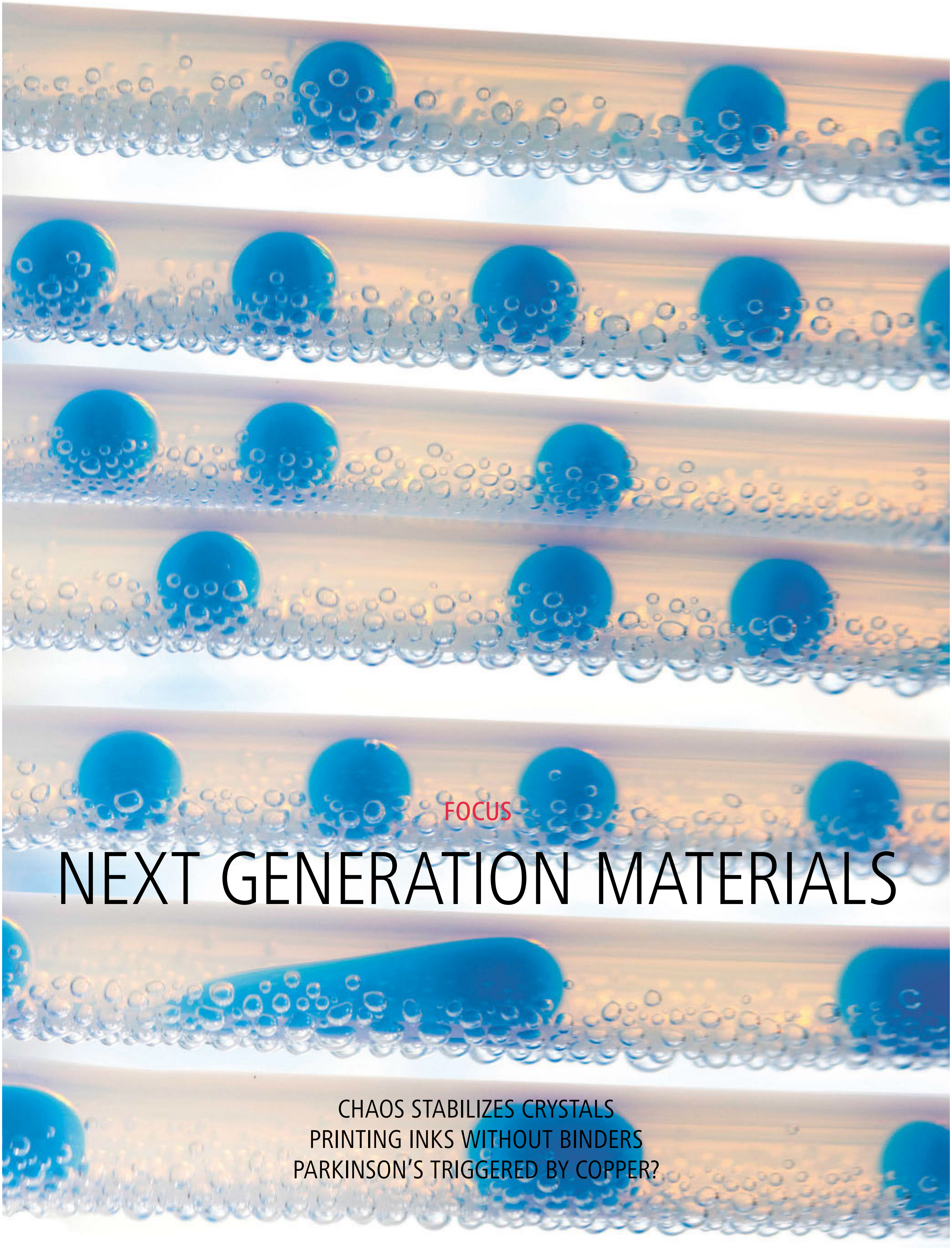
Empa Quarterly

RESEARCH & INNOVATION II #76 II JULY 2022



FOCUS

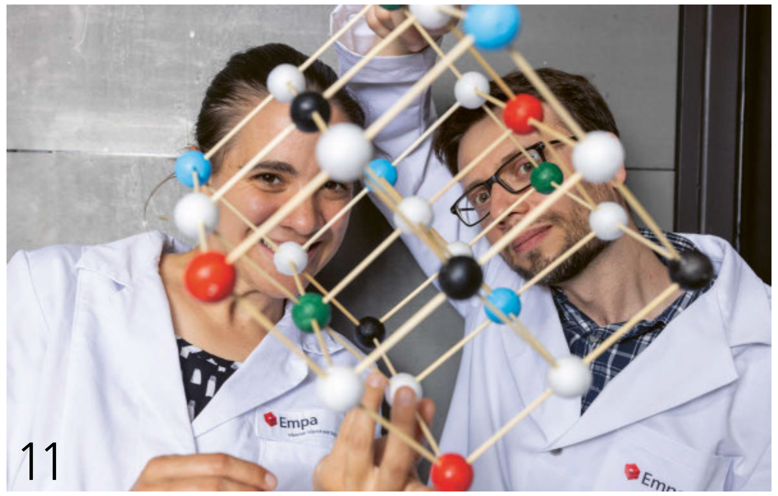
NEXT GENERATION MATERIALS

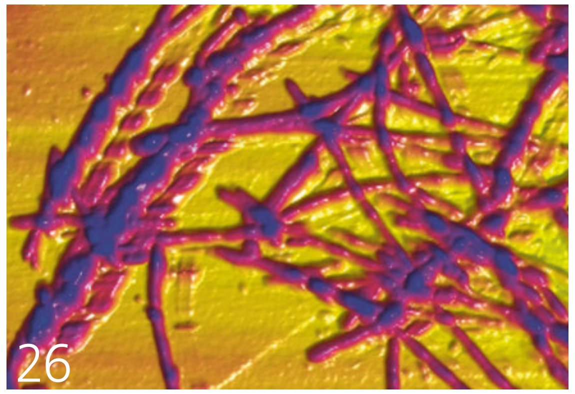
CHAOS STABILIZES CRYSTALS
PRINTING INKS WITHOUT BINDERS
PARKINSON'S TRIGGERED BY COPPER?

www.empaquarterly.ch

[CONTENT]

[FOCUS: NEXT GENERATION MATERIALS]





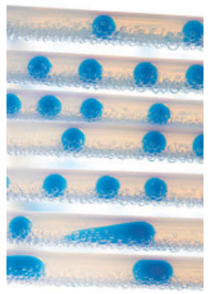
Photos: Nicolas Zonvi / Empa, Felix Wey / Empa, Gian Vaitl / Empa, Empa (2).

[FOCUS]

[TOPICS]

[SECTIONS]

[COVER]



In order to make faster progress in the search for new materials, Empa has built a synthesis device in which different chemical mixtures can be produced as if on an assembly line. In the "Tubular Flow Reactor", small bubbles run through a tube in which the respective reaction always takes place under exactly the same conditions. (See p. 11.) Image: Gian Vaitl / Empa

myclimate neutral Printed Matter
myclimate.org/01-22-436147

[IMPRINT]
PUBLISHER Empa
Überlandstrasse 129
8600 Dübendorf, Schweiz
www.empa.ch
EDITORIAL Empa Kommunikation
LAYOUT PAUL AND CAT.
www.paul-and-cat.com
CONTACT Phone. +41 58 765 47 33
empaquarterly@empa.ch
www.empaquarterly.ch
PUBLISHING SEQUENCE
quarterly
PRODUCTION
rainer.klose@empa.ch

ISSN 2297-7414
Empa Quarterly (English edition)

HOW DO YOU ACTUALLY DO INNOVATION?

Dear Readers,

Many, if not most, technological innovations – maybe with the exception of the software sector – have their origins in new types of materials. It is no coincidence, then, that we speak of the Stone Age, the Bronze Age and the Iron Age – and perhaps soon also of the Concrete Age, when we look around us and see how we "rebuilt" our world with this almost ubiquitous material.

Thus at its core, the question of how to do innovation revolves around the development of novel materials. And that is exactly what we are doing at Empa – as the Focus of the current issue of Empa Quarterly illustrates. There is no one-size-fits-all solution, however. Sometimes our researchers – like Cpt. Kirk and the crew of the "Enterprise" – boldly go where no one has gone before and explore strange new worlds (from a materials science perspective, of course), for instance, by building up crystals from a wild mixture of ingredients, so-called high-entropy materials with amazing properties (p. 11). Sometimes they fail magnificently, like in their attempt to print new types of transistors on paper or polymer foils – only to invent, also thanks to serendipity, a new, now patented process for 3D printing as well as a strange transistor with a kind of memory effect, which could be interesting for AI applications (p. 14). And when it comes to scaling up processes for the industrial production of solid-state batteries – the new trend in battery research – they face countless obstacles, which they are trying to overcome with ever new experimental setups and approaches (p. 18). The path to innovation oftentimes is anything but straight...

Enjoy reading!
Your MICHAEL HAGMANN

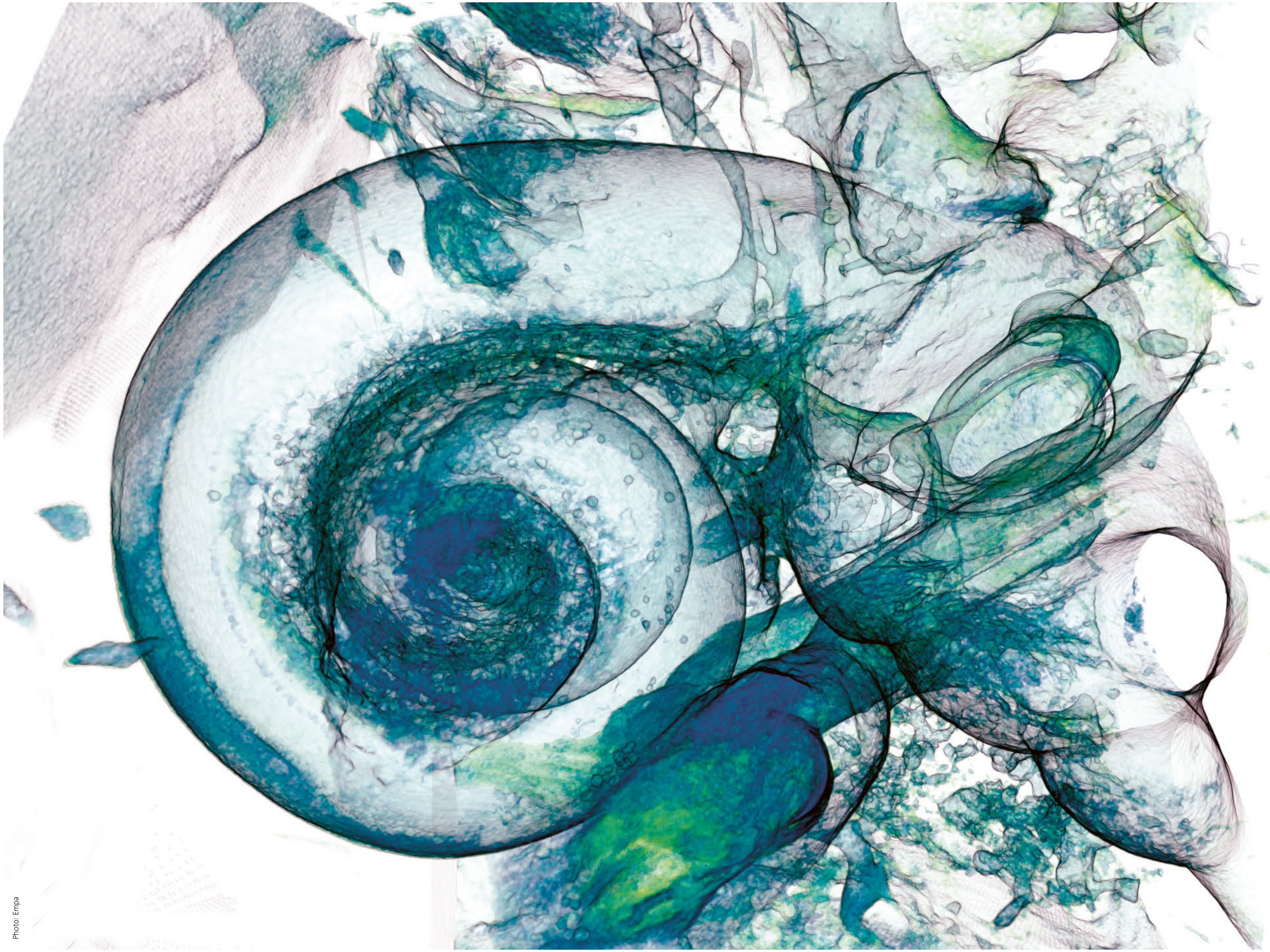


Photo: Empa

ONE PECULIAR PET

The body is the house of the soul, as the philosopher Philon of Alexandria put it some 2,000 years ago. In this house, the so-called cochlea, the snail, is our pet. The delicate bony structure in the inner ear houses our sense of hearing. Researchers at Empa's Center for X-ray Analytics in Dübendorf, in collaboration with the group of Image Guided Therapy at the Artog Center in Bern, examined the cochleae of healthy subjects using microcomputed tomography. The aim of the imaging technique is to precisely determine the microanatomy of the cochlea in order to optimize surgical interventions when inserting hearing prostheses. If hearing is impaired but the auditory nerve still intact, a cochlear implant can help. Inserting the tiny implants is risky, however. Computer tomography scans can provide helpful insights.

Further information on the topic is available at: www.empa.ch/web/s499

A FAREWELL WITH SURPRISES

PRESENT WITH STYLE
In the "LAB NOTEBOOK", all Empa departments designed their own farewell page for Gian-Luca Bona.

After almost 13 years as CEO of Empa, Gian-Luca Bona said goodbye to "his" employees at the three Empa sites. Since September 2009, Gian-Luca Bona has helped to shape and experience Empa's fortunes as the institute's CEO. Looking back on his "long journey since September 2009," the outgoing CEO expressed his gratitude at the last farewell party in the Empa Academy in Dübendorf for the numerous successes that scientists and engineers at Empa have made possible – and, despite current imponderables, looks to the future with great confidence: "Empa should and will continue to be a beacon in Switzerland."

www.empa.ch/web/s604/abschied-gian-luca-bona

Photo: Empa

SOOT PARTICLE MEASUREMENTS FOR THE NEXT GENERATION OF CARS

ROUND ROBIN
The wandering test vehicle, on Empa's roller dynamometer.

Led by the EU's central research laboratory (Joint Research Center, JRC), and together with six leading research laboratories from France, Italy, Japan, China, Poland, Germany and Austria, Empa is developing exhaust emission measurements for the next generation of cars around the world. For this purpose, a typical mid-size car with a gasoline turbo engine was passed from one laboratory to another in two rounds of testing and measured in all the laboratories. The vehicle is called a "round robin" in these cases. A measuring device was passed along with the car from laboratory to laboratory and sent back to the JRC in between for calibration. This gave all participating laboratories the opportunity to compare their own measurement methods and instruments with those of the partner laboratories. In the first round, the car was fueled with E-5 super gasoline, in the second round of testing with E-10 fuel. The new measurement methods are designed to detect particularly small soot particles of 10 nanometers or more emitted by the car. Previously, soot particles smaller than 23 nanometers were not covered by the law. Soot particles of this size can not be breathed out of the lungs by the human body and accumulate there.

www.empa.ch/web/s504

A DIGITAL SPY AGAINST FOOD WASTE

TRAVELLING TWINS
Biophysical twins equipped with sensors travel with vegetables and fruits from the field to the supermarket.

Almost a third of the world's food spoils on its way from the field to the point of sale. Empa researchers are working to reduce this enormous food waste – for example with biophysical twins of fruits and veggies. The properties of the crops are simulated perfectly by polymer models. Moreover, the biophysical twins are equipped with sensors that measure temperature and moisture on the skin and in the pulp of the real crops. In this way, the spy among the produce reports precise data to optimize storage and transport conditions in the cold chain – unlike conventional measuring methods. Most recently, the researchers have expanded the existing range of sensor fruits – apple and mango – to include potatoes and avocados in various sizes, as well as improving materials and the manufacturing process.

www.empa.ch/web/simbiosys

Photos: Empa

"WE ARE DOING SOMETHING HERE THAT IS RELEVANT TO EVERYONE"

A successful implementation of Switzerland's Energy Strategy 2050, personalized diagnostics and therapies for an aging society and a competence center for quantum technologies – Tanja Zimmermann has set herself ambitious goals. In an interview, the new director explains why her heart beats for Empa.

Interview: Michael Hagmann

You took over as director of Empa on 1 June. What are your thoughts and feelings with regard to your new task?
I'm looking forward to an extremely exciting task, and I'm highly motivated to tackle it – because I really have put a lot of heart and soul into Empa. You can see that in my resume. [smiles] I was already splitting wood here as an intern and then climbed the career ladder. So I know how a group leader feels, where a lab head's shoe pinches, and what challenges a department head is facing. And I know that there are many highly motivated teams working at Empa. But of course I also have a lot of respect; I am succeeding Gian-Luca Bona, who has positioned Empa extremely successfully over the last 13 years. Empa is in a better position today than it has ever been since I've known it – and I've known it for a quite a while.

Why is there so much "heart and soul"? What's so cool about Empa?
We are doing something meaningful here, something useful, something that is relevant to the lives of all of us. When you realize at the end of a successful research project: Ah, something has really come out of this, something that has helped company X in a very specific, down-to-Earth way – that is the pure opposite of the ivory tower. It is really very satisfying.

Where do you currently see the biggest challenges that you want to tackle with Empa?
First of all, there is the implementation of the Swiss Energy Strategy 2050, which we will have to achieve as fast as possible, i.e. the development of CO_2-neutral technologies. Empa should play a pioneering role in decarbonization, that's one of the goals I've set myself. Another core topic – the keyword is aging society – is personalized medicine, i.e. the development of more specific diagnostic and therapeutic methods that are tailored to individual patients. How can we prevent or delay the need for hospitalization? Environmental influences such as noise or air pollutants play a significant role in many diseases, especially in densely populated countries like Switzerland.

What can Empa contribute to solving these problems?
By continuing to position Empa as the first address for Swiss industry as "The Place where Innovation Starts". It is important to close the gap between what already works in the lab and its industrial implementation because many brilliant ideas often disappear in this "valley of death". To build bridges here, we have launched a number of technology transfer platforms such as NEST, move and our Coating Competence Center. We need to expand these further, but we also need to go a step further in the value chain, such as the technology transfer centers in the field of Advanced Manufacturing. And then there are the innovation parks.

Good keyword: Both in St. Gallen and in Dübendorf, the innovation parks are located virtually on Empa's doorstep. What do you expect from this proximity?
For us, the innovation parks are natural partners in Switzerland's innovation ecosystem. I envision them as a kind of meeting point, a market place for ideas

Photo: Nicolas Zonvi / Empa

THE NEW BOSS
Tanja Zimmermann has passed through many hierarchical levels at Empa and appreciates the innovative power and creativity of mixed teams.

where all stakeholders from politics, industry, research and society can exchange ideas about innovation. Dialog with society will play a central role in the future, because technologies are influencing ever larger areas of our daily lives. Just think of the rapidly advancing digitalization, artificial intelligence and robotics, but also the energy transition. We have to involve the public at an early stage and take them along with us, otherwise we will fail as a society.

Collaborations and partnerships are indispensable for interdisciplinary research. Which partnerships would you like to expand in the future?
No research institution – no matter how good it is – will be capable of solving the enormous challenges we face on its own; probably not even a country can do this alone. That's why we need to work more closely together, both within the ETH Domain but also with Swiss universities and universities of applied sciences and make better use of synergies. And since I already mentioned international networking: It would be enormously – really: enormously – important for Switzerland to be fully associated with the EU's research programs. It is absolutely imperative that we once again become an equal member of the European research family – also in order to be able to help shape the agenda for the coming years. A longer-term exclusion would have dire consequences for Switzerland's international positioning.

Are there any research priorities that you would like to expand?
We have been working successfully on novel carbon nanostructures such as graphene for several years now and have recently received a grant of 15 million Swiss francs from the Werner Siemens Foundation, as well as an ERC grant and various SNSF grants in the field of quantum technologies. We would like to bundle these activities, for instance in a kind of competence center. Moreover, our activities in the field of data science have been expanding for some time.

You are the first woman to head Empa in 140 years. What does that mean for the institution?
On the one hand, it is encouraging that women can get into these positions. It serves as a role model for younger female researchers. I've been asked several times by younger female colleagues how I've managed to combine everything – career, family, children. My example shows that women can pursue a career in a research environment and have a family at the same time. But we also have to create suitable conditions for this or improve them further. I would definitely like to get more women into senior management positions, we can still do better in this respect.

Times are anything but calm: the aftermath of the pandemic, the non-association with EU research programs, presumably increasing expenditures for national defense. Not exactly rosy prospects for investment in research, are they?
I am convinced that research and innovation will remain of crucial importance for Switzerland. And fortunately, we do have a solid base funding. However, I don't really expect our funding to increase significantly in the years ahead. So we would do well to explore alternative options.

Such as?
We have been operating very successfully with our "Zukunftsfonds" for some time now. This is going better and better, but there is definitely still room for improvement. At the moment, we are seeing donations and grants mainly in the area of medtech and personalized medicine. In future, we want to extend this to our other research areas, such as energy and the environment, but also to support young talents.

What are your personal goals for the next few years?
First of all, I would like to revive and give more momentum to the culture of collaboration at Empa – after two years of pandemic, there are certain signs of wear and tear. For me, being close to our employees is very important, as is personal exchange and mutual inspiration. If we can once again live these values better, motivation and good results will come all by themselves.

Which values are important to you?
Trust and an open, clear communication. And a certain culture of failure, which allows people to make mistakes because that's how we learn – after all, that's what research thrives on. What's more, I would like to promote our young talents better and open up career opportunities for female researchers. In general, diversity is enormously important – I myself have had the best experiences in mixed teams. ■

TANJA ZIMMERMANN

CAREER: Studied wood science at the University of Hamburg, master's thesis at Empa. Then scientist, group leader, from 2011 head of laboratory, since 2017 member of the Empa directorate and head of department "Functional Materials".
RESEARCH: Specialty: cellulose nanocomposites, lecturer at ETH Zurich, member of six international commissions on materials research.

Further information on the topic is available at:
www.empa.ch/web/empa/general-management

IN CONTROL OF CHAOS

Crystals consisting of wildly mixed ingredients – so-called high-entropy materials – are currently attracting growing scientific interest. Their advantage is that they are particularly stable at extremely high temperatures and could be used, for example, for energy storage and chemical production processes. An Empa team is producing and researching these mysterious ceramic materials, which have only been known since 2015.

Text: Rainer Klose

Nature strives for chaos. That's a nice, comforting phrase when yet another coffee cup has toppled over the computer keyboard and you imagine you could wish the sugary, milky brew back into the coffee cup – where it had been just seconds before. But wishing won't work. Because, as mentioned, nature strives for chaos.

Scientists have coined the term entropy for this effect – a measure of disorder. In most cases, if the disorder increases, processes run spontaneously and the way back to the previously prevailing order is blocked. See the spilled coffee cup. Even thermal power plants, which generate a huge cloud of steam above their cooling tower from a neat pile of wood or a heap of hard coal, operate driven by entropy. Disorder increases dramatically in many combustion processes – and humans take advantage of this, tapping a bit of energy in the form of electricity from the ongoing process for their own purposes.

CAN ENTROPY STABILIZE ANYTHING?

Crystals are considered the sheer opposite of disorder. In a crystal structure, all the elements of the lattice are neatly sorted close together in the smallest possible volume. This makes the idea that crystals can be stabilized by the

CHAOS IN THE CRYSTAL
Project leader Michael Stuer with the model of a "chaotic" rock salt structure with five different components.

Photo: Empa

force of entropy and thus create a new class of materials all the more bizarre.

Entropy-stabilized materials are still a young field of research. It began in 2004 with so-called high-entropy alloys, i.e. mixtures of five or more elements that can be mixed together. If the mixture is successful and all the elements are homogeneously distributed, special properties sometimes emerge that do not come from the individual ingredients but from their mixture. Scientists call these "cocktail effects".

EVEN IN THE HEAT, THE CHAOS REIGNS

Since 2015, it has been known that even ceramic crystals can be stabilized by the "power of disorder." In this way, even oversized and miniscule elements fit into the crystal, which would normally destroy it. The Empa research team has already succeeded in inserting nine different atoms into a crystal. The advantage is that they remain stable even at high temperatures – because "rearranging" them would lead to greater order. The natural striving for maximum disorder thus stabilizes the unusual crystal structure – and thus the entire material.

"With up to four components in the crystal, everything is still normal; with five components and more, the world changes," explains Michael Stuer, a researcher in Empa's High Performance Ceramics laboratory. Since the Luxembourg-raised researcher joined Empa in 2019, he has been working on the research field of high-entropy crystals. "This class of materials opens up a wide range of new opportunities for us," Stuer says.

"We can stabilize crystals that would otherwise disintegrate due to internal stresses. And we can create highly active crystal surfaces that have never existed before and look for interesting cocktail effects."

Together with his colleague Amy Knorpp, Stuer is now setting out into the unknown. The two are specialists in the production of fine crystal powder, and they have colleagues at Empa for X-ray and surface analysis to precisely characterize the samples they produce. With their help, Michael Stuer now wants to be at the forefront of the international scene. "The number of publications on the subject of high entropy crystals is increasing very strongly right now. And we want to be there right from the start," says the researcher.

ISLANDS OF KNOWLEDGE

What is needed now is a systematic approach, expertise and a good dose of perseverance. Where do you start? What direction does one take? "At the moment, there is no coherent expertise, no complete overview of this new field of research," Stuer says. "Different research groups around the world are working on limited projects. So individual islands of knowledge are emerging that will have to grow together over the next few years."

Michel Stuer and Amy Knorpp focus on catalytically active materials. The chemical reaction they are interested in involves combining CO_2 and hydrogen to form methane. The aim is to turn a greenhouse gas into a sustainable, storable fuel. "We know that CO_2 molecules adsorb particularly well on certain surfaces and that the desired reaction then takes place more easily and quickly," says Amy Knorpp. "Now we are trying to produce entropic crystals on whose surfaces such highly active regions exist."

CHEMICAL ASSEMBLY LINE

To make progress faster, the researchers have built a special synthesis device with the help of Empa's workshop, in which many different chemical mixtures can be tested one after the other, as if on an assembly line. In the "Segmented Flow Tubular Reactor", small bubbles run through a tube in which the respective reaction takes place. At the end, the bubbles are emptied and the powder they contain can be further processed.

> "With up to four components in the crystal, everything is still normal; with five and more, the world changes."

"The 'Tubular Flow Reactor' has a huge advantage for us: all the bubbles are the same size, which is why we always have ideal and consistent boundary conditions for our syntheses," explains Stuer. "If we need larger quantities of a particularly promising mixture, we simply produce several bubbles with the same mixture one after the other."

THE WINDOWS ON THE RIGHT SIDE

The precursor powder is then turned into fine crystals of the desired size and shape through various drying processes. "Crystals are like houses, they have closed outer walls and some with windows," explains Michael Stuer. Sometimes the shape of the crystal already indicates the window side. For example, when a mixture forms needle-shaped crystals. "The long sides of the needle are the lower-energy ones. Not much happens there. The crystal edges at the tips of the needles, on the other hand, are high-energy. That's where it gets interesting," Stuer said.

For their first major project, the Empa researchers have teamed up with colleagues from the Paul Scherrer Institute (PSI). They are investigating the possible methanation of CO_2 from biogas plants and sewage treatment plants in an experimental reactor. The PSI researchers have already gained experience with various catalysts and repeatedly encounter a problem: The catalyst, on whose surface the chemical reaction takes place, weakens over time. This is due to the fact that sulfur components in the biogas contaminate the surface or that the catalyst surfaces undergo chemical transformation at high temperatures.

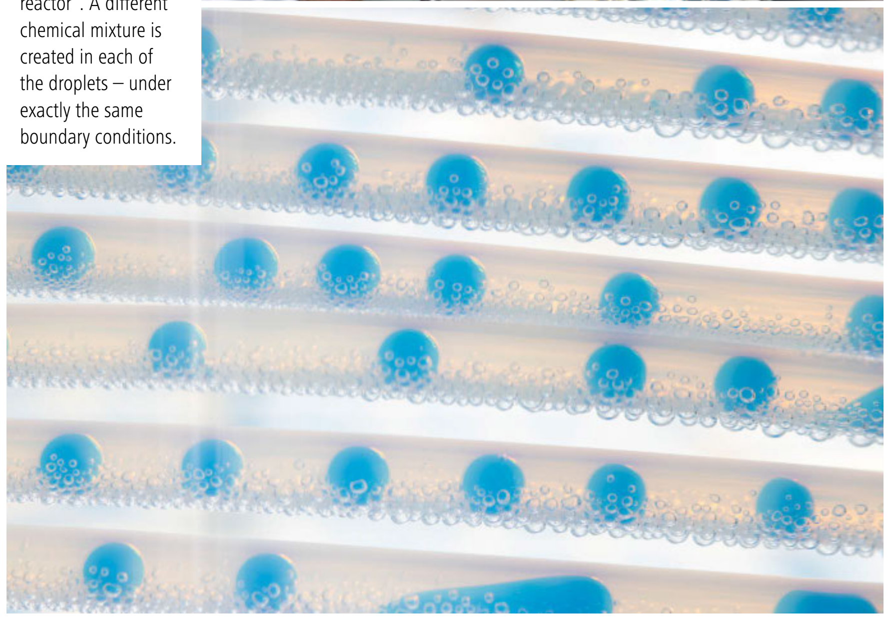
This is where the researchers are looking for a breakthrough using entropic crystals; after all, these do not break down even at high temperatures – they are stabilized by chaos. "We're holding out hope that our crystals will last longer in the process and possibly be more impervious to sulfur pollution," Stuer says.

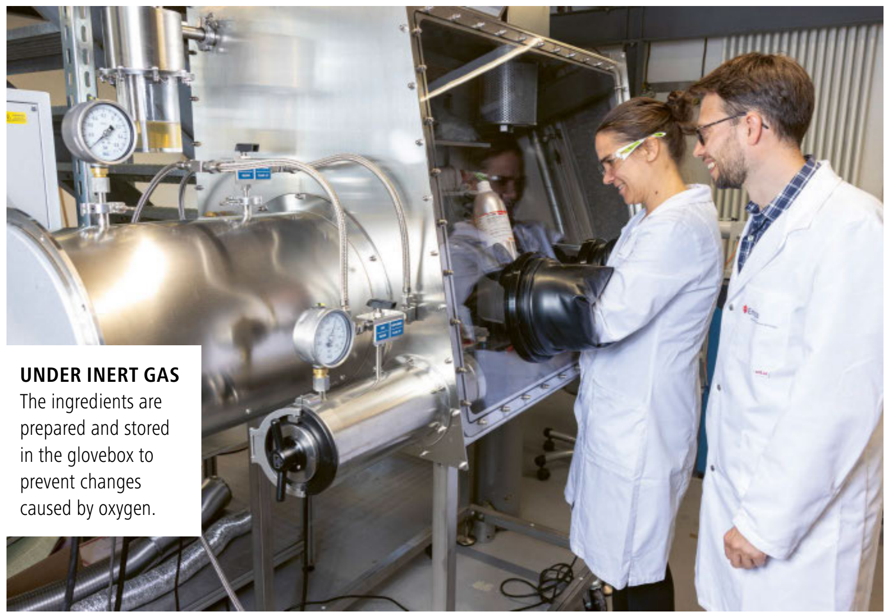
DRAWING A MAP

After that, Empa's crystal specialists are ready for other challenges, such as high-performance batteries, superconducting ceramics or catalysts for car exhaust and other chemical production processes. "It's a dark forest we're walking into," says Amy Knorpp. "But we have a guess in which direction something might be found. Now we're drawing a map of these systems. Somewhere out there, we think, is a treasure chest of insights hidden away." ■

Further information on the topic is available at: www.empa.ch/web/s201/nanopowders-ceramics

ASSEMBLY LINE
Michael Stuer and Amy Knorpp produce their crystal mixtures with a "tubular flow reactor". A different chemical mixture is created in each of the droplets – under exactly the same boundary conditions.





UNDER INERT GAS
The ingredients are prepared and stored in the glovebox to prevent changes caused by oxygen.

Photos: Gian Vaitl / Empa

PRINTING MACHINE
A special machine of this type produces printed circuits from Empa's special inks.

Photo: Empa

HITTING THE BULL'S EYE

In the FOXIP project, researchers from Empa, EPFL and the Paul Scherrer Institute attempted to print thin-film transistors with metal oxides onto heat-sensitive materials such as paper or PET. The goal was ultimately not achieved, but those involved consider the project a success – because of other unexpected and valuable discoveries on the way.

Text: Norbert Raabe

The bar was undoubtedly set high: In the research project Functional Oxides Printed on Polymers and Paper – FOXIP for short – the goal was to succeed in printing thin-film transistors on paper substrates or PET films. Electronic circuits with such elements play an important role in the growing Internet of Things (IoT), for example as sensors on documents, bottles, packaging ... – a global market worth billions.

If it were feasible to manufacture such transistors with inorganic metal oxides, this would open up a plethora of new possibilities. Compared with organic materials such as the semiconducting polymer polythiophene, explains project leader Yaroslav Romanyuk from Empa's Laboratory for Thin Films and Photovoltaics, the electrons in these materials are much more mobile. They could therefore significantly increase the performance of such elements and would not need to be protected against air and moisture with expensive encapsulation.

HEAT AS A CHALLENGE

The problem with inks containing metal oxides: To form a stable transistor, the materials must be sintered after printing – typically in an oven. Alternatively, drying and sintering can be done with light – for example, with low-wave ultraviolet radiation or a xenon lamp: The printed layer is heated with very short flashes of light to protect the substrate. Water, solvents and binders leave the material in the process.

Nevertheless, such processes heat up the substrate to up to 200 degrees – far too hot for paper or PET, which already begins to lose its strength at temperatures around 80 degrees, while other plastics such as polyimides withstand much higher temperatures.

From 2017 to 2021, in a project of the "Strategic Focus Area – Advanced Manufacturing" (SFA-AM) initiated by the ETH Board, experts from Empa, EPFL's Soft Transducers Laboratory and the Polymer Nanotechnology Group at the Paul Scherrer Institute (PSI) worked together on every step of the process: for example, coatings to smooth the surface of paper, ink formulations, irradiation ... – and made quite a bit of progress.

But their "ultimate wish," as Romanyuk says, to print functional thin-film transistors on paper, did not come true: Process temperatures were still too high, the material too rough. And the printed transistors on polymer films ultimately had too low an electrical output.

EXPECT THE UNEXPECTED

Disappointed? No, says Jakob Heier from Empa's Functional Polymers lab: "The project was by no means a failure." Not only because of new insights into technical details, but because of unexpected "side results": "This was a highly exciting project with many surprises",

A COMPETENCE CENTER FOR COATINGS

Closing the gap between laboratory research and industrial production for coatings: That is the goal of Empa's Coating Competence Center (CCC for short). Research is conducted not only on printed electronics, but also on materials, processes and technologies for coatings: methods with which thin layers are vapor-deposited onto substrates, or additive manufacturing, in which components are built up layer by layer. The CCC is structured as a private-public partnership. The idea is that all partners along the value chain, from science to industry, work together to develop new technologies and find innovative solutions.

says Heier, recalling an incident that was to have consequences – involving the material graphene: conductive carbon in atom-thin layers that is also well suited for printed transistors on flexible films.

One doctoral student on the team would not be satisfied that graphene inks could not be printed at higher concentrations. The particles aggregate, they clump together – and a thin film can't form that way. Instead of using just one solvent, the employee tried a special emulsion of graphene and three solvents. But this coating also failed in the first attempt. When the ink was mixed evenly in the next attempt and then subjected to light shear forces, however, the printing succeeded.

WHAT WAS THE REASON?

Curious, the experts investigated the phenomenon and found that the shear forces fundamentally change the structure of the ink. The fine graphene flakes in the liquid reform, so that van der Waals forces now take effect: relatively weak attractive forces between atoms or molecules. The result was a gel-like ink – without binders such as polymers, which otherwise ensure that the liquid retains its consistency and does not segregate.

A PROCESS WITH MARKET POTENTIAL

A solution with practical benefits that also works at room temperature; the ink dries without heating. As it turned out, such van der Waals inks can be produced not only with graphene, but also with other two-dimensional substances for printing. In the meantime, the process has been patented, and some companies, according to the experts, are already showing interest in producing the coveted inks – all this after a coincidence that the team had followed up with healthy curiosity.

Not the only surprise in the FOXIP project, as Yaroslav Romanyuk recounts. A field-effect transistor with an insulating layer of aluminum oxide, printed on a heat-resistant polyimide plastic, revealed a rather peculiar behavior. Instead of a constant signal, as would have been expected, it showed rising waves: The output signal became stronger because it "remembered" previous incoming signals. "To show such a "memory" effect is actually undesirable for a transistor," Romanyuk explains.

But another student on the team had an idea to use the phenomenon in a different way. A transistor with such a memory effect works similarly to circuits in the human brain. Synapses between nerve cells not only transmit signals, but also store them. For computers that mimic the human brain, such a synaptic transistor could therefore be highly interesting. But what could it do?

WITH THE SUPPORT OF MOZART

To explore its potential, the team built an electronic copy of the human hearing process along with the thin-film transistor – and fed it a popular Mozart tune: Rondo "Alla Turca" from Sonata No. 11 in A major. "It had to be a lively piece," Romanyuk says with a smile. This experiment and further analysis showed that the transistor's synaptic function is preserved from a few hertz to nearly 50,000 hertz – a much higher bandwidth than comparable printed transistors. Of course, concrete applications are not yet in sight for this fundamental research, which the team published in the online journal Scientific Reports – in contrast to printing inks without binders. But on the way to new computer technologies, the insights may be a useful step that came as a surprise – as it often has in the history of science.

Such coincidences are the icing on the cake, if you wish, for Romanyuk and many other researchers – especially in projects on the frontier of what is feasible. "We deliberately set our goals very high," he says. "Coincidences play a very big role in this! You set yourself a big challenge and then, suddenly and unexpectedly, these coincidences just happen." ■

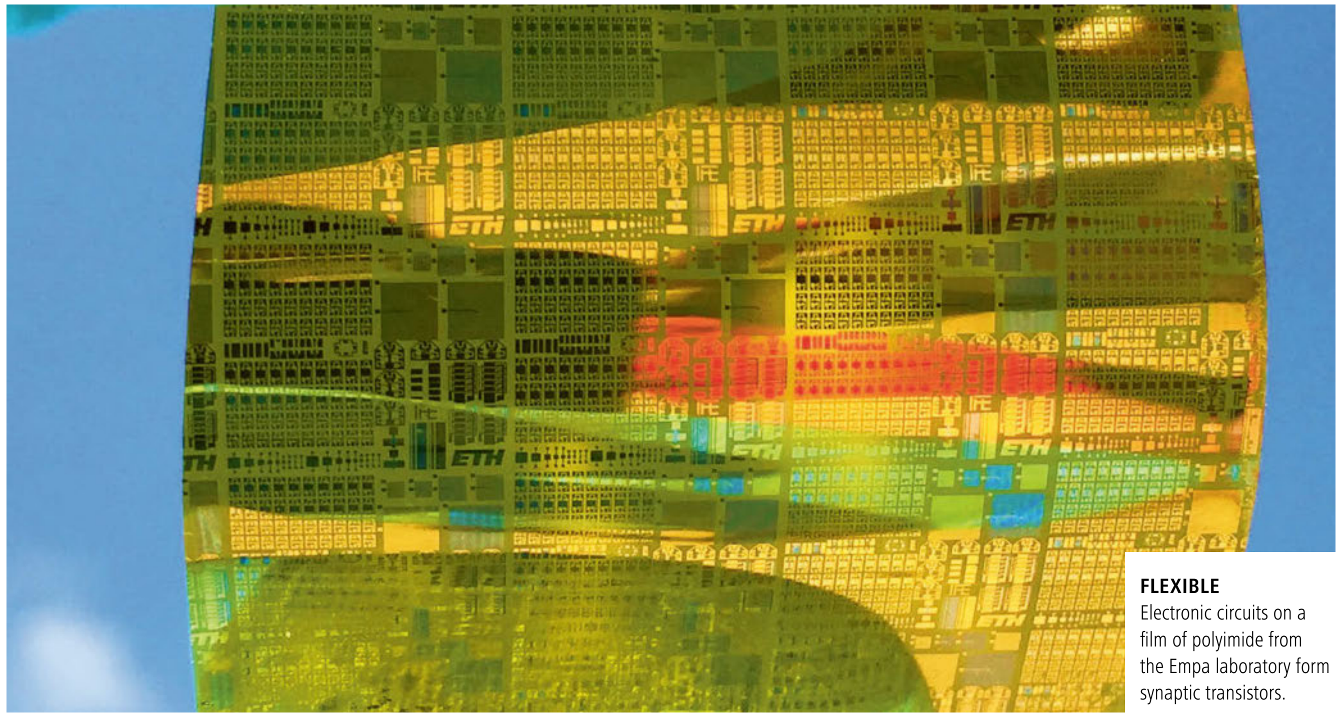
VAN DER WAALS INK
From liquid to paste-like: three consistencies for flexographic printing, screen printing and extrusion printing.

Further information on the topic is available at: www.sfa-am.ch/foxip.html

HIGH-TECH
An employee works on an inkjet printer used for printed electronic components.

Photo: Empa

Photos: Empa



FLEXIBLE
Electronic circuits on a film of polyimide from the Empa laboratory form synaptic transistors.

LEVELING THE PATH FOR SOLID-STATE BATTERIES

Lithium-ion batteries without flammable liquids – so-called solid-state-batteries – are considered the next big thing in battery technology. If there were a breakthrough here, electric cars could become lighter and achieve greater ranges. Empa is pursuing various approaches and is supporting the industry in setting up "gigafactories" for battery production.

Text: Rainer Klose

The solid-state battery is expected to take the electric vehicles to new heights: Vehicle manufacturers promise themselves and their customers shorter charging times, longer ranges, total fire safety and lower costs from the new battery technology. But there are still many unanswered questions about the super battery: Is it coming at all? And if so, when?

COMPETITION AMONG GLOBAL PLAYERS

In April 2022, the Renault-Nissan consortium of companies announced pilot production for solid-state batteries starting in 2024; their first car with this battery technology is to be launched on the market in 2028. VW Group is investing in the U.S. solid-state battery startup "Quantumscape." And Toyota, Ford, BMW and Mercedes-Benz have also entered the race and are investing in solid-state battery startups. Empa's battery research is therefore active in a highly competitive field full of big names.

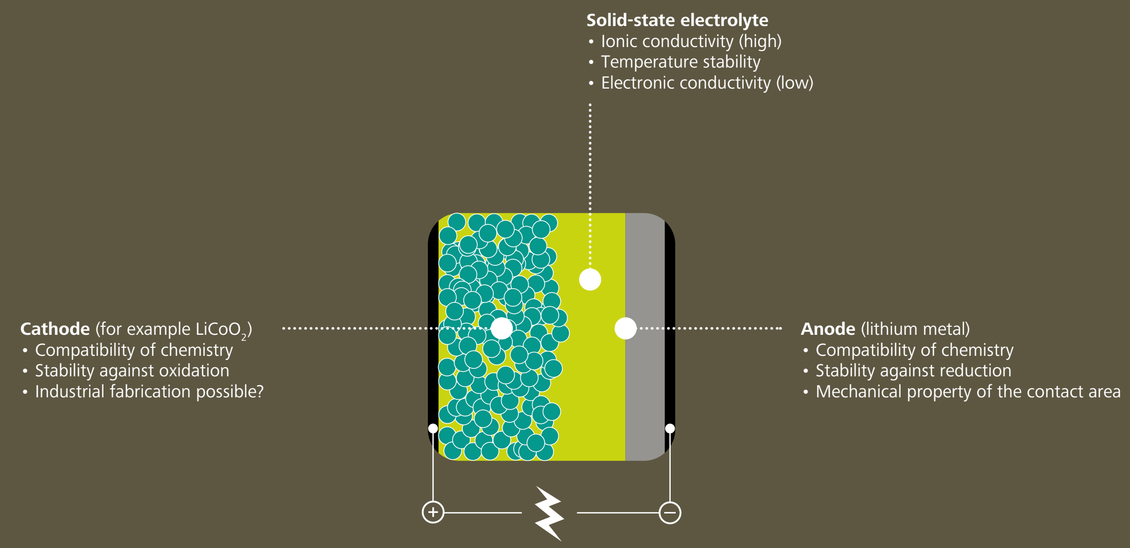
In Dübendorf, several teams from the Empa Materials for Energy Conversion research department are working on this next-generation battery technology.

The potential is immense, says Corsin Battaglia, who heads the department. The technology of the liquid-based lithium-ion battery will soon be largely at its limits, he says. A storage capacity of around 750 watt hours (Wh) per liter of battery volume is the maximum that can be achieved with current technology. This is due to the voluminous anode in each battery cell, which consists of graphite with lithium ions embedded in it.

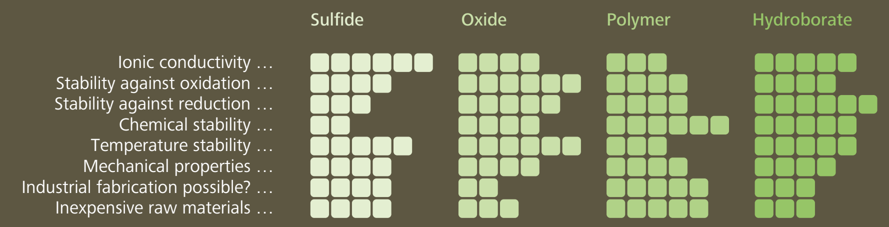
Solid-state batteries, on the other hand, are expected to achieve a storage capacity of over 1200 watt hours per liter. And the cell can be made even more compact, because lithium metal can be used as the anode instead of graphite. In addition, such batteries are temperature-resistant to well over 100 degrees

Graphic: Empa

Hurdles on the way to the solid-state battery



At a glance: Advantages and disadvantages of four major solid electrolyte systems



Graphic: L. Duchene, A. Remhof, H. Hagemann, C. Battaglia; Status and prospects of hydroborate electrolytes for all-solid-state batteries; Energy Storage Materials (2020); DOI: 10.1016/j.ensm.2019.08.032.

MATERIAL DESIGN
Battery expert Corsin Battaglia analyzes measurement results of solid-state batteries.

Celsius. The battery management system that monitors the temperature of the cells can therefore be simplified, and cooling, for example during rapid charging, is also less complex. Solid-state cells are therefore smaller, more powerful and faster to charge.

SQUARING THE CIRCLE

But the transition to next-generation battery technology is no walk in the park, even for global corporations with budgets in the billions. Empa researcher Arndt Remhof from Battaglia's department knows what hurdles solid-state battery technology presents (see also graphic on page 19): "The material we are looking for has to fulfill several properties at the same time," Remhof says. "First, it should be a very good ion conductor, but at the same time a very good electronic insulator." Excellent ionic conductivity is necessary for battery performance. Low electronic conductivity is important to prevent the cell from discharging itself.

And Remhof lists other requirements right away: "To exceed the energy density of existing Li-ion technology, the electrolyte must be stable against lithium metal." In other words, it must be stable against chemical reduction. At the same time, the electrolyte must be stable against oxidation when it comes into contact with the cathode. Only then is it possible to use cathodes with high electrical potentials and achieve the desired, high cell voltages.

SWISS BATTERY STARTUPS

Blackstone Resources AG, headquartered in Zug, is preparing to produce next-generation solid-state batteries in Döbeln, in the German state of Saxony. The company launched a novel 3D printing process in December 2021 – initially still building conventional liquid-filled lithium-ion batteries. But the process is adaptable to next-generation batteries. An Innosuisse project led by the Bern University of Applied Sciences (BFH) and involving Empa, is now set to make mass production of next-generation solid-state batteries possible. The second Swiss solid-state battery start-up, Swiss Clean Battery, which has licensed a technology from High Performance Battery, is also counting on Empa's expertise to set up production.

ALWAYS IN MOTION

In addition, the solid electrolyte should also be stable against aging processes – above all, no cracks or pores should form on the contact surface between the lithium anode and the electrolyte. The problem here is that the volume of the anode changes with every charging and discharging process. The inside of a solid-state battery is therefore in motion throughout its lifetime. The electrolyte has to survive all these changes.

Finally, as the battery charges and discharges, metallic lithium tends to form dendrites, fine lithium filaments that grow from the lithium anode to the cathode, which can cause a short circuit. This is also the reason why the use of lithium metal anodes in conventional liquid-filled Li-ion batteries is not possible. Of course, the solid electrolyte we are looking for should also prevent the formation of these dendrites.

SOLUTION IN TWO WAYS

Research teams at Empa are using two different approaches to try to solve the problems. One team is working on polymer solid electrolytes. Here, the researchers achieved a remarkable breakthrough in early 2022: Together with an industrial partner, they developed a polymer electrolyte based on polymerized salts with a high ionic conductivity at room temperature that is stable in contact with both metallic lithium and high-potential cathode materials and can withstand temperatures up to 300 degrees Celsius. In addition, this electrolyte is also very light, only about 1.3 times heavier than a liquid electrolyte. Experiments with laboratory battery cells the size of a two-franc coin have already been successful. Larger cells are now to be developed in an EU-funded project.

Photo: Gian Vaitl / Empa

Graphic: Circubat.ch

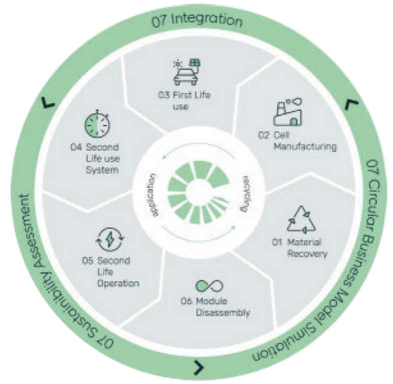
In the second approach, Empa researchers are developing solid electrolytes from hydroborates. "We have already filed a patent application in 2019 for an invention that allows us to crystallize these electrolytes from a solution," Remhof explains. This enables the production of solid-state batteries using processes that are also suitable for mass production. These electrolytes also have high ionic conductivity, high stability in contact with metallic lithium and high thermal stability, and are about the same weight as a liquid electrolyte. In 2020, researchers succeeded in demonstrating a 4-volt solid-state battery. By comparison, current liquid-filled lithium-ion cells operate also at voltages of 4 volt.

After so many success stories, an obvious question: what's the problem? Why isn't anyone producing this battery today? "Firstly, our research results are still quite new; secondly, there is as yet no inexpensive large-scale production for such high-purity hydroborates," answers Empa researcher Remhof. This is currently being developed together with an industrial partner, who is also already planning a large-scale production plant. ■

"The material we are looking for has to fulfill very many properties at the same time."

Further information on the topic is available at: www.empa.ch/web/s501

CIRCUBAT FOR ECOLOGY



INTEGRATED
CircuBAT comprises seven sub-projects from the production process to recycling.

The research project CircuBAT aims to create a circular business model for the production, application and recycling of lithium-ion batteries used for mobility purposes. Seven Swiss research institutions and 24 companies are joining forces to look for ways to boost sustainability in all stages of a battery's life cycle. The project is part of the newly launched Flagship Initiative of Innosuisse, the Swiss Innovation Agency.

SUBPROJECTS LED BY EMPA

Of the seven subprojects, three are led by Empa researchers. The subproject "Production of battery cells", led by Corsin Battaglia, aims to make the manufacturing process more energy-efficient. By far the most energy-intensive step in the production of a lithium-ion battery cell is the drying of the battery electrode after coating. Dry electrode coatings would eliminate this step, resulting in significant energy and cost savings.

The subproject Material Recovery, led by Empa researcher Rolf Widmer, aims to optimize and further develop a recycling process developed by Kyburz Switzerland. In this process, the combustible elements of the battery are separated in a water bath. In this way, copper, aluminum, lithium, manganese, nickel and cobalt are to be recovered in top quality so that they can be used for the production of new batteries.

Further information: www.circubat.ch

HE MAKES IT LIGHT

Belgian-born Wim Malfait is a trained geologist who once searched for gold on behalf of a mining company. Today, he heads the Building Energy Materials and Components laboratory, which develops, among other things, super-lightweight aerogel insulation materials and materials with heat exchange capabilities. Saving energy as a social task – that is more important to him than gold.

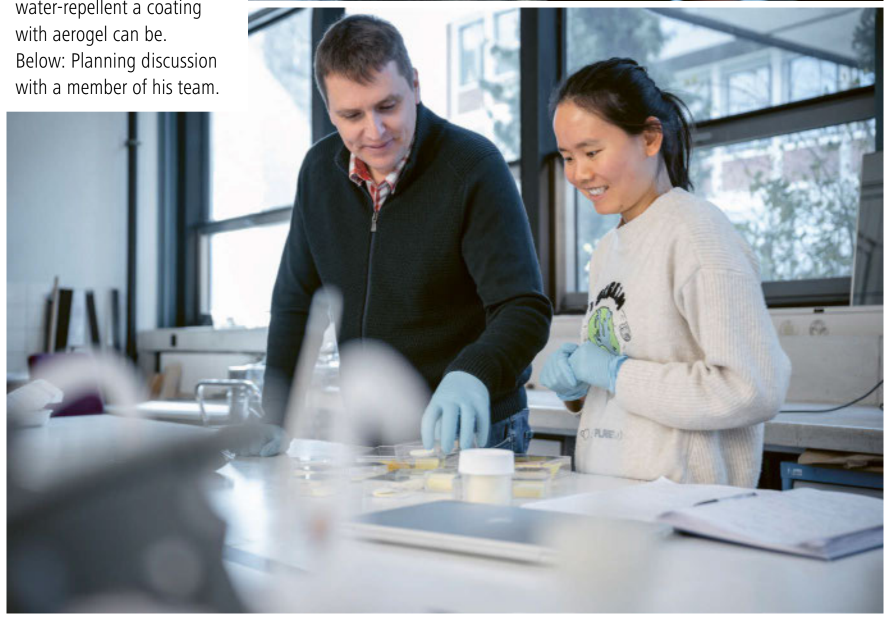
Text: Noé Waldmann

Photo: Felix Wey / Empa

CREATIVE
Wim Malfait develops insulating materials and sorption materials to save energy.

As a teenager, Wim Malfait liked to collect stones on vacation and take them with him as a memento. Volcanic stone in particular fascinated the young Wim Malfait. Even then, he found the material side interesting. After the daunting preparations for the Math Olympiad as a teenager, Wim Malfait preferred to follow his hobby and enrolled in a geology degree program at Ghent University. In the master's program, he promptly landed in volcano research. Together with his fellow students, Wim Malfait conducted research on magma there under the same conditions as in the earth's interior – i.e. under high pressure and at temperatures of up to 1300 degrees Celsius. His expertise in silicate melting and in the use of measuring instruments, especially NMR spectroscopy, stems from this time.

After receiving his master's degree, Wim Malfait took a breather in the private sector. Away from any civilization, Wim Malfait worked for a mining company looking for gold. However, the harsh treatment of the people, and the lack of social benefit in the hunt for gold ("If only it had been copper...") made the young geologist quickly look the other way. What he took with him was the knowledge that success can be forced through collective goal orientation. After that, Wim Malfait worked briefly in soil remediation, where the rigid specifications seemed like excessive formalism to him. So he returned to research.



AEROGEL
Wim Malfait demonstrates with his hand how water-repellent a coating with aerogel can be.
Below: Planning discussion with a member of his team.

Photos: Felix Wey / Empa

THE RIGHT MIX

A doctoral position then drew Wim Malfait to ETH Zurich, where he continued his research in the field of silicate melting. According to his own statements, Wim Malfait hit the jackpot with his doctoral supervisor at the time. "It was the ideal balance between taking an active interest and passively leaving space," says Wim Malfait today. He came to Empa from ETH Zurich via a research project in the "Building Energy Materials and Components" laboratory. With the then head of laboratory Matthias Köbel, Wim Malfait found a similar balance between support and freedom. And his knowledge of metal-glass composites made him a valuable employee for the laboratory. Expertise with silicate melts has enabled Wim Malfait to contribute to the development of a new lower-cost process for producing aerogel. After just over a year at Empa, Wim Malfait became a group leader. And when Matthias Köbel devoted himself to his spin-off, Siloxene AG, and left Empa, Wim Malfait succeeded him.

IMPORTANT SOCIAL TASK

As laboratory head, Wim Malfait has practically laid-out goals. His mission for the lab is clear: to contribute to a reduction in the energy consumption of buildings. This involves not only focusing on insulating materials, but also on sorption materials, i.e. materials with heat exchange capabilities. Heating and cooling buildings plays an essential role in society's overall energy balance.

WIM MALFAIT

CAREER: Initially environmental geologist and prospector for mineral resources, doctorate at ETH Zurich, then a decade of research on melts and volcanoes. Since 2013 at Empa.

RESEARCH: Main goal is to reduce energy demand for heating and cooling buildings by developing new high-performance insulation materials and sorbents – preferably based on biomass.

"For me, research at Empa is characterized by the fact that you want to have – and should have – an impact on society."

In the meantime, Empa, and indeed Switzerland, has become home for Wim Malfait. With his wife and two sons, he spends as much free time as he can in nature to compensate.

"SAVE TO FAIL" CULTURE

The fastest way to gain notoriety in academic circles, as everywhere else, is to publish positive results. It is important to Wim Malfait for his team that negative results do not represent defeats. More important than pure success, he says, is that researchers can pursue their own ideas. "Only through an open climate for creative ideas and a 'save to fail' culture do researchers come up with unconventional hypotheses from which entire laboratories can develop," says Wim Malfait. That's why it's no problem if an experiment – or even two or three months of research – turns out to be a dead end. That's something that has to be endured.

WHEN THINGS GO WELL

Pursuing science as a career brings with it certain emotional peculiarities. For ambitious young researchers, he says, it's not just an interest in research, the will to persevere and a certain sense of purpose that are important, but also a good dose of emotional resilience. "You should enjoy when things go well," the laboratory head thinks, "but you also shouldn't burst into total euphoria at every publication or fall into depression at every paper that gets rejected."

Measuring devices can also cause great emotions – and not only positive ones. For example, Wim Malfait worked for years with solid-state MNR spectroscopy. This instrument has accompanied Wim Malfait throughout his research career to the present day at Empa. "It's like a sibling I never wanted to have," says the scientist with a grin. From harmonious collaboration to total incomprehension and frustration, he says, it's all there.

COLLABORATION FOR SUCCESS

As a rather young laboratory, Malfait and his team are dependent on cooperation within and outside Empa. Whether it's X-ray, endoscopy or other measurements, there is a lively exchange of equipment, expertise and even project ideas within Empa. It is one of the reasons why Wim Malfait likes it so much at Empa. He says the first reflex to inquiries at other labs is always, 'Yes, we should do that.' "My lab gets excellent support, from administration to engineering to custom parts," Malfait says.

So Wim Malfait really likes it at Empa – and he has arrived both professionally and privately. As head of laboratory, Wim Malfait is no longer quite as free as he was as a researcher. He can no longer let himself be driven by pure curiosity, and does not want to lose sight of the laboratory's goals – to develop and improve insulation and sorption materials for the benefit of society. But, what Wim Malfait gets in return for losing degrees of freedom is the knowledge that you are doing socially relevant research and helping the next generation of researchers develop. And that knowledge is a satisfaction all its own. ■

WIM MALFAIT'S TEAM

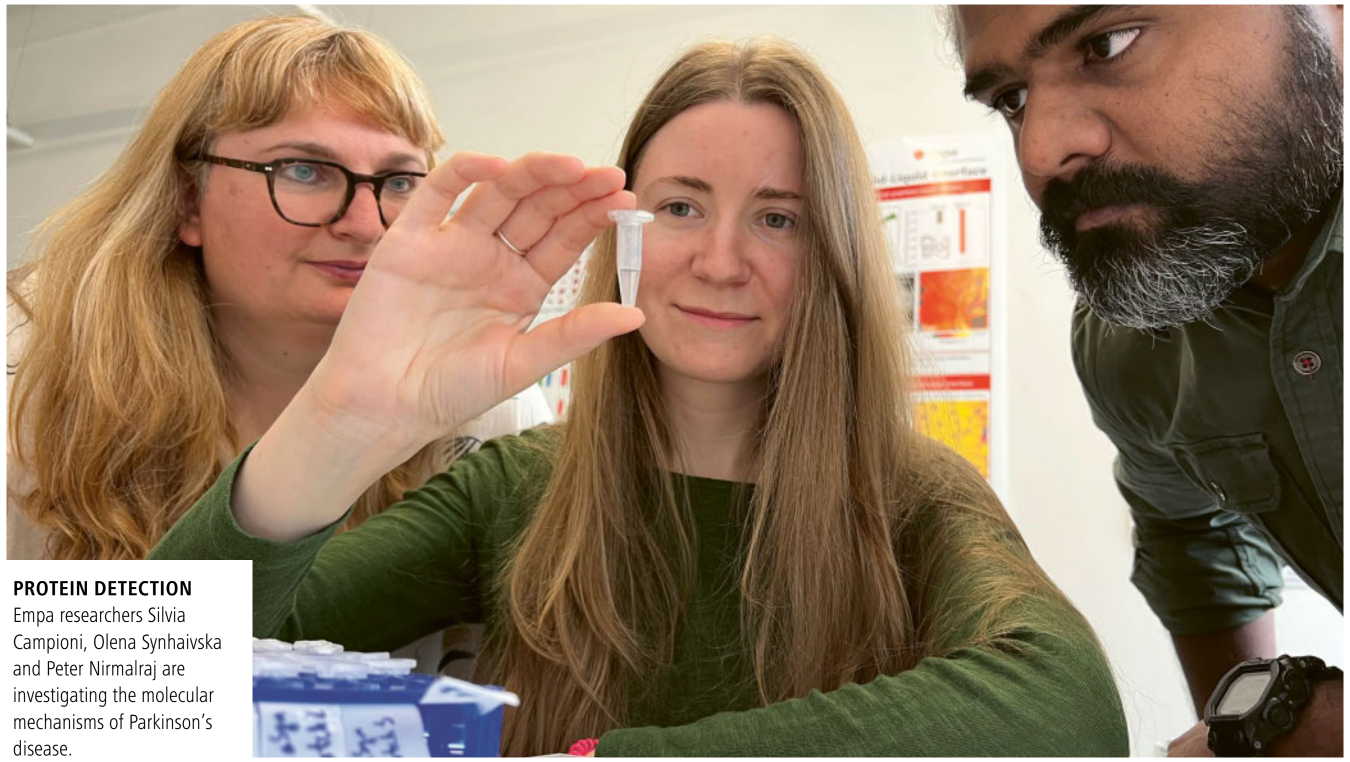
The Buildung Energy Materials and Components laboratory comprises about 25 researchers and works on high-performance insulation materials, including. Aerogel insulation materials for buildings offer extremely efficient thermal insulation and would have tremendous growth potential in the market. But because of its high cost, aerogel will never be able to replace traditional materials like mineral wool. So a cheaper solution that is sustainable is needed. Because only by moving from niche to mass can research results generate their full impact. Wim Malfait's team is therefore looking for resource-saving insulating materials made from biowaste that provide similar insulating performance to conventional materials.

Further information on the topic is available at:
www.empa.ch/web/s312

COPPER UNDER SUSPICION

Copper exposure in the environment and the protein alpha-synuclein in the human brain could play an important role in the pathogenesis of Parkinson's disease. The protein takes on an unusual shape when exposed to large amounts of copper ions. The findings could help develop new strategies for the treatment of neurodegenerative diseases.

Text: Andrea Six



PROTEIN DETECTION
Empa researchers Silvia Campioni, Olena Synhaivska and Peter Nirmalraj are investigating the molecular mechanisms of Parkinson's disease.

Photo: Empa

The causes of Parkinson's disease are not yet fully understood. Long before the onset of the typical muscle tremor, the appearance of defective proteins in the brain could be a first sign. Researchers at Empa and the University of Limerick in Ireland have now taken a closer look at the abnormal shape of these alpha-synucleins in the form of protein rings. In doing so, they were also able to visualize at the nanoscale the connection with environmental pollution by copper. This sheds new light on the development of the neurodegenerative disease and the role of biometals in the disease process. In addition, the findings could provide opportunities to improve early detection and therapy of the disease.

SUSPICIOUS METAL

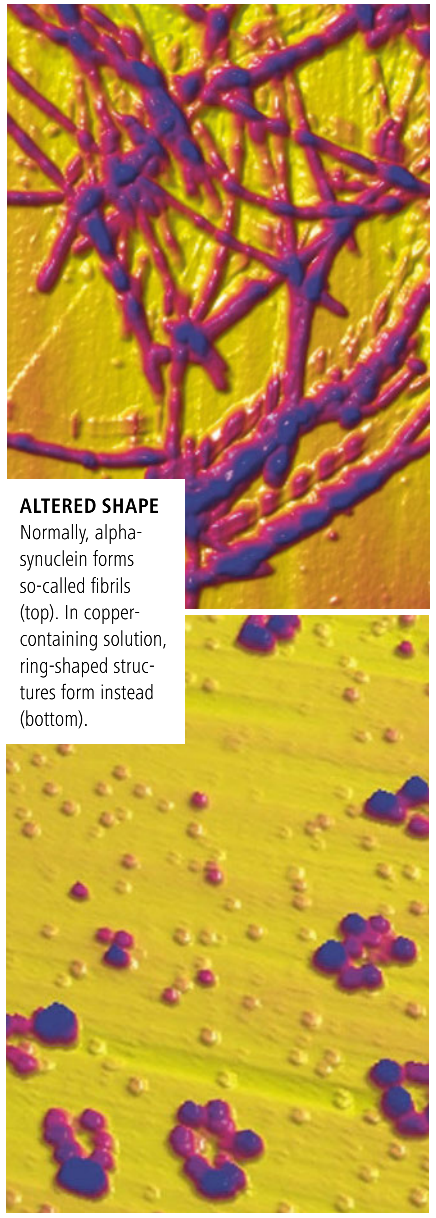
What is known about Parkinson's disease is that neurons in the brain die off, resulting in a deficiency of the neurotransmitter dopamine. In the later stages of the disease, this leads to muscle tremors, muscle rigidity and even immobility. The slowly progressive disease is the second most common neurodegenerative disease in the world after Alzheimer's disease. Environmental factors such as pesticides or metals could promote the occurrence of Parkinson's.

The team led by Empa researcher Peter Nirmalraj from the Transport at Nanoscale Interfaces lab is investigating this hypothesis using imaging techniques and chemical spectroscopy as well as, in collaboration with the team of Damien Thompson at the University of Limerick, computer simulations. The researchers are targeting a protein that is involved in several molecular processes in the development of Parkinson's: alpha-synuclein. In affected individuals, this endogenous protein clumps together and causes nerve cells to die. The researchers suspect that copper in high concentrations interferes with these processes and accelerates the disease process.

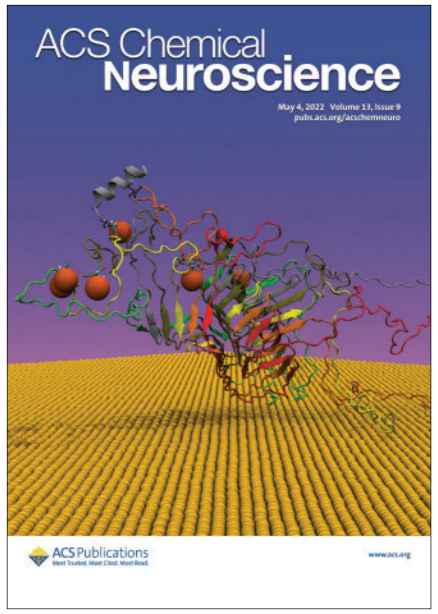
RINGS OF EVIL

To visualize the clumping of the alpha-synuclein at the nanometer scale, Empa researcher Silvia Campioni from the Cellulose & Wood Materials lab produced the protein artificially. Using atomic force microscopy, the researchers were then able to observe the protein, which was initially in solution, over a period of ten days as it formed individual insoluble filamentous structures before finally clumping together to form a dense network of fibrils. Based on the images, the transformation of the soluble protein into clumped fibers about 1 micrometer in length, as they occur during the progression of the disease, can be observed with impressive precision in the laboratory.

If the researchers then added copper ions to the protein solution, completely different structures appeared under the microscope: Ring-shaped protein structures about 7 nanometers in size, so-called oligomers, appeared in the test tube within only a few hours. The existence of such ring-shaped oligomers and their cell-damaging effect are already known. What's more, the longer fiber-like structures appeared earlier than in a copper-free solution.



ALTERED SHAPE
Normally, alpha-synuclein forms so-called fibrils (top). In copper-containing solution, ring-shaped structures form instead (bottom).



Photos: Empa, ACS Publications

"On the one hand, high doses of copper seem to accelerate the aggregation process," says Peter Nirmalraj. In addition, however, this unusual ring-shaped protein structure develops relatively quickly under the influence of copper, which possibly marks the beginning of the pathological process or even triggers it. The researchers also analyzed the binding of copper ions to alpha-synuclein using molecular dynamics computer simulations in tiny steps of 10 to 100 nanoseconds.

EARLY TESTING

Because the oligomer rings are formed at the very beginning of protein transformation, the rings could be used as a target for new forms of therapy, Nirmalraj hopes. In addition, the findings could help advance the development of a Parkinson's test that could detect the disease at an early stage in body fluids, for example, using samples from the spinal fluid. ■

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

SUNFLOWER SOCIETY
Aligning energy requirements with the position of the sun leads more quickly to a sustainable energy system.

ALWAYS FOLLOWING THE SUN

Limiting global warming to 1.5 degrees requires the energy system to be restructured as quickly as possible. But the speed of this transformation is physically limited. An Empa study now calculates the influence of energy storage systems on the maximum possible transition speed – and thus also on the probability of successfully mastering the climate crisis.

Text: Harald Desing

Building infrastructure for a renewable energy system, such as solar panels and batteries, requires a lot of energy in and by itself. At the beginning of the transition to a climate-friendly society, it can only be delivered by the existing, predominantly fossil energy system – and therefore causes CO_2 emissions. However, the more fossil energy and thus emissions are "invested" in the beginning, the faster the transition will proceed and –, even more importantly – the fewer greenhouse gases will be released into the environment in total.

Storage facilities play an important role in scenarios for restructuring the energy industry – from batteries to pumped-storage power plants to synthetic fuels from renewable sources. If they are built and operated in addition to the solar infrastructure on roofs and facades, the energy demand for the transition will increase. Scenarios developed by researchers in Empa's Technology and Society lab now show that the more storage facilities are being built, the longer the system transformation will take and the higher the overall greenhouse gas emissions will be – depending, of course, on the technologies used and on technological progress.

Photos: iStockphoto

SUCCESS – AND FAILURE

One example: If we wanted to maintain our current energy use habits, about 60 percent of the world's solar energy output would need to be stored – and the overall storage capacity would need to be large enough to supply the world's entire energy demand for about three weeks. Even under extremely optimistic assumptions, this scenario would exceed the 1.5 degree target with at least a 50 percent probability.

However, the storage requirement can be significantly reduced through technical measures. For example, the electrification of heating systems for buildings and intelligent appliance controls in many cases allow demand patterns to be made more flexible without having to change the users' energy behavior. Such a scenario could already cut storage requirements by about half.

For the 1.5 degree target, this would mean: In the best case, it would only be exceeded with a probability of 14 percent – namely, if primarily pumped-storage power plants with a high efficiency were used for energy storage. If, on the other hand, a lot of energy were stored in synthetic fuels at today's technical level with a rather low efficiency, the target would hardly be achievable. By comparison, an energy industry that requires hardly any storage could reduce the probability of exceeding the 1.5 degree target to a mere 3 percent.

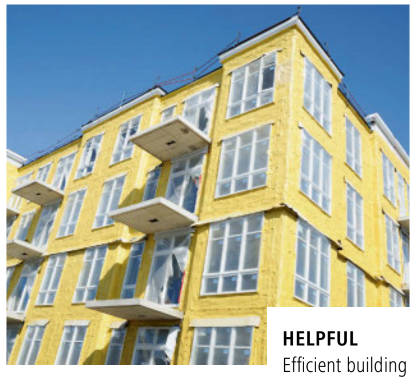
THE SUNFLOWER AS A MODEL

Energy storage therefore has a fundamental influence on the dynamics of the transition and its consequences on climate: The less storage is needed, the faster we can dispense with fossil fuels. Admittedly, this requires a paradigm shift: away from a demand-driven energy system, in which everyone can use energy when they want it. And toward an energy system that follows the path of the sun.

The basic idea of this "sunflower society": Consumers such as industry, transport, households and public institutions concentrate their energy-intensive activities, if at all possible, around midday and in the summer. At night and in winter, on the other hand, they are minimized.

Conceivable measures would be, for example, to replace "active" energy measures with "passive" ones. This means, for example, promoting efficient building insulation instead of heating systems, which have a particularly negative impact in winter. Although the production of such insulation requires energy, it could be produced in times of energy surplus. Or switch to means of transport such as trolley buses, which do not require storage. Simple changes in consumer behavior can also make a contribution, for example by running the washing machine at lunchtime instead of overnight.

Conclusion: If implemented consistently, the sunflower society would have the potential to significantly minimize climate risks and considerably accelerate the transformation of the energy system. This would not only help protect the climate, but also conserve resources and reduce costs, because energy storage systems are also material-intensive and expensive. ■



HELPFUL
Efficient building insulation reduces active energy demand.

STUDY: "SUNFLOWER SOCIETY"

In the Empa study, the global transformation of the energy system was investigated by taking into account feedbacks in the energy balance. The global energy system with all its components was computationally combined into two separate parts, so-called machines: a fossil machine, i.e. today's energy system, and a solar one, the future system including energy storage. Both machines supply energy to society. But the solar machine must first be created or built by using additional energy. Depending on the amount of fossil investment, the reinvestment of solar energy during the transition, the storage technology considering the technical progress as well as the size of the required storage, different scenarios with faster or slower transition phases and with higher or lower CO_2 emissions result. The study was funded by the Swiss National Science Foundation (SNSF) as part of the National Research Program (NRP) 73, Sustainable Economy.

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

EMPA AT THE WEF

INFORMATION
Empa researcher Jakob Heier explains the production of innovative joint implants using "advanced manufacturing".

"How to best serve Switzerland" – that is the question behind numerous research projects and innovations from the institutions of the ETH Domain, said Michael Hengartner, President of the ETH Board, on the fringes of the World Economic Forum (WEF). Answers to this question were provided to Federal Councillor Guy Parmelin and around 60 other high-ranking guests from politics, research and business at an event held at the WSL Institute for Snow and Avalanche Research SLF in Davos. Researchers from the six institutions presented their projects and their innovative research results at six posts. Empa researcher Jakob Heier showed around a dozen products made from a wide variety of materials using advanced manufacturing (AM) technologies such as 3D printing – for example, patient-specific implants, biodegradable mini-batteries made from cellulose and printed sensors on paper and textiles.

www.empa.ch/web/s604/wef-2022

EMPA ON THE ROADSIDE

Cars that autonomously navigate are expected to be a common sight in just a few years from now. But how will pedestrians interact with driverless cars? And what would be the best, safest and most sustainable design for a transportation system that accommodates all modes of traffic? A pilot study of EBP, Empa and Pedestrian Mobility Switzerland examines the interactions between pedestrians and vehicles equipped with an automated parking system.

Empa experts are contributing their vehicle technology know-how to this social science pilot study. On two test days in Thalwil behavioral observations and interviews with passers-by were conducted.

www.empa.ch/web/s504

OBSERVATION
Focusing on the interaction of pedestrians and autonomously parked cars: Empa researchers at the pilot test in Thalwil.

Photos: Empa / Luzia Schär

Photo: Empa

EMPA AT LAKE ZURICH

PREPARATION
Constanca Rosa, researcher at Imperial College London, prepares the MEDUSA drone for launch.

A new dual drone can both fly and land on water to take aquatic samples and monitor water quality, for example. The drone was developed by researchers at Imperial College London and Empa and recently tested together with researchers at the aquatic research institute Eawag for the first time on Lake Zurich. Called the "Multi-Environment Dual Robot for Underwater Sample Acquisition", or MEDUSA in short, its unique design could also facilitate monitoring and maintenance of offshore infrastructure such as subsea pipelines and floating wind turbines.

www.empa.ch/web/s604/medusa-drone

EVENTS
(IN GERMAN AND ENGLISH)

29. – 31. AUGUST 2022
Swiss Battery Days 2022
Zielpublikum: Industrie und Wirtschaft
https://swissbatterydays.empa.ch/
Empa, Dübendorf

08. – 09. SEPTEMBER 2022
Kurs: 3D Drucken in der Medizintechnik
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/medizintech
Swiss m4m Center, Bettlach

12. – 15. SEPTEMBER 2022
Biointerfaces International Conference (BIC)
Zielpublikum: Industrie und Wissenschaft
www.biointerfaces.ch
ETH, Zürich

29. SEPTEMBER 2022
Tage der Technik: Elektromobilität – Unterschätzter Baustein für die Energiewende?
Zielpublikum: Wirtschaft und Industrie
www.tage-der-technik.ch/
Empa, Dübendorf

07. OKTOBER 2022
Course: Energy Harvesting
Target audience: scientist & engineer
www.empa-akademie.ch/harvesting
Empa, Dübendorf

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

THE PLACE WHERE INNOVATION STARTS.

Empa
Materials Science and Technology