Empa Quarterly

RESEARCH & INNOVATION II #72 II JULY 2021

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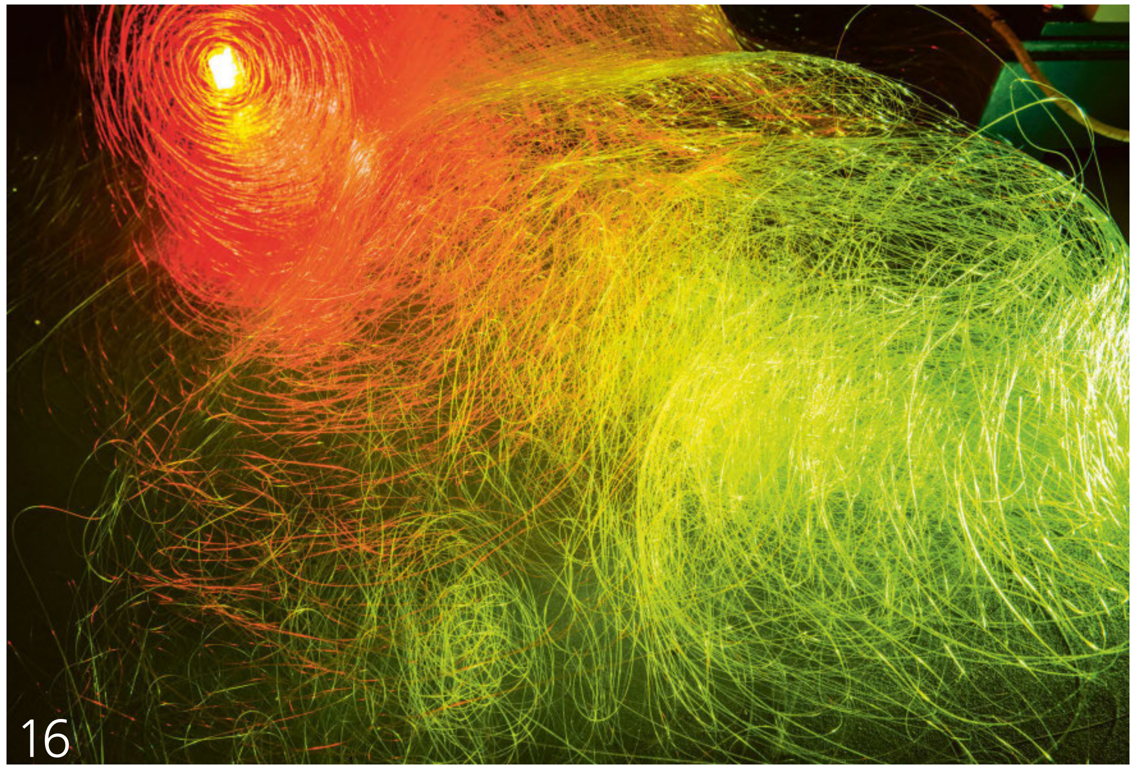
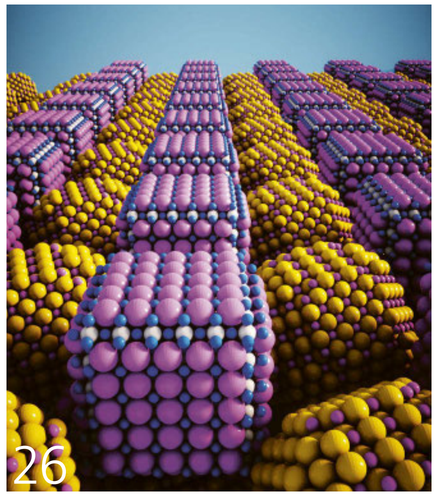
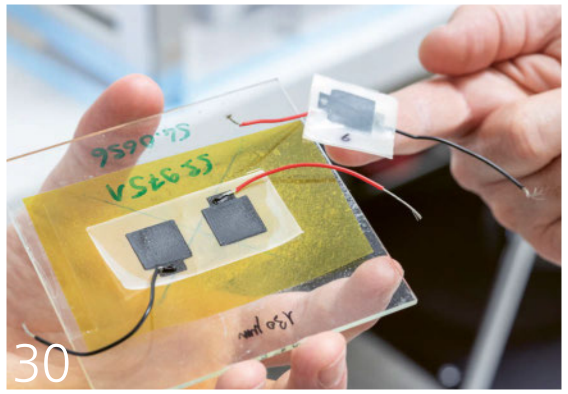
[FOCUS: BETTER FIBERS]







Photos: Gian Vaitl, Nicolas Zonvi, Robert Stürmer, Empa, Pixabay

[COVER]

Everyone knows fibers from torn trouser legs. But Empa fibers can do more: soft cotton becomes fireproof fabric, and liquid-filled polymer can be used as a data line. Empa fibers detect Alzheimer's and make jackets from recycled plastic possible.
Image: iStockphoto

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3D PRINTING FOR PROS

Dear reader,

3D printing has long since reached the mainstream; the Internet is abuzz with more or less useful templates for 3D printers, which are now available on almost all ecommerce platforms. So far, so boring.

But manufacturing a medical implant to replace a defective hip joint, for instance, is probably something that very few hobby 3D printers would dare to do. And quite rightly so, as our photo report from the Swiss m4m Center in Bettlach/Solothurn shows (p. 20). There, patient-specific implants will be manufactured layer by layer from a bed of metal powder. This is an extremely complex, multi-stage process that requires an enormous amount of materials and process engineering expertise.

The Swiss m4m Center is the first Advanced Manufacturing Technology Transfer Center (AM-TTC), a Swiss-wide network that is intended to give Swiss industry a technological edge over international competitors in the field of advanced manufacturing technologies.

Incidentally, this idea originated at Empa as a kind of extension of our very own Coating Competence Center. It's good to see that this is now bearing fruit: The m4m network now counts almost 50 partner institutions.

Enjoy reading!

Your MICHAEL HAGMANN

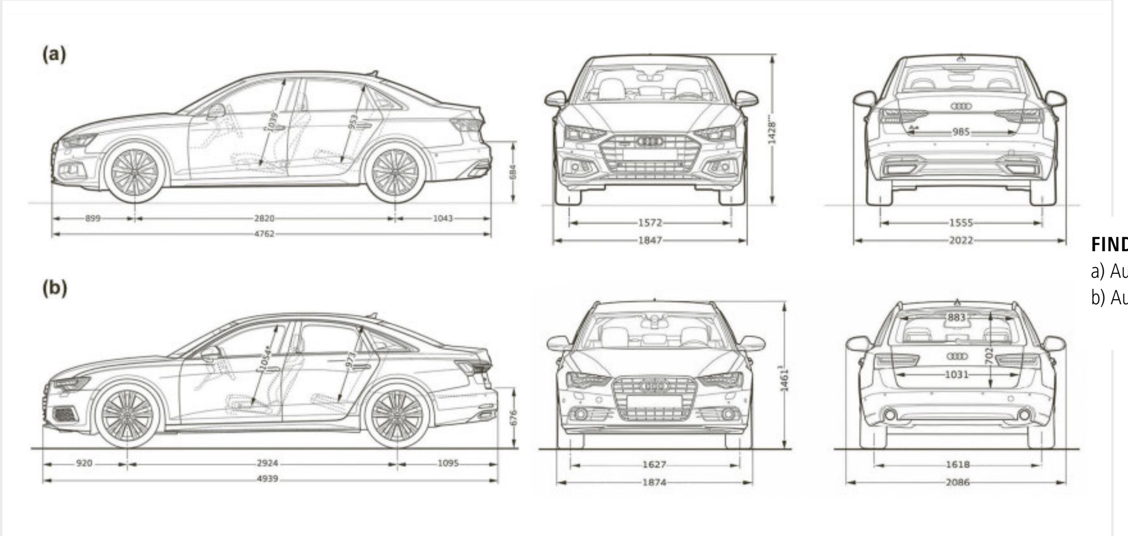
Photo: Nicolas Zonvi

CURRY POWDER? NO, TITANIUM!

The fine powder in this container may seem tempting to friends of healthy spices – but it is definitely inedible: a titanium alloy made of fine grains averaging 35 micrometers in diameter. Nevertheless, the powder is in the service of human health. The fine-rough structures an expert is gently wiping free by hand are the tops of medical implants: hip sockets for people who need a joint replacement. They were created with the help of laser beams that burned them out of the powder layer by layer – so the photo depicts the final stage of production in a 3D printer. You can read more about this innovative medical technology and its opportunities and pitfalls in our photo feature story starting on page 20.

Further information on the topic is available at:
https://www.empa.ch/web/s204

AUTOMOBILE SOCIETY OF CLASSES



FIND THE DIFFERENCE
a) Audi A4 mid-size car
b) Audi A6 upper-class sedan

In order to correctly separate vehicles into classes, for example for mobility pricing, one must be able to clearly distinguish mid-sized cars from upper-class cars and small cars from compact cars. But this is becoming increasingly difficult: in photos, an Audi A4 looks almost the same as an Audi A6, a Mini One looks similar to a Mini Countryman. To date, there is no independent procedure for this. Until now, the classes in each country have been divided by experts – to a large extend at their own discretion. Empa researcher Naghmeh Niroomand has now developed a system that can classify cars worldwide based on their dimensions. Purely mathematical and fair. Thanks to it, the current classification by experts could soon be a thing of the past. At the same time, car classes would be easier and more objectively comparable worldwide. After all, a "mid-size car" is something different in Italy than it is in the USA.

www.empa.ch/web/s504

SANITIZER
The effect of Disigel is currently being tested in the lab.

EXTENDED PROTECTION AGAINST GERMS

A team from the medtech company Lumendo (VD) and Empa is currently developing a hand disinfectant that provides protection that will last several hours. The long-term effect of Disigel is based on a gel that is gentle on the skin but kills germs. The gel is intended to protect against antibiotic-resistant bacteria and viruses. The project is supported by Innosuisse, the Swiss Innovation Agency.

www.empa.ch/web/s404

Photo: Johanne Stettler (Innosuisse), graphic: Audi AG

Photos: Empa, Martin Zeller

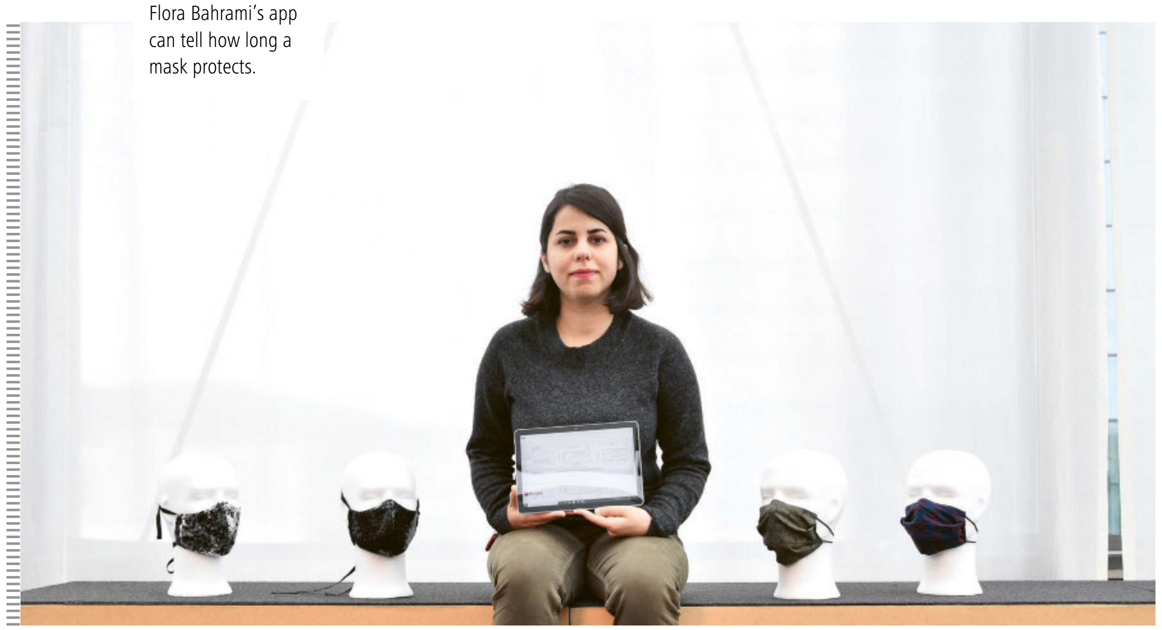
FROM DISMANTLING TO RE-USE

Another construction site at NEST: With the new Sprint unit, NEST gets an office unit built largely from recycled materials. Sprint aims to set new standards for circular construction. However, the office unit is also a reaction to the current COVID-19 situation, which made it clear that we need to adapt our buildings more flexibly and quickly to changing needs.

www.empa.ch/web/nest/sprint

SUSTAINABLE
The flexible offices of the new Sprint unit are being built on the lowest platform of NEST.

PREDICTION
Flora Bahrami's app can tell how long a mask protects.



MASK CHECK VIA APP

Corona mask on one's face itself knew whether it provided sufficient protection in a given situation. Empa researcher Flora Bahrami has now developed an app that can predict the maximum duration of protection in the presence of people who are infected. Depending on mask type, location and activity level, the app calculates how long the situation will be safe. This results in different times for a workout with coughing athletes in the gym or taking a bus along with silent passengers. Also visible: how many viruses one has potentially inhaled, depending on the type of mask and length of stay. "Mask manufacturers can also use the app to optimize product development," says Bahrami.

www.empa.ch/web/simbiosys/remask

JACKETS FROM JACKETS FROM JACKETS …

Manufacture, wear, wash, incinerate: This typical life cycle of garments, which pollutes the environment, is to be changed in the future – towards principles of circular economy with recycling at its core. Using an outdoor jacket made from PET bottles and recycled materials, Empa researchers have investigated whether the product actually delivers what the idea promises.

Text: Norbert Raabe

BLUE OR GREEN?
The outer layer of the first version of the new jacket on the left contains polyester made from recycled PET bottles. The green color shows that recycled materials were incorporated.

Photos: wear2wear

At first glance, it's a normal rain jacket: three layers of polyester, a lining on the inside, a water vapor-permeable membrane on top and water-repellent fabric on the outside, with a hood. But the zipper makes you wonder. Instead of ending at collar height, it pulls up over the forehead ... – who would pull it that far?

The explanation is given by Annette Mark from textile manufacturer BTK Europe, who contributed to this product. The zipper is intended to be an eye-catcher – and is primarily for recycling: Sewn tight with a thread that dissolves in boiling water, it is easier to remove than two fasteners. "Pull once and you're done," says the expert on textiles and recycling. The light green color is also due to recycling: The raw material, a granule made from a mixture of different but single-variety textiles, is dark green – and melting and spinning out the material for new yarns lightens it.

Magnetic buttons, seams, hems: Every detail of the jacket follows the Design-2Recycle approach, as it says on the Wear2wear website. Six companies from Europe's textile industry have joined forces in this consortium to promote circular economy. After all, more than 70 percent of all textiles produced worldwide end up in landfills or incinerators without being recycled.

How can circular economy be achieved in this industry? A team from Empa's Technology and Society lab took a closer look at the jacket and its environmental impact using life cycle analyses over a four-year period of use; including washing it three times. The candidates: a jacket produced without circular economy methods, the "starter version" of the jacket available since 2019 in blue – with an outer layer made of polyester derived from used PET bottles – and the green version from the subsequent recycling process, in which unavoidable material losses are replaced by new polyester.

WEATHERPROOF
The fabric structure of the outdoor jacket in detail.

MICROPLASTIC FIBERS FROM TEXTILES

Textiles made of polyester are making the headlines because they release microplastic fibers – for instance, during washing – which is sometimes considered a threat to humans and the environment. Empa experts have studied the formation and release of microplastic fibers. Their results: Fibers are released primarily at the fabric's edges. Their formation and release depends, among other things, on the type of fiber, surface treatment and the type of cutting. Compared to other textiles, significantly fewer fibers are released from laser-cut textiles during washing. Empa is conducting studies with industrial partners to further reduce the formation of these fibers during textile production. In Swiss wastewater treatment plants, however, microfibers are largely removed from wastewater and incinerated with the sludge.

The researchers' analyses show that the recycled products perform better – in eleven environmental risk categories, including global warming, toxicity to ecosystems and water scarcity. There are strikingly large advantages in air pollution, for example, because fewer pollutants are released without incineration, as well as in water scarcity, especially for the green jacket after the first recycling "loop," for which PET bottles are no longer used.

Other insights from the analyses: In terms of greenhouse effect, the maximum benefit is a good 30 percent. And the use of PET bottles does not bring any major ecological benefits. What is decisive, on the other hand, is the number of recycling cycles to produce new jackets: The balance improves from jacket to jacket – provided the quality of the polyester remains high enough.

In practice, this is challenging, as Mark explains: "Depending on the origin, ▶

the raw material sometimes differs significantly." If the fibers have been coated with certain additives, the nozzles of the spinning machines can become clogged. And in general, the quality decreases with the number of recycling cycles: more irregular structures of the yarn and lower strength.

Annette Mark's conclusion on the Empa analyses: "very realistic" and useful for improvements. "The cooperation was very good," she says, "full transparency and no compromises." The researchers also found the collaboration fruitful. "Open collaboration between science and industry is enormously important," says Empa's Gregor Braun. "Sustainability and circular economy can work well together."

Will the jacket become a market success? "The textile industry is in a state of upheaval. A rethinking is taking place right now that we shouldn't miss," says Annette Mark. But large corporations that are already developing similar products "have completely different options." After all, talks are underway with a sportswear manufacturer – for a fleece jacket, for which the Empa findings could also be useful. ■

Further information on the topic is available at: www.empa.ch/web/s506

HOW ECOLOGICAL IS ORGANIC POLYESTER?
Until now, synthetic textiles have been made, for the largest part, from petroleum. The use of renewable raw materials such as cellulose could improve the environmental compatibility of our clothing. Empa researchers Tijana Ivanović and Claudia Som have now compared the environmental impact of conventional polyester with that of bio-based variants. They concluded that only three of the nine substitute products achieve a similar environmental impact as polyester. The remaining "bio-polymers" performed worse. The reason: The raw materials are currently produced using intensive agriculture, and the conversion rate from raw material to textile fiber is not efficient – for example, four kilograms of corn are needed for one kilogram of fiber. The next step for the researchers will therefore be to look at alternative processes that use deciduous leaves, for instance.

WHICH FIBER IS BETTER?
In the case of textiles, common wisdom has it that it is rather easy to distinguish between those that are friendly to the environment and those that are harmful. Based on rough estimates, polyester was considered the manifestation of evil, while cotton as a natural fiber was seen as the good guy. Empa researcher Mélanie Schmutz has now investigated the environmental impact of fiber production. Her calculations show that in terms of CO_2 emissions, both fiber types are on a par. The water consumption is different, though: The fiber production for a cotton T-shirt leaves a water footprint of 50 cubic meters, which corresponds to a 20 m^2 room filled to the ceiling with water. For polyester, on the other hand, it's less than one cubic meter. In terms of fossil fuel consumption, however, fiber production for a T-shirt made of polyester comes off worse; at just under 25 MJ equivalents, it requires as much as 2,000 AA batteries (cotton: 750 AA batteries). Conclusion: "None of the fabrics is really good or bad. It depends on the requirements of the fiber and the specific manufacturing process," says Schmutz.

LONG LIVE T-SHIRTS!
A T-shirt has to perform – absorb odor, be impressive to the touch and a treat for the eyes. But that's not all: Empa researchers have now studied the environmental performance of a T-shirt made of cotton. The greatest impact on the shirt's environmental footprint was its lifetime, i.e. how long it had been worn. According to the study, shirts that are disposed of after they have been washed at least 44 times come out on top. If you chuck your shirt after just one season (about 11 washes), you increase its CO_2 footprint about 2.5-fold. Moreover, the energy consumption of the shirt increases by around 30 percent if it is tumble-dried after every wash.

Photos: Unsplash, Empa

"RECYCLING IS NOT ALWAYS SUSTAINABLE"

Circular economy and recycling in the textile sector: Switzerland and the EU want to move towards a sustainable industry. The basis for this has been investigated at Empa for quite some time. In an interview with Empa Quarterly, sustainability expert Claudia Som talks about opportunities, pitfalls and ideas for the future.

Interview: Norbert Raabe

Photo: Empa

Ms. Som, together with your colleagues at Empa, you investigated the environmental impact of an outdoor jacket made of recycled material (see page 8). One of the results was that the use of polyester from PET bottles does not yield any advantage – perhaps surprisingly for laypeople. Did you expect that?

Even before our study, we had heard from experts in the packaging industry that "bottle PET" would be better left in the bottle cycle for quality reasons. There were even rumors that resourceful entrepreneurs abroad were producing PET bottles not for beverages, but to profit

CLAUDIA SOM

After studying biology at ETH Zurich and the University of Zurich, Claudia Som joined Empa's Ecology lab in the mid-1990s and began conducting life cycle assessments. Soon thereafter, she established a research group on sustainable industrial production in emerging economies. For a good two decades, she has dedicated herself to research on sustainable innovation. In addition to numerous scientific publications, she has published three guides as a basis for informed decision-making in the early innovation phase for industry. ▶

from the high demand for "recycled PET." Therefore, it is necessary to look closely at where the PET comes from and what quality requirement it must meet for a number of recycling loops – especially if many of those are to be achieved.

Recycling and circular economy in the textile sector has long been an issue in politics as well. You recently conducted a survey among Swiss textile companies to explore the potential. What were your findings?

The idea to take a closer look at production waste in the textile industry came to us during a company visit. Although the company tried to reduce waste and find a sensible reuse, a large part of high-value materials ended up being incinerated. Often, companies also remain in the dark about what buyers do with the material. What was interesting for us was that designers can also help to avoid production waste – for example, by tolerating color deviations.

Today, most clothing ends up in incineration or landfills at the end of its life. How high do you estimate the potential for recycling?

From our contacts with Swiss and European industry, we have learned that successful recycling depends on how well you know the composition and quality of your materials. Moreover, large enough quantities are required for the processes to become economical. Today's clothes that are sometimes made of really wild material mixtures and our "fast fashion" approach with low material quality make successful recycling quite tricky. Thus, we hope that our research on Swiss production waste will contribute to establishing a circular economy faster. After all, in Swiss as well as in European production, the quality of the materials is relatively high, the composition is largely known, and relatively large quantities of the same material are produced.

Does recycling make sense in every case?

Recycling is not always sustainable. On the one hand, the effort required for recycling can be high – if only because of the logistics. On the other hand, problems can arise from material and quality losses or from impurities in every recycling process. The EU and Switzerland want to strongly push recycling. However, this could lead to even greater environmental problems – for example, if the recycling technology requires a lot of resources.

There are now numerous initiatives from manufacturers, such as labels for sustainable products or recycling – this can be quite confusing for customers. Do you have any tips for consumers to find their way around?

Even experts have trouble keeping track of the topic. I recommend the label guides from non-governmental organizations. Consumers should also ask critical questions, such as where the PET comes from, where it is produced. That way, you at least get an idea of how much the suppliers know and how committed they are.

In the Subitex research initiative (see info box) Empa researchers are working together with the textile industry in an interdisciplinary way. What are the most frequent questions companies come to you with?

Substitutes made from bio-based materials are a big topic: Are they really better than fossil-based ones? Are synthetic textiles a problem for the environment because of microplastics? Does it make sense to rely on compostable materials, or is the longevity of the product perhaps more important? Questions like these motivate us to establish a sound basis for an informed decision-making in the industry.

The Swiss textile industry is increasingly focusing on innovative solutions, including novel materials, one of Empa's main research topics. For instance, you compared conventional polyester with bio-based polyester. Which materials do you see as the hope for the future?

Wood-based materials are exciting. A material that can bind CO_2 directly from ambient air, like innovative concrete, would also be interesting – in other words, textiles as a store for greenhouse gases. But that's perhaps a bit too futuristic (laughs).

INFOBOX: SUBITEX – TOGETHER FOR SUSTAINABLE TEXTILES

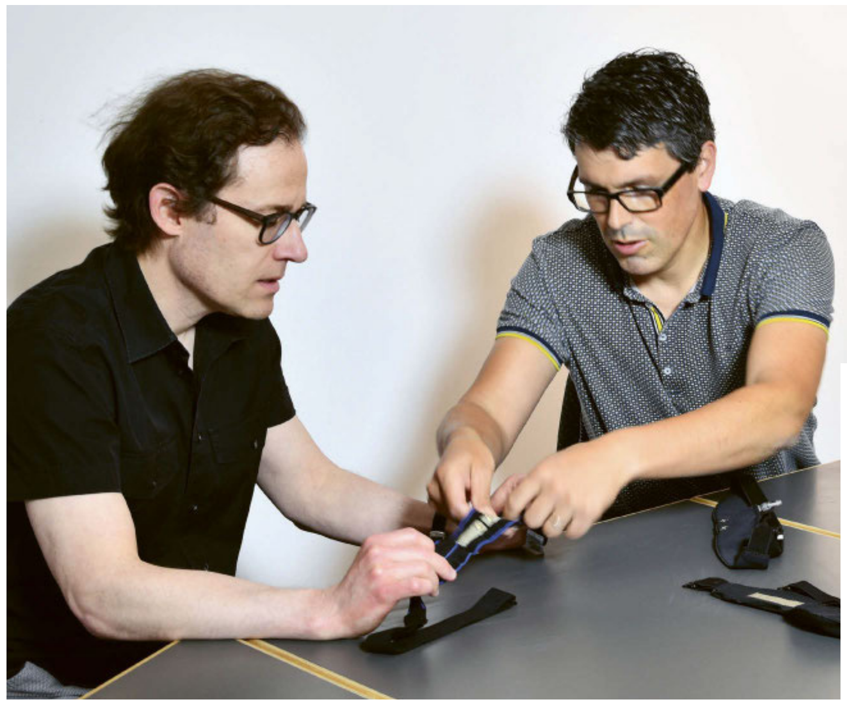
The Subitex research initiative of Empa and the Swiss Textiles industry association aims to enable sustainable management in the textile industry. Through innovative approaches and efficient knowledge and technology transfer, innovations should reach the market faster. Among other things, the researchers are analyzing the environmental impact, developing fibers from bio-based plastics and novel technologies for alternative materials. The initiative was launched in 2014 and, with a recent refocus on textile sustainability, has developed into a wide-ranging innovation network with currently 15 companies. More information on: https://subitex.empa.ch/

Further information on the topic is available at: www.empa.ch/web/s506

EARLY DETECTION OF DEMENTIA

Alzheimer's and other dementias are among the most widespread diseases today. Diagnosis is complex and can often only be established with certainty late in the course of the disease. A team of Empa researchers, together with clinical partners, is now developing a new diagnostic tool that can detect the first signs of neurodegenerative changes using a sensor belt.

Text: Andrea Six



Photos: Robert Stürmer

DIAGNOSTIC BELT
ETH Zurich / Empa master's students Kerstin Kündig and Michael Bürgisser evaluate the sensor belt's data measurement.

EARLY WARNING SYSTEM
Empa researchers Simon Annaheim (right) and Patrick Eggenberger equip the textile belt with sensitive bio-sensors.

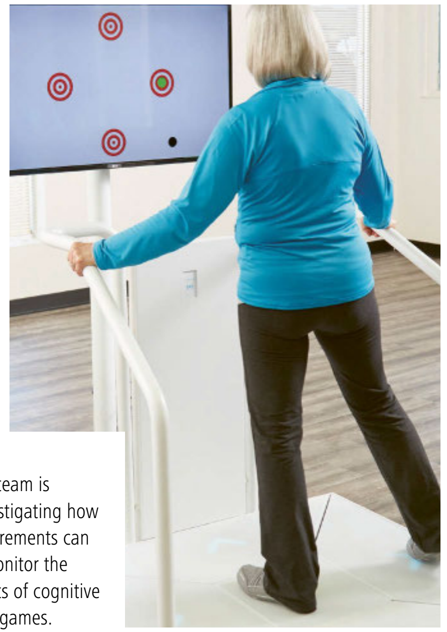
Forgetfulness and confusion can be signs of a currently incurable ailment: Alzheimer's disease. It is the most common form of dementia that currently affect around 50 million people worldwide. It mainly afflicts older people. The fact that this number will increase sharply in the future is therefore also related to the general increase in life expectancy.

If dementia is suspected, neuropsychological examinations, laboratory tests and demanding procedures in the hospital are required. However, the first neurodegenerative changes in the brain occur decades before a reduced cognitive ability becomes apparent. Currently, these can only be detected by expensive or invasive procedures. These methods are thus not suitable for extensive early screenings on a larger scale. Empa researchers are working with partners from the Cantonal Hospital and the Geriatric Clinic in St. Gallen on a non-invasive diagnostic method that detects the early processes of dementia.

SIGNS IN THE UNCONSCIOUS

For the new method, the team led by Patrick Eggenberger and Simon Annaheim from Empa's Biomimetic Membranes and Textiles lab in St. Gallen relied on a sensor belt that has already been used successfully for ECG measurements and has now been equipped with sensors for additional vital parameters. This is because long before memory starts to deteriorate in dementia, subtle changes appear in the brain, which are expressed through unconscious bodily reactions.

These changes can only be recorded precisely when measurements are taken over a longer period of time, though. "It should be possible to integrate the long-term measurements into everyday life," explains Simon Annaheim. Skin-friendly and comfortable monitoring systems are essential for measurements that are suitable for everyday use. The diagnostic belt is therefore based on flexible sensors with electrically conductive or light-conducting fibers as well as sensors for motion and temperature measurement.



TRAINING
The research team is currently investigating how sensor measurements can be used to monitor the training effects of cognitive motor fitness games.

Photos: Dividat AG

To enable such long-term measurements to be used for monitoring neurocognitive health, the researchers are integrating the collected data into in-house developed mathematical models. The goal: an early warning system that can estimate the progression of cognitive impairment. Another advantage is that the data measurements can be integrated into telemonitoring solutions and thus reduce the number of visits to the doctor for preliminary examinations.

SUSPICIOUS MONOTONY

Basically, the human body is able to keep its temperature constant. Nevertheless, the values naturally oscillate in the course of the day. This daily rhythm changes with age and is conspicuous in neurodegenerative diseases such as dementia or Parkinson's disease. In Alzheimer's patients, for example, the core body temperature is elevated by up to 0.2 degrees Celsius. At the same time, the spikes in daily temperature fluctuations are dampened.

In a recently published study, the researchers have now been able to show that altered skin temperature readings measured with the sensor belt actually provide an indication of the cognitive performance of test subjects – and can do so well before dementia develops. The test subjects in the study included healthy people with or without mild brain impairment. This mild cognitive impairment (MCI) does not represent a disability in everyday life, but it is considered a possible precursor to Alzheimer's disease. The subjects took part in long-term measurements and neuropsychological tests. It was found that a lower body temperature, which fluctuated more throughout the day, was linked to a better cognitive performance. In individuals with MCI, body temperature varied less and was slightly elevated overall.

DANCING FOR MENTAL FITNESS

The heartbeat is also subject to natural variations that show how our nervous system adapts to sudden challenges. The small silence between two heartbeats, about one second in duration, has great significance for our health: If this pause always remains the same, our nervous system is not at its best.

In a study with researchers from ETH Zurich, the Empa team has already determined that poorer measurements in older, healthy people can be improved within six months through cognitive-motor dance training. In these "exergames," the test subjects imitated sequences of steps from a video. In contrast, participants who instead only trained in straight lines on a treadmill, but also trained their memory, benefited less.

"The point is to intervene early with appropriate training when the first negative signs can be measured," says Patrick Eggenberger. "With our sensor system, any improvements in cognitive performance can be tracked through movement-based forms of therapy." Studies with long-term monitoring will now be used to clarify how the sensor measurements can be used to predict the progression of mild brain disorders.

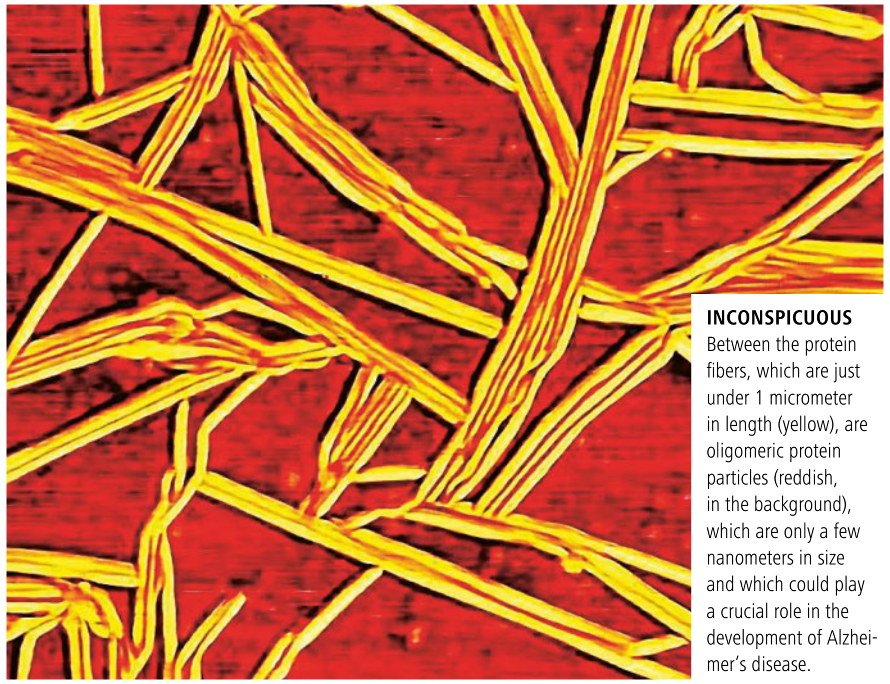
The studies are supported by the Ebnet Foundation, the Ria & Arthur Dietschweiler Foundation, and the Foundation of the Stephanshorn Clinic Medical Association. ■

Further information on the topic is available at:
https://www.empa.ch/web/s401

DETECTING ALZHEIMER'S IN BLOOD

Empa researcher Peter Nirmalraj wants to capture images of Alzheimer's peptides with unprecedented precision. This could allow new insights into the molecular pathogenesis of the neurodegenerative disease – and perhaps open the way to new therapies.

Text: Andrea Six



INCONSPICUOUS
Between the protein fibers, which are just under 1 micrometer in length (yellow), are oligomeric protein particles (reddish, in the background), which are only a few nanometers in size and which could play a crucial role in the development of Alzheimer's disease.

Photo: Empa / Science Advances

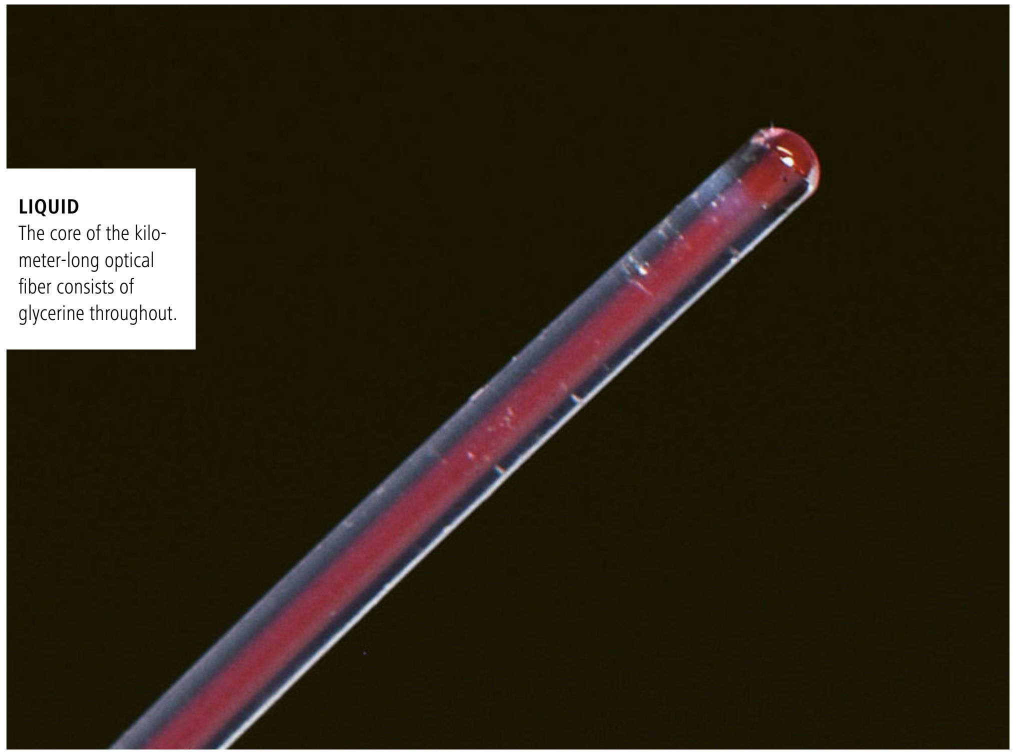
In the beginning, physicist Peter Nirmalraj wanted to gain deeper insights into the process of Alzheimer's disease in order to provide medical research with a basis for possible early diagnostics and new therapies. One step further would be to decipher the role of amyloid beta peptides and tau proteins, which are associated with the neurodegenerative disease. However, if one approaches the tiny peptide structures with a microscope, the view into the molecular universe becomes distorted all too easily. "An imaging technique must not alter the original state of the peptides, otherwise valuable information on their characteristic properties will be lost" Nirmalraj says. That's why the Empa scientist searched for a technique that left the peptides pristine. Thanks to an ultra-clean, pre-treated graphene surface, he was able to capture images of the beta amyloid peptides with an atomic force microscope (AFM) without damaging their natural size, shape and morphology. In addition to the amyloid fibers, even smaller peptide particles, known as oligomers, can be seen. Their role in the pathogenic process may be more important than previously thought, suspects Nirmalraj. Currently, the lab results are being taken further in a pilot study with a team at the Cantonal Hospital of St. Gallen. The study aims to show if and how AFM technology can detect amyloid and tau proteins in blood samples from Alzheimer's patients. ■

Further information on the topic is available at:
https://www.empa.ch/web/s405/biosensing

A DATA RIVER RUNS THROUGH IT

Data and signals can be transmitted quickly and reliably with glass fibers – as long as the fiber does not break. Strong bending or tensile stress can quickly destroy it. An Empa team has now developed a fiber with a liquid glycerol core that is much more robust and can transmit data just as reliably. And such fibers can even be used to build microhydraulic components and light sensors.

Text: Rainer Klose



LIQUID
The core of the kilometer-long optical fiber consists of glycerine throughout.

PRECISION
Rudolf Hufenus' team is a world leader in the production of liquid-filled fibers.

Photos: Robert Stürmer

> "The two components of the fiber must be processed at 200 to 300 degrees Celsius through our spinneret."

In terms of optically conductive polymer fibers, we've tried all kinds of things," says Rudolf Hufenus. "But even with the best solid fiber cores, we can never achieve such elasticity as with our liquid-filled fiber." The special combination of optical and mechanical properties could now open up new markets for Empa's two-component fiber alongside the established glass fiber.

Fiber optic cables are ideal for data transmission over long distances. The technology is tried and tested and is used on a large scale. But glass fibers can only be bent to a limited extent and are very sensitive to tensile stress. Plastic fibers, on the other hand, are typically used for shorter transmission distances: for individual buildings, company premises or in vehicles. The core of these fibers is often made of PMMA – also known as Plexiglas – or the polymer polycarbonate. While these transparent materials are more flexible than glass, they are almost as sensitive to tensile forces. "As soon as a microcrack forms in the fiber core, light is scattered by it and lost," Hufenus explains. "So data transmission initially deteriorates, and later on, the fiber core can even tear completely at this weakened point."

This is where Empa's expertise comes into play: For the past seven years, the Advanced Fibers lab in St. Gallen has been home to a machine that can produce kilometer-long fibers filled with a liquid. With this expertise, Empa is a world leader. "Two-component fibers with a solid core have been around for more than 50 years," says Hufenus. "But fabricating a continuous liquid core is considerably more complex. Everything has to be just perfect." The Empa researcher wondered: Couldn't this liquid core also be used for light transmission? It was the Geneva physicist Jean-Daniel Colladon who first conducted light along the inside of a water jet in 1842 – and thus discovered one of the physical foundations for today's fiber optic technology.

For light conduction in hollow fibers with a liquid core, however, everything has to be newly adjusted. The difference in the refractive indices between the liquid and the transparent cladding material is crucial: The refractive index of the liquid must be significantly greater than that of the cladding material. Only then will the light be reflected at the interface and remain trapped within the liquid core. At the same time, all ingredients must be thermally stable. "The two components of the fiber must pass through our spinneret together under high pressure and at 200 to 300 degrees Celsius," says the Empa researcher. "So we need a liquid with a suitable refractive index for functionality and with the lowest possible vapor pressure to produce the fiber." The team decided on a liquid core made of glycerol and a sheath made of a fluoropolymer.

LARGE REVERSIBLE ELONGATION

The experiment was a success: The fiber the Empa team produced can withstand up to ten percent elongation and then returns to its original length – no other solid-core optical fiber is capable of doing that!

But the fiber is not only extremely stretchable, it can also measure how far it has been stretched. Hufenus and his team added a small amount of a fluorescent dye to the glycerol and examined the optical properties of this luminescent fiber during the stretching process. The result: When the fiber is stretched, the path of the light is lengthened, but the number of dye molecules in the fiber remains constant. This leads to a small change in the color of the emitted light, which can be measured using suitable electronics. Thus, the liquid-filled fiber can indicate a change in length or a tensile load that is occurring.

"We expect that our liquid-filled fibers can be used not only for signal transmission and sensing, but also for force transmission in micromotors and microhydraulics," Hufenus says. The exact composition of the fiber sheath and filling can then be adapted to meet the requirements of the specific application. ■

Further information on the topic is available at:
https://www.empa.ch/web/s402

COST EFFECTIVE
Sabyasachi Gaan uses steam from a commercial pressure cooker to flame retard samples of cotton fabric.

FIREPROOF AND COMFORTABLE

A new chemical process developed by Empa turns cotton into a fire-resistant fabric that nevertheless retains the skin-friendly properties of cotton.

Text: Rainer Klose

Photo: Robert Stürmer

State of art flame retardant cotton textiles suffer from release of formaldehyde and are uncomfortable to wear. Empa-Scientists managed to circumvent this problem by creating a physically and chemically independent network of flame retardant moiety inside the fibers. This approach retains the inherently positive properties of cotton fibers, which account for three-quarters of the world's demand for natural fibers in clothing and home textiles. Cotton is skin-friendly because it can absorb considerable amounts of water and main-tain a favorable micro-climate on the skin.

For fire-fighters and other emergency service personnel protective clothing provides the most important barrier. For such purposes, cotton is mainly used as an inner textile layer that needs additional properties: for example, it must be fireproof or protect against biological contaminants. Nevertheless, it should not be hydrophobic, which would create an uncomfortable micro-climate. These additional properties can be built into the cotton fibers by suitable chemical modifications.

DURABILITY VS TOXICITY

"Until now, it has always taken a compromise to make cotton fireproof," says Sabyasachi Gaan, a chemist and polymer expert who works at Empa's Advanced Fibers Laboratory. "Wash-durable flame retardant cotton in industry is produced by treating the fabric with flame retardants, which chemically links to the cellulose in the cotton. Currently, textile industry has no other choice than to utilize formaldehyde-based chemicals – and formaldehyde is classified as a carcinogen. This has been an unsolved problem for decades. While formaldehyde-based flame retardant treatments are durable, they have additional drawbacks: The OH groups of cellulose are chemically blocked, which considerably reduces the capability of cotton to absorb water, which results in an uncomfortable textile."

NOVEL PHOSPHORUS CHEMISTRY

Sabyasachi Gaan knows the chemistry of cotton fibers well and has spent many years at Empa developing flame retardants based on phosphorus chemistry that are already used in many industrial applications. Now he has succeeded in finding an elegant and facile way to anchor phosphorous in form of an independent network inside the cotton.

NETWORK BETWEEN COTTON FIBERS

Gaan and fellow researchers Rashid Nazir, Dambarudhar Parida and Joel Borgstädt utilized a tri-functional phosphorous compound (trivinylphosphine oxide), which has the capability of reacting only with specifically added molecules (nitrogen compounds like piperazin) to form its own network inside cotton. This makes the cotton permanently fire-resistant without consuming the favorable –OH groups. In addition, the physical phosphine oxide network also likes water. This flame retardant treatment does not include carcinogenic formaldehyde, which would endanger textile workers during the textile manufacturing process. The phosphine oxide networks, thus formed, does not wash out: After 50 launderings, 95 percent of the independent flame retardant network is still present in the fabric.

To render additional protective functionalities to the flame retardant cotton developed at Empa, the researchers further incorporated in situ generated silver nanoparticles inside the fabric. This works fine in a one-step process together with generating the phosphine oxide networks. Silver nanoparticles provide the fiber with antimicrobial properties and survive 50 laundry cycles, too.

A GEL THAT RELEASES DRUGS

The novel phosphorus chemistry can also be used to develop other materials, e.g. to make hydrogels that can release targeted drugs with changing pH. Such gels could find application in treating wounds that heal slowly. In such wounds, the pH value of the skin surface increases and the new phosphorus based gels can be triggered to release proper medication or release a dye that alerts doctors and nurses to the problem. Empa has also patented the production of such hydrogels.

FINISHING IN THE PRESSURE COOKER

"We have used a simple approach to fix the phosphine oxide networks inside the cellulose," Gaan says. "For our lab experiments, we first treated the cotton with an aqueous solution of phosphorus and nitrogen compounds and the steamed it in a readily available pressure cooker to facilitate the crosslinking reaction of the phosphorus and the nitrogen molecules." The application process is compatible with treatment machineries already used in the textile industry. "Steaming textiles after dyeing, printing and finishing is a normal step in a textile industry. So it doesn't require an additional investment to apply our process," states the Empa chemist.

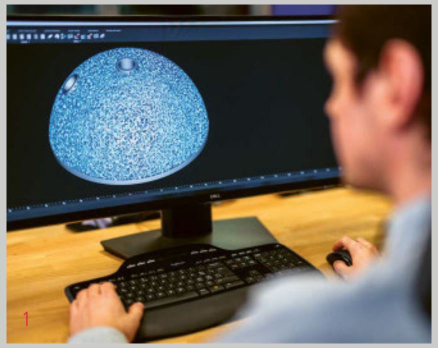
Meanwhile, this newly developed phosphorus chemistry and its application is protected by a patent application. "Two important hurdles remain," Gaan says. "For future commercialization we need to find a suitable chemical manufacturer who can produce and supply trivinylphosphine oxide. In addition, trivinylphosphine oxide has to be REACH registered in Europe." ■

Further information on the topic is available at:
https://www.empa.ch/web/s402

FROM TITANIUM POWDER TO A HIP SOCKET

Additive Manufacturing, AM in brief, is fascinating: As if by magic, complex workpieces grow in 3D printers: layer by layer by layer ... – without human intervention, as it may seem at first glance. But the technology is demanding and requires a lot of manual work with a sure touch, as a visit to the expert team at the Swiss m4m Center in Bettlach shows.

Text: Norbert Raabe, Images: Nicolas Zonvi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THE TARGET IN SIGHT

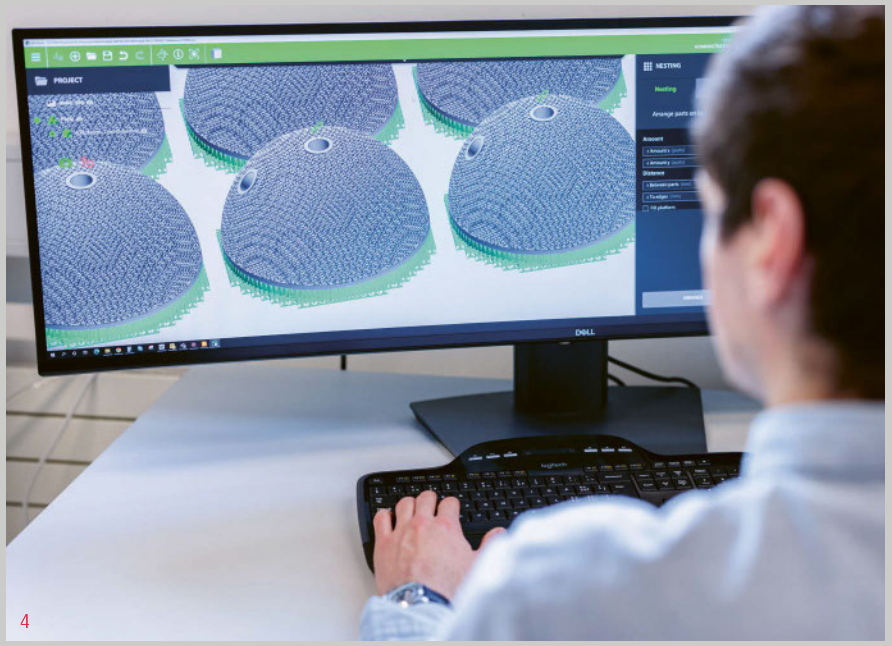
Titanium implants for hip joints are to be created in the 3D printer: hip sockets with a diameter of 50 millimeters, in which patients' thigh bones can move naturally so that they are able to walk again without pain. The surface structure can be seen on the monitor: 0.5 millimeter thin rods form a rough network, with which the implant is to anchor itself in the bone as it grows in. The holes later serve as connections for the screw connection in the hip bone.

FINEST RAW MATERIAL

The powder, from which the printer later "melts" the workpiece, bears the name "Titanium Grade 23": an alloy of round grains, on average 35 micrometers thick. Its composition meets strict requirements for implants. It is biocompatible, corrosion-resistant and easy to coat. The price per kilogram: between 200 and 400 Swiss francs.

CRUCIAL: AS DRY AS POSSIBLE

Project manager Marco Flury, a trained mechanical engineer, measures the moisture in the titanium powder. To ensure that the powder does not form lumps and has the right consistency and mobility for the 3D printer, the value should be below ten percent, according to the expert. In this test, it is 2.2 percent.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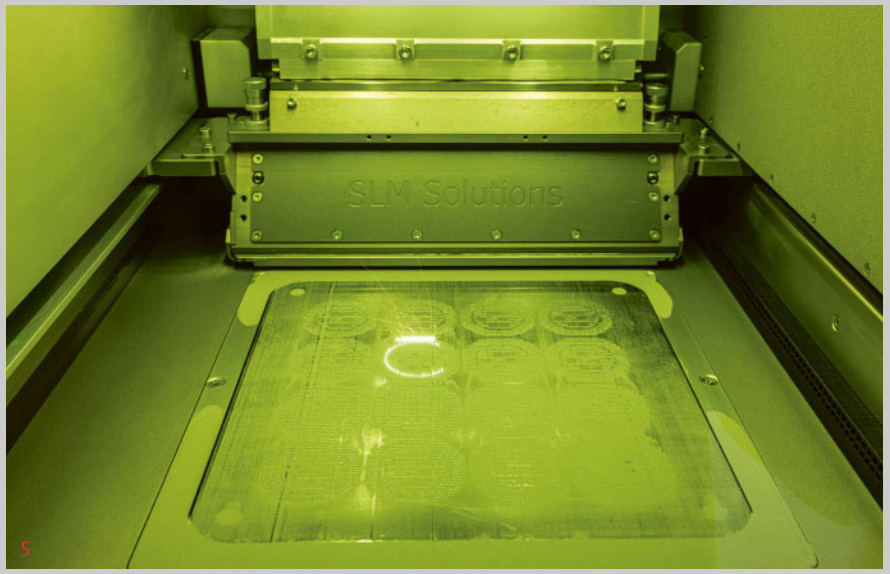
CONVERSION FOR PRINTING

From the design sketch, the computer in the fabrication hall calculates a print model – including delicate additional structures that support the implant as it is being created in the printer and that are later removed (in green). The 3D model is then used to create the command files for each individual layer from which the printer will "layer" the implant. In this case: 902 layers.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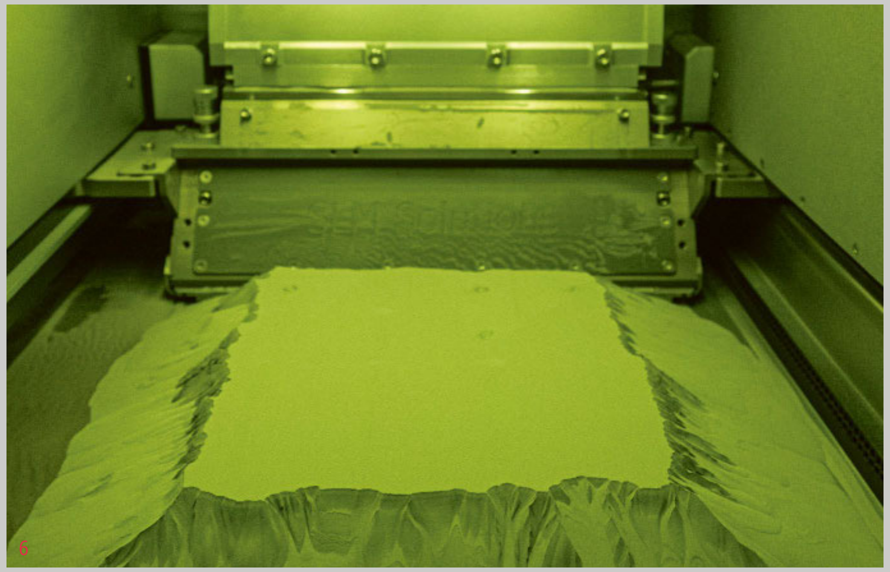
A TOUCH OF TITANIUM

16 implants in one go: The powder layers, each of which is transformed into metal by a laser beam from above, are only 30 micrometers thin. When it is finished, the base sinks just a tiny bit, and the "sled" with the labeling pushes a new powder layer over it, which is lasered again. All this is surrounded by the noble gas argon: It is highly inert – which prevents unwanted chemical reactions. In ambient air, for instance, a laser spark could even trigger explosions when titanium melts with oxygen at around 1650 degrees.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HIDDEN IN THE POWDER

Once the last layer has been lasered, the plate is moved all the way up again. A powder mountain, in which ...

"SWISS m4m CENTER"

The Technology Transfer Center in Bettlach near Solothurn does not work for profit, but promotes 3D printing in the medical technology industry – with further training and innovative projects. The target group are Swiss SMEs that lack experience and equipment for this promising technology. Opened in September 2020, the "Swiss m4m Center" has been certified since mid-April according to the ISO 13485:2016 standard for medical technology products. This step now allows professionals to manufacture real products with the production line they had previously installed and tested. Further information at: www.swissm4m.ch


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8

VALUABLE PIECES

...16 hip cups made of titanium alloy are stuck in place, ready for the next production steps.

THOROUGH CLEANING

Not a single grain of the alloy is allowed to stick. And should certainly not get into the lungs of Swiss m4m specialist Patrick Stämpfli: The technician wears a protective suit, including a blower that keeps particles away from his eyes and respiratory tract. First, a brush is used.

VACUUMING

In the second step, the experts use a special industrial vacuum cleaner.

DISPOSING OF SAFELY

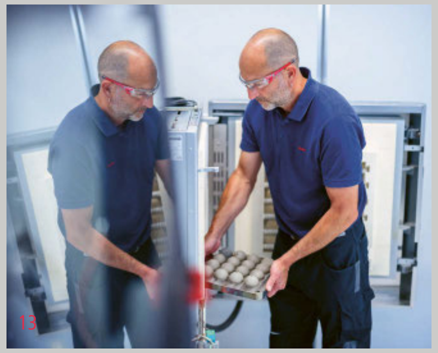
It captures the particles inside it in a water bath so that nothing can escape to the outside. This liquid is then disposed of by a specialized company.

CLINICAL CONDITIONS

From the outside, the implants now look picobello but there is, of course, still a lot of powder inside.

VIBRATE AND ROTATE

To remove leftover grains quickly and completely, a "depowdering machine", which has been specifically installed for that purpose, is being used. Under constant vibration, the machine rotates and turns the entire pallet for about 15 minutes until even the very last grain has trickled out.



RELAXATION IN THE FURNACE

One pitfall of 3D printing is heating in layers. While the top layer is red-hot, the lower layers have already cooled down. These temperature differences put the material under a lot of internal stress – and so-called stress-relief annealing eliminates it: The implants are gradually heated to 600 to 900 degrees in this "furnace" and then slowly cool down again.

Event tip (in German)

9–10 SEPTEMBER 2021
Course: 3D-Drucken in der Medizintechnik
Location: Swiss m4m Center, Bettlach
www.empa-akademie.ch/medizintech

POWERFUL MANUAL LABOR

Only now does Patrick Stämpfli separate the implants from the titanium plate, on which the 3D printer has "burned" them.

FILIGREE TITANIUM

Now the structures that gave the hemispheres the necessary stability during stacking are also visible: tiny supporting walls and channels; just as much material as was absolutely necessary.

"AM-TTC ALLIANCE"

The "Swiss m4m Center" is part of the "AM-TTC Alliance" ("Advanced Manufacturing Technology Transfer Centers"), which was founded on the initiative of the Empa and has a mandate from the State Secretariat for Education, Research and Innovation to evaluate applications and monitor the development of AM-TTC centers. Besides the Swiss m4m Center, there is currently ANAXAM (Analytics with Neutrons and X-Rays for Advanced Manufacturing) at the Paul Scherrer Institute (PSI). Later this year, the AM-TTC Alliance will launch a call with the goal of establishing two to three additional centers. Currently, the Alliance comprises 22 member organizations, among them, in addition to Empa, ETH Zurich, EPFL and other research institutions, companies such as ABB and Siemens, and industrial associations. More information: www.am-ttc.ch

ON THE HOME STRETCH

Easily accessible support structures can be removed DIY-style. But depending on the shape of the implant, machines may also be required, such as a milling machine or lathe, which can be used to precisely machine delicate or hard-to-reach areas.

THE FINISHING TOUCH

Patrick Stämpfli is processing the surface – similar to sandblasting. After 3D printing, however, fine particles of corundum and then ceramic grind the implant. They smooth the material or remove discolorations caused by annealing. In addition, the ceramic particles compact the surface slightly – an advantage if the implant is to be coated later on.

BEFORE AND AFTER

The difference is visible to the naked eye. Cleaned, sterilized and packaged, the lower implant would now be ready for use as an acetabular cup in the OR.

SO FAR UNDERESTIMATED
Air conditioning could account for up to 40% of global CO_2 emissions by 2050. Picture: a retrofitted building cooling system on a facade in Hong Kong.

SOME LIKE IT COOL

Climate-related temperature rises will further increase the cooling demand of buildings. A projection by Empa researchers based on data from the NEST building and future climate scenarios for Switzerland shows that this increase in energy demand for cooling is likely to be substantial and could have a strong impact on our future – electrified – energy system.

Text: Loris Pandiani

Due to climate change, the average global temperature will rise in the coming decades. This should also significantly increase the number of so-called cooling degree days. These measure the number of hours, in which the ambient temperature is above a certain threshold, at which a building must be cooled to keep the indoor temperature at a comfortable level. The rising values may lead to an increased installation of AC systems in households. This could lead to a higher energy demand for cooling buildings, which is already expected to increase due to climate change and population growth.

Photo: Chromatograph on Unsplash

ANALYSIS FROM NEST

To get a better understanding of how massive this increase will be in Switzerland, Empa researchers analyzed the heating and cooling requirements of the NEST research and innovation building. "By including ambient temperatures, we were able to make a projection of the future thermal energy demand of buildings based on the climate scenarios for Switzerland. In addition to climate change, we also took population growth and the increasing use of AC devices into account," explains Robin Mutschler, postdoc at Empa's Urban Energy Systems lab.

NIP-AND-TUCK RACE

The results forecast a significant increase in the demand for cooling energy: In an extreme scenario where the whole of Switzerland would rely on air conditioning, almost as much energy would be needed for cooling as for heating by the middle of the century. In figures, this corresponds to about 20 terawatt hours (TWh) per year for heating and 17.5 TWh for cooling. The required cooling energy was calculated without regard to the technology. If this is provided by reversing a heat pump process, e.g. with COP 3 for cooling, the electricity demand for 17.5 TWh cooling energy is about 5.8 TWh.

The heating demand of the residential units of NEST is comparable to a modern apartment building. These figures are therefore representative if is assumed that the average Swiss building is comparable to the NEST building. When this will be the case depends on the renovation rate. However, even in a more moderate scenario, the cooling demand in Switzerland will increase significantly. The researchers assume an additional energy demand of five TWh per year in this scenario.

IMPACT ON THE SWISS ENERGY SYSTEM

The energy demand of Swiss buildings today accounts for around 40 percent of the total energy demand. The main part of this is used for heating. This will probably remain this way until at least the middle of the 21st century, while the energy demand for cooling buildings is expected to increase significantly. If thermal energy is provided by heat pumps that can also cool, this potentially has a strong impact on the overall energy system and especially on electricity as an energy carrier.

It is assumed that only a small amount of Swiss households currently own an AC unit or system. However, the number of houses with heat pumps is growing. The Empa researchers estimate that the number of households with cooling systems could rise to over 50 percent due to the increase in cooling degree days. This could lead to significant demand peaks on hot days. An additional five TWh of energy demand for cooling would be equivalent to about two percent of today's electricity demand if cooling is provided by heat pumps.

In the more extreme scenario, the electricity demand for cooling could even approach ten percent of today's total demand. However, this will not be evenly distributed throughout the year, but will correlate with hot periods, which can lead to demand peaks. On a positive note, cooling demand is relatively well matched by electricity production from photovoltaic systems. The impact of cooling residential buildings will be significantly higher compared to office buildings, as they account for about two-thirds of the building area.

Based on these findings, it is evident to the researchers that these developments must be taken into account when constructing new buildings and that the possibilities of passive cooling must be fully exploited. "Building architecture should no longer focus only on optimizing heat losses, especially in winter, but also on reducing heat gains in summer," says Mutschler. This could be achieved, for example, through urban planning measures for climate adaptation at district level, the implementation of programs for heat reduction, or the reduction of glazing in buildings. "Moreover, it is crucial that policymakers also address this development and investigate ways to best meet the increasing cooling energy demand while minimizing the impact on the future decarbonized energy system," Mutschler adds. One possible contribution to cooling buildings could come from district cooling systems, which have already been successfully implemented in Switzerland – for example in Geneva. Others are emerging, for instance in Zug. ■

Further information on the topic is available at:
https://www.empa.ch/web/s313

FILIGREE CHEMISTRY FOR MEGA CRYSTALS

An international team led by Empa and ETH Zurich researchers is playing with shape-engineered nanoscale building blocks that are up to 100 times larger than atoms and ions. And although these nano "Lego bricks" interact with each other with forces vastly different and much weaker than those holding atoms and ions together, they form crystals all by themselves, the structures of which resemble the ones of natural minerals. These new mega-crystals or superlattices that are depicted on the cover of the latest issue of "nature" exhibit unique properties such as superfluorescence – and may well usher in a new era in materials science.

Text: Rainer Klose

To really appreciate what a team of researchers led by Maksym Kovalenko and Maryna Bodnarchuk has achieved, it is best to start with something mundane: Crystals of table salt (also known as rock salt) are familiar to anyone who has ever had to spice up an overtly bland lunch. Sodium chloride – NaCl in chemical terms – is the name of the helpful chemical; it consists of positively charged sodium ions (Na+) and negatively charged chloride ions (Cl-). You can imagine the ions as beads that strongly attract each other forming densely packed and rigid crystals like the ones we can see in a saltshaker.

Many naturally occurring minerals consist of ions – positive metal ions and negative ions, which arrange themselves into different crystal structures depending on their relative sizes. In addition, there are structures such as diamond and silicon: These crystals consist of only one kind of atoms – carbon in the case of diamond –, but, similar to minerals, the atoms are also held together by strong bonding forces.

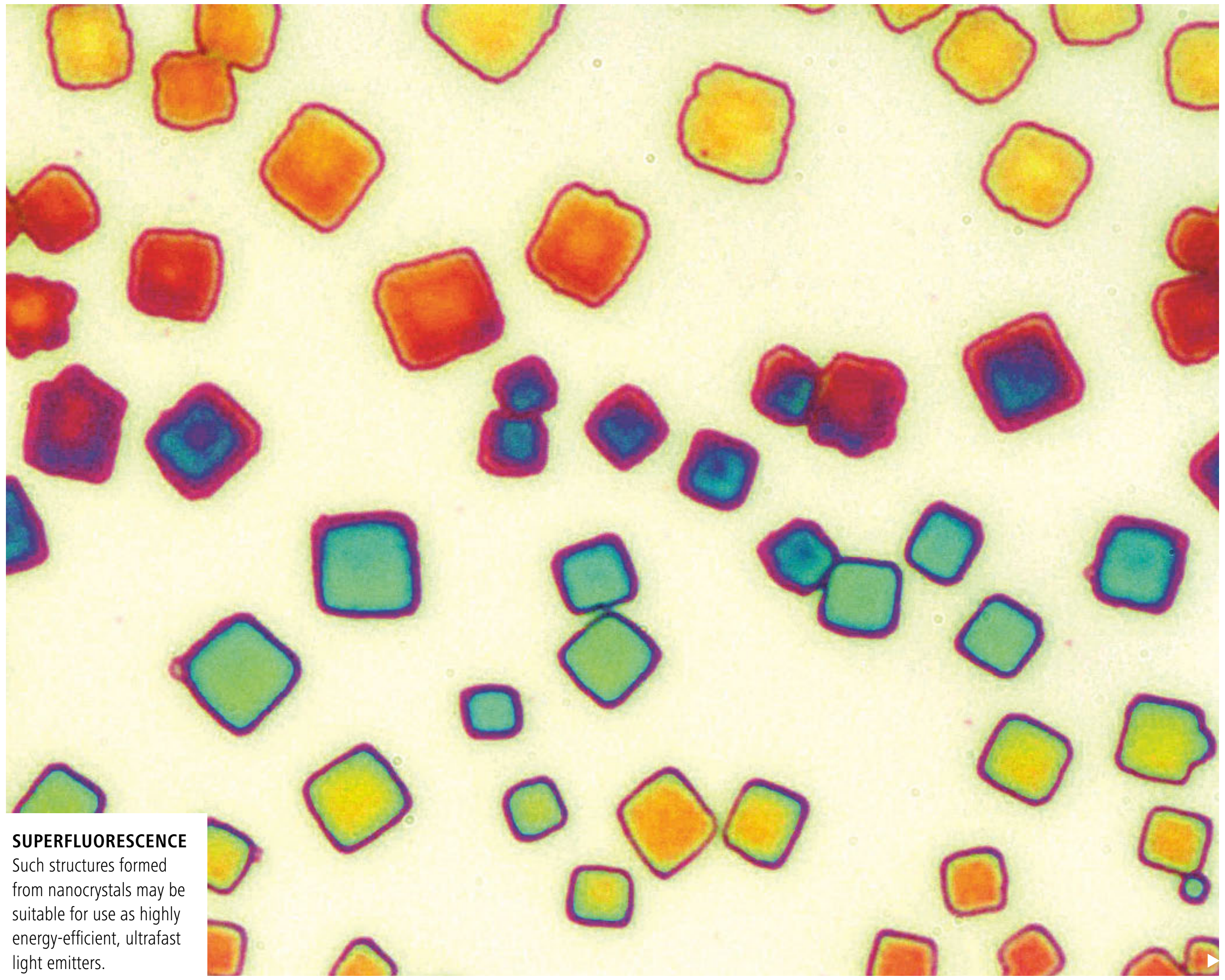
A NEW KIND OF MATTER

What if all these strong bonding forces between atoms could be eliminated? In the realm of atoms, with all the quantum mechanics at play, this would not yield a molecule or a solid-state matter, at least at ambient conditions. "But modern chemistry can produce alternative building blocks that can indeed have vastly different interactions than those between atoms," says Maksym Kovalenko, Empa researcher and professor of chemistry at ETH Zurich.

"They can be as hard as billiard balls in a sense that they sense each other only when colliding. Or they can be softer on the surfaces, like tennis balls. Moreover, they can be built in many different shapes: not just spheres, but also cubes or other polyhedra, or more anisotropic entities."

FINE CHEMISTRY
Maryna Bodnarchuk and her team synthesize the building blocks from which the enlarged crystal structures are formed.

Photos: Empa



SUPERFLUORESCENCE
Such structures formed from nanocrystals may be suitable for use as highly energy-efficient, ultrafast light emitters.

Such building blocks are made of hundreds or thousands of atoms and are known as inorganic nanocrystals. Kovalenko's team of chemists at Empa and ETH is able to synthesize them in large quantities with a high degree of uniformity. Kovalenko and Bodnarchuk, and some of their colleagues the world over, have been working for about 20 years now with these kinds of building blocks. The scientists call them "Lego materials" because they form long-range ordered dense lattices known as superlattices.

It had long been speculated that mixing different kinds of nanocrystals would allow the engineering of completely new supramolecular structures. The electronic, optical or magnetic properties of such multicomponent assemblies would be expected to be a mélange of the properties of the individual components. In the early years, the work had focused on mixing spheres of different sizes, resulting in dozens of various superlattices with packing structures that mimic common crystal structures, such as table salt – albeit with crystal unit cells ten- to 100 times larger.

With their latest article in "nature", the team led by Kovalenko and Bodnarchuk now managed to expand the knowledge a great deal further: They set out to study a mixture of different shapes – spheres and cubes to start with. This seemingly simple deviation from the mainstream immediately led to vastly different observations. Moreover, the chosen cubes, namely colloidal cesium lead halide perovskite nanocrystals, are known as some of the brightest light emitters developed to date, ever since their invention by the same team six years ago. The superlattices the researchers obtained are not only peculiar as far as their structure is concerned,

EYE-CATCHER
The Swiss-made super grids made it onto the cover of nature magazine in May.

but also with respect to some of their properties. In particular, they exhibit superfluorescence – that is, the light is irradiated in a collective manner and much faster than the same nanocrystals can accomplish in their conventional state, embedded in a liquid or a powder.

ENTROPY AS AN ORDERING FORCE?

Upon mixing spheres and cubes, wondrous things happen: The nanocrystals arrange themselves to form structures familiar from the world of minerals such as perovskites or rock salt. All these structures, however, are 100 times larger than their counterparts in conventional crystals. What's more: A perovskite-like structure had never before been observed in the assembly of such non-interacting nanocrystals.

Especially curious: These highly ordered structures are created solely by the force of entropy – that is, the perpetual endeavor of nature to cause maximum disorder. What a perfect joke of nature! This paradoxical assembly occurs because, during crystal formation, the particles tend to use the space around them most efficiently in order to maximize their freedom of motion during the late stages of solvent evaporation, i.e. before they are "frozen" in their eventual crystal lattice positions. In this regard, the shape of the individual nanocrystals plays a crucial role – soft-perovskite cubes allow for a much denser packing than what is attainable in all-spherical mixtures. Thus, the force of entropy causes the nanocrystals to always arrange in the densest possible packing – as long as they are designed such that they do not attract or repel each other by other means, such as electrostatics.

THE DAWN OF A NEW SCIENCE

"We have seen that we can make new structures with high reliability," says Maksym Kovalenko. "And this now raises many more questions; we are still at the very beginning: What physical properties do such weakly bonded superlattices exhibit and what is the structure-property relationship? Can they be used for certain technical applications, say, in optical quantum computing or in quantum imaging? According to what mathematical laws do they form? Are they truly thermodynamically stable or only kinetically trapped?" Kovalenko is now searching for theorists who might be able to predict what may yet happen.

"We will eventually discover completely new classes of crystals," he speculates, "ones, for which there are no natural models. They will then have to be measured, classified and described." Having written the first chapter in the textbook for a new kind of chemistry, Kovalenko is more than ready to deliver his share to make that happen as fast as possible. "We are now experimenting with disk- and cylinder-shaped nanocrystallites. And we're very excited to see the new structures they enable", he smiles. ■

Further information on the topic is available at:
https://www.empa.ch/s207/nanomat-self-assembly

Photo: nature

Photos: Empa

RIP, HYPATIA …

2010
Cluster computer Hypatia in its early days.

2014
Hypatia in the prime of its life.

2021
A silent adieu: Technical supervisor Patrik Burkhalter and scientific supervisor Daniele Passerone retired the cluster computer.

Hypatia, the joint cluster computer of Empa and Eawag, is no more. On 10 March, the well-behaved and fast helper for scientific simulations was dismantled in Empa's basement and loaded onto the trucks of a waste disposal company. Many components of the mainframe will now begin a new life elsewhere. Hypatia was named after one of the few female scientists of antiquity who lived in Egypt in the 4th century.

The end did not come suddenly or unexpectedly, however, but quite planned. In 2007, Empa had begun building the cluster computer, which consisted of inexpensive standard components that were easy to maintain. At the time, this was cheaper than sending data to the Swiss National Supercomputing Center (CSCS) in Lugano.

Hypatia was a real all-rounder; it calculated, among other things, complex atmospheric models and the distribution of air pollutants in cities, noise simulations for air traffic, but also molecular simulations for nanoscientists and data for chemical material analyses.

At 14 years of age, the cluster computer had reached a respectable life expectancy. A recent analysis showed that it is now cheaper and more practical to send computing tasks to Ticino via data line and have them performed at CSCS. Hypatia thus remains at Empa without descendants.

R.K.

ELECTRICAL SUPPLY WITHOUT WORRIES

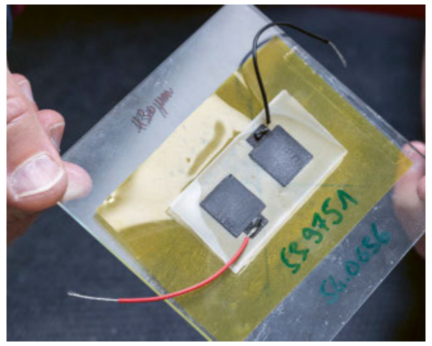
The number of data-transmitting microdevices, for instance in packaging and transport logistics, will increase sharply in the coming years. All these devices need energy, but the amount of batteries would have a major impact on the environment. Empa researchers have developed a biodegradable mini-capacitor that can solve the problem. It consists of carbon, cellulose, glycerin and table salt. And it works reliably.

Text: Rainer Klose

COMPOST
After two months buried in the soil, the capacitor has disintegrated, leaving only a few visible carbon particles.

Photos: Gian Vaitl

NONTOXIC
Xavier Aeby and Gustav Nyström invented a fully printed Biodegradable battery made from cellulose and other non-toxic components.
below: The biodegradable battery consists of four layers, all flowing out of a 3D printer one after the other. The whole thing is then folded up like a sandwich, with the electrolyte in the center.



The fabrication device for the battery revolution looks quite inconspicuous: It is a modified, commercially available 3D printer, located in a room in the Empa laboratory building. But the real innovation lies within the recipe for the gelatinous inks this printer can dispense onto a surface. The mixture in question consists of cellulose nanofibers and cellulose nanocrystallites, plus carbon in the form of carbon black, graphite and activated carbon. To liquefy all this, the researchers use glycerin, water and two different types of alcohol. Plus a pinch of table salt for ionic conductivity.

A SANDWICH OF FOUR LAYERS

To build a functioning supercapacitor from these ingredients, four layers are needed, all flowing out of the 3D printer one after the other: a flexible substrate, a conductive layer, the electrode and finally the electrolyte. The whole thing is then folded up like a sandwich, with the electrolyte in the center.

What emerges is an ecological miracle. The mini-capacitor from the lab can store electricity for hours and can already power a small digital clock. It can withstand thousands of charge and discharge cycles and years of storage, even in freezing temperatures, and is resistant to pressure and shock.

BIODEGRADABLE POWER SUPPLY

Best of all, though, when you no longer need it, you could toss it in the compost or simply leave it in nature. After two months, the capacitor will have disintegrated, leaving only a few visible carbon particles. The researchers have already tried this, too.

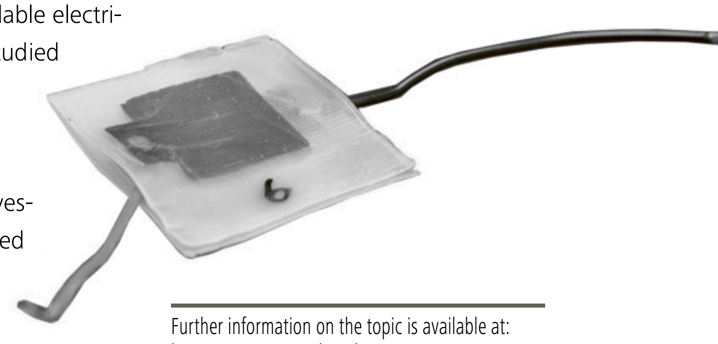
"It sounds quite simple, but it wasn't at all," says Xavier Aeby of Empa's Cellulose & Wood Materials lab. It took an extended series of tests until all the parameters were right, until all the components flowed reliably from the printer and the capacitor worked. Says Aeby: "As researchers, we don't want to just fiddle about, we also want to understand what's happening inside our materials."

Together with his supervisor, Gustav Nyström, Aeby developed and implemented the concept of a biodegradable electricity storage device. Aeby studied microsystems engineering at EPFL and came to Empa for his doctorate. Nyström and his team have been investigating functional gels based on nanocellulose for some time. The material is not only an environmentally friendly, renewable raw material, but its internal chemistry makes it extremely versatile. "The project of a biodegradable electricity storage system has been close to my heart for a long time," Nyström says. "We applied for Empa internal funding in 2018 with our project, Printed Paper Batteries, and were able to start our activities with this funding. Now we have achieved our first goal."

APPLICATION IN THE INTERNET OF THINGS

The supercapacitor could soon become a key component for the Internet of Things, Nyström and Aeby expect. "In the future, such capacitors could be briefly charged using an electromagnetic field, for example, then they could provide power for a sensor or a microtransmitter for hours." This could be used, for instance, to check the contents of individual packages during shipping. Powering sensors in environmental monitoring or agriculture is also conceivable – there's no need to collect these batteries again, as they could be left in nature to degrade.

The number of electronic microdevices will also be increasing due to a much more widespread use of near-patient laboratory diagnostics ("point of care testing"), which is currently booming. Small test devices for use at the bedside or self-testing devices for diabetics are among them. "A disposable cellulose capacitor could also be well suited for these applications", says Gustav Nyström. ■



Further information on the topic is available at: https://www.empa.ch/web/s302

PRESTRESSED PLASTERS FOR OLD BUILDINGS

The technology of stabilizing concrete structures with carbon-fiber-reinforced polymers, thus helping them to last longer, was developed decades ago; among others at Empa. Today, researchers in Dübendorf are working on a new variant with prestressed lamellas – with good prospects for practical application.

Text: Norbert Raabe

Bent concrete beams, cracks on the undersides of bridges, risk of rust for the reinforcement: In Switzerland, many structures are getting on in years. Take national roads, for example: According to the 2019 report of the Federal Roads Office (FEDRO), a large proportion of bridges were built between the mid-1960s to the 1980s – with significantly lower traffic loads than today.

Carbon fiber-reinforced polymers (CFRP) have long been used to refurbish supporting structures that are groaning under their loads: Flat lamellas, bonded to the underside, counteract the load. In the "Ebrog" method (for externally bonded reinforcement on grooves), for instance, which has only emerged in recent years, narrow grooves are milled longitudinally into the girder beforehand: an enlarged surface area for force transmission, which also acts deeper into the concrete. This method was used for the first time in 2018 for a bridge refurbishment in Küssnacht.

Now Empa researchers are developing the method further in an Innosuisse-funded project and in cooperation with S&P Clever Reinforcement Company in Seewen. The team led by Christoph Czaderski from Empa's Engineering Structures lab is testing prestressed CFRP laminates that "actively" reinforce concrete beams: They are bonded with epoxy resin under tensile stress. Once the bond has hardened, the ends are relaxed – and the strips, which "want" to contract, counteract the deflection even more.

What sounds simple at first is tricky in detail – especially at the strips' ends, where enormous tensile forces of up to 14 tons act. To prevent them from tearing off, they have to be fixed reliably. Until now, this has been done with aluminum plates, glued and secured with dowels – but the Empa team has designed U-shaped CFRP stirrups specifically for the new method. The advantages: a more precisely defined transmission of forces and, above all, a metal-free construction – immune to ubiquitous and dreaded corrosion.

"A solution made of a single material is always better than two that behave differently," explains Czaderski. "Especially for the anchoring, we performed a lot of tests in the lab." The team benefited from experience at the Isfahan University of Technology in Iran. "A lot of basic research was done there," Czaderski explains. "Our postdoctoral fellow Niloufar Moshiri came to us with the idea of combining the Ebrog process with prestressing."

The potential is great, as tests in the lab show: The process with prestressing and CFRP stirrups increased the load-bearing capacity of a concrete slab by 77 percent compared with the classic reinforcement method, i.e. without grooves and prestressing. Even without prestressing, the difference was still 34 percent.

IDEA OF AN EXPERT FROM IRAN

In order to bring the technology to the market, large-scale tests on concrete slabs with a span of six meters are to provide further insights before a real refurbishment project will follow later in 2021. Meanwhile, the industry partner is already working on practical aspects. The experts are developing an industrial process for the U-shaped stirrups, which were previously formed by hand from carbon profiles. And the equipment, with which the lamellas have been prestressed up to now, "has to be redesigned for the new process," explains Martin Hüppi, who leads the project at S&P and has been cooperating with the Empa experts for a long time.

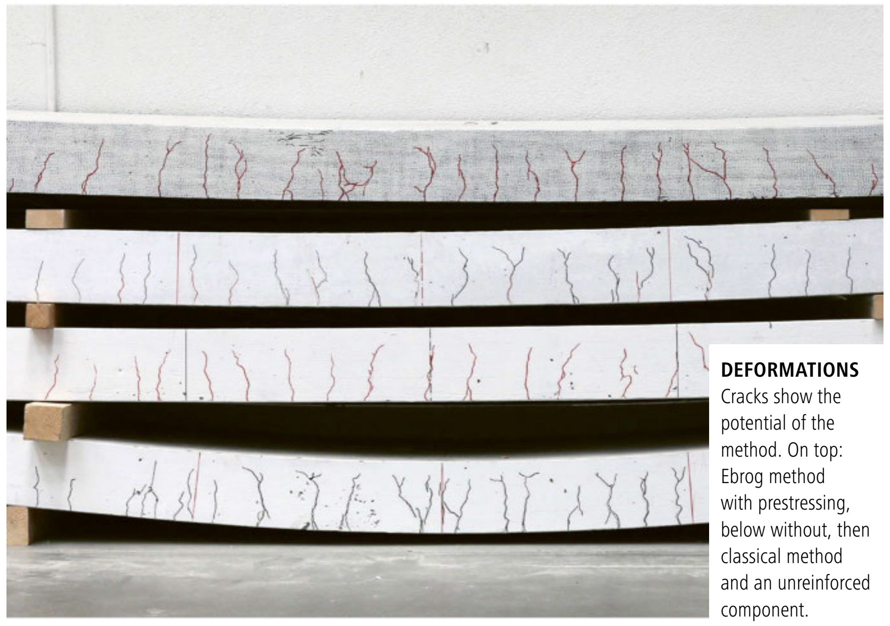
Efforts that could be worthwhile: Any structure that is refurbished rather than rebuilt saves not only costs but also CO_2 emissions. In addition, the process would be easier and faster to handle during installation. "It would also be reasonably priced for building owners," says Hüppi, who sees good opportunities for numerous applications – not only for "rejuvenating" large-scale structures such as bridges, but also in residential renovations. "I absolutely see a market for this," says Hüppi, "and with prestressing, you're only really exploiting the full potential of the material." ■

Further information on the topic is available at: https://www.empa.ch/web/s303

Photos: Empa, S&P Clever Reinforcement Company AG

TRIAL
Epoxy resin as an adhesive for CFRP laminates: Empa researcher Niloufar Moshiri and industry partner Martin Hüppi.

TEST PROJECT
In October 2018, a bridge near Küssnacht was reinforced using the Ebrog method, but still without prestressing.

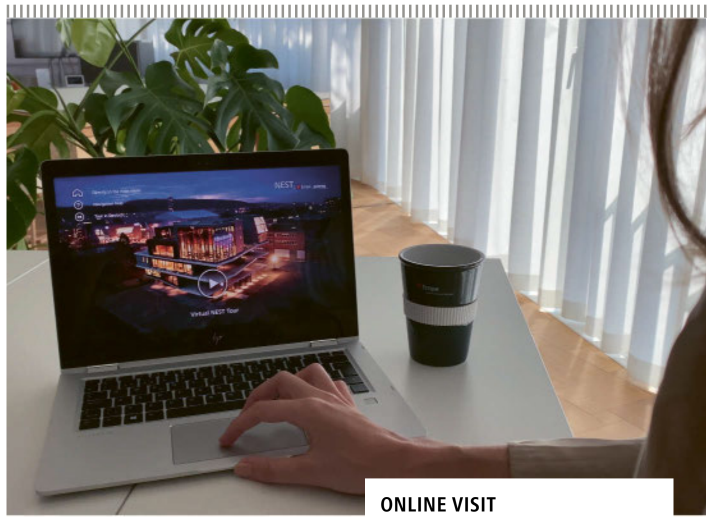


DEFORMATIONS
Cracks show the potential of the method. On top: Ebrog method with prestressing, below without, then classical method and an unreinforced component.

NEST OPENS ITS VIRTUAL DOORS

Until now, tours of NEST have only taken place live and on site. Since June 2021, the entire building can also be visited online and spontaneously. Guests on the virtual NEST tour can visit the individual building modules – known as units – as well as the Energy Hub (ehub) and Water Hub research platforms and move freely through the building. The tour takes them to experts who share their know-how directly with the guests. What's more, there are countless innovative materials, technologies and processes to discover. The virtual tour runs on PC and Mac, smartphones and tablets.

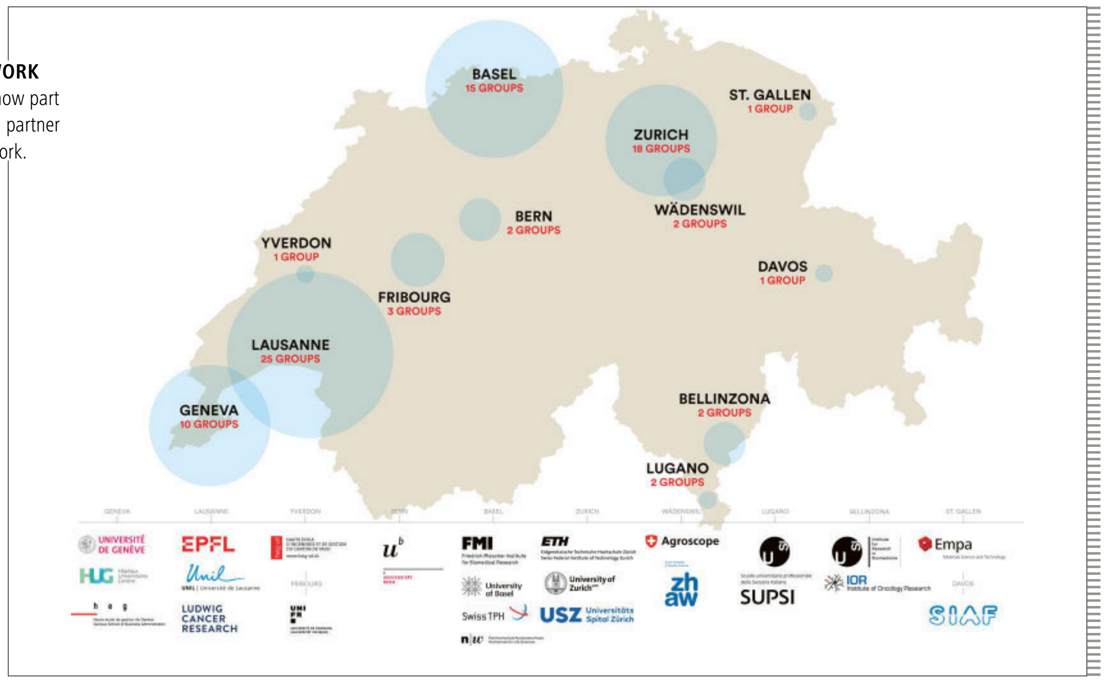
www.empa-virtual.ch/nest



ONLINE VISIT
The virtual tour of NEST runs on laptops, tablets and smartphones.

EMPA AT THE INSTITUTE FOR BIOINFORMATICS

NETWORK
Empa is now part of the SIB partner network.



In January 2021, Empa joined the Swiss Institute of Bioinformatics (SIB) as a new member institution. The SIB is an academic non-profit organization whose vision is to promote excellence in data science for progress in biological research and health. Members include research groups from the most important Swiss universities and research institutes. Empa is represented by the group "Multi-omics for healthcare materials" led by Marija Buljan. The group is part of Peter Wick's "Particles-Biology Interactions" lab and focuses on the unfolding of disease-associated cellular signaling networks to find precise solutions for immunoengineering. The group's activities focus on the generation and analysis of biomedical multi-omics datasets that can support the development of new materials for personalized health applications.

www.empa.ch/de/web/s403/datasci4nanotech

Photos: SIB, Empa

STRATEGIST FOR ENERGY STORAGE

EXPERT
Marcel Gauch analyzes sustainability issues in electromobility.

The umbrella organization of the renewable energy and energy efficiency industry (AEE Suisse) has launched a new working group "Electrical Energy Storage" in May 2021. The group consists of renowned battery specialists, such as Andrea Vezzini, head of the Energy Storage Research Center at the Bern University of Applied Sciences and Arts, and Jonas Mühlethaler from the Institute of Electrical Engineering at the Lucerne University of Applied Sciences and Arts. Empa is represented by Marcel Gauch, an expert in electromobility and also Empa's sustainability delegate. Another Empa-trained expert on the working group is Olivier Groux, project manager for development at Kyburz AG.

https://speicher.aeesuisse.ch/de/ueber-uns

Photo: Empa

EVENTS

(IN GERMAN AND ENGLISH)

13. – 15. JULI 2021
Kurs: Aerogel Industry – Academia Forum
Zielpublikum: Industrie und Wirtschaft
http://www.empa-akademie.ch/aerogel
Empa, Dübendorf und online

01. SEPTEMBER 2021
Kurs: Introduction to Non-Destructive Analysis and X-ray Imaging
Zielpublikum: Industrie und Wirtschaft
http://www.empa-akademie.ch/nda
Webinar via Zoom

09. – 10. SEPTEMBER 2021
Kurs: 3D Drucken in der Medizintechnik
Zielpublikum: Industrie und Wirtschaft
http://www.empa-akademie.ch/medizintech
Swiss m4m Center, Bettlach

09. SEPTEMBER 2021
Kurs: Alkali-Silica Reaction – a Multidisciplinary Approach / Webinar via Zoom
Zielpublikum: Forschung und Industrie
https://www.ch/asr

08. OKTOBER 2021
Kurs: Energy Harvesting (in Englisch)
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/harvesting
Empa, Dübendorf

05. NOVEMBER 2021
Kurs: Tribologie
Zielpublikum: Industrie und Wirtschaft
http://www.empa-akademie.ch/tribologie
Empa, Dübendorf

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

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