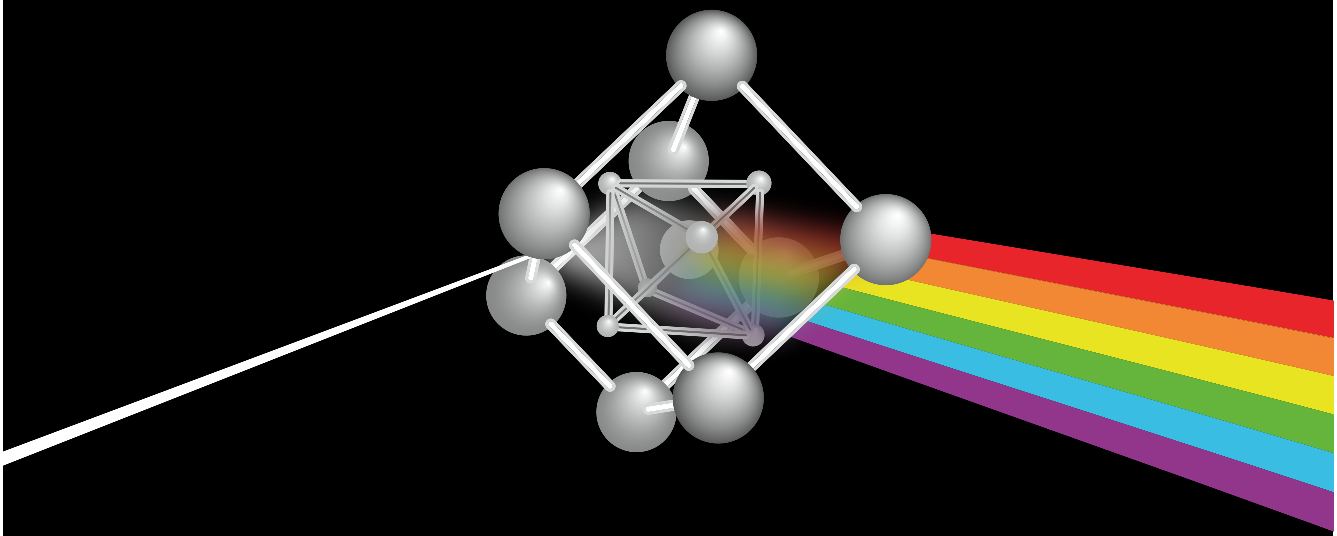
# Empa Quarterly

RESEARCH & INNOVATION II #83 II APRIL 2024

FOCUS: PEROVSKITES

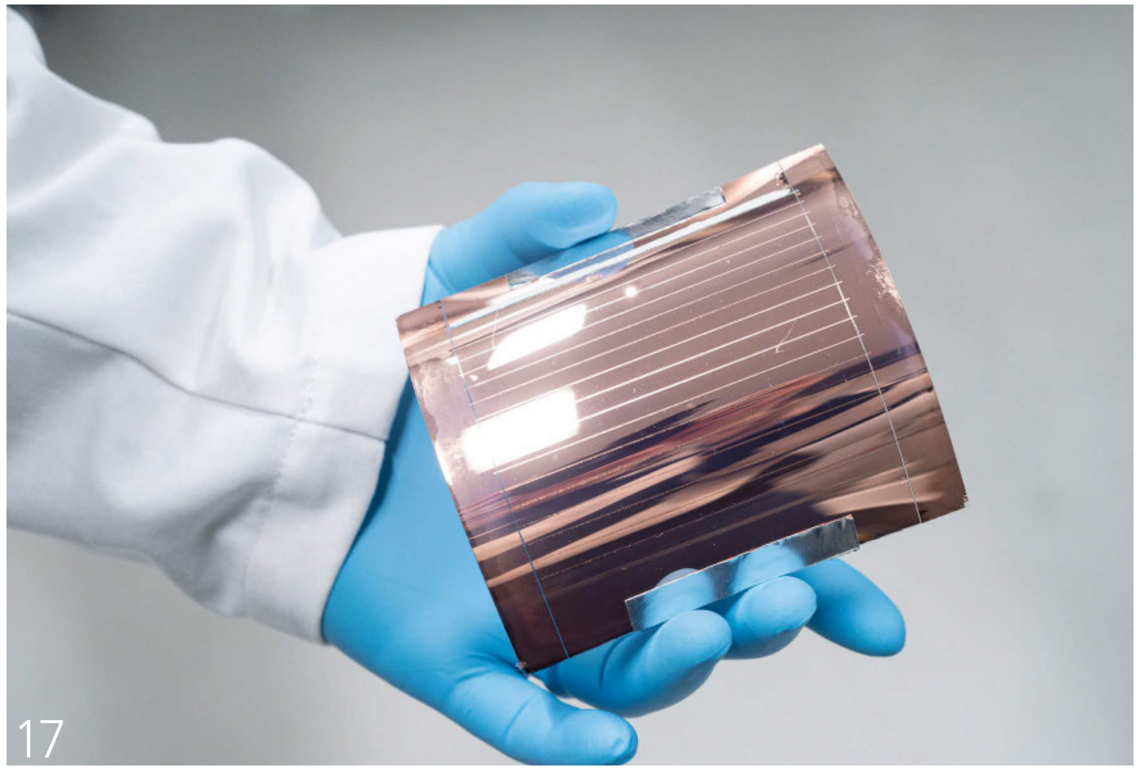
## VERSATILE CRYSTALS

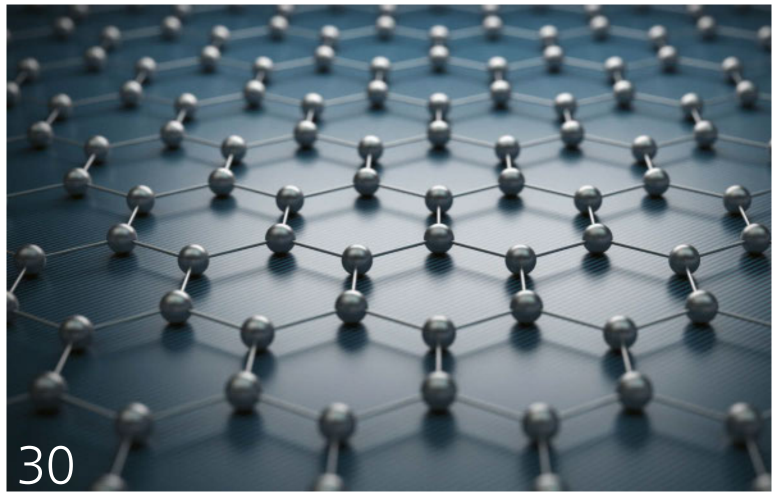


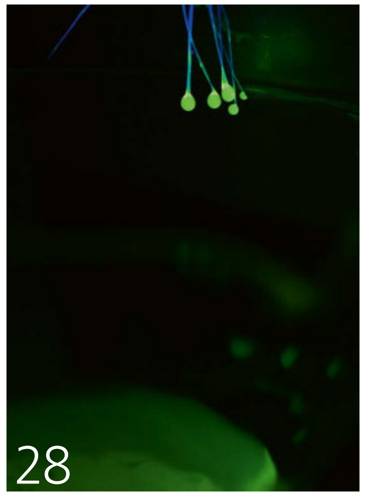
BRILLIANT QUANTUM DOTS
DOUBLE SOLAR CELLS
ECO-FRIENDLY TEXTILES

# [ CONTENT ]

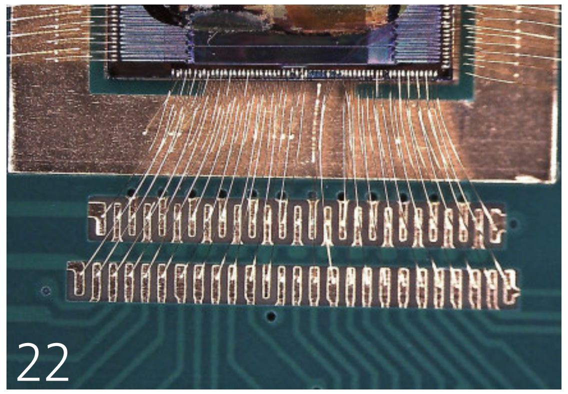
[ FOCUS: PEROVSKITES ]



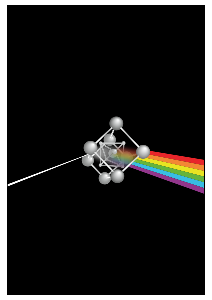





Photos: Empa, graphic: Adobe Stock



[ COVER ]



What makes a perovskite? This material class possesses a unique crystalline structure, which gives it interesting properties, particularly in its interactions with light. Like a far more powerful version of the prism on the cover of Pink Floyd's "The Dark Side of the Moon", perovskites may one day help us emit, capture and use light. Image: Empa




[ IMPRINT ]

**PUBLISHER** Empa
Überlandstrasse 129
8600 Dübendorf, Schweiz
www.empa.ch
**EDITORIAL** Empa Kommunikation
**LAYOUT** PAUL AND CAT.
www.paul-and-cat.com
**CONTACT** Phone +41 58 765 47 33
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quarterly
**PRODUCTION**
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ISSN 2297-7414
Empa Quarterly (English edition)




## A CRUCIAL INGREDIENT

Dear Reader

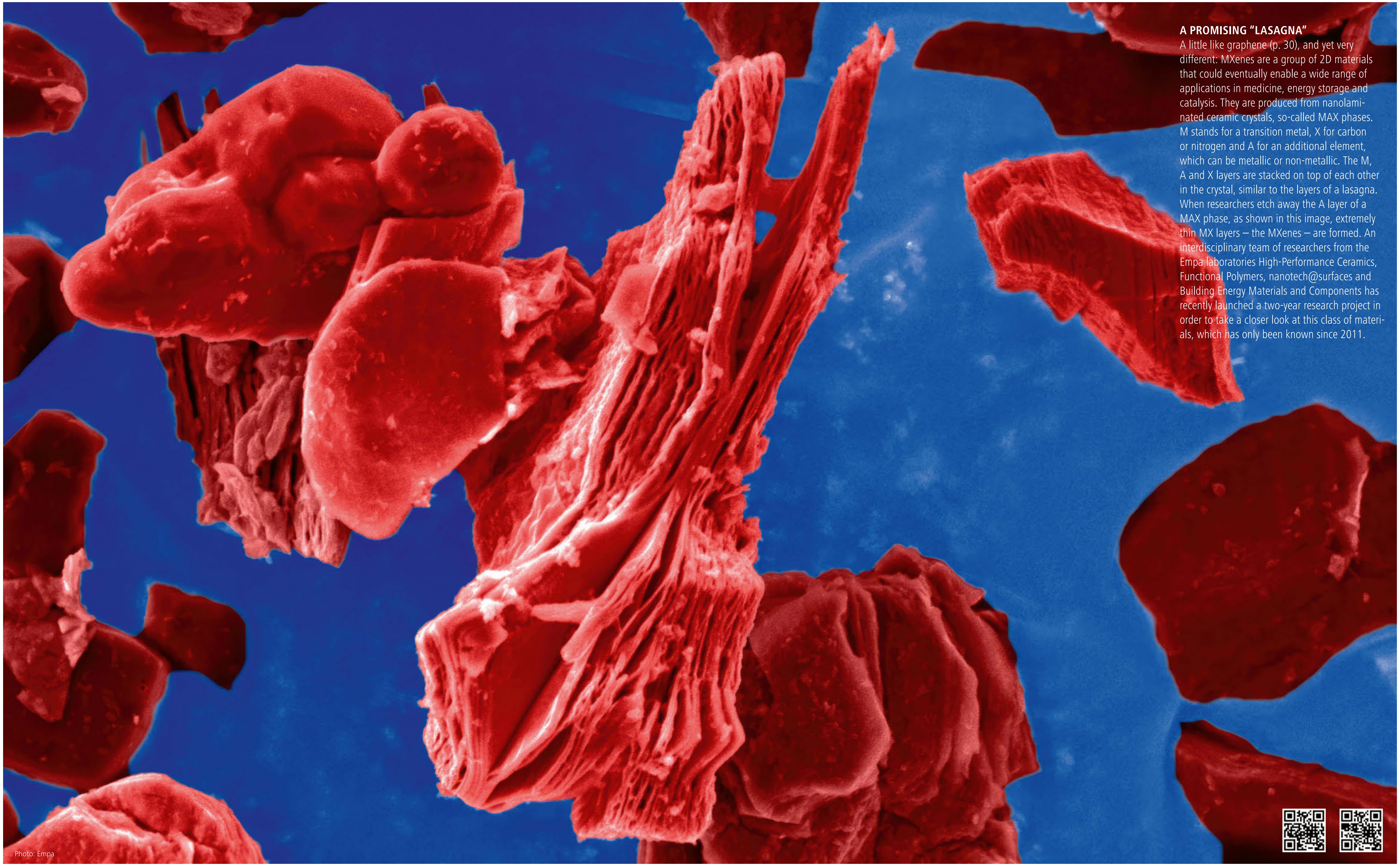
Around two out of three technical innovations are based on novel materials – such as silicon, without which today's ubiquitous microelectronics would be unthinkable, or lithium-ion batteries, which currently power everything from smartphones to electric cars.

Or – and this brings us to the current issue of Empa Quarterly – perovskites. Pero-what? This extremely diverse class of materials is characterized by its special crystal structure and can be expanded practically at will by slightly changing the chemical "recipe". A chemical construction kit to perfectly suit the taste of curious materials scientists. For instance, quantum dots made from perovskite nanocrystals only emit light of a certain wavelength and are thus suitable for innovative screens and displays (p. 20); perovskites might also be applied in new image sensors (p. 22) and ultra-efficient tandem solar cells (p. 17).

Another "miracle material" is graphene, layers of carbon just one atom thick, which Empa researchers are investigating for future applications in quantum technology and nanoelectronics, for example. However, the potential impact of new, hitherto unknown materials on humans and the environment should also be investigated from the outset. This is precisely what Empa researchers have been working on as part of the EU's Graphene Flagship project (p. 30).

If you would like to experience the fascinating world of materials live, you are cordially invited to our open lab day on September 14 at our new research campus in Dübendorf – more on this in the next Empa Quarterly.

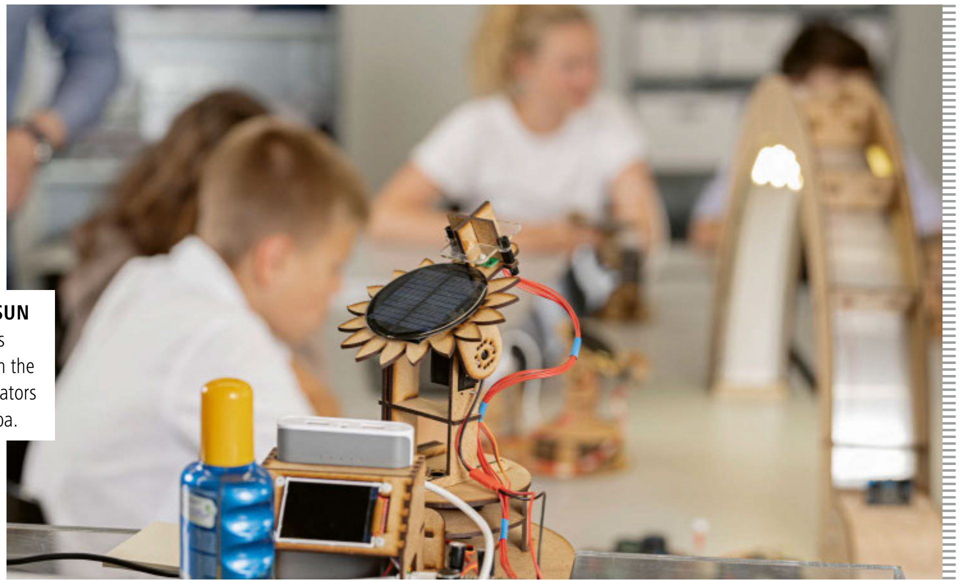
Enjoy reading! Your MICHAEL HAGMANN



**A PROMISING "LASAGNA"**
A little like graphene (p. 30), and yet very different: MXenes are a group of 2D materials that could eventually enable a wide range of applications in medicine, energy storage and catalysis. They are produced from nanolaminated ceramic crystals, so-called MAX phases. M stands for a transition metal, X for carbon or nitrogen and A for an additional element, which can be metallic or non-metallic. The M, A and X layers are stacked on top of each other in the crystal, similar to the layers of a lasagna. When researchers etch away the A layer of a MAX phase, as shown in this image, extremely thin MX layers – the MXenes – are formed. An interdisciplinary team of researchers from the Empa laboratories High-Performance Ceramics, Functional Polymers, nanotech@surfaces and Building Energy Materials and Components has recently launched a two-year research project in order to take a closer look at this class of materials, which has only been known since 2011.

Photo: Empa

## SMARTFELD EDUCATION LAB IS GROWING



**SOAK UP THE SUN**
At Smartfeld, kids learn physics with the help of demonstrators conceived at Empa.

With the support of the IT education campaign, the Smartfeld education lab is expanding its range of services. Pupils from the Werdenberg-Sarganserland and Lake Zurich-Linth regions can now attend STEM workshops on site in Buchs and Rapperswil-Jona, in addition to the location at the Switzerland Innovation Park OST in St. Gallen. The interdisciplinary education initiative was co-started by Empa, among others, in 2018. Empa researchers develop STEM demonstrators for Smartfeld, which are then manufactured at Empa in collaboration with the institute's apprentices. In 2023, Smartfeld attracted well over 4,000 students and more than 300 teachers for workshops and courses.

## A DYNAMIC UNDERSTANDING OF BACK PAIN

Musculoskeletal disorders are the second most common cause of disability worldwide. In order to provide early and effective treatment, we need to better understand the interplay between complex biochemical processes and the body's biomechanics. The pain often only occurs when patients are in motion – and yet, the diagnosis is mainly made using static images. An Empa team wants to change this in a newly launched two-year project involving scientists from the Mechanical Systems Engineering laboratory, the Center for X-ray Analytics and Scientific IT, as well as clinical partners at Inselspital Bern. The aim is to improve the diagnosis of a painful degenerative disease of the spine known as lumbar spinal stenosis using a combination of biomarkers, X-ray images in motion and 3D imaging of muscles and ligaments. In parallel, the researchers also want to develop a secure platform for the management of clinical data.

**HOLISTIC**
Empa researchers want to improve the diagnosis of lumbar spinal stenosis.

Photo: Empa, graphic: Adobe Stock



## TIRES AS A SOURCE OF MICROPLASTICS

**MICROPLASTICS**
Car tires release material into the environment even during "normal" driving.

If you brake hard in a car, the tires will leave a black mark on the road. Tire wear is, however, not only generated during extreme manoeuvers, but also during every "normal" drive; even at constant speed, the tires rub against the road surface, releasing tire material into the environment. This material accounts for a large proportion of the total released microplastics. In a recently published report in response to a postulate from the Swiss parliament, researchers from Empa and the company wst21 summarized the results of numerous studies and presented approaches on how tire wear can be reduced.

## SAVE THE DATE: OPEN LAB DAY AT EMPA IN DÜBENDORF


**"SAVE THE DATE"**
On Saturday, September 14, 2024, Empa opens its doors.

On Saturday, September 14, 2024, Empa opens its doors for an Open Lab Day in Dübendorf. Visitors can get to know the new Empa and Eawag campus, co-operate, and immerse themselves in the world of materials science and technology at Empa. There will be numerous booths, demonstrators and lectures for young and old on the topics of climate change, energy transition, dwindling resources, fascinating materials and healthy life in a healthy environment. Visitors will also gain an insights into the demonstrators NEST, move, ehub and WaterHub, and learn more about apprenticeships at Empa. Interested? Find out more about the event online and in the next issue of Empa Quarterly.

Photo: Adobe Stock, graphic: Empa

# CLEAN AT LAST

Rain jackets, swimming trunks, or upholstery fabrics: textiles with water-repellent properties require chemical impregnation. Although fluorine-containing PFAS chemicals are effective, they are also harmful to human health and accumulate in the environment. Empa researchers are now developing a process with alternative substances that can be used to produce environmentally-friendly water-repellent textile fibers. Initial analyses show: the "good" fibers repel water more effectively and dry faster than those of conventional products.

Text: Andrea Six

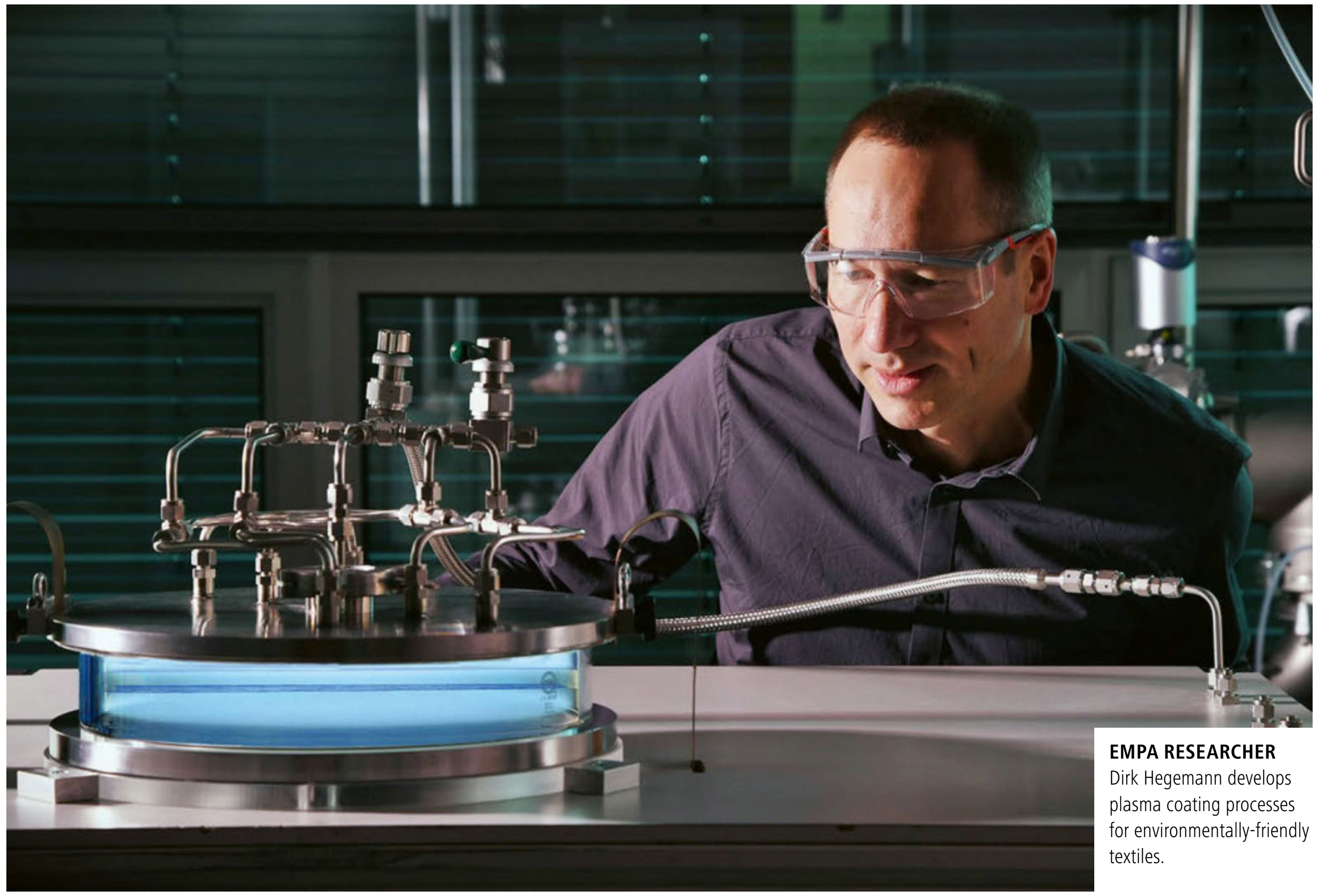
If swimming trunks are to retain their shape after swimming and to dry quickly, they must combine two properties: They must be elastic and must not soak up water. Such a water-repellent effect can be achieved by treating the textiles with chemicals that give the elastic garment so-called hydrophobic properties. In the 1970s, new synthetic fluorine compounds began to be used for this purpose – compounds that seemed to offer countless application possibilities, but later turned out to be highly problematic. This is because these fluorocarbon compounds, PFAS for short, accumulate in the environment and are harmful to our health (see box). Empa researchers are therefore working with Swiss textile companies to develop alternative environmentally-friendly processes that can be used to give fibers a water-repellent finish. Dirk Hegemann from Empa's Advanced Fibers laboratory in St. Gallen explains the Innosuisse-funded project: "We use so-called highly cross-linked siloxanes, which create silicone-like layers and – unlike fluorine-containing PFAS – are harmless."

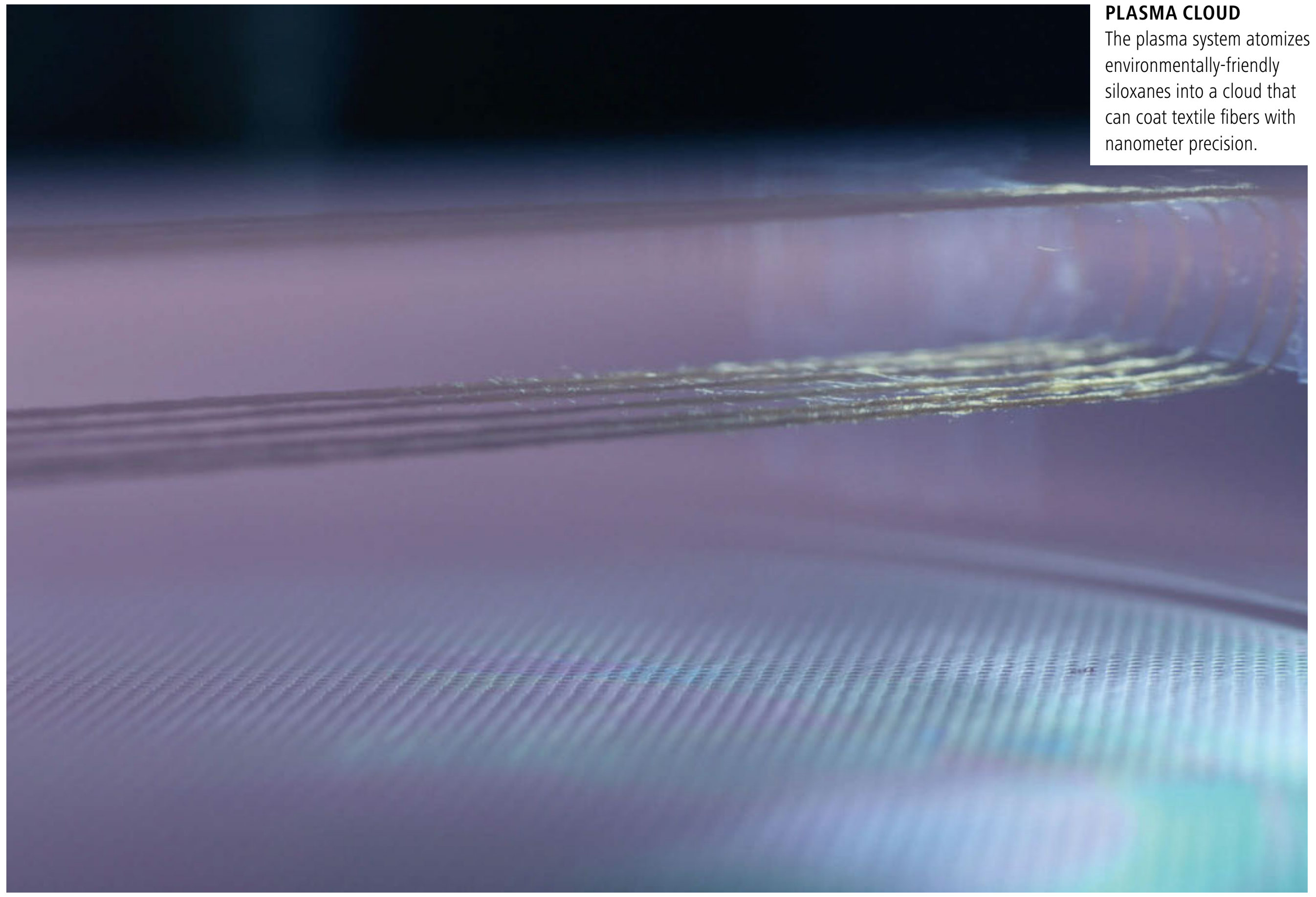
## SHROUDED IN PLASMA CLOUDS

Empa's plasma coating facilities range from handy table-top models to room-filling devices. For the coating of textile fibers, the siloxanes are atomized and activated in a reactive gas. They thereby retain their functional properties and enclose the textile fibers in a water-repellent coating that is only 30 nanometers thin. Fibers coated this way can then be processed into water-repellent textiles of all kinds, for example garments or technical textiles such as upholstery fabrics.

The advantage over conventional wet-chemical processes: Even with complex structured textiles, the seamless distribution of the hydrophobic substances is guaranteed right into all turns of the intertwined fibers. This is crucial, because even a tiny wettable spot would be enough for water to

Photos: Empa





**EMPA RESEARCHER**
Dirk Hegemann develops plasma coating processes for environmentally-friendly textiles.

**PLASMA CLOUD**
The plasma system atomizes environmentally-friendly siloxanes into a cloud that can coat textile fibers with nanometer precision.

penetrate into the depths of a pair of swimming trunks, preventing the garment from drying quickly. "We have even succeeded in permanently impregnating more demanding, elastic fibers with the new process, which was previously not possible," says Hegemann.

### GREAT INTEREST FROM INDUSTRY

In initial laboratory analyses, textiles made from the new fibers with an environmentally-friendly coating are already performing slightly better than conventional PFAS-coated fabrics. They absorb less water and dry faster. However, the miraculous properties of the fluorine-free coating only really come into their own after the textiles have been washed several times: While the performance of conventional PFAS coatings in stretchy textiles declines considerably after repeated wash cycles, the fluorine-free fibers retain their water-repellent properties.

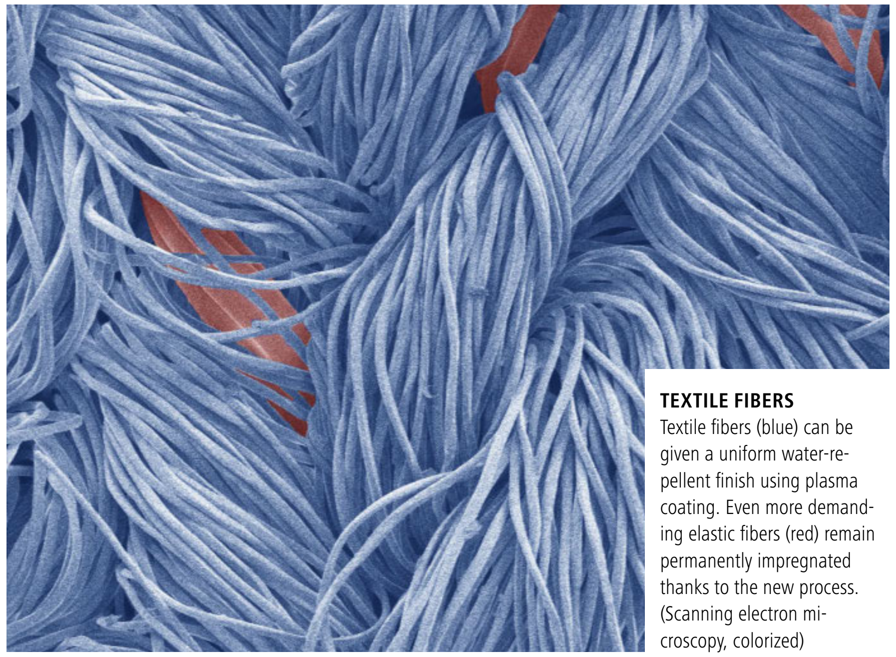
Hegemann and his team are now working on scaling up the fluorine-free laboratory process into efficient and economically viable industrial processes.

### FLUORINE-CONTAINING PFAS: POISONS FOR ETERNITY

PFAS, per- and polyfluorinated alkyl compounds, are a group of synthetic chemicals that have a wide range of applications due to their ability to repel water, oil and grease. They have been in use since the 1970s, for example, in the production of functional clothing, fire extinguishers and frying pans. As carbon-fluorine substances do not degrade but accumulate in the environment and ultimately in the human body, they are referred to as "eternal chemicals". The substances are suspected of causing various health problems in humans and animals, such as cancer, cardiovascular diseases, obesity and developmental disorders. Certain PFAS are already banned, others could follow.

"The industry is very interested in finding sustainable alternatives to PFAS," says Hegemann. The Swiss textile companies Lothos KLG, beag Bäumlin & Ernst AG and AG Cilander are already on board when it comes to developing environmentally-friendly fluorine-free textiles. "This is a successful collaboration that combines materials, fiber technology and plasma coating and leads to an innovative, sustainable and effective solution," says Dominik Pregger from Lothos. And Bernd Schäfer, CEO of beag, adds: "The technology is environmentally friendly and also has interesting economic potential." ■

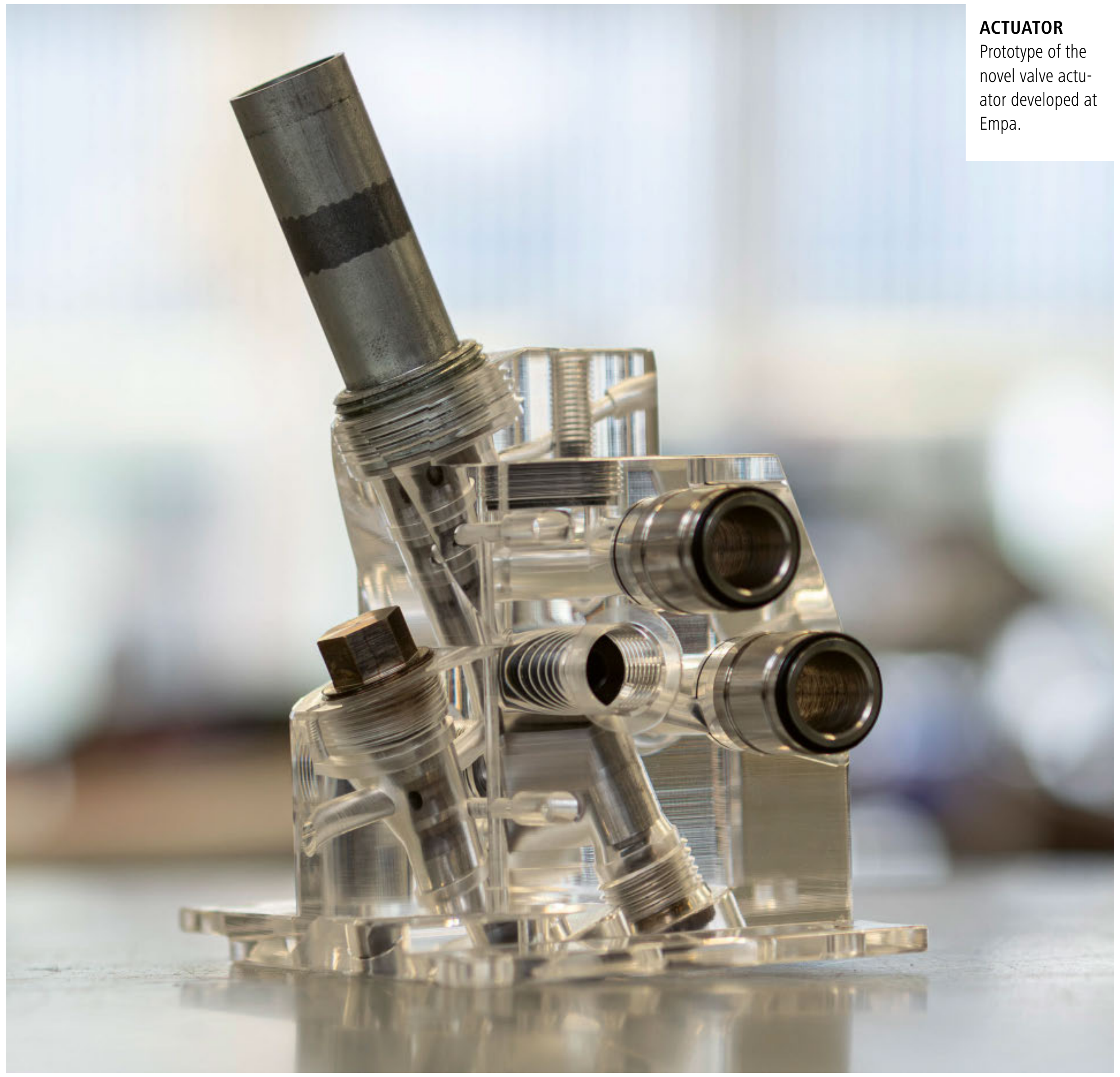
**WHERE WATER CANNOT PENETRATE**
Even stretched fibers allow the water droplet (blue) to roll off. (Microscopy, 30x magnification)



**TEXTILE FIBERS**
Textile fibers (blue) can be given a uniform water-repellent finish using plasma coating. Even more demanding elastic fibers (red) remain permanently impregnated thanks to the new process. (Scanning electron microscopy, colorized)

Photos: AG Cilander / Empa





**ACTUATOR**
Prototype of the novel valve actuator developed at Empa.

Photo: Empa

# THE GREEN MACHINE

Industrial waste heat is an untapped goldmine: it is produced in large quantities, but is hardly used efficiently. A new type of machine developed by Empa scientists and their partners based on an innovative engine technology could change this – also with the help of an Empa Entrepreneur Fellowship, which was recently awarded to Empa researcher and neo-entrepreneur Andyn Omanovic.

Text: Norbert Raabe

▶

Good ideas sometimes take surprising turns. For years, experts at Empa had been working on an innovative valve control system for combustion engines with electro-hydraulically actuated valves, which make it possible to make the gas change much more flexible than with conventional camshaft technology. In a gasoline engine, fuel consumption could be reduced by around 20 percent in typical operation mode for passenger cars. This approach is now being developed further for fuel-flexible engines in cargo vehicles together with a truck manufacturer.

But now this technology could also enable progress in another area. Empa has awarded its former doctoral student Andyn Omanovic an Entrepreneur Fellowship to bring a new type of piston machine with this control system to market. Commercialization will be handled by etavalve GmbH, a spin-off of Empa and ETH Zurich, which was co-founded by hydraulics expert Wolfgang Schneider, who was involved in the development of the technology.

The idea is to use waste heat from processes in the metal or cement industry and other areas more efficiently with the help of the aforementioned piston machine than with current methods that work with turbines. As the cylinder and piston form a closed space, explains Omanovic, the compression and expansion of the process take place in an almost ideal way; this enables an extremely high energy yield: The waste heat is converted into mechanical power via the pistons, which is ultimately used to generate electricity. However, this process can only be implemented at all thanks to the innovative flexible control of the valves.

### AN ENORMOUS POTENTIAL

"Turbines are particularly effective at high temperatures and for power requirements of several hundred megawatts," explains the Empa researcher, "but our piston machine is better suited for temperature ranges of around 500 to 900 degrees, where the waste heat is generated irregularly, and up to the power range of several megawatts." The potential is high: In 2016, the amount of industrial waste heat above 300 degrees in Germany was estimated at around 10 terawatt hours per year. By comparison, according to the Association of Swiss Electricity Companies (VSE), last year around 57 terawatt hours of electricity were consumed in Switzerland.

The use of waste heat from pyrolysis plants, which convert biomass into biochar in order to bind carbon permanently, is also promising – a process that Empa researchers are also working on. The by-product of this process is so-called lean gas, which contains methane and gaseous pollutants and must be incinerated, as required by law. "This is often done with a gas flare without any utilization of the energy," explains Omanovic, "we use this heat to generate electricity with our piston machine."

**INVENTIVE SPIRIT IN THE TEAM**
From left, Patrik Soltic, Andyn Omanovic and Wolfgang Schneider, the founders of etavalve.



### EMPA FUNDING FOR BUSINESS START-UPS

The Empa Entrepreneur Fellowship is awarded to Empa researchers who want to found a start-up based on their research. The fellowships are awarded on a competitive basis and include financial support for one year. Additional support is given to Empa spin-offs in Empa's two business incubators in Dübendorf and St. Gallen.

### BEFORE THE STEP INTO PRACTICE

By the beginning of 2025, a pilot machine is to be built for the energy supplier IWB in Basel, which is pushing the development of biochar plants in Switzerland – designed and built specifically for the properties of the waste heat generated during pyrolysis. Around a year later, according to the developers at etavalve, a small series of piston machines should be delivered to a company that specializes in plants for the combustion of lean gases from landfills or biogas processing. Talks are already underway.

The experts at etavalve are therefore confident that their technology could reach the market in the foreseeable future – despite challenges in technical details such as temperature-resistant materials for the machine and the control strategy for the thermodynamic process, which still need to be mastered. But cost-benefit calculations are also highly promising. "The manufacturing and operation of our very first pilot machine almost covers its costs," says Omanovic, "which is by no means a matter of course for an innovative technology in complex mechanical engineering." ■

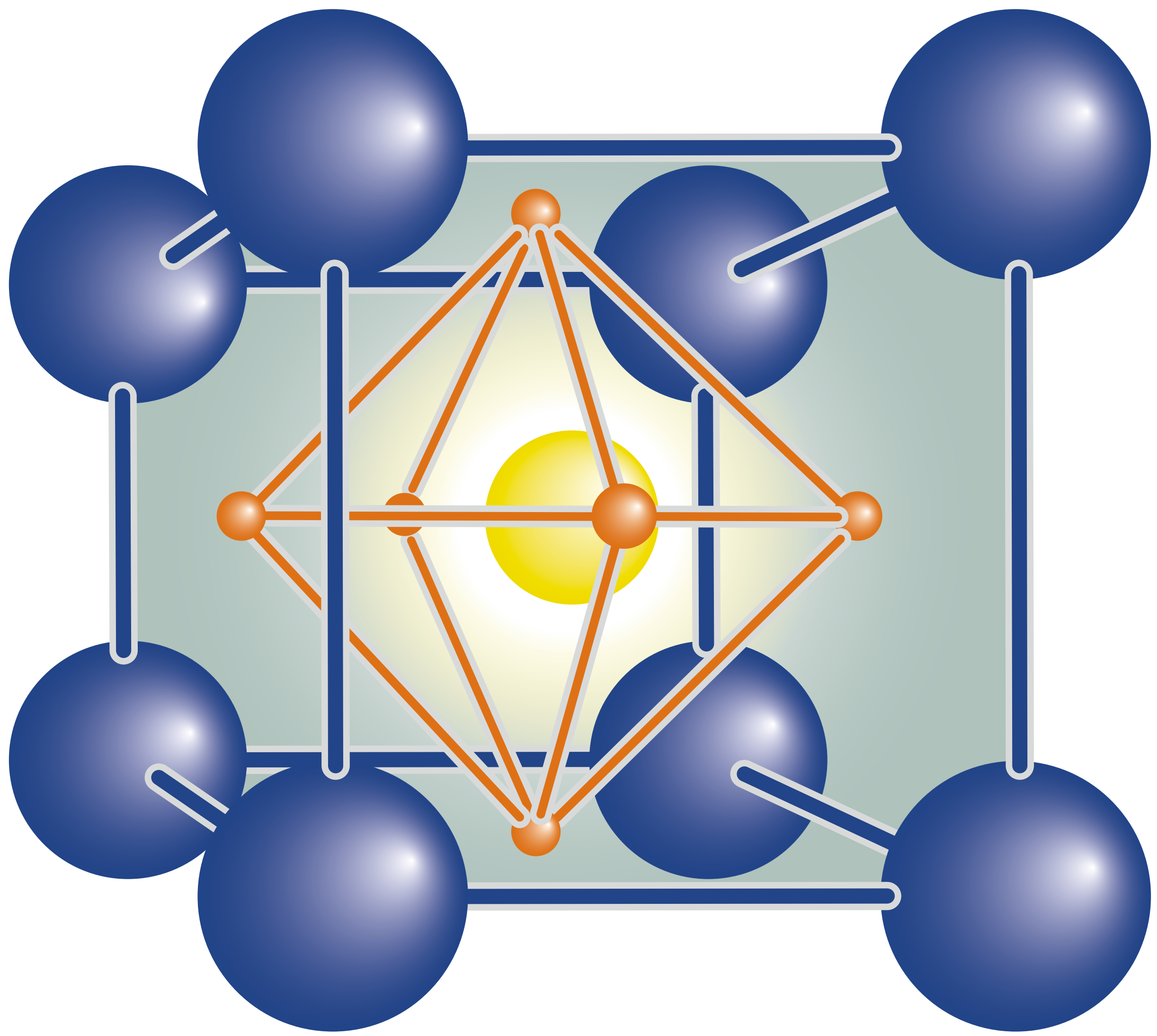
Photos: Empa

**STAR OF THE SHOW**
Pistons, like those used in combustion engines, are at the core of etavalve's machine.

# CRYSTALLINE ALLROUNDER

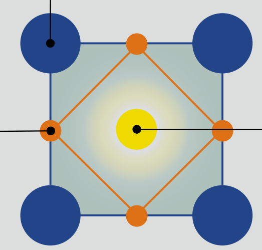
Perovskites are a group of materials with a special crystal structure. This structure gives them unusual physical properties, which can be precisely controlled by varying the exact composition of the perovskite. It is therefore no wonder that perovskites are being researched for numerous applications, especially in optoelectronics. Empa scientists are developing solar cells, image sensors and components for quantum computers based on perovskites.

Graphic: Empa



## *Crystal construction set*

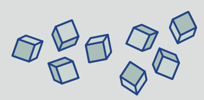
**A** **A large cation**
e.g. cesium or formamidinium



**X** **An anion**
e.g. a halide:
a negatively charged ion of a halogen such as chlorine, bromine or iodine

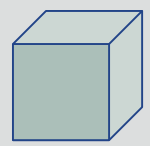
**B** **A smaller cation**
e.g. lead

## *Applications*



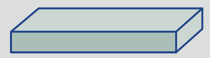
### *Nanocrystals*

Perovskite crystals in the nanometer range exhibit photoluminescence and quantum effects and could be used in novel electronics.



### *Single crystals*

Large single crystals of perovskite (up to one centimeter in size) can function as light or x-ray detectors.



### *Thin films*

Perovskite thin films have promising applications in the manufacture of flexible solar cells.

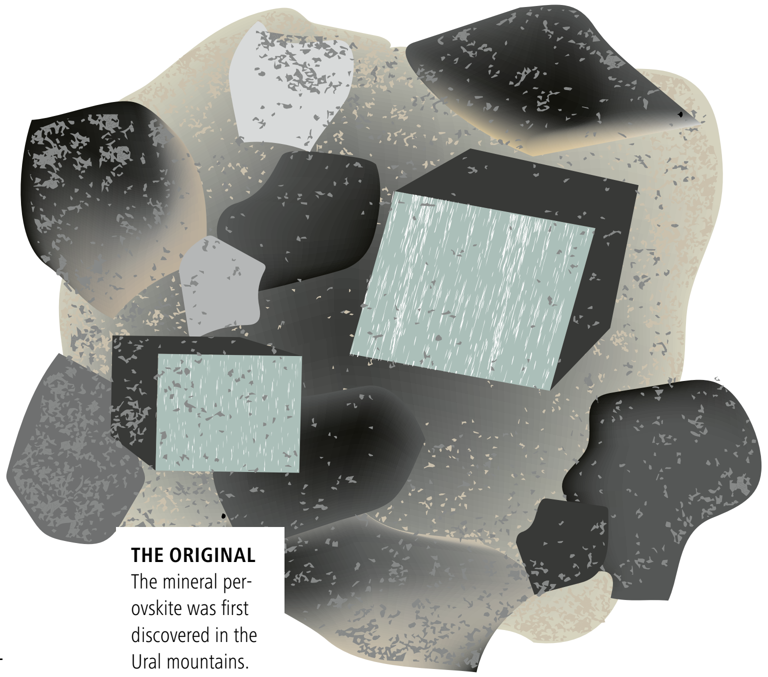
# A BRIEF HISTORY OF PEROVSKITES

The word "perovskite" describes a naturally occurring mineral, but also a whole range of highly specialized synthetic compounds that have promising applications in electronics and photovoltaics. But what do they actually have in common? And who discovered them?

Text: Anna Ettlin

In 1839, the German mineralogist Gustav Rose received a peculiar rock sample from the Ural Mountains. Embedded in the stone was a cubic crystal about seven millimeters in size made of a previously unknown mineral. Rose named the newly discovered mineral perovskite after the Russian nobleman, mineralogist and sponsor of Rose's work – Lev Perovski.

The remarkable crystal structure of perovskite was described in 1926 by the Swiss-Norwegian scientist Victor Goldschmidt. It is based on the chemical formula $ABX_3$, where A and B are positively charged ions, also known as cations. X is a negatively charged anion. In the original perovskite, calcium titanate, A and B are calcium and titanium cations, respectively, while X is an oxygen anion.



**THE ORIGINAL**
The mineral perovskite was first discovered in the Ural mountains.

It is also possible to synthesize perovskites from other A, B and X components. Particularly renowned are lead halide perovskites, which contain lead at the B site and X is a halogen anion such as chloride, bromide or iodide. The A site contains a large cation, usually either cesium or an organic cation such as methylammonium or formamidinium. Lead halide perovskites are good semiconductors whose properties can be fine-tuned by varying their exact composition. They are easy to produce as, for instance, thin films and large single crystals, from ordinary chemicals and solvents, or from melts.

Empa researchers who are working on various applications for lead halide perovskites are taking advantage of their unique properties. In 2014, the team of Maksym Kovalenko at ETH Zurich and Empa, including Maryna Bodnarchuk at Empa's Laboratory for Thin Films and Photovoltaics, for the first time synthesized tiny and monodisperse perovskite nanocrystals, known as quantum dots. They continue intense materials design work in this direction (page 15). Kovalenko's group is also conducting research into image sensors with thin-film perovskites (page 20) as well as gamma and X-ray detectors using single-crystal perovskite layers.

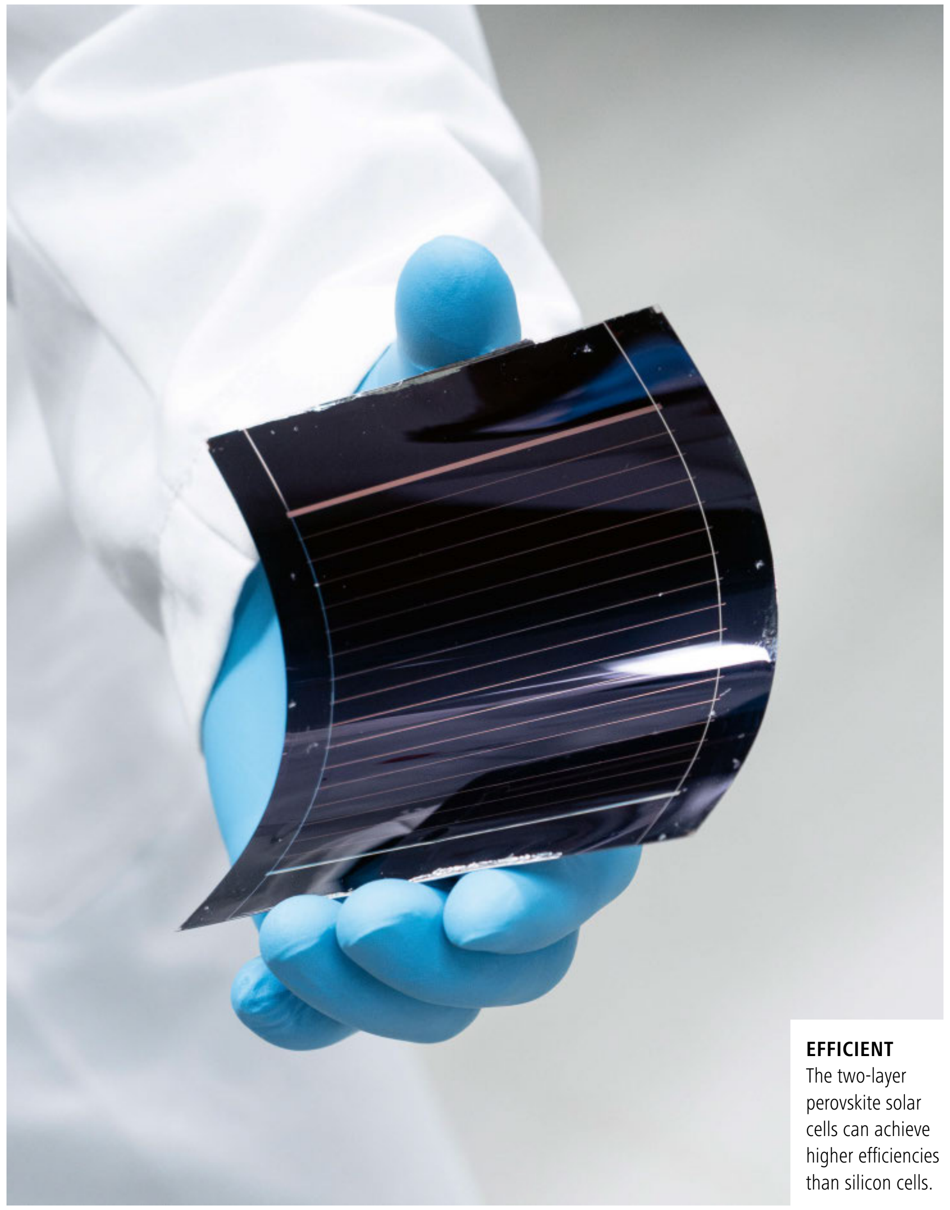
Empa researcher Fan Fu and his team, on the other hand, are focusing on perovskite solar cells (page 18), which promise high efficiency and flexibility. The Laboratory for Functional Polymers, headed by Frank Nüesch, is also working on perovskite solar cells. In 2020, it gave rise to the spin-off Perovskia Solar, only around 30 years after perovskite solar cells were first described – and 181 years after Gustav Rose first obtained the unusual crystal. ■

Graphic: Empa

Photo: Empa







**EFFICIENT**
The two-layer perovskite solar cells can achieve higher efficiencies than silicon cells.

# POWER COUPLE

Two layers for more efficiency: perovskite-based tandem solar cells can capture more sunlight than conventional silicon solar cells. These lightweight and flexible cells have already proven themselves in the laboratory – now, Empa researchers are working on scaling them up and making them ready for the real world.

Text: Anna Ettlin

**MICROSCOPY**
Fan Fu, Severin Siegrist and Federico De Giorgi (from left) examine the solar cells.

**FLEXIBLE SQUARES**
Three prototypes of the perovskite-based thin film solar cells.

Roof tiles are becoming a thing of the past: Today, more and more Swiss roofs boast large black and blue rectangles that convert sunlight into electricity. The blueish color comes from silicon crystals, as the majority of solar cells available today are based on this semiconductor material. But silicon is not the only way to make a solar cell – and possibly not even the best.

Silicon-based photovoltaic cells have been perfected so far that they are reaching the limits of their efficiency. Although a few percentage points of improvement could still be gained, the theoretical upper limit for the efficiency of a single silicon cell is 33 percent. In practice, it is somewhat lower, as small energy losses inevitably occur during the construction and operation of the cells.

The reason for this hard efficiency limit lies in the material properties of silicon. The so-called band gap of the material means that only photons with a certain energy can be converted into electricity. If the energy of the photon is too high, it cannot be fully "utilized" by the solar cell.

## TWO LAYERS ARE BETTER THAN ONE

Solar cells made from other materials offer a way to overcome this limitation, says Empa researcher Fan Fu. The group leader in the Laboratory for Thin Films and Photovoltaics is researching highly efficient solar cells made of perovskite. A single perovskite cell alone does not achieve a higher efficiency, because perovskite as a semiconductor also has a limited band gap. The real strength of this innovative material lies in the fact that, unlike silicon, this band gap can be easily adjusted by varying the exact composition of the perovskite material.

If two perovskites with different band gaps are processed into thin films solar cells and "stacked" on top of each other, the result is a so-called tandem solar cell. One perovskite layer "catches" the photons with high energy, the other one those with low energy. In theory, this allows efficiencies of up to 45 % – much higher than the 33 % of single-junction cells. Alternatively, a perovskite layer can also be added to a silicon cell to create a highly efficient tandem cell.

> "Perovskite cells have a lower $CO_2$ footprint than traditional silicon cells"

However, Fu and his team are currently focusing on all-perovskite tandem cells, in particular as part of the EU research project SuPerTandem, in which a total of 15 European leading research institutions and companies are involved. The aim of the project is to develop flexible perovskite tandem modules with an efficiency of over 30 percent, which can also be produced using scalable and cost-effective processes. This is another strength of perovskite solar cells: "Silicon solar cells usually require high-purity silicon monocrystals that are produced at high temperatures," explains Fu. "Perovskite thin films, on the other hand, can be printed, solution-processed or produced by vapor deposition with a very low $CO_2$ footprint. Small defects that occur in the process only have a minor impact on their optoelectronic properties."

Photos: Empa

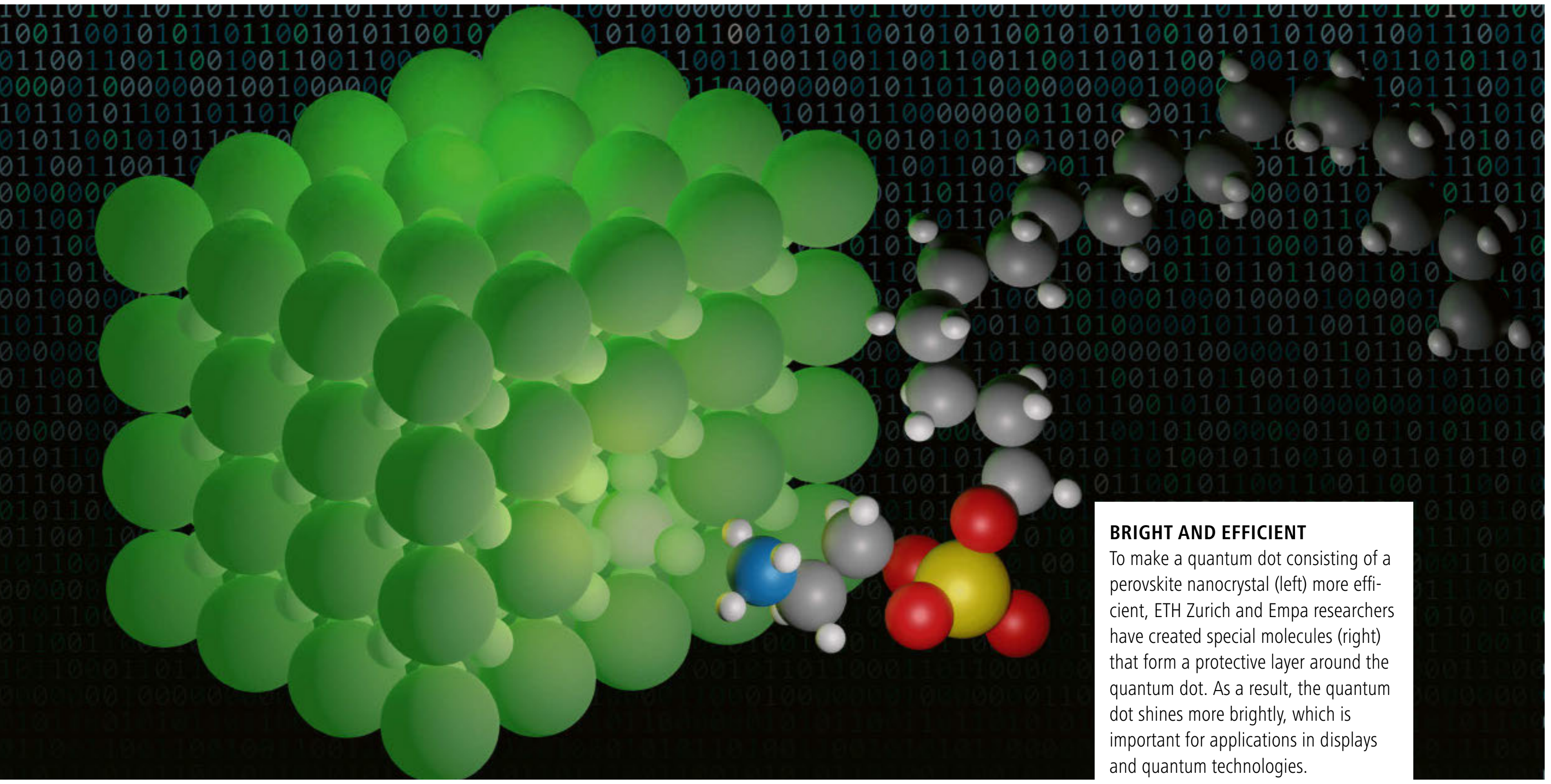
The potential benefits of projects like SuPerTandem are significant, because the higher the efficiency, the less expensive solar power will be at the end of the day. "The cell itself only accounts for less than 20 percent of the cost of a PV system," says Fu. "The remaining 80 percent is accounted for by the cables, the inverters, the junction box and, of course, the labor involved in installation." If the efficiency of the individual cells is increased, a smaller – and therefore more affordable – PV system is sufficient for the same electricity output. Thin-film cells made of perovskite can also be produced on lightweight flexible films instead of heavy, rigid glass plates like silicon cells. This means they can also be used in more locations, for instance on car roofs or on buildings with a low load-bearing capacity.

## FROM THE LAB TO THE ROOF

This potential of perovskite solar cells must now be exploited. In addition to SuPerTandem, Fan Fu's team is also working on two Swiss projects. In a project funded by the Swiss National Science Foundation (SNSF), Empa researchers are working to better understand the fundamental properties and challenges of perovskite solar cells that contribute to their efficiency and stability. And in a project with the Swiss Federal Office of Energy (SFOE), they are putting their existing knowledge into practice by scaling up the tandem cells already developed at Empa.

What else do we need to do to ensure that the black and blue rectangles on our roofs are joined by reddish perovskite films? "First of all, we have to scale up the perovskite cells from the current prototypes of a few centimeters to industrial sizes," says Fu. The cells, which are still somewhat fragile, also need to be effectively protected from the weather. Fan Fu is optimistic that both will be achieved in the next five to ten years. "We are making good progress, and there is a lot of interest from industry," says the scientist. "Researchers have only been working on perovskite-based solar cells for just under 15 years. For comparison, research into silicon cells has been going on for almost 70 years." ■

# SHINE BRIGHT



**BRIGHT AND EFFICIENT**
To make a quantum dot consisting of a perovskite nanocrystal (left) more efficient, ETH Zurich and Empa researchers have created special molecules (right) that form a protective layer around the quantum dot. As a result, the quantum dot shines more brightly, which is important for applications in displays and quantum technologies.

Graphic: Kovalenko Lab

Researchers at Empa and ETH Zurich have developed new methods for making perovskite quantum dots faster and more efficient light emitters, thereby significantly improving their brightness. This is relevant for applications in displays as well as for quantum technologies.

Text: Oliver Morsch / ETH Zurich

Quantum dots are a kind of artificial atom: Just a few nanometers in size and made of semiconductor materials, they can emit light of a specific color or, in extreme cases, even single photons, which is crucial for quantum technologies. The discoverers and pioneers of the commercial production of quantum dots, Moungi G. Bawendi, Louis E. Brus and Aleksey Yekimov, were awarded the Nobel Prize in Chemistry last year.

In recent years, quantum dots made of perovskites have attracted particular attention. Perovskites belong to a class of materials that have a similar structure to the mineral perovskite (calcium titanate). Quantum dots made of such materials were produced for the first time by team of researchers led by Maksym Kovalenko at ETH Zurich and Empa in 2014. These quantum dots made of perovskite nanocrystals can be mixed with liquids to form a dispersion, which makes them easy to process further. Moreover, their special optical properties make them shine more brightly than many other quantum dots. They can also be produced more cheaply, which makes them interesting for applications in displays, for instance.

Working in collaboration with their counterparts in Ukraine and the USA, Kovalenko's team at ETH and Empa has now demonstrated how these promising properties of perovskite quantum dots can be improved further. They used chemical methods for surface treatment and quantum mechanical effects that had never before been observed in perovskite quantum dots. The researchers recently published their results in two papers in the prestigious scientific journal Nature.

## "UNHAPPY" ATOMS REDUCE BRIGHTNESS

Brightness is an important measure for quantum dots and is related to the number of photons the quantum dot emits per second. Quantum dots radiate photons of a specific color (and hence frequency) after being excited, for example, by ultraviolet light of a higher frequency. This leads to the formation of an exciton consisting of an electron, which can now move more freely, and a hole – in other words, a missing electron – in the energetic band structure of the material. The excited electron can fall back to a lower energy state and thus recombine with the hole. If the energy released during this process is converted into a photon, the quantum dot emits light.

This doesn't always work, however. "At the surface of the perovskite nanocrystals are 'unhappy' atoms that are missing a neighbor in the crystal lattice," ETH researcher Gabriele Raino explains. These edge atoms disturb the balance between positive and negative charge carriers inside the nanocrystal and can cause the energy released during a recombination to be converted into lattice vibrations instead of being emitted as light. As a result, the quantum dot "blinks", meaning that it doesn't shine continuously.

## A PROTECTIVE COATING MADE OF PHOSPHOLIPIDS

To prevent this from happening, Kovalenko and his team have developed tailor-made molecules known as phospholipids. "These phospholipids are very similar to the liposomes in which, for instance, the mRNA vaccine against the coronavirus is embedded in such a way as to make it stable in the bloodstream until it reaches the cells," Kovalenko explains. An important difference: The researchers optimized their molecules so that the polar, or electrically sensitive, part of the molecule latches on to the surface of the perovskite quantum dots and makes sure that the "unhappy" atoms are provided with a (charge) partner.

The nonpolar part of the phospholipid that protrudes on the outside also makes it possible to turn quantum dots into a dispersion in non-aqueous solutions such as organic solvents. The lipid coating on the surface of the perovskite nanocrystals is also important for their structural stability, as Kovalenko points out: "This surface treatment is essential for anything we might want to do with the quantum dots." So far, Kovalenko and his team have demonstrated the treatment for quantum dots made of lead halide perovskites, but it can also be easily adapted to other metal halide quantum dots.

## EVEN BRIGHTER THANKS TO SUPERRADIANCE

With the lipid surface, it was possible to massively reduce the blinking of the quantum dots; eventually, a photon was emitted in 95 percent of electron-hole recombination events. To make the quantum dot even brighter, however, the researchers had to increase the speed of the recombination itself – and that requires quantum mechanics. An excited state, such as an exciton, decays when a dipole – positive and negative charges displaced with respect to each other – interacts with the electromagnetic field of the vacuum. The larger the dipole, the faster the decay. One possibility of creating a larger dipole involves coherently coupling several smaller dipoles to each other. This can be compared to pendulum clocks that are mechanically connected and tick in step with each other after a certain time.

The researchers were able to show experimentally that this coherent coupling also works in perovskite quantum dots – with only a single exciton dipole that, through quantum mechanical effects, spreads out all over the volume of the quantum dot, thereby creating several copies of itself, as it were. The larger the quantum dot, the more copies can be created. These copies can bring about an effect known as superradiance, by which the exciton recombines much faster. As a consequence, the quantum dot is faster at taking up another exciton and is thus capable of emitting more photons per second, making it even brighter. An important detail: The brighter quantum dot continues to emit single photons (not several photons at once), which makes it suitable for quantum technologies.

The improved perovskite quantum dots are not only of interest for light production and displays, says Kovalenko, but also for other, less obvious fields. For instance, they could be used as light-activated catalysts in organic chemistry. Kovalenko is conducting research into such applications and several others, for instance within the National Center of Competence in Research (NCCR) Catalysis. ■

# PIXELS TIMES THREE

Capturing three times more light: Empa and ETH researchers are developing an image sensor made of perovskite that could deliver true-color photos even in poor lighting conditions. Unlike conventional image sensors, where the pixels for red, green and blue lie next to each other in a grid, perovskite pixels can be stacked, thus greatly increasing the amount of light each individual pixel can capture.

Text: Anna Ettlin

Family, friends, vacations, pets: Today, we take photos of everything that comes in front of our lens. Digital photography, whether with a cell phone or camera, is simple and hence widespread. Every year, the latest devices promise an even better image sensor with even more megapixels. The most common type of sensor is based on silicon, which is divided into individual pixels for red, green and blue (RGB) light using special filters. However, this is not the only way to make a digital image sensor – and possibly not even the best.

A consortium comprising Maksym Kovalenko from Empa's Thin Films and Photovoltaics laboratory, Ivan Shorubalko from Empa's Transport at Nanoscale Interfaces laboratory, as well as ETH Zurich researchers Taekwang Jang and Sergii Yakunin, is working on an image sensor made of perovskite capable of capturing considerably more light than its silicon counterpart. In a silicon image sensor, the RGB pixels are arranged next to each other in a grid. Each pixel only captures around one-third of the light that reaches it. The remaining two-thirds are blocked by the color filter.

Pixels made of lead halide perovskites do not need an additional filter: it is already "built into" the material, so to speak. Empa and ETH researchers have succeeded in producing lead halide perovskites in such a way that they only absorb the light of a certain wavelength – and therefore color – but are transparent to the other wavelengths. This means that the pixels for red, green and blue can be stacked on top of each other instead of being arranged next to each other. The resulting pixel can absorb the entire wavelength spectrum of visible light. "A perovskite sensor could therefore capture three times as much light per area as a conventional silicon sensor," explains Empa researcher Shorubalko. Moreover, perovskite converts a larger proportion of the absorbed light into an electrical signal, which makes the image sensor even more efficient.

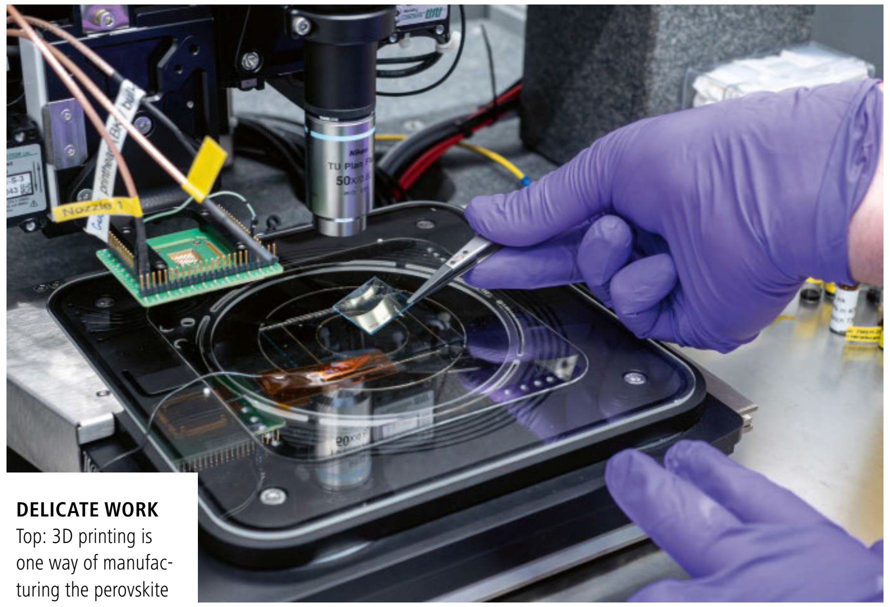
Kovalenko's team was first able to fabricate individual functioning stacked perovskite pixels in 2017. To make the next step towards real image sensors, the ETH-Empa consortium led by Kovalenko had partnered with the electronics industry. "The challenges to address include finding new materials fabrication and patterning processes, as well as design and implementation of the perovskite-compatible read-out electronic architectures", emphasizes Kovalenko. The researchers are now working on miniaturizing the pixels, which were originally up to five millimeters in size, and assembling them into a functioning image sensor. "In the laboratory, we don't produce the large sensors with several megapixels that are used in cameras," explains Shorubalko, "but with a sensor size of around 100'000 pixels, we can already show that the technology works."

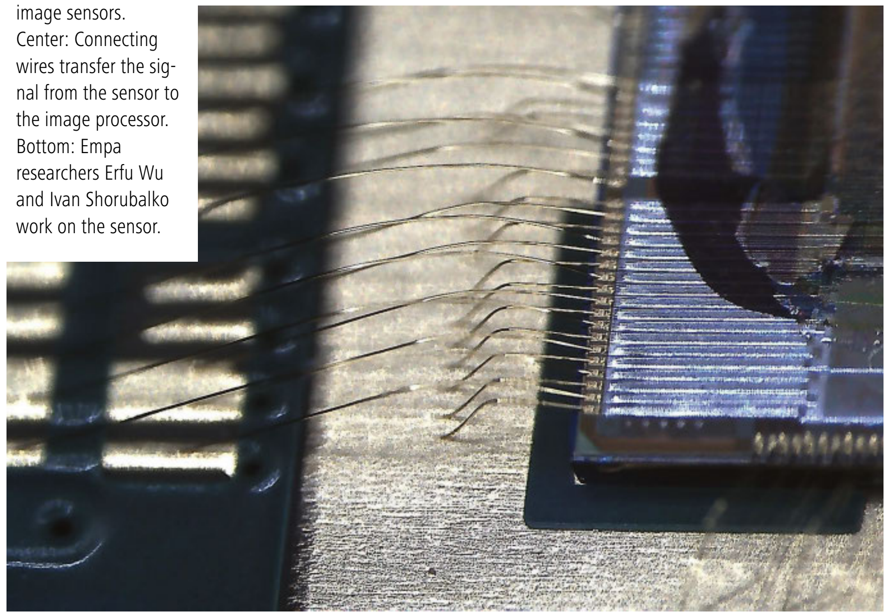
## GOOD PERFORMANCE WITH LESS ENERGY

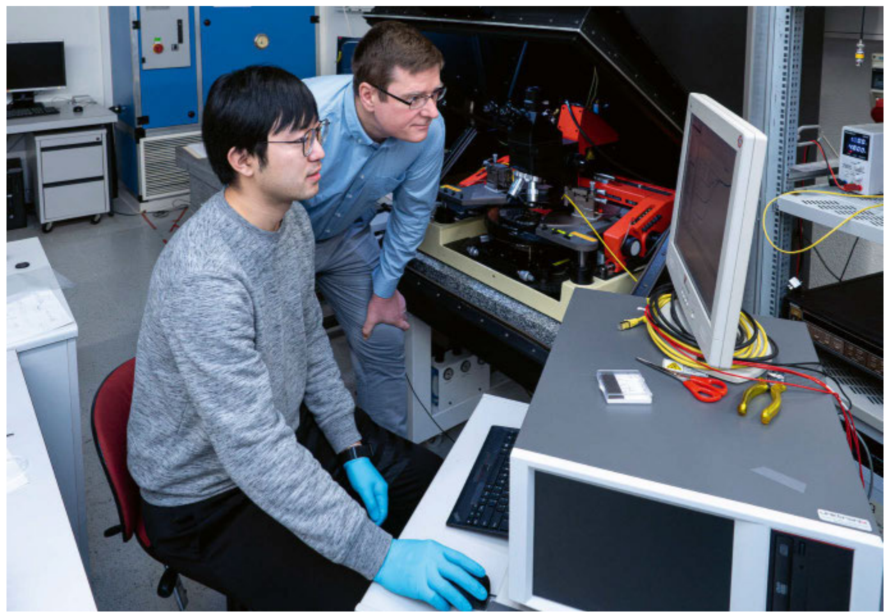
Another advantage of perovskite-based image sensors is their manufacture. Unlike other semiconductors, perovskites are less sensitive to material defects and can therefore be fabricated relatively easily, for example by depositing them from a solution onto the carrier material. Conventional image sensors, on the other hand, require high-purity monocrystalline silicon, which is produced in a slow process at almost 1500 degrees Celsius.

The advantages of perovskite-based image sensors are apparent. It is therefore not surprising that the research project also includes a partnership with industry. The challenge lies in the stability of perovskite, which is more sensitive to environmental influences than silicon. "Standard processes would destroy the material," says Shorubalko. "So we are developing new processes in which the perovskite remains stable. And our partner groups at ETH Zurich are working on ensuring the stability of the image sensor during operation."

If the project, which will run until the end of 2025, is successful, the technology will be ready for transfer to industry. Shorubalko is confident that the promise of a better image sensor will attract cell phone manufacturers. "Many people today choose their smartphone based on the camera quality because they no longer have a stand-alone camera," says the researcher. A sensor delivering excellent images in much poorer lighting conditions could be a major advantage. ■







**DELICATE WORK**
Top: 3D printing is one way of manufacturing the perovskite image sensors. Center: Connecting wires transfer the signal from the sensor to the image processor. Bottom: Empa researchers Erfu Wu and Ivan Shorubalko work on the sensor.

Photos: Empa

# ILLUMINATED IN THE DARK

The best way to treat kidney stones depends on what they are composed of and how they are shaped. Empa researchers are now working on a painless diagnostic procedure using dark-field X-ray imaging. This innovative technology makes it possible to determine the structure and composition of the stones for each patient. The Maiores Foundation is funding the recently launched project.

Text: Andrea Six

Graphic: Empa

### PRIVATE FUNDING THAT MAKES THE DIFFERENCE

The "Empa Zukunftsfonds" is looking for private funding for pioneering research projects that are not yet supported otherwise. If you would also like to give an additional boost to our research, you can find more information here: www.empa.ch/web/zukunftsfonds

Those affected report severe pain: Although kidney stones can go unnoticed for a long time, for many people they cause discomfort at some point in their lives. More than five percent of the population suffer from these multifaceted crystals. The most suitable therapy for this widespread disease depends on the stones' shapes and chemical composition. "Sometimes, however, the type of stone can only be identified once it has been removed by surgery," explains Robert Zboray from Empa's Center for X-ray Analytics.

Such a (costly) operation is not always necessary, though. In some cases, a far more cost-effective change in eating and drinking habits is sufficient. Empa researchers are developing a new diagnostic procedure based on advanced X-ray technologies to ensure that the right treatment – i.e. one that is tailored to each individual patient – is being applied. The new project has recently received support of the Maiores Foundation in Liechtenstein.

### PRECISE AND EFFICIENT

Zboray and his team are looking for biomedical imaging methods that can be used to determine the content, shape and position of kidney stones precisely, cost-effectively and painlessly. Dark-field X-ray imaging is particularly suitable for this. This innovative, multimodal technology uses scattered radiation, which is produced by the interaction of X-rays and kidney stones, on the one hand, and direct radiation, which simultaneously produces a conventional X-ray image, on the other. The combination of the two types of images enables a particularly sensitive determination of the composition of the stone. This even makes it possible to visualize nearly transparent objects as well as fine details of the microstructure. "Our goal is to be able to convert standard X-ray machines in GP offices and hospitals to the new dark-field technology as cost-effectively as possible," says the Empa researcher. ■

# WHEN NANOPLASTICS ARE NOT WHAT THEY SEEM

Textiles made of synthetic fibers release micro- and nanoplastics during washing. Empa researchers have now been able to show: some of the supposed nanoplastics do not actually consist of plastic particles, but of water-insoluble oligomers. The effects they have on humans and the environment are not yet well-understood.

Text: Anna Ettlin

Plastic household items and clothing made of synthetic fibers release microplastics: particles less than five millimetres in size that can enter the environment unnoticed. A small proportion of these particles are so small that they are measured in nanometers. Such nanoplastics are the subject of intensive research, as nanoplastic particles can be absorbed into the human body due to their small size – but, as of today, little is known about their potential toxicity.

Empa researchers from Bernd Nowack's group in the Technology and Society laboratory have now joined forces with colleagues from China to take a closer look at nanoparticles released from textiles. Tong Yang, first author of the study, carried out the investigations during his doctorate at Empa. In earlier studies, Empa researchers were already able to demonstrate that both micro- and nanoplastics are released when polyester is washed. A detailed examination of the released nanoparticles released has now shown that not everything that appears to be nanoplastic at first glance actually is nanoplastic.

To a considerable extent, the released particles were in fact not nanoplastics, but clumps of so-called oligomers, i.e. small to medium-sized molecules that represent an intermediate stage between the long-chained polymers and their individual building blocks, the monomers. These molecules are even smaller than nanoplastic particles, and hardly anything is known about their toxicity either. The researchers published their findings in the journal Nature Water.

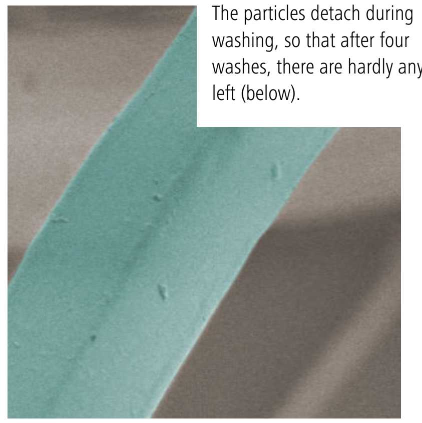
For the study, the researchers examined twelve different polyester fabrics, including microfiber, satin and jersey. The fabric samples were washed up to four times and the nanoparticles released in the process were analyzed and characterized. Not an easy task, says Bernd Nowack. "Plastic, especially nanoplastics, is everywhere, including on our devices and utensils," says the scientist. "When measuring nanoplastics, we have to take this 'background noise' into account."

Photos: Adobe Stock, Empa

**RELEASE**
Textiles made of synthetic fibers release nanoparticles during washing.

## LARGE PROPORTION OF SOLUBLE PARTICLES

The researchers used an ethanol bath to distinguish nanoplastics from clumps of oligomers. Plastic pieces, no matter how small, do not dissolve in ethanol, but aggregations of oligomers do. The result: Around a third to almost 90 percent of the nanoparticles released during washing could be dissolved in ethanol. "This allowed us to show that not everything that looks like nanoplastics at first glance is in fact nanoplastics," says Nowack.



**BEFORE AND AFTER**
The nanoparticles on the surface of the fleece fiber are visible under a scanning electron microscope (above). The particles detach during washing, so that after four washes, there are hardly any left (below).

It is not yet clear whether the release of so-called nanoparticulate oligomers during the washing of textiles has negative effects on humans and the environment. "With other plastics, studies have already shown that nanoparticulate oligomers are more toxic than nanoplastics," says Nowack. "This is an indication that this should be investigated more closely." However, the researchers were able to establish that the nature of the textile and the cutting method – scissors or laser – have no major influence on the quantity of particles released.

The mechanism of release has not been clarified yet either – neither for nanoplastics nor for the oligomer particles. The good news is that the amount of particles released decreases significantly with repeated washes. It is conceivable that the oligomer particles are created during the manufacturing of the textile or split off from the fibers through chemical processes during storage. Further studies are also required in this area.

Nowack and his team are focusing on larger particles for the time being: In their next project, they want to investigate which fibers are released during washing of textiles made from renewable raw materials and whether these could be harmful to the environment and health. "Semi-synthetic textiles such as viscose or lyocell are being touted as a replacement for polyester," says Nowack. "But we don't yet know whether they are really better when it comes to releasing fibers. ■

# INNER VALUES

Medical products such as ointments or syringes reach their limits when it comes to delivering medication locally – and above all in a controlled manner over a longer period of time. Empa researchers are therefore developing polymer fibers that can deliver active ingredients precisely over the long term. These "liquid core fibers" contain drugs inside and can be processed into medical textiles.

Text: Andrea Six

**PRECISION**
Empa researcher Edith Perret is developing special fibers that can deliver drugs in a targeted manner.

Treating a wound or an inflammation directly where it occurs has clear advantages: The active ingredient reaches its target immediately, and there are no negative side effects on uninvolved parts of the body. However, conventional local administration methods reach their limits when it comes to precisely dosing active ingredients over a longer period of time. As soon as an ointment leaves the tube or the injection fluid flows out of the syringe, it is almost impossible to control the amount of active ingredient. Edith Perret from Empa's Advanced Fibers laboratory in St. Gallen is therefore developing medical fibers with very special "inner values": The polymer fibers enclose a liquid core with therapeutic ingredients. The aim: medical products with special capabilities, e.g. surgical suture material, wound dressings and textile implants that can administer painkillers, antibiotics or insulin precisely over a longer period of time. Another aim is to achieve individual, patient-specific dosage of the drug in the sense of personalized medicine.

## BIOCOMPATIBLE AND TAILOR-MADE

A decisive factor that turns a conventional textile fiber into a medical product is the material of the fiber sheath. The team chose polycaprolactone (PCL), a biocompatible and biodegradable polymer that is already being used successfully in the medical field. The fiber sheath encloses the valuable substance, such as a painkiller or an antibacterial drug, and releases it over time. Using a unique pilot plant, the researchers produced PCL fibers with a continuous liquid core by means of melt spinning. In initial lab tests, stable and flexible liquid-core fibers were produced. What's more, the Empa team had already successfully demonstrated, together with a Swiss industrial partner, that this process not only works in the lab but also on an industrial scale.

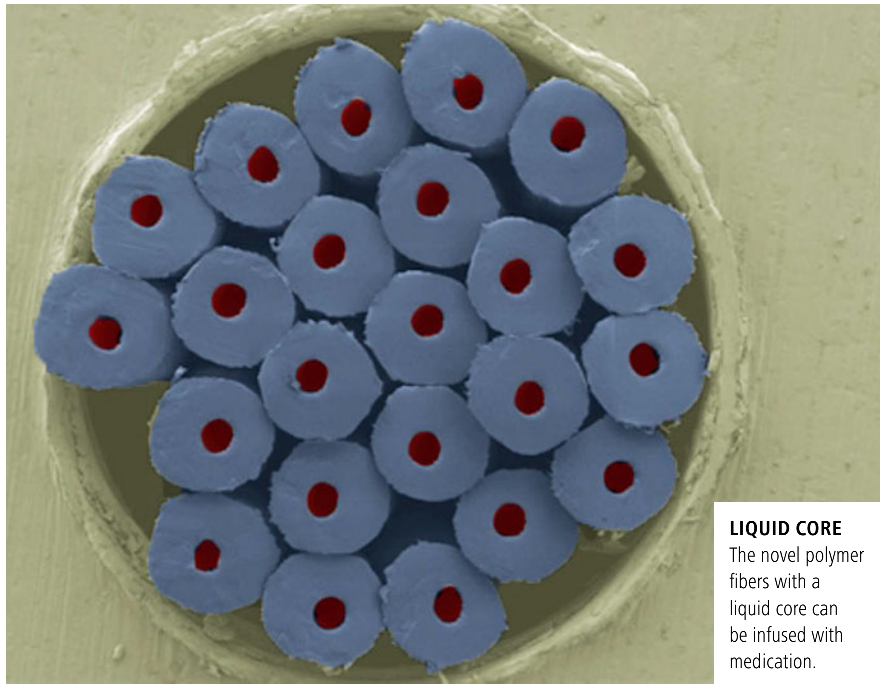
The parameters according to which the medical fibers release an enclosed agent were first investigated using fluorescent model substances and then with various drugs. "Small molecules such as the painkiller ibuprofen move gradually through the structure of the outer sheath," says Edith Perret. Larger molecules, on the other hand, are released at the two ends of the fibers.

## PRECISELY CONTROLLABLE AND EFFECTIVE IN THE LONG TERM

"Thanks to a variety of parameters, the properties of the medical fibers can be precisely controlled," explains the Empa researcher. After extensive analyses using fluorescence spectroscopy, X-ray technology and electron microscopy, the researchers were able to demonstrate, for instance, the influence of the sheath thickness and crystal structure of the sheath material on the release rate of the drugs from the liquid core fibers.

Depending on the active ingredient, the manufacturing process can also be adapted: Active ingredients that are insensitive to high temperatures during melt spinning can be integrated directly into the core of the fibers in a continuous process. For temperature-sensitive drugs, on the other hand, the team was able to optimize the process so that a placeholder initially fills the liquid core, which is replaced later on by the sensitive active ingredient.

One of the advantages of liquid core fibers is the ability to release the active ingredient from a reservoir over a longer period of time. This opens up a wide range of possible applications. With diameters of 50 to 200 micrometers, the fibers are large enough to be woven or knitted into robust textiles, for example. However, the medical fibers could also be guided inside the body to deliver hormones such as insulin, says Perret.



**LIQUID CORE**
The novel polymer fibers with a liquid core can be infused with medication.

### AIMING FOR CLINICAL PARTNERSHIPS

Advancing a new technology? Identifying innovative applications? Empa researcher Edith Perret (edith.perret@empa.ch) is looking for interested clinicians who recognize the potential of drug delivery via liquid core fibers and want to become active in this field.

Another advantage: Fibers that have released their medication can be refilled. The range of active ingredients that can be administered easily, conveniently and precisely using liquid core fibers is large. In addition to painkillers, anti-inflammatory drugs, antibiotics and even lifestyle preparations are conceivable.

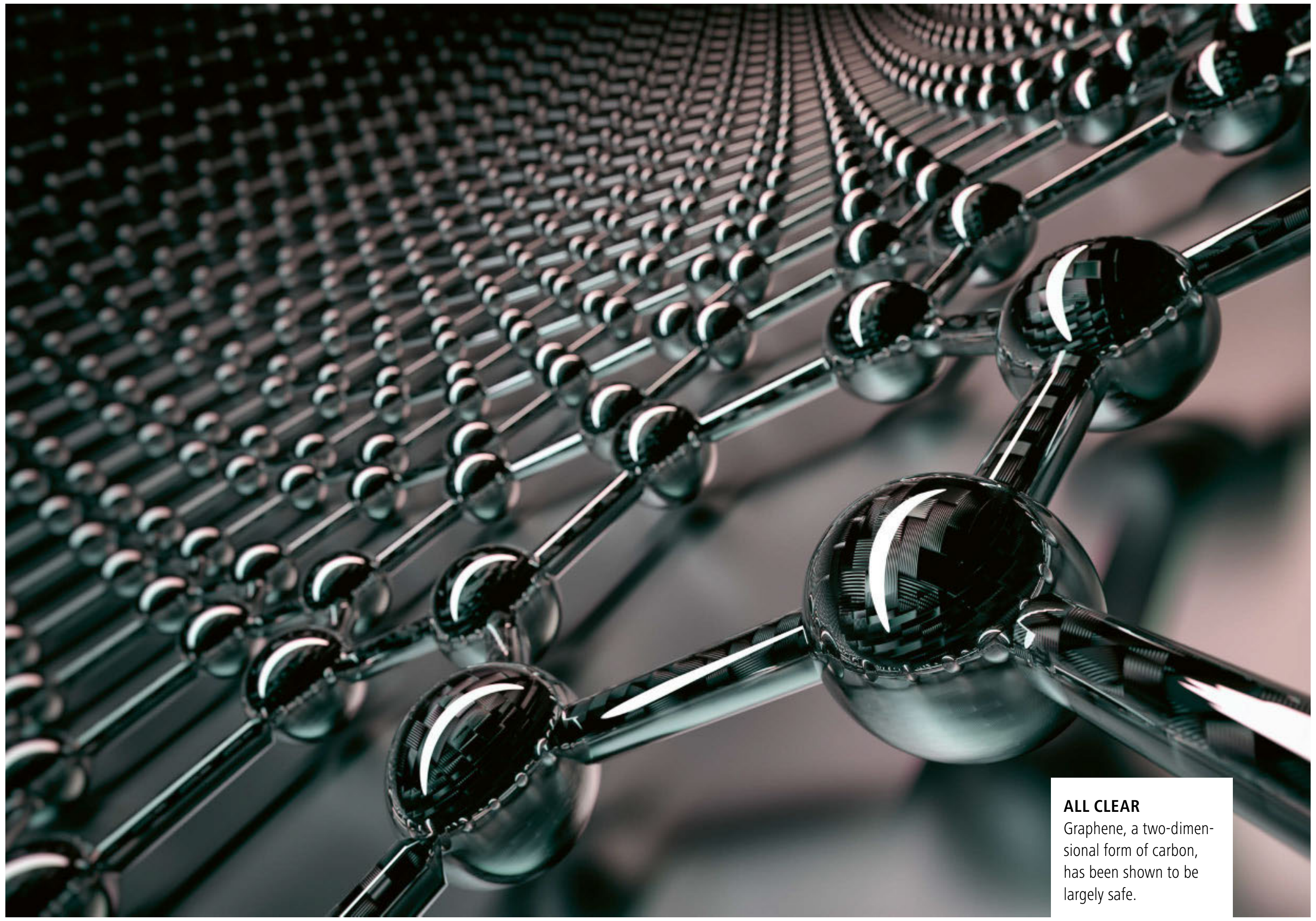
In a next step, the researchers want to equip surgical suture material with antimicrobial properties. The new process will be used to fill various liquid core materials with antibiotics in order to suture tissue during an operation in such a way that wound germs have no chance of causing an infection. Empa researcher Perret is also convinced that future collaboration with clinical partners will form the basis for further innovative clinical applications. ■

Photos: Empa

# GRAPHENE: MOSTLY HARMLESS

The largest EU research initiative ever launched has come to a successful end: the Graphene Flagship was officially concluded at the end of last year. Empa researchers were also involved, such as molecular biologist Peter Wick, who was part of the Health and Environment work package from the very beginning – and has just summarized the findings in this area with international colleagues in a comprehensive review article in the specialist journal ACS Nano.

Text: Michael Hagmann



**ALL CLEAR**
Graphene, a two-dimensional form of carbon, has been shown to be largely safe.

Graphic: Adobe Stock

Think big. Despite its research topic, this could well be the motto of the Graphene Flagship, which was launched in 2013: With an overall budget of one billion euros, it was Europe's largest research initiative to date, alongside the Human Brain Flagship, which was launched at the same time. The same applies to the review article on the effects of graphene and related materials on health and the environment, which Empa researchers Peter Wick and Tina Bürki just published together with 30 international colleagues in the scientific journal ACS Nano; on 57 pages, they summarize the findings on the health and ecological risks of graphene materials, the reference list includes almost 500 original publications.

A wealth of knowledge – which also gives the all clear. "We have investigated the potential acute effects of various graphene and graphene-like materials on the lungs, in the gastrointestinal tract and in the placenta – and no serious acute cell-damaging effects were observed in any of the studies," says Wick, summarizing the results. Although stress reactions can certainly occur in lung cells, the tissue recovers rather quickly. However, some of the newer 2D materials such as boron nitrides, transition metal dichalcogenides, phosphenes and MXenes (p. 4) have not yet been investigated much, Wick points out; further investigations were needed here.

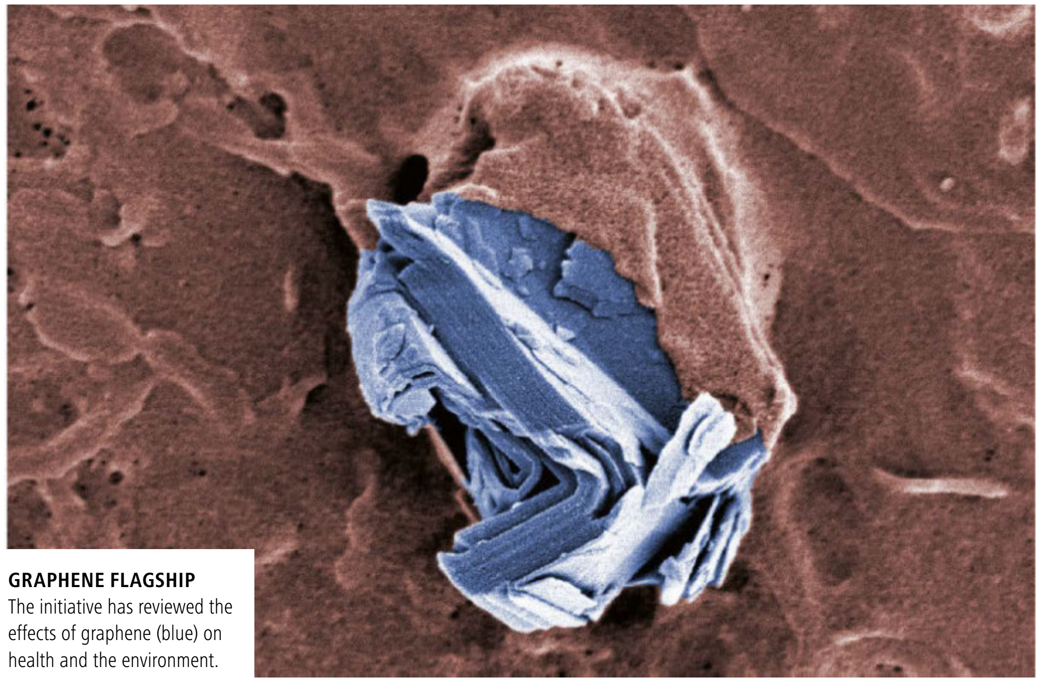
In their analyses, Wick and Co. did not limit themselves to newly produced graphene-like materials, but also looked at the entire life cycle of various applications of graphene-containing materials. In other words, they investigated questions such as: What happens when these materials are abraded or burnt? Are graphene particles released, and can this fine dust harm cells, tissues or the environment?

One example: The addition of a few percent graphene to polymers, such as epoxy resins or polyamides, significantly improves material properties such as mechanical stability or conductivity, but the abrasion particles do not cause any graphene-specific nanotoxic effect on the cells and tissues tested. Wick's team will be able to continue this research even after the flagship project has come to an end, also thanks to funding from the EU as part of so-called Spearhead projects, of which Wick is deputy head.

In addition to Wick's team, Empa researchers led by Bernd Nowack have used material flow analyses as part of the Graphene Flagship to calculate the potential future environmental impact of materials containing graphene and have modeled which ecosystems are likely to be impacted and to what extent. Roland Hischier's team, like Nowack's at Empa's Technology and Society lab, used life cycle assessments to investigate the environmental sustainability of different production methods and application examples for various graphene-containing materials. And Roman Fasel's team from Empa's nanotech@surfaces lab has advanced the development of electronic components based on narrow graphene ribbons.

## A EUROPEAN SUCCESS STORY FOR RESEARCH AND INNOVATION

Launched in 2013, the Graphene Flagship represented a completely new form of joint, coordinated research on an unprecedented scale. The aim of the large-scale project was to bring together researchers from research institutions and industry to bring practical applications based on graphene from the laboratory to the market within ten years, thereby creating economic growth, new jobs and new opportunities for Europe in key technologies. Over its ten-year lifetime, the consortium consisted of more than 150 academic and industrial research teams in 23 countries plus numerous associated members. ▶



**GRAPHENE FLAGSHIP**
The initiative has reviewed the effects of graphene (blue) on health and the environment.

Last September, the ten-year funding period ended with the Graphene Week in Gothenburg, Sweden. The final report impressively demonstrates the success of the ambitious large-scale project: The Flagship has "produced" almost 5,000 scientific publications and more than 80 patents. It has created 17 spin-offs in the graphene sector, which have raised a total of more than 130 million euros in venture capital. According to a study by the German economic research institute WifOR, the Graphene Flagship has led to a total added value of around 5.9 billion euros in the participating countries and created more than 80,000 new jobs in Europe. This means that the impact of the Graphene Flagship is more than 10 times greater than shorter EU projects.

In the course of the project, Empa received a total of around three million Swiss francs in funding – which had a "catalytic" effect, as Peter Wick emphasizes: "We have roughly tripled this sum through follow-up projects totaling around 5.5 million Swiss francs, including further EU projects, projects funded by the Swiss National Science Foundation (SNSF) and direct cooperation projects with our industrial partners – and all this in the last five years."

But the advantage of such projects goes far beyond the generous funding, emphasizes Wick: "It is truly unique to be involved in such a large project and broad network over such a long period of time. On the one hand, it has resulted in numerous new collaborations and ideas for projects. On the other hand, working together with international partners over such a long period of time has a completely different quality, we trust each other almost blindly; and such a well-coordinated team is much more efficient and produces better scientific results," Wick is convinced. Last but not least, many personal friendships came about.

### A NEW DIMENSION: GRAPHENE AND OTHER 2D MATERIALS

Graphene is an enormously promising material. It consists of a single layer of carbon atoms arranged in a honeycomb pattern and has extraordinary properties: exceptional mechanical strength, flexibility, transparency and outstanding thermal and electrical conductivity. If the already two-dimensional material is spatially restricted even more, for example into a narrow ribbon, controllable quantum effects can be created. This could enable a wide range of applications, from vehicle construction and energy storage to quantum computing.

For a long time, this "miracle material" existed only in theory. It was not until 2004 that physicists Konstantin Novoselov and Andre Geim at the University of Manchester were able to specifically produce and characterize graphene. To do this, the researchers removed layers of graphite with a piece of adhesive tape until they had flakes just one atom thick. They were awarded the Nobel Prize in Physics for this work in 2010.

Since then, graphene has been the subject of intensive research. In the meantime, researchers have discovered more 2D materials, such as graphene-derived graphene acid, graphene oxide and cyanographs, which could have applications in medicine. Researchers want to use inorganic 2D materials such as boron nitride or MXenes to build batteries that are more powerful, develop electronic components or improve other materials. ■

Photo: Empa

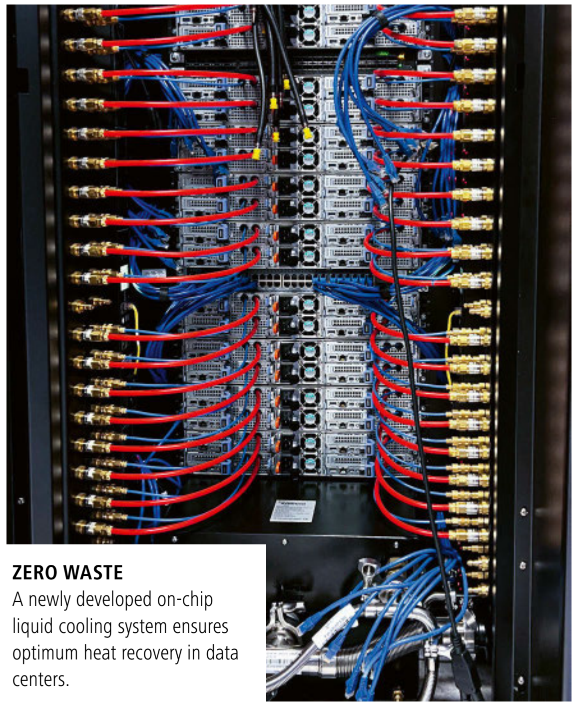
Photo: ZutaCore



# COMPUTERS HEAT BUILDINGS

Zero heat waste: this is the goal of a dozen European companies and research institutions, including Empa, in the Horizon Europe project HEATWISE. The focus is on buildings with extensive IT loads. All waste heat from these systems is to be integrated and utilized in the buildings.

Text: Stephan Kälin



**ZERO WASTE**
A newly developed on-chip liquid cooling system ensures optimum heat recovery in data centers.

Hospitals, universities, research and office buildings have one thing in common: They are packed with technical devices and IT infrastructure. Operating these equipments requires energy – and at the same time generates waste heat that often goes unused. In the Horizon Europe project HEATWISE, twelve research and industry partners from eight countries have joined forces to rethink energy use in buildings with extensive IT loads. "The goal is a zero waste principle," explains Binod Koirala from Empa's Urban Energy Systems lab. "This means that we want to recover as much waste heat as possible and integrate it into the building's heating system." The first task of Binod Koirala and his team will therefore be to identify the potential for heat gains using real data from Empa's research building NEST. They will focus not only on the IT infrastructure – from the servers in the basement to the computers in the offices – but also on the influence of the presence of people on room temperature and potential heat recovery from this.

### NEST AS A PILOT PLANT

The aim is to develop predictive control algorithms that link the energy management of the IT infrastructure with building technology and that can also take other aspects into account. "This includes, for example, the lowest possible $CO_2$ emissions or the most cost-effective operation," says Binod Koirala. These multi-objective control algorithms will then be transferred and implemented in four pilot plants as part of HEATWISE: in an IT research and development center in Poland, in buildings at Aalborg University in Denmark, in a car factory in Turkey and in NEST on the Empa campus in Dübendorf.

### COMPUTING POWER YIELDS HOT WATER

In addition to optimizing energy management, the project is also investigating the use of innovative cooling solutions for high-performance IT systems. For around two years, an edge data center has been operating in the basement of NEST, whose waste heat is already being fed into the medium and low-temperature network and used for heating. The data center, which is currently air-cooled, is now being supplemented by a newly developed on-chip liquid cooling system from Israeli project partner ZutaCore. "This cooling system is designed for optimum heat recovery," explains Koirala. The recovered heat reaches temperatures of up to 70°C. "We can feed this heat directly into the high-temperature network of NEST and use it to power the residents' showers, for example."

The HEATWISE project officially started at the beginning of 2024 and will run for three years. It is supported by the EU as part of the Horizon Europe research and innovation programme and by the Swiss State Secretariat for Education, Research and Innovation (SERI). ■

## EMPA AT WEF


**$CO_2$ AS A RESOURCE**
Mateusz Wyrzykowski presents the new Empa research initiative Mining the Atmosphere.

On the occasion of the World Economic Forum (WEF), the six institutions of the ETH Domain presented highlights from their current research to around 50 high-ranking guests from politics, research and business at the WSL Institute for Snow and Avalanche Research (SLF) in Davos. Among the Empa representatives were Mateusz Wyrzykowski, co-head of Empa's Research Focus Area Built Environment, and Nathalie Casas, head of the Energy, Mobility and Environment department. Guests included Federal Councillor Guy Parmelin, National Council President Eric Nussbaumer, State Secretary Martina Hirayama and the President of the European Research Council (ERC), Maria Leptin, as well as numerous rectors of Swiss universities.

## RAISE A GLASS TO SCIENCE

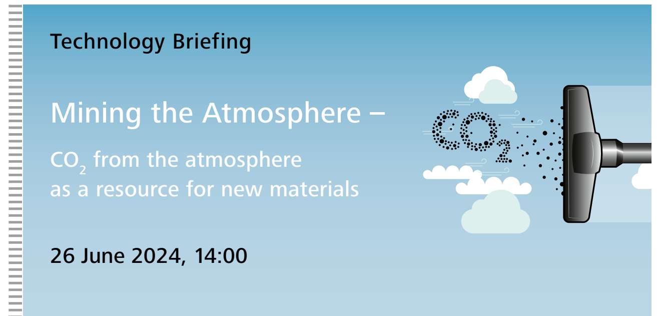

**SCIENCE FOR EVERYONE**
Empa researchers are co-organizing the Pint of Science festival in St. Gallen.

The global science festival Pint of Science will take place from May 13 to 15. During the festival, scientists visit selected bars and cafés and present their research to a wide audience. What started in the United Kingdom in 2013, has grown to include over 400 cities in 25 countries – including Switzerland. The St. Gallen edition of Pint of Science is being organized this year for the second time in a row by researchers from Empa and the Cantonal Hospital of St. Gallen. Speakers will come from Empa, but also from industry and universities in and around St. Gallen. The topics and venues can be found on the festival website.

Photos: Empa

Graphic and photo: Empa

## RECOVERING $CO_2$




If we want to achieve our ambitious climate goals, we must not only curb greenhouse gas emissions, but also "recover" the $CO_2$ that has already been emitted from the atmosphere. At this year's Technology Briefing on the topic of Mining the Atmosphere, Empa researchers will use the latest research results and various practical examples to show how we can extract atmospheric $CO_2$ as a raw material and utilize it in cycles – and at the same time create an entirely new economic system – before the bound greenhouse gas will eventually be deposited in final sinks. The development of $CO_2$-based, value-adding materials and processes will promote and foster the transition from a $CO_2$-emitting to a $CO_2$-binding society. The event will be held in German. Further information on the program and registration can be found on the website.

## EMPA AT SWISSBAU 2024


**MINING THE ATMOSPHERE**
Empa Deputy Director Peter Richner gave a presentation about $CO_2$-negative building materials.

Empa participated at Swissbau 2024 with its NEST research and innovation building. Switzerland's largest trade fair for construction and real estate took place in Basel from January 16 to 19. Experts from Empa and its partners gave keynote lectures and practical talks on sustainable building and innovation in the construction industry and welcomed visitors to the institute's exhibition booth. All presentations are available online.

## EVENTS
### (IN GERMAN AND ENGLISH)

14. MAI 2024
**Kurs:** Klebetechnik für Praktiker
**Zielpublikum**: Industrie und Interessierte an industrieller Klebetechnik
www.empa-akademie.ch/klebetechnik
Empa, Dübendorf

15. MAI 2024
**wissen2go:** Antibiotic Resistance
**Zielpublikum**: Öffentlichkeit
www.empa.ch/web/w2go/antibiotic-resistance
Empa, Dübendorf und online via Zoom

16. MAI 2024
**Topical Day:** Imaging and Image Analysis
**Zielpublikum**: Wissenschaft
www.empa-akademie.ch/imaging
Empa, Dübendorf

26. JUNI 2024
**Technology Briefing:** "Mining the Atmosphere" – $CO_2$ aus der Atmosphäre als Rohstoff für neue Materialien
**Zielpublikum**: Industrie und Wirtschaft
www.empa-akademie.ch/technobriefing
Empa, Dübendorf

25. – 26. SEPTEMBER 2024
**Konferenz:** Swiss ePrint 2024
**Zielpublikum**: Wissenschaft und Industrie
swisseprint.ch
Empa, Dübendorf

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