Materials with brains

Many materials change when exposed to external stimuli. If this reaction is useful, reproducible and controllable, the material is categorised as being "smart". Such materials have a considerable potential for practical applications. In order to exploit this, Switzerland is funding the National Research Programme NRP 62 "Smart Materials". Empa is participating with many projects.

TEXT: Beatrice Huber / PHOTOS: Empa

An example of a smart material: In Empa's Blimp, electroactive polymers (black area) stretch or contract when an applied voltage is turned on and off. The resulting flapping of the tail fin propels the airship forward.

Virtually every material reacts to external stimuli by changing its physical, chemical or biological properties. This can lead to problems. Consider, for instance, train rails which expand and bend out of shape during the extreme heat of summer. These changes, however, can also be a decisive advantage – specifically when materials adapt to their environment and thus can better fulfil their functions, or perhaps start to do so in the first place. If the stimulus is removed, the materials return to their original condition; the reaction to external influences is therefore reversible. If a material also "behaves" controllably and reproducibly, and always exhibits the same reaction to the same stimulus, it's characterised as being "smart". Especially attractive are those materials for which the external stimulus involves little energy. There are many smart systems in nature. For instance, there's the human lens, which is deformed by muscles more, less or not at all depending on where the focus of vision should be.

Materials react to all sorts of stimuli

The stimulus can be mechanical, as in the case with the lens, but also thermal, electrical, magnetic or chemical. What are known as shape memory alloys (see "Ductile materials for mechanical applications") deform or reassume their original shape when exposed to changes in temperature. Hydrogels which release active

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Novel catalysts for natural gas vehicles

The scarcity of oil, climate change and stringent emission regulations, combined with a continuously growing global vehicle fleet, ask for a more efficient and widespread use of alternative fuels. One of these is natural gas, which emits lower levels of nitrogen oxide and CO_2 than petrol or diesel. However, the exhaust from vehicles fuelled with natural gas needs special treatment to remove traces of non-combusted methane, which is a potent greenhouse gas.
Until now, existing catalytic converters from petrol vehicles have generally been adapted to the emission profile of natural gas vehicles. In the project "Palladium-doped perovskite catalysts for natural gas vehicles", the goal of Empa researchers is to develop new types of converters. These should require smaller amounts of precious metals (for example, palladium) and demonstrate increased long-term stability. For this purpose, the researchers are using perovskite metal oxides which react with the chemical composition of their environment. These allow precious metal atoms to enter the crystal lattice in an oxidising atmosphere and exit the surface in a reducing atmosphere.

substances in a controlled fashion due to an external stimulus are interesting for medical applications (see "Nanofibres for intelligent drug delivery"). Piezoelectric materials generate an electric voltage when placed under pressure or tension and therefore are put to use in devices such as deformation sensors. Also included among smart materials are compliant systems. These are flexible enough to allow large deformations but at the same time stable enough that they can withstand large loads (also see the article "You don't win a prize ever day" on page 20).

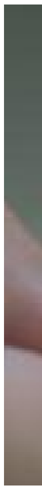
National research programme with heavy Empa participation
In order to take advantage of the innovative potential attributed to smart materials, the Swiss Federal Council launched the National Research Programme NRP 62 "Smart Materials". Within an NRP, researchers from various disciplines and institutions collaborate on projects which focus on solving urgent problems. The Swiss Federal Council selects the topics; the Swiss National Science Foundation (SNSF) manages the NRPs.

For NRP 62, 21 projects from a total of 79 submitted proposals were approved and are being financed with 6.6 million Swiss francs. With six of the 21 projects being led by Empa researchers, Empa was quite successful. What led to this success? For Andrea Bergamini, who has long been working with smart materials and is heading up one of the projects (see "Ductile materials for mechanical applications"), one reason is the long-term experience Empa has with such materials. He adds, "It's easy to keep track of everything going on at Empa, but even so we have numerous experts from several disciplines who can collaborate on very imaginative projects."

Considerable potential for innovation
Traditional systems such as industrial robots with hydraulic drives or airplane wings with conventional stabilisers actually function quite well. But as the number of individual components increases, so does the complexity of the system. The potential of smart materials lies, among other things, in the fact that a material

Ductile materials for mechanical applications

Structures that can change their shape or stiffness on command are much sought after in technology and engineering. A stiff structure is first converted briefly into a soft state and then stiffened again into a new shape. Such materials, for example nickel-titanium shape memory alloys, already exist; however, they lose their stiffness only when heated, which requires considerable energy. A new approach uses electrostatic forces, which are much less demanding from an energy standpoint. These forces generate a "bonding" between thin layers of dielectric material; when the forces are turned off, the adhesion disappears.
In the project "New approaches to shape and stiffness changing materials", Empa researchers are working together with ETH Zurich to study and optimise dielectric materials to obtain an optimal coupling of the layers with the addition of only small amounts of energy. Possible applications include those in aircraft construction. A wing would no longer need mechanical flaps for steering; instead it would change its own shape, guided by electric pulses. Rotors could also adapt themselves to varying aerodynamic situations.



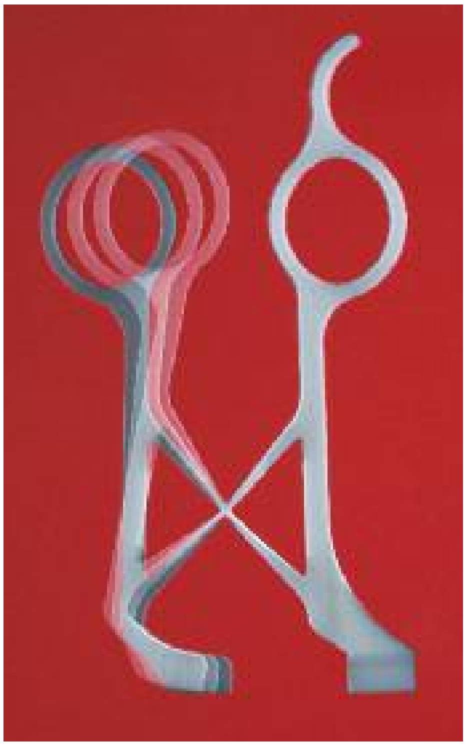
can take on the functions of several individual components. By reducing complexity, the systems become more reliable – there are fewer parts that can fail – and can be better integrated. Fabrication should become easier with maintenance requirements considerably reduced.

It will even be possible to develop systems which were previously pure fiction. An example is airships which fly noiselessly and energy efficiently using "artificial muscles" (also see "New fabrication technology for artificial muscles"). Electroactive polymers, here acting as artificial muscles, stretch or contract when an electric voltage is turned on or off. In the case of Empa's Blimp, a tail fin flaps back and forth to provide propulsion. Such an airship would simply be too heavy if made of conventional materials.

First-time cooperation between SNSF and CTI

What's more, NRP 62 is introducing a completely new element. For the first time, the Swiss Innovation Promotion Agency (CTI) is partnering with the SNSF. That agency promotes knowledge and technology transfer between companies and universities in applied research and development projects. CTI also provides assistance to start-up companies. With NRP 62, the Swiss Federal Council has focussed specifically on Swiss industry because smart materials could in future lead to a crucial competitive advantage. "NRP 62 is clearly focussing on creative scientific work and technical development of new materials and systems which fulfil the criteria "smart" are sustainable and offer an economic potential for the transfer to industry," says Louis Schlapbach, President of the NRP 62 Steering Committee and former Director of Empa, in explaining the goal of this NRP. "I also hope that young scientists and engineers will be educated so they have a wide range of expertise in this area and can then work enthusiastically in an interdisciplinary manner."

No directly marketable products are yet expected from NRP 62. Even so, the direction is clear. "Among the goals is that many projects which are being fully funded in their initial phases by the SNSF are afterwards directed in a second phase towards specific applications," explains Schlapbach. "Then, in a third phase, they can be implemented with a practical focus in conjunction with



"Superelastic" tools for surgery

Compliant systems essentially reproduce the behaviour of conventional mechanical mechanisms. But because these systems exploit elastic deformations within the material, moving parts such as bearings and joints are no longer necessary.
These systems offer major advantages for surgical tools; sterilisation is simpler and more efficient because compliant instruments have no gaps in which bacteria can settle. Accidental lesions are less frequent because the instruments have no hinges which can pinch and injure tissue. And thanks to their inherent monolithic nature – the instruments consist of only one piece – they require almost no manual steps during assembly and hence allow for cost-effective manufacturing.
In the project "Superelastic compliant surgery tools", the goal of Empa researchers is to develop innovative surgical tools based on compliant systems made of superelastic shape memory alloys.

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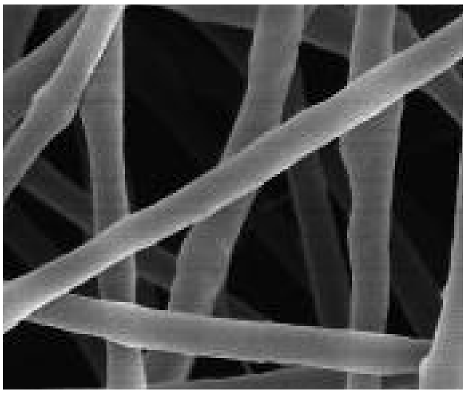
industry partners within a CTI project, leading to the development of prototypes." This is a promising perspective, says Empa's Andrea Bergamini, adding, "For me as an engineer, NRP 62 is quite exciting because this research is very target-oriented, and we must take into consideration real-world conditions." If it is successful, NRP 62 should become a reference model for future cooperation between the SNSF and CTI.

The NRP 62 is divided into four modules: "Smart shape transformers for macroscopic use", "Stimuli-responsive materials for the microscopic range", "Smart drug delivery materials" and "Exploratory research for smart materials". The fourth module concentrates on high risk/high reward exploratory research projects without a fixed field of applicability but which have enormous potential. Empa is heading up projects in all four modules; three in the first and one each in the other three. The projects have a duration of 12 to 36 months. Thus, initial results will probably soon see the light of day. //

Further information: *www.nfp62.ch*



Nanofibres for intelligent drug delivery

Hydrogels can release drugs on demand in a controlled manner and are thus very interesting for medical applications. Those which react to heat or cold are especially attractive because temperature can be changed easily and in a non-invasive manner. The disadvantage of conventional hydrogels is their relatively long response times, which can be from minutes to days.

In the project "Nanofibres for intelligent drug delivery", Empa researchers are working together with the Max Planck Institute for Polymer Research in Mainz (Germany) and ETH Zurich to develop novel types of nanofibres. These consist of two-component nanofibres with a drug-loaded intelligent core. Additionally, they plan to embed magnetic nanoparticles which will allow accurate local heating by magnetic induction. The fabricated nanofibres could be embedded in advanced textiles for therapeutic purposes. They will also open up additional non-medical applications such as clothing which can protect or cool the body.

The photos illustrating the projects do not originate from the projects.


Photo: iStock

Fluid core fibres as shock absorbers and dampers

Synthetic fibres account for more than 70 per cent of worldwide fibre production. In the project "Synthetic fibre with fluid core for damping applications", Empa researchers, together with ETH Zurich, seek to study the dynamic instabilities of fibres made of polymer blends. As yet, there exists little basic knowledge about them. Better understanding should lead to the manufacture of a synthetic fibre with a fluid core by means of a melt-spinning process. The core's structure and material will allow control of flow velocity, viscosity and friction "from the outside", thus giving the fibre adaptive properties.

Possible applications depend on the fibre's detailed properties. For example, if the core is filled with a fluid which hardens when it reaches a certain flow velocity, such a fibre could be used as an adaptive damping element or energy absorber. Other possible applications include acoustic filters, flow dampers or shock-absorbing clothing. The fibre could also be used as reinforcing fibres in ultralight composite materials or in bulletproof vests.

New fabrication technology for artificial muscles

So-called dielectric elastomer (DE) transducers consist of an electroactive polymeric compliant capacitor which undergoes large surface deformations when a voltage is applied. They are attractive as actuators with muscle-like mechanical properties. Such artificial muscles could, for example, be used in robots or in wearable and/or portable orthotics and prosthetics.

In the project "Fabrication technology of smart dielectric elastomer transducers", the goal of Empa researchers is to develop thin, flexible and multilayer films which can produce contraction motion under external tension with relatively low activation voltage and thus can be used as an artificial muscle. The focus is on the development of a process for the fabrication of DE transducers with high robustness and reliability.

"Smart materials give engineers new degrees of freedom"

Great potential is being attributed to smart materials. EmpaNews spoke with Edoardo Mazza, head of Empa's Mechanics for Modelling and Simulation Laboratory and co-initiator of the National Research Programme NRP 62 "Smart Materials", which just recently started up. We discussed these materials but also his research at Empa and ETH Zurich.

INTERVIEW: Beatrice Huber / PHOTO: Ruedi Keller

"Anywhere you have movement, anywhere you have life, mechanics is involved."

Smart materials – how would you describe them?

Smart materials, examples being magnetorheological fluids or electroactive polymers, have the ability to adapt. That means they react to external stimuli by changing their physical and mechanical properties. We want these effects to be reproducible, controllable and ultimately useful. Expressed more directly, we call these materials smart if they do what we want them to do.

What potential do these materials have?

Smart materials give engineers new degrees of freedom. They enable completely new functionality and devices, or known and proven solutions can be optimised or made less expensive. Apart from piezoceramic components and shape memory alloys, at this point there are actually few products on the market which are based on smart materials. Besides basic research, we also need innovative and courageous industrial partners. Not all the material systems we are investigating will live up to their initial promises. On the way to these new products, however, we'll face exciting, far-reaching and interdisciplinary challenges to which students and post-graduates will contribute solutions. This presents us with excellent educational opportunities. This new generation of scientists and engineers will certainly have great potential for the future of our society.

Concerning the National Research Programme NRP 62, which you co-initiated, six of the 21 approved projects are being headed up by Empa researchers. What led to this success?

Empa offers exactly what the NRP request for proposals demanded: comprehensive knowledge in both materials science and engineering. For more than a decade, researchers at Empa have been working with smart materials. In addition, Empa sets its priorities towards making sure that basic research and its transformation into new products go hand-in-hand. This is completely in the spirit of the NRP.

That's also apparent in one special aspect of NRP 62. For the first time, the Swiss Innovation Promotion Agency CTI is involved as a cooperation partner. What does this mean for you as an engineer?

The connection with CTI gives the project a concrete goal because the findings should be implemented in some specific products. For me as an engineer, that's a very positive sign. The Swiss National Science Foundation and CTI represent two cultures which should increasingly enhance each other and not contradict each other.

Your area of research, as the name of your laboratory reveals, is mechanics. What do you find so fascinating about this discipline?

Some people say that mechanics is the mother of physics. And while that's quite an honour, it also makes this discipline sound perhaps somewhat outmoded. The fact is, mechanics is always at the leading edge. It describes the causal connections between forces and motion or deformations. In other words, anywhere you have movement, anywhere you have life, mechanics is involved. Knowledge of mechanics is essential for every modern area of research – whether nanosystems, smart materials, energy technology or biotechnology.

For quite some time you've also been a professor at ETH Zurich. What does it mean for you to work simultaneously at ETH Zurich and Empa?

I'm delighted to have this unusual opportunity. It's very interesting to work for both institutions, although sometimes not that easy. Empa has very knowledgeable and experienced specialists and, in some areas, very good infrastructure. Being there gives me better chances to collaborate with experts from complementary disciplines. As for ETH Zurich, I greatly enjoy my teaching and working together with my students. I greatly value the freedom we have at ETH regarding research and the culture of continuous learning. I see myself as a link which can make the positive aspects of each institution useful for the other, as well.

How do the two institutions enhance each other?

I don't believe in a separation of the missions of the various academic institutions in Switzerland. I see a wide degree of overlap in the objectives concerning basic research, innovation, technology transfer, and the education of our future leaders. Of course, each institution pursues these objectives in a different way depending on its internal organisation, infrastructure and, above all, on the people who work there. Collaboration among the institutions makes it possible for society to benefit optimally from the results they achieve.

You once said that you came to study in Zurich because of its international flair. Have you meanwhile found that flair?

Zurich is a cosmopolitan city. You can sense its international flavour especially in some of the large corporations and research institutions. I find this a valuable source of enrichment for research and in general for society. The institutions of the ETH Domain, and here also Empa, are committed to excellence. Today, excellence must always be evaluated in global terms, and international competition continues to get stronger. This brings to mind initiatives for excellence in Germany or major research programmes in the Far East. In order to retain the highest level of quality in research and education in Switzerland, collaborations such as those between Empa and ETH Zurich are increasingly important. //

Personal background

Since 2006, Edoardo Mazza has been head of Empa's Mechanics for Modelling and Simulation Laboratory and at the same time is Professor of Mechanics at ETH Zurich. He previously studied mechanical engineering there and also earned his doctorate in mechanics. Following completion of his PhD, Mazza switched over to industry and worked at Alstom Power where he was group leader in the steam turbine R&D department. In 2001 he returned to ETH Zurich as an assistant professor, in 2006 he was appointed associate professor, and since 2010 he has been a full professor.

Spark in the dark

Whether on wristwatch dials or for self-illuminated emergency exit signs, luminous substances have long been an integral part of our society. Empa researchers are now developing a new generation of such substances which should light up whiter, more brightly and longer than ever before.

TEXT: Peter Merz / PHOTO: LumiNova

Until the mid 20th century, luminous pigments were blended with radium, which was then replaced by tritium. It is only since 1998, that luminous substances, called "solid state lighting", perform their job without radioactivity; they instead generally contain what are known as afterglow pigments. These continue to operate using the same principle: the crystal lattice of a carrier material such as strontium aluminate is doped with atoms of a second substance.

The design of such pigments is predominantly calculated on a theoretical basis using a computer simulation, as is also done in Empa's Solid State Chemistry and Catalysis Laboratory under the direction of Anke Weidenkaff. "The development of such substances is always a challenge," she explains. "At the early computer modelling stage you must investigate which atoms to embed so that the complicated physical luminescence mechanism functions properly." Only then can the doped atoms move into an energetically excited state when exposed to light. Then, in the dark when no further energy is being added, the atoms return to their original state and in doing so release energy in the form of visible light.

Lighting up longer, more brightly and, above all, whiter

Currently, the best afterglow pigments, patented under the name LumiNova, are created on the basis of strontium aluminate. The patent holder and pioneer in this technology is Nemoto & Co., Ltd. of Japan. That company is now an indirect industry partner of Weidenkaff's project through her work with LumiNova AG (Switzerland), a joint venture formed between Nemoto and the Swiss company RC Tritec Ltd.

In this project, she and her team have been researching a new generation of afterglow pigments since February. The researchers' primary goal is to improve the characteristics of the light's duration and colour. "These illuminants are an exceptionally energy-relevant topic," remarks Weidenkaff, who has a vision that "perhaps in future, thanks to them, there could even be room illumination completely independent of electricity." The Empa team expects to have the first results by the end of the year. //

"First aid" plugs the leak

TEXT: Martina Peter

A hole in an inflatable boat is only a disaster if the air escapes too quickly to reach the safety of land. It's somewhat less dramatic but nonetheless uncomfortable to spend the night on a leaky air mattress. Even in this case, though, you can get some uninterrupted sleep if only the air leaks out slowly enough. In future, self-repairing layers of porous material should ensure that the membranes of inflatable objects are not only water and airtight but also that they can plug up any holes on their own, at least temporarily.

The idea behind this comes from nature. Bionics experts keep on discovering amazing principles of construction which engineers can adopt for countless technical solutions. This is also the case with self-repairing materials. The self-healing process of the pipevine (*Aristolochia macrophylla*), a liana which grows in the mountain forests of North America, gave the biologists at the University of Freiburg, Germany, a decisive clue. When the lignified cells of the outer supportive tissues which give the plant its bending stiffness are damaged, the plant administers "first aid" to the wound. Parenchymal cells from the underlying base tissue expand suddenly and close the lesion from inside. Only in a later phase does the real healing process kick in and the original tissue grows back.

Self-healing inflatable structures

This principle is now being transferred to materials – more specifically, to membranes – in a bionics project sponsored by the German Federal Ministry of Education and Research. An additional layer which foams up whenever a membrane is damaged administers first aid, following the model from nature, and plugs any holes until proper repairs can be made. While researchers from the University of Freiburg under the direction of Olga Speck are busy studying the biological and chemical aspects of the model provided by liana plants, Rolf Luchsinger and Markus Rampf at Empa's Center for Synergetic Structures are working on technical solutions for polymer membranes. Luchsinger's impetus, however, concerns neither inflatable boats nor air mattresses but rather load-carrying pneumatic structures for lightweight construction. His tensarity beams serve as elements for quickly erected, lightweight bridges and roofing.

The study's goal is to understand under which conditions a hole plugs itself up if the foam expands on a membrane following damage. Within the scope of his dissertation, Rampf is studying this process with the help of an experimental setup which places a membrane under pneumatic pressure and then punctures it with a nail. The researchers have already achieved successful interim results. A two-component foam of polyurethane and polyester suddenly expands when exposed to the excessive pressure which arises when air rushes out of a hole.

"It works in the lab," notes Luchsinger, "and we're achieving high repair factors." What does this mean in the real world? Take the case of an air mattress with a volume of 200 litres. Given a certain-sized hole, previously it was necessary to pump it up every five minutes; it now holds for eight hours – enough time to sleep through the night. "We now know enough about the foam that we can enter into discussions with membrane manufacturers about commercialising this technology," according to Luchsinger, when describing the next steps. //

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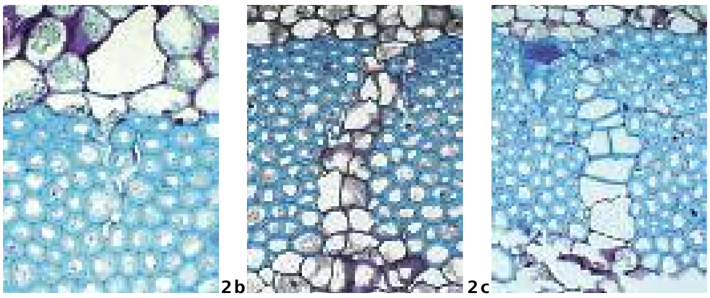

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A membrane made of polyvinyl chloride-polyester (yellowish colour) is punctured with a 2.5-millimeter diameter needle, and at that moment the polyurethane foam (brown) uddenly expands. (Photo: Empa)

2
Cell repair in a pipevine (*Aristolochia macrophylla*). Parenchymal cells of the base interior tissue suddenly expand if the lignified cells of the outside supporting tissue are damaged (a and b), and in a later phase (c) they eventually lignify. (Photos: Plant Biomechanics Group, University of Freiburg im Breisgau)