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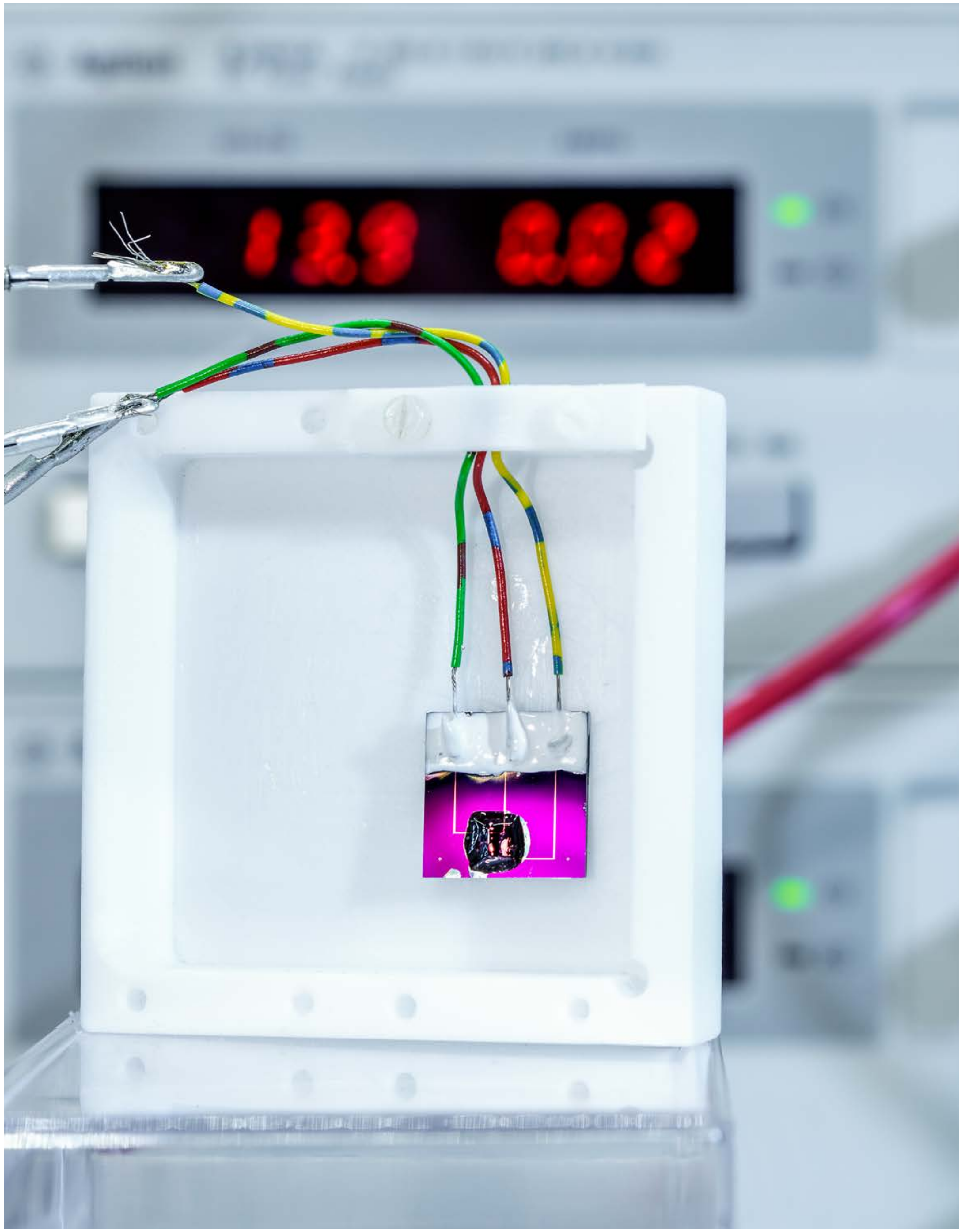
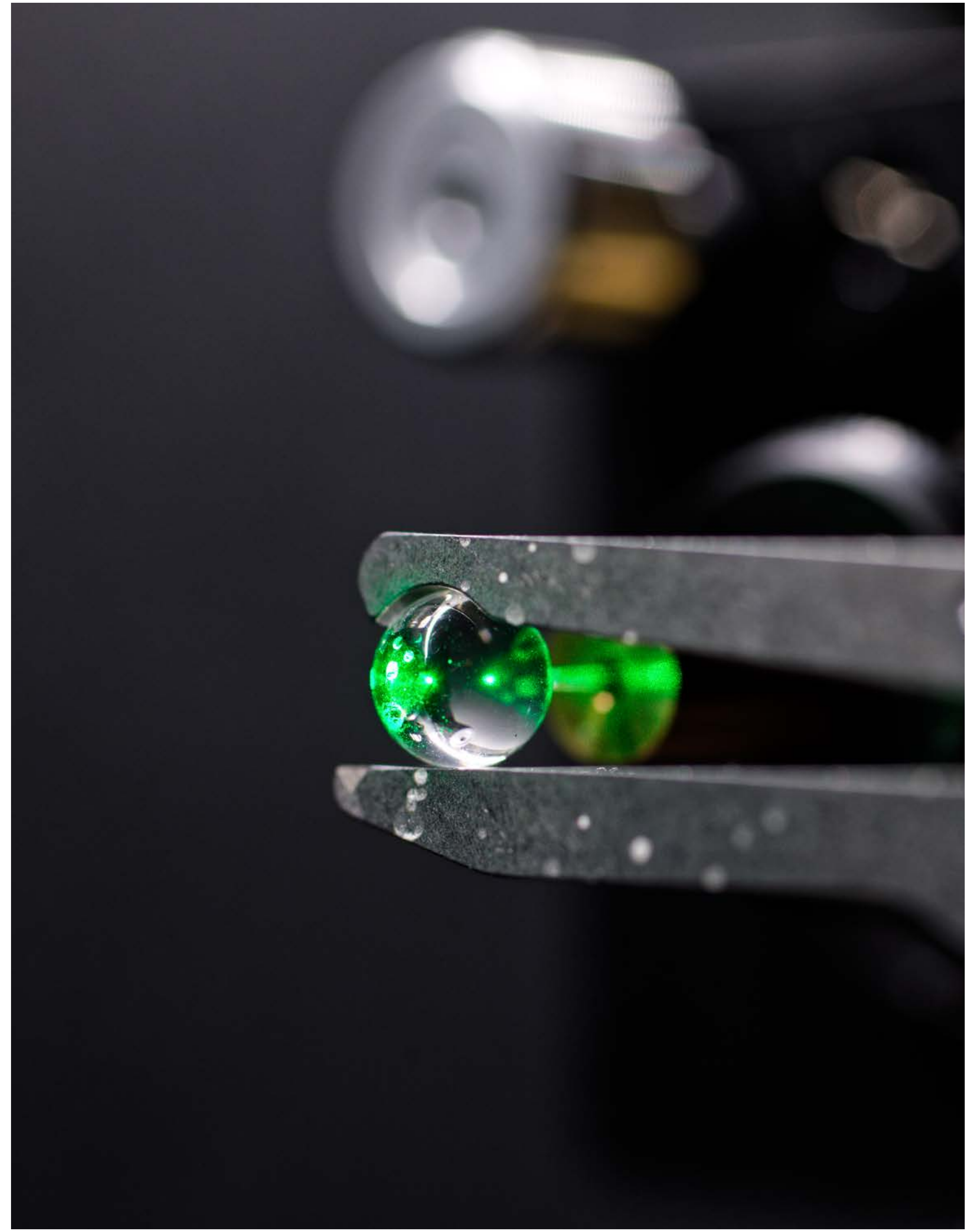
WERNER SIEMENS FOUNDATION

Our mission

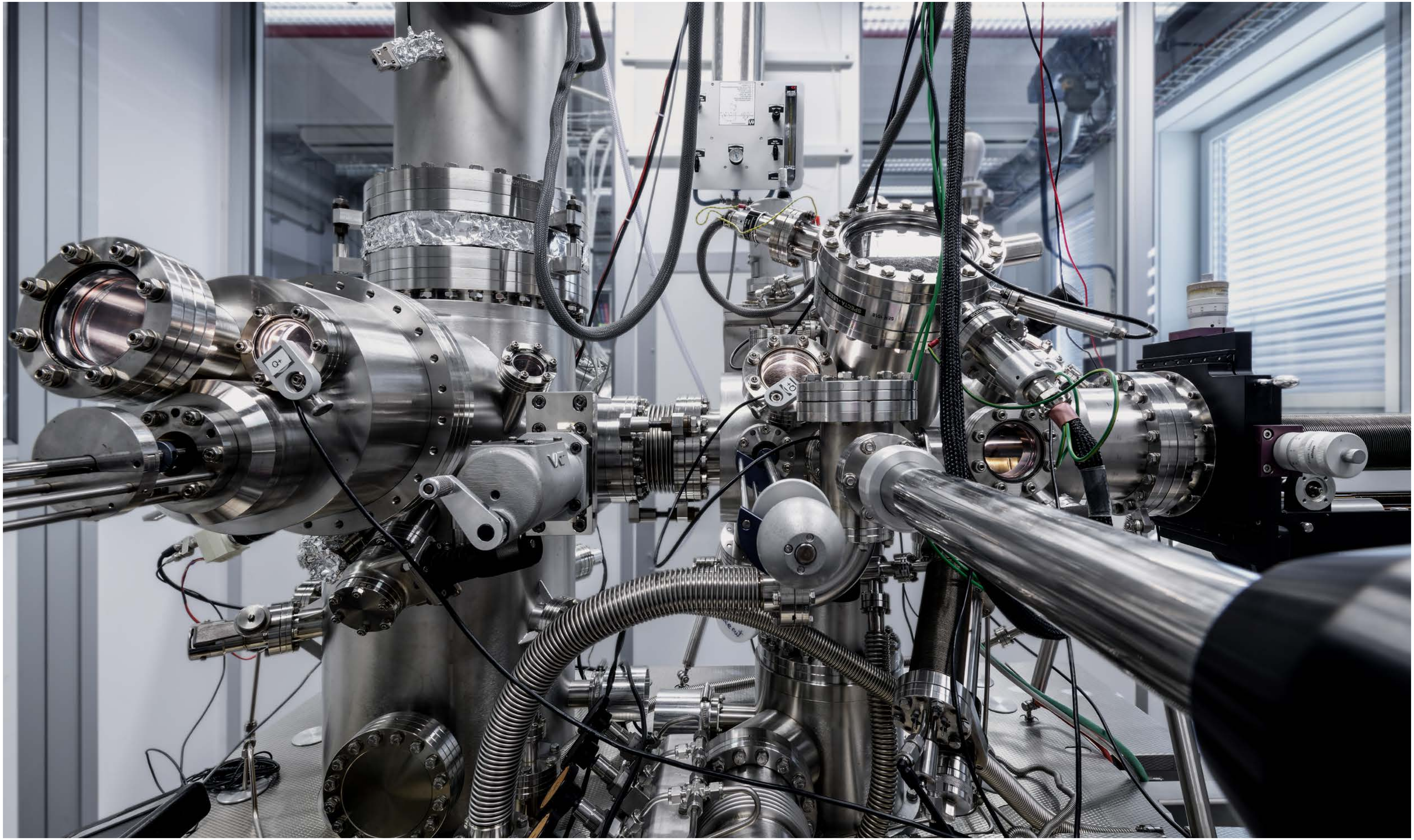
2021 report



Single-atom switch—Center for Single Atom Electronics and Photonics



MIRACLE II—minimally invasive bone surgery using laser technology and the development of intelligent bioimplants



CarboQuant—carbon nanomaterials for quantum technologies in everyday life

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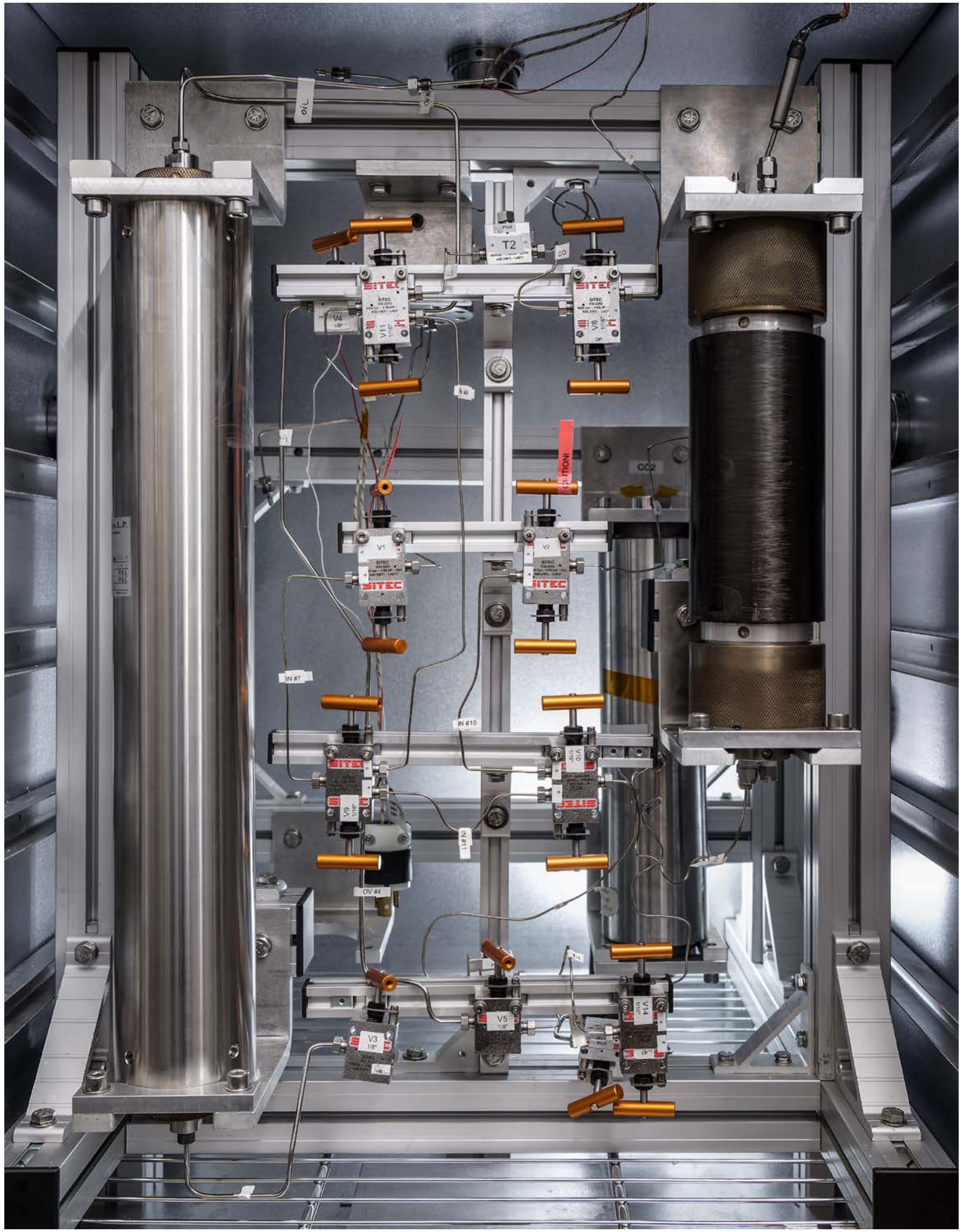

Geothermal energy—harnessing the earth's heat

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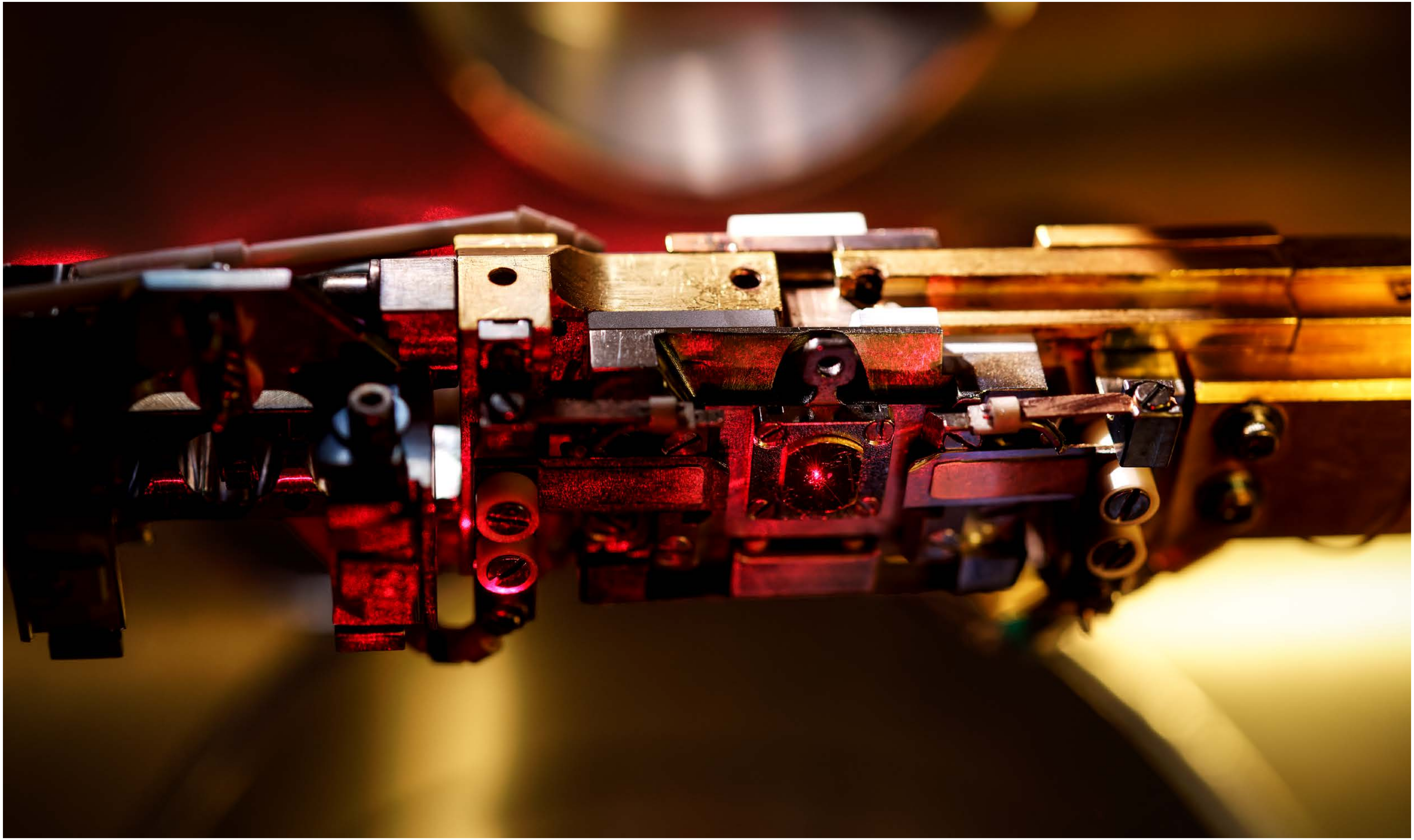
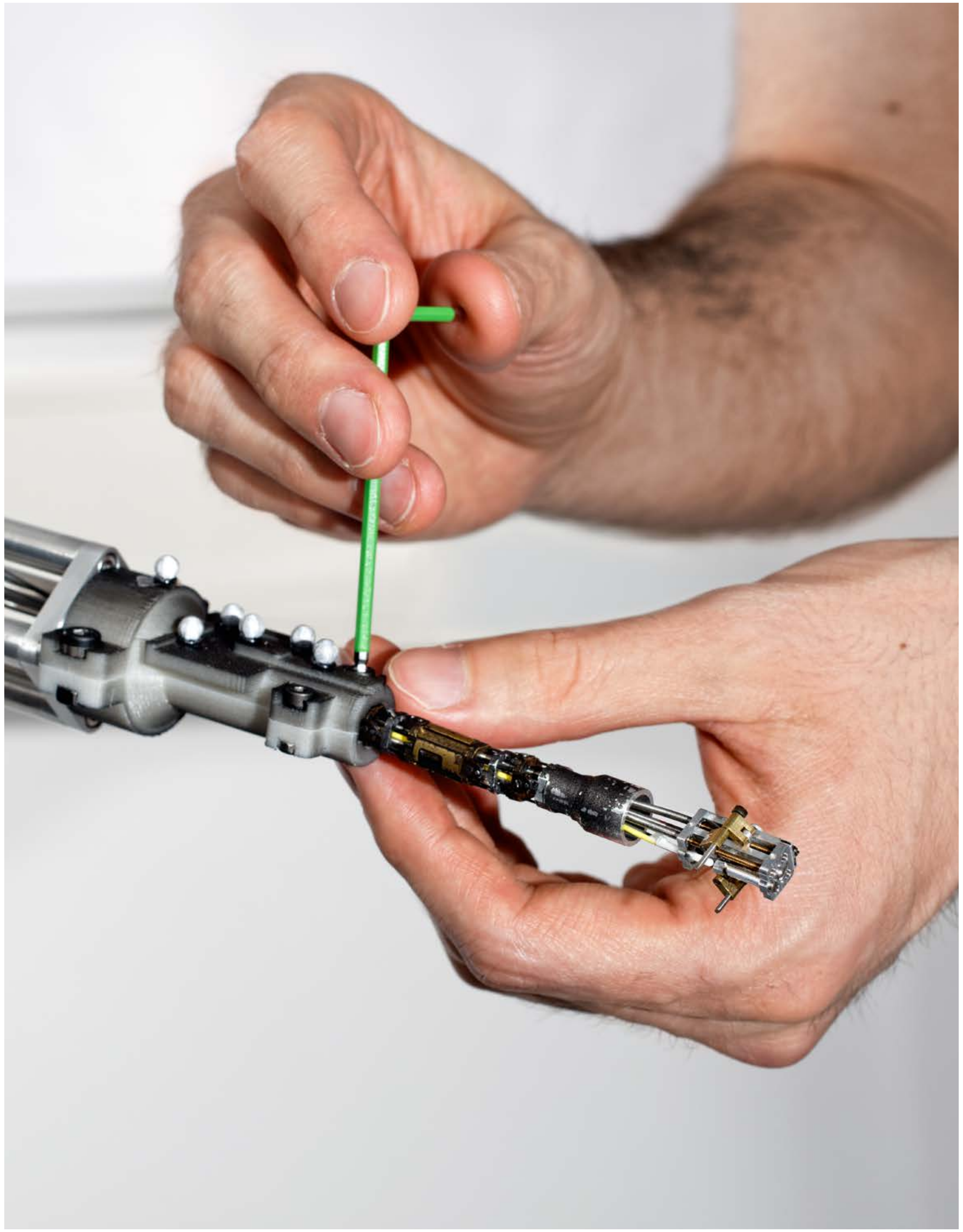


CarboQuant—carbon nanomaterials for quantum technologies in everyday life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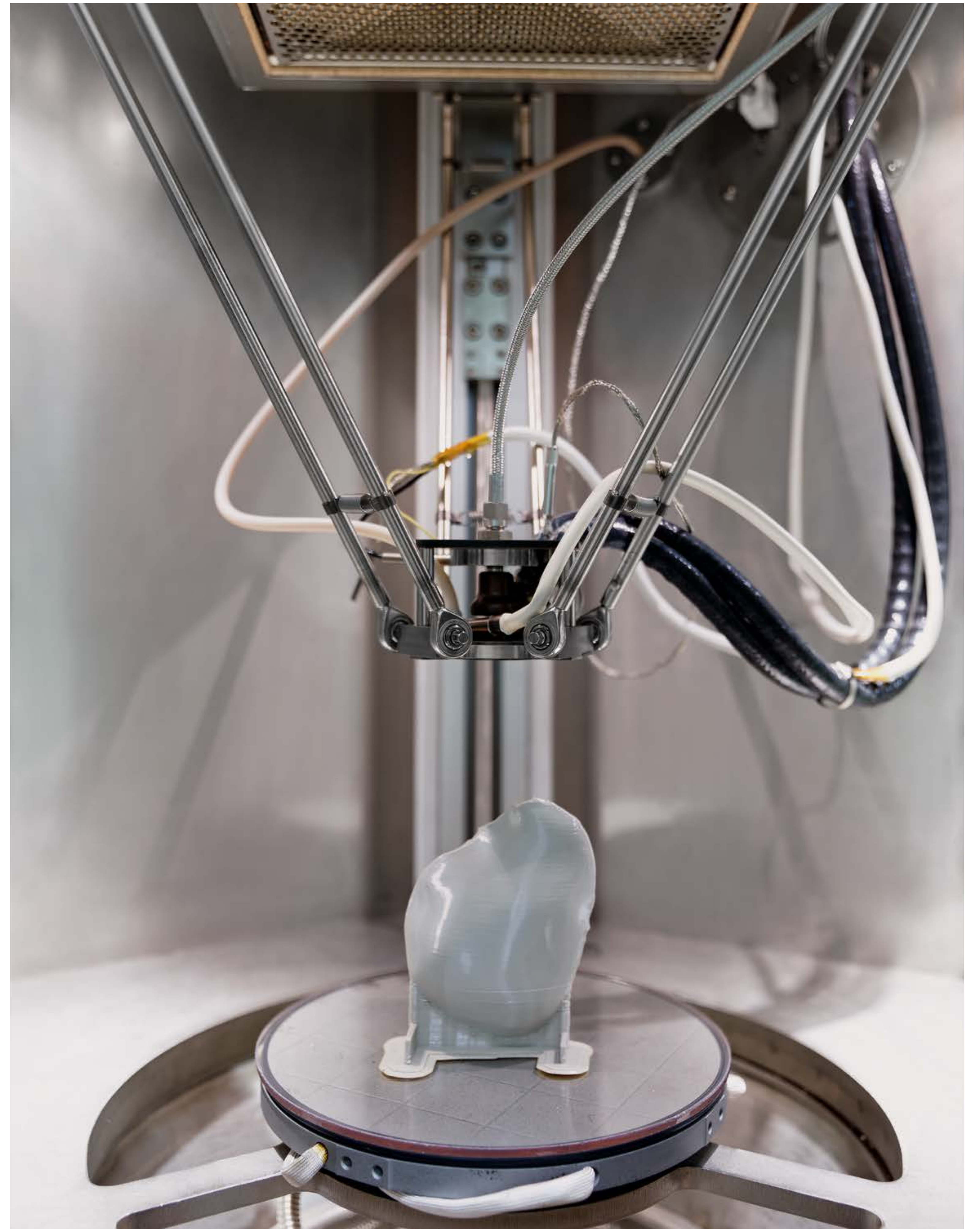
MIRACLE II—minimally invasive bone surgery using laser technology and the development of intelligent bioimplants

Promoting innovation in technology and the natural sciences

The Werner Siemens Foundation supports groundbreaking projects in the fields of technology and the natural sciences. The selected projects in research and education are generally conducted at universities and higher education institutions in Germany, Austria and Switzerland; key requirements include upholding the highest standards and contributing to solving major problems of our time. The Foundation provides generous seed funding to innovative projects with the goal that, after a few years, the projects can be run independently and the results find industrial application. The Werner Siemens Foundation also promotes education and training projects and fosters young talent, particularly in the fields of mathematics, informatics, natural sciences, technology, medicine and pharmaceutical science.

Foreword

Every year, the Werner Siemens Foundation finances up to three new projects in the natural sciences and technology—all exceptional undertakings that have the potential to solve key problems of our time. In 2021, we decided to fund the setup of a centre for viral research (page 45) and a project to develop innovative nanomaterials that have interesting quantum mechanical applications for everyday use (page 25). Also worthy of mention is our newly established professorial chair for the "Economics of Climate Change" at the Potsdam Institute for Climate Impact Research, where scientists will study the economic consequences of global warming—one of humanity's greatest challenges. More information about the new professorial chair is available on our website: www.wernersiemens-stiftung.ch.

In addition to the outstanding research we support, our Foundation naturally remains committed to family projects and needs. The Siemens Family Advisory Board will continue to devote its attention to this work—albeit in a slightly different constellation: in March of 2021, Gerd von Brandenstein stepped down after thirty-five years of service on the Family Advisory Board of the Werner Siemens Foundation. Having begun his activities as an auditor, he was then appointed member of the Foundation and, at the end of his tenure, served as Chair of the Family Advisory Board. In his many years with the Werner Siemens Foundation, Gerd von Brandenstein collaborated with other members of the Family Advisory Board and Foundation Board to initiate changes that shape the direction our Foundation pursues today—and that continue to drive our mission forward.

We extend our deepest thanks to Gerd von Brandenstein for his dedication and foresight. A conversation with our friend and relative is found on page 112.

In 2021, a new member was elected to the Siemens Family Advisory Board: Alexander von Brandenstein, a descendant of Marie von Graevenitz, one of the two sisters who founded the Werner Siemens Foundation in 1923. In Alexander von Brandenstein, the Family Advisory Board has gained a member with a strong sense of family and also valuable business experience in the digital economy.

In March of 2021, I had the honour of being elected Chair of the newly constituted Family Advisory Board. As a lawyer, I look forward to contributing my professional experience in banking and finance as well as my knowledge from years of working for and with family businesses and their families. Fully aware of the mark my predecessor has left, I also have utmost respect for the responsibility that comes with this position.

Focusing on the critical issues of our time and funding projects that have the potential to solve them is a matter close to my heart. The other Foundation bodies also pursue this goal—and I am grateful for the constructive collaboration.

I look forward to new projects and challenges in 2022. And I hope you enjoy reading our report.

Oliver von Seidel
Chair of the Siemens Family Advisory Board, Zug

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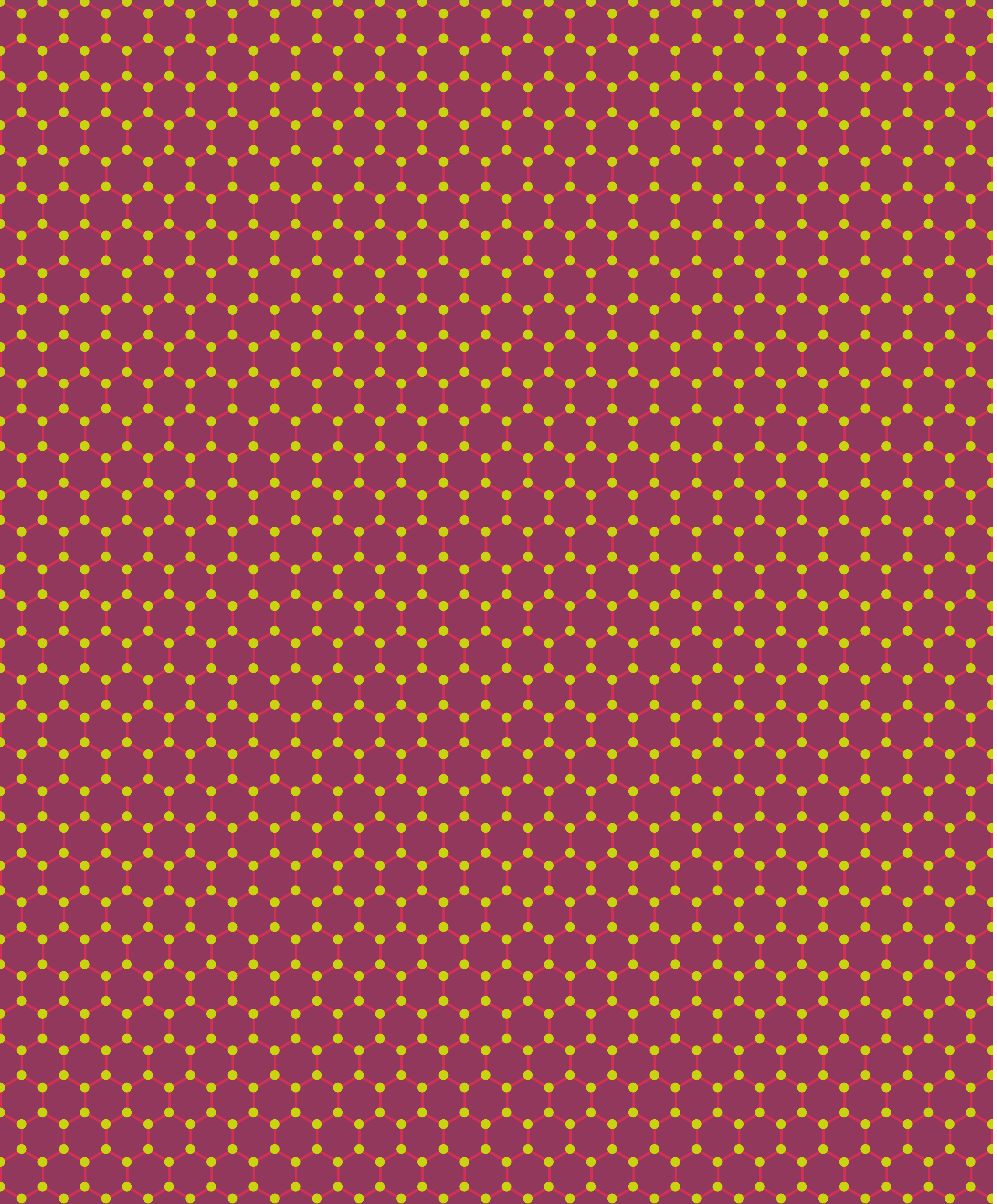
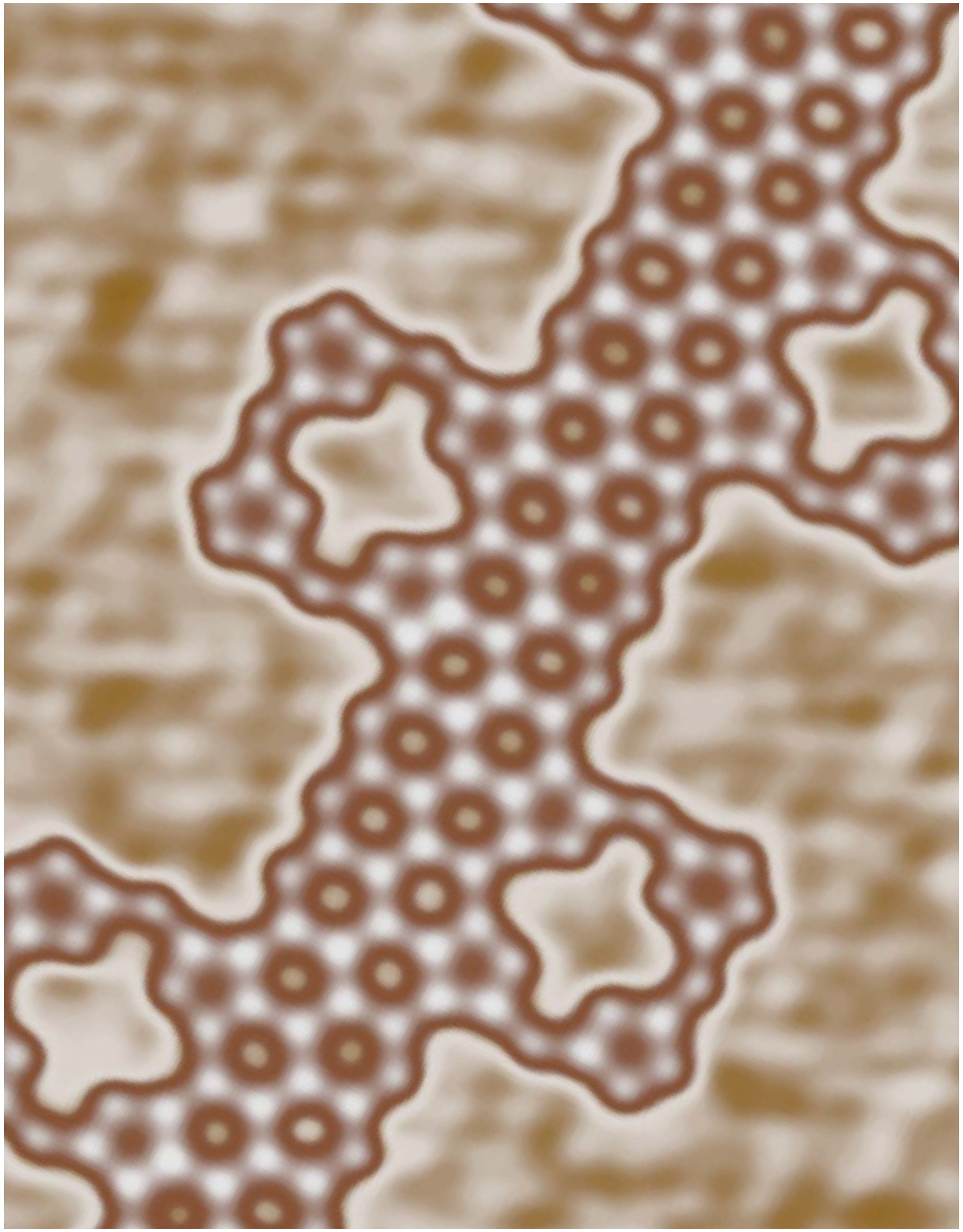


A quantum leap into everyday life

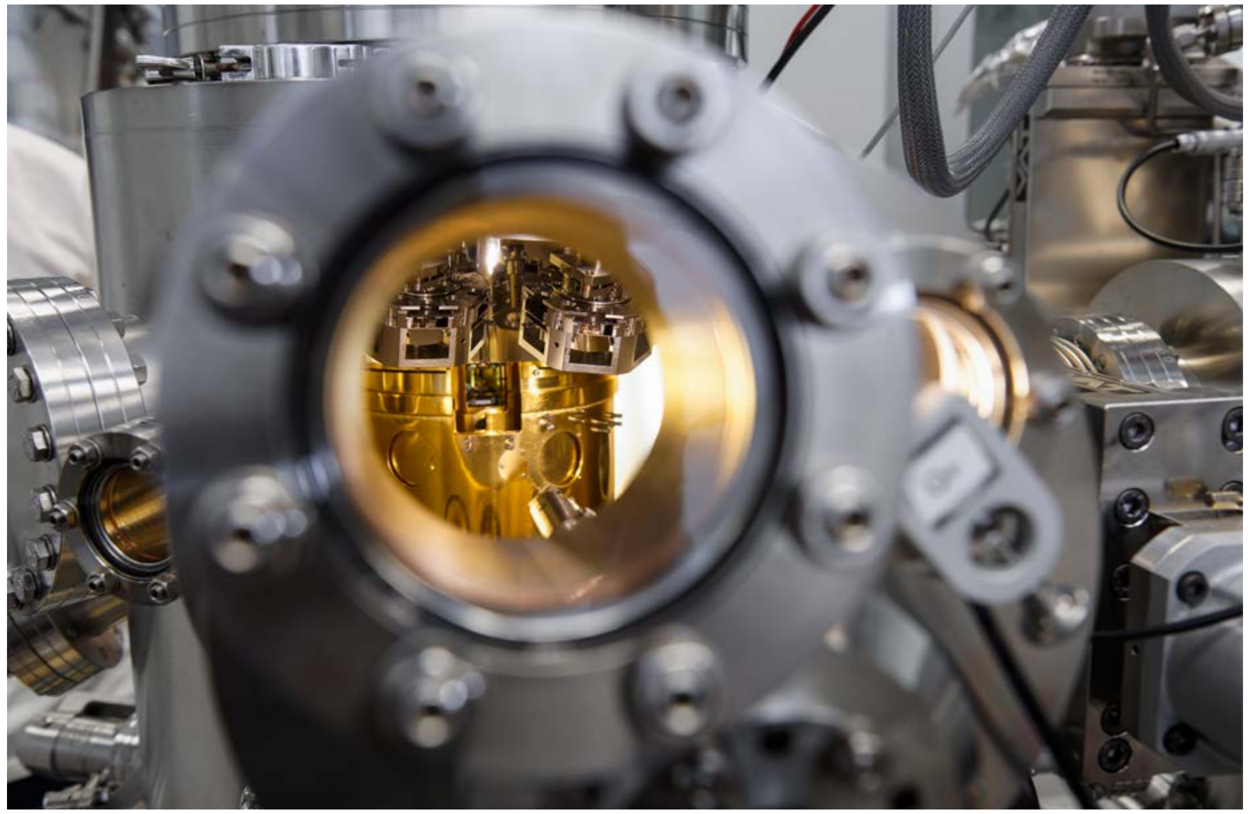
CarboQuant: developing carbon nanomaterials for second-generation quantum technologies



What do stone, bronze, iron, crude oil and silicon have in common? All are raw materials that have helped bring about major advances in human history. Now, in the 21st century, the dawn of the quantum age is at hand: novel “raw” materials like qubits and nanoribbons have the potential to enable our current information technologies to literally take a quantum leap.

Entering the quantum age

Welcome to the nanoworld—and to the realm of quantum physics, where standard rules of reality no longer apply. Nanoparticles and nanomaterials have properties that open up completely new possibilities: building ultra-fast quantum computers to name just one. Project leader Roman Fasel and the CarboQuant team at the Swiss Federal Laboratories for Materials Science and Technology (Empa) want to exploit these properties to develop nanomaterials that can transform quantum technology into an everyday technology.



A glimpse through the peephole into the shimmering golden chamber of the scanning tunnelling microscope, where material samples are measured under vacuum conditions.

A large, strange-looking contraption made of shining metal stands in the middle of the room: a scanning tunnelling microscope. Where the various "peepholes" are located is not immediately obvious—they are hidden away in the tangle of pipes, hoses, screws, plates and cables. But not to worry: Gabriela Borin Barin, chemist and materials engineer in the CarboQuant team at Empa's nanotech@surfaces Laboratory, knows the complex machine inside and out. Walking towards one of the circular windows, she peers into the scanning tunnelling microscope and turns a knob to move a delicate pair of pliers positioned within, where the interior environment is an almost perfect vacuum. With the knob, Borin Barin continues to manoeuvre the pliers very carefully deeper into the device in order to remove a material sample from a minuscule shelf.

The material that Borin Barin is about to measure is brand new. She triggered a series of chemical reactions on a gold foil to fabricate a specific carbon structure: a long thin ribbon consisting of a single layer of interconnected atoms—a nanostructure. Borin Barin first designed the nanostructure and then synthesised it on the basis of her concept. It is precisely these kinds of carbon nanoribbons that she and her CarboQuant colleagues at Empa, in Dübendorf, Switzerland, are planning to use to create completely novel electronic components. Specifically, they want to develop electronic components based on quantum states in order to build computers so powerful that the supercomputers of today will look like humble pocket calculators in comparison.

Infinitesimal dimensions

To illustrate the point, Oliver Gröning, deputy head of the CarboQuant team, rummages in his pocket for his smartphone. "The phone looks modern, but the technology inside is fifty years old," Gröning says. Of course, the processors in today's electronic devices are faster and smaller than ever before, "but the physics they're based on hasn't changed".

Researchers in the CarboQuant project have now set their sights on the next big development. Or rather, on a smaller dimension: the nanodimension. Indeed, when we step into the nanoworld, classical physics enters the realm of quantum physics. "Quantum physics starts at a size of about ten nanometres," Gröning explains. One nanometre is equal to one thousand-millionth of a metre. For comparison, a single human hair measures seventy thousand nanometres in circumference.

New rules apply

And in the nanoworld, the rules of our visible reality no longer apply—in quantum physics, particles can simultaneously have physical properties that contradict each other in classical physics. Or two particles can be physically far apart yet nonetheless linked and capable of influencing each other. "It's these types of quantum effects that we aim to exploit," Gröning says. To do so, the researchers must be able to control their materials down to the nanodimension—meaning down to the atom.

Distinguishing individual atoms

In the lab, Gabriela Borin Barin continues to turn the knob carefully, moving the pliers with the sample and placing it into the section of the scanning tunnelling microscope where the material will be measured. Only the gold foil on which the nanostructures were synthesised can be seen—the new material itself is invisible to the naked eye.

The entire procedure is extremely sensitive. “The scanning tunnelling microscope reacts to each and every vibration,” Borin Barin says. For this reason, the device is housed in the lower level of the lab building, where there is less risk of disturbance. In addition, the microscope is placed on a type of shelf equipped with a system capable of absorbing even the slightest of vibrations. These precautions ensure that the microscope’s measurements can be rendered as such high-resolution images that the researchers are able to identify individual atoms in their newly created materials.

Every shape a new material

The shape of the nanoribbons is not left to chance. The long edges hold all the potential—indeed, the structure of these edges is what determines the material’s quantum electronic properties. And although the nanoribbons designed and synthesised by the team only differ at the edges, they have fundamentally different electronic properties. “By slightly tweaking the shape of the nanoribbons, we’re creating an entirely new material,” says Gröning.

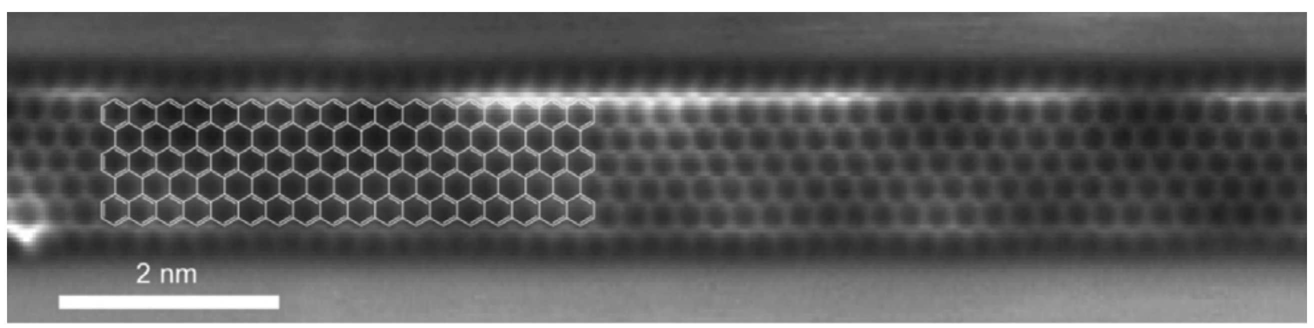
But to what end? To answer this question, a comparison with conventional, bit-based electronics is useful. Bits, the smallest computational unit, can have either one of two states: they can be a zero or a one. In the quantum world, however, these two states can overlap: it is possible for a unit to be a zero, a one—or both states simultaneously. This property is what enables circuits made of qubits—the components in quantum computers—to perform several computational operations at the same time, whereas a standard, bit-based circuit functions on a linear timeline. This means that the performance of a quantum computer increases exponentially with each additional qubit.

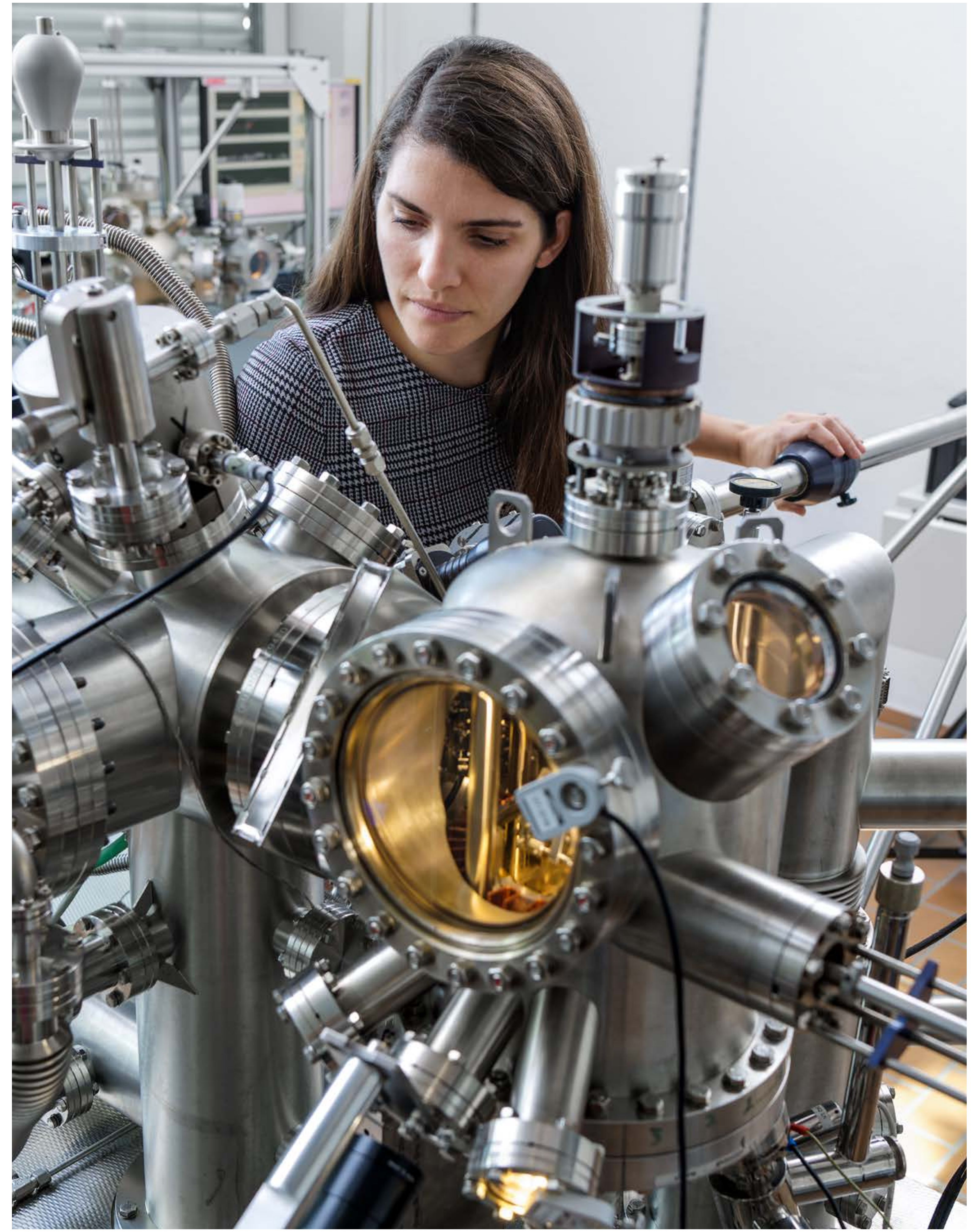
Another quantum effect is the linking of particles, called quantum entanglement in technical jargon. Quantum entanglement is used to program quantum computers or to write code for extremely secure encryption.

Exploiting quantum effects

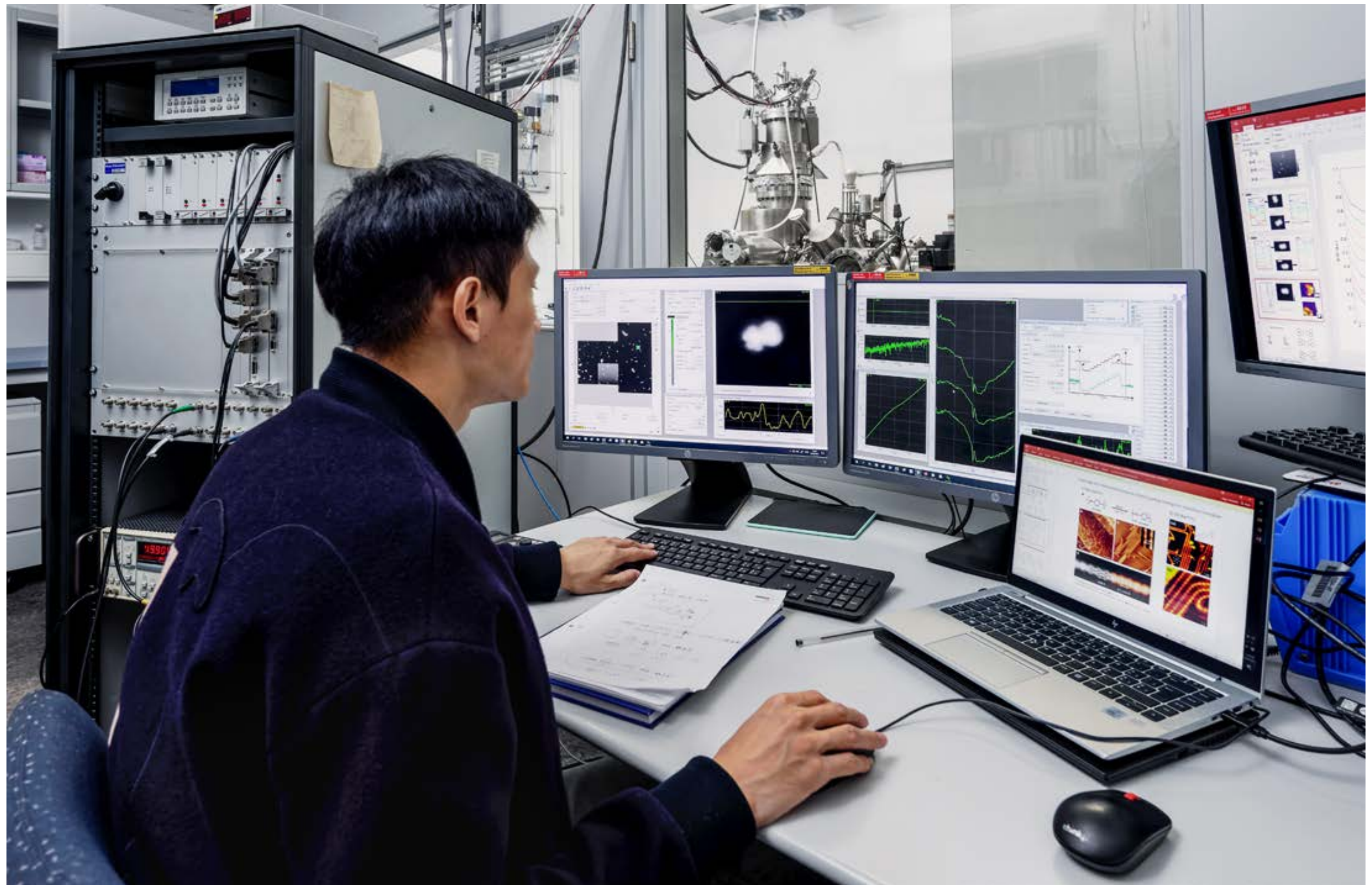
The Empa researchers want to furnish their CarboQuant nanoribbons with these kinds of useful quantum effects and are particularly interested in electron spin: the rotational momentum of electrons. The team have already discovered that, with the right nanoribbon structure, the electron spins of both edges can be linked. In turn, this creates a kind of superhighway for spin states, comparable with the electric charge pathways in conventional electronics. “If we succeed in controlling these spin states, we can use them for quantum electronic components,” Gröning says.

Magnified by a factor of ten million: the atomic structure of a carbon nanoribbon synthesised by the CarboQuant team. When researchers tweak the long edges, completely novel electronic properties arise, allowing each modification to materialise as an independent new material.

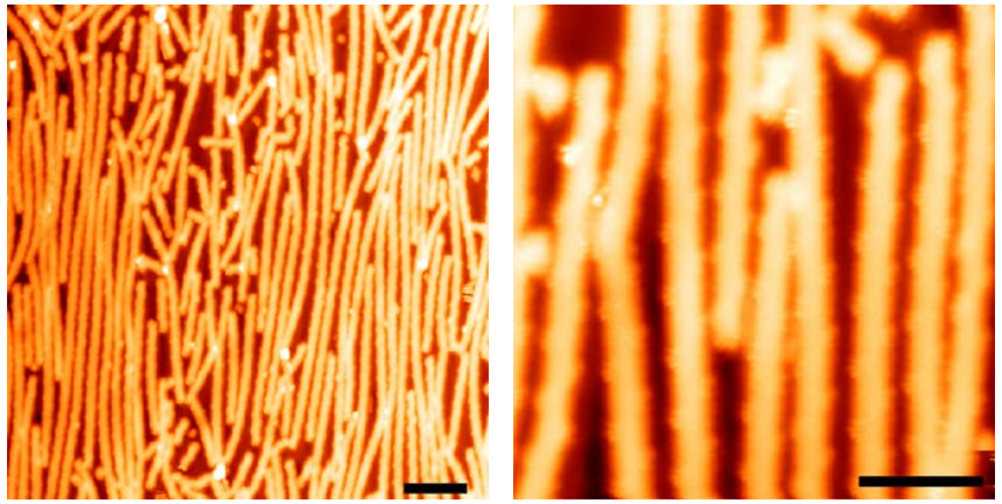




Chemist and materials engineer Dr Gabriela Borin Barin from the CarboQuant team places a sample of a newly created carbon nanoribbon in the scanning tunnelling microscope.



The control panel of a scanning tunnelling microscope where the newly synthesised carbon nanoribbons are continuously visualised and analysed during the measurement.



An image of carbon nanoribbons rendered by the scanning tunnelling microscope at different magnifications. The black scale bars at the bottom indicate a length of 5 nanometres. For comparison: a human hair has a diameter of roughly 70 000 nanometres.

Wants to exploit the possibilities of quantum physics for everyday purposes—quantum sensors or secure communications, for example: project leader Roman Fasel from Empa's nanotech@surfaces Laboratory, in Dübendorf near Zurich.

Synthesis in a vacuum

Back in the lab, Borin Barin begins to take measurements of her nanoribbon sample. Because the procedure is so delicate, measuring the material takes place in a high vacuum chamber, where a barely visible, ultra-fine needle made of a platinum-iridium alloy probes the sample, causing electrons to flow across the minuscule distance between the tip of the needle and the sample. This generates a measurable electric current, and the effect—known as quantum tunnelling—makes it possible to map a precise image of the new nanoribbon down to the last atom. Now, Borin Barin has to wait just a few hours until the image of her nanoribbon is ready.

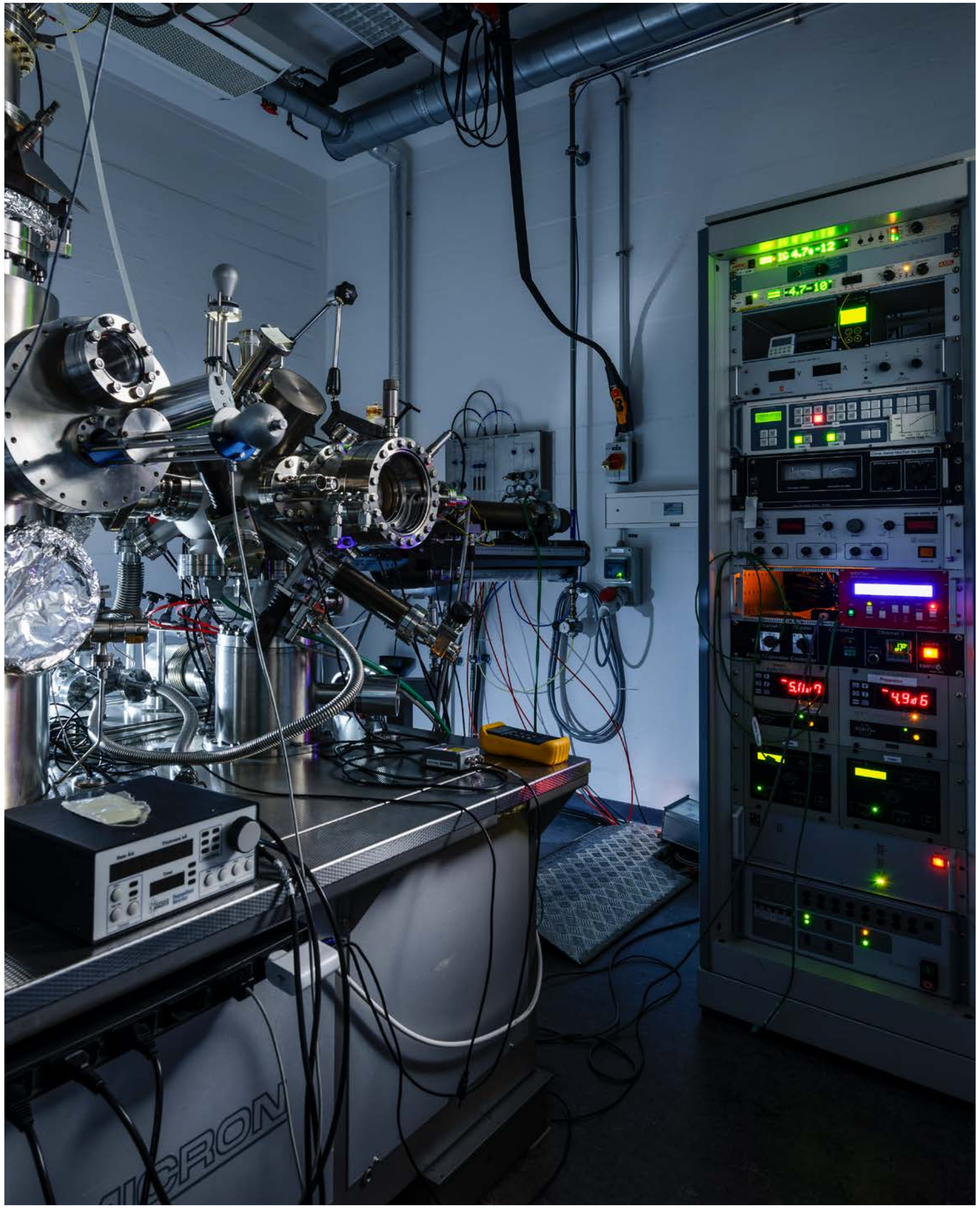
Nanoribbons are not only measured but also synthesised in a vacuum. To be precise: in a synthesis chamber separate from the microscope chamber. Borin Barin transfers the starting materials (the gold foil and the precursor molecules that will be synthesised to form a nanoribbon) through a type of ventilation shaft into the ultra-high vacuum. When moving the materials into the synthesis chamber, the shaft is opened and then quickly reverted to a vacuum state. “If we had to open the synthesis chamber itself, we would have to wait an entire week for the system to be ready for use again,” Borin Barin explains.

The synthesis procedure itself consists of a sequence of various cooling and heating phases, up to a maximum temperature of four hundred degrees Celsius. If the researchers want to fabricate a specific new structure, they must first go through a step-by-step discovery process to identify the necessary conditions. The scanning tunnelling microscope is also used to monitor whether the intended reactions actually take place and whether the nanoribbon structure produced corresponds to their designs.

The key to success

Another, smaller device that looks like a distant cousin of a diving bell is located in a corner of the lab. This machine is responsible for automatically carrying out the synthesis processes. The nanoribbons it synthesises can be transferred into a normal environment (ambient atmosphere), enabling the researchers to analyse the materials’ optical and electronic properties outside the vacuum chamber and to integrate them into electronic components.

The researchers have been working for quite some time on developing the high-precision synthesis methods for their nanoribbons. Three years ago, they began to understand how they would have to design the nanostructures to create stable spin quantum effects. “That’s the key to future developments,” says Gröning. “We’ve now reached the point where we can permanently encode complex quantum states in the nanostructures. Now the next great challenge is understanding how to control and further develop these quantum states.” Thanks to funding from the Werner Siemens Foundation, the team will be able to spend the next few years converting these challenges into ever more successes.



The scanning tunnelling microscope system in operation. Because measuring the carbon nanoribbons is such a sensitive procedure, each and every disturbance—sound or vibration, for instance—must be avoided. Even the lights are dimmed.

Wanted: gigantic computing power

The race to develop new nanomaterials for quantum technology is in full swing. Participants include the CarboQuant team as well as numerous other researchers and companies throughout the world. How does the Empa CarboQuant project in Switzerland differ from the rest, and what are its objectives? A discussion with Roman Fasel, project leader and director of the nanotech@surfaces Laboratory, and deputy project leader Oliver Gröning.

Physicists and engineers across the globe are on the hunt for quantum effects. Why the hype?

Roman Fasel: Quantum technology is simply the last real frontier remaining in electronics, and the enormous advances made in nanotechnology in the recent past mean that entering the realm of quantum technology is within reach. It's probably this pioneering spirit that has driven much of the research. And thanks to this progress, we're now able to construct the complex structures of our nanoribbons with such precision that we can exploit and manipulate quantum effects—and that on a scale where just a single atom makes a huge difference. It's impossible for electronic components to go into greater detail.

When quantum technology is talked or written about, quantum computers and the anticipated explosion in computing power are generally the issue. But why do we need more computing power?

Fasel: That's a fair question. And it's true that, over the past fifty years, computers have become increasingly powerful, even with today's semiconductor technology. Just imagine: today, every single smartphone has more computing power than was used for the moon landing. But there are still many problems our computers can't yet solve.

For example?

Fasel: One example would be weather forecasts that are accurate for more than just a few days. Another would be more precise global climate prognoses. For more exact predictions, the models that describe these phenomena need to be calculated in much greater detail and on a much smaller scale. But when calculations are made on a smaller scale, the computing capacity required increases exponentially. Today's computers quickly reach their limits. Other science disciplines, or the financial sector, would also benefit from more exact models.

Oliver Gröning: This is precisely where quantum computers come in: with each additional qubit, computing power increases exponentially. In conventional computers, by contrast, processor speed increases on a linear axis. And there we'll always lag behind when it comes to challenges involving exponential scales. These problems can only be addressed by a computer capable of exponential scaling: a quantum computer.

In your search for the right materials for quantum electronics, you've decided to focus on structures made of graphene—a material consisting solely of carbon. Isn't that a major limitation?

Gröning: No, because carbon is an extraordinary element. About eighteen percent of our body weight is made up of carbon, and every organic molecule is carbon based. This is because the carbon atom can form a wide range of different chemical bonds. Sometimes it has four neighbours, sometimes three, sometimes two. In molecular structures, carbon can combine to form one-dimensional chains, two-dimensional planes or, as in the case of the diamond, ordered three-dimensional structures. No other material has this structural flexibility. With carbon, we can design multiple new geometries.

How do you do this?

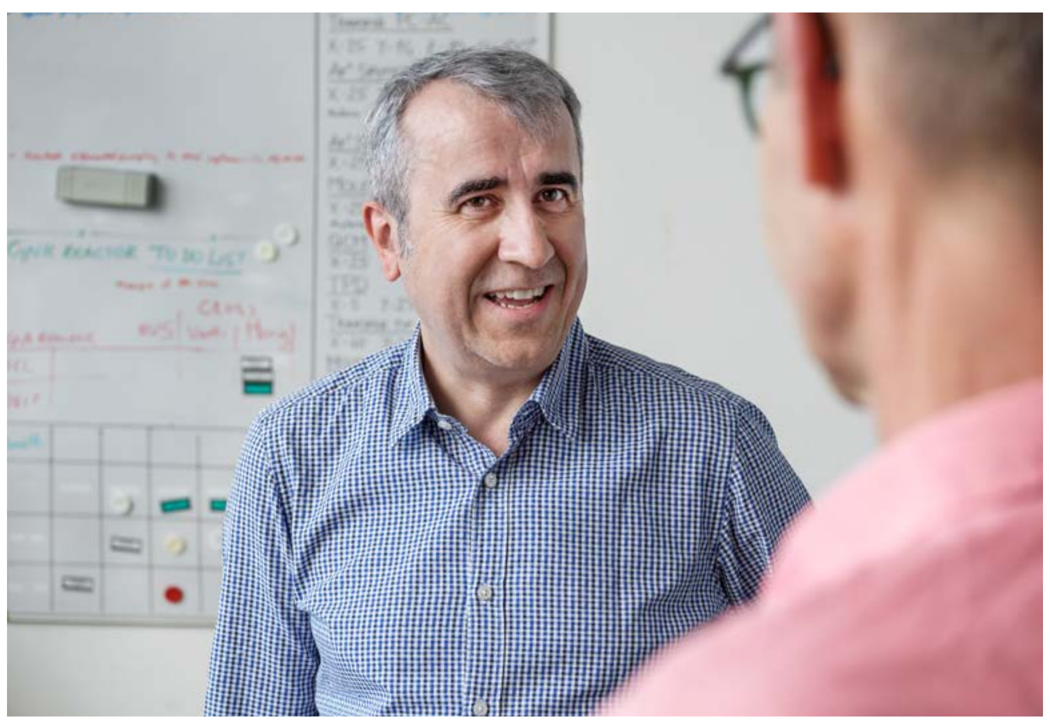
Gröning: We reverse previous approaches. Until now, researchers have generally begun with the material. In experiments or computer simulations, they then study specific materials to learn about their interesting properties. We propose doing the opposite. First, we define the properties we want to have and then look into what structures could have these properties and how we could design corresponding structures.

Fasel: To realise our idea, we want to develop a technology platform where nanoribbons, as the basic material, are available, as are the expertise and the infrastructure necessary for targeted further development. We've built up the basis at Empa over the course of the past twelve years. We can now create precisely designed graphene nanoribbons, and we've developed an understanding for how we have to change their structures to control quantum effects. We now want to expand this foundational knowledge into a platform.

What are the first steps to creating a platform?

Gröning: To begin with, we want to generate a larger library of different nanoribbon structures and establish a well-functioning infrastructure and methodology to characterise and further develop the nanoribbons. This calls for a lot of detailed groundwork that may not immediately deliver spectacular results, but which is indispensable for making progress.

Fasel: This is another reason why our project needs long-term funding that goes beyond the usual two- or three-year grants awarded to individual projects. It's like the discovery of the continents hundreds of years ago. If you only sail from port to port, you'll never cross the ocean. For that, you'll need a large ship with sufficient provisions—enough that you don't face starvation at the first calm. Today, we don't know for sure where the journey will lead us. But Magellan didn't know that either when he set sail in 1519 to find the western route to the Spice Islands.



Together with their research groups, they want to exploit quantum mechanical effects for everyday purposes: physicists Oliver Gröning (left) and Roman Fasel have known each other since their student days and are a practised team.

Project leader Roman Fasel (right) and his deputy, Oliver Gröning, discuss the next steps in the CarboQuant project, which is now receiving funding from the Werner Siemens Foundation.

The competition is fierce, with companies like IBM and Microsoft investing billions in the development of their quantum technologies and quantum computers. Can you hope to keep up?

Fasel: No, but that's not our goal. In addition to our carbon nanoribbons, there are indeed many other approaches being pursued, some of which are already quite far advanced. For example, extremely sensitive measurement sensors based on quantum effects have already been developed, and we have the silicon-based or superconducting qubits that were used to construct the first quantum computers. But all these approaches draw on phenomena that occur only at extremely low temperatures close to absolute zero. This is also why they need gigantic and horrendously expensive cooling systems that rely on liquid helium. By contrast, our carbon nanoribbons are stable at normal ambient temperatures. As such, it's not the first generation of quantum technologies that interests us. We're specifically working on the second generation: a quantum technology that doesn't require huge, costly cooling systems, that consumes less electricity and that's based on carbon—an element that is non-toxic, inexpensive and widely available. In short, we're looking to realise a quantum technology that at some future time will better serve our everyday needs.

The ABCs of quantum physics

Only dyed-in-the-wool specialists really understand quantum physics. But that's no reason to prevent the layperson from trying. While our puzzle may not explain the quantum realm in every detail, it provides easy-to-understand definitions.

Quantum mechanics
Quantum mechanics is a theory in physics used to describe the physical properties of particles and processes at the scale of the atom. It provides the foundation for atomic and elementary particle physics, and for quantum chemistry and quantum technology.

Nanometre
One nanometre is equal to one thousand-millionth of a metre—which is at the scale of the individual atom and where quantum effects become visible and malleable.

Quantum superposition
In the quantum world, superposition is possible, meaning certain states can overlap—those of electron spins or qubits, for instance. This effect explains a quantum computer's ability to perform multiple operations at once.

Quantum entanglement
In this quantum effect, several particles are interconnected, despite not being physically linked and sometimes even separated by large distances. The effect can be used in various applications—programming quantum computers, to name one.

Qubit
A qubit, or quantum bit, is the smallest unit of information in a quantum computer, comparable to a bit in classical computers.

Spin
Spin is the rotational momentum and the associated magnetic moment of particles such as electrons. In the case of electrons, spin can have two values: spin up or spin down. In quantum technology, this property is used for data storage and processing.

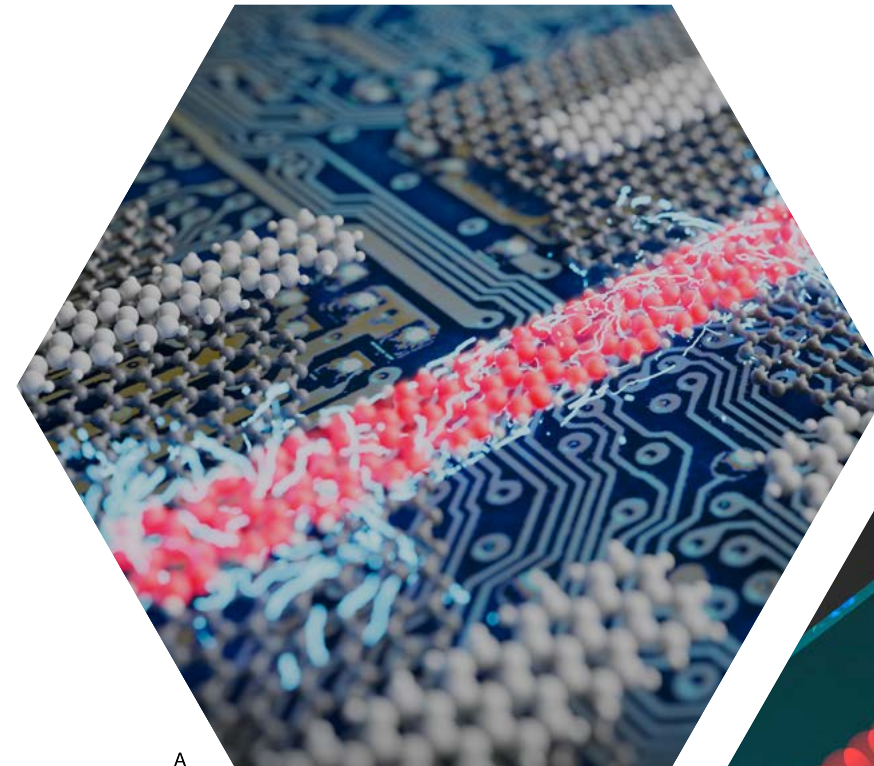
Coherence time
Coherence time is a key parameter in quantum effects. It corresponds to the amount of time a quantum state remains stable before it begins to lose itself in the innumerable possibilities of the quantum world.

Carbon
Carbon is one of the most common and most important elements in living beings and organic molecules. It is also the element capable of forming the greatest variety of chemical bonds.

Graphene
Graphene is a carbon material with a honeycomb structure. It is two-dimensional, consisting of just a thin, single-atom layer.

Graphene nanoribbon
A graphene nanoribbon is a strip of graphene that is only a few atoms wide. The edges of the ribbons can be designed to have interesting quantum mechanical properties; these are the properties that the CarboQuant team want to analyse and refine.

Quantum tunnelling
Quantum mechanical particles like electrons can bridge the distance between two fine pieces of metal if the gap is small enough. This principle is called "quantum tunnelling" and is used in scanning tunnelling microscopy to render images of atomic structures by mapping electron flows.



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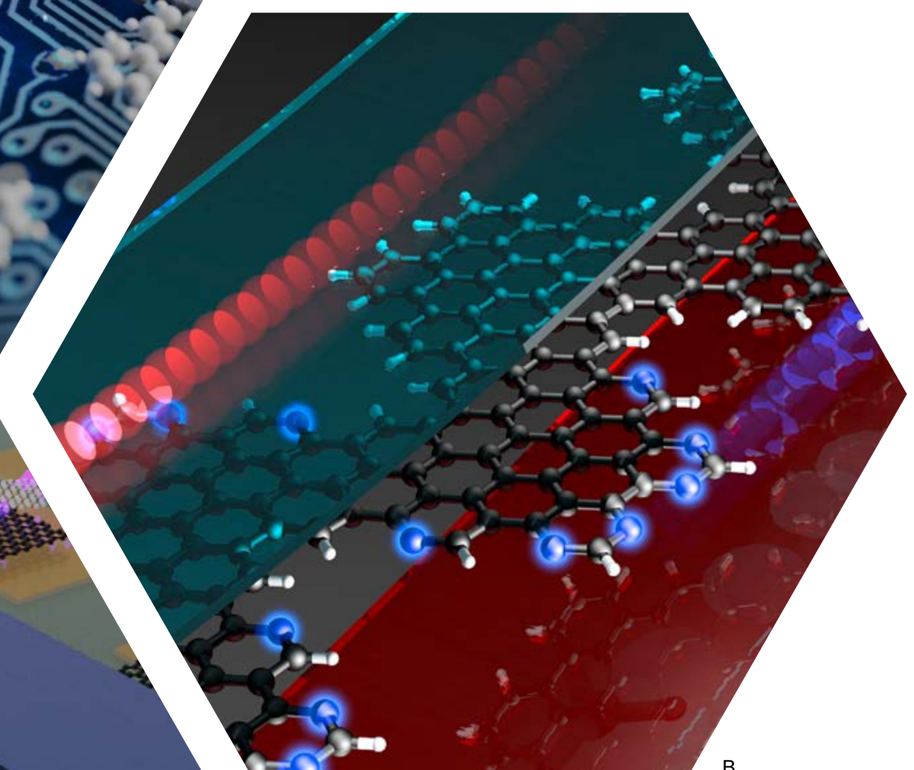

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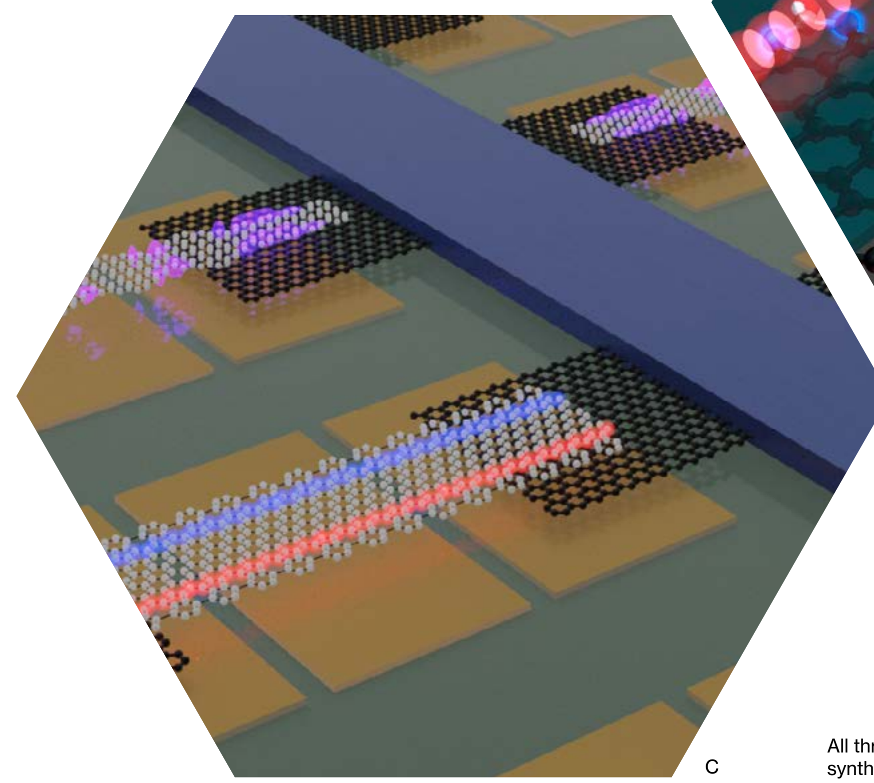

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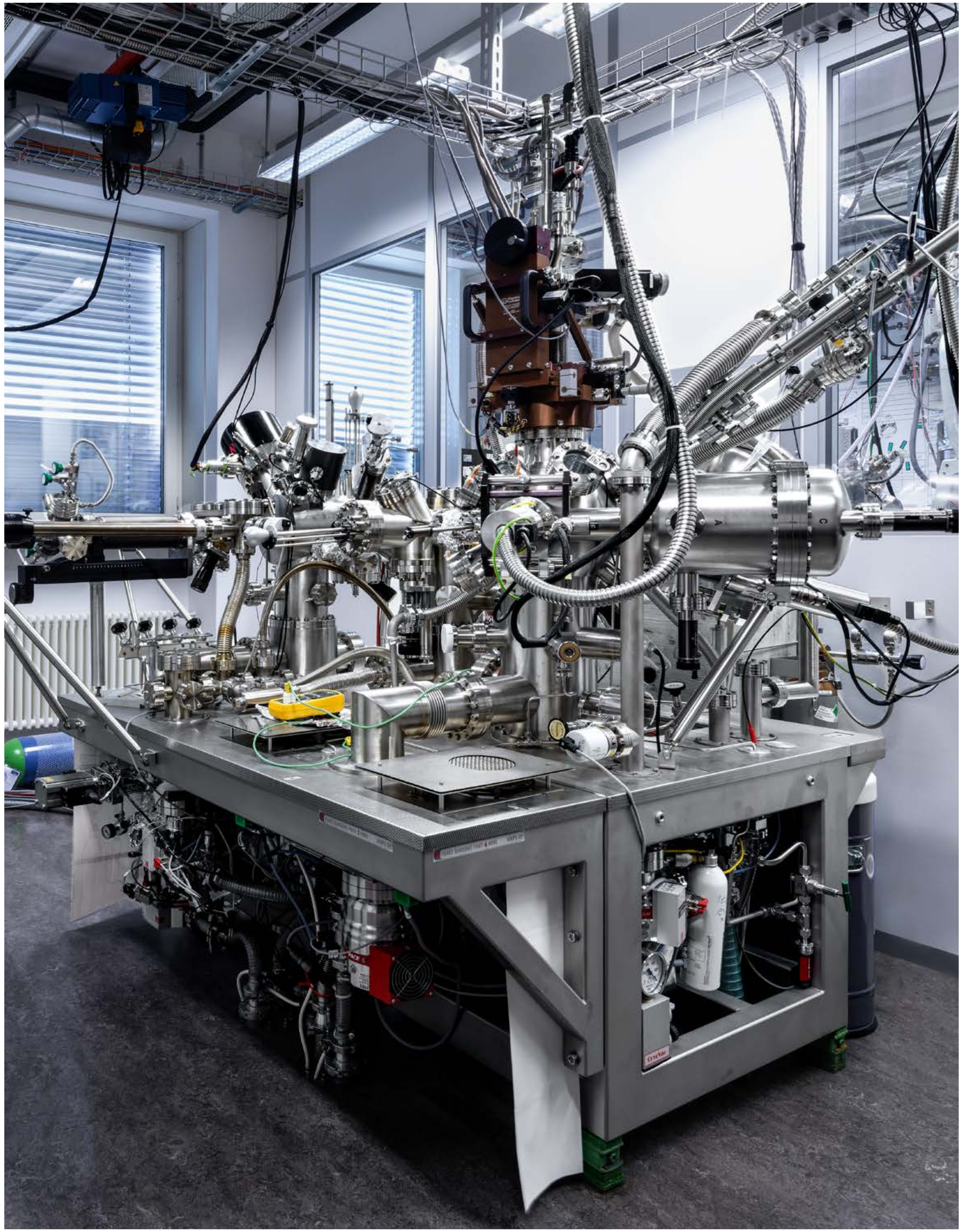
All three images are schematic renderings of carbon nanoribbons synthesised at Empa, the Swiss Federal Laboratories for Materials Science and Technology. (© images: Mickael Perrin, Empa)

Image A visualises the integration of carbon nanoribbons (red) as an active element in an electronic component.

Image B illustrates sections of a carbon nanoribbon that have different chemical compositions. The upper part consists solely of carbon (green); there, electrons are responsible for electrical conductivity. The lower part of the nanoribbon also has nitrogen atoms (blue) in addition to the carbon atoms; here, electrical conductivity functions via the holes.

Image C shows carbon nanoribbons (light-grey structures) in a field-effect transistor architecture between two graphene electrodes.



Facts and figures

Project

The CarboQuant team at the Swiss Federal Laboratories for Materials Science and Technology (Empa) in Dübendorf near Zurich aim to establish a methodology and an infrastructure to further develop carbon nanostructures whose quantum effects can be used for electronic components. The overall goal is to develop quantum electronic components that function at room temperature and that can be used for everyday purposes.

Support

The Werner Siemens Foundation is financing the infrastructure and the salaries of specialists and junior researchers in the CarboQuant project; the funding also covers material costs.

Funding from the Werner Siemens Foundation

15 million euros over 10 years

Project duration

2022 to 2032

Project leader

Prof. Dr Roman Fasel, Adjunct Professor at the Department of Chemistry, Biochemistry and Pharmaceutical Sciences at the University of Bern and Head of nanotech@surfaces Laboratory at the Swiss Federal Laboratories for Materials Science and Technology (Empa), Dübendorf, Switzerland

Collaboration in organic synthesis

Technische Universität Dresden, Germany; Max Planck Institute for Polymer Research, Mainz, Germany; Nagoya University, Nagoya, Japan

Collaboration in nanofabrication, characterisation and quantum computers

Binnig and Rohrer Nanotechnology Center, Rüschlikon, Switzerland; Technical University, Delft, Netherlands; University of California, Berkeley, USA

Collaboration in theory and simulations

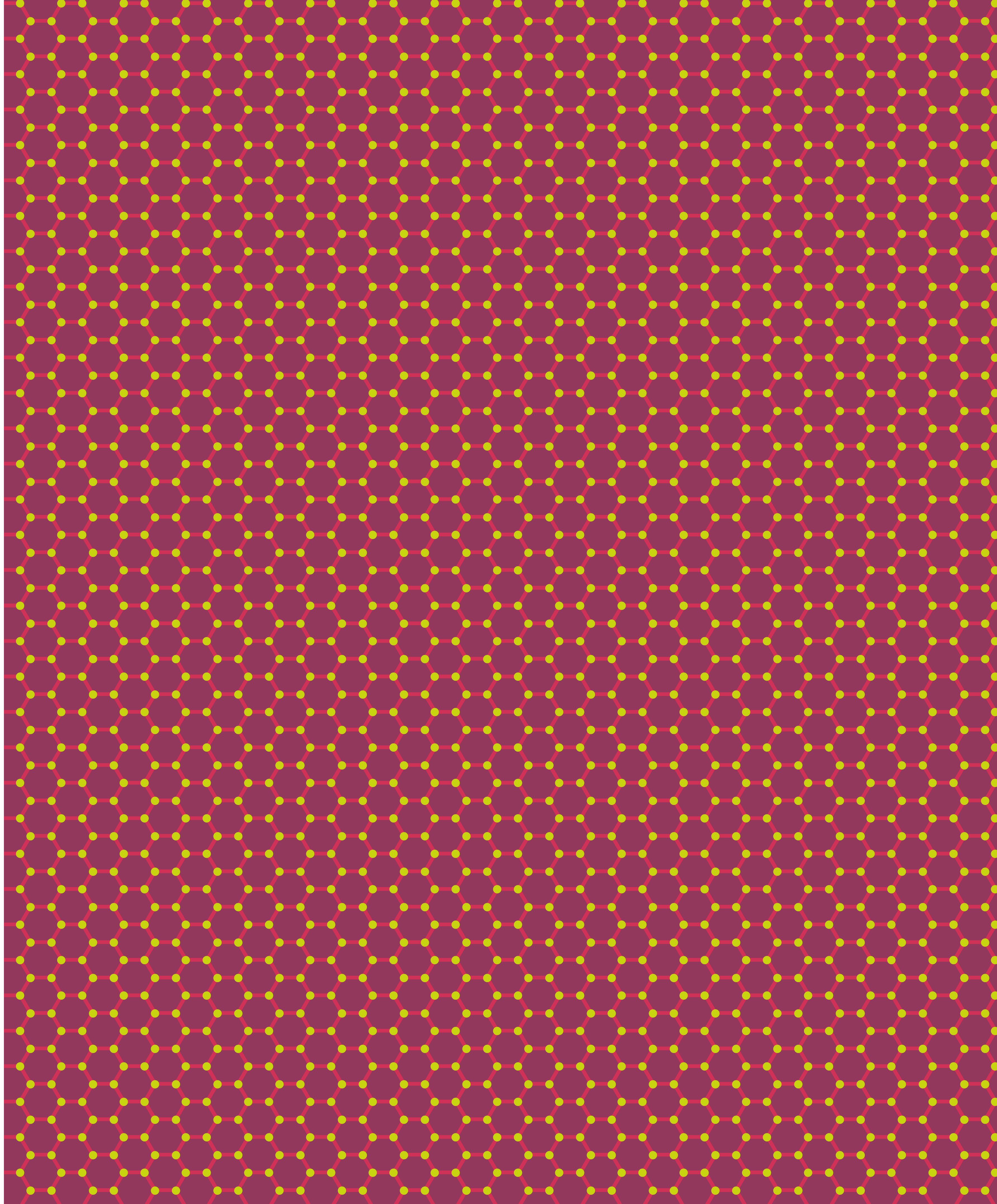
International Iberian Nanotechnology Laboratory (INL), Braga, Portugal; Rensselaer Polytechnic Institute, Troy, USA

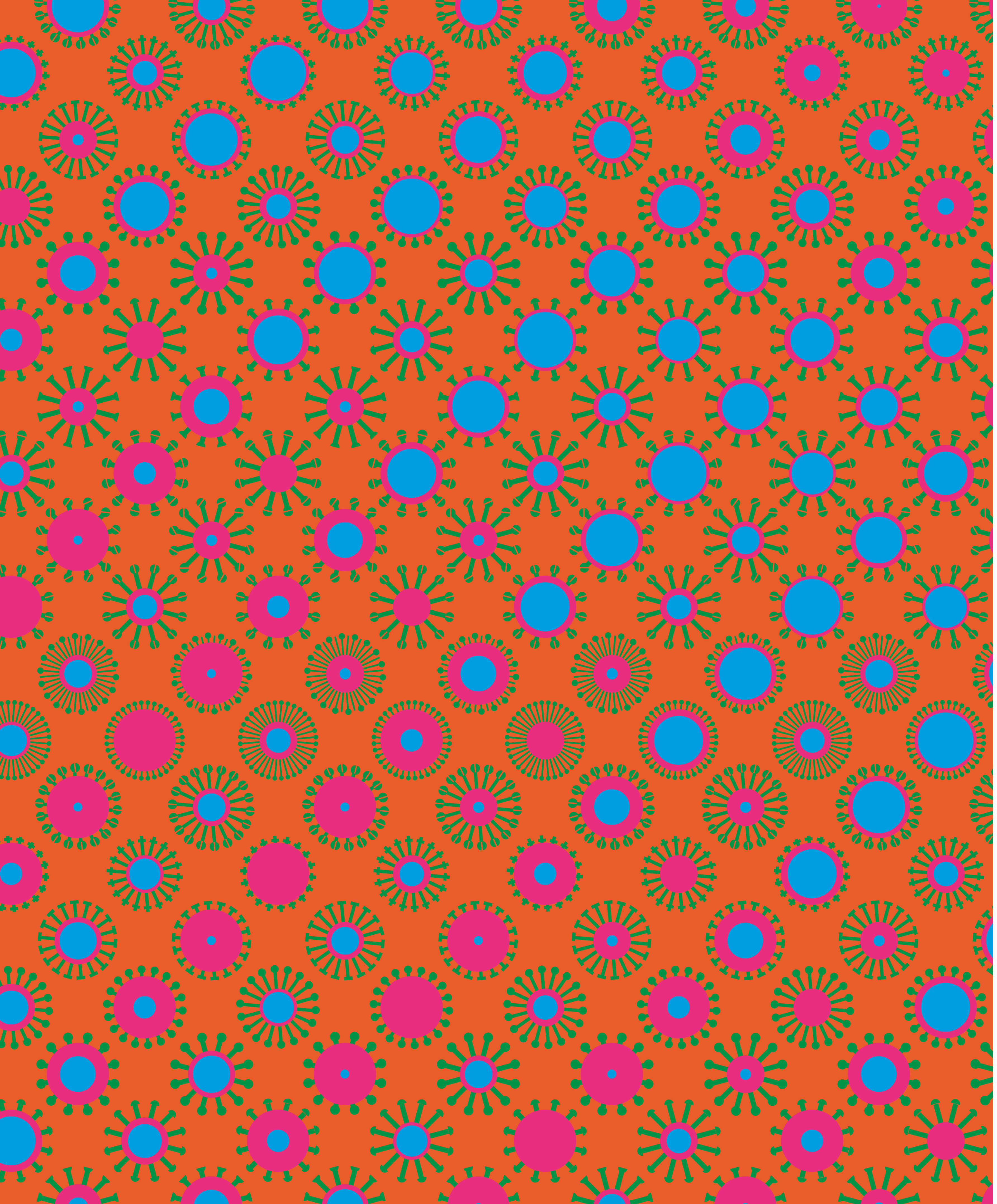
A mammoth system for minuscule atoms: the ultra-high vacuum unit with scanning tunnelling microscopy and a photoelectron spectrometer enables researchers to study the chemical and electronic properties of a material sample at the level of the atom.

quantum mechanical carbon based quotidian

Innovation

The Werner Siemens Foundation is supporting the CarboQuant project at Empa—because recent scientific advances have made the development of nanomaterials for quantum electronic components that function at room temperature feasible. Next-generation quantum computers could then be used for everyday purposes.





Double trouble for viruses

Establishment of the Werner Siemens Foundation Center for Antivirals Research at EPFL

Catch and squeeze—and the virus is gone, just like that. This is far from being a joke, even if the novel approach to fighting viral infections is modelled using a comical-looking orange plastic ball. The innovative method has proven so effective against certain virus types that it is now being further developed at the École polytechnique fédérale de Lausanne.

Lausanne one, virus nil

Francesco Stellacci, professor at the École polytechnique fédérale de Lausanne, envisions a two-pronged approach to treating viral infections of any kind: should a virus manage to evade his novel broad-spectrum drug, a tailor-made antiviral will step in to finish the job. Thanks to the Werner Siemens Foundation, Stellacci can now set up a new research centre to realise his innovative strategy.

Materials scientist Francesco Stellacci is taking aim at viruses. With his interdisciplinary team, he wants to develop not only a broad-spectrum drug to treat viral infections but also an antiviral agent capable of targeting specific diseases.

The coronavirus pandemic has changed our lives—a statement that rings doubly true for Francesco Stellacci, professor of materials science at the École polytechnique fédérale de Lausanne (EPFL). Like the rest of us, he has been forced to come to terms with the pandemic as a private individual. But the situation has also had a major impact on his professional life. Indeed, before the pandemic, people often looked somewhat askance when Stellacci talked about his research focus of the past ten years: developing a broad-based antiviral drug. Is that even possible, they wanted to know. And aren't vaccines more important?

Since the advent of the novel coronavirus, however, Stellacci's idea of a broad-based antiviral drug has gained significant traction. To be sure, the international research community attained unprecedented success in developing vaccines against Sars-CoV-2, and that in record time. Nevertheless, it remains unclear whether the vaccines will offer protection against all new variants of the coronavirus.

Broad-spectrum antiviral drugs

Also far from certain is whether the research community will be able to produce a vaccine as quickly during the next pandemic. "That's why it's important that we also seek drugs that are effective against viruses in addition to developing vaccines," says Stellacci. An antiviral that can treat a wide range of virus infections would not only save human lives: it would also preserve the world from reliving the chaos of the past year should another pandemic arise.

Thanks to funding from the Werner Siemens Foundation, Stellacci and his team at the EPFL Supramolecular Nanomaterials and Interfaces Laboratory can now dedicate their energies to developing a broad-spectrum antiviral drug. Their collaboration partners include specialists in virology and infectious diseases at the University of Geneva and the Geneva University Hospitals.

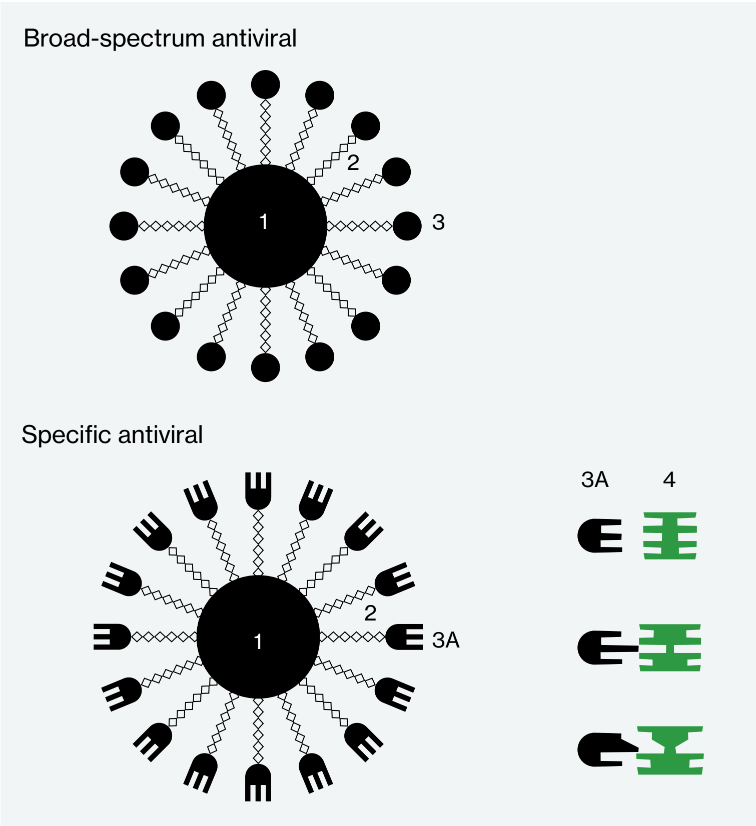
Lausanne takes the lead

To create their drug, the researchers take specific sugar molecules and modify them so that they can outsmart a virus. The method is as follows: the altered molecules pretend to be parts of a human cell, whereupon the virus is tricked into bonding with these "dummy" cells—a fatal error, because the sugar molecules are equipped with "tentacles" that exert so much pressure on the virus that it explodes. Unlike existing antiviral drugs, this approach both inhibits reproduction and irreversibly destroys the virus. The score is now Lausanne one, virus nil.

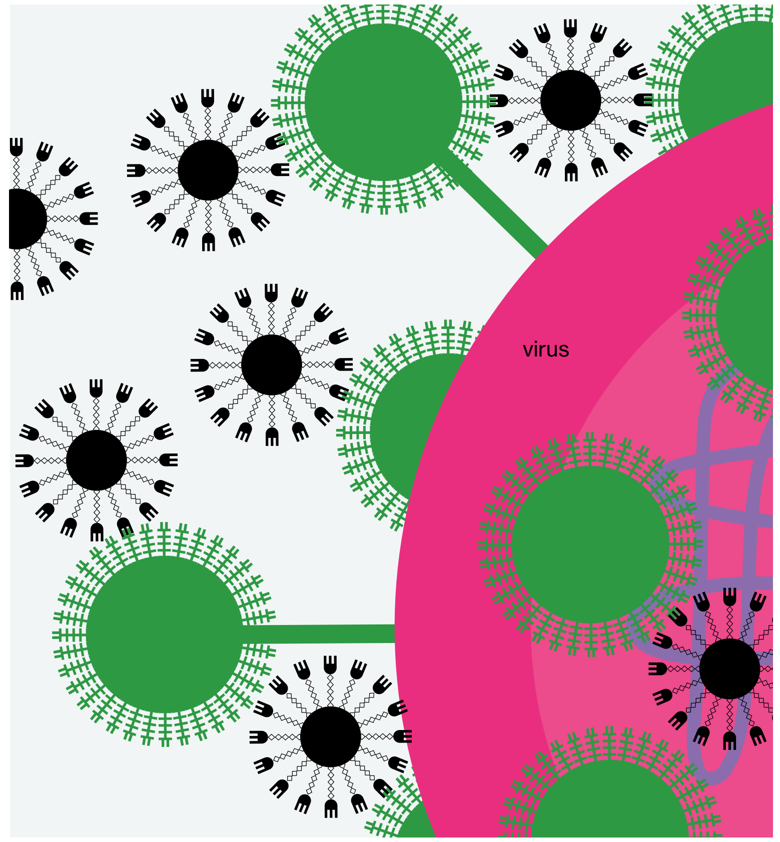
Since the spring of 2020, Stellacci and his team have developed two versions of a broad-spectrum antiviral agent, as the researchers need two different types of sugar molecules to function as the dummy cells in order to lure as many different virus types as possible into latching on to the molecules, where they are squeezed until they burst. The first agent is designed to treat Covid-19, Zika, Dengue fever and other viral diseases. The second agent specifically aims to combat the many different kinds of influenza viruses.

Initial test results are encouraging

Both agents were already so far advanced in 2020 that initial studies on animals would have been possible. However, the



1 Modified sugar molecule
2 Tentacles
3 Universal docking sites
3A Specific docking sites
4 Docking sites on the virus



The specific antiviral (black) latches on to the virus precisely using a lock-and-key principle.

experiments were delayed, because the external project partners were busy conducting tests for Covid-19 vaccines. The trials finally began in May 2021, and the novel agents were tested for both safety and efficacy.

The initial results are promising. The agent designed to treat influenza has a significant advantage over Tamiflu, the most effective flu drug developed to date. Tamiflu is effective only when taken within thirty-six hours of being infected, but the first flu symptoms generally present roughly twenty-four hours after infection. “By the time a patient seeks medical help and receives Tamiflu, it’s often already too late,” Stellacci says. The agent developed by his team remains effective even later in the course of a disease, making it much more suitable for medical care.

The agent has also been tested against Sars-CoV-2 and related viruses. Its toxicology levels were safe in initial tests on animals, and its efficacy results very encouraging. The aim is to have completed extensive tests of both broad-spectrum agents in animal models by 2023 so that clinical trials can begin.

A specific antiviral

After awarding Stellacci a one-year grant in 2020, the Werner Siemens Foundation decided to provide long-term funding for his innovative project. This financial support is what made it possible for Stellacci in 2021 to turn his attention to realising another of his visionary projects. To protect humans (as well as animals and plants) from viral diseases we need more than broad-spectrum antiviral drugs. The situation is similar to bacterial diseases, as Stellacci explains: “Even the best broad-spectrum antibiotic isn’t effective against every kind of bacteria.” Serious bacterial infections are first treated with a broad-spectrum antibiotic, generally penicillin, and patients often require no further treatment. But if they fail to recover, the exact pathogen is identified in the lab, and patients receive an antibiotic that is effective against this specific strain of bacteria.

Stellacci envisions a similar approach to treating viral diseases: first the patient should be given a broad-spectrum antiviral. If this fails to bring about the desired results, the virus type is identified in the lab and the patient then receives a specific antiviral drug.

To develop specific antiviral drugs, the researchers are aiming to create a standardised procedure that will enable them to produce effective agents for both already known viruses and emerging viruses within a short time span. The coronavirus pandemic has placed this need in sharp relief: although vaccines were developed very quickly, finding drugs that are effective in treating Covid-19 has proven much more elusive.

Learning from the body’s own defence mechanisms

To realise his vision of a specific antiviral, Francesco Stellacci plans to combine two approaches. The first is his broad-spectrum antiviral drug that applies mechanical pressure to destroy viruses. The second concerns developing a specific antiviral drug based on the most effective way to combat viruses that evolution has come up with: antibodies. The great advantage of antibodies is that they have the right shape to bind to specific parts of a virus, akin to how the right key fits into a lock. Once antibodies have latched on to a virus, its binding sites are occupied and it can no longer infect human cells.

Antibodies for every kind of virus can be taken from the blood of people who have recovered from a virus—and we are lucky to have antibodies for all viral infections, as the human race has so far survived every disease caused by a virus. For instance, the plasma of recuperated Covid-19 patients was used to develop Sars-CoV-2 vaccines. Francesco Stellacci is convinced that antiviral drugs can be built using the same principle: “We’ve rarely taken advantage of this possibility, and there are currently only very few antibody-based drugs for treating viral infections.”

Tentacles combined with antibodies

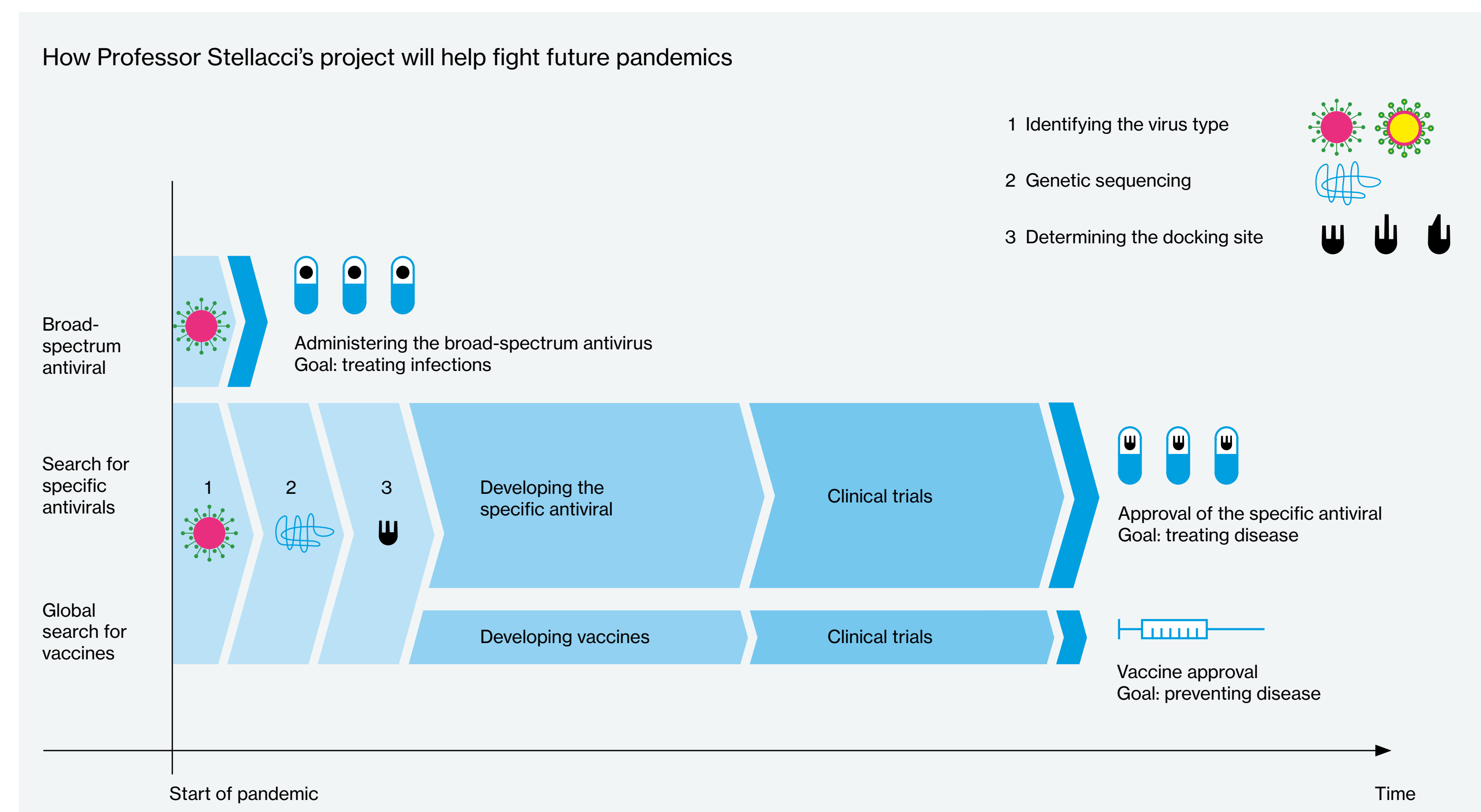
Like the broad-spectrum antivirals, Stellacci’s specific antiviral drugs will consist of modified sugar molecules and tentacles. The difference is that they will also contain a part of the antibody that binds to the specific virus (see diagram page 50). This is how the researchers can exploit the advantages of antibodies while also avoiding their drawbacks, the greatest of which being that antibodies block viruses rather than destroying them. In Stellacci’s model, the sugar molecule and its tentacles are responsible for the task of irreversibly damaging the virus. The result will be an agent that combines the antibody’s precise binding to a virus with the capacity to destroy the pathogens. That would make the score Lausanne two, virus nil.

To prevent the viruses from becoming resistant to an agent (as is increasingly the case with antibiotic drugs) the specific antivirals are designed to target what is known as the “conserved parts” of a virus. These parts of a virus rarely mutate, as they are so essential to its survival. Once an agent binds to this critical site, the virus cannot easily free itself by mutating, thus increasing the probability that the agent will retain its efficacy for a long time.

A new research centre

Stellacci plans to use the long-term funding from the Werner Siemens Foundation to set up a centre of excellence at EPFL: The Werner Siemens Foundation Center for Antivirals Research. The centre’s ambitious goal is to ensure that an agent to treat a new viral disease is ready for clinical trials just six months after the virus’s genome has been sequenced. A standardised method for creating different specific agents is what will make this possible. The approach will also facilitate an efficient supply of antiviral agents for patients in Switzerland and Europe.

Francesco Stellacci and his team now have until 2023 to prove their concept. By then, they plan to have tested not only the broad-spectrum agents but also the first specific antiviral agents in animal models. In addition, they will submit a detailed strategy for establishing the Werner Siemens Foundation Center for Antivirals Research.



How long it will take to develop antivirals and vaccines is difficult to predict. The data in the diagram are based on the assumption that a broad-spectrum antiviral will be developed before the next pandemic begins.

“Our virus centre will be part of a global network”

Francesco Stellacci is certain that future pandemics are unavoidable. To be prepared, innovative research as well as collaboration on a global scale are necessary—for example, at the future Werner Siemens Foundation Center for Antivirals Research, whose setup is financed by the Werner Siemens Foundation.

He began testing his innovative antiviral agents thanks to support from the Werner Siemens Foundation: project leader Francesco Stellacci on campus at the École polytechnique fédérale de Lausanne (EPFL), where he plans to set up the future viral research centre.

Professor Stellacci, how have you experienced the pandemic year 2021?

Francesco Stellacci: It’s been a difficult year for us all. On the positive side, we’ve probably learned more about the Sars-CoV-2 virus than about any other virus. And that in record time. The virus first appeared in December 2019 and by the spring of 2020, its genome had already been sequenced and antibodies identified. No one would have believed the global research community capable of such rapid and coordinated action. I assume that this will happen even more quickly with emerging novel viruses than it did with the coronavirus—now we have both experience and an infrastructure that didn’t exist before the pandemic.

We now have vaccines for Sars-CoV-2. Is it still important that we find drugs to treat it?

A vaccination is always the top priority when we’re dealing with viral diseases. But we shouldn’t forget that people all over the world will never be vaccinated at the same rate. In Africa, for example, it will take a long time—if it ever happens—before everyone who wants to be immunised has received a shot. And the risks surrounding testing vaccines on humans would be less dangerous if drugs for treating a viral infection were already available. These medications give us time to develop a vaccine, although it should be noted that there are still many viruses for which no vaccine exists—HIV to name one. And while the vaccines for the coronavirus are incredibly effective, that’s in no way the case for all vaccines. What would happen if the next pandemic were caused by a virus that is as effective at evading vaccines as HIV? These are all reasons why antiviral drugs will remain important.

Do you think we have to expect future pandemics?

Certainly. Since the 1970s, we’ve been dealing roughly every four years with an epidemic or pandemic caused by new viruses—from HIV to the coronavirus. The growth in the world’s population and globalisation are the root causes, and they’re also the reason why epidemics or pandemics will probably occur even more frequently in future. And while many viruses could be the trigger, the greatest danger is posed by those viruses that cause respiratory diseases: they’re airborne, so it’s more difficult to protect ourselves against them. In my opinion, the next pandemic will most likely be caused by influenza viruses, as they reappear every year with slight mutations. It’s also possible that the coronavirus will stay with us in a similar way.

How can we prepare ourselves for pandemics?

There’s an urgent need to convene on a global level and to discuss future ways of dealing with this kind of situation. We need to ask ourselves how we should proceed when a pandemic is on the horizon and how we should organise the division of labour. It’s crucial that we plan ahead and better anticipate what threats might come our way. And we need more research on viruses. To date, there are still only a few specific antiviral drugs, and developing new agents remains time intensive. This has to change.

You want to establish a centre for antiviral research at EPFL. What will it look like?

Currently, we’re working on defining the new centre. We have until 2023 to formulate our vision and present a concept that the Werner Siemens Foundation can decide on. The motivation is clear: in the history of medicine, viral diseases have been neglected for far too long. This is seen in the fact that there are numerous cancer research centres in Europe, yet only a few institutions dedicated to researching viruses. The new EPFL centre will help close this gap. We want to become a major viral research centre in Europe and to create global networks and platforms for knowledge exchange. Our goal is to win the fight against future pandemics and to treat dangerous viral infections.

Why is Lausanne the right place?

Several EPFL research groups have already expressed interest in working at this kind of a centre. Among them are groups already active in researching viruses, but there are also those that would like to enter this field with new ideas. This means that, in addition to my group’s approach, the new centre would also pursue other strategies to combat viruses. It’s a fantastic constellation, because we need a diversity of ideas to increase our chances of success—the goal of fighting viruses is too important to put all our eggs in one basket. And if we succeed in attracting other backers in addition to the Werner Siemens Foundation, we can extend our work to researching areas beyond developing antiviral drugs—like vaccines against viral infections, for example.

If all goes well, will you and your colleagues begin setting up the centre in 2023?

Yes, although thanks to the second grant from the Werner Siemens Foundation, which we received in the spring of 2021, we can already start purchasing research equipment and make it available throughout the entire university. This shared facility will unite research groups, and the various groups will have the opportunity to immediately begin testing new ideas for antiviral agents. The best-case scenario is that we’ll already have developed new, promising approaches to combating viruses when we officially open the Werner Siemens Foundation Center for Antivirals Research in 2023.

Facts and figures

Project

Francesco Stellacci is working on antiviral drugs that apply mechanical pressure to destroy viruses. In one part of the project, he and his team are developing broad-spectrum antivirals. In another, the researchers want to produce agents fortified with antibodies that can target specific kinds of viruses.

Support

The Werner Siemens Foundation supported the innovative project in 2020 at the start of the coronavirus pandemic with a one-year grant and approved a second grant in 2021 that will run until 2023. By then, broad-spectrum antiviral drugs should be ready for clinical trials and the researchers able to deliver proof that a standardised production of antiviral drugs to combat specific viruses is feasible. At the same time, the team will also submit a detailed proposal for a Werner Siemens Foundation Center for Antivirals Research at the École polytechnique fédérale de Lausanne (EPFL).

Funding from the Werner Siemens Foundation

5 million Swiss francs (2020–2021)
4.5 million Swiss francs (2021–2023)

Project duration

2020 to 2023

Project leader

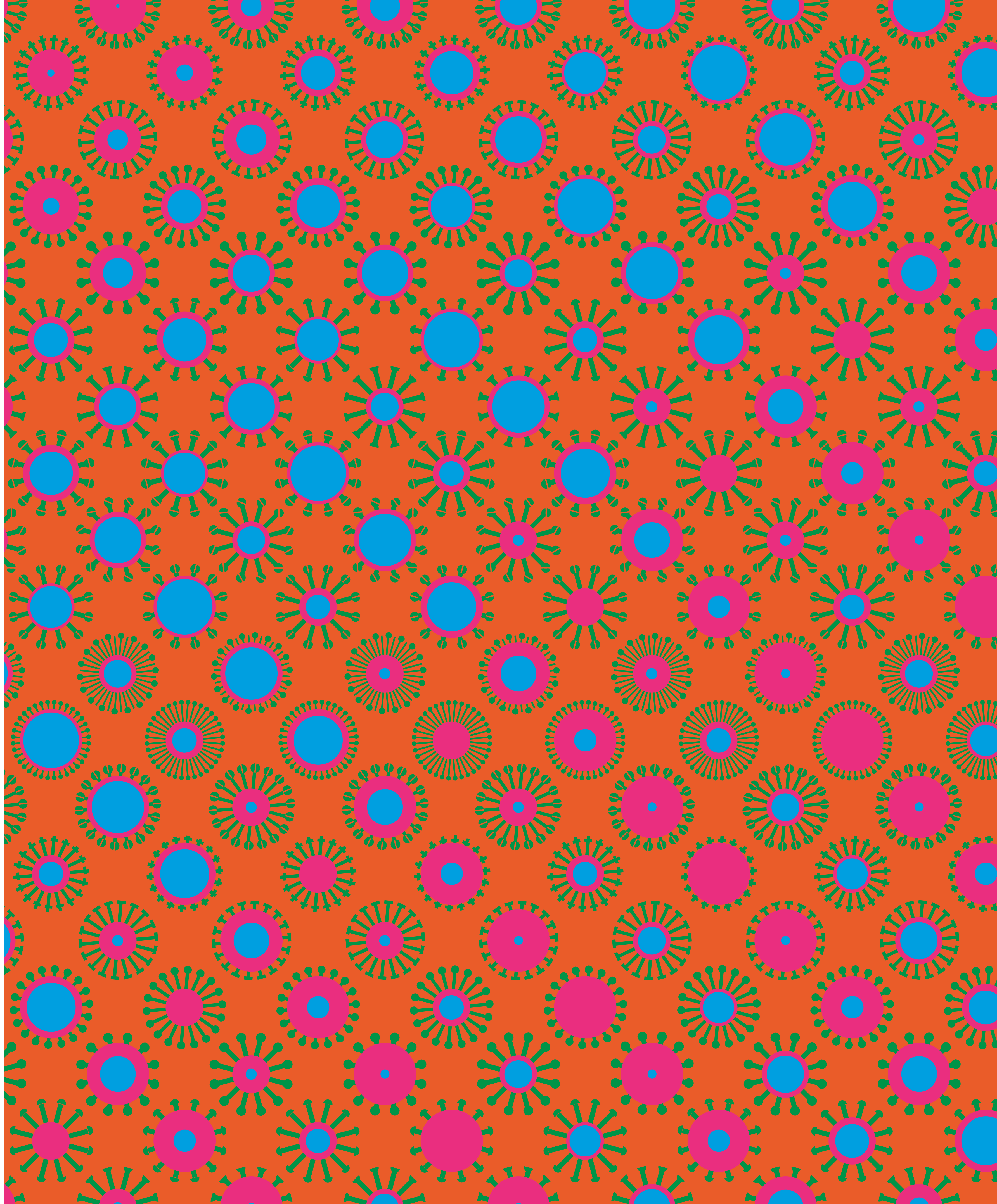
Prof. Dr Francesco Stellacci, Supramolecular Nanomaterials and Interfaces Laboratory, Institute of Materials, École polytechnique fédérale de Lausanne (EPFL), Switzerland

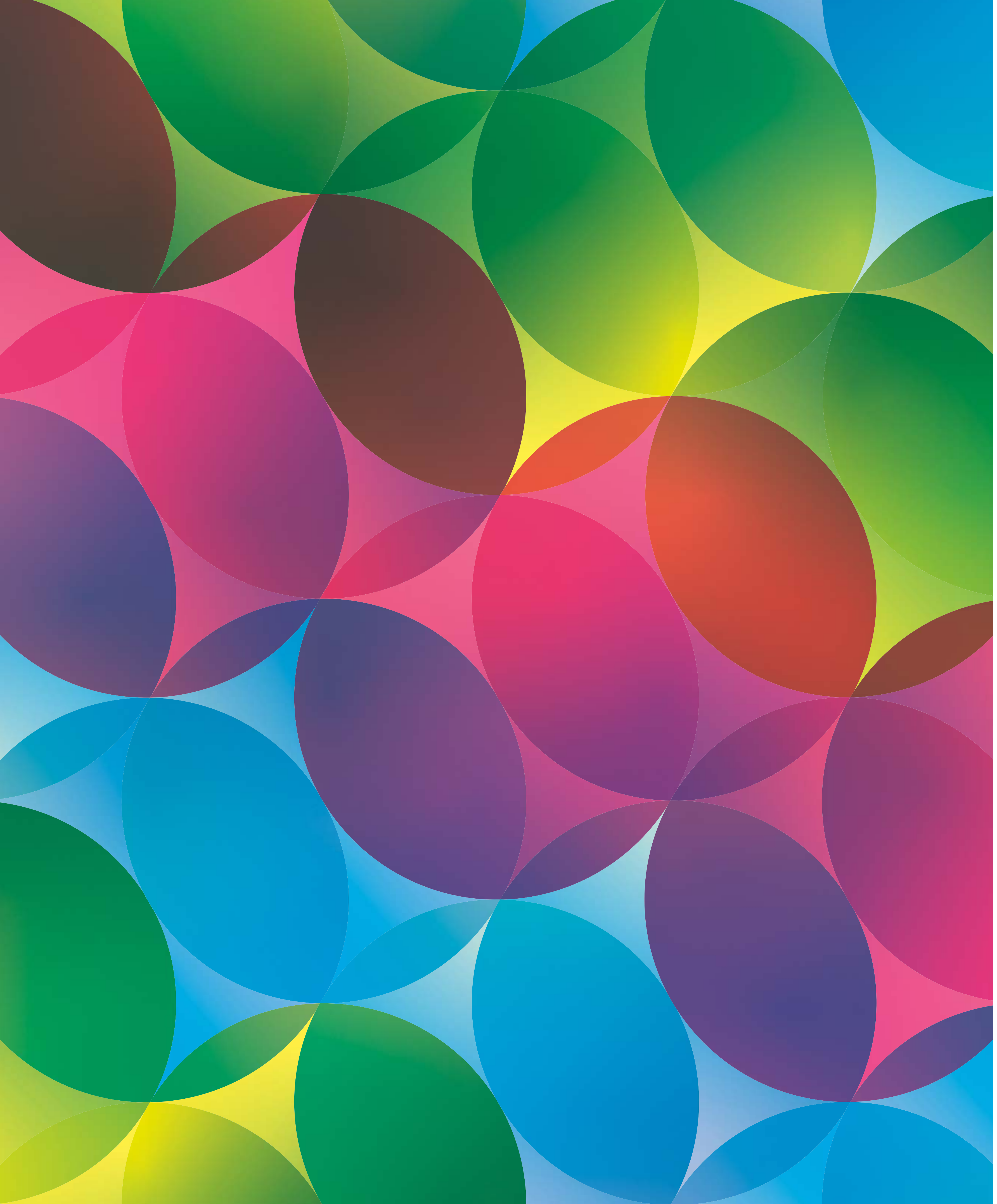
Several virus types continue to pose a danger to humans and animals to this day. At the Werner Siemens Foundation Center for Antivirals Research, which is scheduled to open in 2023, virus researchers from all corners of the globe will contribute their expertise so that, in future, dangerous viruses can be brought under control quickly and effectively.

general specific standardised

Innovation

The Werner Siemens Foundation is supporting the novel approach taken by Francesco Stellacci and his team for developing antiviral agents. And research into viruses can be intensified thanks to the establishment of the Werner Siemens Foundation Center for Antivirals Research at EPFL—because it is crucial that we are better protected against dangerous viral infections and better prepared for future pandemics.





All inclusive: MIRACLE II

Minimally invasive bone surgery using laser technology and now: the development of intelligent bioimplants

An unusual sculpture graces the 3D Print Lab at the University Hospital Basel, proving that top-notch researchers are also up for some light-hearted fun. The spooky structure calls to mind ghostly hands bearing a message from beyond: nothing is impossible here—soon, the lab's 3D printers will even fabricate made-to-measure bone implants for ghosts.
A miracle? MIRACLE II.

All in sight, all under control

The various robotic components developed are already well aligned: the medical "joystick" detects where on the body a surgical intervention is necessary, and the surgeon, wearing 3D goggles, views a virtual 3D model constructed on the basis of CT scans.

With their innovative robot-guided laser, the MIRACLE II team at the University of Basel and the University Hospital Basel are aiming to make minimally invasive surgery on bones and cartilage a reality. Their smart system of interacting robots—ranging from a large robotic arm to a tiny endoscopic laser scalpel—is already being tested for first applications in knee surgery. In addition, the researchers are working to develop 3D-printed bone implants that can be inserted using minimally invasive techniques.

Every patient undergoing an operation hopes for a simple intervention with no large incisions. In minimally invasive procedures, surgeons operate using endoscopes inserted through tiny incisions in the body, which is less traumatic for the patient and promotes swifter recovery. Since 2014, researchers in the MIRACLE project have been working to make minimally invasive surgery possible on bones. To this end, the team at the University of Basel and the University Hospital Basel are developing an integrated, smart system of robots that can cut bones gently and safely.

Four research groups in MIRACLE II

Based on the considerable success of the first project phase, the Werner Siemens Foundation has awarded the MIRACLE team funding for a further six years. As in the first phase, MIRACLE II will be led by Philippe Cattin, Professor of Image-Guided Therapy and Head of the Department of Biomedical Engineering (DBE) at the University of Basel and the University Hospital Basel. Cattin leads the project's navigation group, which is tasked with preparing 3D-rendered models of CT scans for use in operations. The laser group, currently led by Azhar Zam, and the robotics group led by Georg Rauter are also remaining on board for the project's second phase.

New to the team is clinician Florian Thieringer, an oral and cranio-maxillofacial surgeon at the University Hospital Basel, who also leads the DBE research group Medical Additive Manufacturing (Swiss MAM). The new co-leader of MIRACLE II is head of the fourth group in the project: "Smart Implants". Indeed, bone incisions are only one element of bone surgery—after that, damaged sections of bone must be stabilised with a well-fitting implant. For this reason, Thieringer and his research group are seeking ways to customise bone implants for individual patients and insert them using the least invasive surgery techniques possible (see interview on page 66).

The integrated robot

In the first project phase, Georg Rauter's team succeeded in developing the various robotic components, which were united in an integrated robot system in 2021. The base component, an approximately 1.5-metre robotic arm, is mounted on a guide rail next to or above the operating table so it can be moved into position over the part of the body requiring surgery. At the top of the robot arm are the motors powering the delicate surgical instruments to be inserted in the body: these include a flexible, six-jointed robotic endoscope that guides the laser to the surgery site, and the laser scalpel itself—a miniature robot that can latch on to the bone with two tiny "arms" and make incisions to the precision of one-tenth of a millimetre.

The researchers have also made great progress on the actual laser. When making incisions, it can now simultaneously monitor incision depth and differentiate between bone and soft tissue. Azhar Zam and his team of laser physicists made this development possible by using three different laser sources: one that cuts, and two that characterise tissue. The researchers synchronised the three light sources using a combination of shutters, mirrors and a controlling software program. Their next challenge is to miniaturise the system so that the laser beams can be channelled from a compact source through glass fibres into the endoscope tip.

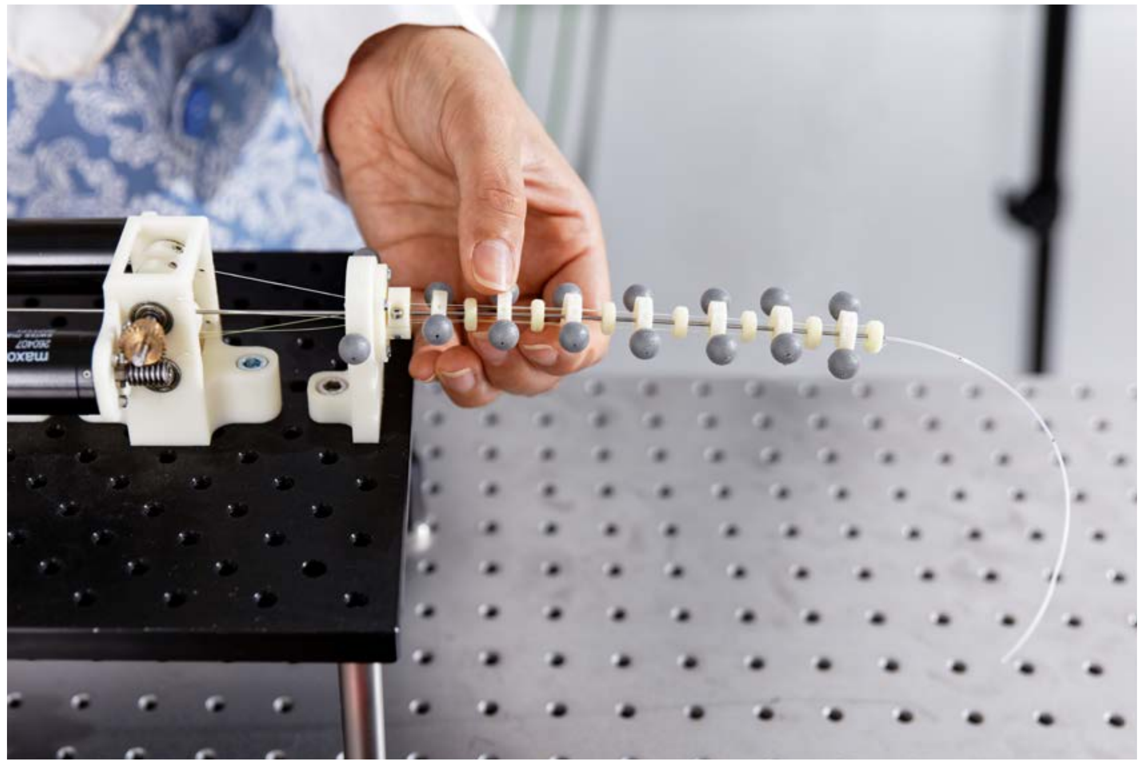
First applications in knee surgery

The MIRACLE II team are already testing the application for use in knee surgery. "The knee is the largest joint in the body with the thickest bones," explains Georg Rauter, head of the robotics group. "This makes it a good candidate for testing: if we can make minimally invasive incisions in knee bones, we can do it elsewhere, too." The system may also prove useful in repairing knee cartilage. To develop such real-world applications, the researchers are working with various partners, including surgeons from the University Hospital Basel.

Meanwhile, the researchers are continually enhancing the capabilities of the various robotics components. In one development, the endoscope is capable of automatically following a specific point thanks to a tiny camera and a clever algorithm. In practice, the focal point is determined by the surgeons—in case the patient moves or is nudged during an operation, or in case the endoscope is required to observe the point from a different angle while also keeping it in constant focus.

Intuitive handling

It is not enough, however, that the robot system functions well: of equal importance is its handling. Specialists must be able to control the robot system with ease, despite its wide range of movement capabilities—a key concern for Georg



Numerous sensors will enable high-precision control over the robotic components during a surgical intervention.

Rauter and his team. Their solution lies in a novel intuitive kinematic system, a type of interactive lever on the robot arm. In the lab, postdoctoral researcher Nicolas Gerig demonstrates how the machine is used at the operating table. Using the lever, he guides the endoscope gently from the breast of a skeleton "patient" down to its left knee. Because the robot arm weighs a hefty eleven kilograms, the researchers have integrated a sophisticated software program that translates the readings from the remote control's force sensors into the correct actions. Indeed, no surgeon has the strength to manoeuvre such a heavy apparatus unassisted during an operation.

Augmented reality leads the way

But the researchers are not stopping there: the MIRACLE II team have also integrated the robot into the augmented reality (AR) system developed by Philippe Cattin's navigation group. The system renders patient CT scans as virtual 3D models; using special data goggles, physicians can then explore the models to plan surgical interventions. In the long term, the aim is to use these 3D images directly during an operation, which is why Cattin and his group are exploring ways to use a software program to project the three-dimensional CT scans automatically and precisely over the patient lying on the operating table. And the team have recently made a significant breakthrough: "It's now possible to steer the robot directly from within the AR environment," explains Cattin. "The surgeons have everything in sight: the robot-guided endoscope, the 3D-rendered CT scans and, of course, the patient."

Every kind of movement must be possible, and every position must be exactly right: testing the robotic arm with the laser scalpel at the endoscope tip, in the MIRACLE II lab in Allschwil near Basel.

Implants from the printer

What properties must an implant have to promote gentle, effective healing in bones? This is the question being addressed by the MIRACLE II research group “Smart Implants” led by Florian Thieringer. The oral and cranio-maxillofacial surgeon is establishing a platform at the University Hospital Basel to provide patients with smart, 3D-printed bone implants that are made to measure. A conversation with the new co-leader of the MIRACLE II project.

Florian Thieringer, the new co-leader of MIRACLE II, wants to develop personalised bone implants that can be inserted in minimally invasive procedures. In the photograph: a titanium jawbone implant inserted through the patient's oral cavity to stabilise a damaged jawbone.

A new clinician has joined the MIRACLE II team: surgeon Florian Thieringer has taken over the role previously held by Hans-Florian Zeilhofer.

Florian Thieringer, with the launch of MIRACLE II, you have taken over the role of project co-leader from Hans-Florian Zeilhofer, who has since been conferred emeritus status. How did you come to join the team?

Florian Thieringer: In the early 2000s, I was studying with Hans-Florian Zeilhofer just as his group started researching how 3D-printed implants could be used to simplify complex operations. One of the most important things I learned in my twenty years of work with him was this: when developing new methods, cross-disciplinary collaboration is indispensable. That’s why it was important to the MIRACLE II team to keep a clinician who regularly operates on patients in the project.

You’re developing 3D printing methods to produce bone implants. Why?

With 3D printers, we can produce implants that are made to measure for an individual patient and a specific operation. We can then use minimally invasive techniques to insert them in the body. For example, I recently operated on a patient whose jawbone had to be stabilised following damage by a tumour. Based on the patient’s CT scans, we were able to design a sleek 3D-printed titanium implant that we could insert directly through the oral cavity, without making any cuts to the face. Smart implants can potentially replace standard implants in many other surgical procedures, too, allowing for minimally invasive procedures that are gentler on the patient.

Are customised implants already in regular use?

Yes, but until now, hospitals, including the University Hospital Basel, have had to order made-to-measure implants from external firms—an expensive and time-consuming process. We want to change that by making customised implants routinely available at our hospital. To this end, we recently purchased a new 3D printer for our in-house 3D Print Lab. It’s a big machine that prints using PEEK (polyether ether ketone), a high-performance polymer that we’ve researched intensively in recent years as a material for implants. Beginning in 2022, we’ll already be able to produce tailor-made implants in just a few hours—and that close to the operating theatre, directly at the point of care. This way, we can integrate smart implants seamlessly into existing treatment processes to benefit as many patients as possible. This approach has already proven successful with the other equipment in our 3D Print Lab.

What have the 3D printers already been used for?

At the University Hospital Basel, we already use our 3D Print Lab to produce surgical templates and patient-specific anatomical models. Such models are excellent tools when planning operations and discussing procedures with patients. Indeed, 3D-printed models are extremely valuable in both medical education and surgical planning: when doctors hold a three-dimensional model in their hands, they literally grasp—in both senses of the word—a patient’s anatomy. Because the 3D Print Lab is now integrated in the treatment processes, physicians can order the required models directly in the central patient information system. In addition, future physicians at the University Hospital already learn

Prompt delivery of 3D-printed anatomical models, surgical templates and, in future, made-to-measure implants: surgeons benefit from the in-house 3D Print Lab at the University Hospital Basel.

The large 3D printer (shown in full size on page 68, at right) can fabricate implants and bone structures that will later dissolve in the body.

during their studies how to translate data from imaging techniques like CT and MRI into a 3D rendering that can be printed. As such, 3D printing has become a standard procedure for us.

What are the next steps?

We're working on various approaches. For instance, we want to investigate the potential of 3D-printed implants in other applications—trauma surgery involving face or head injuries to name one example. Until now, it's taken too long for patient-specific implants to be fabricated and delivered. With our new 3D printer, however, we can make such applications possible. We're also conducting research with the Swiss Federal Institute of Technology Zurich (ETH Zurich) to learn how we can make implants even smaller. Our idea is to fold them like origami figures, allowing us to use the least invasive interventions possible when inserting them in the body. In future, we also want to conduct in-depth research on biological implants. In particular, we want to develop net- or honey-comb-like structures over which bone tissue can regrow and which could be used to promote regeneration in patients who have lost bone mass due to infections. These kinds of bioimplants could even be produced from materials that, after a certain time, are absorbed by the body—in other words, the implants naturally decompose when the patient no longer needs them.

The fine art of 3D printing: when developing its bioimplants, the MIRACLE II project will benefit from the experience gathered at the University Hospital Basel.

Facts and figures

Project

The MIRACLE II teams want to make simple, minimally invasive interventions a reality for a diverse range of bone operations. At the Department of Biomedical Engineering (DBE) at the University of Basel and the University Hospital Basel, they are developing a robot-guided system that cuts bones using laser technology and fabricating 3D-printed bone implants that are custom-made for individual patients.

Support

The Werner Siemens Foundation financed the initial MIRACLE project from 2014 to 2021. Based on the considerable success of the first project phase, the Foundation is also supporting the MIRACLE II project from 2022 to 2027.

Funding from the Werner Siemens Foundation

15.2 million Swiss francs for MIRACLE
12 million Swiss francs for MIRACLE II

Project duration

2015 to 2021 MIRACLE
2022 to 2027 MIRACLE II

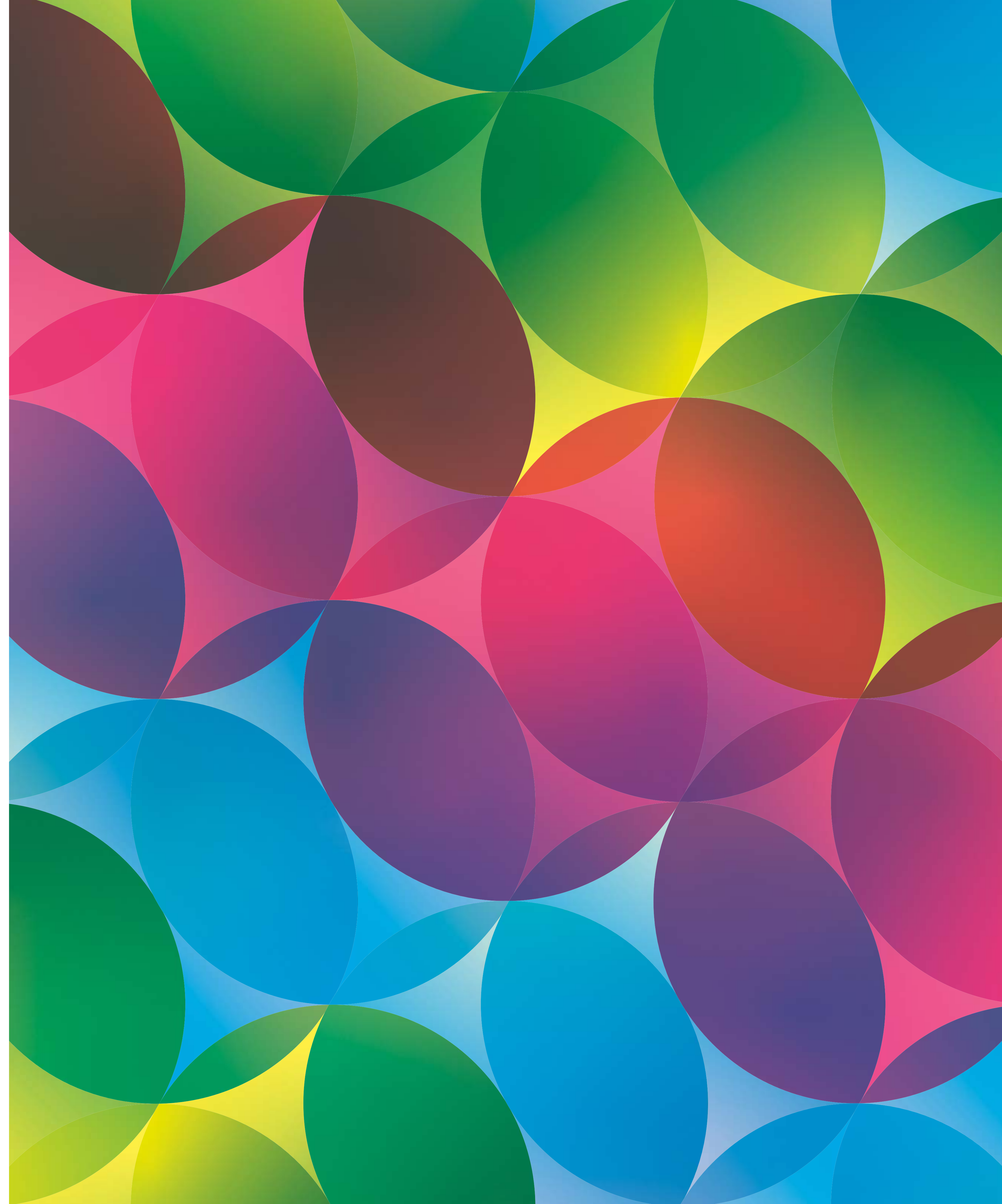
Project leaders

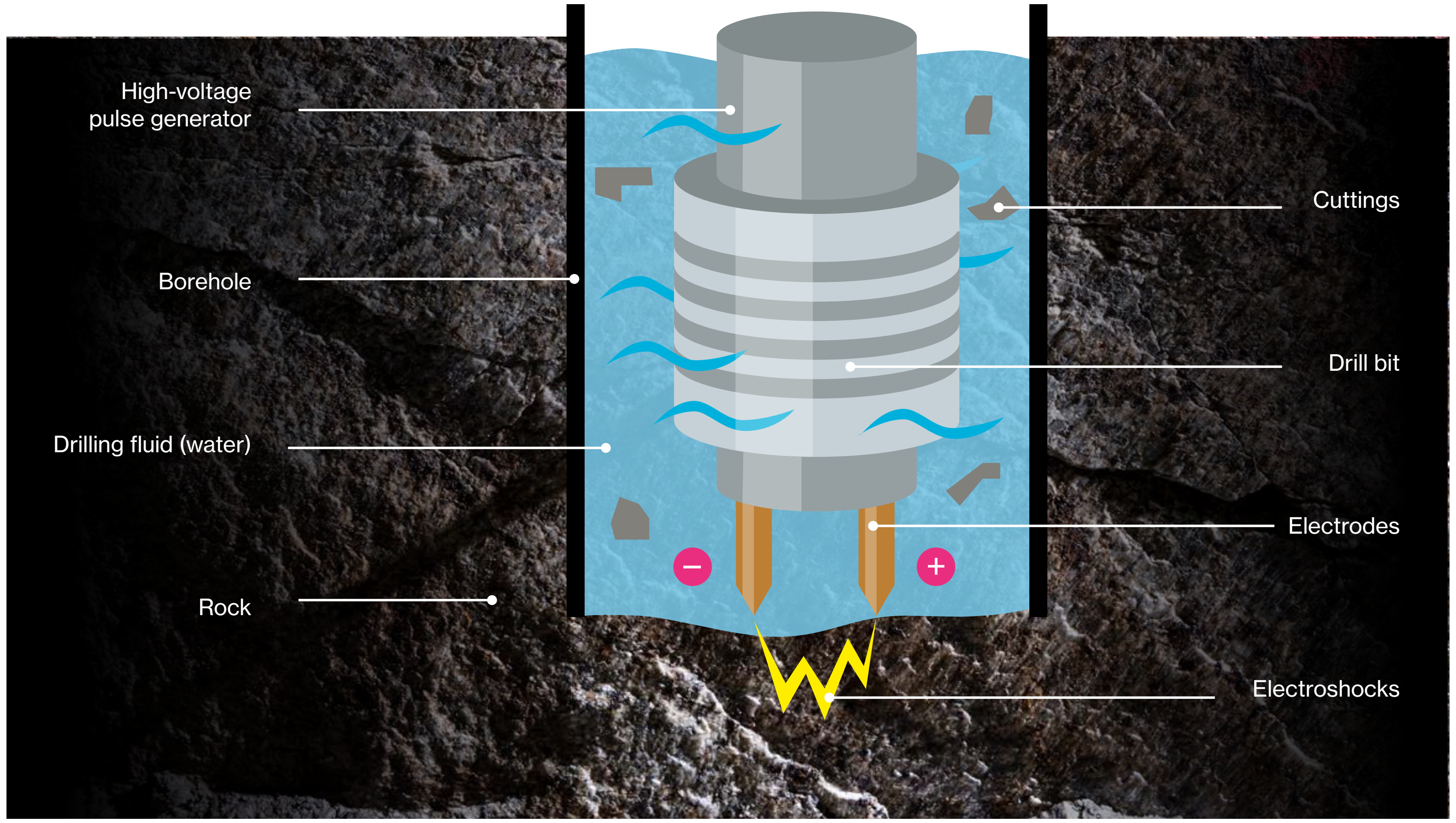
Prof. Dr Philippe Cattin, Professor of Image-Guided Therapy and Head of the Department of Biomedical Engineering (DBE) at the University of Basel, Switzerland
PD Dr. mult. Florian M. Thieringer, Head of Medical Additive Manufacturing (Swiss MAM) and the "Smart Implants" research group at DBE; co-leader of MIRACLE II and of the 3D Print Lab and senior surgeon for oral and cranio-maxillofacial surgery at the University Hospital Basel, Switzerland

patient-friendly minimally invasive made to measure

Innovation

The Werner Siemens Foundation is supporting MIRACLE II—because the goal of the first project phase is in sight: bone surgery that is minimally invasive, robot-aided and computer-controlled. In addition, the MIRACLE II team are developing personalised, 3D-printed implants for use in minimally invasive bone surgery.





Jolts instead of drills: to penetrate rock layers deep in the earth's crust, the electropulse drill generates electric shocks that in speed and intensity are similar to lightning bolts and that create a plasma state in the rock.

Underground lightning bolts

Update: Werner Siemens Endowed Chair "Geothermal Energy and Geofluids" at ETH Zurich

The earth's crust is a gigantic heat reservoir. But accessing this infinite source of energy has proven elusive thus far. Now, however, an electropulse drill developed by geophysicist Martin O. Saar could provide the solution for harnessing the earth's heat—and using it for cost-effective power generation.

The heat pumps and downhole heat exchangers used for heating residential buildings exploit relatively small temperature differences: the underlying principle functions when the fluid in a heat exchanger records just ten degrees—temperatures found already at depths of less than one hundred metres beneath the earth's surface. For large-scale power generation, however, higher temperatures are needed, and this kind of heat is generally found only many kilometres deep in the earth's crust, with the exception of volcanic regions like Iceland.

Researchers have spent decades seeking ways to access the heat in the earth's crust, as there are few areas in the world where underground rock layers are naturally so porous as to enable hot water to be simply pumped up to the surface from a reservoir and subsequently used to generate power. Where the subsurface is impermeable, the rock layers must first be blasted open; as such, harnessing this kind of petrothermal geothermal energy at a depth of five to eight kilometres often relies on triggering artificial, unpredictable earthquakes. A further problem is that underground water is often saturated with salt, which can precipitate (cause deposits) when the water cools, clogging pumps and rock pores. Last but not least, drilling at these depths is hard on the drill bits, which must be replaced on a daily basis.

Electroshock therapy for rock layers

All this has motivated Professor Martin O. Saar to work with his research group at the Swiss Federal Institute of Technology Zurich (ETH Zurich) and their academic and industry partners on the development of new drilling methods. One highly promising technology already undergoing testing is an electropulse or plasma drill, which the team have named Plasma Pulse Geo Drilling (PPGD). With PPGD, brief electric impulses lasting less than 500 nano-seconds are generated by massive jolts of up to 600 000 volts. Two electrodes affixed to the rock surface then act like a massive lightning bolt, engendering a so-called plasma state (the fourth state of matter) in the rock layer. The instantaneous thermal expansion and pressure plasma that result are enough to mechanically break up the rock. This method inverts conventional drilling principles, which apply pressure from above: with PPGD, tensile force is exerted on the rock from below. The major advantage of this approach is that only a quarter of the energy of conventional methods is needed to act on the rock and fracture it.

Downsizing the generator

One current challenge is the size of the pulse generator used to produce the 600 000 volts. At present, it is so large that it needs a shipping container to function as a Faraday cage. Saar aims to reduce the generator's size to a diameter of a mere fifty centimetres, allowing it to be sunk several kilometres into the earth through a narrow borehole. That the pulse generator fit into the borehole is critical, as the electric pulses must be generated directly where the drill bit is located. Were an electric cable to deliver power, the high-voltage pulses would increase too slowly, resulting in a short circuit between the electrodes located in the drilling fluid. Only "high-speed lightning bolts" have the capacity to traverse the rock in the intended arc and to break up the rock from below.

Drilling sideways

Martin O. Saar is already testing the Plasma Pulse Geo Drilling technology in collaboration with SwissGeoPower, a geothermal power plant builder, an undertaking financed by an Innosuisse Grant of the Swiss Innovation Agency. In recent years, SwissGeoPower has made a significant contribution to further developing PPGD; the German Fraunhofer Research Institution for Energy Infrastructures and Geothermal Systems is also participating in the tests. "This method would be a real breakthrough. Drilling would become much less expensive, and geothermal energy generated from particularly deep depths of over four kilometres would finally be competitive," says Martin O. Saar.

Moreover, the system could do what traditional rotary drills are incapable of: creating cavities in the subsurface that are larger than the borehole leading to it. This is because the electropulse drill can bore sideways, implementing even complex geometric specifications with utmost precision at depths of up to ten kilometres. The technology would also make it possible to improve the connection between borehole and heat reservoir. With this method—which is economically interesting and does entirely without fracking—fluids and energy could be extracted from, or stored, deep in the earth. As such, it harbours great potential for applications beyond geothermal energy production, including energy and carbon dioxide storage, groundwater use, oil and gas extraction and nuclear repositories.

Strong support

The signs are promising. As principle researcher in an association of research groups from ETH Zurich, the Paul Scherrer Institute, the Eastern Switzerland University of Applied Sciences as well as private companies, Martin O. Saar received additional project funding in October of 2021: an Innosuisse Flagship Grant worth nearly twelve million Swiss francs. Now, work on reducing the size of the high-voltage pulse generator can proceed with united forces.

Funding from the Werner Siemens Foundation
10 million Swiss francs

Project leader
Prof. Dr Martin O. Saar, Werner Siemens Foundation Endowed Chair of Geothermal Energy and Geofluids at the Swiss Federal Institute of Technology Zurich (ETH Zurich), Switzerland

Project duration
2014 to 2023

Mountain acts as a giant sensor

Update: deep geothermal energy in the Bedretto Underground Lab in the Swiss Alps

The Bedretto Underground Lab is attracting interest from all corners of the globe. To ensure that even more experiments on deep geothermal energy can be conducted in the unique facility, construction work to enlarge the lab is scheduled for the winter of 2021, thanks to funding from the Werner Siemens Foundation. An additional kilometre of the former ventilation arm in the Furka tunnel—part of the Matterhorn-Gotthard railway line—is being restored and a second cavern converted into an underground lab. At the same time, the team are conducting tests to guarantee the safety of geothermal energy.

More research groups want to work in the Bedretto Underground Lab than there is room for. Thanks to funding from the Werner Siemens Foundation, a second underground lab can be built in the Saint-Gotthard Massif in the south-west Swiss Alps.

Taking a tour of the Bedretto Underground Lab is somewhat akin to embarking on time travel. Starting at the tunnel entrance in the Swiss village of Ronco, a path of some two kilometres leads through the interior of Piz Rotondo in the Saint-Gotthard Massif and on to the one-hundred-metre-long cavern, where researchers have set up the underground lab. “It’s a walk through Alpine history,” says project leader Domenico Giardini, professor of seismology and geodynamics at the Swiss Federal Institute of Technology Zurich (ETH Zurich). “Evolutionary developments that took place over hundreds of millions of years are visible here.”

Soon, the walk through granite and gneiss will be even longer, as a second lab is scheduled to begin operations in April 2022. The new facility will be located five hundred metres further into the interior of the mountain, where there is a cavern system with a total length of over eighty metres and a diameter of six metres—ideal conditions for a second underground lab.

A second underground lab

Thanks to funding from the Werner Siemens Foundation and in agreement with the tunnel owner, the extension can now be realised. Over the distance of another kilometre, the path through the tunnel is being paved, the ceilings reinforced, and each and every weak spot stabilised. In addition, workers are installing network cables, electric cables and water pipes as well as systems for ventilation, monitoring and security. Construction began in the winter of 2021 and is due to be completed roughly six months later. “The extension means we’re doubling our research capacity,” says project leader Domenico Giardini. “We’re buying time and rock volume.”

Giardini explains that converting the second cavern into a lab became a desideratum already early on. “But we didn’t think we’d be needing more space so soon.” Global interest in the Alpine lab is what has pushed it beyond its current capacity. For instance, the EU’s European Research Council is participating in research in the Bedretto Underground Lab with the largest ERC grant ever awarded to an earth science project. In addition, numerous universities and industry partners have expressed an interest in collaborating. “We came to the conclusion that we either had to stop all new projects or construct the extension right away,” Giardini says.

Geothermal energy for the winter months

The increased interest in the lab built into the Swiss Alps is no great coincidence. After all, geothermal energy is believed to be an indispensable technology for achieving climate neutrality. Indeed, existing sustainable energy sources like water, solar, wind and hot thermal energy are unable to cover our energy demand in winter; to compensate, Switzerland’s federal energy strategy calculates that by the year 2050, roughly seven percent of Switzerland’s power supply will stem from geothermal energy.

In theory, tapping into the earth’s heat to generate power is fairly simple. First, two holes are drilled deep into the earth where the rock is hot—at a depth of five kilometres, temperatures range between 150 and 200 degrees Celsius. In a second step, water is pumped into the first borehole, where it begins seeping through fine cracks in the rock until it reaches the second borehole. On its way, the water gets so hot that it exits the hole in the form of steam. This steam is then channelled into a turbine and used to produce electricity.

Safe fissures

A major drawback, however, is that hard rock like granite is nearly impermeable by nature, which is why geologists provide some outside assistance: they apply high pressure to the rock—in technical jargon, the rock layers are “stimulated”—causing fissures to form. This procedure requires painstaking care, as it can otherwise trigger major, and consequently devastating, earthquakes. This was the reason that Switzerland’s best-known geothermal energy project to date, which began not quite fifteen years ago in Basel, had to be abandoned.

Now the researchers in the Bedretto Underground Lab are seeking less invasive ways to generate fissures in the granite. They have already tested one promising method in the “Destress” project concluded in 2021: in a series of steps, staggered over time and in contained areas of the mountain, the team stimulated the deep rock layers to create controlled fissures. “It’s a major breakthrough for tapping into geothermal energy,” says Marian Hertrich, geophysicist at ETH Zurich and manager of the Bedretto Underground Lab.

Heat reservoirs to store warmth

The researchers are also testing an alternative method of energy storage: heat reservoirs. Rather than drilling down 5000 metres to produce electricity immediately, they want to determine whether a moderate depth of 1500 metres would be sufficient for heating the water during the summer months when electricity is available in great supply. During the cold winter months, power could then be generated from the heat stored in the reservoirs.

Heat reservoirs have two major advantages. First, dangerous earthquakes are much less likely to be triggered at more moderate depths. Second, costs are lower—partly due to savings on infrastructure expenses, but also because the electric power needed to pump the water through the rock layers is practically free in summer: already today, surplus energy is produced on peak days in summer, but a technology to store this power has not yet been developed. “In Germany, there are two to three days per month when electricity is sold at negative prices,” says Giardini.

New PhD programmes

Despite the many technological advances, not all aspects of heat storage have been fully explained. “When we pump large volumes of water into the rock layers, considerable stress changes occur. And the chemical balance is upset—all of which are complex processes,” Hertrich explains.

The researchers now want to study these “complex processes” in greater detail. To this end, several top European universities have joined forces in the new “International Training Network”, in which thirteen PhD students from ETH Zurich, TU Delft, RWTH Aachen and the Politecnico di Milano are conducting feasibility studies of the proposed heat storage method. The programme began in the autumn of 2021 and will last three to four years. “The focus is on the development and safe operation of geothermal water reservoirs,” says Hertrich. Some of the studies will be conducted in the Bedretto Underground Lab.

The most important part of the second underground lab will be the borehole (in the photograph with a red cover). Its diameter must be roughly twenty centimetres for the numerous sensors that record and monitor experiments to fit inside.

International collaboration

Numerous other research projects are also being conducted in the Bedretto Underground Lab—often in collaboration with industry partners. One such project uses a novel, high-resolution measurement instrument called the Step-Rate Injection Method for Fracture In-Situ Properties (SIMFIP). Installed inside the borehole itself, the aim is for the instrument to register changes in the rock even before the mountain is activated—a major innovation. “When the stress levels in the mountain are high, we have to proceed with a great deal of caution,” says Hertrich. “The new technology could prove extremely helpful in this area.”

The SIMFIP measurement instrument also offers a prime example of how important international collaboration is for research into future energy production: the instrument was developed by a US research institution and calibrated in Aachen, Germany, while a researcher at the University of Neuchâtel in Switzerland is responsible for interpreting the data.

World’s largest sensor

Across the globe, the Bedretto Underground Lab is one of a kind. With the high-resolution measurement system in operation since last summer, “part of the mountain has been converted into a giant sensor”, says project leader Giardini. Seven boreholes of depths up to three hundred metres were equipped with sensors and reinforced with cement to ensure the rock is, so to speak, unaware of the installation and that it reacts like intact granite. The team are now conducting experiments to stimulate the rock layers and cause fissures to form; a stimulation session is scheduled every one to two weeks. “That’s how long we need to evaluate and analyse the massive amounts of data delivered by the sensors in the boreholes,” says Hertrich.

Funding from the Werner Siemens Foundation

12 million Swiss francs (2018–2026)
An additional 3.58 million Swiss francs for the extension (2021)

Project leader

Prof. Dr Domenico Giardini, Professor of Seismology and Geodynamics, Swiss Federal Institute of Technology Zurich (ETH Zurich), Switzerland

Project duration

2018 to 2026

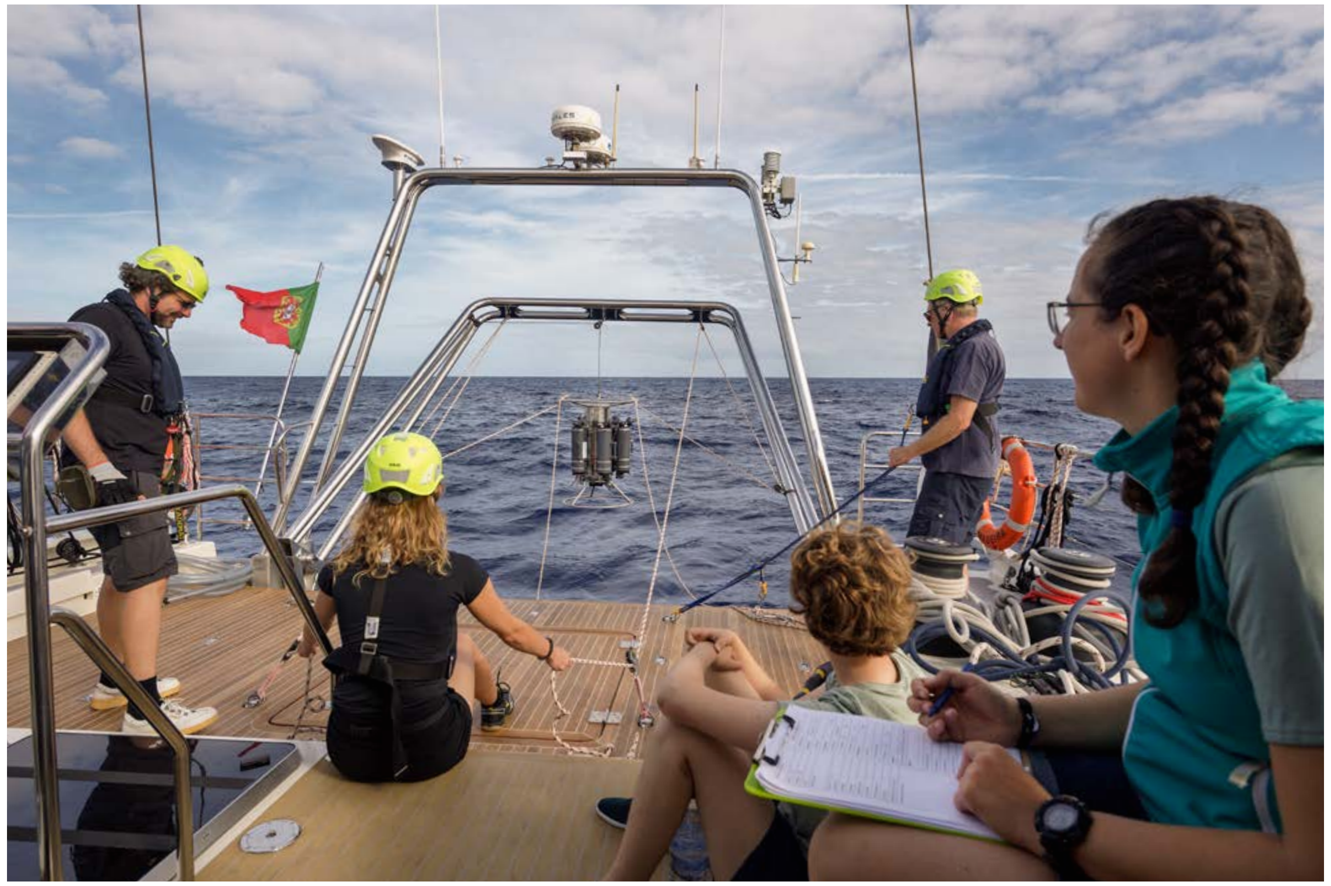
Intern-*ship*: all hands on deck

The interns are thrilled to be part of the *Eugen Seibold* research vessel and her mission. “We were fully integrated from the start,” exclaims budding earth and climate scientist Jonas Schneider. “The team are just great, and they’re so patient in sharing their expertise with us.”

How is the ocean faring right now, and how is global warming influencing its health? For two years, the core team on the sailing yacht *Eugen Seibold*—a research vessel operating with funding from the Werner Siemens Foundation—have been collecting data to answer these fundamental questions. The experienced marine researchers often invite junior scientists to join them on the expeditions. For three lucky students from the Swiss Federal Institute of Technology Zurich, the chance came at the end of September 2021, when they spent two weeks working on the *Eugen Seibold* as interns. The photos illustrate their adventure on the high seas.

During the internship, the three students have the opportunity to explore a topic of their own choice. Jonas Schneider (second from left) and Sixtine Dromigny (right) focus on the physical properties of seawater, while Janine Schmitter (third from left) is interested in the single-celled organisms living in the sea. In the photo, the three are looking at their first plankton sample. Project leader Ralf Schiebel (left) has transferred the magnified view of the microscope live to the computer. Bachelor’s student Janine Schmitter is fascinated: “I would love to work in oceanography one day. These will probably be the two most interesting weeks of my life.”

At the stern of the *Eugen Seibold*, geologist Ralf Schiebel explains to the students how the stratification of the ocean influences the team's sampling strategy.



Positioning the water sampling rosette requires skill, as the ocean waves set the valuable device swinging—and in windy weather, the boat can also roll dramatically. Protected from injury by steel-toed shoes and a helmet, marine biologist Hedy Aardema (centre) uses rope hoists to stabilise the rosette, which she then carefully manoeuvres into the sea.

Space on the *Eugen Seibold* is limited, so the floor is also used. In the picture, marine chemist Hans Slagter (grey T-shirt) explains to two of the interns how the FerryBox—installed under the lab bench—measures the ocean water's key physical environmental parameters: salinity, carbon dioxide and chlorophyll levels, pH value and temperature. Seen in the foreground is the dry lab with the mass spectrometers, which make continuous recordings of the turnover of carbon dioxide and other gases in the ocean's upper water column.

Tired but happy after a long day's work, the researchers return to the harbour at Marina Rubicón on the Canary Island of Lanzarote. After spending the night there, they will set off the next morning with renewed vigour in the direction of 29°N 15°W to continue profiling the waters of the Atlantic Ocean.

Funding from the Werner Siemens Foundation

3.5 million euros: 2015–2019
construction, technical installations and tests on the *Eugen Seibold*
3 million euros: 2020–2030
costs for operating the *Eugen Seibold*

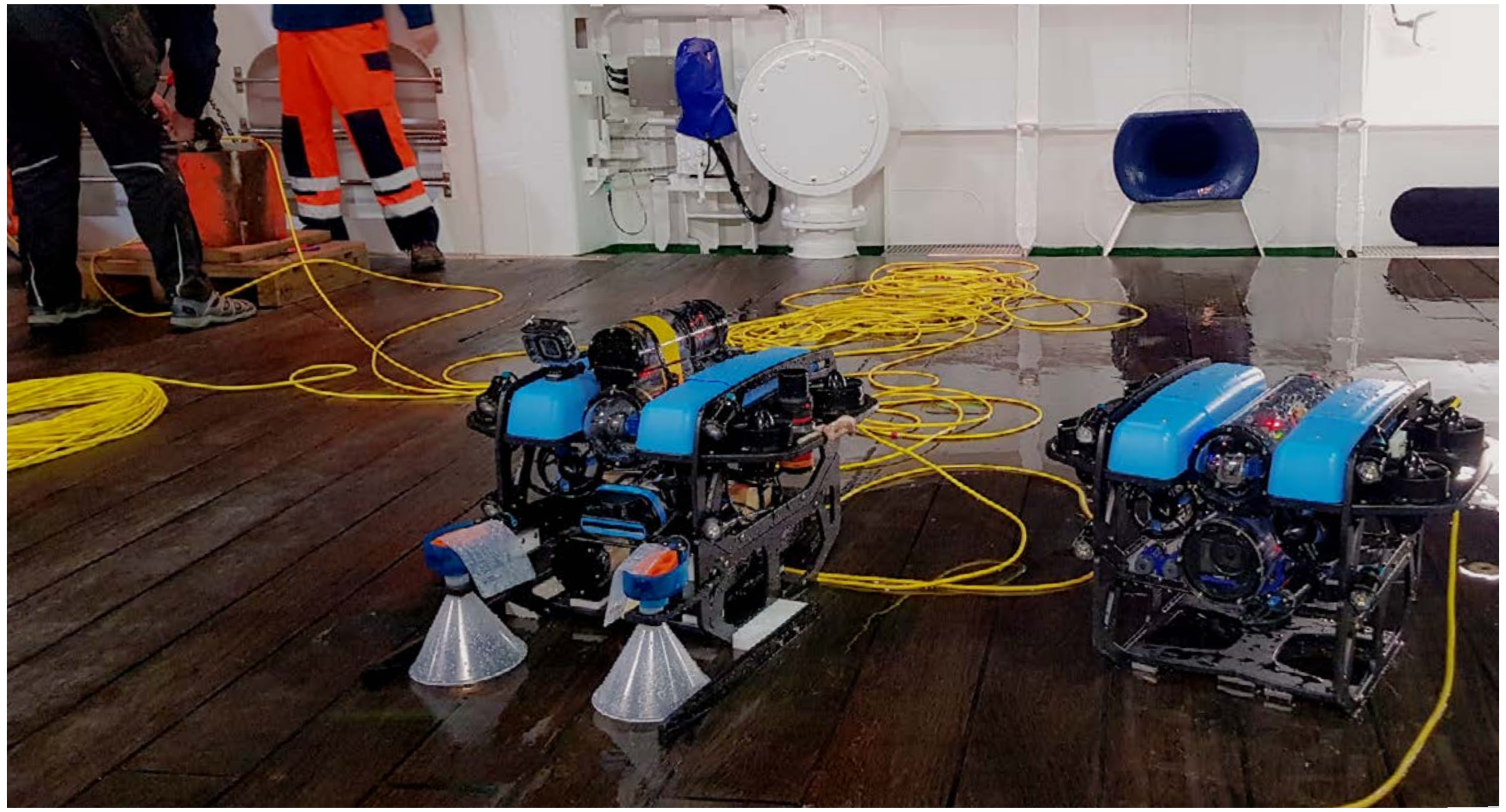
Project leaders

Prof. Dr Gerald Haug, Director of the Department of Climate Geochemistry at the Max Planck Institute for Chemistry in Mainz, Germany, and Professor at the Swiss Federal Institute of Technology Zurich (ETH Zurich), Switzerland

Dr Ralf Schiebel, Group Leader of Micropaleontology at the Max Planck Institute for Chemistry in Mainz, Germany

Project duration

2015 to 2030



They know the coordinates and can hold heir position even in stormy weather: the two remote-controlled miniature ROVs proved their mettle during tests in the North Sea.

Gentle robots in rough waters

Update: Innovation Center for Deep-Sea Environmental Monitoring at MARUM, University of Bremen

Should the delicate ecosystems in the ocean floor be disrupted by deep-sea mining, the consequences will be devastating. Now, researchers at the Innovation Center for Deep-Sea Environmental Monitoring in Bremen are developing underwater robots to identify and map ecologically valuable deep-sea regions. The team have made excellent progress: their robots are already capable of holding their ground, even in strong currents.

Smartphones, electric cars and solar panels require large quantities of minerals like copper, zinc and cobalt. Because on-land deposits are limited, an increasing number of countries and businesses are making plans to mine the ocean floor for valuable resources. But this kind of deep-sea mining would damage life in the seabed for decades to come.

Terra incognita

Before the ecologically valuable organisms of the deep sea can be protected, we must first know where they are located—yet the deep sea remains largely a terra incognita, unexplored territory. To remedy this, researchers at the Innovation Center for Deep-Sea Environmental Monitoring at MARUM of the University of Bremen are developing a novel system to map the ocean floor. Head of the centre is environmental technologist and Werner Siemens Foundation Endowed Chair Ralf Bachmayer.

An underwater dream team

Mapping the deep sea—what sounds simple is a highly complex job, which is why Bachmayer and his team are taking a multipronged approach. Two underwater robots move in tandem, just above the ocean floor. The remotely operated vehicle (ROV) that is higher up covers a broad swath of the seabed to provide researchers with a general overview. Then, a smaller, autonomous underwater vehicle (AUV) records this same section of the seabed in high-resolution detail. Together, the general overview and the details deliver a relatively exact picture of the ocean floor.

To be fully autonomous in its movements, the AUV—affectionately dubbed "Manatee" by the researchers—has to be able to navigate on its own. This is easier said than done at the bottom of the deep sea, where GPS is out of range and where the vehicle can very easily drift off course in the strong ocean currents. "This makes it critical that the AUV can maintain its position and orientation in the water," says Bachmayer. To this end, he and his team developed a modular control system, which they then installed and tested on a miniature ROV.

North Sea as a proxy for the deep sea

The coronavirus pandemic prevented Bachmayer and his team from testing their device in the deep sea, as many research vessels were stuck in harbour for months. But the researchers were not to be deterred: "We teamed up with geologist Miriam Römer from the University of Bremen, who had planned an excursion to the North Sea." Römer's goal was to study how methane escapes the ocean floor of the North Sea.

The interdisciplinary group sailed from the port of Emden in northern Germany on 8 January 2021. They boarded the research vessel *Maria S. Merian* with the two miniature ROVs equipped with the new control system. The ROVs completed a total of twelve dives in the North Sea—surmounting the stormy winter weather and the dictates of the tides. During each roughly two-hour dive, Bachmayer and his team conducted detailed tests on the new control system.

Position held, gas trapped

The control system relies on sensors to detect depth, position and acceleration of the ROV. An algorithm then processes the signals to determine the ROV's current orientation and direction. This information and the intended movement profile are delivered to the control system, which translates the data into steering signals for the vehicle's propulsion drives. These signals enable the vehicle to auto-matically maintain its position and orientation in the water. "Our control system proved its mettle in the North Sea," Bachmayer explains. "Now we can try it out in future tests with Manatee."

The collaboration with Miriam Römer also had another, unexpected positive outcome. Bachmayer's team created a device that helped the miniature ROV to collect gas samples—for example, the methane samples that Römer is interested in studying. In the past, larger vehicles were needed for this type of work, and the new device turned out to be an absolute innovation. "We were all beaming with satisfaction when we disembarked from this successful mission," Bachmayer says.

An overcoat for Manatee

Back at the Innovation Center for Deep-Sea Environmental Monitoring in Bremen, the researchers constructed a thermoplastic outer shell to insulate the sensitive sensors and steering elements in the interior of AUV Manatee. The researchers have already calculated theoretical projections on how the newly encased Manatee will react in the water. Over the course of the coming year, they want to test the capabilities of the gentle robot in practice, this time in an open body of water like Lake Constance.

Funding from the Werner Siemens Foundation
4.975 million euros

Project leader
Prof. Dr Michael Schulz, Director of MARUM – Center for Marine Environmental Sciences at the University of Bremen, Germany

Project duration
2018 to 2028

Controlled impurities

Update: developing optimised thermoelectric materials at IST Austria

In 2021, researchers in the group led by physicist Maria Ibáñez were still developing their thermoelectric nanomaterials with interesting properties "by hand". Starting in 2022, the team will be working in their new lab with state-of-the-art equipment that makes seeking the best thermoelectric nanomaterials much, much faster.

In theory, thermoelectric materials are capable of converting temperature differences found anywhere—whether in car engines, refrigerators or water pipes—into electricity. In practice, however, these materials are still too inefficient and costly for wider application. Now, physicist Maria Ibáñez and her research group at IST Austria are working to develop optimised thermoelectric materials that can generate electricity from everyday appliances and devices.

Since February of 2021, the Mars rover Perseverance has been pottering about on our neighbouring planet, collecting rock and soil samples and seeking evidence of former life. Everything on the tireless multitasker, including the robot's cameras and measurement systems, is powered by a thermoelectric generator. The device operates on the basis of a special material that can harvest electricity from temperature differences: highly energetic electrons move from the warm side of the material to the cold side, thereby generating electric voltage. Although thermoelectric energy sources like this are durable and reliable, present-day materials are also inefficient and expensive. As a rule, they are used only when no other energy source is available and when the costly expenditures are insignificant in relation to the entire project—as is the case with space exploration.

In search of ideal materials

Maria Ibáñez wants this to change. As head of the Werner Siemens Foundation Center for Research in Thermoelectric Materials at the Institute of Science and Technology Austria (IST Austria), she aims to develop novel thermoelectric materials capable of converting temperature differences found in a wide variety of ordinary devices and appliances into electricity. There are numerous possibilities, Ibáñez says: "We could use the cold in refrigerators or the waste heat from computers or car engines."

The physics professor and her interdisciplinary research group are currently synthesising numerous potential thermoelectric materials and changing their molecular structure to give them the desired properties. "Because the principle functions on the basis of temperature differences, a thermoelectric material needs to simultaneously conduct electricity well but heat poorly," Ibáñez explains. Moreover, the material should generate the maximum possible amount of electrical power from an existing temperature difference.

Aqueous solutions

To develop cost-effective thermoelectric materials, Ibáñez is eschewing customary production methods that require either high pressure or high temperatures. Rather, she uses aqueous solutions to manufacture materials with precisely defined nanostructures, and this at temperatures below the one-hundred-degree Celsius mark.

Her team has recently garnered promising results using tin selenide (SnSe), the most powerful thermoelectric material known. In the past, tin selenide has been produced and tested in the form of single crystals, a complex and expensive process. In just a short time, however, Ibáñez has succeeded in submitting several publications on her aqueous tin selenide synthesis.

New lab, state-of-the-art equipment

Her new material, a powder made of nanocrystals, cannot quite match the performance of the single-crystal form, but not much is lacking. Ibáñez is satisfied: "Developing this new material has taught us a great deal about the subtleties of the synthesis and the reasons for its weaker performance." Analyses conducted by the physicist and her team have revealed that impurities had crept into their synthesis: ions had bonded with the material particles, thus influencing the thermoelectric output. "Equipped with this knowledge, we can now try to control these ions in the manufacturing process and even make them work to our advantage. It's possible that they can actually boost the efficiency of the synthesis," Ibáñez explains.

These insights will also prove valuable when researching other families of materials. Ibáñez is currently designing a high-throughput infrastructure for the new lab she plans to move into at the end of 2021. There, her group will be able to pursue a number of routes as they develop and analyse several different materials at the same time—and make even swifter progress than in the past.

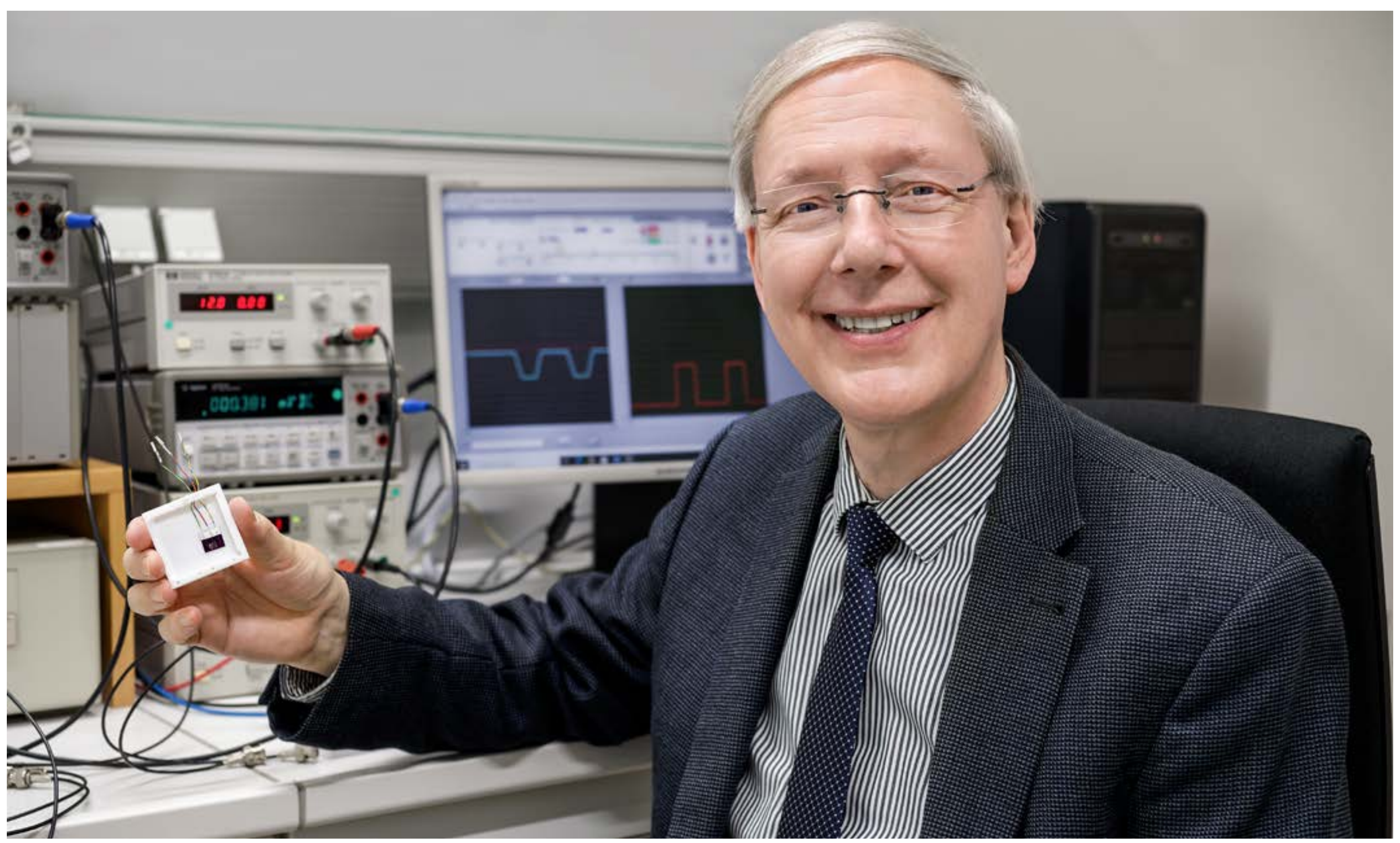
Funding from the Werner Siemens Foundation
8 million euros

Project leader
Prof. Dr Maria Ibáñez, Institute of Science and Technology Austria (IST Austria), Austria

Project duration
2020 to 2028

Tin tops silicon

Update: Center for Single Atom Electronics and Photonics at ETH Zurich



Physicist Thomas Schimmel presents his invention: the single-atom switch cast in gel (black).
A close-up of the single-atom switch is found on page 2 of this report.

The single-atom transistor developed by physicist Thomas Schimmel has the potential to reduce the massive energy consumption in digital devices by a factor of ten thousand. Moreover, the energy the technology saves could be channelled into boosting the performance of next-generation computers.

Downloading a podcast to our phones for a workout at the gym. Meeting colleagues via Zoom. Streaming a film in the evening. All these conveniences are made possible by a nearly invisible, yet mighty electronic component: the transistor. There are billions of them on microchips, and these transistors are what enable our digital devices to do the actual work of computing.

This much is clear. But today's transistors have a major drawback: they require a massive amount of energy to process data. "Data communications and processing account for more than ten percent of global electricity consumption in industrialised countries," says nanotechnology expert Thomas Schimmel at the Karlsruhe Institute of Technology. "If the internet were a country, it would be the sixth-largest energy consumer in the world."

Single-atom technology

Professor Thomas Schimmel is a research partner in the single-atom switch project conducted at the Swiss Federal Institute of Technology Zurich (ETH Zurich); the project receives funding from the Werner Siemens Foundation. Schimmel is considered a pioneer in single-atom electronics; in his Karlsruhe lab, he invented a mind-bogglingly efficient single-atom transistor that could significantly lower energy consumption in computers. Now, he is collaborating with the teams of his ETH Zurich colleagues, Professor Jürg Leuthold (project leader) and Professor Mathieu Luisier, to translate the innovative invention into practical application.

Much like a normal light switch, the single-atom transistor consists of a switching element and two tiny electrodes that are separated by a gap; here, however, the incredibly narrow opening has the diameter of just one atom. When the switch is turned on, a single metal atom is flipped into the gap, closing the circuit. The resulting flow of electricity can be used to power common electronic devices—for example, a halogen lamp, as Schimmel has demonstrated in his Karlsruhe lab.

Lowest control voltage

A control voltage is responsible for moving the atom, thus for turning the single-atom switch on and off. And the control voltage needed to operate the single-atom switch is one hundred times lower than what is required for today's silicon semiconductors. Schimmel and his team have also succeeded in radically reducing the voltage from some thirty millivolts in their first single-atom switch prototype to a mere three-to-six millivolts in the latest version.

The ratio between voltage and energy consumption is exponential rather than proportional. This means that when voltage is reduced by a factor of ten, energy consumption decreases by a factor of one hundred. As such, the single-atom switch already uses ten thousand times less energy than today's silicon semiconductor technology.

Tin instead of silver

The researchers achieved the energy reduction by making electrodes out of tin rather than silver. "We first used silver, because it was the easiest way to realise the single-atom transistor," Schimmel explains. But then, he and his team began testing the physical and electrochemical properties of other metals, paying particular attention to their viability for single-atom technology. "Our single-atom transistor made of tin is a true milestone in our research," says Schimmel.

In addition to conducting applied research for developing the novel, energy-efficient transistor, the team are also exploring fundamental questions in physics. For instance, they have observed that a single atom's conductivity is not a fixed quantity; rather, it depends on the atom's environment and its structural organisation in a collective with other atoms. "This fundamental understanding is critical, as it's key to finding a technological application," Schimmel says, adding that, "we can only control what we understand".

Indeed, the step from lab prototype to mass production is a major challenge and numerous issues must first be resolved. Of particular importance is how single-atom transistors can be switched simultaneously on a large scale in order to perform the logical operations required of a computer chip. Schimmel and his team plan to address this question next.

Boosting performance

Schimmel is convinced that the single-atom transistor has the potential to revolutionise the digital world in another way, too. Silicon semiconductor technologies have nearly exhausted their capacity to improve performance; any increase in their computing power will make redirecting waste heat more difficult, and cooling semiconductor chips in computers will become a major problem.

With the single-atom transistor, however, the ten-thousandfold reduction in energy consumption could be converted towards boosting performance. Schimmel explains: "If we lowered energy consumption by even just a factor of one hundred, we could still use the reserve energy to increase the world's overall computing power by a factor of one hundred."

Funding from the Werner Siemens Foundation
12 million Swiss francs

Project leader
Prof. Dr Jürg Leuthold, Head of the Institute of Electromagnetic Fields, Swiss Federal Institute of Technology Zurich (ETH Zurich), Switzerland

Project duration
2017 to 2025

A digital Red Cross

Update: Centre for Cyber Trust at ETH Zurich

Because the digital infrastructure of humanitarian institutions is vulnerable to cyberattacks, the team at the Centre for Cyber Trust are developing digital emblems to protect these systems.

In September of 2020, the University Hospital of Düsseldorf suffered a critical blow: a cyberattack on its servers brought the hospital to a standstill for a whole week. The blackmailers behind the malware relented when they realised they had not, as planned, hit the university itself. Tragically, the situation was resolved too late for one patient who had to be removed to another hospital—and who later died.

What exactly happened? Professor Peter Müller, co-leader of the Centre for Digital Trust at the Swiss Federal Institute of Technology Zurich (ETH Zurich) explains how these attacks work: "The malware is programmed to independently attack computers that lack sufficient protection. Often, the hackers have no real control over the attacks." A weakness in their "business model". Indeed, cybercriminals who blackmail firms aim to fly under the radar. A high-profile case like an attack on a hospital increases their risk of being tracked down by the authorities.

To date, the protections in place for digital infrastructure in public and humanitarian institutions like electricity works and hospitals leave them vulnerable to cyberattacks. Nor is there a digital Red Cross alerting malware programs that the targeted infrastructure is protected under international humanitarian law. Seeing the need for a digital protective emblem to act as a warning sign, the International Committee of the Red Cross approached the Centre for Cyber Trust at the end of 2020. "Just as recognised symbols show parties in armed conflicts what stands under protection, the digital infrastructure of humanitarian organisations must be made recognisable to cyber operators," explains Professor David Basin, co-leader of the Centre. Together with his research group, Basin has developed a concept for how such a digital protective emblem could function (see diagram). In order for an emblem to be accepted by attackers (be they nation states or criminal organisations), it must first and foremost be seen as trustworthy and impartial. But what precisely promotes or undermines the trust of these actors? This question, which considers IT security from a behavioural perspective, is being addressed by Professor Matthew Smith, the project's research partner at the University of Bonn.

Funding from the Werner Siemens Foundation
9.83 million Swiss francs

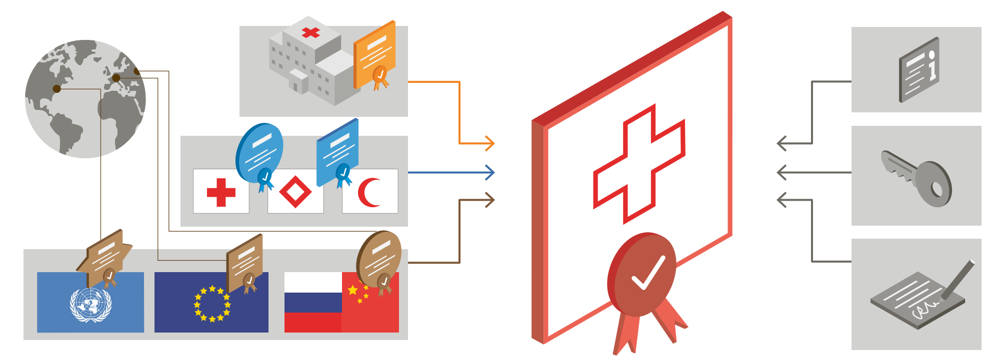
Project leaders
Prof. Dr David Basin, Prof. Dr Peter Müller, Prof. Dr Adrian Perrig, Department of Computer Science, Swiss Federal Institute of Technology Zurich (ETH Zurich), Switzerland
Prof. Dr Matthew Smith, Institute of Computer Science, University of Bonn, Germany

Project duration
2019 to 2027

Status quo

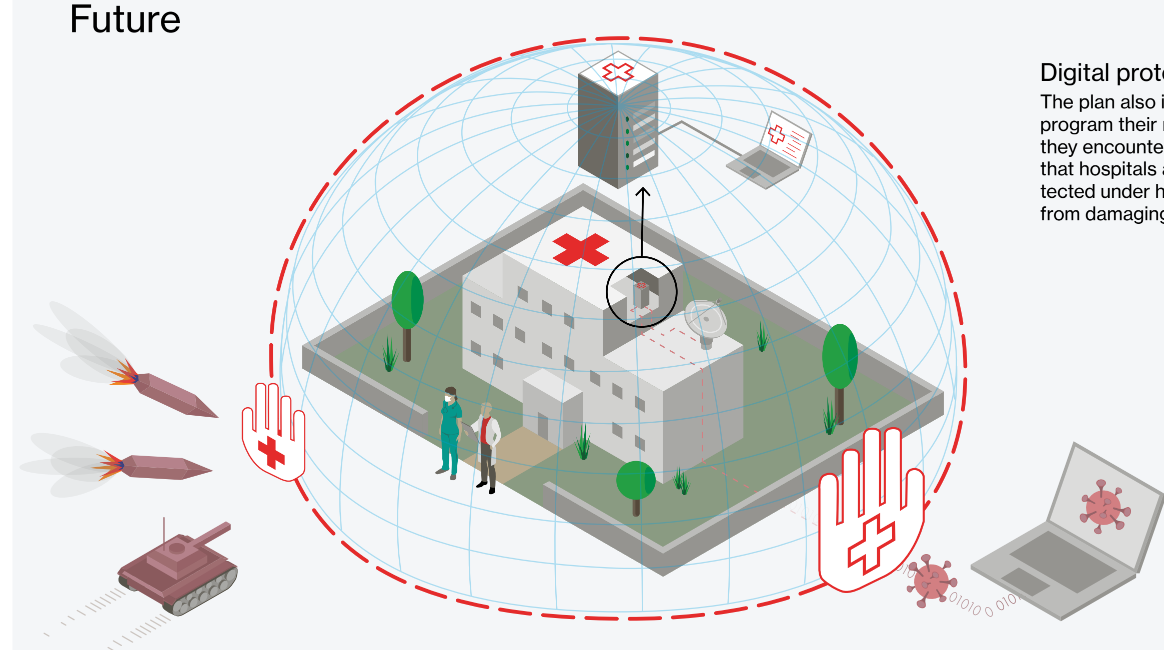
Protected by the Red Cross
In war, hospitals are protected under international humanitarian law. Three protective emblems—the Red Cross, Red Crescent and Red Crystal—are used throughout the world to mark hospitals and shield them from military attack.

Vulnerable to cyberattacks
A malware attack on a hospital server that is connected to the internet can result in patient deaths. Vital hardware and equipment are rendered inoperable and hospital staff are unable to order new supplies of medicines and other essential materials.



Introducing digital protection
In future, a new digital protective emblem will send a message when a malware attack is carried out: "Stop! The targeted organisation and its digital infrastructure are protected by international humanitarian law." It is critical that the digital protective emblem is trustworthy and protected against misuse—and that malware programs are coded to check the authenticity of a digital protective emblem. Certificates, cryptographic keys and digital signatures will serve for the technical implementation. Three levels of protection are possible, depending on the authority guaranteeing the certificate's authenticity: the entity requiring protection itself; its parent organisation; or international organisations or national governments.

Future



Digital protective emblem
The plan also includes persuading cyber operators to program their malware to be automatically halted when they encounter digital protective emblems. It is hoped that hospitals and other critical infrastructure protected under humanitarian law would then be shielded from damaging cyberattacks.

Werner Siemens Foundation Endowed Chair Bergita Ganse is responsible for coordinating the interdisciplinary smart implants project.

An expert all-round

Update: smart implants at Saarland University Medical Center

At Saarland University Medical Center, a team of specialists from the fields of medicine, engineering and computer science are developing intelligent implants that will enable complex bone fractures to heal with fewer complications. Werner Siemens Foundation Endowed Chair Bergita Ganse has recently been appointed coordinator of the broad-ranging project; her aim is to exploit synergies between the diverse disciplines—while contributing knowledge from outer space.

In the earth's orbit, everything is as light as a feather—astronauts can push off with a mere finger and glide effortlessly across the space station. Yet as heavenly as zero gravity may initially feel, in time it presents problems. "We have to work our muscles and bones, otherwise they start to deteriorate," says trauma surgeon Bergita Ganse, who has spent many years studying solutions to the issue. Her research has helped the European Space Agency (ESA) and and the National Aeronautics and Space Administration (NASA) to further develop their training methods for astronauts—through the use of special weight training equipment, treadmills and exercise bikes, for example.

High ambitions

These days, Bergita Ganse's research setting is firmly earth-bound, and in March of 2021, she was appointed Werner Siemens Foundation Endowed Chair at Saarland University in Homburg, Germany. In her new role as coordinator of a team of medical, engineering and computer science experts, she wants to help revolutionise the treatment of fractured bones through the use of smart implants. The implants of the future will not only stabilise bones, but also independently detect and counteract incorrect weight bearing—what Ganse calls an ambitious but attainable goal. Indeed, she is not shy of aiming high herself: a hobby athlete, Ganse formerly competed at the European Masters Championships in the Throws Pentathlon event.

Innovation through collaboration

With her background, Ganse believes she is optimally positioned to mediate between the various disciplines. In her most recent post, she received a research grant to work at the Research Centre for Musculoskeletal Science and Sports Medicine at Manchester Metropolitan University in England. Prior to that, she conducted research into implants and other subjects in Aachen, earning her habilitation (professorial qualification) in experimental orthopaedic surgery. Ganse is also very familiar with the workings of a medical clinic, having completed her Medical Specialist Qualification for orthopaedics and trauma surgery as well as for physiology at Charité in Berlin, at the German Aerospace Center (DLR) and at the university hospitals in Cologne and Aachen. During her time at DLR and in Manchester, she practically "lived among engineers", as she tells it; nor is she a stranger to the questions explored by computer scientists, with whom she has collaborated in various research projects. "My goal is to unite these diverse worlds," says Ganse, "because innovation is often dependent on specialists from various disciplines passing the ball to each other."

Material that moves

In 2021, engineers at the Center for Mechatronics and Automation Technology in Saarbrücken achieved an initial breakthrough: they succeeded in building a so-called demonstrator that incorporates an actuator component—an implant made of metal and synthetic materials that can contract and expand. The "shape memory" properties of the materials is what makes this possible: the nitinol wires shorten when they are warmed by an electrical current and "relax" again in the absence of voltage, thereby mechanically stimulating the fractured bone. The researchers have now filed the first patents for their prototype construction.

Although the prototype features an actuator component, it still lacks adequate sensory characteristics, let alone intelligent properties. Indeed, before the implant is ready for use, it must be able to precisely measure the forces acting on the bone and process this information, which the prototype cannot yet do. Another challenge is the power supply—both implantable, fully autonomous solutions and inductive charging could be used. Moreover, the implant's compatibility with the human body must be ensured. By using currently known implantable materials and encapsulations, Ganse is certain that the goal is fundamentally realistic.

How much weight bearing is ideal?

The technology is already highly advanced. But without medical research, even the most intelligent implants are not fit for purpose. Before smart implants can actually aid the healing of fractured bones, two central questions must be answered: Which forces and pressures act on bones when walking and performing everyday activities? And, what is the ideal weight to put on a healing fracture? The medical specialists in the group of project leader Professor Tim Pohlemann are currently collecting the necessary background data by using sensors in shoe soles. And identifying ideal weight bearing is also a matter with which new Werner Siemens Foundation Endowed Chair Bergita Ganse is well acquainted: "The issues to address are, in principle, similar to those in space research."

Funding from the Werner Siemens Foundation

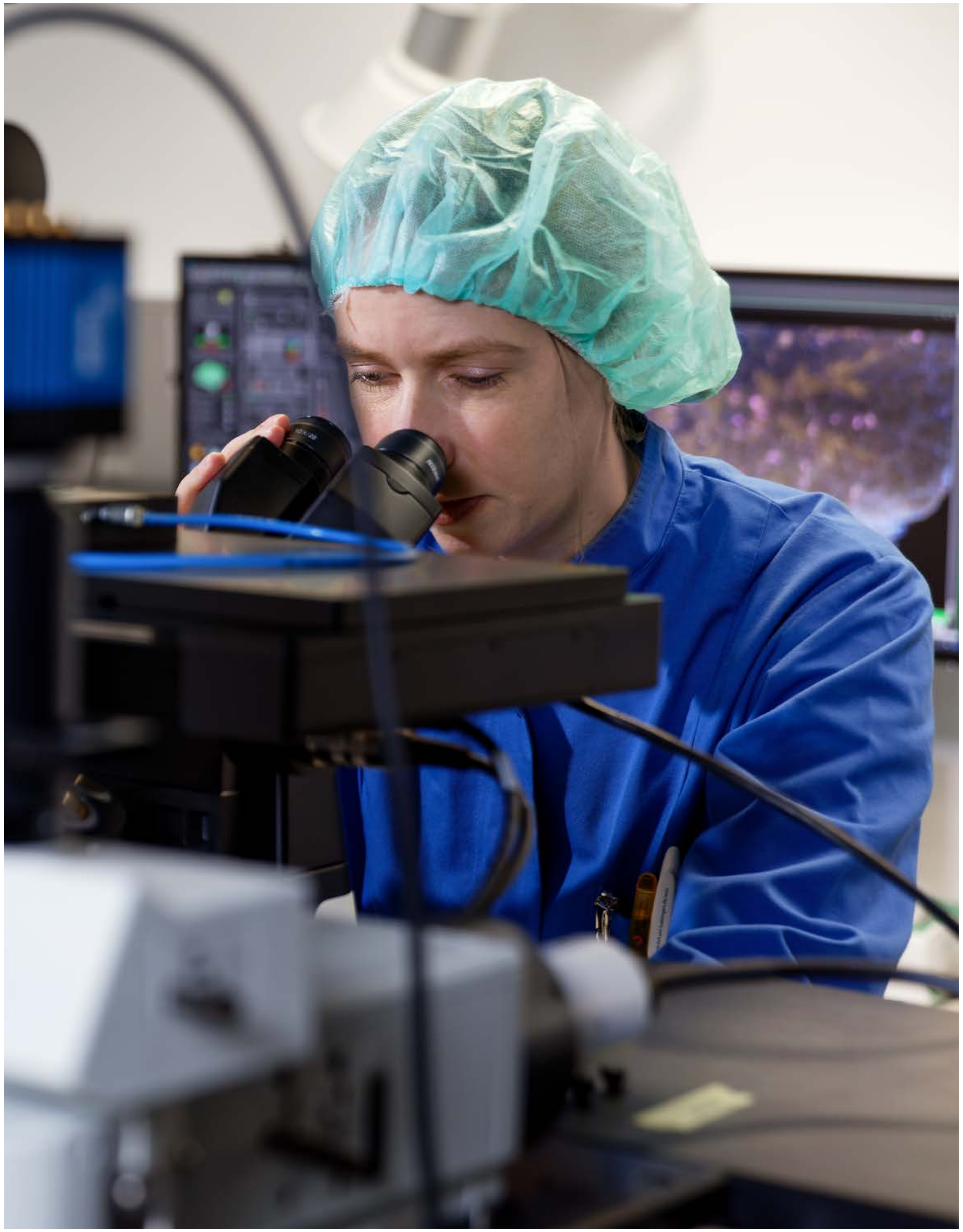
8 million euros

Project leader

Prof. Dr Tim Pohlemann, Department of Trauma, Hand and Reconstructive Surgery, Saarland University Medical Center, Homburg, Germany

Project duration

2019 to 2025



Observing the living cell

Update: medical imaging techniques at the Werner Siemens Imaging Center in Tübingen

Despite major advances in modern medicine, there are still many diseases that evade detection and treatment. To remedy this, researchers at the Werner Siemens Imaging Center in Tübingen are developing new imaging techniques that enable greater precision when examining tissues and molecules. Recently, the team have made great progress in cancer therapies and the early detection of Parkinson's disease.

Peering into living organisms: cell biologist Bettina Weigelin can now precisely characterise tumours thanks to the new intravital microscope at the Werner Siemens Imaging Center.

Cancer is the leading cause of early death in the Western world—and in Germany and Switzerland, most deaths in men over forty-five and in women over twenty-five are cancer related. “Although we have good treatments for many cancers, the disease often returns after a few years,” says Bettina Weigelin, group leader at the Werner Siemens Imaging Center (WSIC) in Tübingen, Germany. With her team, she is seeking methods to better characterise tumours and to improve cancer therapies with this new-found knowledge.

To achieve their ambitious goal, the Tübingen researchers have a powerful new tool: their intravital microscope, a microscopy technique used to examine living tissue, even entire organisms. The microscopy system, which was set up at the start of 2021, fills an entire room—a lab space where researchers are required to wear disposable overalls. In addition to the microscope itself, the system has three high-energy infrared lasers. “With this laser technology, we can actually see inside a sample, not just observe its surface,” Weigelin explains.

To examine a specimen, the researchers first mark the cells they want to track—often tumour and immune cells—with fluorescent proteins. Under the microscope, the lasers then stimulate the cells, rendering them visible down to a tissue depth of two millimetres. “Only very few intravital microscopes in the world can achieve this depth penetration,” says Weigelin.

In the lung of a mouse

Weigelin and her team are mainly interested in better understanding how immunotherapies influence tumours. They are compiling this knowledge through experiments on mice in which the animals are given a mild anaesthetic and placed under the microscope. Previously, the researchers had focused on skin cancer, but the new unit allows them to analyse tumours that are situated deeper in the body. They are now preparing their first breast cancer experiments.

The team have also begun investigating metastases. “With many types of cancer today, the primary tumours are no longer the cause of death. Rather, patients die of metastases in their bones or internal organs,” says Weigelin. On her computer, she opens images of a mouse’s lung, where several round spots are glowing: metastases. These images were made using another kind of microscopy—light sheet fluorescence microscopy. Although this technique does not render live organisms visible, it illuminates layers, or slices, of entire organs. The magnified image of the metastases in the mouse’s lung reveals how the immune cells are fighting the tumour. At the edge of the growth, however, it becomes apparent that the dividing tumour cells are winning the battle. “Although the immune cells often recognise the tumour cells, they’re unable to destroy them,” says Weigelin. “We want to find out why this is the case and use this understanding to develop new therapies.”

Destroying sleeper cells

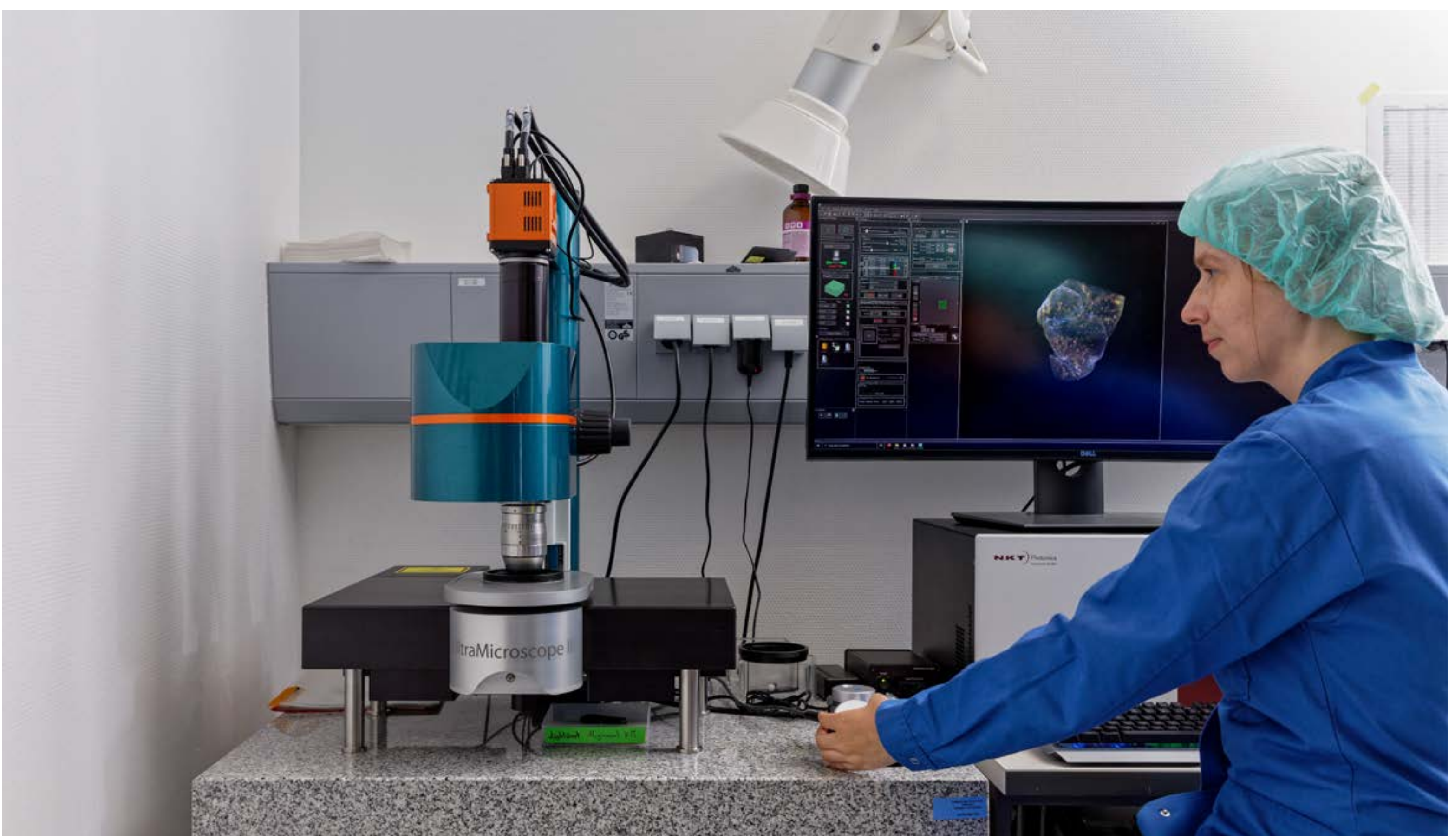
The WSIC group led by the centre’s director, Professor Bernd Pichler, is studying another phenomenon in tumour cells: senescence. Cells in a senescent state are still alive, but they no longer divide; several cancer drugs exploit this mechanism to stop the growth of tumours. However, as Pichler explains, “it’s impossible to drive all of a tumour’s cells into a senescent state”. Moreover, senescent cells secrete signals that stimulate growth in the other cancer cells. “As a result, tumours that had been suppressed begin to grow again,” Pichler says. “To prevent this from happening, we need to pinpoint exactly when we should destroy the senescent cells with drugs.” To determine this precise moment, the team have developed a senescence tracer, which consists of a molecule that marks senescent cells with radioactive tracers, making the cells visible in a positron emission tomography (PET) scan. The researchers at WSIC have already tested their method in preclinical trials. Currently, a phase I clinical trial is under way—the world’s first-ever clinical trial of a senescence tracer.

The method has already delivered encouraging results. In collaboration with the University Hospital Tübingen, Pichler’s team used the senescence tracer on patients with glioblastoma tumours that had proved resistant to all other therapies. Although these brain tumours are highly aggressive, patients whose treatments were administered on the basis of a PET scan with the senescence tracer lived longer. “One fifty-year-old patient lived several more months with a good quality of life,” says Pichler.

Early detection of Parkinson’s

The WSIC team are also researching early detection of neurodegenerative diseases like Parkinson’s. “In Parkinson’s, a certain type of protein, so-called Lewy bodies, are deposited in the brain long before the first symptoms appear,” says group leader Kristina Herfert. She and her team have now developed the world’s first tracer that binds to Lewy bodies, rendering them visible in the PET scan. “This delivers a reading that shows how the disease has progressed thus far,” explains Herfert. In future, it is hoped that the new tracer will help doctors to monitor whether a therapy is working—perhaps even make early detection of Parkinson’s a reality. After promising results in preclinical trials with mice and with human brain tissue, the plan is to test the tracer already next year in a clinical trial with patients.

Recently, WSIC group leaders Kristina Herfert and Bettina Weigelin were appointed professors at the University of Tübingen, prevailing over formidable international competition in the appointment procedure. “It’s evidence of how strong our team is, and it also enhances the reputation of our centre,” says Pichler. “I’m very proud.”



Bettina Weigelin is an ideal addition to the team at the Werner Siemens Imaging Center: the cell biologist is specialised in the characterisation of tumours and in understanding the efficacy of immunotherapies.

Bettina Weigelin, new group leader of “Multiscale Immunoimaging” at the Werner Siemens Imaging Center and professor of preclinical imaging of the immune system at the University of Tübingen, Germany.

Funding from the Werner Siemens Foundation

12.3 million euros (2007–2016)
15.6 million euros (2016–2023)

Project leader

Prof. Dr Bernd Pichler, Werner Siemens Foundation Endowed Chair and Director of the Werner Siemens Imaging Center (WSIC) in Tübingen, Germany

Project duration

2007 to 2023

Interpreting ancient dental plaque

Update: palaeobiotechnology research in Jena—seeking ancient natural products with antibacterial properties

In their search for ancient antibacterial agents, the palaeobiotechnology researchers are analysing dental plaque samples from all corners of the globe—and have made some unexpected findings in the process.

Creating modern-day antibiotics from prehistoric genetic material is the goal of the new research discipline palaeobiotechnology in Jena. In her search for ancient DNA, archaeologist Christina Warinner has also made some surprising discoveries about human history.

Professor Warinner, you and your research team at the Max Planck Institute for Evolutionary Anthropology are working with biotechnologist Dr Pierre Stallforth and his team in Jena on this unique palaeobiotechnology project: you're analysing the dental plaque of early humans for genetic material that can be used to combat resistant bacteria of today. How has the project progressed?

Christina Warinner: We're very satisfied, although the first half of the year was overshadowed by the coronavirus pandemic. This means it wasn't possible to ship any new dental calculus samples from our find sites in Mongolia to our labs in Germany. So we changed our plans and decided to concentrate our energies on bioinformatics—and we made excellent progress.

What sort of progress?

When we find DNA sequences in prehistoric dental plaque, it's critical to know whether we're dealing with ancient or contemporary genetic material—which might stem from a contamination on site. Bioinformatics methods are very helpful here, because they render sequences in the genetic material visible. But first we had to develop the software programs for the analyses, which we did last year. That's what enabled us to study the calculus samples we had already collected.

Have you already found antibiotic agents?

Our job is to pass on our analyses of the samples to Pierre Stallforth and his team. They're specialised in seeking specifically for antibiotic substances—and they've already found several interesting candidates. This is the beauty of our project: we're doing something useful for the present age while also learning more about the past.

Can you explain what you mean?

When my group analyses the archaeological specimens, we're also studying the evolution of the oral microbiome, meaning all microbes in the mouth. Because traces of microbes remain in dental calculus for millennia, they can provide answers to unresolved questions on human history.

What insights have you gained so far?

We made some very surprising discoveries and published articles in major journals last year. For example, we compared the dental plaque of modern humans with that of both Neanderthals and primates like chimpanzees and gorillas. We found out that ten groups of bacteria have made up the largest part of the oral microbiome for some forty million years. This suggests there is a stable core microbiome. At the same time, however, half of these bacteria are poorly studied and don't even have a name.

We modern humans and chimpanzees have similar microbes in our mouths?

We do indeed have the same ten main groups of bacteria, but they present differently. The major differences are found in a certain streptococcus subgroup. This kind of bacteria is almost entirely absent in chimps, but it's the major group in both humans and Neanderthals, where the oral microbiome consists largely of streptococcus bacteria.

Why is that important?

This streptococcus genus is specifically adapted to breaking down starches—or carbohydrates. The fact that they're also abundant in the mouths of Neanderthals suggests that starchy foods like roots, tubers and seeds played a role in the human diet already long before the advent of agriculture and the evolution of modern humans.

Is this a new insight?

Yes, it is, and it has very interesting implications. A big brain needs lots of energy, and starch is the most energy-rich source of food. So this might imply that our ancestors began developing bigger brains because they began eating more starch. Until now, the theory was that larger brain size came about when our ancestors started hunting, and that animal protein was the decisive source of energy.

Are there even more secrets hidden in ancient dental plaque?

Yes, I'm certain that dental calculus will reveal more about how the brain in hominids evolved. And it might help resolve other unanswered questions like when we began using fire. Starch is more digestible when it's cooked, so it's possible that cooking became part of human history much earlier than previously thought. Of course, there are no answers yet, but our findings are very thought-provoking. What's particularly inspiring about our work is that we've made so many discoveries already in the process of working towards the project's goal of finding antibiotic agents.

Funding from the Werner Siemens Foundation
10 million euros

Project leader
Dr Pierre Stallforth, Head of Palaeobiotechnology at the Leibniz Institute for Natural Product Research and Infection Biology – Hans Knöll Institute in Jena, Germany

Academic partner
Prof. Dr Christina Warinner, group leader of Microbiome Sciences at the Max Planck Institute for Evolutionary Anthropology, Leipzig, Germany, and Associate Professor at Harvard University in Cambridge, USA

Project duration
2020 to 2029

Gut bacteria to treat cancer

Update: MedTechEntrepreneur Fellowships funding programme at the University of Zurich

Molecular biologist Dr Ana Montalban-Arques in her lab at the University Hospital Zurich: thanks to a MedTechEntrepreneur Fellowship from the University of Zurich, she is preparing her promising, patient-friendly colon cancer treatment for market entry.

Molecular biologist Ana Montalban-Arques is preparing her novel colon cancer treatment for market entry—thanks to a MedTechEntrepreneur Fellowship from the University of Zurich.

The millions of miniscule but powerful microbes that inhabit our body and gut—collectively known as the microbiome—have long been a source of fascination for Dr Ana Montalban-Arques. Ever since her first in-depth study of microbes for her master's thesis over ten years ago, her interest in intestinal bacteria has grown steadily. "Science is increasingly showing the extraordinary effect that these microscopic organisms have on our bodies," says the postdoctoral researcher. "Microbes don't just help us digest food—they also fortify our immune system."

From Spain to Switzerland

After studying molecular biology in her homeland of Spain and completing her PhD in Austria, Montalban-Arques took on a postdoctoral position in 2018 in microbiome research at the University of Zurich (UZH) and the University Hospital Zurich. With her team, she has demonstrated that patients with colorectal cancer—the most common form of colon cancer—have a different composition of gut microbiome compared to healthy persons: they lack sufficient bacteria from the Clostridiales order. When Clostridiales bacteria are administered to mice with colon cancer, their immune system becomes strong enough to effectively attack the tumour—with no side effects whatsoever. Moreover, her team has proven that the treatment is effective not only for colon cancer—the bacteria can also activate immune cells to combat tumours in skin, breast and lung cancer.

Promising bacterial mix

These results bode well for the future, especially as a considerable percentage of cancer patients respond poorly to current treatments or suffer a relapse—a situation that inspired Montalban-Arques to venture into entrepreneurship and translate her research results into patient care. Supported by her professor, Michael Scharl, she successfully applied for a UZH MedTechEntrepreneur Fellowship; now she has until March 2022 to prepare for her future role as entrepreneur and CEO of "Recolony", her spin-off company.

"There's much to learn, as the world of entrepreneurship is new to me," she says. The MedTechEntrepreneur Fellowship, which is financed by the Werner Siemens Foundation, will support her project with coaching, networking events and entrepreneurial know-how, including information about patents and regulatory procedures for pharmaceutical products.

The next step for the team on the path to a marketable product is to produce the bacterial mix in freeze-dried capsules that are simple to administer. In the best-case scenario, the mix will form the first-ever cancer therapy that not only uses bacteria to enhance the effectiveness of other immunotherapies, but in which the microbiome itself functions as a stand-alone immunotherapy. Ultimately, the Clostridiales bacterial mix could help heal colon cancer, stop relapses from occurring and prevent the growth of tumours in at-risk persons.

Effective against various cancers

In addition to professional support, the MedTechEntrepreneur Fellowship from UZH includes a grant of 150 000 Swiss francs, which Montalban-Arques will use to finance the production of the bacterial mix. Her project is also supported by the Swiss National Science Foundation.

Should the clinical trials go according to plan, the medication will be ready for market in 2030. But Montalban-Arques already has a greater vision: "My aim is to develop specific bacterial mixes as an immunotherapy for different types of cancer."

Cultivating networks

Ana Montalban-Arques is one of thirteen MedTechEntrepreneur Fellows. Since the launch of the programme in 2018, twenty-eight junior researchers have submitted applications, and six new companies have already been established. "Covid-19 couldn't put a dent in our will to found companies," says Michael Schaepman, President of UZH and former head of the fellowship programme. "The fellowship holders have overcome the challenges posed by the pandemic. And they'll benefit in future from this unforeseen experience."

The pandemic has underscored the value of mutual support and knowledge exchange among the fellowship holders, as they often face similar challenges, such as how to build a team or finance their company. "With the increasing number of current and completed projects, it's becoming more and more important to promote networking among the fellows," says Schaepman. Plans are under way not only to expand networking opportunities among current fellows, but also to establish exchange with former fellowship holders. Indeed, their know-how and experiences are invaluable for future entrepreneurs.

Funding from the Werner Siemens Foundation

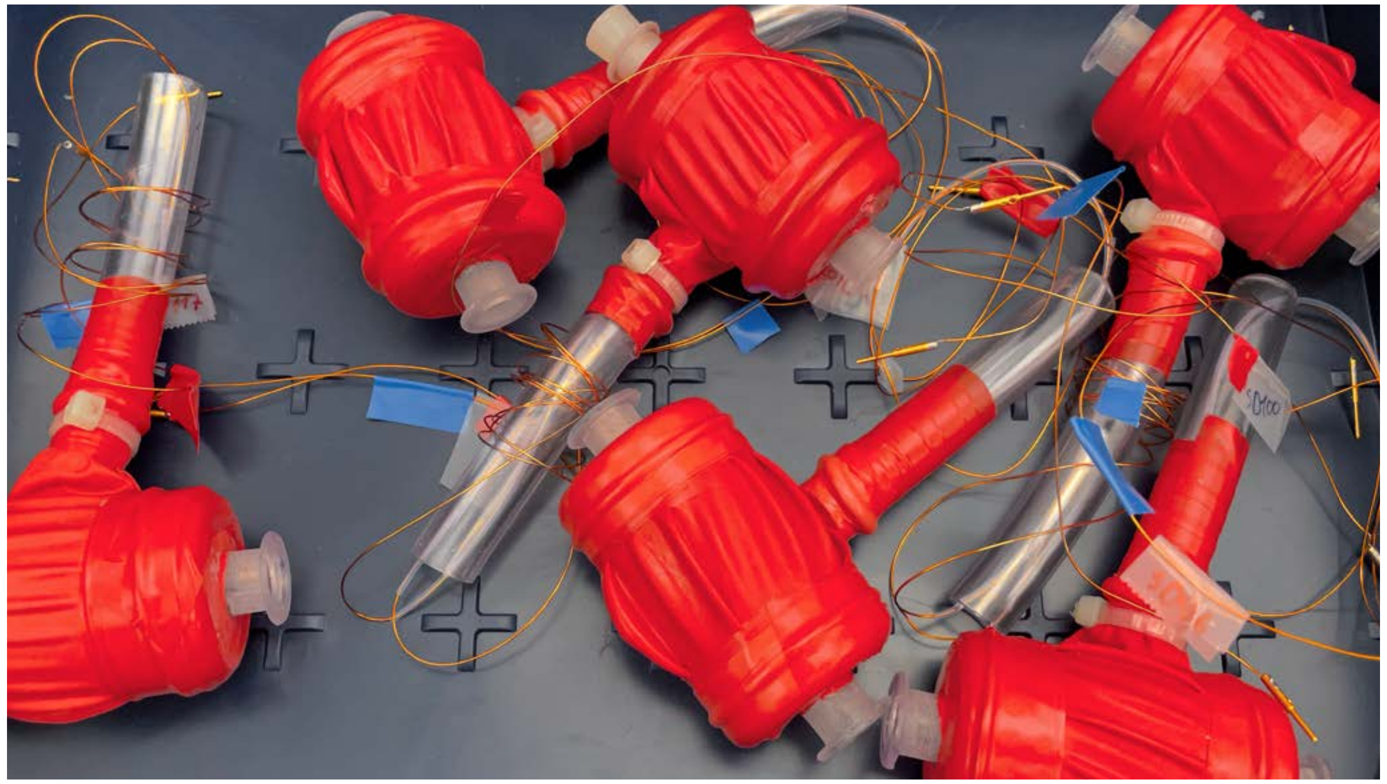
10.67 million Swiss francs over a period of 10 years

Project leader

Prof. Dr Elisabeth Stark, Vice President Research, University of Zurich (UZH), Switzerland

Project duration

2018 to 2027



The artificial muscle inserted in the aorta can now muster 7000 volts to give weak hearts a boost.

A portable heartbeat

Update: Center for Artificial Muscles in Neuchâtel

Placing an artificial muscle in the aorta to support the hearts of patients with cardiac insufficiency—this is the aim pursued by researchers at the Center for Artificial Muscles. And they are nearing their goal in leaps and bounds: after just a three-year development phase, they have now tested the first prototype of their artificial muscle on a pig heart—with very encouraging results.

Some two hundred thousand people in Switzerland suffer from cardiac insufficiency. Medication is generally prescribed to treat the disease, but the heart's pumping capacity often diminishes over time. In severe cases, ventricular pumps are inserted to help the weakened organ do its job until a donor heart is available. However, this life-saving measure has its price: invasive surgery is necessary to place the mechanical pumps inside the heart, where they can cause wear and tear on the heart lining and destroy red blood cells. Now, researchers at the Center for Artificial Muscles (CAM) at the École polytechnique fédérale de Lausanne (EPFL) are working on a less invasive solution—an artificial muscle that is fitted into the aorta to give weak hearts a boost.

Soft and elastic

In contrast to ventricular pumps, the artificial muscle consists of a soft, elastic material and does entirely without rigid metal parts. "It's malleable and can meld with the tissue," says microengineer and CAM director Yves Perriard. The muscle expands and contracts to change the circumference of the aorta and thus the pressure exerted on the left ventricle of the heart, which is responsible for pumping oxygenated blood through the aorta and into the body's circulatory system. The principle is as follows: if the artificial muscle helps the aorta dilate at the right time, the left ventricle can do its job of pumping blood through the body with less effort.

In essence, the artificial muscle is a plastic membrane encased in carbon layers capable of conducting electricity—and electrical impulses are what control the membrane. When an electrical current is switched on, the membrane expands; when the voltage is switched off, the membrane contracts again. The prototype membrane is encased in a stabilising plastic scaffold and covered with an additional thin layer to seal it off from body fluids.

Lab experiments were conducted and the principle was proven to work: to test the artificial muscle, the team developed an apparatus that simulates both heart chambers as well as blood circulation through the aorta. The muscle functioned as planned and reduced pressure in the left ventricle.

First operation a success

The first animal experiment was carried out in April of 2021. In a complex operation, surgeons made an incision in the aorta of a pig and inserted the artificial muscle, while also positioning several sensors that measure how the aorta muscle impacts the heart and circulation. "This trial was an extremely important milestone," says Yoan Civet, Managing Director of CAM. "If the aorta ring hadn't worked in the animal experiment, we would have had to completely rethink our approach."

But the test was a success—to put it mildly. The pressure on the animal's left ventricle dropped, and the impulses from the aorta ring helped the pig heart pump more efficiently. The heart muscles also expended less energy, and the flow of blood through the aorta increased. Moreover, the researchers gained a detailed understanding of how the movements of the artificial muscle in the aorta should be aligned with the pulse to provide optimum support to the heart.

Pocket-sized voltage

Currently, the artificial muscle can boost the pumping capacity of the left ventricle by roughly ten percent. About twice as much would be needed to support a human heart in the long term. "We're now focusing on finding ways to convey the necessary ten thousand volts into the body and to the artificial muscle," Perriard says. At present, electric cables are used to conduct the voltage; in future, however, the aim is to develop a wireless, portable power source. But "generating this much voltage in a small device is a major technical challenge", says Perriard. The team aim to miniaturise the electronic power supply in a step-by-step process by first reducing it to the size of a small box measuring roughly twenty-by-ten-by-ten centimetres, then to the dimensions of a device so small that patients could wear it. The researchers also have plans to take the design of the aorta ring to the next level. Specifically, they are seeking a way to wrap it around the aorta, thus avoiding an incision and preventing the artificial muscle from coming into contact with blood.

The heart is just a start

Artificial muscles could also help patients with facial paralysis or people suffering from urinary incontinence. The team have already launched their research into these areas. To alleviate urinary incontinence, the researchers aim to design a small ring that would be fitted around the urethra to function as an additional sphincter. For use in facial surgery, the team are collaborating with the University Hospital Zurich to develop flat membranes able to support, and possibly even replace, facial muscles.

Funding from the Werner Siemens Foundation

12 million Swiss francs

Project leader

Prof. Dr Yves Perriard, Director of the Center for Artificial Muscles (CAM) and the Integrated Actuators Laboratory, École polytechnique fédérale de Lausanne (EPFL), Switzerland

Project duration

2018 to 2029

Who we are

Daring darlings

The founders and benefactors of the Werner Siemens Foundation:
Charlotte and Marie—*Anna and Hertha*—Nora

Anna, the oldest daughter of industrialist Werner Siemens (left, in 1882), and her half-sister Hertha, twelve years her junior, transferred their substantial fortune to the Werner Siemens Foundation in 1931; the Foundation was established by their cousins Charlotte and Marie in 1923.

In recent years, several works exploring the history of the Werner Siemens Foundation have seen publication, including the 2020 double biography of Anna and Hertha Siemens, two of the Foundation's benefactors. Although Anna and Hertha led very different lives, the half-sisters remained close and, in 1931, they decided to bequeath the greater part of their substantial fortunes to the Werner Siemens Foundation.

Anna and Hertha Siemens were half-sisters; their father was industrialist Werner Siemens. Their childhoods, however, were strikingly different. When Anna was just six years old, her mother, Mathilde Drumann, died. Anna and her three siblings often had to do without their beloved father for weeks, as Werner Siemens was focused on establishing his firm, Siemens & Halske, and frequently away on business. By contrast, Hertha, twelve years Anna's junior, was the first child of Werner and his second wife, Antonie Siemens. At the time of Hertha's birth, Siemens & Halske was running smoothly and fifty-four-year-old Werner Siemens felt free to spend more time with his family—and quite literally stargaze with his youngest daughter.

Unlike sisters

The half-sisters were also decidedly different in character. Already as a child, Anna was called headstrong, resolute and somewhat shy, whereas Hertha was a peacemaker, good-natured and idealistic. In their married lives, the women were also separated by geographical distance: Anna wed the paper manufacturer Richard Zanders in 1887, and the couple settled in Bergisch Gladbach in Rhineland; Hertha married the chemistry professor Carl Dietrich Harries in 1899 and moved with him first to Kiel, then Berlin. But the two women also had much in common. In particular, they shared a deep love for their father and the large, far-flung Siemens family. And neither woman had children.

Beloved father

Werner Siemens was a devoted family man who cultivated a strong sense of community. Gregarious by nature, he often invited the families of his siblings and friends to spend weeks at his Charlottenburg estate in Berlin. This is how Anna and Hertha became close to their aunts, uncles and cousins from a young age. "My little children are thriving," Werner wrote to his sister-in-law in London in 1861. "Willi and Anna in particular are blossoming like young roses [...]. All the cousins spent nearly the entire day together and made a right lively, high-spirited little troupe." [1]

Before her death, Werner's wife Mathilde looked after Anna and her other children during his long business trips. She wrote frequent letters to her husband, enclosing photographs of the "darlings, our treasures".[2] Indeed, the frequent correspondence in the Siemens family was a major source of information for Anna and Hertha's biographers.

Early loss of mother

But Anna's happy early childhood was overshadowed by serious illness. She herself nearly succumbed to diphtheria, and her mother died of tuberculosis in 1865. It was a loss that left a deep mark on six-year-old Anna. Werner looked on in concern as his oldest daughter grew more and more reserved. He tried to offer fatherly advice: "Once you have understood that Christian love is the driving force that ennobles and blesses humanity [...], your heart will soften and be open to love, and this will make love grow yet more powerful." [3] But Anna continued down her own path, which was only partly in line with prevailing ideas of how a refined young lady should conduct herself.

Werner Siemens's second marriage

In 1869, Werner Siemens fell in love with Antonie Siemens, a distant relative from Hohenheim in southern Germany, and the couple married. Although Werner had hoped that Anna would welcome his second wife as a new mother, Anna refused point blank—despite her great love for her father. Yet not all was difficult, and young Anna also knew happier moments, filled with both carefree and notable experiences. When she was eleven years old, she was invited to the children's ball at the royal court. And when she was fifteen, her parents entrusted her with the demanding task of supervising construction work on the Charlottenburg villa during their absence. Werner sent her instructions from Ireland—letters that also reported on the dramatic difficulties of laying the transatlantic telegraph cable between Ireland and North America.

Half-sister Hertha

Born in 1870, Werner Siemens's youngest daughter, Hertha, had a much more harmonious childhood. In addition to her birthplace of Berlin Charlottenburg, she also had a home in Hohenheim in southern Germany, where her mother was from. She spent her summer holidays with her grandparents at the Hohenheim castle, making the acquaintance of university rectors, agricultural scientists, botanists, chemistry professors and future Nobel Prize laureate and discoverer of X-rays, Wilhelm Conrad Röntgen—and all their families.

Researchers as friends

At home in Charlottenburg, Werner Siemen's circle of friends also included scientists, giving young Hertha further opportunities to learn about the world of research; she was interested in physics and mathematics but also in painting. At the time, however, women were not allowed to study at university or at an art academy. It was only thanks to her father's active support that Hertha could attend some courses.

With Anna's marriage in 1887, all of Hertha's older half-siblings had left home. Hertha felt a little lonely and, as her father put it, sought to "bring some youthful life to the

Anna's early life was marked by tragedy, but her married life brought comfort and ease: at a tennis court with her husband, Richard Zanders (standing), and friends in 1887.

Happy times: open-minded Hertha with her brother Carl Friedrich during their student days in Munich (1895).

home".[4] But in reality, the old father and teenage daughter very much enjoyed their time together. They conducted experiments in the private lab at Charlottenburg and carried out studies in astronomy.

Travels with her parents

In 1890, Werner Siemens decided to visit Kedabeg and Kalakent in the Caucasus, where he and his brother Carl owned a copper mine. "Papa always acts as though it's impossible to take a young girl on such a journey. I'm waiting patiently to see what rules they'll impose on me," Hertha wrote to Anna.[5] Her patience paid off, as the adventurous trip taken by the small family turned out to be an unforgettable experience. "If there's such a thing as reincarnation, I was certainly once one of these half or entirely wild creatures that galloped through life on horseback. When things get downright crazy, I always feel right at home and very much alive," Hertha wrote from Baku.[6]

Werner's death

Werner Siemens spent more time with his youngest daughter than with any of his other children. They had the same inquisitive mind and shared a desire to understand the world in great detail. Hertha lived with her mother and father up to her marriage, and she took advantage of the privileges offered in her family home, becoming intimate with her parents' circle of friends and acquaintances. She acquired a natural ease at moving in the world, much like her father. This served her well when Werner Siemens died in 1892, at the age of seventy-six. Hertha was able to look forward and, despite being only twenty-two years old, claimed she felt like "a complete and rational human being with an opinion worthy of respect".[7]

A paper manufacturer and a chemistry professor

Both Hertha and Anna married for love, and both women actively supported their husbands' careers. Thanks to the extensive networks and the financial security the sisters brought into their marriages, many a difficult situation was mastered. However, neither sister was spared misfortune: Hertha's child, born on 11 November 1900, survived only fourteen hours, and Anna's husband was killed in a tragic gun accident in 1906. The fact that Anna and Hertha had no children may partly account for their lifelong commitment to philanthropic causes.

Philanthropic work

In 1909, Hertha established the Hertha von Siemens Foundation, whose mission was to enable employees and managers at the Siemens factories to take affordable holidays in Bad Harzburg. Hertha also looked after affairs at the Siemens children's home and had the Siemensstadt day-care facilities enlarged. She also used her understanding of art to purchase works by as-yet unknown artists, including an autumn landscape by Vincent van Gogh, which she bought in 1905 when the Dutch artist was still highly controversial.

Anna was instrumental in developing an avant-garde housing project that she initiated with her husband in 1897 and maintained after his death. The "Gronauer Wald" project was designed as a single-family housing estate near the forest, and all strata of society were welcome to move in—from working-class families to company managers. The project was a success, and by 1937, five hundred and twenty houses had been constructed. In addition to her philanthropic work, Anna was committed to fostering close ties among the large Siemens family. She worked with forty-nine of her relatives to set up a family foundation. And she worked tirelessly to buy the house in Goslar that had belonged to the first known member of the Siemens family, later converting the building into a museum.

War and inflation

The Siemens family was impacted by the hyperinflation that raged through Germany in the aftermath of World War I. In December of 1918, Hertha took on the delicate task of showing Anna the economic difficulties facing both the Siemens factories and the family finances.

Their experience of inflation and currency reform—not to mention the fact that Communist Russia had expropriated and expelled their cousins Charlotte and Marie—led Hertha and Anna to consider how they should best safeguard their assets. In 1926, the two women (both of whom were widowed by this time) agreed to sell their Siemens & Halske shares to the Mira Treuhandgesellschaft AG (a trust company) in Schaffhausen, Switzerland. They had the purchase price paid out in annual instalments, and the balance earned interest at Mira, thus providing Anna and Hertha with a secure income.

Generous benefactors

Five years later, in 1931, Anna and Hertha transferred their Mira assets (roughly 1.4 million Swiss francs) to the Werner Foundation established by their cousins Charlotte and Marie in 1923; the Foundation also assumed Mira's other duties. In their wills, both women stipulated that the rest of their assets would go to the Werner Foundation, with the aim of ensuring long-term benefits for the descendants of Werner and Carl von Siemens. It was also around this time that the sisters changed the name of the Werner Foundation to the Werner Siemens Foundation.[8]

On 19 December 1938, Anna celebrated her eightieth birthday. Her younger sisters and brother—Hertha, Käthe and Carl Friedrich—surprised her with a visit. It would be the last time that Werner Siemens's oldest and youngest daughter would meet: Hertha died the following January, and Anna in July of 1939. As though the two sisters had even agreed on the year of their death.

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1 Béatrice Busjan and Yvonne Gross: Anna Siemens und Hertha Siemens. Published by the Werner Siemens Foundation, Thomas Helms Verlag, Schwerin, 2020, p. 14.
2 Busjan/Gross, 2020, p. 19.
3 Busjan/Gross, 2020, p. 32.
4 Busjan/Gross, 2020, p. 126.
5 Busjan/Gross, 2020, p. 131.
6 Busjan/Gross, 2020, p. 133.
7 Busjan/Gross, 2020, p. 139.
8 Busjan/Gross, 2020, p. 194.

A patchwork family—the Siemens in their Charlottenburg villa circa 1875: Werner Siemens and his second wife, Antonie, holding their children Hertha and Carl Friedrich. Seated left and standing right: Arnold, Käthe, Willy and Anna, Werner Siemens's children from his first marriage to Mathilde Drumann, who died in 1865.

Governing bodies

Siemens Family Advisory Board

Descendants of Werner von Siemens and his brother Carl von Siemens sit on the Siemens Family Advisory Board. The Siemens Family Advisory Board supports the work of the Foundation Board and holds important veto rights.

Oliver von Seidel
Chair
Düsseldorf, Germany

Dr Christina Ezrahi
Member
Tel Aviv, Israel

Alexander von Brandenstein
Member
Hamburg, Germany

Foundation Board

The Foundation Board manages the ongoing activities of the Werner Siemens Foundation.

Dr Hubert Keiber
Chair
Lucerne, Switzerland

Prof. Dr Peter Athanas
Member
Baden, Switzerland

Beat Voegeli
Member
Rotkreuz, Switzerland

Scientific Advisory Board

The Scientific Advisory Board is an independent body that supports the Foundation Board in identifying suitable projects. Board members are responsible for reviewing and assessing the quality of proposals submitted to the Foundation.

Gianni Operto, Chair
Ebmatingen, Switzerland

Prof. Dr Gerald Haug, Member
Max Planck Institute for Chemistry
Mainz, Germany, and
ETH Zurich, Switzerland

Prof. Dr.-Ing. Dr h. c. Matthias Kleiner, Member
President of the Leibniz Association, Berlin, Germany

Prof. Dr Bernd Pichler, Member
University of Tübingen, Germany

Prof. Dr Peter Seitz, Member
EPFL, Switzerland

In conversation with Gerd von Brandenstein

Gerd von Brandenstein has stepped down after thirty-five years of dedicated service at the Werner Siemens Foundation.

Gerd von Brandenstein demonstrated considerable foresight throughout his successful thirty-five-year tenure at the Werner Siemens Foundation. He is now stepping down due to age and has passed the Chair to Oliver von Seidel. Both men are descendants of the founders of the Siemens group. Gerd von Brandenstein's great-grandmother was Carl von Siemens's daughter Marie von Graevenitz who, together with her sister Charlotte, founded the Werner Siemens Foundation.

Last summer, successor Oliver von Seidel paid a visit to Gerd von Brandenstein. The following is a conversation between two distant relatives and friends.

Oliver von Seidel: Which assignments on the Werner Siemens Foundation Board did you enjoy most?

Gerd von Brandenstein: The Foundation Board, the Board of Trustees* and the Scientific Advisory Board worked well together most of the time, and this collaboration gave me particular pleasure. An intense period I remember was around 2003, when we took on the challenge of converting the Werner Siemens Foundation into a mixed foundation—one focusing not only on the interests of the family but on philanthropic work, too.

And what did you enjoy less?

The job of explaining the uniqueness and special qualities of the Foundation to outsiders.

Do you have any personal highlights from your thirty-five years on the Foundation Board?

These would be the innovative projects we've been able to support. Their achievements continue to be of wide benefit and have been documented in the Werner Siemens Foundation's yearly report since 2017. The other thing that remains with me, and which pleases me greatly are the deep friendships that have arisen from this work. I hope that we can long continue these wonderful and personal relationships, even if my service is now over.

What do you see as the biggest challenge facing the Werner Siemens Foundation in the coming years?

During my time on the Foundation Board and as its Chair, I took part in decisions that led to substantial changes at the Werner Siemens Foundation. Here, it was of great importance to take the family's perspective into consideration. Today, a key issue is the growing difficulty of reconciling the Foundation's values and purpose with outside interests and an ever-expanding Siemens family. Protecting the Werner Siemens Foundation while including and fostering the family in a meaningful way is the goal the next generation must aim for. I believe they can do it.

What do you wish the family and the Werner Siemens Foundation for the future?

In my opinion, identity and a sense of belonging form the basis of a healthy family structure. My wish for the Siemens descendants is that, in addition to drawing inspiration from the past and strengthening their identity as members of the Siemens family, they can find new content that connects them, and that they will become ever more effective at generating their own resources. I am confident that—with the added support of the Foundation—this will be possible.

With regard to the Werner Siemens Foundation, do you know of any guiding principle in the family that has been passed down from generation to generation?

There is a phrase that has become etched in my mind over time—one I often associate with the approach to life held by the company's founder, Werner von Siemens, and his brother Carl: "Plus est en vous." French isn't my native language, but I know that this expression is not only an encouraging way of saying "It's your turn now"—it also means that the next generation are trusted to make "plus", meaning "more", of the future. The Siemens family are capable of this, I'm certain.

* In 2020, the Foundation Board and the Board of Trustees were renamed Family Advisory Board and Foundation Board respectively.

Selection process

Selection criteria

Every year, the Werner Siemens Foundation finances up to three new groundbreaking projects in the fields of technology and the natural sciences. The projects are generally conducted at higher education institutions in Germany, Austria and Switzerland. Requirements include upholding the highest standards and contributing to solving key problems of our time.

As a rule, each project is awarded generous funding of 5 to 15 million euros or Swiss francs. Projects are selected in a multistep procedure by the Scientific Advisory Board, the Foundation Board and the Family Advisory Board of the Werner Siemens Foundation.

In addition to projects, the Werner Siemens Foundation funds exceptional programmes in education and in the promotion of young talent in STEM subjects.

The Foundation does not support activities in the arts, culture, sports, leisure, politics, disaster relief, nor does it support permanent projects, commercially oriented projects, project co-sponsoring with other foundations, individual scholarships, costs of studying or doctoral theses.

Project application

Project proposals must be submitted in writing to the Werner Siemens Foundation. The selection process is as follows:

1 Project proposal is appraised for compliance with the Foundation's funding criteria
2 The Scientific Advisory Board evaluates the project
3 The Scientific Advisory Board presents its recommendation to the Foundation Board and the Siemens Family Advisory Board
4 The Foundation Board and the Siemens Family Advisory Board consider the project for approval
5 Final decision
6 Contract

The selection process takes approximately six months.

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