's wise not to blindly trust marketing slogans (especially your own). So we did a spot of digging – prompted by the upcoming presentation of the Empa Innovation Award, which was launched ten years ago to honor promising ideas "with great market potential". And we began to wonder: did these innovations really spark a successful business? Which ones managed to make a go of it on the market? You will find the answer – which we found quite reassuring (that much we can reveal) – from page 10 onwards.

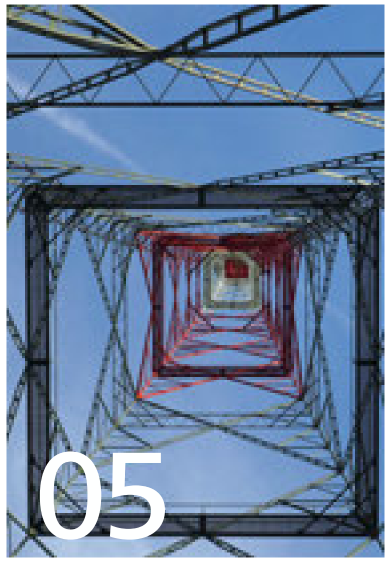
Another slogan I admittedly really like reads: "The smartest places on Earth." This time, it was coined by someone else: two American authors who pinpoint the most productive hubs for global innovation in a new book. And yes, you guessed it: Empa is among them. You will find a book review on page 24.

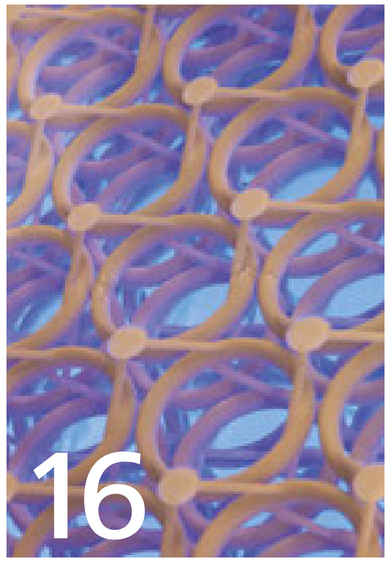
Regular readers of EmpaQuarterly will also notice that, like in the April issue, a luxurious timepiece graces the pages of our magazine once again. Last time, it was gold-coated fibers on the Big Bang Broderie Gold from Hublot; this time, it's a Speedmaster Moonphase, the latest model from Omega. The bezel on this luxury watch is made of red ceramics developed in Empa's labs – a world first (p. 8).

Enjoy reading!

Focus: Empa Innovation Award

A ten-year success story





Cover
Close-up of a phononic crystal. These synthetic crystal structures designed on the computer are able to absorb vibrations of particular frequencies and convert them into frictional heat. The revolutionary damping material can be produced on a 3D printer and may herald the start of a new era in mechanical damping.
Photo: Empa. **From page 16**

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From broadcaster to receiver

In 2008 the medium-wave national radio station Beromünster, famed way beyond Switzerland's borders, finally called time on its service and the 217-meter-high Blosenbergturm was granted landmark status. The broadcasting tower now has a new role: it will aid research by serving as an air monitoring station in the National Air Pollution Monitoring Network (NABEL). Thanks to its prime location, Empa experts can keep an eye on pollutant emissions across the entire Swiss Central Plateau, from Lake Constance to Lake Geneva.

TEXT: Martina Peter / PICTURES: Empa

The broadcasting tower is in a spectacular spot: at 800 meters above sea level, it offers an unobstructed, 360-degree view, which carries many advantages. From the 1930s, not only could radio programs be broadcast throughout the Swiss Central Plateau, but also directly across Switzerland's borders. During the Second World War, this made national radio station Beromünster a key independent source of information in neighboring countries, which were swamped with propaganda.

Although the transmitter's giant copper coil still sits in a Faraday cage in a small cabin at the foot of the tower, it no longer transmits these days. Instead, pumps hum, sucking in the outside air and conducting it into the measuring station, where two air experts from Empa, Christoph Hüglin and Stefan Bugmann, are busy beavering away. While Bugmann checks the devices and changes filters, Hüglin explains how research came to be conducted here: "After the radio service ceased broadcasting, a new use was sought for the tower – just the opportunity we'd been waiting for. The location is just the ticket as the site is not just ideal for transmitting radio waves, but also gathering information on the composition of the air." The broadcasting tower allows "air to flow freely", he continues. In other words: there are no obstacles or forests to prevent the air currents from spreading pollutants throughout entire atmosphere here.

Beromünster and Jungfraujoch

The Beromünster location boasts similar conditions to the site on the Jungfraujoch, which can also rely on a "free flow of air". The Alpine research station is able to record air pollutants from half of Europe while the Beromünster station takes readings on the entire Swiss Central Plateau – from Lake Constance to Geneva and even across the border into neighboring regions of Germany and France; both are key elements in national and international programs, which keep an eye on air pollution.

Empa runs the National Air Pollution Monitoring Network (NABEL), which has included the Beromünster station since the summer of 2016, on behalf of the Federal Office for the Environment (FOEN). In conjunction with the University of Bern and ETH Zurich, the Empa team has already measured carbon dioxide (CO_2), carbon monoxide (CO) and methane (CH_4) on five different levels of the tower in the last few years. The station has now been expanded to other pollutants.

The 217-meter Blosenbergturm of the former National Radio Station Beromünster has been listed since 2008. It is painted grey-green up to a height of 40 meters. The round engineering cabin is located at a height of 150 meters.

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In terms of equipment, the Jungfraujoch station serves as a model for the new NABEL station. At both stations, Empa installed highly sensitive analytical instruments, which can continuously detect the tiniest of traces, such as nitrous oxides (NO_x) and ozone (O_3). These studies require powerful analytical measuring technology that is available online around the clock – such as the quantum cascade laser spectrometer developed by researchers from Empa's Laboratory of Air Pollution/Environmental Technology together with its partners. It is also expected to detect and quantify laughing gas isotopes (N_2O) as of the end of the year. The instruments even gage whether N_2O molecules stem from combustion processes in power stations or were produced "biologically", such as in sewage plants.

As Stefan Bugmann turns his attention to calibrating the measuring equipment inside the former transformer box, Christoph Hüglin demonstrates the so-called impactors on the roof, which suck the air upwards with pumps and the fine particulates in the air land in a filter at the bottom. But not all of them: thanks to special flow technology, only gaseous substances and fine particulates smaller than ten micrometers are conducted inside the station. The filters are brought to Empa every two weeks, where they are evaluated in the lab on top of the data transmitted online.

As the tower's new operator, Empa will increasingly focus on air pollutants that break down rapidly, e.g. nitrous oxides and greenhouse gases, Hüglin explains. Apart from long-term measurements, shorter research campaigns are also planned to measure certain sub stances more comprehensively over a certain period. //

The fine particulate matter is collected in so-called impactors on the roof of the former control center at the foot of the tower. Christoph Hüglin (left) and Stefan Bugmann not only analyze the reading transmitted online, but also the contents of the filters.

Air Pollution Monitoring

Switzerlands National Air Pollution Monitoring Network (NABEL) monitors the air pollution at 16 locations across Switzerland. Additional stations are scattered around the country and gage the pollution at typical locations, such as inner-city roads, highways and residential areas. Inaugurated on 26 October, the Beromünster station represents rural areas below 1,000 meters above sea level.

Video
Panoramic drone flight around the Beromünsterturm at an altitude of 150 meters.
https://youtu.be/Q8IowoSVdJA

Finally red!

Empa researchers have pulled off a masterstroke of ceramics research: as of now, a dark-red ceramic bezel adorns a Swiss luxury watch – a world premiere and stunning example of top-flight materials science.

TEXT: Rainer Klose / PICTURES: Empa, Omega

The "Speedmaster" by Omega is legendary. To this day, it is the only watch to be certified for spacewalks by the American space agency NASA. Back in 1962, an Omega "Speedmaster" blasted off into space in a Mercury capsule on Walter Schirra's wrist. It was also worn by an American astronaut during the first spacewalk in 1965, the moon landing in 1969 and every Space Shuttle mission since. Besides the "Speedmaster Professional", which travelled into space, however, there are other models of the luxury watch on the market – including diamond-encrusted versions for women or ones with a moon dial (interesting for us earth-dwellers but useless for astronauts).

Empa has now also contributed an eye-catching part to these technical icons "made in Switzerland": the red ceramic bezel on the Omega "Speedmaster Moonphase Co-Axial Master Chronometer", which goes on sale in the fall, was developed at Empa's High-Performance Ceramics lab. "Until now, no-one had succeeded in producing deep-red ceramics," says project leader Jakob Kübler, who accomplished the feat with two of his colleagues. Black, blue and green ceramics are commonplace, pink ceramics are popular in medical engineering. "But red is tricky," says Kübler; "we knew that going in."

Anyone who works with the clock and jewelry industry has to meet no end of requirements: the new material mustn't be toxic, of course, so any compounds containing lead or cadmium are out of the question for color schemes. A glaze on the ceramics is unfit for a watchcase, too, as it could chip off if used a lot. The bezel, therefore, needs to be produced from colored full ceramics. The white numerals are engraved later on and the letters and numbers filled with amorphous platinum. The ceramic material also has to survive this step; it mustn't be too brittle or break during the process.

But can't one just add a red dye to white ceramics? "No," says Kübler. "Even the best organic pigments are unable to withstand the temperatures of 1,300 to 1,900 degrees Celsius necessary to sinter the ceramics." There was only one thing for it: to do what nobody had done before and find a way to make bright red full ceramics (the closest had only ever been dark pink).

A secret recipe in the making

So Kübler and his colleagues Roman Kubrin and Gurdial Blugan rolled up their sleeves and knuckled down to some research. The bezels on the "Speedmaster's" sister model are made of zirconium oxide in blue, brown and green. The use of the material is so popular in the watch industry that processing, engraving and polishing it has become routine. Nonetheless, there isn't a suitable red dye for this kind of production.

The Empa team first turned to aluminum oxide, a common, white ceramic material used in artificial hips and as a seal in taps, for instance. The addition of a tiny amount of chromium – a proportion of up to around one percent – was already known to give aluminum oxide a pink sheen – not exactly the ideal color for an expensive man's watch, though. And unfortunately, adding more chromium turns the color dark purple, not red. All the same, the formula was promising. Months of experimenting followed, where the researchers specifically mixed tiny amounts of other inorganic additives into the ceramics. And finally the color changed from rust-brown and pale yellow to a deep red.

3

By mid-2015, the time had finally come: Omega's designers inspected Empa's color samples and decided on a shade of red to adorn the new collection. Empa then delivered material samples to the Swatch Group, where production specialists studied how Empa's ceramic material could be engraved and processed. After all, the red bezel wasn't made of the same material as the blue, brown or green models. The extremely complex, multi-stage manufacturing process for red ceramics was developed within the scope of a joint CTI project between the Swatch Group and Empa, and has been patent-pending since March 2016.

The first watch in the collection to hit the market was the Omega "Speedmaster Moonphase" with a steel case, a blue face and a blue bezel. This was soon followed by models in rose gold (with a brown face and bezel) and yellow gold (with a silver-colored face and dark-green bezel). The top of the range will be a limited platinum edition of the watch with the red Empa bezel, with only 57 pieces to be sold worldwide. The 45,000-franc watch is adorned with a platinum face, which contrasts marvelously with the red moon dial – also made of Empa ceramics. //

1
Sintered ceramic particles. Besides chromium, tiny traces of other inorganic additives are needed to create the deep red color.

2
Ceramic test pieces made using different formulae: from pale yellow and rust-brown to a lovely, deep red.

3
The top-of-the-range model of the Omega Speedmaster Moonphase is made of platinum and limited to a run of 57 watches. The bezel, moon dial and date magnifier frame are all made of red Empa ceramics.

1

2

Masoud Motavalli, winner of the 2014 Innovation Award 2014, displaying reinforcement steel from a shape memory alloy. Electrical current is sufficient to pre-stress pieces of concrete with it.

The Empa Innovation Award

A ten-year success story

When Empa presented its first Innovation Award back in 2006, no-one could have imagined everything that followed. Today, the prize is regarded as an honor en route to scientific success. This year, ten groups of researchers have applied for the coveted accolade. But how successful have the previous winning projects been? Time to look back.

TEXT: Rainer Klose / PICTURES: Empa, Decentlab, Compliant Concept, re-fer, iStockphoto.

Receiving a prize for a good business idea is one thing. However, only time will tell just how well the idea actually works, how quickly it makes its mark on the market and what potential it harbors in the long run – not to mention whether Empa's judging panel for the award actually demonstrated foresight. So, as the Innovation Award is celebrating its tenth anniversary, let's venture a look back at the past prize winners.

In hindsight, it is evident that while the projects were technically on point when they won the award, they were yet to realize their full economic potential. Every so often, a change in direction was necessary and sometimes only a combination with other technologies or a follow-up project ultimately resulted in a breakthrough. Nonetheless, all the prize winners have one thing in common: each and every one of them paved the way for an economically relevant innovation, which served as the basis for economic success.

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2006

Felix Weber from the Structural Engineering Laboratory received the first Empa Innovation Award for the controlled damping of cable-stayed bridges.

Wind and rain can cause the long stay cables on these bridge constructions to start vibrating like harp strings. As every bridge is unique and exposed to local weather conditions, not all of these vibrations can be predicted. Weber teamed up with the Munich-based company Maurer Söhne AG to develop a system that solves these problems: it involves measuring the vibrations and relaying them to an active damping element, which specifically absorbs the actual vibration. The system was installed on the Franjo Tudman Bridge in Dubrovnik in 2006. The following year, Maurer Söhne AG equipped the Sutong Bridge in China with it, at 1,088 meters the second longest cable-stayed building in the world.

The controlled vibration damper for girder bridges is a progression of the cable damper. In conjunction with his industrial partner, the Empa researcher kitted out the 2,500-long Volgograd Bridge in Russia with the new system in the fall of 2011. Although it had only opened in 2009, it had to be closed again temporarily in 2010 due to severe vibrations.

2007

Martin Amberg, Dirk Hegemann and Manfred Heuberger from the Advanced Fibers Lab were awarded the prize for metallized fibers with an unaltered textile character.

The globally unrivalled technique devised at Empa enables metals such as gold, silver, aluminum, stainless steel, copper or titanium to be "vapor-deposited" on the fibers at room temperature. Meanwhile, this kind of coated thread is produced by the company Serge Ferrari Tersuisse SA in Emmenbrücke near Lucerne; Swicofil AG (also based in Emmenbrücke) is in charge of sales and product development.

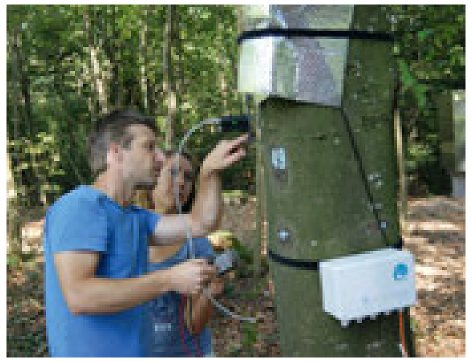
The gold-coated fibers caused a sensation in the fashion industry with special applications – especially as the thread is soft, kind to the skin and machine-washable without compromising the coating. The company Roccoco Dessous sells lingerie embroidered with 24-carat gold threads in exclusive stores, and a new watch by the luxury brand Hublot boasts Empa's gold thread on its face. However, electrically conductive metal threads are also used successfully in an industrial context. For instance, Swicofil developed a particularly durable brush made of gold fibers to conduct electrostatic charge away from machines while they are running.

2008

Glauco Feltrin and his colleagues from the Empa spin-off Decentlab won the Innovation Award for wireless sensor network monitring.

These networks consist of individual hubs and a base station. Every hub is a small, energy-saving computer equipped with various sensors, which register the surrounding conditions. The computer collects the data and radios it on to the nearest hub, which serves as a relay station. The base station is connected to the evaluating lab via the cellular network and supplies the data via an encrypted connection. The networks can easily be extended: every additional hub looks for a suitable relay station under its own steam and is, therefore, fit for immediate use. This also enables failed hubs to be bypassed.

Decentlab sells and refines the technology. So far, wireless sensor networks have been used, among other things, in construction monitoring (movements in bridges, heat flows in buildings), forest and soil research, and air quality monitoring.



2009

Josef Kaufmann, Jörn Lübben and Walter Trindler won the Innovation Award for novel bi-component fibers to increase the ductility of concrete, a popular building material, which can withstand extremely high pressures.

Unfortunately, it already gives out with low tensile loads. Only steel reinforcement helps here as it is able to absorb the tensile forces. Wherever it isn't possible to embed large steel grids – such as in thin cellar walls, industrial floors, cement slabs, tunnel facings or window sills – concrete can be reinforced by adding steel fibers. However, these are heavy, expensive, harbor a serious risk of injury on account of their stiffness and can rust. In order to overcome these drawbacks, the Empa team developed a bi-component fiber. The fiber core consists of inexpensive polypropylene, the fiber sheath a special customized polymer which, chemically and mechanically speaking, is just the ticket for use in cement-bound materials.

The product is currently sold by Brugg Contec AG in St. Gallen and used all over the world: tunnels in Austria, harbor installations in Poland and Singapore, industrial floors in Hungary, and hydroelectric power plants in Costa Rica are already capitalizing on Empa's expertise in concrete research.

2010

Michael Sauter and Gion Barandun, the founders of the Empa spin-off Compliant Concept, won the Innovation Award for their intelligent hospital bed.

Healthy people change position two to four times an hour while they are asleep. The elderly and sick move less frequently in their sleep, which may be down to paralysis, sleeping pills or painkillers they have been given or simply a lack of strength. As a result of this physical inactivity, the risk of bedsores (decubitus) – a painful condition that requires proper care – increases in a matter of hours. In nursing homes, immobile patients are, therefore, routinely turned several times a night.

This is where the Mobility Monitor devised by Sauter and Barandun comes in: it helps reduce the burden on the nursing staff and avoids having to wake the patients unnecessarily – if they have moved themselves and no longer need to be turned. And if a patient ought to be turned after a certain time, the Mobility Monitor alerts the staff. By the same token, the device also recognizes wake-up phases and typical movement patterns before a patient wants to get out of bed, which helps prevent falls during the night.

The new Sunnegarte dementia ward at Sunnewies nursing home in Tobel (Thurgau) became one of the first centers in the world to be equipped with Mobility Monitor beds. The comprehensive sleep monitoring system should improve the patient's quality of sleep and pain monitoring.

2012*

Thomas Stahl, Samuel Brunner, Mark Zimmermann and Matthias Koebel received the Innovation Award for their special super-insulating aerogel plaster, which they co-developed with the company Fixit AG.

There are 1.5 million old buildings in Switzerland and this building stock shapes city- and landscapes. However, 43 percent of the fossil fuels imported currently go on heating houses. A super-insulating plaster is, therefore, an ideal solution to renovate old buildings which can't be (or may not be on heritage grounds) clad in thick polystyrene sheets, either inside or out. The special plaster developed by Empa contains the best insulating material that can be produced industrially: aerogel. Used in space travel, the material is extremely light and sensitive. Nonetheless, the Empa team succeeded in producing the plaster in such a way that it can be sprayed on with commercially available plastering machines.

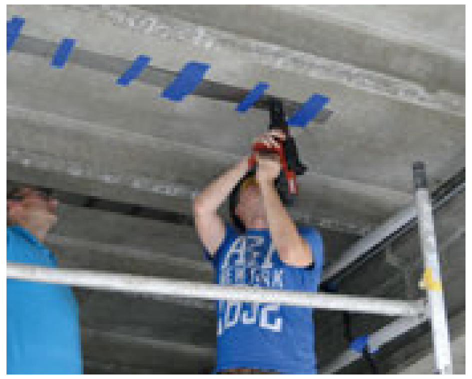
Fixit launched the product on the market in 2013 and meanwhile sells it all over Europe in conjunction with its affiliates Röfix (Austria) and Hasit (Germany). Recent increases in aerogel production efficiency have enabled the prices to be halved, which is bound to boost the demand for the insulating plaster further.

2014

Masoud Motavalli and a team from the "Structural Engineering" and "Joining Technologies and Corrosion" Labs won the award for the shape memory steel they developed as a new pre-stressing material for the building industry.

During the production of pre-stressed concrete, an initially unstressed steel cable or bar is subsequently stressed, which compresses the concrete and gives it a greater load-bearing capacity. The Empa researchers devised a shape memory alloy based on inexpensive steel, which can be used for pre-stressing purposes, but also to reinforce structures retrospectively. Pre-stretched plates measuring five meters in length and 1.5 millimeters thick are attached to the underside of the concrete beams with the aid of special nails and electrified. Once the plates are hot, the steel alters its crystalline structure and tautens, which can generate lasting tensioning forces of up to 330 megapascals (330 newtons per square millimeter).

The company re-fer, an Empa spin-off, sells and refines this technology. After successful tests, the first structures are scheduled to be pre-stressed with strips of shape memory steel in early 2017.



2016

The new prize winners will be announced on 8 November against the backdrop of this year's Empa Technology and Innovation Forum (ETIF).

Ten research projects were entered this year. For regular readers of *EmpaQuarterly*, the winners will be familiar faces: eight of the ten entrants have already been presented in detail on these pages over the last three years; we will be reporting on the two remaining projects in this issue.

Once again, 2016's prize-winning research project is bound to do its Innovation Award forebears proud and ensure that Swiss industry remains a frontrunner among the international competition.

*Since 2010 the Empa Innovation Award has been presented every two years, alternating with the Empa Research Award.

Empa Innovation Award 2016

Switching off vibrations

Macroscopic crystal structures can absorb unwanted vibrations or filter noise – without any electronics or electricity whatsoever. They can be lighter and more solid than previous conventional insulating material and can even be tailored to their intended purpose. Is acoustics on the brink of a revolution?

TEXT: Rainer Klose / PICTURES: Empa

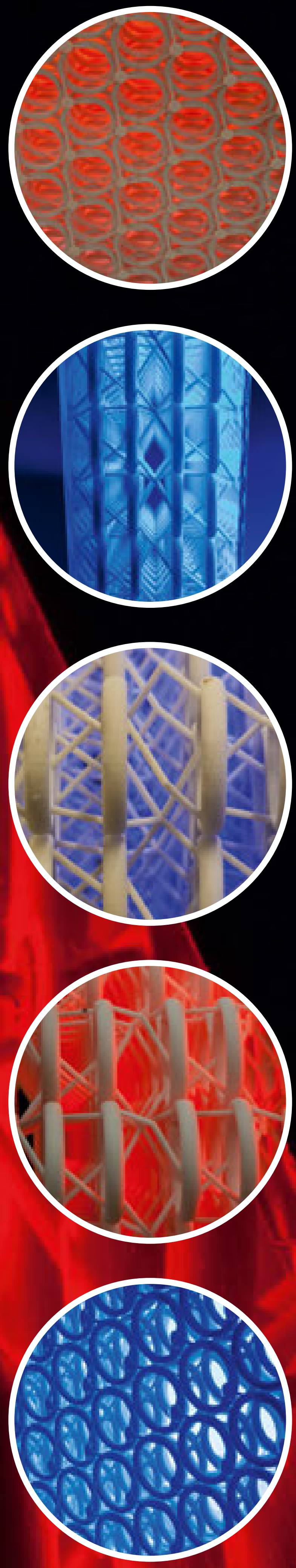
The research project was so risky that industrial companies would unlikely have tackled it – which made it the perfect assignment for Empa: Are there any materials that exhibit a high mechanical load-bearing capacity, but are able to absorb sound and vibrations on account of their inner structure? Without any foam rubber, springs or dampers whatsoever? Materials which solve the old engineering dilemma between stability and damping low-frequency vibrations? Which enable a ship's engine to be fixed in such a way that the entire hull no longer hums, for instance? Theoretical physicists predicted such materials – so-called phononic crystals. However, only a handful of scientists worldwide already had these peculiar synthetic materials in hand and managed to test their properties on the actual object.

Now, after three years of research, a team from Empa finally proved it: these materials do exist. What's more, they are already patent-pending. In September 2016, the researchers produced test structures made of an aluminum alloy on their own 3D printer for the first time to refine the noise and vibration damping method further. Without modern production methods, such as 3D printing with metals, it would be virtually impossible to make phononic crystals. So in a way, the incredible damping material had to wait for the invention of 3D printing to be discovered.

Inspired by an idea from California Institute of Technology (Caltech), Empa researchers Tommaso Delpero and Andrea Bergamini embarked on their ambitious project together with Empa acoustics experts Stefan Schoenwald and Armin Zemp in 2013. First of all, they calculated that the ultra-light, three-dimensional metal grid structures with cells on a millimeter scale as developed at Caltech ought to absorb ultrasound frequencies (100 kHz). The next question: Are there also structures that absorb sound within an audible range or low-frequency vibrations – which would open up a wealth of possible applications? And can these materials be "tuned" to a specific vibration frequency?

Testing a diamond structure

Delpero conducted initial tests with the structural model of a diamond. This kind of structure, made out of tetrahedron connectors and small tubes, hangs as a demonstration piece in most chemistry labs in schools and universities. Delpero mounted the model between two sheets of aluminum and excited the lower sheet with diverse frequencies. The result was flabbergasting: The crystal reflected some waves completely. With real diamonds, x-rays are bent and scattered in this way. The diamond model, which was thousands of times larger, had influenced mechanical vibrations with wavelengths that were several times larger in exactly the same way.



Ivo Leibacher (left) revised the computer model of the phononic crystal for 3D printing. Christian Leinenbach operates the metal 3D printer at Empa. It took 40 hours to print out the model.

Replicating natural crystal structures on different scales, however, is not an engineering solution to damp unwanted frequencies. For particularly low frequencies, this would require meter-sized, i.e. extremely heavy crystal structures – impractical for most purposes. The answer: Delpero and Bergamini had to come up with a synthetic crystal structure that doesn't exist in nature, but offers additional adjustment options.

Long road towards a synthetic crystal

After a year's worth of reading and thought experiments, they found the solution: A ring inside the crystal structure connected to other "atoms" in a special geometric way amplifies the inertia of the components. The diameter and mass of the ring enable the structure to be adjusted to the absorption of certain frequencies. The key advantage over natural crystal structures: While the moving mass essentially rotates in the direction of the sound wave in conventional crystals, the ring fitted by the Empa researchers rotates on the plane vertical to the longitudinal waves, where there is plenty of room wasted in conventional crystals.

The two researchers tested their theory on a 3D model made of synthetic material. And sure enough, the synthetic crystal did exactly what had been asked of it. The exact same sound frequencies the researchers had calculated in advance didn't get through.

Bergamini explains just how much potential the invention has: "Until now, as we know from cars, a spring component and a damping component were needed to absorb vibrations." While high frequencies and sounds can be damped by lightweight materials, deeper sounds and vibrations have required materials with a greater mass thus far. "Now we've succeeded in breaking this rule," says Bergamini. "In future, it will also be possible to damp low frequencies with lightweight materials – namely with a specially calculated phononic crystal. Another advantage: The crystal is rigid and can bear weight – which means it isn't a soft, springy base."

A dream for engineers

This opens up completely new prospects for applications in mechanical engineering. Until now, unwanted frequencies have often been treated with adaptive systems – i.e. sophisticated measuring and control technology. "Such active damping systems are considered the last resort for any problems that can't be solved otherwise," says the scientist. "However, engineers would really like to build something uncomplicated that lasts and doesn't need to be monitored constantly while in operation." Phononic crystals don't need any external control mechanisms. They work on their own without electricity or monitoring electronics – always as anticipated.

The Empa researchers have already been approached by a major German group, which expects the novel damping method to give them a competitive edge. And Tommaso Delpero switched to industry following his research years at Empa; a car manufacturer specializing in noise reduction technology in Winterthur now benefits from his talent.

The next step: 3D printing

Meanwhile, the project at Empa has moved onto the next phase: Ivo Leibacher, a new member of Bergamini's team, has prepared his predecessor's computer models for 3D printing in metal. The structure had to be adjusted in certain details – in some places, for instance, more material was needed to enable the test piece to be produced flawlessly using the so-called powder-bed method on Empa's own 3D printer. Leibacher pre-calculated his model's properties and included the key data on the aluminum alloy used into his calculations.

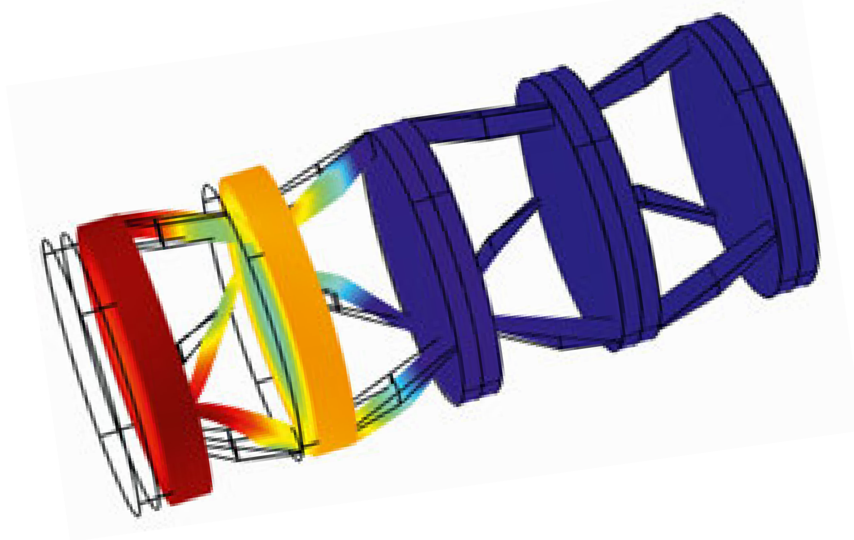
Although the transition from a theoretical model to a practical test is not without its difficulties, the Empa specialists operating the 3D printer are on hand with help and advice. Once it has been printed, the structure still needs to be annealed before it is able to prove the correctness of the calculations and theoretical models in the practical vibration test.

Project head Andrea Bergamini (left) rejoices with his team: Ivo Leibacher, Armin Zemp and Stefan Schoenwald. Together, they created three model generations of vibration-damping crystals.

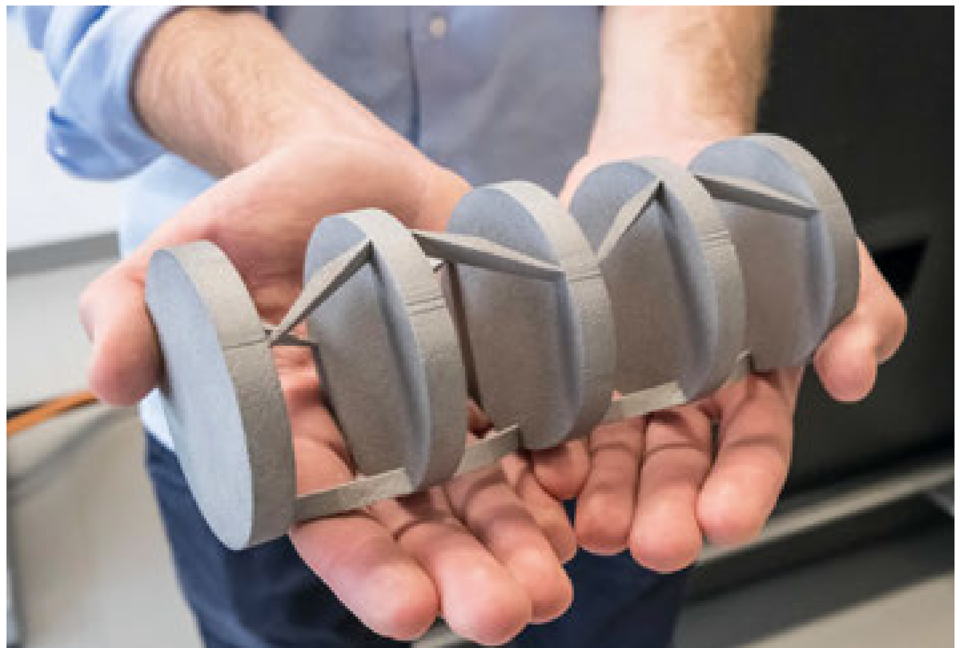
Meanwhile, Andrea Bergamini already has the next experiments in mind. For instance, the vibration-damping units of the phononic crystal might be arranged one after the other in different sizes. Thanks to this built-in gradient, it would be possible to eliminate different undesirable frequencies in one fell swoop.

Earthquake protection and privacy

We can already speculate about possible applications for the phononic crystals. Apart from noise reduction in the car industry and mechanical engineering, earthquake protection is also conceivable. Buildings would have to be constructed on special crystal structures, which are able to absorb the very low-frequency seismic vibrations. Shielding conference rooms against eavesdropping is also on the cards. Therefore, we can afford to be excited about the fields in which we will encounter the Empa invention in years to come. //



Theory and practice: The computer model reveals how a single grid cell of the crystal is able to absorb vibrations.



Bottom photo: The aluminum model created on the 3D printer. Its vibration properties tally well with the calculations.

Voyage to Lilliput

In his doctoral thesis at Empa's nanotech@surfaces laboratory, Leopold Talirz focused on com-putational modeling of novel materials, specifically ribbons of the "wonder material" graphene. His goal: testing the basic building blocks for the electronics of tomorrow down to the atomic level. In this guest article, he explains what drives his research and lets us take a peek into a typical day at work.

TEXT: Leopold Talirz / PICTURES: Empa

For a machine to work, all its cogs need to mesh together. While this might sound obvious, what does it really mean in practice? Does every cog need to be manufactured to perfection? No, of course there is room for deviations, provided they fall within the prescribed production tolerance.

The manufacturer's tolerance is governed by the intended application. For a screwcap on a plastic bottle, for instance, deviations of up to a millimeter might be acceptable; for a modern key to turn in the lock, on the other hand, the tolerance plummets to a micrometer scale, where it already comes down to the proverbial hair's breadth. And if a fine mechanical wristwatch is supposed to keep time accurately for a month, we enter the realms of splitting hairs. These days, however, the bounds of possibility are explored in electronic devices, not mechanical ones. The processor in a current smartphone is manufactured to a precision of a few nanometers, less than a thousandth of a hair's breadth. My research revolves around materials for the processors of tomorrow, which demand ultimate production tolerance: atomic precision.

Smaller and smaller, faster and faster

But first let's rewind a little: Why is this extreme precision needed in digital electronics, of all things? The reason lies in the insatiable global hunger for computational power. The smaller the electronic switch, the more switches fit on a chip and the more computational power the chip can generate. Smaller switches are also less sluggish and can be switched more rapidly. This triggered a historically unparalleled development of miniaturization, the result of which we carry around in our pockets: technological marvels with a billion electronic switches (transistors) on a chip the size of a thumbnail.

The heart of the transistor – the semiconductor, which can be switched on and off – still consists of the ele-ment silicon. However, a breadth of 20 nanometers already corresponds to fewer than 100 silicon atoms. No wonder miniaturization is grinding to a halt. Numerous researchers worldwide are working on ideas as to how it can advance regardless. One idea is to switch from silicon to so-called "two-dimensional" materials, of which single-atom-thick sheets can be produced. Graphite, the material in our pencils, belongs to this class. It consists of extremely stable layers of carbon atoms, which are stacked comparatively loosely and can thus easily be "stripped off". André Geim and Konstantin Novoselov were awarded the Nobel Prize in Physics in 2010 for demonstrating that single atomic layers of graphite (known as "graphene") can be stripped off intact and exhibit outstanding electronic properties.

The downside: graphene is no semiconductor

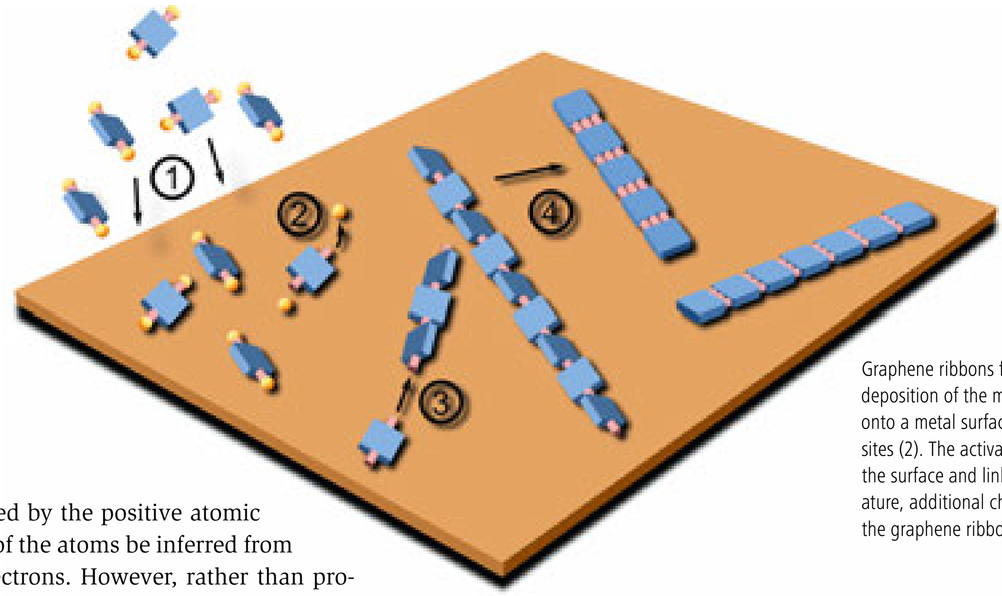
Besides its numerous advantages over silicon, however, graphene has one major drawback: It is not a semi-conductor and can't be switched off completely. A graphene transistor is therefore more like a dimmer than a switch, and if a billion interconnected transistors each dim the electricity on a chip instead of switching it off, the digital logic collapses.

There is a way out, though: Narrow ribbons of graphene exhibit semiconducting properties. For them to switch off properly, however, the ribbons must only be a few nanometers wide. And there's more: As the ribbons become so narrow, they need to be cut with painstaking precision, right down to the atomic level. Even the tiniest error can compromise the mobility of the electrons and slow down the transistor's switching speed. But cutting graphene into ribbons with atomic precision? For a long time, that sounded like plain wishful thinking.

Shortly before I began my doctoral thesis at Empa's nanotech@ surfaces laboratory, researchers there had succeeded in producing such graphene nanoribbons for the first time: all exactly seven carbon atoms wide, with immaculate edges. How was that possible? By changing perspective: Instead of cutting the ribbons out of graphene, they were assembled from small molecular building blocks that had been synthesized by colleagues from the Max Planck Institute for Polymer Research in Mainz (Germany). When these molecules are vapor-deposited onto a surface that activates their two docking sites and enables the molecules to glide freely, you basically only need to set the right temperature and wait a few minutes for the graphene ribbons to assemble themselves.

Quality control with the scanning tunneling microscope

This was the breakthrough we had all been waiting for. But how do you tell whether a graphene nanoribbon is actually atomically precise? Even with the best optical microscope, it is impossible to see the tiny ribbons, let alone check their atomic structure. Scanning tunneling microscope to the rescue! It essentially consists of a sharp tip, which scans back and forth, hovering extremely closely above the ribbons. This tip can "see" the electrons, i.e. it registers where they prefer to stay and where they don't. As the negatively charged electrons are attracted by the positive atomic cores, the positions of the atoms be inferred from the image of the electrons. However, rather than providing clear maps of the atoms, these microscope images (see picture on the right) tend to be blurry snapshots that have to be decoded to understand them.



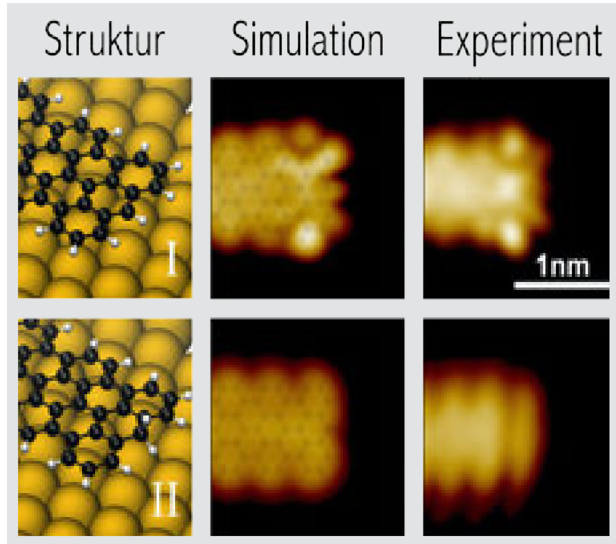
Graphene ribbons from the molecular kit: Vapor deposition of the molecular building blocks (1) onto a metal surface activates their docking sites (2). The activated molecules move across the surface and link up (3). At elevated temperature, additional chemical bonds form (4) and the graphene ribbons are complete.

This is where I come in. While my colleagues in the lab were working on the scanning tunneling microscope, I was sitting in front of the computer, using our current knowledge of the mathematical laws of quantum mechanics to predict what these images should look like. One particularly interesting case was the atomic structure at the end of the graphene ribbons. As it turned out, it was difficult to produce ribbons that were longer than 30 nanometers, and an obvious step was to inspect the end points of the ribbons, at which they had stopped growing. The images revealed a broadening of the electron distribution towards the end of the ribbons and a peculiar shape – like a caterpillar's head with two eyes and three antennae. The ends of other ribbons, on the other hand, looked nothing like this. Puzzling – had unwanted atoms snuck in here? And if so, where were they? Time to investigate!

The culprit: hydrogen

The microscope's high resolution and the extreme cleanliness of the experiments in ultra-high vacuum narrowed down the possible atomic structures to a handful of suspects, and each candidate was simulated on the computer. The calculations have to take into account both the graphene ribbon and the surface upon which it is assembled: in other words, hundreds of atoms and thousands of electrons. Luckily, in the internet age the next supercomputer is just a few keystrokes away – in this instance, it was Monte Rosa at the Swiss National Super-computer Centre (CSCS) in Lugano.

The comparison of experimental and calculated images yielded clear evidence that hydrogen atoms had at-tached to the end of the graphene ribbons. A single hydrogen atom leads to a weakly bound electron that creates the "caterpillar's head" in the microscope. If it is joined by a second hydrogen atom, the electron is bound strongly and the caterpillar disappears – case closed. How does this knowledge help us move forward? When the docking sites of a growing ribbon are blocked by hydrogen, it can no longer grow. So, in order to produce longer ribbons, we should find ways to prevent the docking sites from coming into contact with hydrogen.



Minor difference, major impact: The ribbon ends I (top) and II (below) merely differ in terms of a single hydrogen atom (white). Nonetheless, in agreement with the computer simulation (center), the scanning tunneling microscope (far right) detects a heavily altered electron distribution.

This case is one of many I examined during my doctoral thesis, along with countless others that are still waiting to be solved. In a nutshell, we are still a far cry from a graphene-nanoribbon processor that is ready for serial production. But one thing I can say from experience: Once you've got used to atomic precision, there's no going back. //

Space age material for the masses

Aerogel is the perfect material for many insulation purposes. It is heat-resistant up to 600 degrees, ultralight, non-toxic – and provides excellent thermal insulation. Only its complicated and expensive production causes quite a headache. An Empa start-up is about to revolutionize the manufacturing process. If successful, there will soon be affordable aerogel for everyone.

1

TEXT: Rainer Klose / PICTURES: Empa

Needless to say, NASA has already had it for a long time: aerogel, a kind of mineral foam that only weighs around 100 kilograms per cubic meter. Rocket makers soaked the light material in fuel to render rocket stages safer, and space researchers used the supermaterial to collect comet dust in space and brought it back to Earth. But owners of old buildings in Switzerland are also reaping the benefits from its tremendous insulation performance: in 2013 the construction company Fixit brought an innovative aerogel insulating render it had co-developed with Empa to the market, which does not compromise historical façades and even insulates them more effectively than polystyrene foam.

However, the material remains scarce and expensive. Two US-based manufacturing companies dominate today's global markets. Still, the production process is slow to boot up and accelerate. This is because aerogel manufacturing requires complex processing, a healthy dose of patience – and large quantities of chemical solvents. Until now, that is.

Empa researcher Matthias Koebel and his team are well on their way to changing all this. Koebel runs the laboratory for "Building Energy Materials and Components" at Empa, which is devoted to research on aerogels and other porous materials. Together with his colleagues, he has developed a new production method and already patented it. The technique saves a substantial proportion of the chemical solvents used thus far. To date, solvents have had to be painstakingly rinsed out of the moist gel and replaced with others before the time-consuming drying phase is even possible. "We call the alternative we've developed the one-pot method," explains Koebel. "Instead of performing a full solvent exchange, we only need to remove around ten percent of the solvent mixture and add ten percent of a catalyst mixture. After a brief period of warm storage, our gel is ready for drying." The key advantage: it only takes a total of five hours to produce, compared to twelve in the past.

Production line in preparation

Armed with this knowledge, the researchers are now tackling the production process. To mass produce the coveted material, it is not enough to make individual pots or tubs of aerogel one by one. Large quantities and scalable processes require a kind of production line, Henry Ford style. Koebel explains his view of a large scale process: lab tests with small containers, which his team used to produce the aerogel, were successful; the Empa team has the chemistry under control. For mass production, Koebel does not want to use large batch-type reactors but insists that continuous production is the future. More like in a large bakery, the raw materials should be fed in at the front, piled onto carts, and the wet gel comes out the back ready for drying.

"It's not quite that simple, of course," says Koebel and laughs. "Otherwise, everyone would be doing it." During the journey through a manufacturing tunnel, the fresh gel solidifies and "sweats" liquid, which is then removed and replaced with a catalyst mixture or other reagents. Once a hydrophobization catalyst has been added, the gel must remain inside the tunnel for the time it takes the reaction to occur. The gel then becomes hydrophobic and can be dried. By adding polymer-based hardeners or other additives, the firmness or other material properties of the aerogels could also be improved specifically or tailored to the customer's needs. Depending on the aerogel recipe, the trick is control residence time and reagent addition inside the tunnel as well as the right temperatures for each stage so all the chemical processes involved in making the perfect gel can be controlled. The addition of reagents in this way enables the chemistry and the material properties of the finished product to be customized for various applications and products.

Koebel is now in the process of founding a start-up company in collaboration with several partners from the construction, industrial insulation and automotive industries, who are all interested in reasonably priced aerogels. If all goes as planned, the production of affordable aerogel should be realizable on an industrial scale within three years. //

1
Aerogel from Matthias Koebel's test production.

2
Aerogel has to be hydrophobic in order to be used at construction sites: Matthias Koebel (right) and his assistant Lukas Huber pour catalyst into their pilot plant start this chemical reaction.

3
Final production step: The last solvent evaporates in the drying oven; the aerogel loses weight and solidifies.

2

3

Empa one of "the smartest places on Earth"

A new book investigates where innovations are born. Besides the classic rustbelt in the northern USA, the authors also place Europe and Switzerland under the microscope. And they are impressed by what Empa achieves here.

TEXT: Paul W. Gilgen* / PICTURES: PublicAffairs Books

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ISBN: 978-1-61039-435-2

Perhaps the title *The Smartest Places on Earth* can also be understood as "the most exciting places in the world". After all, as the subheading reads and the illustration suggests, the book is about the thrilling transformation of rundown industrial regions (primarily in the US) into bubbling hotbeds of innovation. This doesn't just mean an inevitable structural change in the economy and the adaptation of its value creation processes (which the famous Austrian economist Joseph Alois Schumpeter refers to as "creative destruction"), but also the regeneration of society and its institutions in the early 21st century.

The two authors analyze a large number of these "rustbelts" in the US, outline the astonishing transformation there and describe its success factors. They are always the same: assisted by "bridge builders" (whom the authors dub "connectors") at the respective interfaces, close cooperation in the form of public private partnerships (PPP) between science, industry and politics, that is:

- universities and research facilities that are organized in a multidisciplinary way and open to collaboration with industry
- companies, which focus on modern, knowledge-based sectors (e.g. micro-/nanotechnology, medical engineering, life sciences) and are open to collaboration with science
- governments, which create future-shaping framework conditions (e.g. in the incentives to found start-ups, in fiscal policy and venture capital (VC), in job market regulations, etc.). In the US, this form of cooperation has been exemplified highly successfully for quite some time by the Research Triangle Park (RTP) in North Carolina.

Moreover, from several cradles of innovation ("brainbelts") in Europe, the authors selected five, which they visited and analyzed, conducting lengthy interviews: Dresden (Germany), Eindhoven (Netherlands), Lund-Malmö (Sweden), Oulu (Finland) and Zurich (Switzerland). The authors laud dual vocational education and training wherever it exists in Europe (including Germany and Switzerland) as a success factor and a competitive advantage, and lament the lack of such educational structures in the US as a major shortfall. The chapter on Zurich is entitled "Zurich: A New Kind of Currency". While the old "currency" consisted of financial and insurance companies and the associated financial center, the new "currency" is primarily being minted by the life sciences. Charles Weissmann (ETH Zurich) and his start-up Biogen AG is right at the beginning of this new era. And the foundation of the Bio-Technopark™ in Schlieren is the obvious continuation. The involvement of Novartis and Roche in the fledgling companies settled there just goes to show how the life science cluster stretches from Zurich to Basel. And although the choice of Basel over Zurich for ETH Zurich's SystemsX (system biology) department initially came as a surprise, the decision was, therefore, logical and well-founded.

The authors go on to describe the first technology park – the one in Zurich – and the spread of this successful model for a technology park throughout Switzerland. The major achievements of the longstanding director Thomas von Waldkirch are granted the recognition they deserve – today, the Technopark Zurich Foundation is presided over by Empa CEO Gian-Luca Bona.

Applied research as a cornerstone for modern production

And finally, under the heading "Basic and Applied Research", three research institutions – the Fraunhofer Society (Germany), TNO (Netherlands) and Empa (Switzerland) – are examined thus: "… most important is the extensive network of public-private entities, they are key building blocks in the creation of the smart manufacturing world in which sharing brainpower is essential." The book's authors hail Empa, its focus and its achievements together with its affiliated start-up incubators, and particularly emphasize how efficiently the knowledge acquired here is shared and disseminated.

As far as innovation is concerned, being classed among the most exciting places in the world is tantamount to an accolade. Empa can thus feel vindicated in continuing along the path the institute has been pursuing. //

Nobel Prize in Chemistry: Empa involved in research work

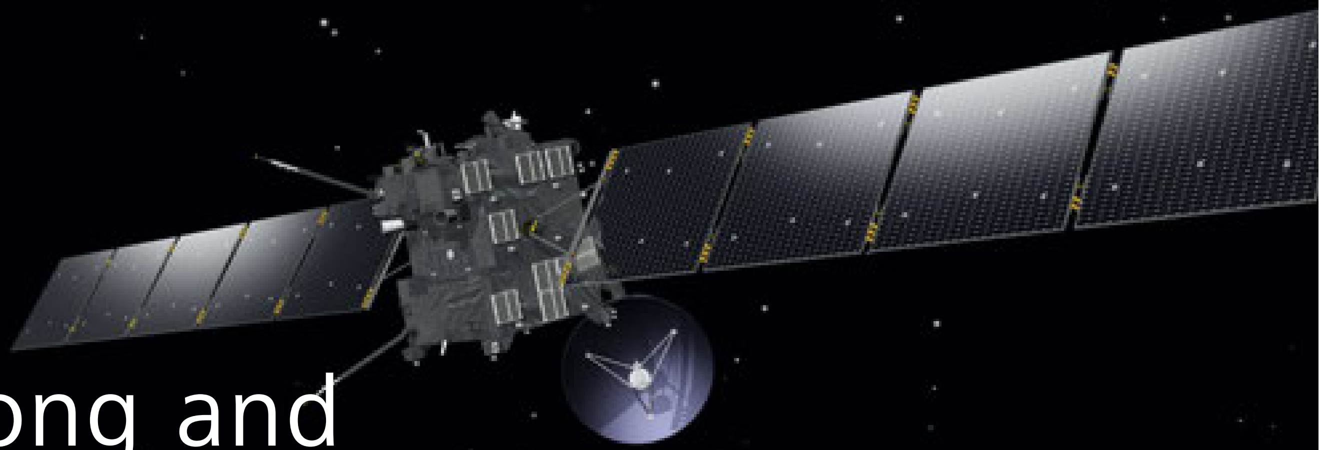
Empa is delighted to acknowledge the awarding of the Nobel Prize in Chemistry 2016 to Bernard L. Feringa, Fraser Stoddart and Jean-Pierre Sauvage – as it made a major contribution in 2011 to a research project carried out by Bernard L. Feringa. Karl-Heinz Ernst, head of the Empa research group "Molecular Surface Science", used a scanning tunneling microscope to get a model car to move that is comprised of a single molecule – making it probably the world's smallest electric car.

The nano car, developed by Empascientists Karl-Heinz Ernst and Manfred Parschau together with Feringa and his working group at the University of Groningen, is 4 x 2 nanometers in size – around one billion times smaller than a VW Golf – and travels on four electrically driven wheels in an almost straight line over a copper surface. The "prototype" made it to the cover of the renowned science magazine "Nature" in 2011.

Mario Jenni, center, with Gian-Luca Bona (CEO of Empa), left, and Peter Frischknecht (managing director of Feld3), right.

The fact that the 308-page book contains only a handful of illustrations renders this figure all the more meaningful.

* Paul W. Gilgen, was an assistant to Empa director Louis Schlapbach and previously ran the departments of "Ecology" and "Marketing, Knowledge and Technology Transfer". He retired in 2010 after 23 years at Empa.



So long and thanks for the probes, Rosetta!

For twelve years, the space probe Rosetta served mankind. The European Space Agency (ESA) mission is now drawing to a close as the probe reaches its final resting place on the target comet Tschuri on September 30, 2016. The verdict: The mission of Rosetta and its lander Philae, the first probe to touch down on a comet, was a roaring success.

TEXT: Cornelia Zogg / PICTURES: ESA

Researchers from the University of Bern and Empa, who were jointly responsible for developing the analysis instrument ROSINA ("Rosetta Orbiter Spectrometer for Ion and Neutral Analysis"), proudly monitored Rosetta's journey through space; an expedition which began in March 2004 when, primed for lift-off, Rosetta was loaded with eleven different instruments and left Earth onboard an Ariane 5 carrier rocket with an unprecedented mission: to follow a comet after a voyage of twelve years, collect data on it and actually set down a lander on its surface – a first in the history of space travel.

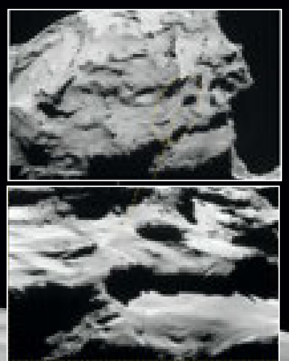
After an initial gravitational slingshot from earth in March 2005 and another from Mars two years later, she encountered the asteroid Steins on her way through space and, after a third swing-by in 2009, the asteroid Lutetia. Rosetta then went into hibernation for three years before reporting back "for duty" right on cue in January 2014. In May that year, she prepared for her rendezvous with the target comet 67P/Churyumov-Gerasimenko – or Tschuri for short.

Landing on a comet by remote control

Rosetta finally reached her destination in August and landed her passenger of twelve years, Philae, on the comet to obtain data from both the atmosphere and the surface of the comet. Philae spent two whole years on Tschuri. And while it got lost on the comet's surface, Rosetta conscientiously continued with her work as she orbited the solitary, icy boulder in space.

This Friday, on September 30, 2016, Rosetta's long voyage comes to an end, having covered a total distance of 6.4 billion kilometers. As it is impossible for the space probe to return to Earth, her "minders" at the ESA let her touch down on the comet shortly before one o'clock p.m.CET.

Rosetta's final resting place is in the comet's Ma'at region, named after the Egyptian goddess of truth and justice and ruler of the stars – a truly worthy spot for the industrious probe.

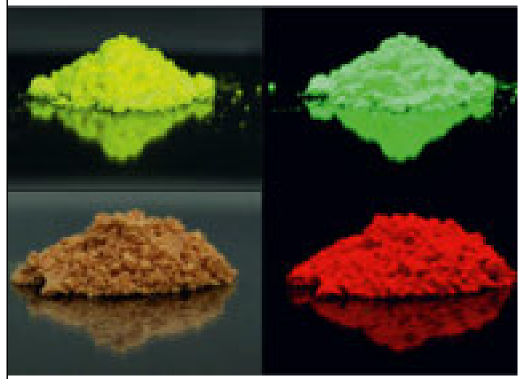


Rosetta's final resting place: The Ma'at region on the comet 67P/Churyumov-Gerasimenko, or Tschuri for short.

Video
Rosetta orbited the comit from August 2014 to May 2016. This is the final flight path of the last two days.

http://sci.esa.int/rosetta/58306-rosetta-s-final-path/

Fluorescent dyes of a new generation



Lead halide perovskite crystals not only can detect radiation but can also serve as a novel class of brightly fluorescent "inorganic pigments". In 2015 Maksym Kovalenko's Team discovered that colloidal lead halide perovskite nanocrystals emit bright light in the entire visible spectral range and are stable in ambient air. Most importantly and contrary to nearly all conventional quantum dots, these novel phosphors do not require laborious encapsulation into other matrices for bringing about their bright luminescence.

In their latest paper, recently published in "Nano Letters" they describe how to prepare such nanocrystals in an easy way. They drenched mesoporous silica with a perovskite precursor solution and simply dried out the solvent. The nanocrystals – formed and encapsulated in the silica matrix – exhibit a very bright photoluminescence, both with visible light and under UV radiation. The color of these "inorganic dyes" can be tuned by both quantum size effects as well as by the chemical composition of the crystals. Also exhibiting intrinsic haze due to scattering within the composite, such materials may find applications as replacements for conventional phosphors in liquid-crystal display technologies in future flat-screen TV's.

Empa becomes a film set

For two weekends in May, Empa's metal hall was transformed into a film set when a group of students from Zurich University of the Arts (zhdk) shot their final graduation film *Les Heures Encre* ("The Ink Hours") there. The 30-minute movie is set in a fictitious metal factory called Cedras in the French-speaking part of Switzerland, where the staff are supposed to resist the competition from China on increasingly tight deadlines. A foreman eventually commits suicide out of despair and a worker subsequently attempts to blackmail the boss.

The socio-critical drama was filmed by a 30-strong crew in Empa's metal workshop and some offices. The highlight was a fire stunt in a recreated office slap-bang in the middle of the metal hall.

The film is set to premiere in Zurich on 30 October. The editorial team will keep its fingers crossed for the upcoming short film festivals and wishes *Les Heures Encre* every success!

Pictures:
Diego Hauenstein
Peacock Film

Events (in German)

21. November 2016

Kurs: Hightech-Keramiken
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/ht-keramik
Empa, Dübendorf

28. November 2016

Kurs: Nicht-Silizium-Materialien der Mikrosystemtechnik
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/nonsilicon
Empa, Dübendorf

12. Januar 2017

Klebetechnik für PraktikerInnen
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/klebetechnik
Empa, Dübendorf

18. Januar 2017

Additive Manufacturing – quo vadis?
Industry and Science
www.empa-akademie.ch/tbaddmanu
Empa, Dübendorf

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

Your way to acces Empa's knowhow:

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