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The magazine for everyone who is passionate about science and research

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XPLORE

10 ideas for tomorrow’s world

A World Sustained by the Miniscule

No smartphone to connect us with friends all over the world, no car to guide us safely through the urban traffic, and no computer to process huge quantities of data across continents in order to give us answers to pressing questions within a matter of seconds – none of these achievements would be possible without micro- and nanotechnology. They are the small yet powerful key that drives innovation, creates connections and opens up horizons that appear beyond reach. All of this begins in Chemnitz, where tiny innovations make a big impact.

10 ideas for tomorrow's world

Dear Readers,

Innovations transform the way we live. They make our everyday lives easier, drive progress and rise to the challenges of the future. Yet it takes courage and creativity to break new ground before they can be turned into reality. Today's ideas are shaping tomorrow's world – a world in which cutting-edge technologies will enhance our lives. Behind these innovations are many bright minds who work every day in our research institute to help the economy and society progress through science. In our new annual magazine **XPLORE**, we give these people a face. They are representative of our entire team of committed colleagues who want to make our future a little better with their passionate inventive spirit.

Join us on a voyage of discovery as we explore ten exceptional ideas that we are working on with the aim of creating a pleasant, safe and sustainable future. Take a look behind the scenes of our research activities and gain fascinating insights into forthcoming developments.

Find out how we are making electronic systems more reliable, giving new impetus to the energy transition, creating new possibilities for agriculture with energy self-sufficient sensors and helping supercomputers to achieve peak performance.

We are researching these and many other fascinating projects together with our internal and external partners. Our special thanks go to these partners and our entire team – without them, none of our successes would be possible.

I hope you enjoy reading this magazine and discovering our ten ideas for tomorrow's world!

Best regards,
Harald Kuhn

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01 & 02

Subjects
Test and Reliability

By establishing the new European Test and Reliability Center, Fraunhofer ENAS is expanding its range of services in these fields. This center of excellence fills a gap in "Silicon Saxony" and will allow the institute to offer its customers in Germany, Europe and the world even more comprehensive support when solving complex technological challenges.

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"We find errors before they occur."

The Bridge over the Valley of Death

A center of excellence run by Fraunhofer ENAS and its partners, which is unique in Europe, is aiming to take the testing of semiconductors to a new level.

Integrated circuits are highly complex components. They are like megacities on a microscale. As many as several billion electronic components constitute the buildings, which are interconnected by an extremely fine and highly complex network of roads and bridges. Electrical currents flow along these roads, which, just like traffic in a city, serve a variety of purposes: gathering information, amplifying signals or storing data. These integrated circuits form the basis for virtually all modern electronic devices, from computers and smartphones to washing machines and cars. They make digitalization and thus technological progress possible in the first place – or they halt it when errors or failures occur.

"We aim to foster synergies and facilitate the transfer of knowledge to the industry."

Electronic systems are highly complex nowadays. The smallest defects that are not identified during the development phase can later lead to huge failure rates in the production stage or, in the worst-case scenario, during use. This is why testing and reliability assessments are becoming more and more important. Modern processes detect error sources at an early stage and prevent disruptions during operation. Innovations must also be tested under extreme conditions to ensure their reliability and durability for new applications in areas such as the automotive and energy sectors. Yet many small and medium-sized companies find it too expensive to maintain extensive departments and carry out the necessary preliminary research themselves.

External service providers, however, are primarily based in Asia, while in Europe there are still far too few opportunities to test semiconductor components. This gap, which is also of geopolitical significance, has now been closed by the new European Test and Reliability Center (ETRC) in Chemnitz. Prof. Harald Kuhn came up with the idea. The director of Fraunhofer ENAS brought it with him when he took up the post five years ago and has been working on it ever since. It is now a reality: "There are already a number of notable players in the Chemnitz region who have proven technical testing expertise. With the help of the ETRC, we will pool this expertise, aim to foster synergies and facilitate the transfer of knowledge to the industry."

Fraunhofer ENAS received start-up funding of more than 9.5 million euros from the Free State of Saxony to establish the ETRC. In order to run the center sustainably and increase its effectiveness, the plan is also to support it using financial contributions from the private sector. This combination of public funding and industrial financing is designed to establish the ETRC as a scientific beacon in Chemnitz, from which the regional economy will also benefit. Harald Kuhn sees the ETRC as a strong "pull factor" attracting notable high-tech companies to Chemnitz in particular and thus Saxony as a semiconductor location. "The ETRC will enable us to consolidate Germany's technological supremacy because companies will have the opportunity to test their innovations here in the future. Accordingly, we are making the semiconductor industry less dependent on geopolitical risks and international supply chains," explains Harald Kuhn.

Micrometer precision:
The 3D computed tomography scanner can be used to view and analyze the tiny internal structures of electronic components.

Setting standards in reliability testing

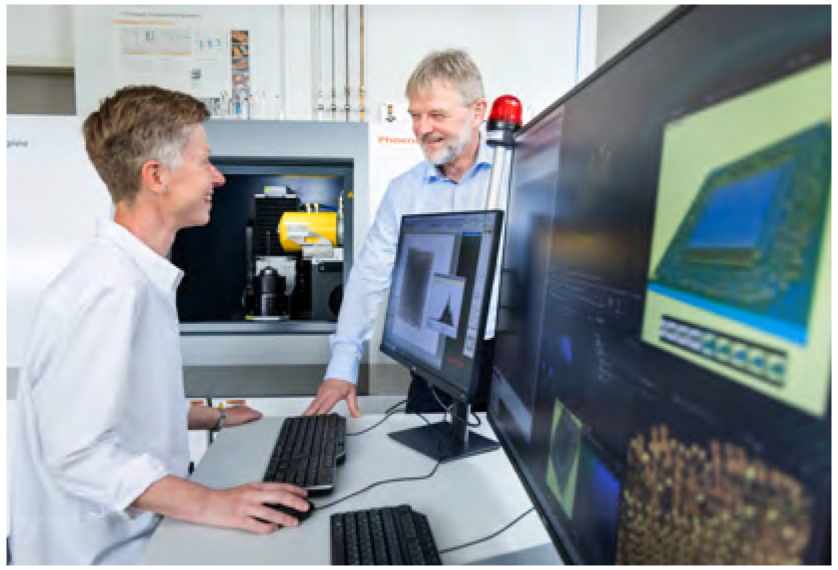
The scientific basis for the new center is based on Fraunhofer ENAS' history and experience in the field of thermomechanical reliability research. The experts in Chemnitz have been working in this field for around 30 years. In the 1990s, the early generations of Pentium processors were tested, giving way to more modern chips for mobile phone and smartphone models later on. "We are among the best in the world when it comes to reliability testing," says Harald Kuhn, who himself possesses extensive testing expertise: At semiconductor giant Infineon, he spent many years designing test systems, developing new test methods and making a number of industry contacts.

He now works with some of them as part of his role at the ETRC.

The center of excellence is fully integrated into Fraunhofer ENAS. From 2025, offices and test laboratories will be set up there in the existing buildings. The director of the institute was also able to attract external colleagues from the field of science as partners, including Prof. Ulrich Heinkel, Prof. Thomas Basler and Prof. Bernhard Wunderle from Chemnitz University of Technology. They teach and research on subjects such as formal test methods, mathematics, computer science and high-power reliability. "We will take a targeted approach to their involvement in the future and thus enhance our portfolio of expertise," he says. Then there are strategic industry partners from all over the world, who will contribute their experiences and practical requirements.

Around 18,500 small and medium-sized enterprises (SMEs) are based in Chemnitz and the surrounding region, mainly in the automotive and mechanical engineering sectors, which are currently undergoing fundamental change.

Elke Noack and Sven Rzepka evaluate the 3D CT scan of a new electronic component.



Electronics is setting the pace of innovation here. These companies need effective support to perform the necessary tests. In the ETRC, such tests are being given a new platform – and a community that facilitates close cooperation to set projects in motion. "Together with the professors at the universities, the numerous SMEs in Saxony and international industry partners, the ETRC constitutes a strong and powerful consortium without equal in Europe," says a delighted Harald Kuhn: "And at the heart of it all is Fraunhofer ENAS."

Flawless from the outset

One important aim of the ETRC is to identify future trends at an early stage and stay at the forefront of developments – not least in areas such as artificial intelligence (see article on page 14), neuromorphic computing (see page 30) or quantum technologies (see page 20). Besides Fraunhofer ENAS, other institutes of the Fraunhofer-Gesellschaft have also been researching quantum technologies for a number of years. However, these technologies need to be tested before they can be used in practice – an area that has often been neglected in the past and has proven to be extremely challenging from a technical perspective. Harald Kuhn explains: "We are making the testing of quantum systems one of our core focus areas because they will have a significant impact on our future."

"This opens up new perspectives for the future."

Fraunhofer ENAS is thus also fulfilling a key commitment of the Fraunhofer-Gesellschaft by bringing scientific developments out of the laboratory into industry. All too often, innovations only reach a technological readiness level that proves their functionality under laboratory conditions, but not beyond. They end up in the "valley of death." This is the name given to the phase in which most innovations falter. The development process ends before they reach market maturity. Harald Kuhn wants to change this with the new center: "We are building a bridge over the valley of death by ensuring that defects are detected and eliminated by our testing routines in the design phase of new products and thus at an early stage. This enables us to ensure that electronic systems function flawlessly from the outset and can go into mass production more quickly. Technologies that previously would have failed are thereby making the leap into the economy and society."

The ETRC is built on two pillars: one focusing on tests, the other on reliability assessments.

Prof. Sven Rzepka is responsible for the second area at Fraunhofer ENAS. The engineer has been heading the department "Micro Materials Center" for 12 years. This is where chips and components used in micro- and power electronics undergo experimental testing. The aim of these tests is to ensure that products meet their promised lifespan and that their design, materials and construction are optimally chosen to achieve the required level of reliability. "To this end, we expose prototypes to thermal stress and accelerated aging processes and then inspect them under the microscope or using computed tomography," explains Sven Rzepka.

Testing is a game changer

However, he has less and less time for protracted experiments and evaluations because the development cycles of new products are getting shorter. " At the same time, reliability assessments are getting more complex," says Sven Rzepka. There are numerous examples of this, such as autonomous mobility, Industry 4.0 and smart grids: "More sensors, storage systems, processing units and converters are being installed everywhere to measure the environment, understand data, make decisions and then act on them," says the experienced engineer. However, the number of potential error sources will also increase with every component and every additional functionality. In autonomous vehicles, for example, real high-performance computers must be used and they need to work under extreme conditions: "Whether the car is exposed to extreme temperatures of -40 °C during a cold night in Finland or heats up to +80 °C while parked outside the supermarket in Sicily, whether it rains, snows, or potholes rattle everything around – the electronics must work perfectly in all these scenarios."

Test and reliability specialists such as Sven Rzepka are responding to the trends that are cutting development times and driving a need for systems to be more complex and resilient. He explains: "We want to replace many physical tests with simulations that are 100 to 1,000 times faster." A central aspect of his work is the "digital twin" – a digital image of the real product that interacts with its physical counterpart in real time. This can be used to assess the product's reliability within a matter of hours, instead of taking weeks or months.

Sven Rzepka also programs digital twins for particularly critical components. These are not used during the development phase, but during the operation phase of the electronics and are responsible for determining the so-called "remaining service life" of the component. Each of these programs monitors a critical component and warns of any impending failure in a timely manner. These warnings mean that the system can be regulated, switched off and serviced in good time before any damage occurs.

Digital twins are versatile and efficient. Precise knowledge is needed to be able to use them to realistically model the behavior of physical components. Practical experiments therefore remain indispensable because they provide the basic data for the digital twins. Thanks to the many years of experience possessed by Sven Rzepka and his team, the new ETRC at Fraunhofer ENAS already has an extensive library of test data and models at its disposal. This already makes it possible to carry out reliability tests for product updates by means of simulation. Sven Rzepka stresses: "We are constantly learning and continuously improving the performance of our digital twins. One day, we will be able to test and optimize new products using solely digital means." Mass production can begin immediately after that.

"We will soon be able to test and optimize new products using solely digital means."

This big promise is known as "first time right" and means that a new product works perfectly from the first batch. However, it requires a rethink in the development chain before it is possible. Institute Director Harald Kuhn points out that products and processes are often scaled at a time when they are still unstable because they have been insufficiently tested and verified: "With batch sizes running into the millions, this can prove catastrophic with an error rate of just one percent." He recommends considering tests and reliability assessments during the design phases of products and processes and integrating them from the very beginning. "This approach is known as 'design for test' and 'design for reliability,' and by embracing it we can significantly reduce the number of defective products and the development time."

03

Subject

Packaging for Power Modules

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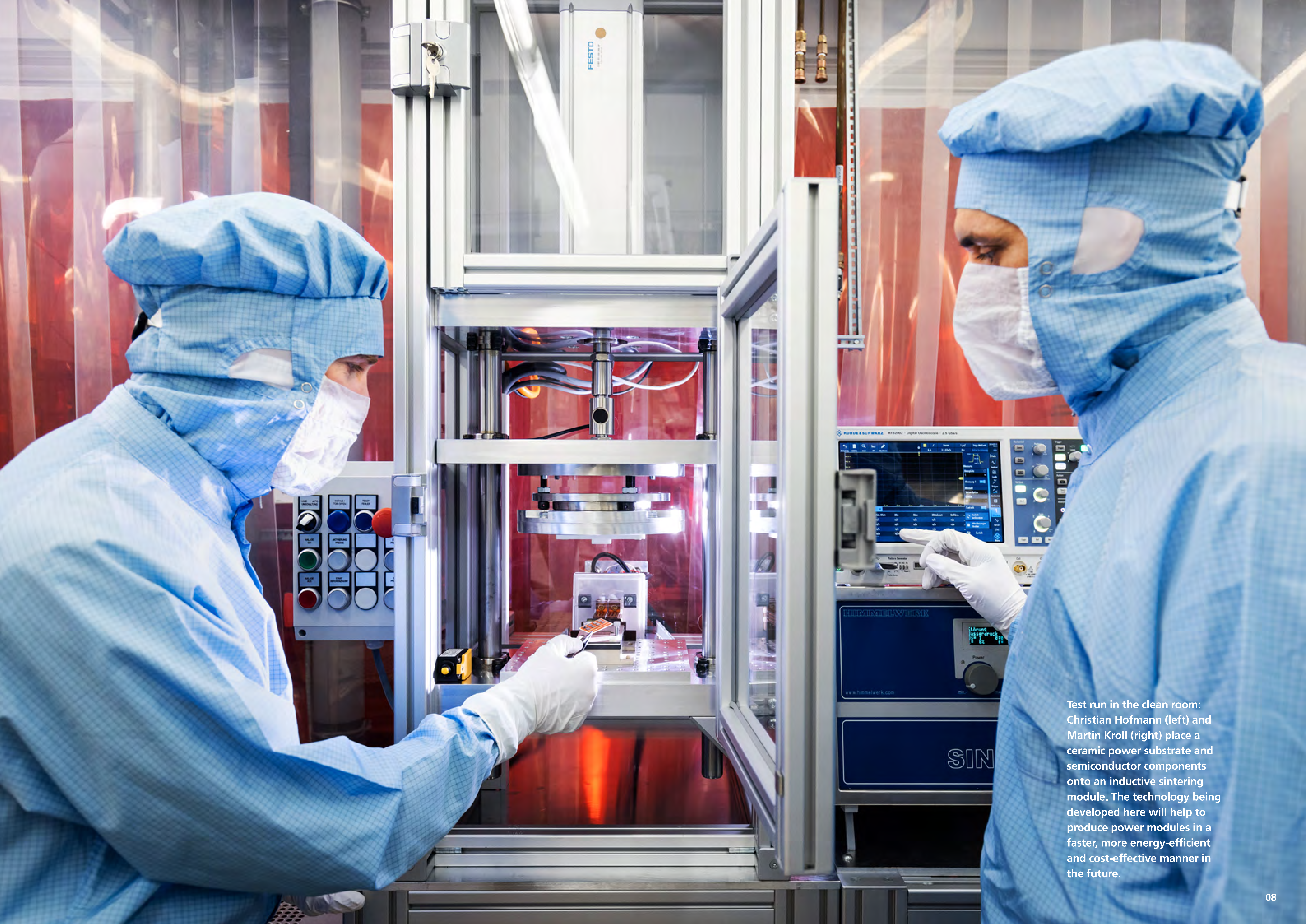
"We are solving the detailed issues of the energy transition."

Small things can sometimes have a big impact: The power modules that Christian Hofmann and his team work on at Fraunhofer ENAS could make it much cheaper to use renewable energy sources in the future.



Test run in the clean room: Christian Hofmann (left) and Martin Kroll (right) place a ceramic power substrate and semiconductor components onto an inductive sintering module. The technology being developed here will help to produce power modules in a faster, more energy-efficient and cost-effective manner in the future.

A Boost for the Energy Transition

Fraunhofer ENAS and Chemnitz University of Technology have developed a new process for producing power modules. This could make the production and use of renewable energy sources much cheaper.

Electric cars are regarded as the future of private transport. When they are charged with green electricity, they produce no emissions. This is in stark contrast to vehicles with combustion engines, new sales of which are set to be banned within the European Union from 2035. That is why a growing number of cars on Germany's roads are electric. Yet the number is growing more slowly better than hoped for – and that is mainly due to the price.

In Germany, it is hard to find a new electric car priced under 25,000 euros. Prices need to fall if the mobility transition is to be a success.

Engineers are therefore trying to optimize the vehicle components and streamline their production. The parts need to be more powerful and, at the same time, less expensive. With the aim of making a key contribution to this essential aspect of the mobility transition, Christian Hofmann from the "System Packaging" department at Fraunhofer ENAS is conducting research into new bonding processes for the manufacture of power modules. These are responsible for converting and managing electrical energy. The background: Green electricity is supplied either as alternating current – from wind turbines, for example – or as direct current from facilities such as solar farms. The electrical energy must be converted into alternating current for the power grid. However, batteries used in electric vehicles, for example, can only be charged with direct current and only produce direct current. Electric motors, on the other hand, generally require alternating current. Accordingly, these currents have to be converted several times during transmission.

The necessary power modules are core components of electric vehicles and have become more and more powerful over the course of time. As a result, ever larger currents are now flowing in ever smaller spaces: "To prevent the electronics in the modules from overheating, the biggest challenge involves dissipating the heat generated quickly and reliably," says Christian Hofmann. This is where the new process comes in: Together with colleagues from Fraunhofer ENAS and Chemnitz University of Technology, the scientist is developing a promising new process for manufacturing these modules: inductive particle sintering.

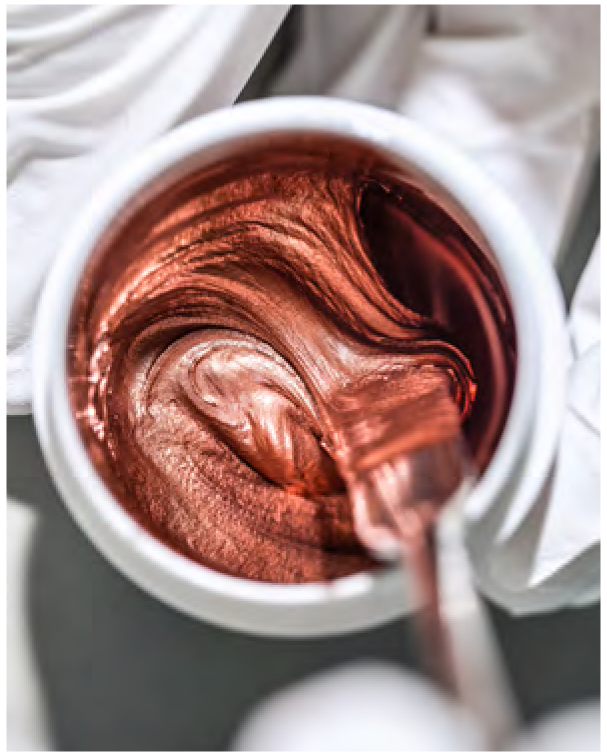
From the workshop to the laboratory: Martin Kroll, research associate at Chemnitz University of Technology, examines a classic induction coil. His team's aim is to make the operating principle of such coils suitable for use in the field of microtechnology.

E-cars, photovoltaics and wind power are possible uses

With particle sintering, the microchips no longer have to be soldered onto the module components, which significantly improves thermal conduction. Instead, they are assembled using a paste of microparticles made up of the metals silver or copper, both of which exhibit high thermal conductivity. "We are trying to optimize this so-called sintering process to the greatest possible extent," says Martin Kroll, head of the "Thermal Bonding and Process Technology" department at Chemnitz University of Technology, who is working on inductive particle sintering together with Christian Hofmann.

What makes the research of Christian Hofmann and Martin Kroll so unique is that they have managed to sinter the chips by means of inductive heat input. Instead of heating the entire component to bond the chip, they can bring selective parts of the sintering paste to temperature – in a "minimally invasively" manner, so to speak. This has several advantages:

It protects the component from temperature damage, consumes less energy, is significantly faster and also more cost-effective. "This makes the modules more reliable, more durable and less sensitive. They can withstand harsh environments and environmental influences as well as high energy and heat densities," explains Christian Hofmann. These are all factors that help to achieve the major goal of making e-mobility more attractive. What's more, such modules could also be used in photovoltaic plants and wind turbines in the future.



Special formula: With the help of this sintering paste, which consists of copper particles, binding agents and other additives, the semiconductor parts are bonded to the module components. The paste is supplied by the company Heraeus Electronics GmbH & Co. KG.

> **"The modules are getting more reliable and more durable."**

Until 2026, the interdisciplinary team of Fraunhofer ENAS and Chemnitz University of Technology will be working on putting these findings into practice in specific applications, as part of the "KuSIn" cooperation project, among others. Together with the automotive supplier Schaeffler, the technology group Heraeus Electronics, the plant manufacturer Budatec and the Fraunhofer Institute for Microstructure of Materials and Systems IMWS, they are developing copper-based sintering pastes, tools, machines and processes with the aim of using the inductive particle sintering of microelectronic silicon carbide chips to manufacture power modules for electric motors on an industrial scale. "We are currently testing the induction sintering process, together with a new sintering paste, on ready-to-use components for the first time. We see this as an opportunity to establish Chemnitz as the world's leading research location for inductive heating processes in microtechnology," says Martin Kroll.

04 Subject
Artificial Intelligence

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"We are accelerating research with the aid of algorithms."

In order to drive technological innovation, we need faster development of powerful microchips. Dr. Jan Langer and his team at Fraunhofer ENAS are researching into what contribution AI can make.

Patterns in a Sea of Data

In the global innovation race, new semiconductor chips must be developed at an ever faster pace. Research is being carried out at Fraunhofer ENAS to establish how artificial intelligence (AI) can help.

Exploiting the wealth of data: Tom Rothe from Jan Langer's team oversees the development of new chips at Fraunhofer ENAS. This process could get much faster in the future with the aid of artificial intelligence.

> **"We bring together knowledge spanning various disciplines like few other research institutes."**

When microchips or nanosystems are being developed at Fraunhofer ENAS, Dr. Jan Langer's team often looks over the shoulders of the researchers in the laboratories. Not that they literally stand behind them to observe every movement. They are actually keeping an eye on the large amount of data that is generated in the course of the manufacturing processes in the plants.

They analyze the sea of data that is created during the development of semiconductors with the help of AI algorithms: "If we can gain a deeper understanding of the processes taking place here, we can optimize them," says Jan Langer. The 44-year-old engineer heads the "Data-Based Methods" team, which was set up at the institute in 2021. The team is now made up of eight scientists, supported by students from a wide range of disciplines such as mathematics, physics and electrical engineering.

At the start of the process chains that they analyze is usually the silicon wafer that serves as the basis for the chips and systems. Layers of different materials, such as silica or metal, are gradually added to it. This process can best be compared to when a confectioner builds up different layers of dough and cream to create a cake. When manufacturing semiconductors, physical and chemical processes are used to incorporate the finest structures into each layer that is added to the wafer. These are up to 10,000 times thinner than a human hair. They are filled with copper, for example, and any irregularities are then polished off to create a perfectly smooth surface. The technologists call this process "planarization."

Digital twins save resources

To ensure that a chip ultimately works, each of these highly complex processes must be performed in exactly the right order. The slightest of deviations would render the chip useless. The problem when developing new chips, however, is that at the beginning of the process chain, nobody knows the most promising "recipe" for the process. It still needs to be developed. And this is precisely where AI can help. It is able to recognize patterns among the vast mass of process data and show researchers the way. "Based on the data and our prior knowledge of the process, we use AI to construct a digital twin that allows us to simulate the end result of the new process. Our models can thus save an incredible amount of time because development processes are accelerated and measurement steps during production are superfluous," says Jan Langer.

During development, the researchers draw on the experience of the experts in their team and embrace the principle of trial and error, explains Jan Langer. "We keep on experimenting until the result is satisfactory." However, this approach is problematic for two reasons. Firstly, it takes too long. "Ever faster innovation cycles require new chips and systems at ever shorter intervals," says Jan Langer. Their development must therefore be accelerated. Secondly, the environmental factor must be considered. "The experiments produce harmful substances that must be disposed of properly." The advantage of digital twins is that they save valuable resources.

Interdisciplinary expertise at Fraunhofer ENAS

Jan Langer and his team are still analyzing the process chains primarily on the basis of data generated in the clean rooms of Fraunhofer ENAS. "But we are already in talks with companies to gain an insight into their data," says Jan Langer. He is confident that there will soon be greater demand for their methods. Partly because there is growing pressure on manufacturers to accelerate their development processes. But also because Fraunhofer ENAS is in "pole position," as it were: "At many institutes around the world, data scientists and microtechnology experts mostly work independently of each other," says Tom Rothe. That is why the 27-year-old physicist decided to join Jan Langer's team: "We bring together knowledge spanning various disciplines like few other research institutes. By having a direct communication channel to our technology and simulation experts, we are creating the ideal conditions to make tremendous advancements in this area in the coming years."

05 Subject **Sensors**

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“We supply power plants as small as a fingernail.”

In the future, sensor platforms that supply themselves with energy could monitor processes in agriculture, logistics or production. The sustainable technology is currently being developed by Dr. Alexander Weiß and his team at Fraunhofer ENAS.

Continuous Monitoring with Zero-Power Sensors

Big hopes:
Alexander Weiß and Katja Meinel with a prototype of the zero-power sensors, which has been developed in conjunction with the universities in Chemnitz, Paderborn and Bochum. The technology could soon replace countless sensor batteries in plants and machinery.

The idea of an energy self-sufficient sensor for monitoring mechanical parts is nothing new – but a team from Fraunhofer ENAS has produced a solution for the first time using piezoelectric transducers.

Anyone who checks in their suitcase at Frankfurt Airport is sending it on a journey before it has even taken off. After the check-in process, it travels along miles of conveyor belts before being sorted in large halls and finally loaded onto the plane. Several thousand motors drive this system. Even if just one of them fails, besides bringing the suitcase operation to a standstill, the fault can delay processes throughout the airport.

To prevent this from happening, each individual motor could be monitored by a sensor in the future. If it detects unusually strong vibrations, it triggers an alert. The motor is then serviced before any damage occurs. This is known as predictive maintenance – one of the most promising aspects of a networked Industry 4.0. It is set to significantly reduce machine downtime.

Intense activity behind the scenes:
At Frankfurt Airport, miles of conveyor belts deliver travelers' luggage to the right gate. Systems like these could be monitored by energy self-sufficient sensors in the future.

"If we wish to turn this vision into reality, we need countless sensors," says Dr. Alexander Weiß, head of the "Smart Systems" business unit at Fraunhofer ENAS. However, so many networked sensors would not only consume huge amounts of electricity, they would also have to be regularly serviced and – if they are powered by batteries – generate a great deal of toxic hazardous waste. Unless the sensors could supply themselves with energy. Self-sufficiently.

Sustainable sensor concept: no wear, no waste

That is the idea behind zero-power sensors. What was long considered utopian has been turned into reality by a team of eight people at Fraunhofer ENAS in cooperation with partners from Chemnitz University of Technology, Ruhr University Bochum and Paderborn University. Together they have developed a sensor that draws energy from the movement of the part it is monitoring. It also has a built-in memory, where the sensor stores how long and how strongly it vibrates. This information can be read out at any time via a wireless interface.

What is particularly special about the concept is that even if the monitored component is idle for a longer period of time, meaning no energy is supplied to the sensor, the data in the memory is secure.

"Our sensor is maintenance-free and can be operated indefinitely."

"Our sensor is maintenance-free and can be operated indefinitely," says Alexander Weiß. There is no wear, no fatigue and no waste.

The data is stored in the resistor

The innovative sensor developed by Fraunhofer ENAS has three components: a piezoelectric transducer that serves as the energy source, a memristor, the data storage unit, and an interface for reading out the information and resetting the memristor.

The piezoelectric transducer is at the heart of it all. It generates a voltage when forces act on it – for example, when the monitored part vibrates unusually strongly. It converts mechanical energy into electrical energy. Its current then flows into the memristor. This is a portmanteau of "memory" and "resistor." Alexander Weiß explains how it works: "The longer the memristor draws current from the piezoelectric transducer, the more its electrical resistance changes.” The change in resistance can be read out via the interface. This value indicates whether the part has been vibrating unusually strongly and, if so, for how long. When the data is read out, the memristor is reset to its original resistance. The sensor is like new.

Ideal for predictive maintenance

“We were the first research group in the world to design a piezoelectric transducer unit that can provide sufficient energy for the memristor even with the slightest vibrations,” says 44-year-old Alexander Weiß. “That was a major milestone.” And on a really small scale: The sensor’s energy unit measures just two square centimeters and has a total of 20 piezoelectric transducers connected in series. Even tinier is the memristor, which can be scaled down to a size of 600 nanometers.

The team spent four and a half years researching into the sensor before they were able to show under laboratory conditions that the zero-power concept works. Now the scientists still need to convince potential customers, ideally those in the mechanical engineering sector. The reason for this is that even a larger production machine would have to be monitored with hundreds of sensors in order to benefit from the advantages of predictive maintenance. Two suitable companies have closely accompanied and advised the project team in recent years: Ulrich Rotte Anlagenbau und Fördertechnik GmbH and MSF-Vathauer Antriebstechnik GmbH & Co. KG. “The former built the suitcase conveyor belts at Frankfurt Airport,” says Alexander Weiß. “I would say that the company could really benefit from our sensor.”

Mini power plant: This vibration detection system featuring a piezoelectric transducer and memristor will make it possible to operate energy self-sufficient smart sensors for Industry 4.0 in the future.

Ephemeral Technology

A team from Fraunhofer ENAS has developed a sensor system for agriculture that is almost completely compostable.

When conventional sensors develop a fault, they end up in the trash. Even if some components are recyclable, most of the resources are still lost. A team led by engineer Sven Voigt from Fraunhofer ENAS wanted to change this and asked itself the following question: Can we produce sensors made solely from environmentally friendly materials?

After three years, they managed to come up with a smart sensor system for agriculture that is almost completely compostable. Wherever possible in the design process, they avoided plastic and other toxic materials that do not easily degrade. In a second step, they substituted conventional components with environmentally friendly alternatives: They used biodegradable polyester, printed electronic switches on paper, and made sensors out of plaster or traces out of carbon: “These are all materials that decompose in the soil,” says 41-year-old project manager Sven Voigt. What’s more: “The materials are inexpensive. If we mass-produce the sensors, we are talking about a matter of cents.”

Plows can simply bury the sensors

However, some microelectronic elements still contain silver, copper and silicon. These valuable substances do not belong in the compost. As such, they must eventually be replaced in order to achieve the project’s aim. “But we have nearly done it,” says Sven Voigt.

Once the team has achieved this aim, the life cycle of the new sensor technology will look something like this:

The innovative sensors will measure soil moisture and nitrate values of cultivated fields, as well as the leaf moisture of cultivated plants. Farmers can use this information to target specific areas in need of irrigation or fertilization. This saves resources, protects the soil and optimizes yields. When the sensors reach the end of their life, they can simply be buried by the plow – and since they are completely degradable, they will even fertilize the field.

Recyclable: Sven Voigt from the “Smart Systems” Business Unit developed the sensor system that is designed to help farmers provide sufficient water or fertilizer.

06 Subject
Quantum Technologies

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“We trap ions – for business, research and security.”

Dr. Steffen Kurth and his team at Fraunhofer ENAS are developing quantum chips based on “ion traps.” The chips form the basis of quantum computers, which will play a key role in the expansion of computing capacity, research productiveness and cybersecurity in Europe in the future.

The Ion Trap

Ions are small, volatile and almost impossible to contain. Those who manage to control them could soon build a quantum computer that will change our world.

The dimensions in which quantum engineers think can best be illustrated using the example of a human hair. If the hair were split lengthwise into 700,000 equal parts, each of these hair slivers would be the same size as an ion, approximately 0.1 nanometers. And it is the ions that matter.

"We are witnessing the dawning of a new era," says Dr. Steffen Kurth from Fraunhofer ENAS. Ions, positively charged atoms, are close to being able to store information and perform computing functions, thereby ushering in a new era: the era of quantum computing.

Quantum computers could fundamentally change our world in just a few years. Their computing power exceeds that of conventional computers many times over. Decrypting a coded message, for example, which currently takes weeks to complete, could be done within a matter of minutes in the future. Quantum computers could also play a key role in efficiently developing materials, researching climate issues, performing calculations for new drugs or working out complex logistics routes. They will also play a pivotal role in energy-efficient data centers of the future and artificial intelligence. What's more, quantum computing represents a key strategic technology for states. "Germany and Europe must be at the forefront of this development in order to be able to successfully hold their ground in the global competition in the long term," says Steffen Kurth.

"We are witnessing the dawning of a new era."

Technological race

That is why Germany is investing a great deal of money in the development of a German quantum computer: Two billion euros have thus far been set aside for research and development projects, with another three billion earmarked for the coming years. Since it is not yet possible to tell which quantum technology will win the race, the government is supporting various approaches. These include quantum computers that make use of super-

Cybersecurity crime scene: Quantum computers could decrypt any message encoded in line with current standards within a matter of minutes. For this reason, work is already being done on "post-quantum cryptography" – an encoding process that also provides protection against quantum computers.

Steffen Kurth and Anne-Katrin Schumann, research associate at Fraunhofer ENAS, operating a wafer prober. Photonic components that are central to quantum chips of future generations are analyzed here.

conductors and those that require photons to work. There are also quantum computers in which ions interact with each other – and this is precisely the technology that the experts at Fraunhofer ENAS are researching under the direction of Steffen Kurth, financed with funds from the German Federal Ministry of Education and Research (BMBF) and the German Federal Ministry for Economic Affairs and Climate Action (BMWK).

The secret of "qubits"

The most important difference between quantum computers and conventional computers is the way in which they process information: Conventional computers work on the basis of bits, which can only be in one of two states: either 0 or 1. Quantum computers, meanwhile, work with "qubits," which, in simple terms, can be in several states at any given time. Another quantum effect, known as entanglement, sees the computing power of the system double in size with every qubit that is added to a quantum computer. Entanglement also enables a quantum computer to process data in parallel. It is mainly this effect that gives the computer its speed.

"In quantum computers that work on the basis of ions, individual ions carry the information and perform computing operations," says Steffen Kurth. Yet the researchers at Fraunhofer ENAS are facing a challenge: Besides their minuteness, ions are volatile and difficult to contain. The solution: an "ion trap." In very simple terms, this can best be described as a chamber in which there is an extreme vacuum. An ultraviolet laser is used to "shoot" atoms in this chamber in order to convert them into positively charged ions.

"Young people have the rare chance to help shape the development of a technology that has never existed before."

The challenge is to keep the ions stable

In order to store data on the ions, the scientists utilize their energy states, putting the ions into different internal energy states using laser light and microwave fields. This is how they add information to the individual ions and allow them to interact with each other. "We are talking about gate functions here," says Steffen Kurth. This process describes the actual task of computing. Laser light is used once again to evaluate the data. The ions react to it with a light pulse, thereby divulging the stored information. A camera observes these impulses and transmits them to a control computer.

One of the major challenges in all of this is to keep the ions – or qubits – stable. Any disturbance caused by heat or electric fields destroys their quantum state and renders the computing operation useless. Compared to quantum computers that are based on superconductors, for example, the quantum information in the ion trap is stable for a surprisingly long time according to Steffen Kurth. The scaling of the number of trapped ions represents another hurdle. "The quantum computer of the future should be capable of performing parallel computing operations with several hundred ions," explains Steffen Kurth. But there is still a long way to go.

The research team is currently working on integrating the individual elements of the ion trap – such as electrodes for trapping and transporting the ions, photodetectors, micromagnets, light paths for various lasers, microwave antennas and a whole host of electronic chips – into a complex ion trap chip that is only a few millimeters in size and has a three-dimensional structure.

In doing so, the institute's experts are drawing on their long-standing proficiency in the field of micro- and nanotechnology. This proficiency especially lies in the development of technologies for joining wafers and chips, so-called bonding, where three-dimensional microcomponents are produced by fusing them layer by layer. In recent years, research work at Fraunhofer ENAS has focused in particular on electrical and optical connections between the individual planes and optical metasurfaces. "We are now applying these findings to build ion traps," says the scientist.

Steffen Kurth is optimistic that this feat can be accomplished in three to four years. "But we wouldn't be able to do it on our own. Our partners from the Research Fab Microelectronics Germany (FMD) are indispensable to the work we do."

What's more, there are already companies and start-ups that are putting the work of quantum researchers to good use. In spring 2024, for example, the semiconductor manufacturer NXP presented an industrial-grade trapped-ion quantum computer in Hamburg, which was manufactured exclusively in Germany.

"This is a real milestone," says Steffen Kurth. At the same time, he wishes to make clear that "The era of quantum computing has just begun." A fact that will incidentally also have an impact on job prospects in this area. "Young people who are entering this field today have the rare chance to help shape the development of a technology that has never existed before. The global high-tech industry in particular will offer a wide range of attractive career opportunities in this area in the future."

Driving Innovation for Cutting-Edge Technology

The Research Fab Microelectronics Germany (FMD) pools the technological expertise of 19 leading research institutes in the fields of electronics, optics and laser technology in the project "Quantum and Neuromorphic Computing Modules" (FMD-QNC). The participating institutes share clean rooms and knowledge, providing a central point of contact for partners and customers from industry and the scientific community. The network is further strengthened by universities, which play a key role in the microelectronics innovation system. More than 5,000 people currently work at the institutes of the FMD, including more than 3,000 researchers.

07

Subject
Parylene-Based Packaging and Ultrasonic Transducers

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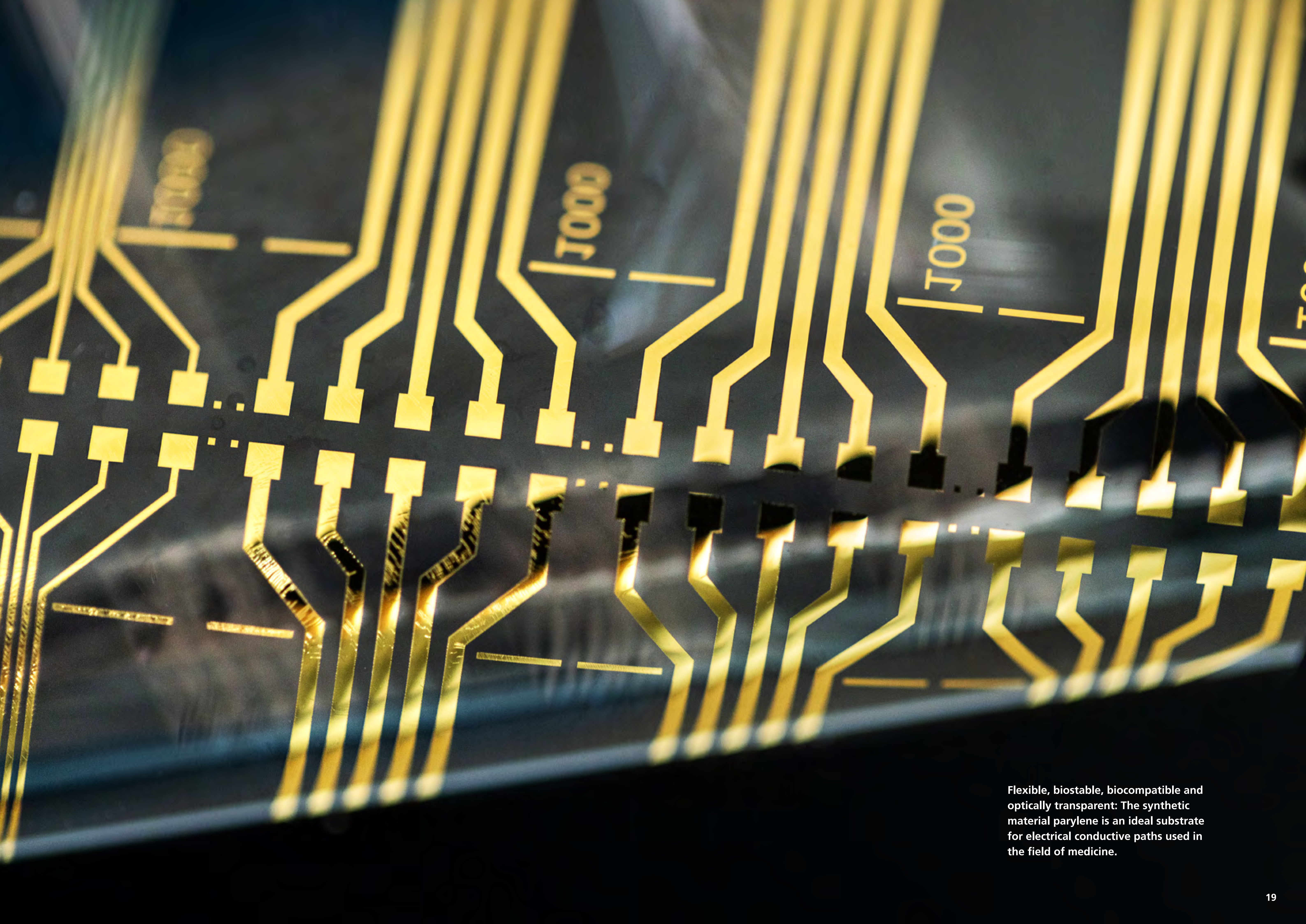
"We are paving the way for the medicine of the future."

An extraordinary substrate for flexible printed circuit boards and miniaturized ultrasonic transducers: Together with his colleagues at Fraunhofer ENAS, Dr. Maik Wiemer is setting the course for revolutionary medical applications.



Flexible, biostable, biocompatible and optically transparent: The synthetic material parylene is an ideal substrate for electrical conductive paths used in the field of medicine.

All-Around Talent for Microsystem Technology

The synthetic material parylene opens up completely new possibilities in the field of microsystem technology. At Fraunhofer ENAS it is used to develop printed circuit boards that are thinner than anything seen before.

Smart medical technology is increasingly being used to monitor vital parameters. And for good reason: Blood pressure sensors, pacemakers and insulin pumps help to maintain the health of chronically ill people and even save lives. The smaller devices such as active implants are, and the more independently they work, the more pleasant it is for the individual to wear. The conventional metal housings currently in use, however, make it difficult to meet these two criteria because they only allow limited wireless energy and data transmission.

And even the most reliable electronic implant sometimes runs out of steam. Its energy reserves are exhausted every few years. Then a surgical procedure is needed to replace the entire device. Wouldn't it be great if this kind of intervention could be avoided in the future? If the entire device could simply be recharged instead of having to replace it along with its energy source – with no operation, from the outside, just like it can be done nowadays with smartphones and electric cars. This very idea is not some distant future vision: Fraunhofer ENAS has spent many years researching into a material that is helping to make miniature, self-powered medical devices a reality. This material is called parylene.

This synthetic material is a real all-around talent. New application areas for this polymer's diverse properties are being unlocked in various projects initiated by Fraunhofer ENAS. Among the "talents" of parylene – whose full chemical name is poly(para-xylylene) – is its suitability to be used as a thin coating material that acts as a reliable barrier to protect against the ingress of gases and water, as well as all common acids and bases.

"The material possesses very special properties, which is why it has become established in a wide range of areas in recent years," says Dr. Maik Wiemer, head of the "System Packaging" department at Fraunhofer ENAS. "Based on its outstanding barrier properties, we have now unlocked many different application areas." The scientist says that parylene is both biostable and biocompatible: When used in living organisms, there are no negative interactions, which makes it a promising material, particularly from a medical perspective.

Parylene used for the first time as a substrate

In addition to biocompatible encapsulation and miniaturization, parylene can also be used to enable inductive charging of batteries in smart medical applications, such as implants. The material makes it possible to apply an extremely thin coating, which means that the charging process suffers no interference on account of the shielding effects. Researchers at Fraunhofer ENAS have already demonstrated that charging from the outside is possible. What's more, parylene is transparent and can therefore also be used for the encapsulation of optical components, such as light-emitting diodes.

"Parylene is biostable and biocompatible, making it particularly interesting for medical applications."

Flexible options: An ultra-flexible printed circuit board has been attached to the round head of a screw.

Besides its current use as a membrane or barrier layer, the researchers have recently found two new application areas for parylene. Firstly, parylene can be used as an adhesive in the production of micro-electromechanical systems (MEMS). This makes it possible to stack different chip functionalities on top of one another because parylene is suitable for joining different material combinations. In addition to its biocompatibility and transparency, parylene also has advantages compared to conventional materials in terms of size and temperature stability.

Parylene is now also used as a substrate for the production of ultrathin and, where necessary, flexible printed circuit boards. The synthetic material polyimide is one example of a classic substrate used in the production of flexible printed circuit boards. Commercially available printed circuit boards manufactured on this basis generally have a thickness of at least 200 micrometers, or 0.2 millimeters.

For the first time, Fraunhofer ENAS has now managed to use parylene as a substrate, making it possible to produce ultrathin printed circuit boards that are just 20 micrometers thick as well as being much more flexible and biocompatible. They fold much better, can be fitted into small cavities and are available for applications where rigid printed circuit boards are not an option. According to Maik Wiemer, conceivable application areas include small systems with limited installation space, where the printed circuit board needs to exhibit a high degree of flexibility.

Franz Selbmann, who has a key role in driving the development of the new parylene applications at Fraunhofer ENAS as part of his doctoral studies, mentions three other important usage areas: the monitoring of lightweight structures, intelligent adhesive tapes, and wearables, which are small, connected computers worn on the body. "Better performance is achieved everywhere thanks to flexible parylene-based electronics," says the scientist.

Wearables, which keep track of the body temperature, pulse rate or blood sugar level, are getting lighter and more flexible, and can be integrated into wristwatches or clothing almost without being seen. Similar benefits are possible with intelligent adhesive tapes, which can monitor the expansion of joints in buildings with the aid of a strain gauge. Franz Selbmann mentions sensors that analyze the fatigue of mechanically moving vehicle parts as another potential application in the area of lightweight structures: "Parylene-based detectors laminated directly into these components will be able to supply even more accurate data than the conventional systems currently in use."

Now that Fraunhofer ENAS has found three different uses for parylene – as a coating, as an adhesive for bonding and as a substrate for ultrathin electronics – Franz Selbmann and his colleagues are now focusing their attention on linking all three aspects with each other and integrating them into processes suitable for industrial use in the future. Cooperation with the first industry partners has already begun.

Ultrasound 2.0

Ultrasound is generated using the piezoelectric effect. Until now. At Fraunhofer ENAS, a new technology has now been developed that will turn the field of ultrasound upside down in more ways than one.

Ultrasonic transducers are now considered essential devices in the modern world. They are used in many different areas: from the parking assistant in the car and the sonar for helping fishermen to locate schools of fish on the high seas to the ultrasound examination of unborn babies during pregnancy.

All of these applications are based on the same fundamental principle: Vibrations are generated, through which ultrasonic waves are emitted. The important information for the respective application can then be read out from the echo of these waves.

The vibrations are generated with the aid of the so-called piezoelectric effect: Piezoelectric crystals deform when an electrical voltage is applied – and begin to vibrate. The ultrasonic waves generated in this way then go on a journey.

At Fraunhofer ENAS, new types of ultrasonic transducers have been developed that break with this tradition:

Quality research: Nooshin Saeidi from Maik Wiemer's team at Fraunhofer ENAS develops micromachined ultrasonic transducers to pave the way for medical imaging as well as new therapeutic applications.

They are known as "capacitive micromachined ultrasonic transducers" (CMUTs). Instead of the piezoelectric effect as seen in conventional ultrasonic technology, CMUTs rely on a tiny membrane to generate vibrations. Like computer chips, this is manufactured on the basis of silicon. By using this new technology, the Fraunhofer researchers have succeeded in creating a disruptive innovation that takes the field of ultrasound to a new level in more ways than one.

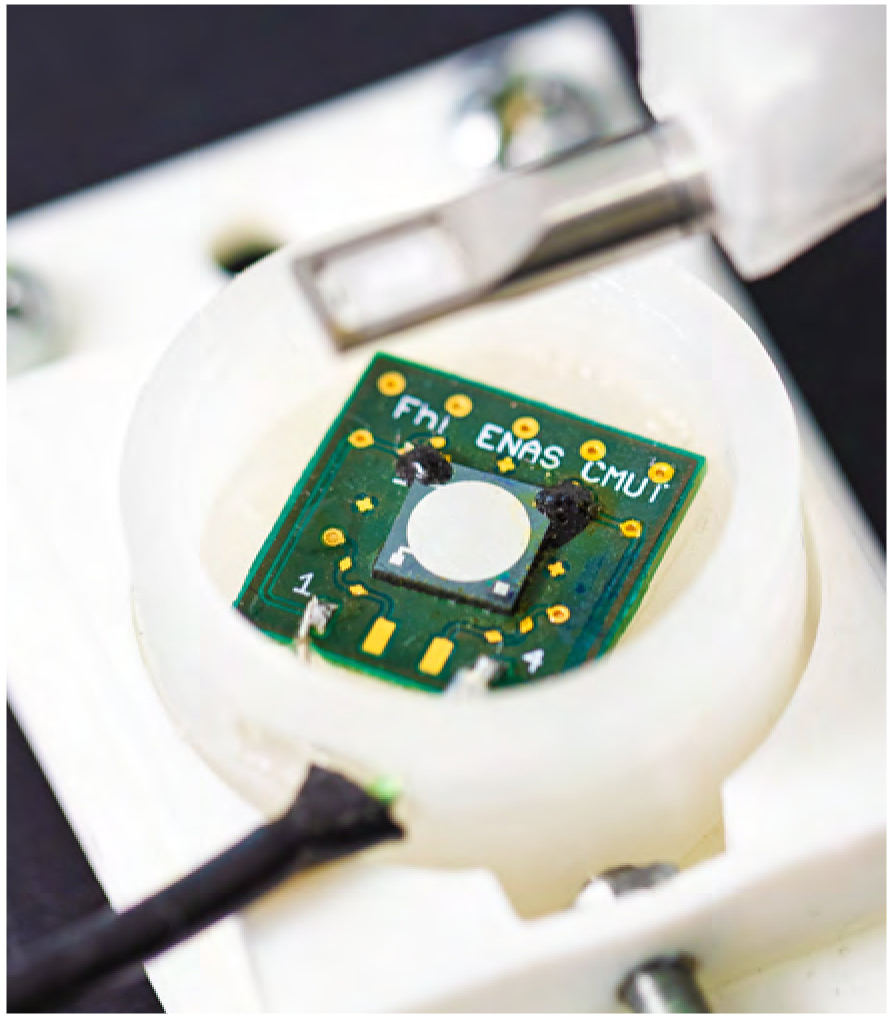
New scenarios for tumor therapy

For one thing, it has been possible to significantly miniaturize ultrasonic transducers, says Dr. Nooshin Saeidi, head of the group "Micro Acoustic Systems" at Fraunhofer ENAS. "The smallest medical ultrasound probes used so far measure just a few millimeters. By using the new technology we have developed, it is now possible to produce components for ultrasound examinations that are considerably smaller than one millimeter in size. In terms of miniaturization, there are now few limits to where we can go with it," explains the scientist. In the future, it will be possible to develop endoscopic instruments so fine that they can be inserted into blood vessels in minimally invasive procedures to examine them from the inside. It is also conceivable that they can be used for tumor therapy, among other things: Examination and treatment of tiny cancer cells using ultrasound, for example, could be much more precise, according to Nooshin Saeidi.

"A single CMUT can replace several expensive devices."

The second significant innovation is that the CMUTs are capable of real multitasking. Staying with the example of medicine, different ultrasound devices have previously been used depending on the subject of the examination – one for the liver, another for the abdomen and yet another for the skin. "This is no longer necessary with our new ultrasonic transducers," explains the researcher. "A single CMUT can generate several frequencies and thus replace several expensive devices."

The third innovative leap will also result in cost savings: The manufacture of traditional ultrasonic transducers is a complex process, not least because certain parts of every transducer need to be assembled manually. This costs time and money. "With our new silicon technology, this is now a thing of the past," stresses the scientist. "We can manufacture ultrasonic transducers in batches and thus produce hundreds of CMUTs within a very short space of time. What's more, we can offer our customers everything from one single source, from the idea and design to the development of individual components and the integration of our transducers into systems – that represents real added value."



Sophisticated technology: Capacitive micromachined ultrasonic transducers are especially useful due to their high degree of miniaturization and performance.

Pooling expertise, exploiting synergies

Another advantage of CMUTs is that they are not sensitive to high temperatures, a property that enables them to be used for geothermal exploration projects in deep rock layers, for example, with temperatures in excess of 200 °C, to search for mineral resources.

This, according to Nooshin Saeidi, is not some distant dream: "As part of a flagship project involving eight partners from research and industry, a fully functional high-temperature ultrasonic transducer was developed specifically for these scenarios." With the aim of pooling expertise and exploiting synergies, Fraunhofer ENAS works alongside the Fraunhofer Institute for Photonic Microsystems IPMS and the Fraunhofer Institute for Silicon Technology ISIT on the Fraunhofer cooperation platform for micromachined ultrasonic transducers. "This allows us to work together to optimize and further develop CMUTs. By doing so, we will be able to find even better answers to various technical challenges in the future – involving applications used in medical diagnostics, for example," says the scientist.

08

Subject
Neuromorphic Computing

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“We have the smallest parts of a big revolution in our sights.”

It combines remarkable computing power with relatively low energy consumption: A lot of hope is being placed on “neuromorphic computing.” Dr. Sven Zimmermann’s team at Fraunhofer ENAS is researching this groundbreaking computing technology, which mimics the way the human brain works.

Energy-Efficient Supercomputers

Artificial intelligence (AI) could soon consume more electricity than is available worldwide. Experts at Fraunhofer ENAS are therefore already working on a solution: “neuromorphic computing.” An insight into a fascinating – and energy-efficient – technology of the future.

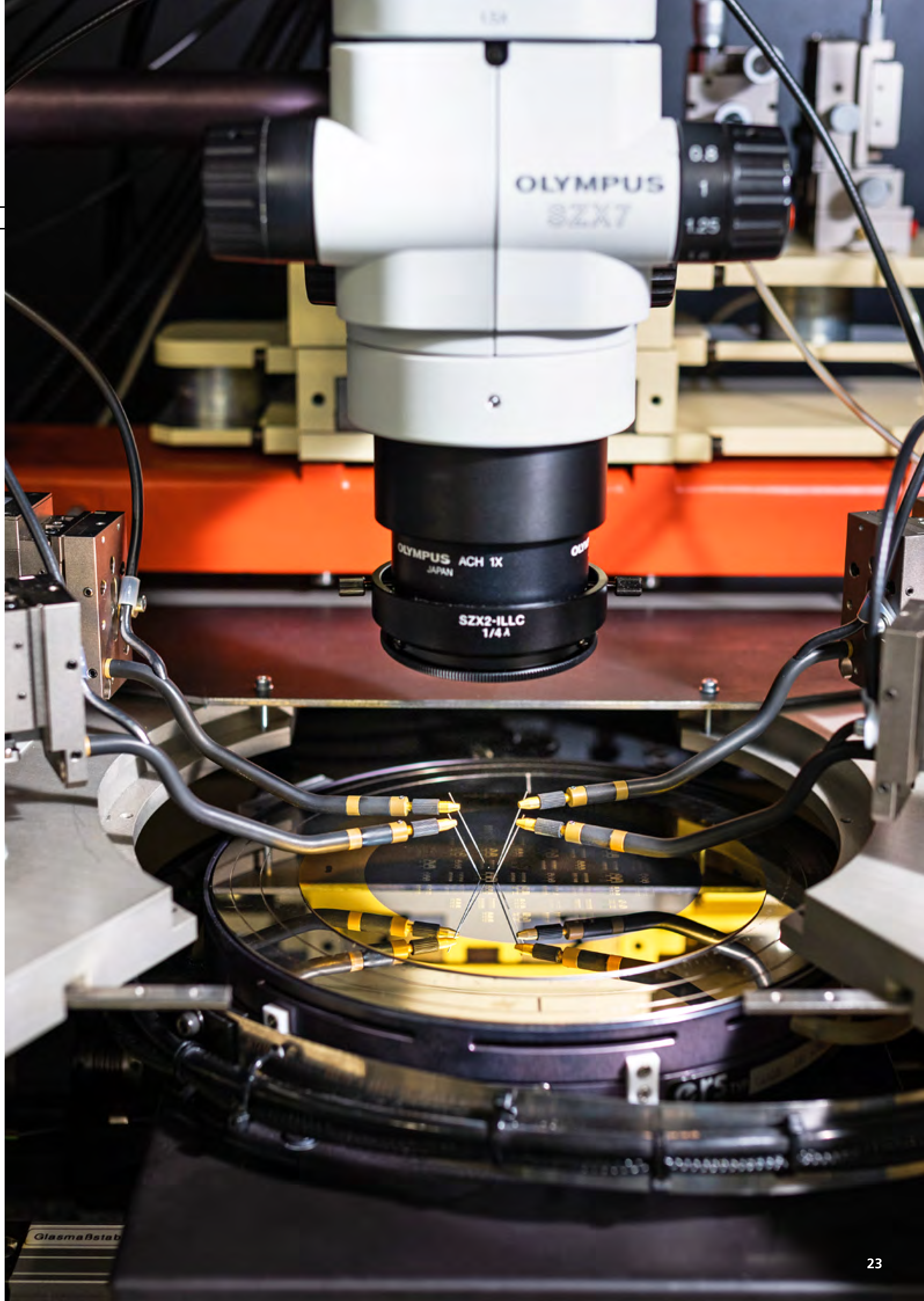
> **“We must develop technologies that need far less energy.”**

The wafer designed to change the world measures 20 centimeters in diameter and sparkles a greenish color in the light of the clean room at Fraunhofer ENAS. Research associate Shan Song wears light blue coveralls and a face mask as she uses a robotic arm to maneuver the round silicon wafer from a white box into a stainless steel structure the size of a washing machine. The system into which the wafer is placed is a physical vapor deposition chamber (PVD), where it is gradually coated with titanium, platinum, titanium oxide, or bismuth ferrite, and gold. At the end of a process chain that includes many other work steps and can take several months, Shan Song holds a semiconductor wafer in her hand that brings a scientific dream another step closer: replicating the human brain.

“Neuromorphic computing” is the name researchers have given to the attempt to develop a computer that works in a similar way to the human brain. The key to this new technology is a component that Shan Song manufactures in the clean room. It is known as a “memristor” – a portmanteau of the words “memory” and “resistor.” It is the reason why the chip on which the scientist is working will fundamentally differ from current digital chips. That’s because the memristor is not only able to process information. It can also store it. It is this dual function that is modeled on human synapses.

Key features: speed and efficiency

Two main hopes are being pinned on the new computers, which experts refer to as “hardware accelerators for deep neural networks.” One of them is speed. With a parallel data processing ability, neuromorphic computing has a key advantage over digital computers, in which the processor and memory work separately from each other. Here, the pathway along which data and commands flow from one place



Close-up: **The wafer prober is used to analyze “memristive components” that are needed for the revolutionary computers.**

"I think that we will have developed functioning chips within the next ten to twelve years."

to another inevitably becomes a bottleneck that limits the speed of work. Computers with memristors, meanwhile, process and store data in one and the same structure, as it were. As a result, they require only a fraction of the time taken by current computers to perform complex computing operations.

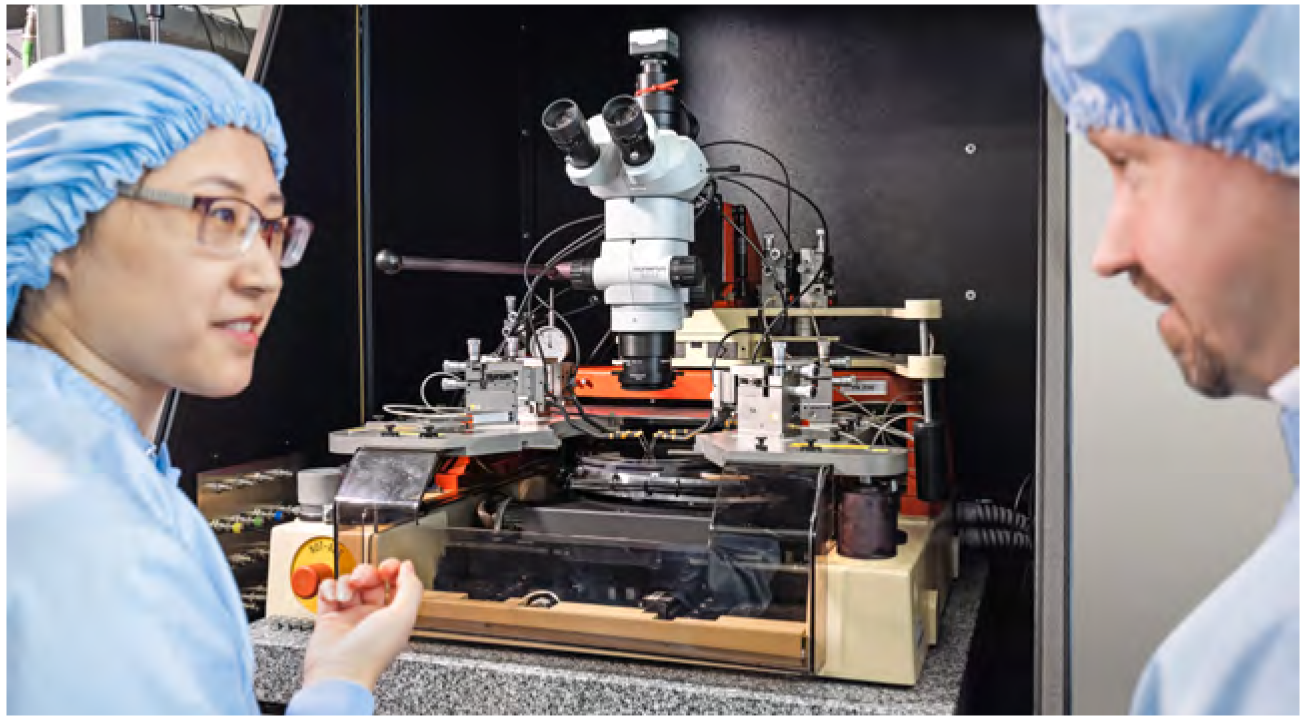
This is advantageous for applications that run in real time, such as autonomous driving. If a child runs in front of a car, for example, the vehicle must immediately perform an emergency stop. A single second delay in the reaction time can be the difference between life and death in such situations. Even though modern graphics processing units are capable of this computing speed, they require a great deal of power: A graphics card from the newest generation consumes between 400 and 500 watts. Our brain, which has countless other abilities besides driving, needs just 20 watts.

And this is precisely the second key feature of neurocomputers. They consume considerably less energy than conventional computers. In view of the rapid growth in memory capacity and computing power, their efficiency is a strong argument for neurocomputers.

It takes energy-efficient computing technology

Data centers already consume up to five percent of the world's available energy. The AI boom in particular will lead to a rise in this figure. Estimates put the figure at up to 30 percent. As a consequence, in just 20 years, it may no longer be possible to produce enough energy worldwide to meet the needs of AI, says Dr. Sven Zimmermann, head of the "Nano Devices/PVD" group at Fraunhofer ENAS. Given this scenario, he says that producing more and more energy will not suffice as a solution. "We have to develop technologies that require much less energy."

Teamwork: Nanotechnologists Shan Song and Sven Zimmermann are developing a neurocomputer at Fraunhofer ENAS.



Many researchers are confident that neuromorphic computing could be one solution to the problem.

To understand how a neurocomputer works, it is worth taking a look inside the human brain. Here, the axons or nerve endings transmit electrical signals from one neuron to the next, an effect known as "spiking." At the end of an axon is the synapse, which influences the transmission of stimuli between the connected neurons. The intensity of a synapse changes depending on how often the associated neural pathway has transmitted an impulse sequence. This is how the brain learns. The special thing about this is that the neuron only sends signals if it has received sufficient stimuli from the cell body and its processes.

The memristor behaves in exactly the same way. The more often current flows through it, the greater the change in its resistor. Researchers call this effect "intrinsic plasticity." The size of the resistor then serves as an analog storage unit. Since special memristors can also provide other functions such as threshold switching and self-oscillation, these components can be used to recreate the brain in hardware form, as it were.

One day, the neuromorphic chips that Shan Song and Sven Zimmermann are working on with their team will play in the same league as our brains. For now, they remain in the research stage. Alongside the PVD process, the scientists are also using lithography to build the chip. "Imagine it like the darkroom used in analog photography," says Shan Song. The wafer is given a special coating before light is shone through a mask to achieve the correct structure. Etching processes are then used to turn the masking into functional components in the final stage. It is both a lengthy and complex task because the chip's calculations will have to be even more precise in the future. In addition, the performance of a neurocomputer is currently several orders of magnitude lower than that of the human brain.

The aim is to fit as many memristors as possible onto one chip

The challenge for Shan Song and Sven Zimmermann now involves fitting as many memristors as possible onto one chip. To date, the researchers have succeeded in arranging 10 x 10 memristors in a crossbar array. This figure is set to rise to several thousand and even as high as 10,000. And to achieve this, they must reduce the size of a memristor from 20 micrometers to 600 nanometers. Researcher Shan Song believes Fraunhofer ENAS is on the right track: "I think that we will have developed functioning chips within the next ten to twelve years."

Recreating the Brain: A Long-Term Project

The human brain is the most complex organ that nature has ever produced. It contains 86 billion neurons – about as many cells as there are stars in the Milky Way. The neurons communicate with one another via multiple contact points (the synapses). They give humans capabilities that no supercomputer has thus far been able to match.

The idea of recreating the human brain has been around since the 1950s. At Cornell University, psychologist Frank Rosenblatt built a machine that simulated how neurons in our brain communicate with each other. The machine was able to recognize images – it could distinguish a dog from a cat, for example. Even back then, a neural network formed the basis for image recognition, but it worked with just a few neurons that functioned mechanically.

A breakthrough came in 2008 when researchers invented the memristor (the synapse). Now scientists are working on integrating memristors into a chip. However, one challenge that still has to be overcome on the way to achieving the neuromorphic computer involves developing artificial neurons whose complexity comes close to that of the human neuron. Yet here, too, viable solutions are in sight.

09

Subject
Hydrogen

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"We are helping to store the power of the sun and wind."

Those who wish to make full use of renewable energy sources must convert wind and solar power into transportable hydrogen at low cost. A technology needed for this – a new kind of printing process – is currently being developed by Prof. Ralf Zichner and his team at Fraunhofer ENAS.

Using Printing Technology to Produce Green Energy

A team at Fraunhofer ENAS is working on a printing process that can be used to produce green hydrogen more quickly and efficiently in the future.

The globally unique ink has been developed by Ralf Zichner and his team. Thanks to this ink, the anode and cathode can now be printed onto a film made of Nafion using the inkjet process. That is how the heart of the electrolyzer is made.

Almost 60 percent of the electricity generated in Germany now comes from "renewable" sources: The sun, wind and water are delivering more energy than ever before. But there is a catch: If there is too much wind in the offshore wind farms in the North Sea, the grid capacity is often not sufficient to transport the generated electricity to the south, for example. Then the operators have to shut down the wind turbines at the very moment when they could be working most efficiently. According to the Bundesnetzagentur (Federal Network Agency), more than 10,000 gigawatt-hours of green electricity were lost as a result in 2024 – enough to supply the entire city of Frankfurt for more than a year.

One solution to this problem is hydrogen. By means of electrolysis, the surplus energy could be used right by the wind turbine to split water into hydrogen and oxygen. The extracted gas could then be compressed and delivered by truck or pipeline to factories and municipalities all over the country. Here, the hydrogen could be converted back into electricity in a fuel cell. The green electricity from the wind turbines would therefore not be lost, but could simply be used at a later date. Except: The technology used in this process is still extremely expensive. An electrolyzer is largely manufactured manually, which means that the investment costs currently run to between 690 and 1,000 euros per kilowatt of electrical power.

"We want to play our part in making sure that hydrogen can be widely used as an energy source."

To help the cost of these plants fall as quickly as possible and ensure that less green electricity is lost, the German Federal Ministry of Education and Research (BMBF) has invested hundreds of millions of euros in the "H2Giga" research initiative. As part of the initiative, 130 partners from industry and science are working together to get the electrolyzers to a stage where they can be mass-produced. In a subproject of this mega undertaking, five Fraunhofer institutes have teamed up to develop new production processes – among them Fraunhofer ENAS. "We want to play our part in making sure that hydrogen can finally be widely used as an energy source," says Prof. Ralf Zichner, head of the "Printed Functionalities" department at Fraunhofer ENAS.

He and his team are focusing on a key component of the electrolyzer that is one of the biggest cost drivers: the catalyst-coated membrane (CCM). This can best be compared to the plastic wrap found in the kitchen. It is made of Nafion, a special kind of synthetic material with properties similar to Teflon. On this plastic film in the electrolyzer there is an anode made of iridium dioxide and a cathode made of carbon-supported platinum. This is where water molecules are converted into hydrogen and oxygen. "The catalyst-coated membrane is at the heart of the electrolyzer," says Ralf Zichner.

A globally unique ink

In order for the film to be effective, the iridium dioxide and platinum particles must be mixed into two separate inks prior to application and then printed. Until now, a process known as "slot-die coating" has typically been used for this purpose. Here, the ink is applied to an intermediate substrate with a slot nozzle and therefore not directly onto the membrane. "This method is complex, expensive and not very economical," explains Ralf Zichner. That is why he and his team are researching into an innovative process that can be used to accelerate this process, while making it cheaper and more precise. The scientists want to print the anode and cathode directly onto the membrane using the inkjet process. "This sounds very simple in theory, but it is extremely difficult to do," says Ralf Zichner.

First of all, they had to develop a special ink that is globally unique and adheres to the membrane. They then adapted the printing process to the new kind of ink. And now, as part of the "H2Giga" project, the researchers are trying to optimize the entire process so that it can be used on a larger scale in industry. "We need to make sure that the nozzles don't fail so that the process remains reliable over a long period of time – that is the biggest challenge in the entire development project," says Ralf Zichner. Their aim is to be able to present the final results by the end of 2025.

If they pull it off, they could reduce the cost of the catalyst-coated membrane by almost a third. Ralf Zichner cautiously estimates that this alone would make the electrolyzer at least ten percent cheaper. This would be a huge step forward, not least because these savings could play a key role in hydrogen becoming the energy source of the future.

In addition to the technological role played by Fraunhofer ENAS in reducing the manufacturing costs of electrolyzers and fuel cells, it is also focusing on the safety aspect. This includes leak detection in the hydrogen tanks, which are set to be fitted with new sensors from Fraunhofer ENAS. These sensors are extremely precise and sensitive. They can also be used for monitoring purposes – to ensure the safe use of hydrogen as a fuel for aircraft, for example – which could revolutionize aviation.

10 Subject
Medical Technology Applications

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"We are writing the next chapter of biosensor technology."

Dr. Mario Baum and his colleagues at Fraunhofer ENAS are developing sensor systems that enable innovative food testing and help determining biomedical parameters quickly and reliably.

The Mini Laboratory

A new rapid testing procedure co-developed by Fraunhofer ENAS is set to help detect contaminants in food.

Foodstuffs are a sensitive commodity. The last major food scandal was some time ago, but that doesn't mean that food producers aren't constantly having to deal with contamination. Undesirable substances can end up in a product via different routes. Good control systems are therefore needed to ensure quality and safety. For small producers, however, continuous monitoring is difficult to implement. Unlike large companies, they have no laboratories where they can carry out their own tests.

What they ideally need is a fast and straightforward solution for on-site testing. This is precisely where "h-ALO" comes in, a project funded by the EU[1], involving ten partners from five EU countries, among them Fraunhofer ENAS. Between the start of 2021 and mid-2024, the consortium led by the National Research Council of Italy (CNR), made up of research institutes, biotech and IT companies, as well as food manufacturers, developed a new test system that is set to enable producers to quickly check their goods for common types of contamination on their premises: antibiotics, pesticides, heavy metals and pathogens.

Tracking down pathogens: Mario Baum and Andreas Morschhauser are working on an analysis algorithm for a new food test.

Some of the project partners had already cooperated on a previous project – with researchers from Fraunhofer ENAS also on board due to their knowledge in the field of microfluidics. The "Moloko"[2] project saw researchers successfully analyzing quality parameters in milk. In the "h-ALO" project, this idea was developed further.

> **"We miniaturize a laboratory process that would otherwise require a pipette, hot plate and much more besides."**

"Microfluidics essentially involves processing tiny quantities of liquids, usually on a microliter scale," says Andreas Morschhauser, an expert in fluidic systems and technologies at Fraunhofer ENAS. "We miniaturize a laboratory process that would otherwise require a pipette, hot plate and much more besides, and put it into a credit card-sized cartridge, where it runs automatically. Ideally, you have a device where you only drip a sample onto a test field, and a result is available within twenty minutes."

Behind the seemingly simple application lies highly complex technology. At the heart of it all is a new kind of nanoplasmonic biosensor. The biosensor is the size of a postage stamp and contains several light sources, a thin nanoplasmonic lattice structure made of gold and several photodiodes. Biofunctionalization makes the nanoplasmonic lattice sensitive to heavy metals, biomolecules and bacteria. Analyzing a food sample involves firstly preparing and filtering it before placing it on the sensor, where the respective impurities, such as bacteria, can dock onto the previously applied antibodies.

The biosensor itself was developed and manufactured by a team of Italian scientists. It needs the right environment for it to work, however. One of the main tasks for the colleagues at Fraunhofer ENAS was to integrate it into the cartridge. The other involved technical management. "Highly diverse disciplines were represented in the project, including photonics, microfluidics, electronics and biotechnology. These tasks needed to be coordinated. Since microfluidics is at the interface with all technologies, we took on this task in conjunction with the CNR," says Andreas Morschhauser.

The aquaponics company The Circle from Italy also had a hand in developing the "h-ALO" system, representing many end users. Aquaponics is a closed system that combines fish farming and the cultivation of plants using hydroponics. Contamination caused by external animal feed or fertilizers is particularly serious here due to the common hydrological and nutrient cycle, upsetting the balance between fish and plants. Three other liquids were also examined: honey, milk and craft beer.

The "h-ALO" represents a promising approach for producers because it allows them to react quickly in the event of detecting any contamination. The data is supplied via a cloud solution, providing a basis on which they could decide how to react to the contamination, either by adjusting the production process or disposing of the batch, for example. This would increase safety for consumers and improve the quality of their products.

However, there is still a long way to go before they can hold such a device in their hands. The project ended in June 2024, and now manufacturers must be found for the test system. For now, important foundations have been laid that can also be transferred to other application areas.

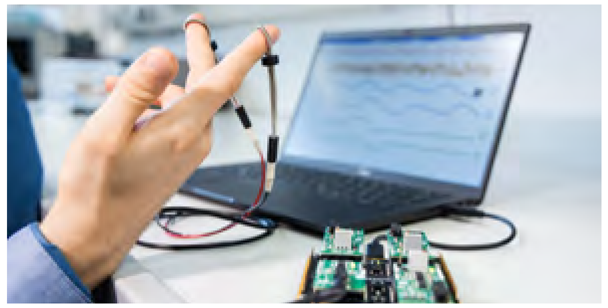
1: GA 101016706 2: GA 780839

The Stress Monitor

New sensors are set to help detect diseases at an early stage.

The idea is fascinating: Small, smart, electronic patches are placed on the skin to monitor certain biomedical parameters and raise the alarm as soon as the body shows the first signs of a health problem. "It may sound futuristic, but it is perfectly feasible," says Sven Lobner.

The key technology here is the integrated microfluidics. Since June 2024, the young researcher has been a research associate at Fraunhofer ENAS and a doctoral student at the TU Bergakademie Freiberg. He is writing his doctoral thesis on this subject. "In addition to the vital data, the aim is to integrate other biomarkers into the measurement, which have previously only been measured invasively, and combine them with established sensors and other ascertained data," says the young scientist. "The concept is point-of-care diagnostics. These parameters will then no longer have to be determined by means of a complex process in the laboratory. Instead, they can be measured regularly in situ and analyzed in real time." His thesis is entitled "AI-based data fusion for physiological multisensor technology on wearables," and is funded by the Sächsische Aufbaubank as part of the ESF Plus doctoral scholarship program for industry. Results are expected in four years.



Finger exercise: Sensors measure the electrodermal activity (EDA) of the skin, which can play a role in stress monitoring, among other things.

Well Positioned for the Future

A comprehensive change process is set to make Fraunhofer ENAS fit for the future. Institute Director Prof. Harald Kuhn and Administration Manager Dr. Tina Kießling are talking about intelligent structures and open communication.

Professor Kuhn, you took over as the director of Fraunhofer ENAS in September 2020. What were your goals when you took office?

HK: When I took over as director of the institute, we were in the middle of the coronavirus pandemic. It was not an easy time, and yet we as an institute mastered this challenge. Above all else, the coronavirus pandemic once again showed us the huge potential of the technologies developed at Fraunhofer ENAS, with subjects such as renewable energy, green mobility and artificial intelligence (AI) since taking on ever greater global importance, and micro- and nanotechnology constituting fundamental "enablers" for all these innovations. A motivated, committed and highly professional team is absolutely essential when it comes to shaping technological progress in these fields, having a stake in the technologies of the future and standing firm in the face of international competition. Whether in science or administration, as a researcher or trainee – every single employee makes our institute the unique and high-performing place it is with their passion, technical expertise and team spirit. Only together can we secure our ability to innovate in the future, pave the way for new key technologies and continue to grow as an institute. We can be proud of what we have achieved in recent years: Our budget has grown from 18 million euros in 2020 to over 30 million euros. And the number of people we employ – from across 20 different nations – has also increased from 161 in 2020 to more than 240.

What have you done to boost the institute's growth?

HK: In 2021, for example, we set up the new "data-based methods" team against the backdrop of the fact that AI has not only become an indispensable part of our everyday lives, but also essential to industry, providing a huge boost in innovation. By using modern, digital algorithms and drawing on expert knowledge, we are able to optimize semiconductor processes. Thanks to this linking of the real and digital worlds, we can provide real added value. Today, four years later, our AI expertise has made us one of the world's leading institutes in the field of semiconductor processes.

Another important step was the restructuring of the institute. We have focused our strengths along the entire value chain of intelligent systems into three business units: "Process, Device and Packaging Technologies," "Smart Systems" and "Test and Reliability Solutions." This enables us to skilfully combine previously separate areas of expertise and thus react much faster and more efficiently to market requirements and customer needs.

All in all, it is important to build on the institute's research and development expertise and its excellent reputation.

Dr. Kießling, how would you describe the transformation of Fraunhofer ENAS? What do the changes mean in terms of the organization of the institute?

TK: We are still in the middle of the change process. This partly involves the new structure that we

Dialogue on equal terms: Harald Kuhn and Tina Kießling in conversation on the institute's roof terrace.

have established with the three business units. In addition, we have created the "Marketing," "Corporate Strategy," "International Sales," "Infrastructure," and "FAB Management" staff units. They all operate across the boundaries of the individual business units with the aim of providing efficient support. The FAB Management, which takes care of research equipment and particularly our clean rooms, is actively involved in decisions about investments in high technology, for example. This central form of management allows such decisions to be made by viewing the institution in its entirety – beyond the boundaries of individual business units. Another advantage of this central approach is that we can show much more transparently how we use our funds. As a Fraunhofer Institute, we work with public funding, and we have to account for how it is spent in detail. This is now much easier. The challenge, however, is that different parties within the institute need to communicate with each other: the management, researchers, various administrative departments, and the staff units. This increases the complexity of the entire organization.
HK: It also creates new areas of tension. These can be particularly well illustrated by the example of the staff units, not least because they have to perform several roles at the same time. On the one hand, they serve as service units for the scientists. If, for example, our researchers need new technical equipment, the relevant staff units – in this case the FAB Management – is their first point of contact. On the other hand, the same staff units also plays a governance role by defining framework conditions and specifications for the institution with the aim of achieving the optimal acquisition. This leads to complex role constellations. The challenge of complying with strict public law regulations on the one hand and meeting the requirements of the dynamic market on the other is particularly evident in procurement processes. This makes it necessary to establish clearly defined coordination and approval processes. Our aim is to organize these processes in a way that eases the workload for our scientists to the greatest possible extent. Even though we still have some way to go, we have already been able to take the first important steps on the path to achieving this goal.

Is the workload already beginning to feel easier for your employees?
TK: We are continuously working to ensure that our scientists have to deal with fewer administrative tasks. However, this only works to a limited extent. That's because there are always new requirements that we have to tackle. In recent years, for instance, we have introduced new legally prescribed systems for organizing and documenting our activities. These include a data protection system, an energy management system and an environmental management system. These management systems help us to systematically organize our processes, structure them even better, and make them transparent and comprehensible for everyone in order to comply with legal regulations. We are also working on consolidating our various management systems by adopting an integrated approach. This will enable us to take a holistic view of our processes, reduce the workload and optimally pool resources.

The organizational form you describe requires a mutual understanding of science, administration and staff units. How can this be fostered?
TK: It takes good communication across all levels for it to work. To foster this, we have established an institute-wide meeting between science and administration, which is held once a month. In this meeting, employees have the opportunity to make suggestions for improvement and discuss them. We take the outcome of these talks very seriously. In addition, we have brought together different strands of expertise in interdisciplinary teams. These teams deal with data structures or management systems, for example, and work together to develop viable solutions for the entire institute. Ultimately, the dialogue and a better mutual understanding help us to continuously improve and grow as an organization.
HK: The issue of how we communicate with one another is key. That is why we have held a series of workshops in which we actively engage with the subject of how we wish to shape our institute culture. The essential aim is to get the employees to share their ideas and suggestions and then use them as a basis for working out specific steps for the institute. One area of interest concerns an open, positive error culture. Errors and failures are important, especially in the field of science. It is the only way we can continue to develop and make progress. The managers in particular, myself included, need to serve as role models here. We want to establish a culture where mistakes are allowed to happen, as long as they are talked about openly – and people learn from them.

"The issue of how we communicate with one another is key."

Professor Kuhn, you mentioned global competitive pressure. What can the institute do to be successful under these circumstances?
HK: If we wish to benefit from global developments in the semiconductor market, we need to build strategic partnerships. The Research Fab Microelectronics Germany (FMD) is one such example. A total of 13 research institutes have joined forces under the umbrella of this association, leveraging their power to drive progress in the field of micro- and nanoelectronics. By doing so, expertise can be pooled and new challenges can be mastered together. It is equally important that we as an institute learn to think beyond the bounds of our individual business units in matters concerning acquisition. The project of one business unit may, for example, lead to follow-up orders for another business unit – because it possesses the expertise needed in later phases of the same project. In order to recognize such potential, we work hard to "break out of the silo mentality." If we learn to grasp the institute in its entirety and thus see it as a joint project, we will be well positioned for the future. We have already done important work to set the course and are on the right track for the future.

Listening to one another: Good communication across all levels is one of the main aims of the change process at the institute.

Good Reasons to Choose Chemnitz!

Chemnitz is the hidden champion among Saxony's cities: It is diverse, dynamic and attractive. There are many good reasons to live, research and work here.

10

Chemnitz ranks an excellent tenth out of 71 cities nationwide in the city ranking compiled by the Prognos research institute, making the city one of the top-rated in terms of quality of life.

50

A total of 50 research and development institutions, including Fraunhofer ENAS and the Smart Systems Campus, a network for microsystems technology, are working on numerous innovations. A flourishing start-up scene, meanwhile, is making the ideas of the future marketable.

25

Recreational areas make up 25 percent of the city's area, giving each resident around 200 m² of green space. Just an hour's drive south of the city, the Ore Mountains are the perfect place for an excursion with their breath-taking scenery and numerous sights.

8,600

At Chemnitz University of Technology, about 8,600 students from around 90 countries earn high-quality degrees in almost 100 courses of study. The university is cosmopolitan and boasts a strong international network.

5.50

Dream homes in renovated art nouveau buildings or in the quieter outskirts of Chemnitz are still affordable. The average rent price excluding bills is 5.50 euros per square meter.

4.0

Semiconductor products from one of the most important locations for micro-electronics in the heart of Saxony are key drivers of digitalization, while the production facilities are showcase projects of Industry 4.0. In the region between Chemnitz, Freiberg and Dresden, around 2,500 companies employing a total of 70,500 people are currently active in the field of microelectronics.

18,500

Chemnitz is at the heart of a region with a rich industrial tradition. In 1881, for example, the physicist and chemist Adolf Ferdinand Weinhold described the principle of the thermos flask here. In 1885, the mechanical engi-neering company Wanderer-Werke was founded, which also devel-oped the Wanderer W23. Today, the roughly 18,500 trade businesses and industrial companies – from hidden champions to corporations – generate annual added value of around nine billion euros.

2025

Chemnitz is the European Capital of Culture in 2025 under the motto "C the Unseen." With a varied program that addresses key issues of our time, the city wants to be a good host for Europe – and is investing more than 90 million euros in urban development, infrastructure and tourism. Find out more at: www.chemnitz2025.de

Sources: City of Chemnitz, sachsen.de, Prognos, Statista, Chemnitz University of Technology

251,699

Around a quarter of a million people live in Chemnitz. But the city's catchment area is home to more than 1.4 million people who live and work here. The city's gross domestic product rose from 7.5 billion euros in 2012 to around 10 billion euros in 2022.

Future. Made in Saxony

Did you know that one in three chips produced in Europe comes from Saxony? Together with research and development facilities, the major chip manu-facturers form the backbone of "Silicon Saxony" between Chemnitz and Dresden. A vibrant land-scape of successful SMEs has developed around the chip factories. Fraunhofer ENAS is part of this inno-vative ecosystem. Why not also make Chemnitz your city! You will find cooperation opportunities and career prospects here: www.enas.fraunhofer.de

Outstanding Research

For three researchers at Fraunhofer ENAS, 2024 was a special and successful year. Congratulations!

"Best Paper Award" for Fraunhofer ENAS researcher

They are thinner than a human hair, just one millimeter long – and yet sturdy enough to penetrate the top layer of skin: Ultra-thin needles could make it much easier to measure clinically relevant vital signs, turning the task of monitoring the health status of patients into a painless process in the future. Tom Enderlein, who works as a research associate at Fraunhofer ENAS in the "Health Systems" department and at the Center for Micro and Nano Technologies at Chemnitz University of Technology, has now developed an approach that enables polymer-based needles to be produced cost-effectively and in large quantities. With resounding success: His work was acknowledged with the "Best Paper Award" at the Smart Systems Integration Conference on April 17, 2024.

Tom Enderlein

Dr. Jan Albrecht

A focus on reliable electronics

Faulty electronic components can lead to the failure of entire systems. The "Test and Reliability Solutions" business unit and especially the "Micro Materials Center" at Fraunhofer ENAS are therefore investigating the reason why electronic components fail – and how this can be avoided. Dr. Jan Albrecht also dealt with this question in his dissertation. Together with an industrial partner, he developed a process for determining the bond strength of thin films on wafers. "A precise understanding of these processes is essential for ensuring that these systems function properly," says Dr. Jan Albrecht, who has worked at Fraunhofer ENAS since 2013 and is head of the "Component Reliability" group. He was awarded a doctorate at the beginning of 2024. Particularly special is the fact that the process he developed has been used in industry since 2021 – before he even completed his doctoral thesis.

Innovative printed electronics

It is generally known that inkjet printing technology is used to get ink onto the paper. Perhaps less known is the fact that it can also be used to manufacture live conductors on three-dimensional objects, such as car doors or aircraft parts. Dr. Robert Thalheim researched such a process as part of his dissertation. The printing and packaging engineer has been a research associate at Fraunhofer ENAS since 2017. His work has also involved programming a robot that can move the printhead in any direction and even print on curved object surfaces. Specific application examples included printed heating elements on a stadium seat, a printed sensor system on a construction helmet and a printed wiring harness on a car door. After five years of intensive research, he was able to complete his doctorate in August 2024 – with top marks.

Dr. Robert Thalheim

Research and Development for Integrated Smart Systems

Fraunhofer ENAS is your specialist for smart systems and their integration into a wide range of applications. From the initial idea to the design, along with technology development, prototype testing and technology transfer, we are a reliable research and development partner for start-ups, SMEs and large companies.

Our three business units – "Process, Device- and Packaging Technologies," "Smart Systems" and "Test and Reliability Solutions" – are set up along the entire value chain of intelligent systems to offer you specific support in every phase of the innovation process.

Smooth processes, highest quality standards, and the strategic development of our institute are ensured by "Administration/QM" and the staff units "Infrastructure", "FAB-Management," "Marketing," "Corporate Strategy," and "International Sales."

Fraunhofer ENAS is certified according to ISO 9001:2015 (quality management) and ISO 50001:2018 (energy management).

Would you like to get to know us?
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The Institute in Numbers

Budget

(in million euros)	2019	2020	2021	2022	2023
Total budget	18.6	18.3	27.3	25.4	30.8
Operating budget	17.4	16.1	19.5	22.2	24.8
Capital expenditure budget	1.2	2.3	7.7	3.2	5.9
Business earnings	4.8	5.0	10.7	13.3	6.7

Number of employees

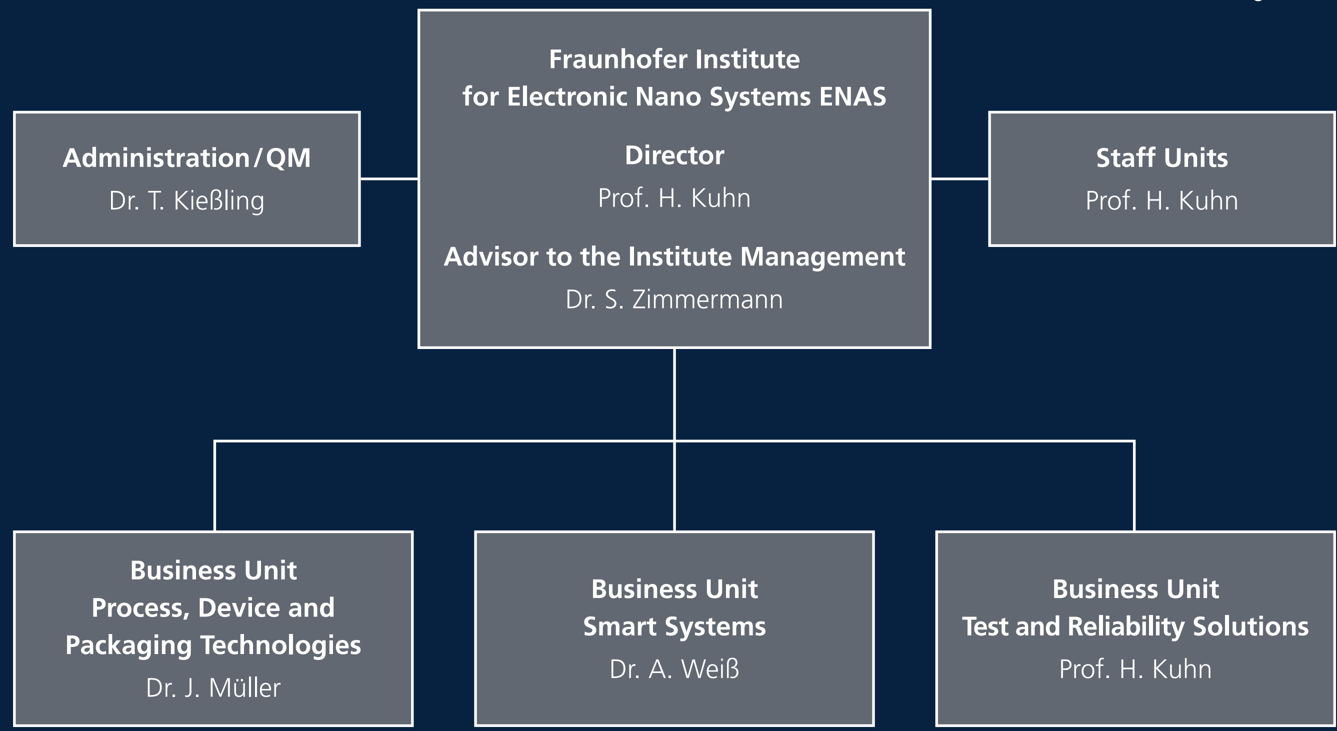
	2019	2020	2021	2022	2023	2024
Employees in total (Chemnitz and Paderborn, excluding students)	166	161	190	198	213	246
of whom experts	79 %	77 %	79 %	78 %	76 %	79 %
Apprentices	8	8	8	6	8	8
Research associates and interns	37	28	47	55	59	71

Other figures

	2019	2020	2021	2022	2023	2024
Active patent families in total	42	48	48	45	45	43
Newly granted patent families	7	6	3	2	1	0
Final theses	22	12	26	39	35	27
Dissertations	4	6	7	3	2	5
Scientific papers	101	53	66	66	81	69

Last updated: December 31, 2024

The Organizational Structure at a Glance



“Those who valiantly generate ideas pave the way for the future.”

And the journey begins here:

www.enas.fraunhofer.de

linkedin.com/company/fraunhofer-enas