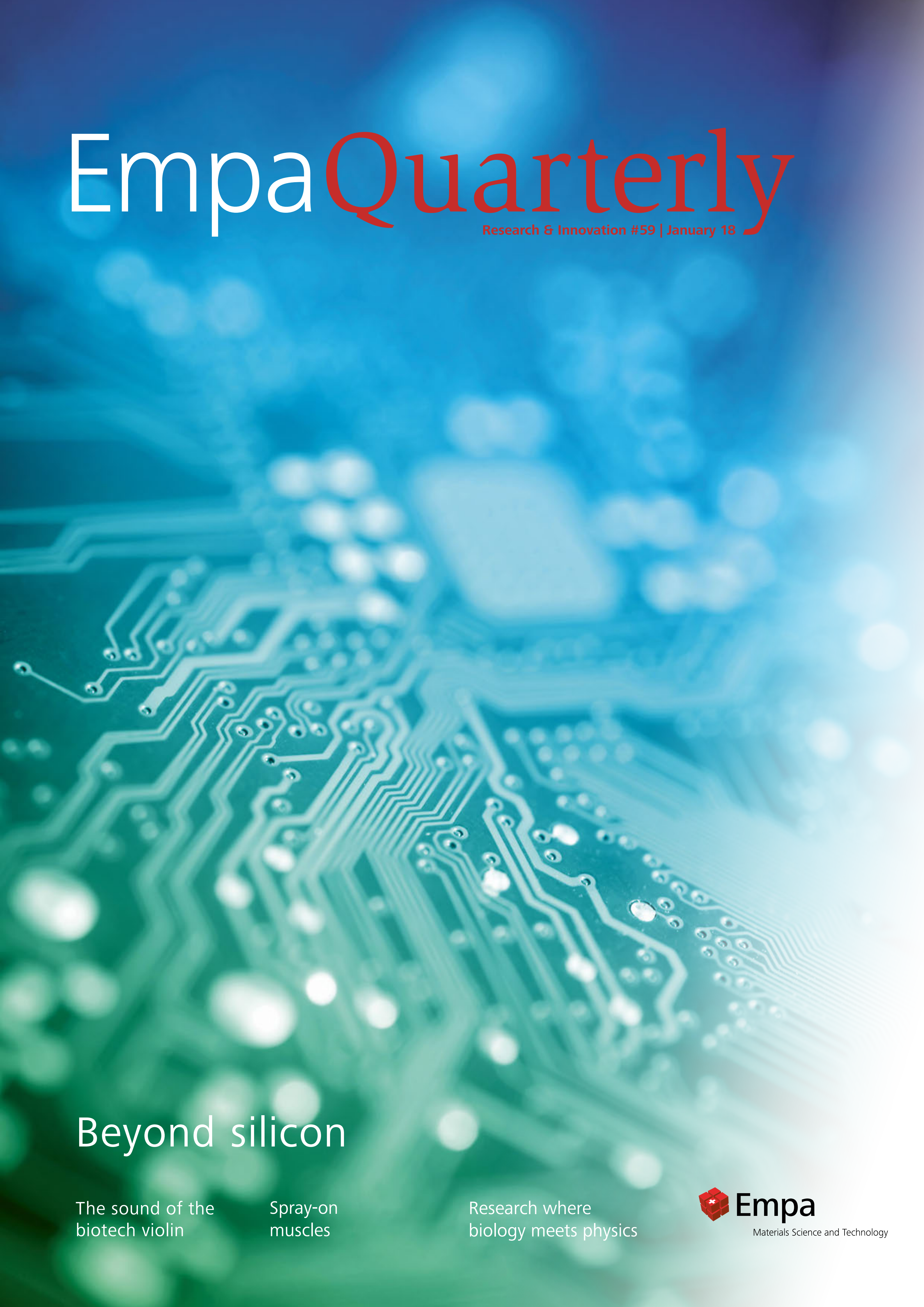
EmpaQuarterly

Research & Innovation #59 | January 18



Beyond silicon

The sound of the
biotech violin

Spray-on
muscles

Research where
biology meets physics

Empa
Materials Science and Technology

MICHAEL HAGMANN Head of Communications

Carbon miracle?

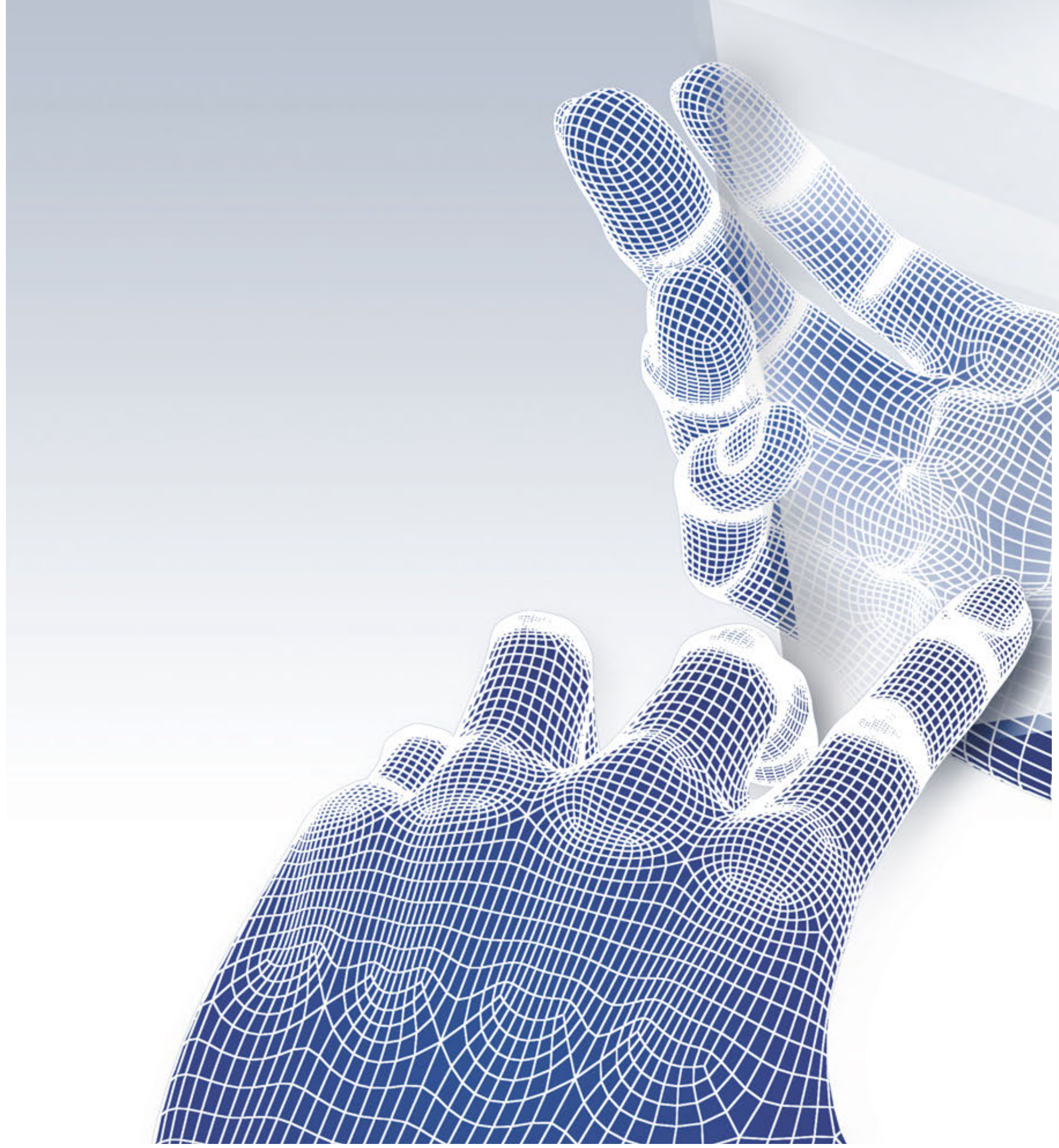
Dear reader

Ever smaller, ever faster, ever more powerful. This is what we expect from our electronic gadgets with each new release. More specifically, this means more and more computing power in an ever smaller space. To illustrate this, a comparison: the latest generation of smartphones has roughly the same computing power as a supercomputer in the mid-1990s – but the latter required an entire room and didn't simply fit in our pocket.

So far, "Moore's Law" has bestowed this miraculous boost upon our computers, smartphones and the like. But the "prophecy" expressed by Intel founder Gordon Moore back in 1965 is likely to reach the limits of what is physically feasible with conventional silicon technology. New materials and technologies are, therefore, in demand – such as the "miracle material" graphene, from which Empa researchers have now, for the first time, produced a nanotransistor (p. 12). Who knows, maybe the electronics of the future will be based on carbon.

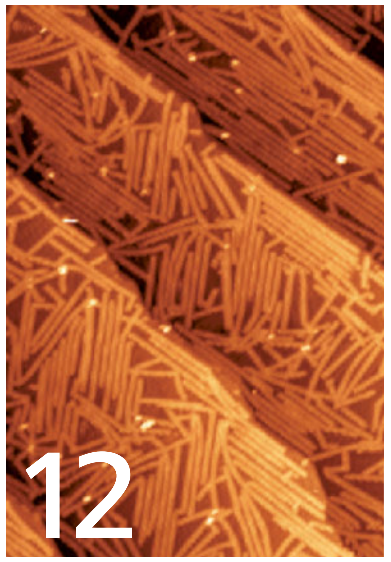
Carbon is also the main atomic constituent of wood. Thanks to a fungal treatment Empa researchers have "refined" it into a truly masterful sounding tonewood to produce biotech violins that are in no way inferior to a Stradivarius. A visit to Empa's acoustics lab should show whether or not the high expectations are fulfilled (p. 4).

I wish you an exciting reading, all the best for the New Year – and so long till the next issue!



Focus

Nano-electronics



Cover
Silicon microchips are shaping the present – but the material is reaching its limits. Conductor paths and oxide layers are barely a few atomic layers thick and extremely difficult to make any smaller. Empa is on the lookout for materials for the next generation of electronics.
***Page 08 – 17.** Picture: iStockphoto.*

Imprint
Publisher Empa, Überlandstrasse 129,
8600 Dübendorf, Schweiz, www.empa.ch
Editorial & Layout Communications
Contact Phone +41 58 765 47 33
empaquarterly@empa.ch, www.empaquarterly.ch
Published quarterly
Advertisment Marketing rainer.klose@empa.ch
***ISSN 2297-7414** EmpaQuarterly (English ed)*

PERFORMANCE myclimate neutral Printed Matter
No. 01-17-878615 – www.myclimate.org
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FSC www.fsc.org MIX Papier aus verantwortungsvollen Quellen FSC® C016087

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Sinfonia ai funghi

Do violins made of wood that had been treated with fungi sound the same as a fine, antique instrument? Acoustics experts at Empa are currently studying the body and soul of instruments made of "mycowood". Precision structure-borne sound measurements and psycho-acoustic tests with volunteers should reveal whether a fungal treatment can really improve an instrument.

TEXT: Andrea Six / PICTURE: Empa

Exactly why certain violins, such as a Stradivarius, sound so special remains a mystery. Global warming is one explanation, says Francis Schwarze from Empa's Applied Wood Materials lab in St. Gallen. "Nowadays, trees grow more rapidly and unevenly than during a very particular cold spell in the 17th century, when the wood for Stradivari's instruments was felled," explains the wood researcher. Apparently, today's timber has less favorable properties for violin-making.

And so Schwarze set out in search of a way to modify wood to resemble its antique counterpart. He managed to recruit a helper from nature: a natural fungus that causes white rot in trees, which the researcher used it on the material under controlled conditions in the lab. Sure enough, the hyphae transformed the maple and pine wood into a material that is just the ticket for violin-making.

The white rot pathogens come from the sluggish brigade and eat appreciatively: for the two to three months, in which the germs feasted away on the timber for the biotech violins, they barely affected the wood's mass. "Other pests break down up to 50% of the mass in the same time," says Schwarze. The violin fungi, on the other hand, were content with 0.5 to 1%. All the same, the fungus eventually had to be stopped in its tracks. "As soon as the wood structure had reached the desired state, the fungi were removed using a germicidal gas."

The mother of all violins

The goal was to manipulate the density of the wood, which is crucial for the sound, in such a way that the material is on a par with that used in the antique Italian instruments. Schwarze's fungal treatment was modeled on a fine, antique violin by Guarneri del Gesù, the "Caspar Hauser" from 1724. Like his contemporary, Stradivari, Guarneri (1698 – 1744) made instruments in Cremona, Italy, which are highly coveted because of their special sound and played by great soloists today.

However, even the best material is no use if the craftsmanship is not up to scratch as well. Hence, master violin-makers produced exact geometric copies of the Guarneri violin using mycowood. Although music has always been a matter of taste, the acoustics researchers at Empa are interested in how a violin's sound can be assessed objectively. The new project at Empa's Laboratory for Acoustics/

>>

Noise Control in Dübendorf is, therefore, studying the sound of the biotech violins from the very moment it is produced to the feeling it unleashes in its listeners.

A series of instruments, including the original, an untreated copy and various violins made of tonewood treated with fungi, are being tested. After all, the biotech instruments are supposed to demonstrate their capability according to scientific criteria.

The soul of a fungus violin

In the first step, Armin Zemp and Bart van Damme measure how the sound waves spread in the violin wood. As a musician's individual bowing style might distort the results, an electromagnet stimulates the instrument's strings for these structure-borne sound measurements. Moreover, the experiment is conducted in a special low-reflection lab, which does not cast the outgoing sound back onto the violin. In the meantime, a scanning laser doppler vibrometer records the vibrations of the material, measuring their frequency and amplitude at around 100 points on the violin's body. "This will determine whether the waves spread differently in the wood," says Zemp. "It will be particularly exciting to compare the mycowood violins with the original."

After the violin's body, however, its soul also needs to be measured: psychoacoustics experts are testing how people experience the sound of the biotech instruments. In the AuraLab for listening tests at Empa in Dübendorf, Beat Schäffer and Reto Pieren have been working with test subjects who have to evaluate audio samples of the instruments. Based on standardized questionnaires, the psychoacoustics experts are thus endeavoring to single out significant sound properties of the individual violins. "This will reveal whether we can establish a causal relationship between the wood structure, sound measurements and auditory sensation," says Pieren.

Even in the run-up, the mycowood violins received plenty of praise. The first specimens have already competed successfully against a 1711 Stradivarius in a blind test in front of an audience. The musicians who were given the opportunity to play the biotech instruments included Oleg Kaskiv, a violin pro and professor at the International Menuhin Music Academy in Gstaad. Kaskiv is infatuated: "The mycowood violins have a warm, colorful sound that approximates the old Italian instruments."

And although the instruments are still new and thus have not yet been played in sufficiently, it is already easier to tease sounds out of them an untreated violin is unable to produce. As concert halls are getting ever bigger, the musician finds the mycowood instruments with their powerful, carrying, warm sound particularly interesting. The current experiments will reveal whether the volunteers from the psychoacoustic tests are equally thrilled. //

Replacement for tropical wood

Swiss Wood Solutions, ein Spin-off von Empa und ETH Zürich, hat eine Alternative zu Tropenhölzern für den Instrumentenbau entwickelt. Ihr Produkt aus modifiziertem Schweizer Bergahorn «Swiss Ebony» hat die Eigenschaften von Ebenholz. www.empa.ch/web/s604/swiss-wood-solutions

Walter Fischli, who holds a PhD in biochemistry and an honorary PhD from the University of Basel, co-founded the pharmaceutical company Actelion. As President of the Board of Trustees of the Walter Fischli Foundation in Allschwil (Basel-Land), which supports scientists and musicians, he is the ideal partner for the interdisciplinary mycowood project at Empa.

"My dream is a string quartet with mycowood instruments"

Walter Fischli, whose foundation is funding the violin project at Empa, loves playing the biotech violin Caspar Hauser II. He reveals why the instrument is still a greenhorn and the story behind its name.

You're clutching the mycowood as we speak. How does it feel?

What's really surprising to me: it feels like an antique violin, even though it's brand new. The biotechnological wood treatment has given the instrument something of the full sound of the famous Italian violins. And even in pieces that would overstretch many modern instruments the mycowood violin remains powerful, colorful and flexible. I find it sounds very interesting.

But by itself a feeling is not enough to prove a violin's quality…

The experiments currently being conducted at Empa compare the sound of the violin treated with fungi and that of the antique original to an untreated instrument. As we are focusing on physical measurements and experiments involving test subjects, which can be analyzed statistically, it's going to be much more scientific than anything that's been done before. The trio of science, sound technology and music, i.e. Empa's acoustics lab, the Basel-based recording studio Idee und Klang and the renowned violinist Oleg Kaskiv, will put the mycowood violin through its paces during the tests. It's incredibly exciting and will reveal whether or not the fungus-treated Caspar Hauser II actually sounds better than an untreated violin.

Caspar Hauser II. Where does the biotech violin's name actually come from?

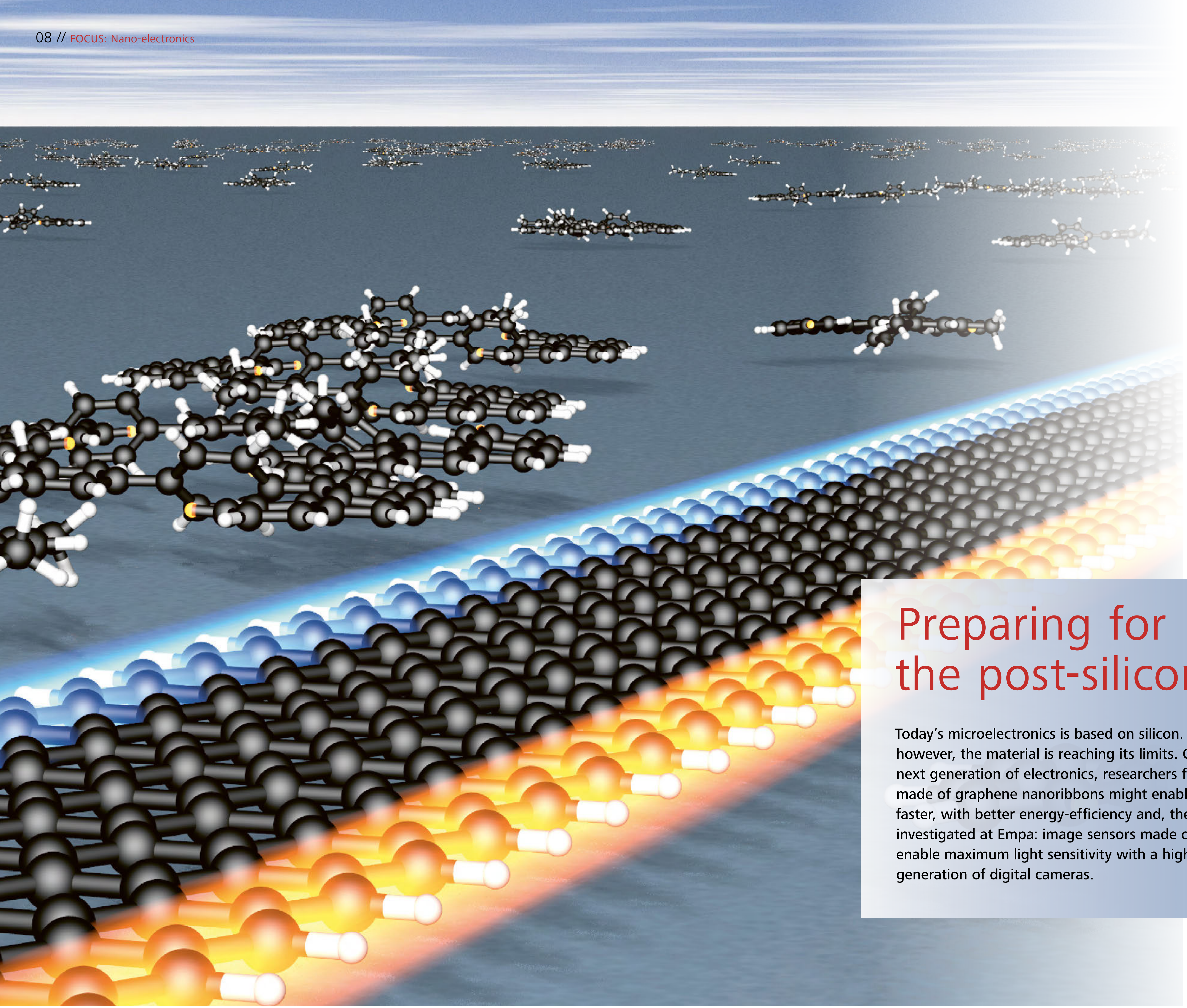
The mycowood violin is an exact copy of a great Italian violin made by Giuseppe Guarneri in the 18th century. It suddenly appeared out of the blue after Guarneri's death. Even though it can clearly be identified as a Guarneri del Gesù, its background remains a mystery. It reminded my friend and violin expert Michael Baumgartner of the story of Caspar Hauser, one of the most enigmatic figures of the 19th century. The mystery surrounding where Caspar Hauser came from gave rise to a myth that was pounced upon in literature, art and music. That's why we named the original Guarnari violin Caspar Hauser. So logically, the mycowood violin now goes by the name of Caspar Hauser II.

If the mycowood violin passes all the tests, what's in store for it in future?

Caspar Hauser II is a new violin, a greenhorn. It takes time to play in wooden instruments. This will show whether it – along with other mycowood violins – will also develop positively in the future. We've been in touch with Basel Music Academy and the International Menuhin Music Academy in Gstaad. Eventually, the goal is to end up with instruments geared towards talented young musicians with limited financial resources.

Would you like to round off the instrument project with these violins?

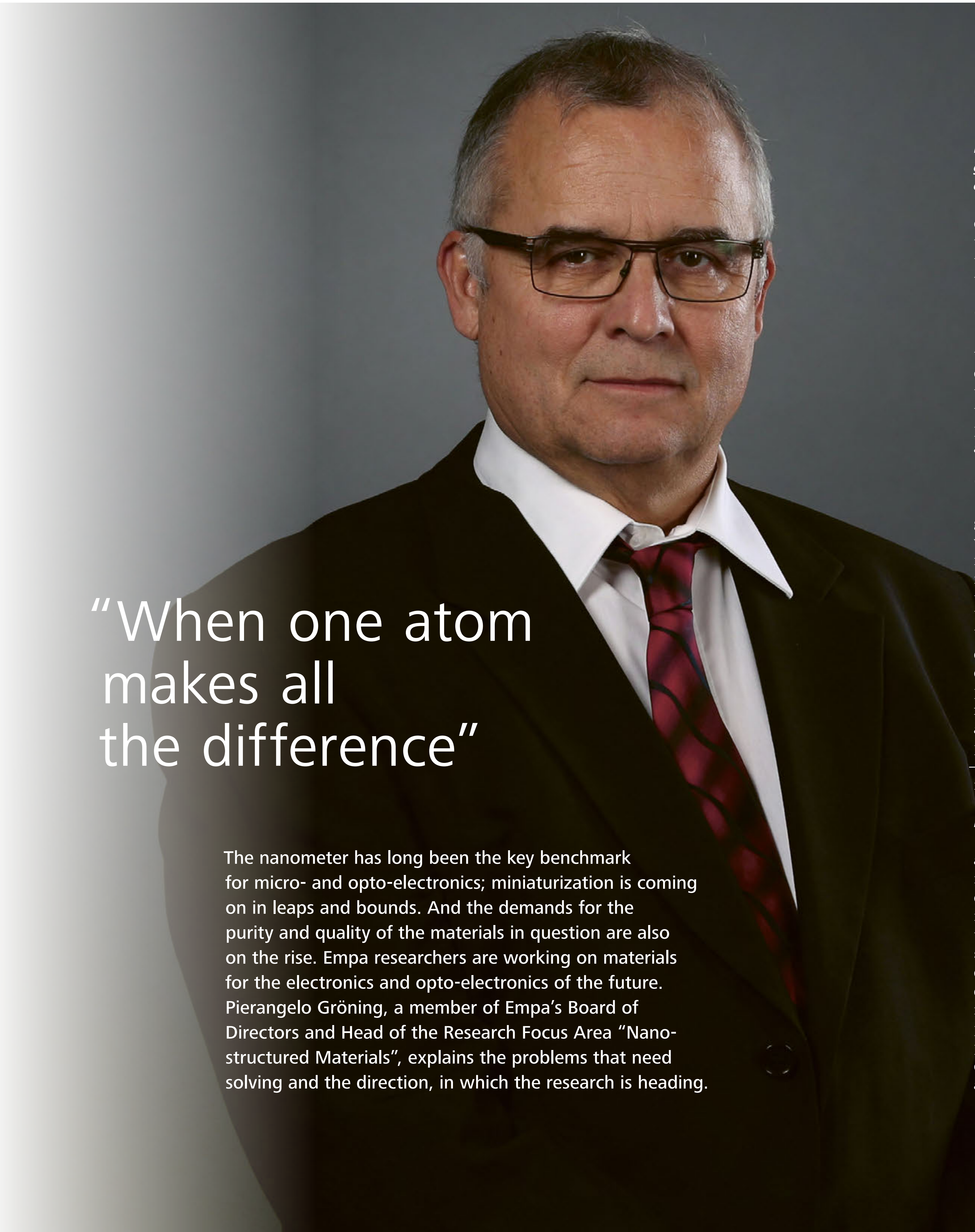
My dream would be a mycowood string quartet with two violins, a viola and a cello. At the moment, we're looking into whether a viola can be made from wood treated with fungi. A viola has a much bigger sound than a violin. Perhaps there will be much greater sound differences between untreated instruments and a fungus-treated viola. A riveting follow-up project!



Customized graphene nanoribbons
The basis for graphene nanoribbon transistors: specially designed molecules (black) serve as building blocks. On a gold surface they polymerize into graphene ribbons with specially molded edges (blue, yellow).
The graphene nanoribbons are semiconductors and can thus be used as base material for transistors – potentially paving the way for the computers of tomorrow.

Preparing for the post-silicon era

Today's microelectronics is based on silicon. With the increasing miniaturization, however, the material is reaching its limits. On the lookout for base materials for the next generation of electronics, researchers from Empa have struck gold: transistors made of graphene nanoribbons might enable the computers of the future to run faster, with better energy-efficiency and, therefore, much cooler. Another topic being investigated at Empa: image sensors made of perovskite nanocrystals – which enable maximum light sensitivity with a high resolution, one step towards the next generation of digital cameras.



“When one atom makes all the difference”

The nanometer has long been the key benchmark for micro- and opto-electronics; miniaturization is coming on in leaps and bounds. And the demands for the purity and quality of the materials in question are also on the rise. Empa researchers are working on materials for the electronics and opto-electronics of the future. Pierangelo Gröning, a member of Empa’s Board of Directors and Head of the Research Focus Area “Nanostructured Materials”, explains the problems that need solving and the direction, in which the research is heading.

INTERVIEW: Rainer Klose / PICTURE: Empa

Mr Gröning, you supervise research on transistors made of graphene nanoribbons and perovskite nanocrystals. What connects these two research fields?

In our research on graphene nanoribbons and perovskite nanocrystals, we work on materials that only unfurl their unique properties due to their extremely small dimensions. In expansions of over ten nanometers, these properties all but vanish or are no longer technologically interesting.

What motivates Empa to develop novel nano-electronics?

Firstly, it is the fascination of using unique material properties that, technologically, are only unfurled in objects with expansions of a handful of nanometers. Secondly, it is the precision necessary to synthesize these nano-objects – in extreme cases, it comes down to every single atom. And last but not least, we’re fascinated by the possibility of influencing, i.e. adapting, these properties with “small” atomic modifications.

Why do we have to replace silicon in electronics?

The transistor was invented in 1948 in the form of a bipolar germanium transistor. However, it soon became clear that silicon was better suited for the MOSFET architecture of a transistor as it forms a natural oxide layer, which can be used as a dielectric material for the gate. The MOSFET architecture also enabled the miniaturization of the transistor, which meant the first integrated silicon-based circuit could be installed in 1958. Our microelectronics has been based on silicon ever since. The latest transistors have lateral dimensions of fewer than 20 nanometers and an oxide thickness of only four or five atomic layers. But this also means the power loss per square meter keeps increasing and it is getting extremely difficult to conduct away this heat. The energy needs for computers and displays shouldn’t be underestimated, either. Around three percent of the energy worldwide is expended for the internet alone – and rising. If we want to counter this trend, we need better materials and new production methods to process them.

New production processes?

Yes, a good material is necessary but by no means sufficient for a new technology. In microelectronics, the entire process chain in industrial production is optimized for the element silicon. When it comes to silicon, there are no secrets or pitfalls in production anymore. So before we can replace this system with something completely new, we need a considerably better material and then a promising technological approach as to how this can be processed. With our graphene nanoribbons and perovskite nanocrystals, we have developed two material classes with outstanding physical properties for the electronics of tomorrow and future displays. As far as the production processes are concerned, it will be less challenging for perovskite nanocrystals than for graphene nanoribbons. In the case of the latter, we have absolutely no idea yet how to realize a robust and cost-effective technology to produce chips.

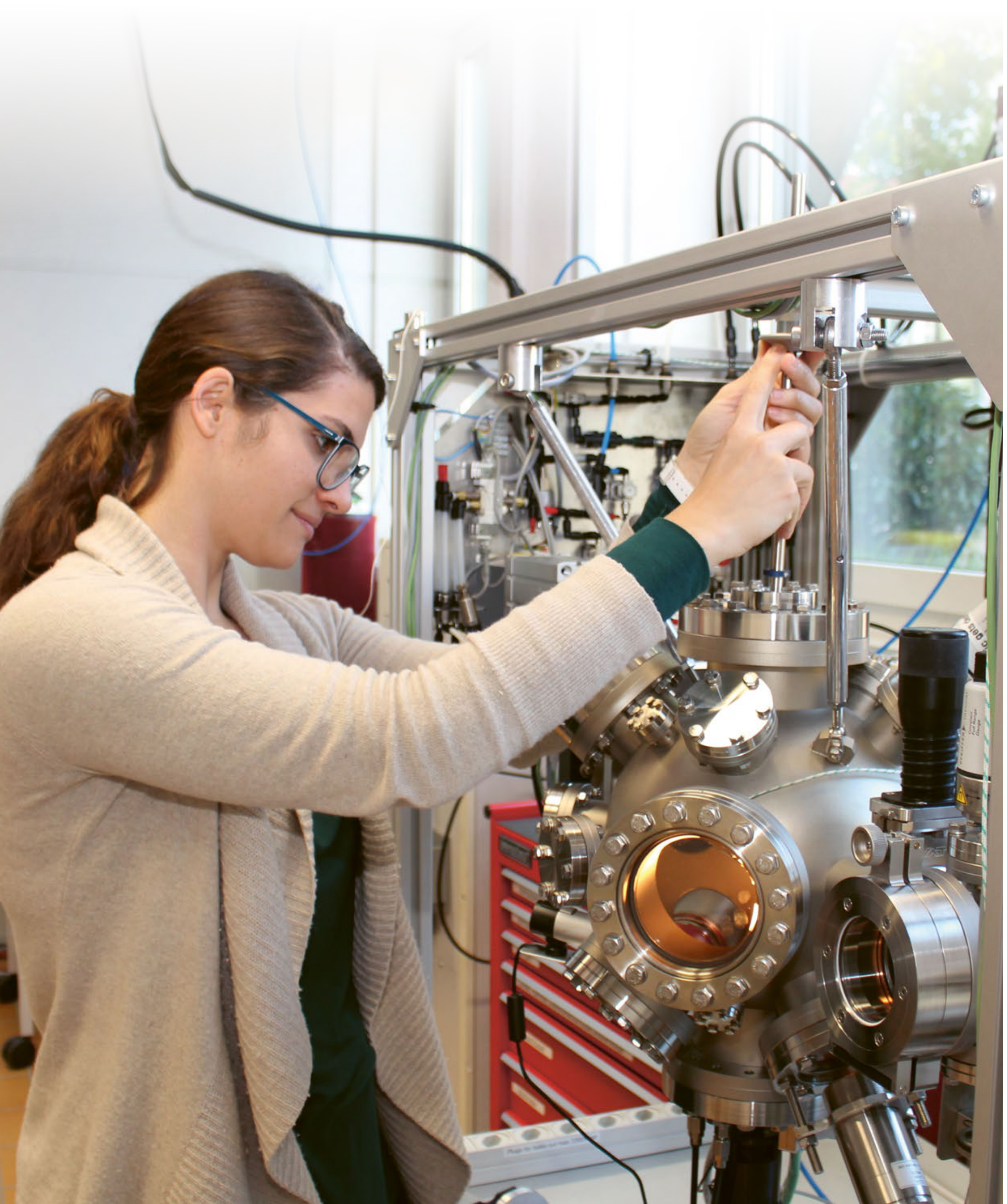
What are the largest scientific challenges in the switch to graphene electronics?

First of all, graphene is a semi-metal, not a semi-conductor, so it is absolutely unsuitable as an electronic switch – as a transistor. But quantum mechanics predicts that narrow graphene ribbons of only a few nanometers in width can behave like a semiconductor. Quantum mechanics also tells us that the edges of the ribbons mustn’t have any defects to preserve the unique electronic transport properties – and one single missing atom is already a defect here! With a bottom-up approach, we‘ve been able in recent years to show that atomically precise graphene nanoribbons of a wide variety of forms can be synthesized from suitable, specially designed precursor molecules. Depending on the form, the nanoribbons can be metallic or semi-conductive. Due to their atomic perfection, the nanoribbons display the outstanding transport properties that are expected from graphene.

And where is the journey heading for halide perovskite nanocrystals?

The nanocrystals light up in different colors of the visible light spectrum if irradiated with energy-rich UV light. In order to achieve the desired colors, there are two “setting screws” – the size of the crystals and the doping with trace elements. And here, too, like with the graphene nanoribbons, the physical properties are governed by single atoms. But unlike graphene nanoribbons, which react in a highly sensitive way to atomic defects, halide perovskite nanocrystals are very tolerant in this respect, especially regarding their photoluminescence. As with perovskites in general, you can easily dope halide perovskite nanocrystals, i.e. modify or, in technical terms, “tune” the electronic properties and thus also the photoluminescence. Doping means incorporating suitable foreign atoms. For a perovskite nanocrystal with an edge length of ten nanometers, this means precisely one foreign atom. With the halide perovskite nanocrystals, we have a unique, technologically robust toolbox at our disposal that may – and most probably will – trigger innovations in numerous fields of application. One key application, for instance, is the quantum dot monitor, which is far more brilliant than an OLED monitor and also easier to produce. Before this can be achieved, however, the stability of the nanocrystals needs to be improved and a method for their industrial production has to be developed.

Purebred graphene transistors



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Empa researcher Gabriela Borin Barin evaporates specially prepared molecules in high vacuum to grow graphene nanoribbons.

Transistors based on carbon nanostructures: what sounds like a futuristic dream could be reality in just a few years' time. An international research has now succeeded in producing nanotransistors from graphene ribbons that are only a few atoms wide, as reported in the current issue of “Nature Communications”.

TEXT: Karin Weinmann / PICTURES: Empa, iStockphoto

Graphene ribbons that are only a few atoms wide, so-called graphene nanoribbons, have special electrical properties that make them promising candidates for the nanoelectronics of the future: while graphene – a one atom thin, honeycomb-shaped carbon layer – is a conductive material, it can become a semiconductor in the form of nanoribbons. This means that it has a sufficiently large energy or band gap in which no electron states can exist: it can be turned on and off – and thus may become a key component of nanotransistors.

The smallest details in the atomic structure of these graphene bands, however, have massive effects on the size of the energy gap and thus on how well-suited nanoribbons are as components of transistors. On the one hand, the gap depends on the width of the graphene ribbons, while on the other hand it depends on the structure of the edges. Since graphene consists of equilateral carbon hexagons, the border may have a zigzag or a so-called armchair shape, depending on the orientation of the ribbons. While bands with a zigzag edge behave like metals, i.e. they are conductive, they become semiconductors with the armchair edge.

Cutting does not work well

This poses a major challenge for the production of nanoribbons: if the ribbons are cut from a layer of graphene or made by cutting carbon nanotubes, the edges may be irregular and thus the graphene ribbons may not exhibit the desired electrical properties.

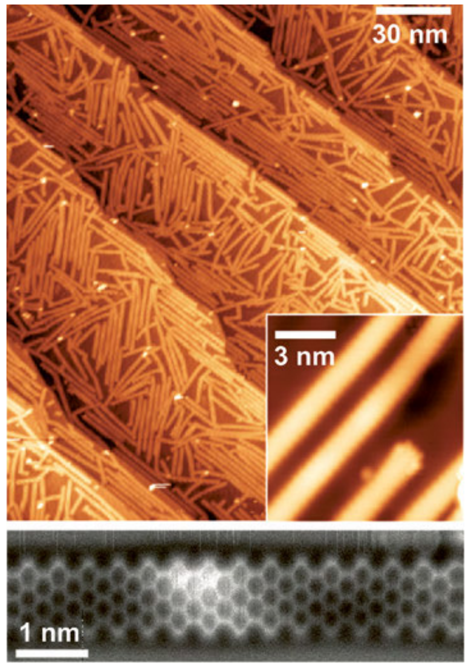
Empa researchers in collaboration with the ‘Max Planck Institute for Polymer Research’ in Mainz and the ‘University of California’ at Berkeley have now succeeded in growing ribbons exactly nine atoms wide with a regular armchair edge from precursor molecules. The specially prepared molecules are evaporated in an ultra-high vacuum for this purpose. After several process steps, they are combined like puzzle pieces on a gold base to form the desired nano-ribbons of about one nanometer in width and up to 50 nanometers in length.

Problems with oxide layer

These structures, which can only be seen with a scanning tunneling microscope, now have a relatively large and, above all, precisely defined energy gap. This enabled the researchers to go one step further and integrate the graphene ribbons into nanotransistors. Initially, however, the first attempts were not very successful: Measurements showed that the difference in the current flow between the “ON” state (i.e. with applied voltage) and the «OFF» state (without applied voltage) was far too small. The problem was the dielectric layer of silicon oxide, which connects the semiconducting layers to the electrical switch contact. In order to have the desired properties, it needed to be 50 nanometers thick, which in turn influenced the behavior of the electrons.

However, the researchers subsequently succeeded in massively reducing this layer by using hafnium oxide(HfO_2) instead of silicon oxide as the dielectric material. The layer is therefore now only 1.5 nanometers thin and the “on”-current is orders of magnitudes higher.

Another problem was the incorporation of graphene ribbons into the transistor. In the future, the ribbons should no longer be located criss-cross on the transistor substrate, but rather aligned exactly along the transistor channel. This would significantly reduce the currently high level of non-functioning nanotransistors. //



above
The microscopic ribbons lie scattered across the gold substrate. Each one consists of nine adjoining carbon atoms and is 50,000 times thinner than a human hair. Image from the scanning tunneling microscope (orange) with computer graphics of the atomic structure (gray).

German raw materials, Swiss precision, American finish

Four research teams from three countries create graphene nanotransistors

Technische Universität Dresden

Prof Dr. Xinliang Feng

- Design and chemical synthesis of the raw components for graphene nanoribbons

Max Planck Institute for Polymer Research Mainz

Prof. Dr. em. Klaus Müllen

- Design and chemical synthesis of the raw components for the graphene nanoribbons

Empa, nanotech@surfaces

Prof. Dr. Roman Fasel

- Synthesis of the graphene nanoribbons on gold surface (length: ~30 nm)
- Quality control in a scanning tunneling microscope
- Realization of non-conductive, structured substrate chips
- Quality control with Raman spectroscopy

University of California, Berkeley Dept. of Electrical Engineering and Computer Sciences

Prof. Dr. Jeffrey Bokor

- Lithographic structuring of the substrate chips (platinum contact points, dielectric layer and back gate)
- Nanolithographic manufacturing of electrodes (20 nm spacing)
- Characterization of the electrical properties at a millionth of an ampere

Cut out or grow?

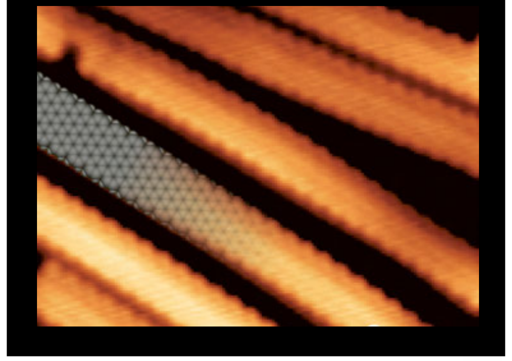
Although graphene can be manufactured industrially, it is unsuitable for transistors: the graphene sheets conduct electricity in all directions – much like with a copper plate. For transistors, however, semiconductors are called for.

Thin graphene strips – referred to as nanoribbons – display these semiconductor properties. These strips can either be cut out of a graphene sheet using lithographic methods or obtained from industrially manufactured carbon nanotubes by cutting them up along their axis. Both methods, however, produce ribbons with a large number of defects on their edges, which affects how the electrons move through the graphene nanoribbons.

Therefore, the Empa researchers synthesize graphene nanoribbons "bottom-up" from single molecules that have been synthesized at TU Dresden or the Max Planck Institute for Polymer Research in Mainz. This method produces perfect edges without any defects and the graphene nanoribbons conduct electrons in a well-defined manner.

The video "Electron wave propagation in graphene nanoribbons" (see link below) reveals just how much a defect on the edge of a graphene nanoribbon can influence its electronic properties. The electron cloud can only pass through the flawless graphene (the wave is scattered in the graphene strip with the defect). The video is based on Empa computer simulations.

The basis for manufacturing transistors is the ability to produce larger quantities of flawless graphene nanoribbons and transfer them to a suitable substrate, which the Empa team has now succeeded in doing.



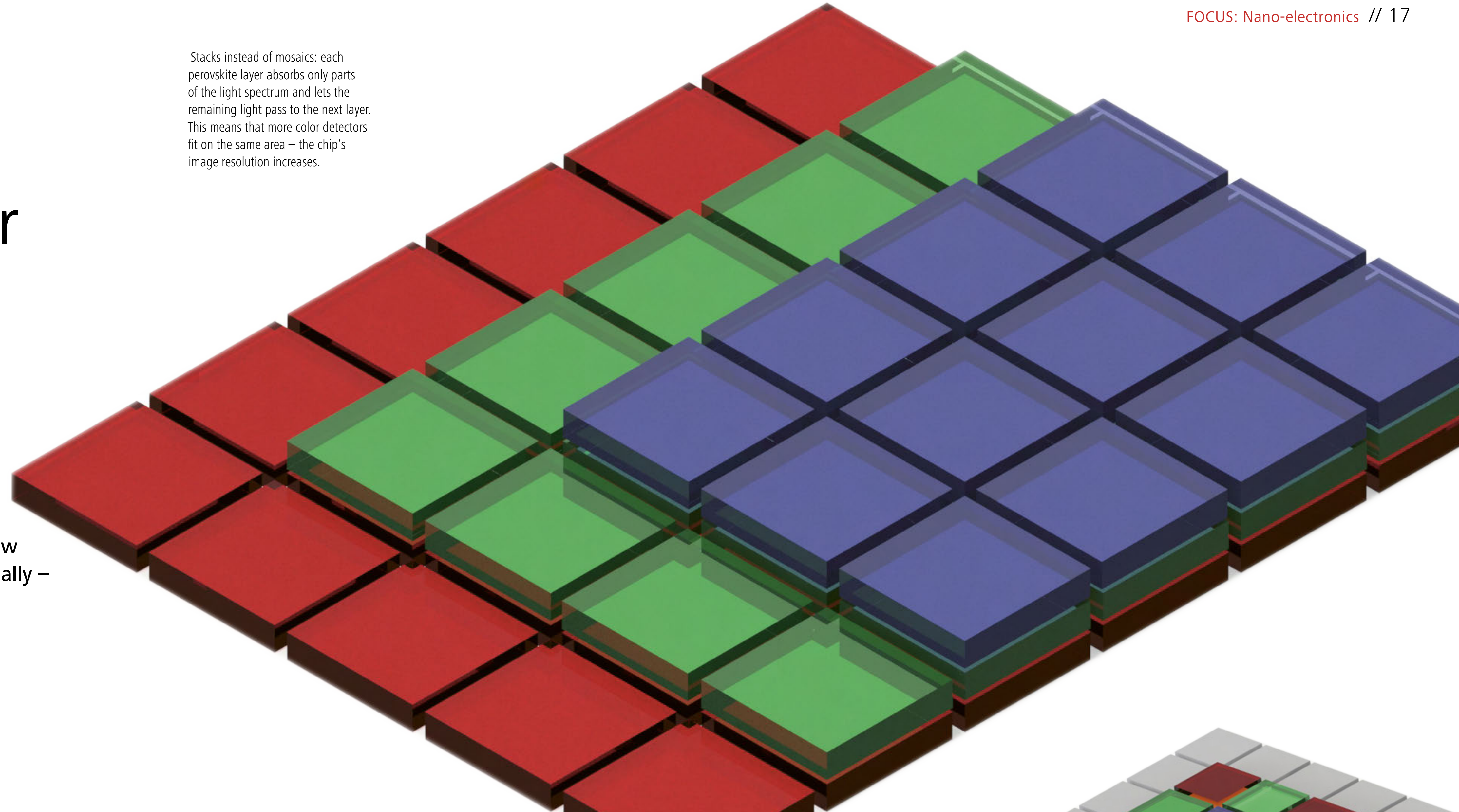
Video
Electron wave propagation in graphene nanoribbons

https://youtu.be/inqftSJf91E

Pixel-Tuning for your smartphone

Red-sensitive, blue-sensitive and green-sensitive color sensors stacked on top of each other instead of being lined up in a mosaic pattern – this principle could allow image sensors with unprecedented resolution and sensitivity to light to be created. However, so far, the reality hasn't quite met expectations. Researchers from Empa and ETH Zurich have now developed a sensor prototype that absorbs light almost optimally – and is also cheap to produce.

TEXT: Karin Weinmann / PICTURES: Empa



Stacks instead of mosaics: each perovskite layer absorbs only parts of the light spectrum and lets the remaining light pass to the next layer. This means that more color detectors fit on the same area – the chip's image resolution increases.

The human eye has three different types of sensory cells for the perception of color: cells that are respectively sensitive to red, green and blue alternate in the eye and combine their information to create an overall colored image. Image sensors, for example in mobile phone cameras, work in a similar way: blue, green and red sensors alternate in a mosaic-like pattern. Intelligent software algorithms calculate a high-resolution color image from the individual color pixels.

However, the principle also has some inherent limitations: as each individual pixel can only absorb a small part of the light spectrum that hits it, a large part of the light is lost. In addition, the sensors have basically reached the limits of miniaturization, and unwanted image disturb-ances can occur; these are known as color moiré effects and have to be laboriously removed from the finished image.

Transparent only for certain colors

Stack instead of mosaic: the perovskite layers each absorb only part of the light spectrum. Image: Empa

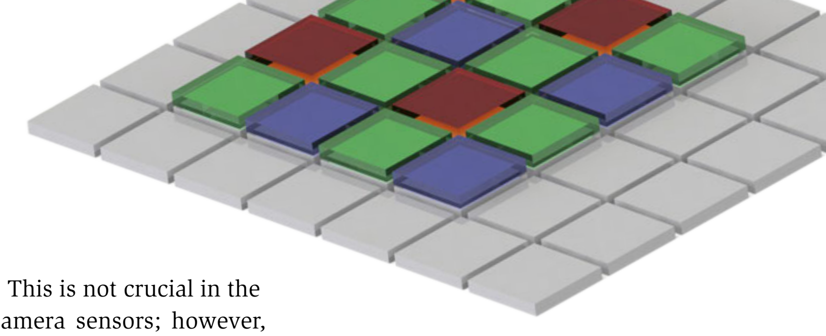
Researchers have, therefore, been working for a number of years on the idea of stacking the three sensors instead of placing them next to each other. Of course, this requires that the sensors on top let through the light frequencies that they do not absorb to the sensors underneath. At the end of the 1990s, this type of sensor was successfully produced for the first time. It consisted of three stacked silicon layers, each of which absorbed only one color.
This actually resulted in a commercially available image sensor. However, this was not successful on the market because the absorption spectra of the different layers were not distinct enough, so part of the green and red light was absorbed by the blue-sensitive layer. The colors, therefore, blurred and the light sensitivity was thus lower than for ordinary light sensors. In addition, the production of the absorbing silicon layers required a complex and expensive manufacturing process.

Accurate recognition of colors

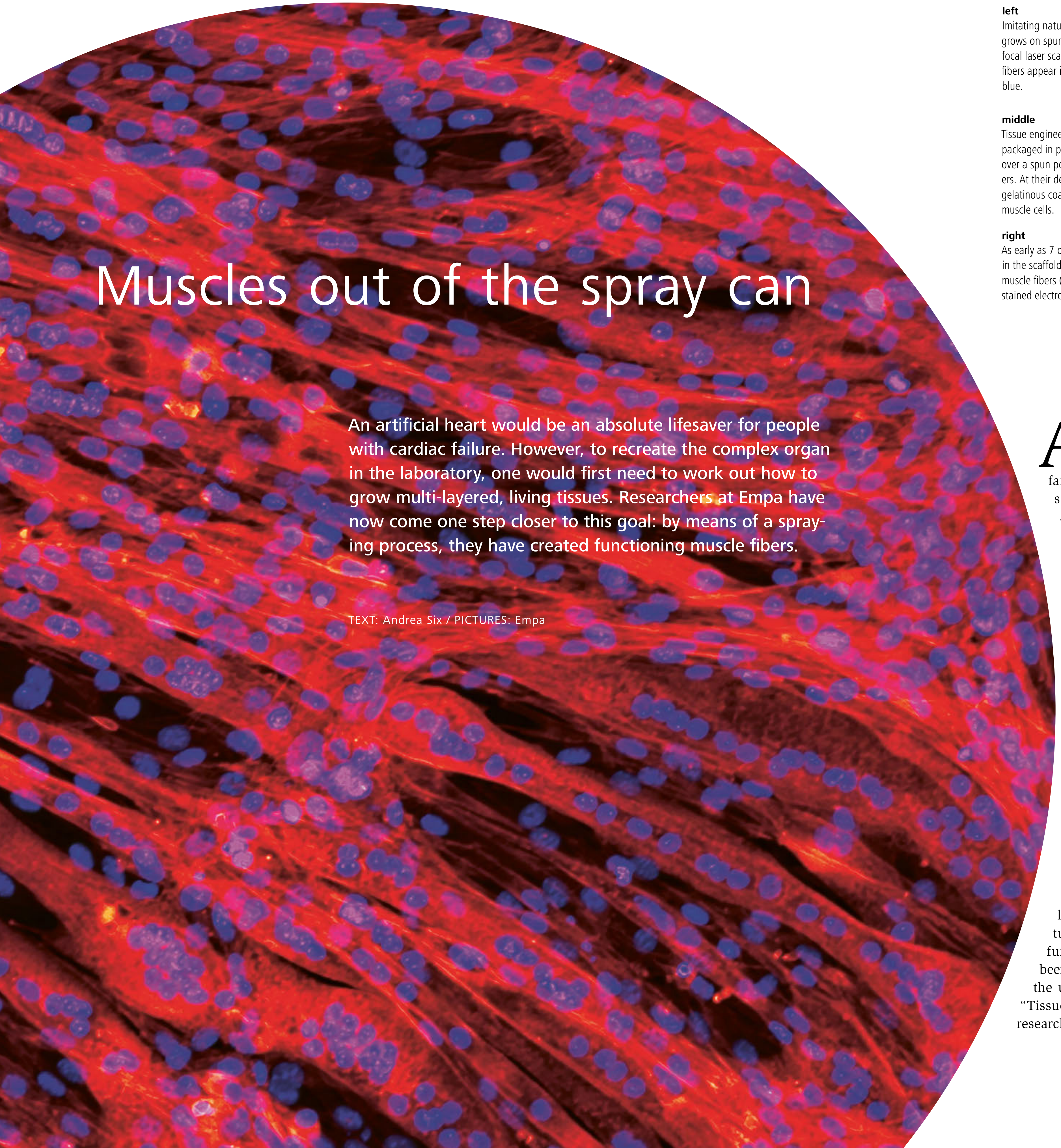
Empa researchers have now succeeded in developing a sensor prototype that circumvents these problems. It consists of three different types of perovskites – a semiconducting material that has become increasingly important during the last few years, for example in the develop-ment of new solar cells, due to its outstanding electrical properties and good optical absorption capacity (see "Further reading"). Depending on the composition of these perovskites, they can, for example, absorb part of the light spectrum, but remain transparent for the rest of the spectrum. The researchers in Maksym Kovalenko's group at Empa and ETH Zurich used this principle to create a color sensor with a size of just one pixel. The researchers were able to reproduce both simple one-dimensional and more realistic two-dimensional images with an extremely high color fidelity.

The advantages of this new approach are clear: the absorption spectra are clearly differentiated and the color recognition is thus much more precise than with silicon. In addition, the absorption coefficients, especially for the light components with higher wavelengths (green and red), are considerably higher in the perovskites than in silicon. As a result, the layers can be made significantly smaller, which in turn allows smaller pixel sizes. This is not crucial in the case of ordinary camera sensors; however, for other analysis technologies, such as spectros-copy, this could permit significantly higher spatial resolution. The perovskites can also be produced using a comparatively cheap process.

However, more work is still needed in order to further develop this prototype into a commercially viable image sensor. Key areas include the miniaturization of pixels and the development of methods for producing an entire matrix of such pixels in one step. According to Kovalenko, this should be possible with existing technologies. //



Conventional image sensor: the pixels for the individual colors are arranged next to each other. The chip needs more space than its stacked counterpart; the resolution is lower.



Muscles out of the spray can

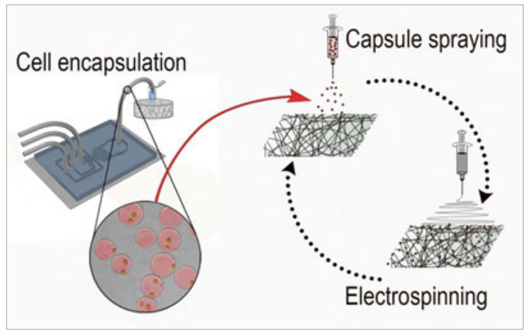
An artificial heart would be an absolute lifesaver for people with cardiac failure. However, to recreate the complex organ in the laboratory, one would first need to work out how to grow multi-layered, living tissues. Researchers at Empa have now come one step closer to this goal: by means of a spraying process, they have created functioning muscle fibers.

TEXT: Andrea Six / PICTURES: Empa

left
Imitating nature: A network of muscle fibers grows on spun plastic scaffold. Under a confocal laser scanning microscope the muscle fibers appear in red, and the cell nuclei in blue.

middle
Tissue engineering of muscle fibers: Cells are packaged in protective capsules and sprayed over a spun polymer scaffold in several layers. At their destination, the cells shed the gelatinous coating and develop into mature muscle cells.

right
As early as 7 days later, the cells join up in the scaffold (white) and form elongated muscle fibers (yellow), as shown in this stained electron microscope image.



Anyone who requires a transplant because of cardiac failure must hope for a suitable donor organ. An artificial heart that does not trigger any rejection reactions in the body after implantation would be an elegant alternative. “The Zurich Heart project” of the research alliance University Medicine Zurich, of which Empa is a partner, is currently developing such an artificial heart. To ensure that the laboratory-made pump is tolerated by the body, the aim is to envelop and coat it in human tissue, much like a cloak of invisibility. Until now, the culturing of multi-layered functional tissues has been a major challenge in the up-and-coming area of “Tissue Engineering”. Empa researchers have now succeeded in letting cells develop into muscle fibers in a three-dimensional synthetic polymer scaffold.

“The human heart is naturally composed of several layers of different tissues,” explains Lukas Weidenbacher of “Empa's laboratory for Biomimetic Membranes and Textiles” in St.Gallen. Muscle fibers in the lining play a decisive role in the structure, for they are responsible for the stability and flexibility of the constantly beating heart. Culturing muscle fibers that grow in multiple layers is challenging, however, because the cells must first be embedded in a three-dimensional scaffold. “To be sure, it is possible to create three-dimensional polymer structures that closely resemble human tissue, by means of so-called electrospinning for example,” says Weidenbacher. During this process, gossamer-like threads of liquid polymer are interlaced in the manner of natural tissue. But the harmful solvents that are required for this process are poison for the sensitive cells.

Slobbery protection

The researchers at Empa have therefore packaged the valuable cells in protective capsules. Gelatin sheaths contain one to two cells each. This protects the cells from the solvents. A special spraying process, called electrospraying, makes it possible to inject the capsules into the pores of the spun scaffold. “Cells that are protected in this way survive the spraying very well,” explains the materials scientist. And once the cells have settled at the desired location, the gelatinous capsule dissolves within minutes.

Scanning electron microscope images show that the cells feel at home in their synthetic polymer nest: As soon as the capsules have dissolved, the immature precursor cells begin to join up and to mature to form elongated muscle fibers. The aim is to end up with a structure that resembles natural muscle tissue as closely as possible. “As the artificial heart is constantly perfused by the blood circulation, it is important that the surfaces are of a quality that prevents coagulation,” says Weidenbacher.

Invisible to the immune system

The researchers have used the immature muscle cells of a mouse cell line for their series of experiments. These precursor cells differentiated in the scaffold and produced proteins that normally occur in muscle. However, in the future the aim is to clad the implantable artificial heart with cells that derive from the patients themselves. In this way, a personal heart could be grown for the patient that remains “invisible” to the body's immune system. //

Looking beyond the horizon

Michel Calame is Head of the Transport at Nanoscale Interfaces Laboratory at Empa. The name says it all: the physicist aims to conduct research at the interface between physics and biology, where damp systems meet dry electronics and nano-devices display quantum mechanical effects because they are so minuscule. System boundaries are his speciality.

TEXT: Rainer Klose / PICTURES: Empa, private

Someone's on a voyage of discovery here. You can already sense it after a few seconds. Although the term "voyage" doesn't exactly do Michel Calame's tempo justice. Perhaps fact-finding mission would be more apt? Either way, it involves venturing into poorly charted territory – a white patch on the research map. Calame doesn't like conducting his research within familiar systems – in the world of crystals, bio-organisms or regular nanostructures. Instead, he looks for the point where one system ends and meets another; where the laws of one world fade and those of the other start to take effect.

Out of the dry and into the wet

Evidently, he has always been searching. A degree in physics in Neuchatel and a PhD in superconductive thin films, then a brief spell at the Federal Institute of Metrology (METAS), where he was involved in the development of novel cryogenic transistors. He then moved to Rockefeller University in New York, to a research group devoted to molecular biophysics. "Biophysics? Dreadful – it's wet!" as his classmates said at the time, explains Calame. Even though physicists aren't particularly fond of getting their hands wet, he found himself captivated by this foray into a world beyond his horizons. "Living organisms are far too interesting to leave them to biologists!"

In research terms, he has been a cross-border commuter ever since. "Interfaces" – the boundaries and meeting points between different materials, but also research disciplines – spark his curiosity. "Observations on a nanometer scale are particularly nice," says Calame; "that's where physics meets chemistry and biology. Here, at the nanoscale, the wave nature of electrons becomes clear. Here, I can see quantum effects at room temperature." His explanation is swift and concise, and you can see his face light up.

Calame has been running the Transport at Nanoscale Interfaces lab with around 40 members since October 2016. An inquisitive boss is one thing – but where exactly is the fact-finding mission taking him and his team? He embarks on a brief detour through physics before outlining his research field: in the 1980s individual atoms, for the first time, became tangible objects; Don Eigler from the IBM Research Center in Almaden (incidentally where Empa CEO Gian-Luca Bona worked for a number of years) arranged 35 xenon atoms on a surface to spell the letters "IBM". "Later, in the 1990s, we were astounded by the successes in nanofabrication – it was like playing Lego in the nanoworld," says Calame.

Today, however, the interest no longer solely lies in producing small structures, but increasingly the functionalities that can be achieved with them. All sorts of transport phenomena occur and the interpretations drift apart depending on the research discipline: physicists might for instance more often investigate charge transport, while chemists will look into charge transfer. One scientist considers the flow as a whole, the other observes individual charges hopping around. Nonetheless, the boundaries between the disciplines are increasingly blurring from one year to the next. An "intermediate zone" is forming and Calame and his colleagues are enticed by a goal in this very field: engineering with multi-atomic components, such as functional molecules, crystallites or quantum dots.

Atomic clusters are the tiniest units we can still work on using reasonable technical means. "We can still manipulate a molecule or a nanocrystal to engineer its electronic shell; that's no longer possible in the same way on an individual atom," says the Empa researcher. Calame has been working in this field for more than ten years. In 2008 his name appeared on a paper about molecular switches that respond to visible light. The co-author was Ben Feringa, a 2017 Nobel Prize laureate in Chemistry. If individual switches are a wonderful thing – what about an architecture with millions of nanoparticles that organize themselves on a surface under their own steam and still integrate those functional switches? How do you get from there to an interaction with biological systems? And how does this pave the way for the nanoelectronics of tomorrow?

This is where colleagues from related disciplines at Empa come in: in Roman Fasel's nanotech@surfaces lab, graphene, which is regarded as the electronics building block of the future, is synthesized in the form of nanoribbons (see Page 12); Hans Hug, a microscopy specialist, and his team manipulate electron shells on atoms in the Nanoscale Materials Science lab; Maksym Kovalenko investigates the self-organization of nanoparticles at both Empa and ETH Zurich; at the Biomimetic Membranes and

Michel Calame in his laboratory.

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Michel Calame in discussion with his team-member Sahana Sarkar.

Textiles lab, René Rossi studies the surface properties of human skin and develops functional textiles; and Katharina Maniura from the Biointerfaces lab looks into biofilms on inorganic materials.

Using Empa expertise
This scientific environment also explains why Michel Calame ended up at Empa after 16 years of teaching and research at the University of Basel. “Empa has everything I need: scanning tunneling and transmission electron microscopes, NMR and UV-Vis spectroscopy, focused ion beams (FIB) for surface patterning and analyses and advanced X-ray analytical methods. And there are also the people here who know how to use them. I need the knowhow available in the materials sciences here to understand my systems better,” says Calame.

And an added bonus about the move to Empa: “The proximity to the mountains and lakes.” Calame grew up in Val de Travers, west of Lake Neuchatel. The scientist enjoys going on hikes to relax. First of all, however, the new family home – a 44-year-old house above Greifensee – needs to be made shipshape for the future. Which, for the time being, means more construction dust than fresh, mountain air. Calame will remain faithful to his academic home, the University of Basel, for a few more years. He was made an adjunct professor of nanosciences there on 26 October. “Let's put the atoms and molecules to work,” is his motto and he reiterates the purpose of it all: here, at the nanoscale – this is where the building blocks for new switches and new computers can be found, where the key to new human-machine interfaces lies and where personalized medicine will root. Targeted therapeutic interventions might thus be possible, which may one day make popping large numbers of pills, which inundate the entire body and all its organs and tissues, a thing of the past.

He looks back on the 20th century: the «century of physics». Relativity, quantum mechanics, chaos theory, NASA, space travel, nuclear fission. For him, the 21st century will more likely be shaped by neuroscience and biotechnology. “I was born in 1969 – so I’m a child of the space age,” says Calame. “For the generation of researchers currently coming up through the ranks, however, the scientific race will no longer be about the moon. It might well be about the innermost working of human beings; understanding the brain, understanding life.” //

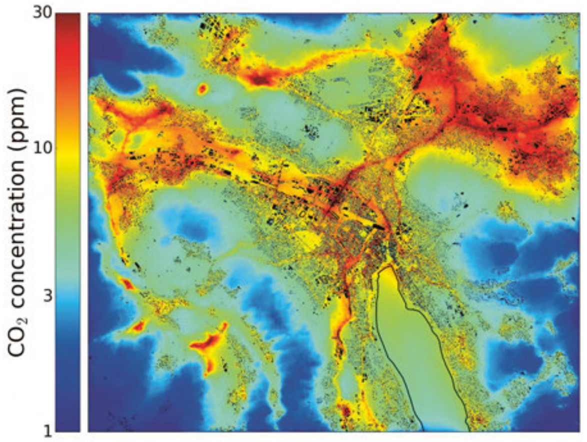
Hiking in the Swiss alps with daughter Emily.

Local CO_2 observation across Switzerland

Switzerland is to gain a dense, globally unique atmospheric CO_2 measuring network: 300 sensors will permanently collect up-to-date readings, to provide near-real time information on man-made emissions and CO_2 uptake by the biosphere.

The Carbosense4D project will combine data science methods, atmospheric observations, and atmospheric transport modelling to determine the evolution of carbon dioxide (CO_2) over Switzerland at high spatial and temporal resolution. Three hundred low-cost CO_2 sensors distributed over Switzerland in the framework of the ongoing CarboSense project will be offering an unprecedented density of continuous CO_2 observations. Accurate knowledge of the 4-D distribution of CO_2 is of great interest to study anthropogenic CO_2 emissions and exchange fluxes with the biosphere, for the validation of satellite CO_2 observations and to provide lateral boundary conditions for models tracking city-scale CO_2 emissions. Overall, CarboSense4D will help improving our understanding of the regional carbon cycle and contribute to the independent validation of national greenhouse gas reduction pledges in the light of the international Paris climate accord.

http://www.carbosense.ch/

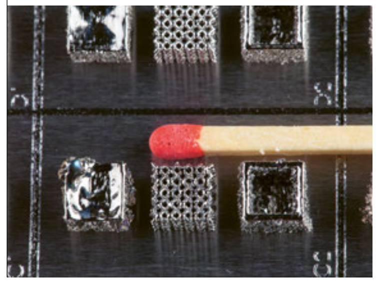


The distribution of the carbon dioxide concentration in the City of Zurich averaged over 2013 and 2014. Thanks to the readings from the sensor network, this kind of model calculation will be more precise in future.

Alloys from the laser printer

In the future, new designer alloys for aerospace applications can be manufactured using the 3-D laser melting process (Additive Manufacturing). Pioneering work in this field was provided by Empa researcher Christoph Kenel, who works today at Northwestern University in Chicago. Empa grants him the Empa Research Award 2017.

Titan-Aluminum alloys are combining low density, high strength and oxidation resistance at elevated temperatures and are therefore of high technical relevance e.g. in aerospace engineering. The aim of the awarded PhD thesis of Christoph Kenel was to develop a novel titanium aluminide (TiAl) alloy, particularly for use in beam-based additive manufacturing technologies, and to include nanosized oxide dispersoids to improve their high temperature mechanical properties. Christoph Kenels research was supervised by Christian Leinenbach at Empa’s Advanced Materials Processing laboratory.



left
These small-sized samples are made of oxide dispersion-strengthened titanium aluminides and have been printed as part of a PhD thesis.

right
Christoph Kenel receives the prize from Brigitte Buchmann, a member of Empa’s Board of Directors.

PICTURES: Empa

SWISS BAU

BRINGT ALLES ZUSAMMEN.

16. – 20. Januar 2018

Visit Empa at the Swissbau Innovation Lab in Basel. Together with our partners, we demonstrate what digitization means in the building sector.

Hall 1.1, Stand L88

Visit Empa at the Motor Show in Geneva! We are being hosted by the Erdoel-Vereinigung stand and will be showcasing sustainably produced fuels of the next generation.

Hall 6, Stand 6239

Events (in German)

23. Februar 2018

Empa-FSRM-Kurs Graphen und Kohlenstoff-Nanoröhrchen
www.empa-akademie.ch/graphen
Empa, Dübendorf

8. März 2018

VGQ Technikertag 2018
Zielpublikum: Mitglieder VGQ und Interessierte
www.vgq.ch
Empa, Dübendorf

12. – 13. April 2018

3-Länder-Korrosionstagung
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/3-Länder
Empa, Dübendorf

23. – 24. April 2018

C-A-S-H II – 2nd Workshop on Calcium-Silicate Hydrates Containing Aluminium
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/cash
Empa, Dübendorf

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

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