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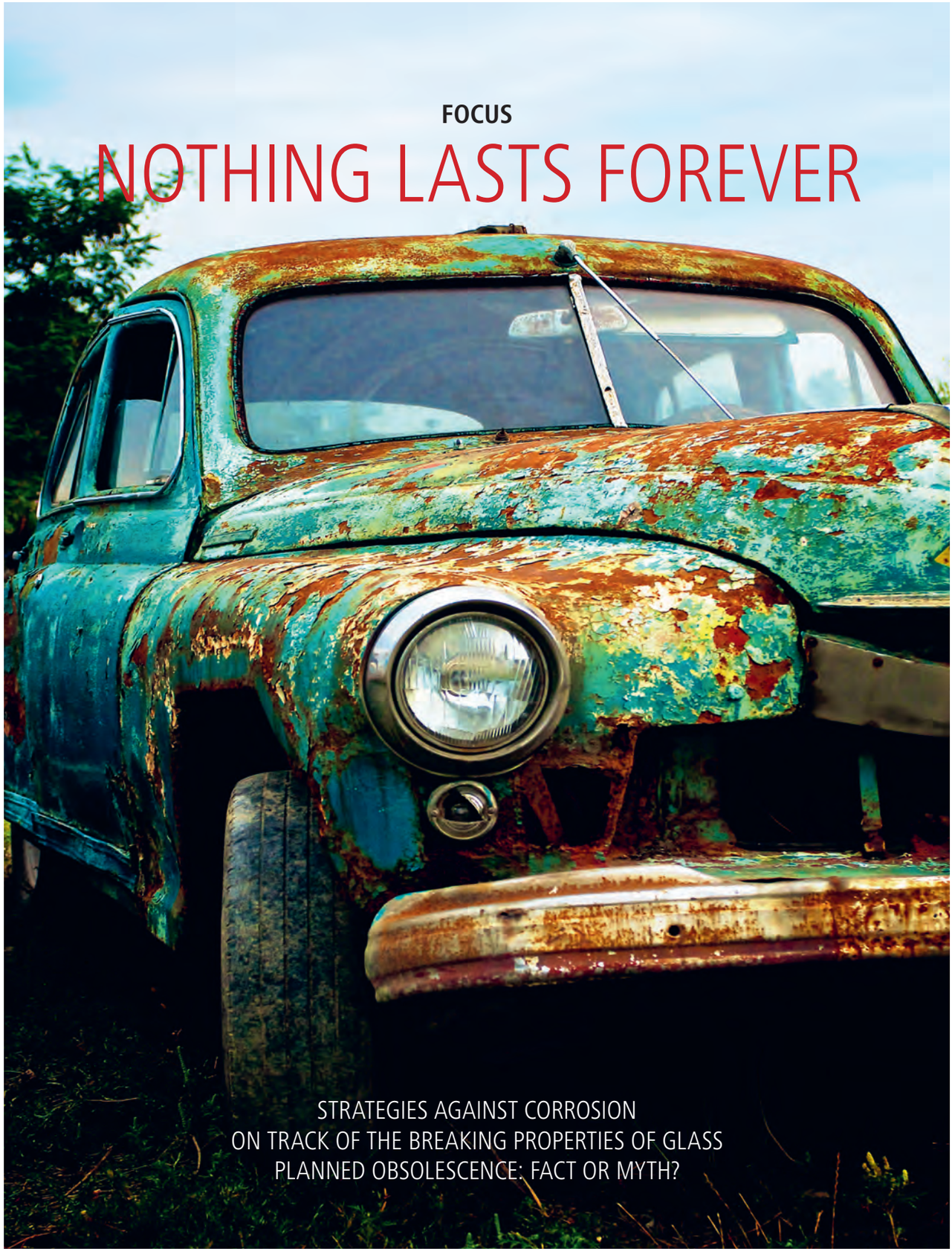

FOCUS

NOTHING LASTS FOREVER

STRATEGIES AGAINST CORROSION
ON TRACK OF THE BREAKING PROPERTIES OF GLASS
PLANNED OBSOLESCENCE: FACT OR MYTH?

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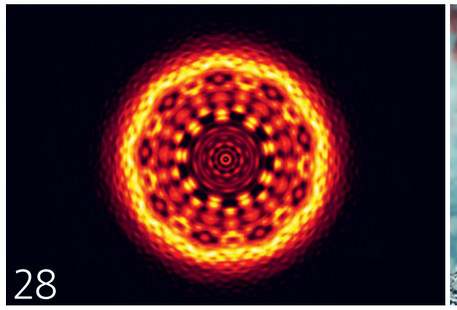
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[COVER]

When materials corrode, they lose important properties – and can fail. Empa is researching ways of understanding these processes – and preventing them if possible.
Image: istock

Photos: Unsplash, Empa

Photo: istock

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"ALL THINGS MUST PASS"

Dear readers,

On his eponymous 1970 solo record ex-Beatle George Harrison shared this wee bit of wisdom with us: In general, there's only one direction – downhill. As soon as something has seen the light of day, the ravages of time are gnawing at it. If you want to oppose this gradual decay, you have to put in a hell of a lot of effort.

It is often stated that, in the old days, everything used to be better – at least as far as the service life of products is concerned. Wouldn't it even be conceivable then that, in their eagerness for higher revenues, companies would implant a programmed expiry date in their products? The truth is – as so often – more complicated, though, as the article on p.13 shows.

Ageing and fatigue processes also play a crucial role in materials science. Because only if you understand these down to the nitty-gritty details can you predict or even prevent possible failure at an early stage, say, by repairing or reinforcing them in good time. Failure analyses such as those carried out after the collapse of the Morandi Bridge in Genoa are, therefore, extremely informative.

On the other hand, a thorough understanding of the "weak spots" of materials and systems also helps to develop novel materials that no longer age – or at least not as quickly –, disintegrate or fail (p. 6). In some cases, however, transience is a desirable feat; for instance with self-dissolving surgical screws that save patients a second operation (p. 21).

Enjoy reading!

Yours MICHAEL HAGMANN

Photo: Deeptanshu Sivaraman und Michal Ganobjak

FROZEN CLOUDS
Aerogels are the lightest known solids. These nanoporous structures have potential applications in pharmaceuticals, thermal insulation and catalysis. Manufactured from cellulose, the world's most abundant polymer, with attractive properties such as biodegradability and recyclability, this is a non-traditional aerogel. Its properties are synonymous with "clouds", which show its low density and translucency.

Further information on the topic is available at:
www.empa.ch/de/web/s604/aerogel

SLOW DECAY

"Corrosion" comes from Latin "corrodere": to gnaw something to pieces. This refers to the gradual destruction of a substance due to the influence of other substances in the environment. Specialists at Empa take a close look at such processes and can find timely ways to prevent material failure due to corrosion – long before disasters such as those in Genoa occur.

Text: Rainer Klose

CORROSION IS EVERYWHERE
It destroys valuable infrastructure and costs billions. However, not only well-known metals corrode: new composite materials and thin-film technologies raise new questions. Empa finds answers.

Photo: iStock

The owner of a new Swiss industrial facility for the production of high-tech machinery was faced with a mystery: Kilometres of brand new stainless steel and aluminium pressure and cooling lines, worth several hundred thousand Swiss francs began to corrode while still under construction. What had attacked the metals so quickly? Empa experts took a close look at the entire system: Were corrosive building materials involved, were cleaning agents to blame or had the wrong materials simply been selected? Finally, they found the "culprit" in form of a small bottle on a workshop truck: Instead of using a professional leak tester, the assembly team had used a universal cleaning agent from the supermarket to locate leaks with the foam. But the supermarket agent contained acids and chlorides that corroded the metals.

New scene: The caretaker of a school in eastern Switzerland notices corrosion on the ceiling lamp fixtures in the gymnasium during cleaning work during the 2019 spring holidays. The school administration consulted the architect who had supervised the construction at the time. He informs Empa. The isolation cladding at the ceiling is dismantled. Result: The entire ceiling construction shows massive safety-relevant corrosion damage. A few years earlier, during the renovation, the workers had drilled metal hooks through insulation plates made of phenolic resin foam, being unaware about the material properties. Water condensation caused the insulation to become damp. The phenolic resin foam then developed strong acids, which caused the fixing hooks to rust throughout.

ENGINEER AND NATURAL SCIENTIST – TWO HEARTS IN ONE CHEST

Is such failure analysis the typical activity of corrosion researchers? Are they something like the pathologists of the construction industry who dissect corpses of material and are always looking for perpetrators? Not at all. Corrosion researchers are much more than that. They work at the interface between materials science and construction on the one hand, chemistry and physics on the other. With one leg they are engineers, with the other natural scientists. Furthermore, they not only look at past mistakes – they also think of the future.

An example: hydrogen. The aimed energy revolution will make it necessary to convert large quantities of excess electricity into hydrogen in the next few years. This is one way to store solar and wind power from summer until winter. However, this not only requires storage tanks, but also pipes, valves, nozzles, transport vehicles and various accessories, such as counters for the quantity of gas supplied. All this must be made of high-strength steel that can withstand hundreds of atmospheres of pressure and be fitted with seals that prevent leaks for years to come. However, hydrogen penetrates some steels and leads to embrittlement of the steel even at normal ambient temperatures. At temperatures above 300 degrees Celsius, the hydrogen also chemically reacts with the carbon content of the steel and deteriorates its quality. Empa is already researching the mechanisms of hydrogen embrittlement and developing materials for the energy supply of the future.

COURSE «ELEKTROCHEMISCHE CHARAKTERISIERUNG UND KORROSION» (in German)

A one-day course on this subject will take place on 7 February 2020 at the Empa Academy in Dübendorf. The course begins with an introduction to corrosion and important standard electrochemical measurement techniques. At the end of the course, the participants will be able to identify the most important types of corrosion and know which findings and corrosion parameters can be obtained with the aid of electrochemical measurement techniques. Further information and registration under https://bit.ly/2kfuEK9

TRACING CORROSION WITH MICROSENSORS

Fatally, hydrogen is not only produced intentionally – it can also be formed during corrosion and penetrate the material. Stored in minute quantities, it has the same destructive effect there: It makes high-tech alloys brittle and fragile. In order to understand what happens and how it can be prevented, researchers have to zoom in closely on the microstructure of a material and investigate the chemical reactions in tiny areas affected by corrosion. Empa has developed its own microsensors that can analyze surfaces of less than one hundred thousandth of a square millimeter and detect less than one millionth of a percent by weight of hydrogen. Using these methods, they investigate critical zones in components, such as welded seams, which become brittle due to atomic hydrogen and could ultimately fail.

Lars Jeurgens has been leading the Empa laboratory for "Joining Technologies and Corrosion" since 2012 and, together with his team, maintains a well-balanced mix of research and industry-related services. "We have graduates from ETH Zurich and EPFL in our team and use the concentrated knowledge of these two leading engineering schools," says Jeurgens. He himself was born in the Netherlands and worked at the Max Planck Institute in Stuttgart for a long time. "Corrosion knows no boundaries – that's why we are very well connected internationally with experts from academia and industry and exchange ▶

the latest findings and methods. It is very valuable for us to share these experiences. Together, many complex problems can be solved more easily and quickly".

MANY THINGS TO DO

In addition, there is truly enough to do for the corrosion specialists. The automotive and aircraft industries, for example, are increasingly working with composite materials consisting of a wide variety of materials. Little is known about their corrosion behavior in harsh operating environments. In many places, alloys of iron, titanium and aluminum are also used. They owe their corrosion resistance to a tiny, nanometer-thin passive oxide film on their surface, which requires special analytical methods just to detect it – only then the material surface can be tailored for its corrosion resistance.

"Corrosion belongs on the checklist – not only at the end of a project, but already during the drawing board phase."

Finally, the application of functional coatings to miniaturized electronic devices and components raises new corrosion issues. Lars Jeurgens gives the following example: "If I make a turbine with a corrosion-resistant coating and a hundredth of a millimeter of material thickness is lost every year, this is unproblematic. However, the same coating on an electronic device that is only one hundredth of a millimeter thick would be completely degraded within a year. What appears corrosion-resistant on a large scale is far from being so on a micrometre scale. We therefore need new concepts for classifying the corrosion sensitivity of a material for a given application."

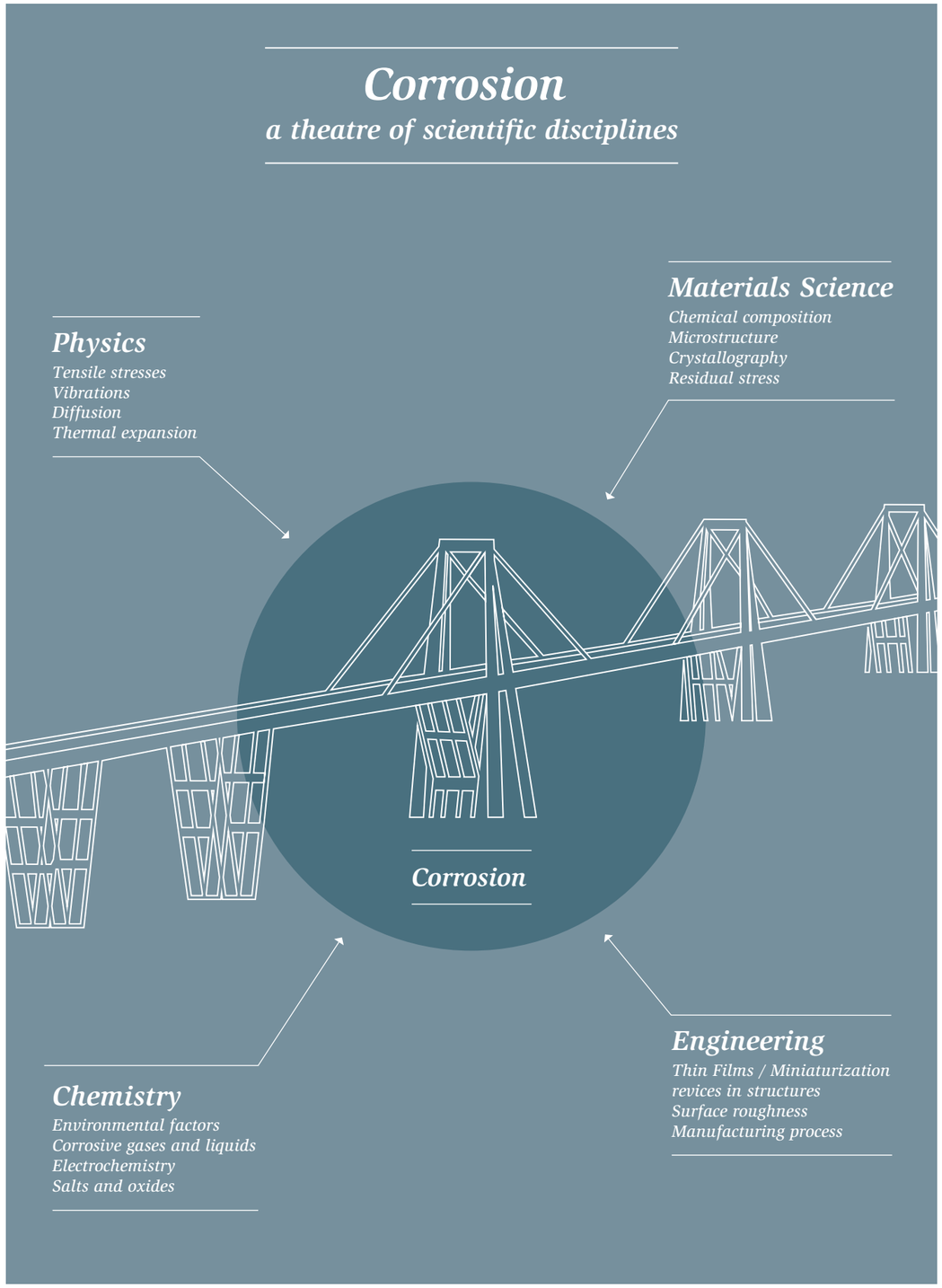
CORROSION – ALSO IN THE HUMAN BODY

Sometimes corrosion occurs even where it is least suspected: In the middle of the human body, amidst its warm, apparently harmless body fluids. Empa's experts are investigating degradation by localized corrosion on materials such as stainless steel and titanium alloys, which are often used for implants as well as silicon, which is present in numerous new implanted components. Little happens on large, smooth surfaces, but human body fluids can do a great deal in microscopically small crevices resulting from design or construction.

Recently, an Empa team was able to demonstrate the slow dissolution of a silicon-bonding layer in the laboratory. Between the titanium implant and the wear resistant coating a microscopic crevice may form. In the absence of oxygen, a very aggressive medium can develop there slowly, which can then destroy the silicon-bonding layer with the help of the body's own phosphorus compounds. Using special probes, Empa researchers are also able to elucidate the local corrosion chemistry in such fine crevices and even accelerate the corrosion processes for experimental purposes. In this way, the expected service life of an implant can be predicted quite accurately even before the operation.

Corrosion research is enormously important in many real-life applications, and yet the work of the "pathologists of the engineering world" is often still underestimated. Lars Jeurgens and his colleagues are working hard to reinforce the importance of expertise in this field at universities and technical colleges. "Corrosion assessment belongs on the checklist for every building project and every product development – not only at the end, but already during the drawing board phase," says Jeurgens. "Oftentimes, we are only asked for an analysis when the colour brochures for their product have already been printed. But at that point, we are often unable to do anything for our clients anymore." ■

You will find contact persons for the subject of corrosion under: www.empa.ch/web/s202/services



Grafic: Hug & Dorfmuller Design AG

UNBREAKABLE

Can glass flow at room temperature and thus withstand hard impacts? A theory from the 1970s predicted exactly this. Empa researchers have now provided the proof. The results could form the basis for robust 3D printed glass microarchitectures.

Text: Rainer Klose

"No one in the world has ever seen what we have measured," says Rajaprakash Ramachandramoorthy. "We've tracked the breaking properties of glass further than any previous research team." Raj – his nickname among colleagues – works in the Empa lab "Mechanics of Materials and Nanostructures" led by Johann Michler.

The team explores material properties on a very small scale: Machines they have developed themselves use tiny stamps to press columns just a few micrometers thin, so-called micropillars. In the electron microscope, and with the help of the most precise force measurements, they can observe how the micropillar breaks or deforms. These results allow the researchers to draw conclusions about the internal structure of materials.

PRESSING FOR MINUTES AND HAMMERING IN A FRACTION OF A SECOND

Ramachandramoorthy and his colleague Jakob Schwiedrzik have now used this method to examine fused silica glass – and discovered properties that have little to do with the macroscopic world of glass: Glass is as tough as modelling clay when pressed very slowly, it can tear and burst when pressed a little faster – and at very short, fast pressure impulses it behaves again tough and yielding. "Our slowest compression test took about 20 minutes," says the Empa researcher. "Our most rapid impulse on the micropillar, on the other hand, took only 100 microseconds. It is comparable to the blow of a hammer."

THEORETICAL PREDICTIONS FROM THE 1970S VERIFIED

For the first time, the Empa researchers now provide empirical values and measurement data for material properties that could thus far only be postulated in theory. The deformation properties of amorphous materials such as glass were predicted at the end of the 1970s independently by two physicists, Frans Spaepen at Harvard University and Ali S. Argon at the Massachusetts Institute of Technology (MIT). Both theories, we will call them "glass flow theories" here, point in the same direction and say: Whoever wants to build a break-resistant microchanical system, should rather build it from glass than from crystalline silicon. Because glass withstands high forces better.

Photo: iStock

VISCOUS AS CLAY?
Empa researchers are investigating the breaking properties of glass.

But this could never be proven experimentally. Only very slow compression tests were possible at the microscale. On the other hand, at the macroscale, dynamic experiments with high speeds trigger a shock wave in the test specimen that superimposes the deformation mechanisms. Then something happens we all know from experience: The glass breaks as soon as the shock wave encounters a material defect that almost always occurs in large test specimens.

THE EXPERIMENT CAN ONLY SUCCEED WITH THE MICROCOLUMN

Ramachandramoorthy and Schwiedrzik found a suitable solution at Empa: They use micro-columns of etched glass that are so small that, statistically speaking, they no longer contain any material defects that could distort the results. At the same time, the shock wave is no longer a problem: It now runs so quickly through the microscale test specimen that the effect does not interfere with the hammer blow that shifts the glass atoms. Now both effects can be documented separately. For the first time, the 40-year-old glass flow theory of Spaepen and Argon can be verified through experiments.

"Now many glass manufacturers want to know more about the microproperties of their products."

3D-PRINTED GLASS COMPONENTS FOR WATCHES

Research at Empa has already attracted a great deal of attention in the Swiss watchmaking industry and among manufacturers of microelectromechanical systems (MEMS). They could provide the basis for 3D-printed glass microcomponents that could be built into shock-resistant watches or robust measuring instruments. In March 2019, the Swiss luxury watch brand Ulysse Nardin presented the prototype of a watch called FREAK neXt, which was equipped with a luminous minute hand made of glass. The glass component, a very fine capillary filled with fluorescent liquid, was produced by the Swiss specialist company Femtoprint using ▶

DELICATE
The minute hand of this watch prototype is made of glass and filled with a fluorescent liquid.

Photo: Ulysse Nardin

3D printing. But from a prototype for the watch case to a shock-resistant series product, there is still a lot of development to be done. The Empa researchers now want to lay the foundations for this.

GLASS MANUFACTURERS ARE LINING UP

In the meantime, Rajaprakash Ramachandramoorthy is not only in demand as a supplier of new ideas for the watch industry. After they published the results with pure silicate glass, manufacturers of float glass and borate glass asked for an expert opinion. They all want to know more about the micro-properties of their products. The next research projects are already underway. "With our method, we can basically investigate any material system including amorphous materials, metals, polymers, biomaterials and ceramics," he says.

He also wants to use the machinery developed in the Empa lab in Thun for an extensive series of experiments: "In the future, we want to measure the mechanical properties of materials between minus 150 degrees and 1000 degrees Celsius at a wide range of testing speeds." Looking at the properties of tiny microcolumns could soon pave the way for some major material innovations. ■

Further information on the topic is available at:
www.empa.ch/web/s206

BUILT-IN EXPIRY DATE

Whether mobile phone or automatic toilets – electronic devices are becoming increasingly complex. And who hasn't heard stories of devices that fail precisely after the warranty has expired? According to Empa researcher Peter Jacob, however, the shorter lifespan is not a malicious "planned obsolescence", but is mainly due to enormous cost pressure. He and his team investigate cases of damage with detective meticulousness.

Text: Karin Weinmann

ROBUST
Old transistor radios could easily be repaired – the repair of modern radios is often hardly worth the effort.

Photo: iStock

Anyone who purchased a radio around the 1950s spent a large chunk of money on it – but could rely on it being relatively easy to repair in the event of damage. If a modern radio set no longer functions today, it is in most cases disposed of and replaced by a new one. There is a simple reason for this: while the radio from the 1950s consisted of commercially available components and a few easily replaceable standard tubes, today's radios contain electronics with thousands of transistor functions connected in microchips. These chips are usually manufactured for specific applications. If the radio fails a few years after purchase, there are often simply no spare parts left.

COST PRESSURE ALONG THE CHAIN

This explains why electronic devices are often no longer repaired – but why do they often only last a short time? "There is usually no bad will behind this either," says Jacob. The problem lies elsewhere: in a global competitive situation with enormous price pressure – and long supply chains. Internal cost specifications are often very strict, especially for large quantities. Components are specified at their limits. "Today, a capacitor is often subjected to extreme loads at its limits, even if the engineer would prefer a safety margin. This applies not only to lowcost electronics such as flashing children's toys, but even to professional electronics – in cars, for example.

The cost pressure is enormous – and is passed on along the supply chain. These are often long and complex; more than 100 different suppliers are often involved in a car air conditioning system alone. This does not make troubleshooting trivial. This also involves a lot of money. Especially in the case of high-volume products, it can be a matter of survival for smaller suppliers if a defect can be proven to have been caused by them. Such cases are investigated by the Center for Electronics and Reliability Technology at Empa as a neutral contact point with detective meticulousness.

THE DEVIL IS IN THE DETAILS

Sometimes the team under the direction of Peter Jacob encounters clear construction errors: In a sanitary system, the circuits with a voltage of 5 volts were simply too close to those operated with 230 volts. The damp environment in the bathroom did the rest – dangerous short circuits were the result.

In other cases, the search for the cause of a failure turns out to be a complex interplay of causes. Jacob mentions an example of a car manufacturer where new vehicles of a certain type landed in the workshop after about 10,000 kilometres – always with the same defect where a certain part of the engine control unit failed. Interestingly, this only happened in countries with no speed limit – and once the unit was repaired, the defect never happened again. A closer inspection showed that the unit had been installed between rubber hoses without grounding. The Empa researchers used a non-contact electrostatic voltage probe to measure the charge on the metal housing of the unit. And lo and behold: no failure was observed at a speed of less than 150 km/h. If the car drove faster, however, high electrostatic voltages suddenly appeared on the housing – higher than Jacobs' probe could even measure. It turned out that the voltage was caused by the extremely high air flow and its turbulence and could not flow off due to the lack of grounding. The high voltage reached the control unit and destroyed it in a very short time. But why did the problem only occur in the first 10,000 kilometres? The researchers also found an explanation for this: after this distance, enough dirt and dust had collected on the rubber hoses to make them electrically conductive – and to replace the missing grounding. In both cases – the sanitary facilities and the cars – the defects always occurred in the same place – but by no means planned.

MYTH OR INTENTION?

So is the planned obsolescence really just a myth – and the ever faster product life cycles owed solely to a system in which consumers thirst for new technology and manufacturers and suppliers are forced to operate the components to their limits in accordance with competitive and cost pressure? It's not that simple. In fact, there are demonstrable examples where companies are deliberately using obsolescence strategies to force customers to buy new equipment.

The dubious honor of the first documented case of planned obsolescence comes to light bulbs: The light bulbs developed by Thomas Edison were so durable that they had to be replaced far too rarely – and the big light bulb manufacturers failed to make a profit. In the 1920s, the manufacturers' cartel therefore agreed to limit the lifespan of their products from 2500 to 1000 hours. The filament was shortened slightly at the same operating voltage, resulting in a lower burning time. Manufacturers with more durable products were fined. With success: sales of light bulbs increased massively – until the Second World War finally made it impossible to coordinate the manufacturers from now hostile countries and forced the cartel to dissolve.

Today, planned obsolescence cases often involve software: for example, ink cartridges in printers are equipped with chips that make printing impossible as soon as the fill level of the cartridge falls below a certain limit. The cartridge must be replaced even though more than enough ink is available.

Smartphones, too, are not immune to planned obsolescence: in 2018, Apple and Samsung were fined millions because their operating system updates made older devices so slow that users felt compelled to replace them.

Planned or not – that software shortens the lifespan of technical products instead of extending it as once hoped is becoming more and more apparent: The mechanism of software updates leads to ever new demands being made on the hardware. This probably contributes more to the devaluation of devices than the planned obsolescence.

And if the "Internet of Things" becomes a reality, software obsolescence threatens to become even more frequent. Because now all everyday objects potentially become dependent on software updates. Empa had to experience this with many perfectly functioning microscope cameras when they suddenly had to be replaced in series because of a Windows software update. On the Internet of Things, situations are no longer far away where a perfectly cooling refrigerator has to be replaced – because the circuits used in it are no longer compatible with the latest software update. ■

Further information on the topic is available at:
www.empa.ch/web/s498

CONTROLLED
A classic case of planned obsolescence: the printer reports that the ink cartridge is empty and blocks printing even though there is still enough ink left.

Photo: Empa

SENSORS FOR AUTOMATED DRIVING

PRECISE
The team of Empa's "Automotive Powertrain Technologies" department with the Lexus provided.

Sensor systems play a central role in autonomous driving. They record the vehicle's environment and provide the necessary information to ensure that the car is steered safely through traffic. In actual use, however, these sensors are exposed to a wide variety of weather and environmental influences, as well as mechanical stress. Empa and Lexus have now agreed to work together to improve sensor technology for automated vehicles. As part of the cooperation, Lexus provides Empa with a test vehicle that will now be equipped with various sensors and a data acquisition sys-tem to investigate the behavior of the sensors in operation.

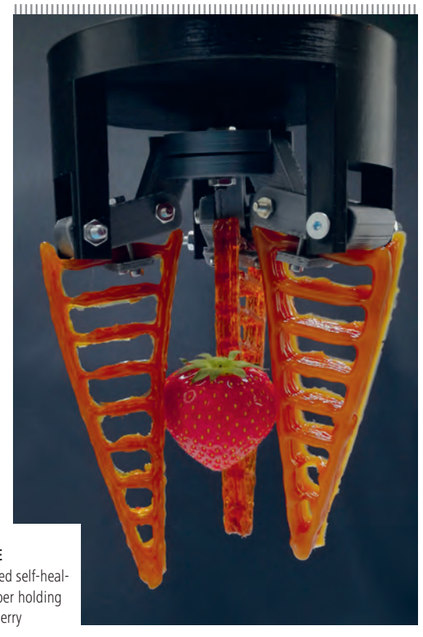
www.empa.ch/web/s604/lexus

SHOCKING
5000 tons of plastic end up in the environment.

5000 TONS OF PLASTIC RELEASED INTO THE ENVIRONMENT EVERY YEAR

Plastic should not be found in the environment. In order to estimate for the first time the exact extent of plastic pollution in Switzerland, the Federal Office for the Environment (FOEN) has mandated Empa researchers to calculate how much plastic gets into the environment. Empa has analyzed the seven most frequently used types of plastic. According to the study, more than 5000 tons of plastic are discharged into the environment every year. The results show that the plastic load on and in soils is much greater than in waters.

www.empa.ch/web/s604/mikroplastik-bafu



GENTLE
3D printed self-healing gripper holding a strawberry

SELF-HEALING ROBOTS THAT "FEEL PAIN"

Robots play an increasingly important role in everyday life. In order to be able to handle fragile objects skillfully and to guarantee human safety, many robots will be made of flexible materials in the future. However, this makes them susceptible to cracks caused by sharp objects – repairs are expensive. As part of the SHERO project (Self-HEaling soft RObotics), an international team of researchers in collaboration with Empa is working on technologies with which such robots can independently "heal" damage. Self-healing materials such as flexible plastics, from which the robots are built, offer a possible solution. The ambitious goal of the European project is to create a robot from self-healing material that detects damage, initiates the necessary steps and rectifies the defect itself. In this way, it can complete ongoing work processes and then be completely repaired during service work.

www.empa.ch/web/s604/self-healing-robot

COMPLEX
In winter, the production of solar power drops significantly, but this is precisely when the demand for electricity is highest. How can we close this gap?

HEADING TOWARDS THE ENERGY FUTURE

Much work still lies ahead of us if Switzerland is to do without fossil fuels in the future. A new Empa study published at the end of June in the journal "Energies" proposes two solutions: storing large amounts of energy in summer and limiting our demand in winter, or generating energy in the "sunny south" or "windy north" of the world and transporting it here. The Empa researchers see their study as a thought-provoking impulse for politics and society.

www.empa.ch/web/s604/energieversorgung

Photos: Empa (2)

Photos: istock, Vrije Universiteit Brussel

THE WOOD PARADOX

HIGH-TECH WOOD
Delignified, deformed, compacted and made water-repellent.

Photo: Empa/ETH Zürich

It can be deformed as required and is three times stronger than natural wood: the wood material developed by Marion Frey, Tobias Keplinger and Ingo Burgert at Empa and ETH Zurich has the potential to become a high-tech material. In the process, the researchers remove precisely the part of the wood that gives it its stability in nature: lignin.

Text: Stephan Kälin

Wood is one of the oldest materials in the world. Wood is light, has excellent mechanical properties, regrows – and binds CO_2. Against the background of the current climate debate, the last two properties in particular raise the question of how wood can be used even more and better. Ingo Burgert's research group at Empa and ETH Zurich have been investigating this question for years. Their aim is to improve the natural properties of wood and equip it with new functions that will broaden the application range for wood.

Together with Tanja Zimmermann, the current head of Empa's "Functional Materials" department, Ingo Burgert has already created astonishing wooden objects in the "Vision Wood" unit of the NEST experimental building: Door handles made of antimicrobial wood, mineralized wood for improved flame resistance or a pinboard made of magnetized wood are just a few examples. After around three years of practical testing, a positive conclusion can be drawn for the first two examples in the "Vision Wood" student apartment. However, there is still room for improvement in the latter. The latest research work of the "Wood Materials Science" group at ETH Zurich and Empa is now opening up new possibilities: "We have found a way of significantly improving the mechanical properties of wood and at the same time making it even easier to equip it with new properties," says Burgert. ▶

FLEXIBLE WHEN WET, STABLE WHEN DRY

The key lies in delignification and compaction of the wood. Chemically, wood essentially consists of three components: Cellulose, hemicellulose and lignin. The lignin ensures that the long cellulose fibrils are stabilized and do not bend. "We use acid to remove this lignin from the wood and thus remove the natural adhesive," explains Marion Frey, who is currently doing her doctorate in Burgert's team. The result: The wood – or rather the remaining white cellulose – can easily be brought into any shape when wet: Between the cells – where lignin once provided stability – water distributes, dissolves the cell connections and ensures deformability. When the delignified wood is dried, the cells interlock – which in turn leads to stable compounds. The material is then additionally compacted by pressing, so that the researchers ultimately end up with a material about three times stiffer and more tensile than natural spruce. Furthermore, adding a water-repellent coating ensures that the interior of the wood can no longer become damp and thus retains its desired shape.

SIMPLER FUNCTIONALIZATION

Besides the deformability, the removal of lignin from wood comes with another effect: It leads to a higher porosity. "This is a great advantage for the functionalization of wood. Because there is more space between the cells and in the cell walls, it is easier to introduce other substances into the wood structure that give the modified wood new properties," says Tobias Keplinger. For example, iron oxide can be inserted into the wood to magnetize it. In their experiments, the researchers were able to show that wood without lignin can be magnetized much better than natural wood – which was previously used in the NEST unit "Vision Wood.

PLIABLE AND STRONG
Above: With the removal of lignin, the wood loses its color. After compaction, it is three times stronger than the original material. Below: A bicycle helmet or a wall element made of delignified wood: designer Meri Zirkelbach dealt with concrete product ideas in her master's thesis.

APPLICATIONS IN CARS AND AIRPLANES

The researchers see possible applications of their new material in the automotive, aviation and furniture industries. Designer Meri Zirkelbach has already implemented her first product ideas as part of a master's thesis. The results include a bicycle helmet, the interior trim of a car door and the side mirror of a vehicle. ■

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

Photos: Meri Zirkelbach, Empa/ETH Zürich

THE SCREW THAT DISSOLVES

Where bones fracture, surgeons often have to join the fragments with implants. Magnesium orthopedic screws, which over time dissolve in the body, spare patients another operation after healing is completed and reduce the risk of infection. What happens inside the body during this process, though, is still largely unknown. To develop optimized alloys and orthopedic screws with functionalized surfaces, Empa researchers are now investigating magnesium corrosion.

Text: Andrea Six

When surgeons want to fix bone fragments after a fracture, the critical question is what type of implants to use: screws and plates made of titanium or steel, which are mechanically and chemically very stable in the body, but have to be removed later on by another surgical procedure? Or implants made of organic materials that dissolve over time but can have certain other drawbacks, such as lack of mechanical strength or unfavorable degradation products? Empa researchers are currently working on solving this dilemma: tiny magnesium implants and screws. These are mechanically robust at first but dissolve later on in the body in a controlled way that does not cause tissue damage.

Such magnesium implants are particularly interesting for medical orthopedic applications in children whose bones are growing rapidly. The biodegradable screws do not impair the child's bone growth and save the small patients a second surgery. In addition, the risks of infection can be minimized and costs can be cut. "Magnesium is more commonly regarded as a white powder that is often taken as a dietary supplement," says Arie Bruinink from Empa's Laboratory for"Joining Technologies and Corrosion". Implants made of magnesium alloys are not only biocompatible, however; they also have mechanical properties during the first delicate healing phase that are bonelike and, therefore, even more suitable than those of titanium.

The blessing of a resorbable screw can also be its curse. After all, the dissolution is associated with complex corrosion processes that alter the surface structure and yield a number of products – that might or might not be hazardous. Depending on the type of magnesium alloy, hydrogen gas can develop during degradation due to insufficient corrosion resistance – to an extent that even a gas cushion is being formed under the patient's skin. Although it is in the surgeon's intention that magnesium screws are degraded by corrosion, during which magnesium oxidizes and hydrogen is produced, the formation of gas cushions should be avoided. If all of a sudden more hydrogen gas is formed than the body can remove, the healing process of the fragile bone can be disturbed.

However, it is precisely this bio-corrosion, to which a magnesium screw is exposed, that has so far been poorly understood. This is where Empa's corrosion researchers come in, using specially devel- ▶

oped analytical methods to depict bio-corrosion in the body under conditions that are as realistic as possible. The goal: optimal alloys of magnesium and other biocompatible elements as well as new surface properties for resorbable magnesium screws. Ultimately, the researchers aim for a slow, well-controlled degradation of the implants that does not lead to gas pocket formation within the tissue.

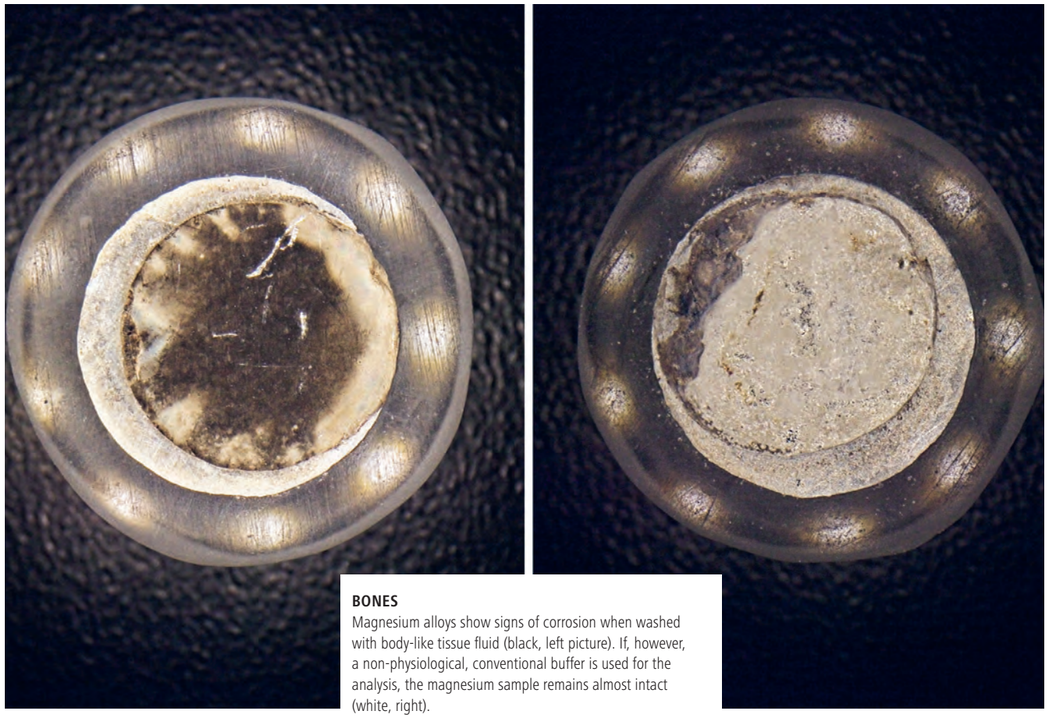
"So far, it is already clear that the reaction is different depending on the level of acidity in the tissue," explains Bruinink. In a slightly acidic environment, large amounts of hydrogen gas are formed during magnesium corrosion; at a pH value in the alkaline range, carbonate-containing products are produced, among other things, which can even inhibit the desired magnesium degradation. In a neutral environment with a pH value of 7.4, such as in blood, magnesium hydroxides and phosphate products are formed, which at least slow down further corrosion. Blood – as a potent buffer – is able to keep its pH value within a constant range. According to Bruinink, magnesium implants have hitherto been analyzed in comparably potent but rather non-physiological buffer systems. He does not consider this procedure to be realistic.

"Blood is a juice of very special kind" – this is how Goethe's restless scholar Faust put it. Whether Doctor Faust knew anything about the so-called interstitial fluid, is not known. The saline fluid with its approximately ten liters far exceeds the volume of blood in the human body. This underestimated "juice" moves slowly between tissues and cells at a speed a hundredfold slower than a snail. And it is precisely this interstitial fluid that is of crucial importance if new implants are to be developed. The healing process of a bone fracture, which is controlled by immune cells and is intended to produce a well-balanced structure of bone resorption and remodeling, is primarily embedded in interstitial fluid.

The acidity of the tissue fluid, however, is subject to much greater variability than that of blood. Depending on the body part and tissue condition, a variety of parameters can affect the inserted screw. In order to provide a realistic prognosis of the course of bio-corrosion in the body, Bruinink has developed experimental analysis techniques and flow cells, in which the pH regulation is modelled on the body. In a battery of ten flow cells, for instance, the researcher inserts samples of magnesium alloys that are washed by artificial interstitial fluid – with the same slowness as in the human body.

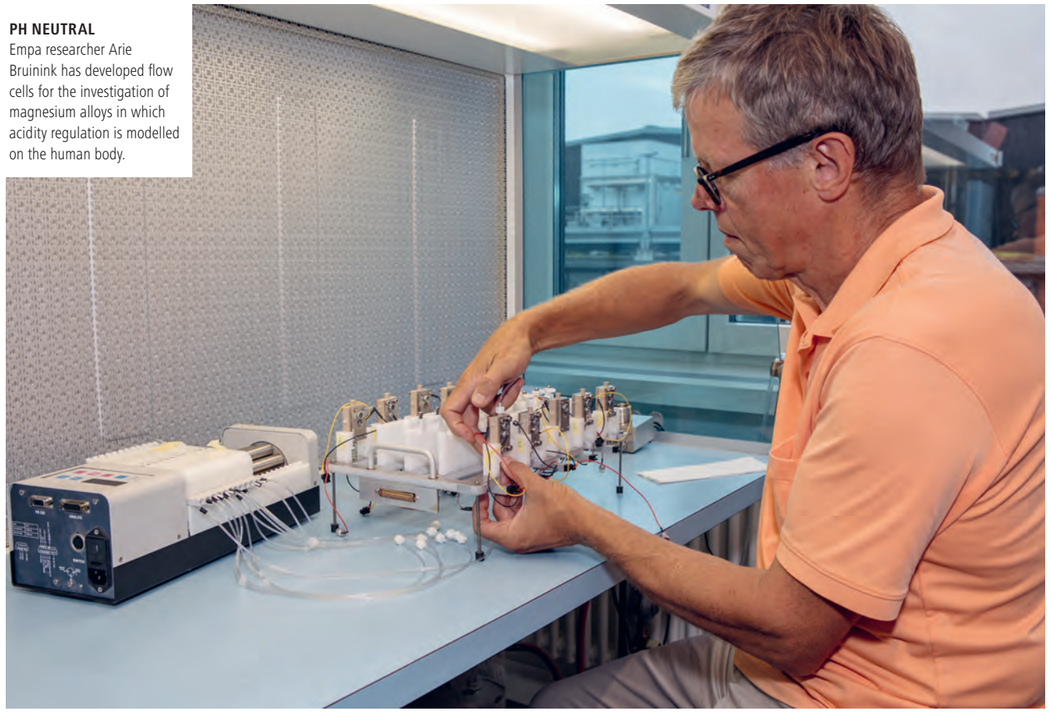
In addition to pH measurements, detailed electrochemical characterizations are currently being carried out on the small flow cells. Electrochemical potentials, electrical impedance changes of the interfaces as a feature of corrosion and the generation of hydrogen are evaluated. "The flow cell is a tiny lab that simulates the reality of bio-corrosion," says Bruinink. In the next step, the alloy samples will be brought together with living cells in the minilab in order to imitate events in the body in even greater detail. Bruinink: "As soon as it is clear what actually happens to the magnesium alloys during bio-corrosion, we will be able to produce suitable implants with functionalized surfaces that, for example, promote beneficial reactions of the biological environment." ■

Further information on the topic is available at:
www.empa.ch/web/s202



BONES
Magnesium alloys show signs of corrosion when washed with body-like tissue fluid (black, left picture). If, however, a non-physiological, conventional buffer is used for the analysis, the magnesium sample remains almost intact (white, right).

Photo: Empa



PH NEUTRAL
Empa researcher Arie Bruinink has developed flow cells for the investigation of magnesium alloys in which acidity regulation is modelled on the human body.

Photo: Empa

AN OPEN EAR FOR NOISE

A rippling stream is Jean-Marc Wunderli's favourite sound. However, his everyday research has little to do with calming natural sounds. He deals with completely different ones: noise from aircraft turbines, train noise, busy roads, wind turbines and now even drones. All these emissions are part of the research activities of Empa's Acoustics / Noise Control Lab, which Wunderli is heading since last July.

Text: Cornelia Zogg

Sounds accompany our everyday lives – some cause stress, others promote recovery. While noise abatement in recent decades has been primarily concerned with reducing the loudest noise levels, densification and the increasing use of technology have led to constant largescale noise. Jean-Marc Wunderli, new head of Empa's Acoustics lab, would like to counteract this trend: "Current research results show that stress caused by noise is better tolerated if access to green areas and recreation areas is guaranteed." Over the next few years, the researchers in Wunderli's team in-tend to increasingly address this issue and develop the scientific basis for improved protection of beneficial acoustic landscapes. The focus is on urban areas and the question of how quality of life and health can be maintained and promoted even in densely populated areas.

ON THE TRAIL OF NOISE CHARACTERISTICS

For Wunderli, noise research does not focus on the number of decibels, but on the human being. "Human perception is much more complex than it could be represented by a mere decibel number," says Wunderli. Wind turbines are a classic example. Compared to street noise, residents feel much more disturbed by the noise of wind turbines at the same noise level. The researcher explains that this is due to the composition and frequency of the acoustic signals. A low frequency, to the beat of our heart, narrows the listeners. "People living near wind turbines explain that they have the feeling that the sonorous humming of the wind turbines forces them into a certain heart rhythm, which naturally triggers stress in them," says Wunderli. Not only acoustics as a branch of physics is one of his core subjects, but also so-called psychoacoustics. Wunderli and his colleagues also work closely with sociologists, psychologists and epidemiologists to investigate not only noise itself, but also its effect on humans.

When Jean-Marc Wunderli started his research career as an ETH cultural engineer at Empa, the lab of Acoustics differed considerably from what it is today. "The Acoustics lab was like a kind of small engineering office," says Wunderli. As part of his work, he assessed noise sources as shooting ranges. At

Photo: Empa / Gian Vaitl

JEAN-MARC WUNDERLI
New head of the Acoustics / Noise Control Lab at Empa

that time, research was not the main focus. But when, around the turn of the mil-lennium, Empa began transforming itself from a classical testing institute into a modern research institution, the department also changed. "At that time, there was even a discussion about privatizing acoustics," explains Wunderli.

But this idea was then buried – fortunately, as he adds. Empa, as an independent institution, is central and its expert reports enjoy an enormous status. "We benefit enormously from our close networking with administration, politics and industry," explains Wunderli. On the one hand, Empa researchers are contact persons for federal offices such as the Federal Office for the Environment (FOEN) or the Federal Office of Energy (SFOE). On the other hand, they work closely with industry partners to develop materials and technologies that help reduce noise.

FROM GIANT JETS TO TINY DRONES

Even with rather unconventional questions, Switzerland relies on the competence of Empa's acousticians, for example in the procurement of new combat jets. Empa accompanies the ongoing evaluation process, measures the noise level of the jets in operation and creates source models for all candidates. This allows the simulation of individual flights and entire operating scenarios. This makes it possible to assess the noise pollution the population will be exposed to after the introduction of new jets.

The fighter jets of today are perhaps the drones of tomorrow, and here, too, the Federal Offices have relied on Wunderli's expertise to take a look into the future. Technological progress is opening up completely new possibilities here, as initial experiments with drone transports have shown. What it means when hundreds of drones suddenly buzz through Swiss cities is hard to imagine today. How loud can it actually be? And how annoying is it perceived? Questions Wunderli's team is investigating. One way to imagine such soundscapes is what is known as auralization – making acoustic landscapes audible. The researchers use algorithms to generate the exact emissions from various noise sources, such as trains. Everything is completely digital and computer-generated.

> "Human perception is much more complex than it could be represented by a mere decibel number."

NOISE MAKES PEOPLE ILL

In the coming year Wunderli will become President of the Federal Commission for Noise Abatement, where he currently holds the office of Vice-President. Limit values are of great concern to him, not least because they are an important driver for building up the necessary pressure to implement technical solutions in practice. "Together with air pollution, noise is one of the most important environmental impacts on people," he explains. Noise is not only a sensation that is assessed as pleasant or unpleasant, but also has surprising medical effects: around 500 heart attacks per year and around 2500 cases of diabetes in Switzerland can be attributed to the consequences of noise. Noise also entails economic costs. "It is an important topic, but also a field of tension," says Wunderli.

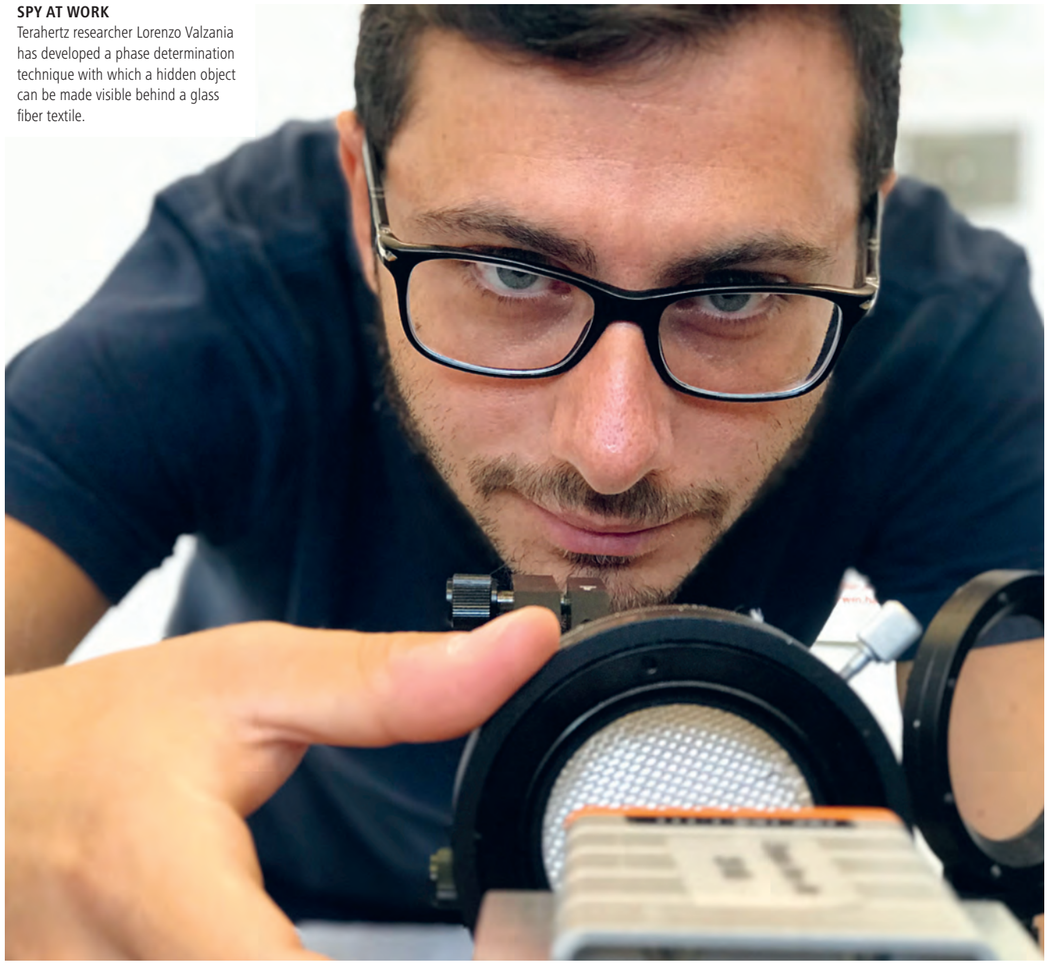
One of these areas of tension is air traffic, which is an indispensable part of the modern world, but which also causes harmful air emissions and noise. And according to Wunderli, this area of tension will not be solved in the future either. However, Empa's acousticians provide the scientific basis for political discussions and work closely with all those involved on technical solutions that can at least reduce the negative effects.

The Empa researcher himself is of course more sensitive to noise through his work, also because he is aware of its effects. In his leisure time he therefore prefers to enjoy the tranquillity of nature, for example when walking his dog or on holiday far away from tourist centres. As head of the Acoustics lab at Empa, he must already have an open ear for all noise issues on a professional level. ■

Further information on the topic is available at:
https://www.empa.ch/web/s604/zuglaerm-simulation

MEASURING NOISE
Jean-Marc Wunderli doing noise measurements of fighter jets at Payerne airfield. Empa accompanies the ongoing evaluation process for the purchase of new combat aircraft with extensive measurements and models the expected noise pollution of the various combat jet candidates.

Photos: Rolf Dammer, VBS



SPY AT WORK
Terahertz researcher Lorenzo Valzania has developed a phase determination technique with which a hidden object can be made visible behind a glass fiber textile.

Photo: Empa

ON YOUR MEDICINE'S SECRET SERVICE

Whether a wound heals well under a dressing cannot be seen from the outside. Empa researchers are now enabling a view through the bandage à la James Bond. The refined application of terahertz radiation could promote the analysis of multi-layered tissues for medical purposes and be used for wound treatment or the diagnostics of blood vessel plaques.

Text: Andrea Six

An evening at the casino, the secret agent in the tuxedo pulls the latest gadget out of his pocket: bluetinted specs. And with a look through the spyglasses, James Bond immediately sees through the casino villains' clothes and spots their weapons under their jackets in "The World Is Not Enough".

However, not only fictional figures like Bond's creative quartermaster Q are interested in the "X-ray view". In reality, the view through fabric is already being used, for instance at airport security checks using so-called body scanners. Empa researchers are developing new methods that allow a close look at a wound, for example, without having to remove the dressing, so that the unobstructed view of hidden objects can also be used in biomedicine.

> "While body scanners at the airport have a resolution in the millimeter range, Empa researchers have optimized it to two tenths of a millimeter."

This does not involve the use of ionizing electromagnetic radiation, as is the case with X-ray examinations by MDs, but rather terahertz radiation in the wavelength range from 0.1 to 1 millimeter. Thus, the waves range between warming infrared and radio waves and are not harmful.

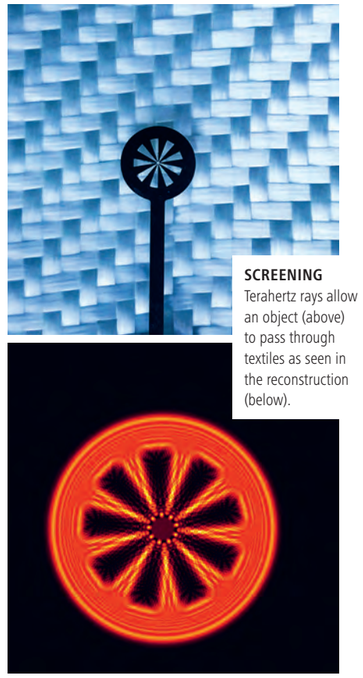
TRANSPARENT TEXTILES

The team led by Peter Zolliker and Erwin Hack from the "Laboratory for Transport at Nanoscale Interfaces" in Dübendorf has now completed a project funded by the Swiss National Science Foundation (SNF*), in which terahertz radiation is not only intended to detect concealed objects, but also to determine the interaction between the hidden target object and the visible surface. This further development of terahertz technology can in future be used, for example, for the gentle observation of wounds that are wrapped in a dressing.

The new technology has several advantages: On the one hand, the patient is not exposed to the risk of infection and the fragile healing tissue is not damaged by a frequent removal of the dressing. On the other hand, the monitoring of complex wounds, like burns or chronic skin damage, is necessary and contributes to a personalized medical treatment. Terahertz rays, for which a large number of materials such as textiles, plastics, paper and wood are completely transparent, allow non-contact inspections. "So far, the image resolution of terahertz systems has been rather poor," explains Empa researcher Lorenzo Valzania. Moreover, the effect of textiles on the skin could not be directly observed.

SHARPENING DOWN TO THE NANOMETER RANGE

If, of course, the interactions of textile and skin are to be determined, the properties of the covering material must also be taken into account in the image reconstruction of the skin surface. Therefore, Valzania has developed a new phase determination technique, with which the desired object and the covering textile can be detected by means of transmission geometry. Among other things, a continuous wave gas laser as the source of the Terahertz radiation and a surface detector that records the resulting diffraction patterns are required. With the help of a special phase determination algorithm, a coherent, 3D reconstruction of both structures can be created since the algorithm allows the separation of the radiographic functions of the two objects. The process is comparable to collecting and separating paper at the office printer when several print jobs are mixed and end up in the output tray.



SCREENING
Terahertz rays allow an object (above) to pass through textiles as seen in the reconstruction (below).

While body scanners at the airport have a resolution in the millimeter range, the Empa team has succeeded in optimizing it in their experiments down to two tenths of a millimeter. Even better resolutions all the way down to the nanometer range are to follow soon. In future, blood, skin profiles and textiles should thus be easily distinguishable. Other biomedical applications include cancer diagnostics without the use of contrast media and non-invasive analysis of blood vessels with suspicious plaques. ■

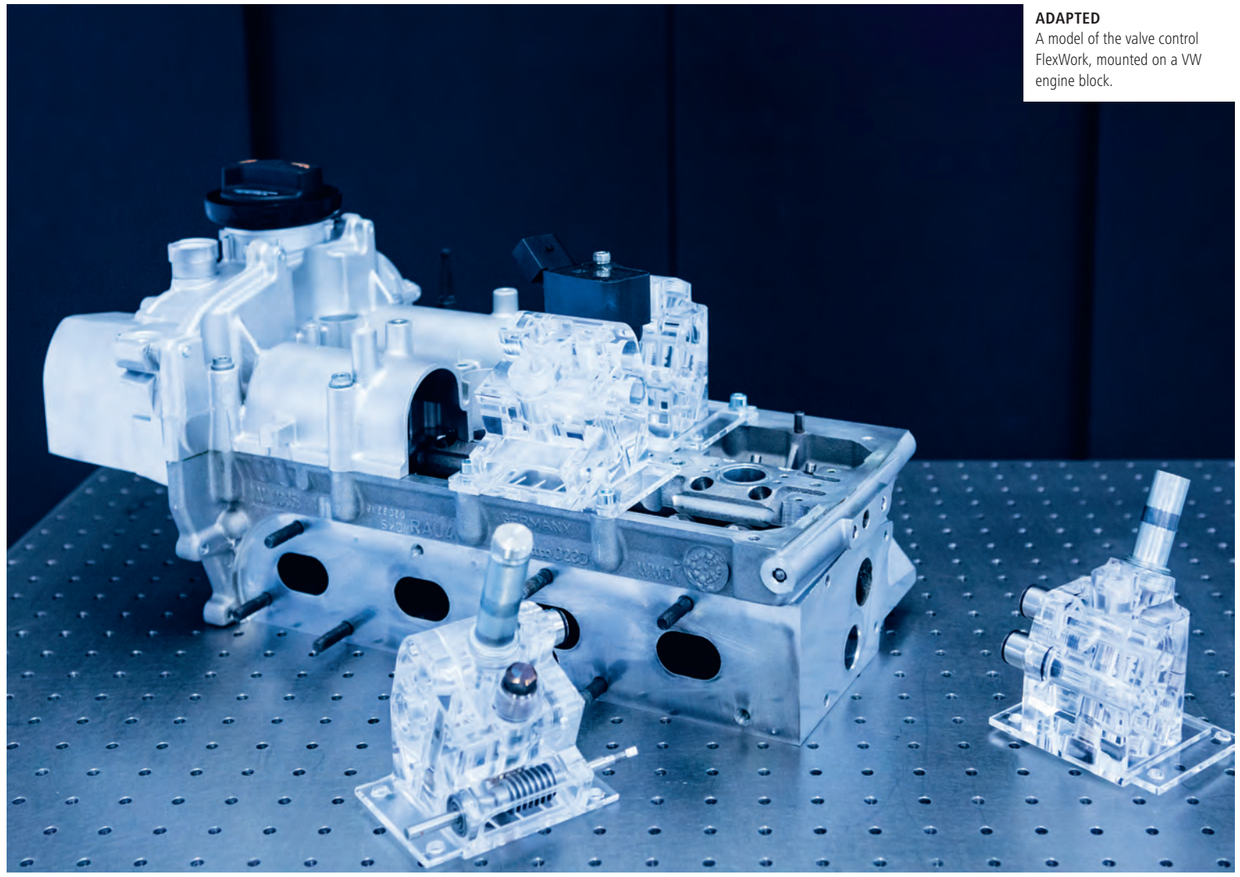
*SNF project "Mechanical contact of skin and textiles: THz imaging and modelling of the interface"

Further information on the topic is available at:
www.empa.ch/web/s405/thz-lab

ECOTUNING FOR ENGINES

An innovative, electrohydraulically actuated valve train for combustion engines was developed at Empa. Valve lift and timing can be freely selected. The technology has been running successfully for months on a VW four-cylinder engine block in Empa's test stand and shows fuel savings of up to 20 percent. The modified VW engine now also manages "big-bang" ignition sequences like on a racing motorcycle.

Text: Patrik Soltic und Rainer Klose



ADAPTED
A model of the valve control FlexWork, mounted on a VW engine block.

Photo: Empa

The valve train is the "respiratory organ" of combustion engines: it manages the aspiration of fresh air and the discharge of exhaust gases, which is referred to as "gas exchange". Today, only me-chanically driven camshafts are used in series production for this purpose, often equipped with an additional mechanism, some of which are quite complex. This allows to modify a valve movement pattern given by the camshaft, which is not possible without an increase in friction. At the same time, flexibility is not given to the desired extent. What is in demand – among other things for adaptation to changing fuel properties – are fast valve movements even at low speeds, stroke adaptations and cylinder-selective widely variable valve timing.

OPTIMIZED GAS EXCHANGE AND LESS FRICTION SAVE FUEL

Patrik Soltic and his team at Empa's Automotive Powertrain Technologies laboratory, together with hydraulics specialist Wolfgang Schneider, invented and developed an electrohydraulic valve train that is significantly more flexible than today's series production technology. The valves are actuated hydraulically and controlled electrically via a solenoid coil. As soon as a control current flows, a specially designed hydraulic valve opens, allowing hydraulic fluid to open the gas exchange valve to the desired extent in milliseconds counter to a spring. When the current is switched off, the gas exchange valve is closed again by the spring force and feeds a large part of the hydraulic energy required for opening back into the hydraulic system. The system achieves a significantly lower en-ergy requirement over a wide operating range compared to camshaft-driven systems. Together with an optimized gas exchange, the fuel consumption of the test spark-ignition engine is about 20 percent lower than with conventional valve control using a throttle in combination with camshafts in the low load range typical for passenger cars.

ADAPTABLE TO RENEWABLE FUELS

By selecting the operating parameters, the opening and closing times as well as the valve lift for each cylinder can be chosen completely unrestricted. This means that each engine operating condition can be varied from cycle to cycle, for example by intelligent load control, by selecting the residual gas quantity remaining in the cylinder (exhaust gas recirculation), or by deactivating unneeded cylinders without the driver noticing. This makes the engine highly adaptable to new renewable fuels: Oxygen-containing fuels such as methanol or ethanol, for example, allow more residual gas to remain in the cylinder. Natural gas, biogas and syngas generated from wind and solar power offer increased antiknock properties, and the valve train can react flexibly to this as well. In addition, alternative combustion concepts can also be implemented comparatively easily, for example homogeneous selfignition: a fuelair mixture is ignited at the right moment without ignition sparks by setting the correct conditions towards the end of compression. The mixture is combusted almost without pollution.

CYLINDER HEAD WITHOUT OIL

Another speciality of the system set up at Empa is the choice of hydraulic fluid: instead of using oil as usual, a waterglycol mixture, i.e. engine cooling water, can be used. Due to its physical properties, this medium is very suitable for fastswitching hydraulic systems, as it is very stiff and therefore creates fewer hydraulic losses. This makes the cylinder head completely oilfree, which can allow a cheaper engine oil with extended change intervals to be used for the rest of the engine.

SEVERAL MONTHS OF TESTING OPERATION

As part of the "FlexWork" project funded by the SFOE, the new valve train was put into operation in a passenger car engine powered by natural gas and derived from a VW 1.4l TSI engine. The required components were manufactured by Empa's own workshop. The control system for the test engine was developed by the Empa researchers themselves. The valve train has been running on an Empa engine test bench since October 2018 and has already survived many millions of cycles in fired engine operation flawlessly.

The FlexWork valve control needs only low-cost components. No expensive, very fast switching valves and no complex sensors are required. Empa is in discussions with engine manufacturers for the transfer of this technology, which is suitable not only for combustion engines but also for compressors. ■

Further information on the topic is available at:
www.empa.ch/web/s604/flexwork

ROMANTIC REPLICAS

To play a piece of music as it was conceived by the composer is a trend. But where can the rare historical instruments be found? The solution would be exact copies of the coveted originals. A team of Empa researchers is analysing such replicas with the aim of reproducing historical trombones with their typical sound.

Text: Andrea Six

EXACT COPY
The historical original (front) of a romantic trombone was compared by acoustics researchers with an exact replica (middle) by experts from the brass instrument maker Egger in Basel and a modern instrument (back)

Photo: Empa

Musicians and conductors of the classical music scene demand it, and the Basel based instrument maker Rainer Egger wants to deliver replicas of Romantic trombones. These instruments are special because of their dark sound, which allows the symbolism to come into its own in the compositions of that time. Empa researchers are also involved in the Innosuisse project "The Sound of Brass" at the Bern University of the Arts, where they analyse the material and sound of the historical originals – and compare the results with the first replicas. The project aims to show how replicas can be produced that are equal in sound to historical instruments – or even surpass them.

Egger, the implementation partner of the project, has specialised in historically informed instrument making and wants to revive the "German Romantic Trombone" from the 19th century. Brahms, Mahler and Bruckner may have written their compositions for these trombones, to which contemporaries attested a "fabulously soft and full tone". "Today's trombones sound different," explains Egger. He is convinced that construction, material and manufacturing techniques are responsible for the unique sound. However, this has not yet been scientifically proven.

PRECISE CAUTION

Empa researcher Martin Tuchschmid from the Empa Laboratory for "Joining Technologies and Corrosion" therefore investigated 64 romantic trombones. He used mobile energy dispersive X-ray fluorescence spectrometry to determine which materials instrument makers had worked with at the time – a non-destructive method used to investigate metallic materials in construction and industry. This resulted in a "material catalogue" that lists the alloys used in meticulous detail. For example, one learns that different parts of the trombone such as the wreath, bell and slide were often made of different materials. Brass, the reddish copper alloy tombak and nickel silver, a copper alloy with nickel and zinc, were frequently used. "The analyses resembled an archaeological excavation," says Tuchschmid. It was simply not known what the historical trombones were made of.

WARM, DARK, GENTLE

Instrument maker Egger then selected suitable materials and rebuilt the trombones by hand. Egger's hypothesis: The replicas should sound warmer, darker and softer than modern instruments. This can be physically measured in the form of sound frequencies and amplitudes. To ensure that the sound in such experiments is not influenced by the musician's playing technique, Egger, together with experts from Empa's Acoustics and Noise Reduction Department, also developed a device that stimulates the air column in the trombone in a controlled manner.

The Empa researchers analyzed the sound of the replicas and originals in a low-reflection laboratory. They used a scanning laser Doppler vibrometer to determine how the material behaved while playing. Their conclusion: material, production technique and design of the instrument have a clear influence on the sound and structural dynamics of the trombone. "For the first time, we were able to show that the standing sound waves in brass instruments interact with the material via res-onances, which significantly influences playability and sound," explains Empa acoustic researcher Armin Zemp.

The analyses also revealed indications for instrument making, such as the ideal position for cross struts and specifications for thermal treatment. "If the sheet is annealed, internal stresses are re-duced. This makes the trombone sound much softer because the vibration behavior of the material changes," says Zemp. In addition, harder alloys with a higher zinc and nickel content result in a higher sound power level.

> "The replicas should sound warmer, darker and softer than modern instruments."

Initial reactions from experts show that the replicas produced in this way are quite convincing. Ian Bousfield, lecturer for trombone at the Bern University of the Arts, has already played such an instrument at concerts with the Biel Solothurn Symphony Orchestra. "The audience even found that the replicas sometimes sound more expressive than the original," says the trombone professor. ■

Further information on the topic is available at:
www.empa.ch/web/s202

SECOND PLACE FOR SWISSLOOP

SUCCESSFUL
The Swissloop team wins the silver medal at the Hyperloop Pod Competition.

At the final of the SpaceX Hyperloop Pod Competition in Los Angeles, the "Claude Nicollier" transport capsule from Swissloop accelerated to an impressive 252 km/h on the 1.25 kilometre test track. The students from Empa, ETH Zurich and other Swiss universities took second place. They also received an innovation award for their linear induction motor. And to complete the Swiss triumph, a team from the EPFL finished third.

www.empa.ch/web/s604/swissloop

HYDROGEN MOBILITY LIVE

At the Elmar-Expo in the Swiss Museum of Transport, visitors of all ages made a pilgrimage to the electric motorcycles, the electric Vespa and the electric bicycles of several Swiss manufacturers. The specialists from Empa and Avenergy Suisse were on site to inform them about hydrogen mobility. In the simulation of the Empa hydrogen filling station, every visitor could try out how safely and quickly a fuel cell vehicle can be filled with sustainably produced hydrogen.

www.empa.ch/de/web/s604/move700bar

VIVID
Hydrogen expert Florian Freund (right) explains the drive of the Hyundai Nexo.

Photos: Empa (2), Adam Karas

RECYCLING
Digitalisation allows new advances in the recycling of rare metals.

EXPERIENCE DIGITIZATION

On the Swiss Digital Day on 3 September, more than 90 partners brought the topic of digitisation closer to the public under the motto "experience digital together". Empa was also there to show visitors how digitisation is enabling progress in the field of personalised medicine and the recycling of rare metals.

www.digitaltag.swiss

EVENTS
(IN GERMAN AND ENGLISH)

30. OKTOBER 2019
Kurs: Additive Fertigung von Metallen
Zielpublikum: Wissenschaft und Industrie
www.empa-akademie.ch/addfert
Empa, Dübendorf

4. NOVEMBER 2019
RFA-Seminar Digitalisierung im Bauwesen
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/rfa
Empa, Dübendorf

25.–27. NOVEMBER 2019
Kurs: Advanced X-Ray Diffraction Methods for Coatings
Zielpublikum: Wissenschaft und Industrie
www.empa-akademie.ch/ccmx
Empa, Dübendorf

27. NOVEMBER 2019
Kurs: Polymerwerkstoffe für technische Anwendungen
Zielpublikum: Öffentlichkeit
www.empa-akademie.ch/polymerwerkstoffe
Empa, Dübendorf

28. NOVEMBER 2019
Sensors: from Academic Research to Industrial Use
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/technobriefing
Neuchâtel

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