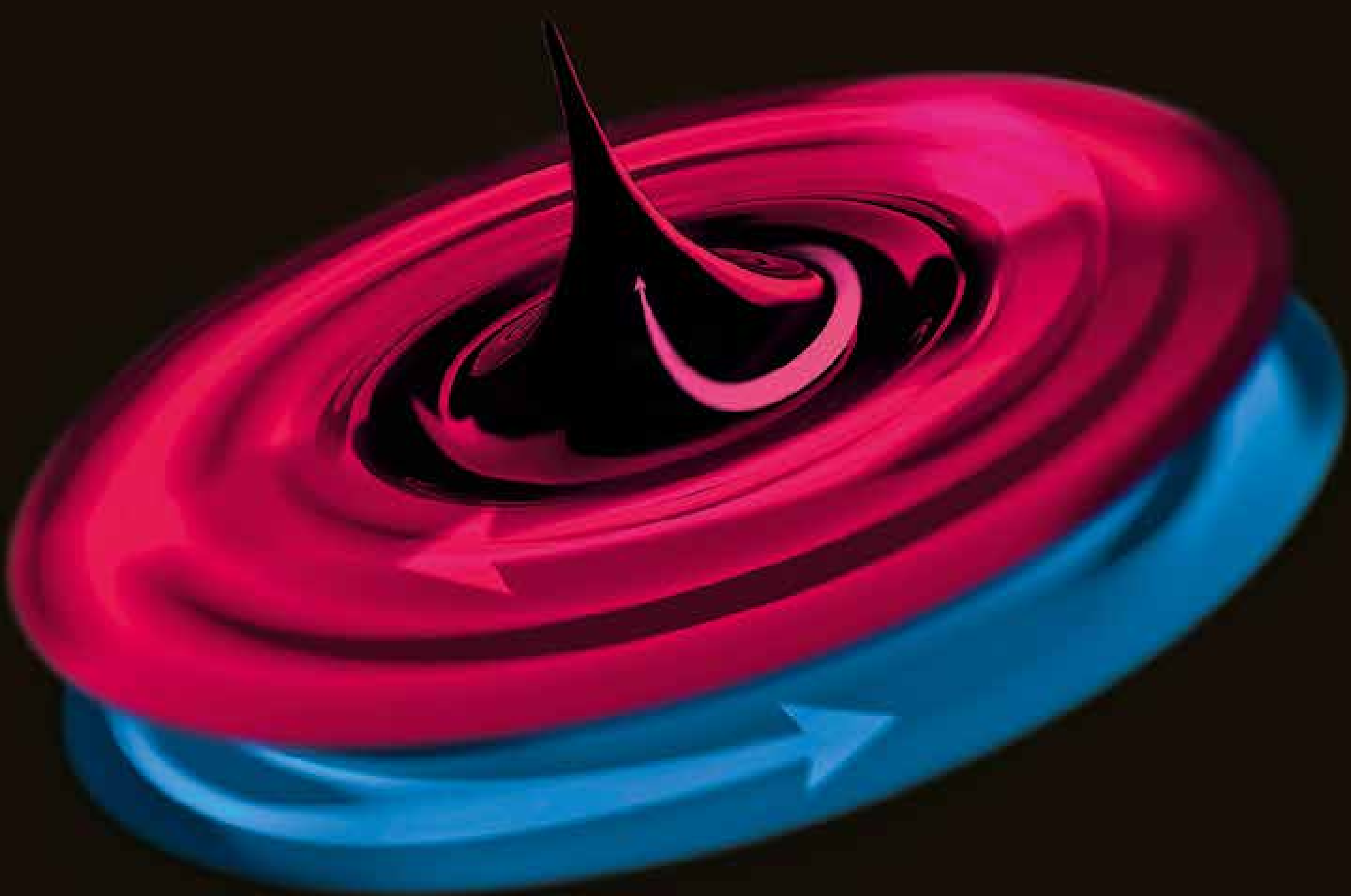
discovered

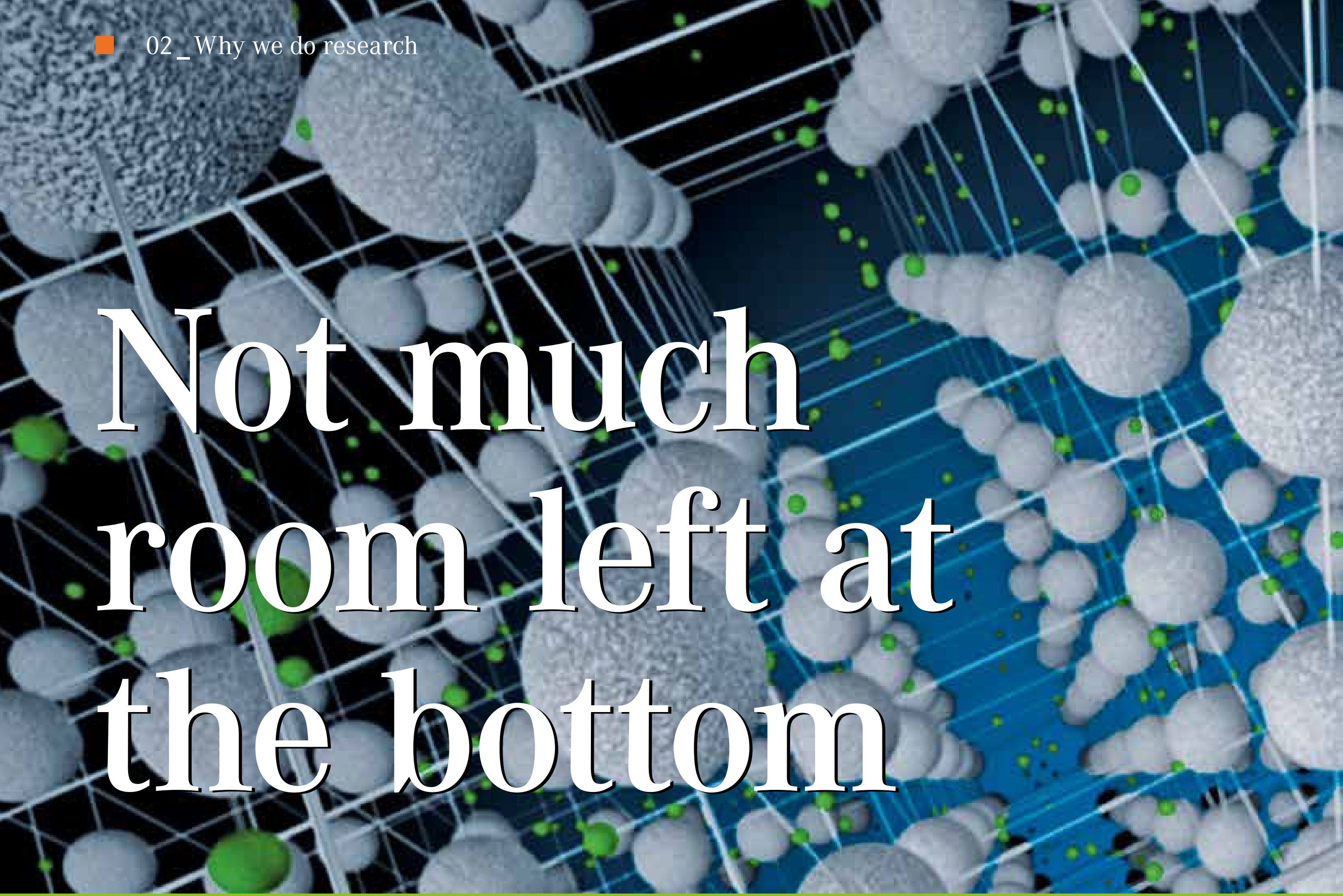
THE HZDR RESEARCH MAGAZINE

hzdr.de
1.18



A new spin in nanoelectronics

HZDR
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

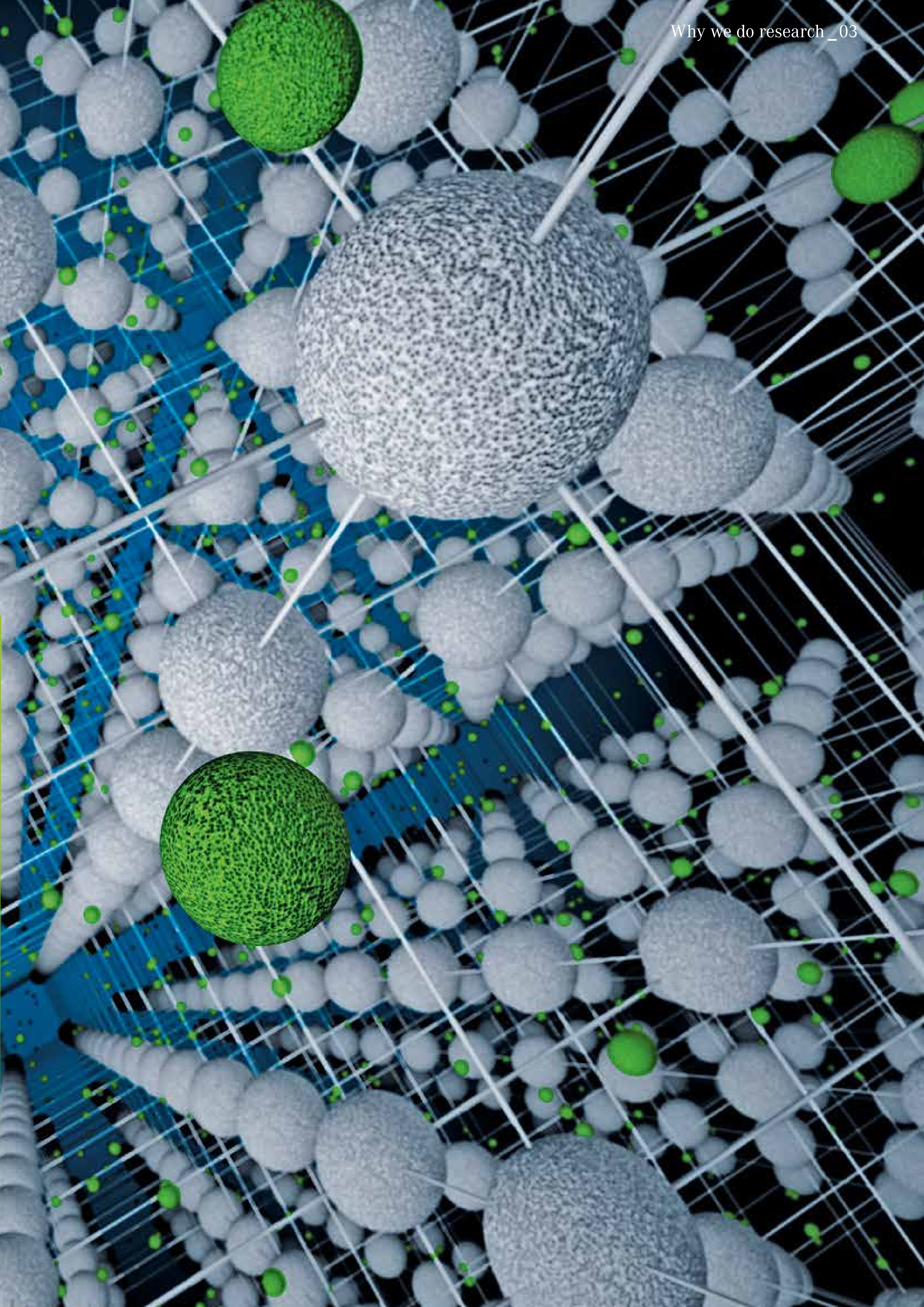


Not much room left at the bottom

14 nanometers – smaller than most viruses. That is the scale to which the semiconductor industry has shrunk structures on its most advanced microprocessors, confirming one of the predictions made by physicist Richard Feynman about 60 years ago: In his lecture “There’s Plenty of Room at the Bottom”, he presented a draft of ideas on how technology could work on the microscopic level. While it gathered little attention at the time, today, the lecture reads like a nanotechnology roadmap. Slowly but surely, though, the development is reaching its physical limits. As the scales get smaller, quantum mechanical effects set in which render the components’ behavior hopelessly unpredictable.

There is an even more problematic issue, though, which illustrates that even the atomic level is starting to get crammed. Because when electrons collide with atoms, they emit heat to the crystal lattice. The tighter the elements are packed into the microprocessors, the hotter these processors get. Beyond a certain point, the heat has nowhere else to go and the processors simply fail. HZDR scientists are therefore searching for alternative methods of information processing. For instance, the Dresden physicists are experimenting with nanometer-sized circuits which self-assemble from strands of DNA, and they are also looking into spintronic and magnonic elements.

Unlike present-day information processing technology, these components no longer rely on electrical currents, but rather on the electrons’ magnetic momentum – their spin. Information can be transported and processed via spin waves or spin currents that are carried by conduction electrons without any troublesome heat generation. Room at the bottom may still be tight, but it is used better.



Source: A. Wirsig

Dear readers,

Magnetism has fascinated humanity since ancient times. Right back around 1100 – at a time when many people still believed in a huge mountain of magnetic ore in the far north – Chinese inventors produced the first compass. In the middle of the 13th century, the scholar Peter Peregrinus defined the concept of the "pole" and described how they attract and repel each another. Since then, our knowledge of magnetism has grown continuously. Today, we utilize magnetic effects without giving it a second thought – to store data, play music and videos, but also to have our bodies examined.

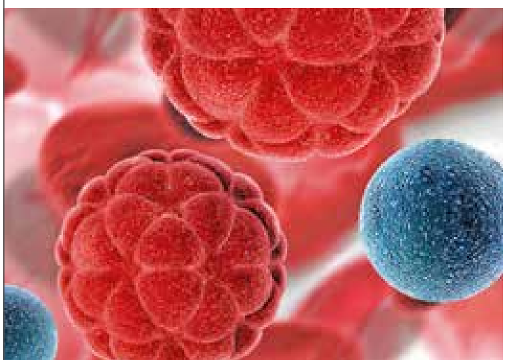
At our Dresden High Magnetic Field Laboratory, scientists from all over the world use the extremely strong magnetic fields to influence the properties of novel materials. In this way, they gain insights into superconductors and magnetic phenomena. Following the development of quantum mechanics at the beginning of the last century, research has long since delved into the very tiniest dimensions – to the atomic origins of magnetism, the particle spin. And this opens up a host of new opportunities and issues for scientists.

For example: whether and how this spin can be best utilised for modern nanoelectronics. Many of HZDR's physicists are working on these issues and we want to use this new issue of our research magazine "discovered" to present their approaches. I look forward to receiving your comments and suggestions and hope you enjoy reading all about them.

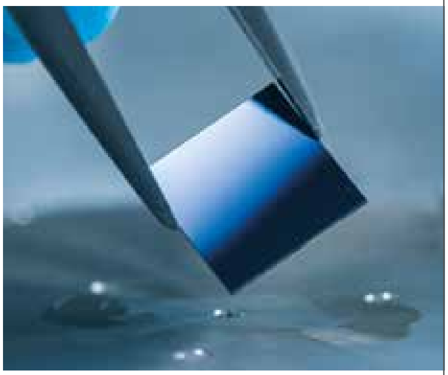
Simon Schmitt
Communications and Media Relations at HZDR

Content

Portrait



Research



Title

A new spin in nanoelectronics

Cover picture: A mini-antenna for tomorrow's data processing – with the help of a magnetic vortex, scientists at the Helmholtz-Zentrum Dresden-Rossendorf can generate very short spin waves. To do so, they use two extremely thin ferromagnetic platelets separated by a non-magnetic layer. Due to the narrow spatial limitations, a natural antenna is formed because the spins can only position themselves along concentric circles. In a tiny field in the middle, this forces them to become erect and point away from the surface.

Panorama

Research Highlights

TUMOR GENETICS

Fusions in the genetic code

By conducting detailed molecular analyses researchers at the National Center for Tumor Diseases (NCT) in Dresden and Heidelberg were able to detect growth-promoting gene fusions in pancreatic tumors. The studies showed that in these cases, part of what is called the NRG1 gene fuses with part of another gene. In contrast to pancreatic cancers that feature the typical mutation in the so-called KRAS gene, which are virtually unresponsive to medication, cancer cells containing these fused structures are vulnerable. These insights could yield new personalized therapy approaches. Researchers at the two NCT locations now plan to conduct a detailed study to explore how to optimize treatment with targeted medication.

Publication:
C. Heining et al., in Cancer Discovery, 2018
(DOI: 10.1158/2159-8290.CD-18-0036)

ASTROPHYSICS

Where's the dust?

An international team of researchers, including HZDR physicists, was able to solve an old unanswered mystery of the origin of oxygen isotopes in meteoritic stardust. The tiny specks provide precise clues on the physical processes inside the stars from whose ashes they stem. So far, however, studies on meteorites have not yet detected the characteristic footprint of stars that are four to eight times heavier than our sun, even though observations with infrared telescopes have shown that these stars exist in large numbers. Experiments at the Italian Laboratory for Underground Nuclear Astrophysics (LUNA) suggested that the destruction rate of the rare oxygen isotope ^{17}O is higher than previously assumed, which alters the predicted isotope footprint. Once they had incorporated the new reaction rate into their star models, the researchers' predictions matched the measured properties of certain stardust particles.

Publication:
M. Lugaro et al., in Nature Astronomy, 2017
(DOI: 10.1038/s41550-016-0027)

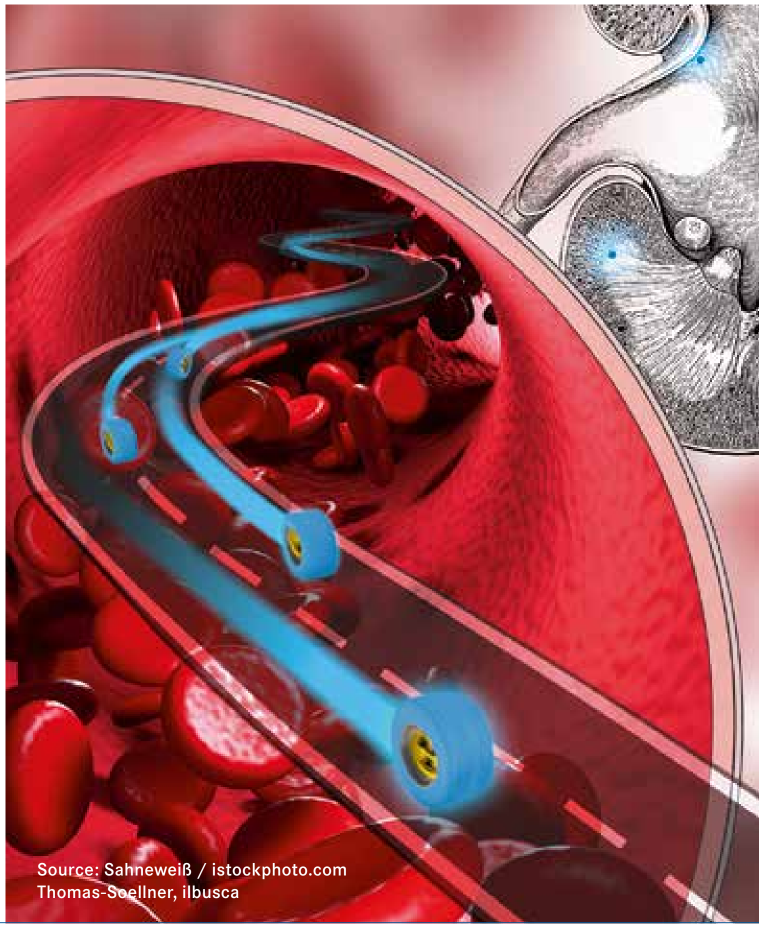
Source: NASA, ESA, and C.R. O'Dell
(Vanderbilt University)

RADIOPHARMACEUTICALS

Lightning-fast silicon

Thanks to their versatile multi-functionality, tiny nanoparticles are considered promising medical tools, for instance to detect tumors. Armed with a shell that renders them invisible to the immune system and radioactively marked, these particles can travel through the bloodstream, ideally cluster near the diseased cells, and thus detect them. Their ionizing radiation, however, makes it vital that the substances leave the body as fast as possible to avoid undue stress on healthy organs. Up to now, this has prevented them from being used in medical applications. Researchers from HZDR and the universities of Strasbourg and Padua have now managed to generate ultra-small silicon nanoparticles and carbon nanocrystals, measuring less than five nanometers each, and track them via positron emission tomography (PET) as they spread throughout the organism. They discovered that both types of particle are secreted very fast via the kidney, which means they might make great tools for cancer diagnostics.

Publication:
N. Licciardello et al., in Nanoscale, 2018
(DOI: 10.1039/c8nr01063c)



RESOURCE TECHNOLOGY

It's all in the mix

The efficiency of flotation-based processing of ultra-fine metal-containing valuables from ores greatly depends on the particle size of the valueless surrounding rock, as HZDR and TU Freiberg researchers have now been able to confirm for the first time. The process of flotation involves mixing water with finely ground rock. Added air bubbles then drag precious minerals to the surface where they are carried away in a froth. Experts previously assumed that it was only the size of the target particles that impacted the results, which would mean that the recovery would deteriorate as the target particles got smaller – an increasing problem for processing, since minerals are often found very finely disseminated in ores. The new studies on the minerals magnetite and quartz have shown, however, that fine (10 to 50 micrometers) and ultrafine (smaller than ten micrometers) target materials can be recovered at the same yield provided that the surrounding rock is also fine. The rate drops drastically, even for fine particles, when the valueless granules are ultrafine, i.e. smaller than ten micrometers.

Publication:
T. Leistner et al., in Minerals Engineering, 2017
(DOI: 10.1016/j.mineng.2017.02.005)

GEOCHEMISTRY

Pulsing away

Contrary to previous assumptions, crystals in liquids do not dissolve evenly, but rather in pulses. HZDR researchers and their colleagues at the Center for Marine Environmental Studies at the University of Bremen (MARUM) recently discovered this unexpected phenomenon. The process of how crystalline material reacts with liquids is vital for technical and medical applications, such as metal corrosion or the absorption of medicaments in the body. The studies have now provided new insights into how material is released over time and in space. This has an impact on risk and safety prognoses, for instance for radioactive waste processing. The results also demonstrate that dissolution is not just the inverse process of continuous crystal growing, as no such pulses have been observed during crystal growth.

Publication:
C. Fischer, A. Lüttge, in Proceedings of the National Academy of Science, 2018 (DOI: 10.1073/pnas.1711254115)

The gateway to a new world of electronics

Nanostructures have special magnetic properties that HZDR researchers can measure precisely. This could pave the way for a future generation of particularly efficient digital technologies.

_ Text . Uta Bilow

Anyone thinking back to the days before PCs were ubiquitous sometimes asks themselves how we used to store and process information, how we did calculations and how we communicated. Digital technology and computers have brought about a revolution that reaches into nearly all areas of life. The frequency for this development was defined in Moore’s Law – which states that the number of transistors on a chip doubles every two years – and, in the past, the efficiency of computers really did progress unabated.

But technical progress in computer chips is gradually grinding to a halt. Not just that the production of conventional microprocessors is becoming ever more complex, but we are also slowly approaching the physical limits of how small transistors can actually be made. Scientists at the Helmholtz-Zentrum Dresden-Rossendorf are therefore already working on the next stage: magnetic analogies to conventional electronics. The magic word which is supposed to open the gateway to this world is nanomagnetism.

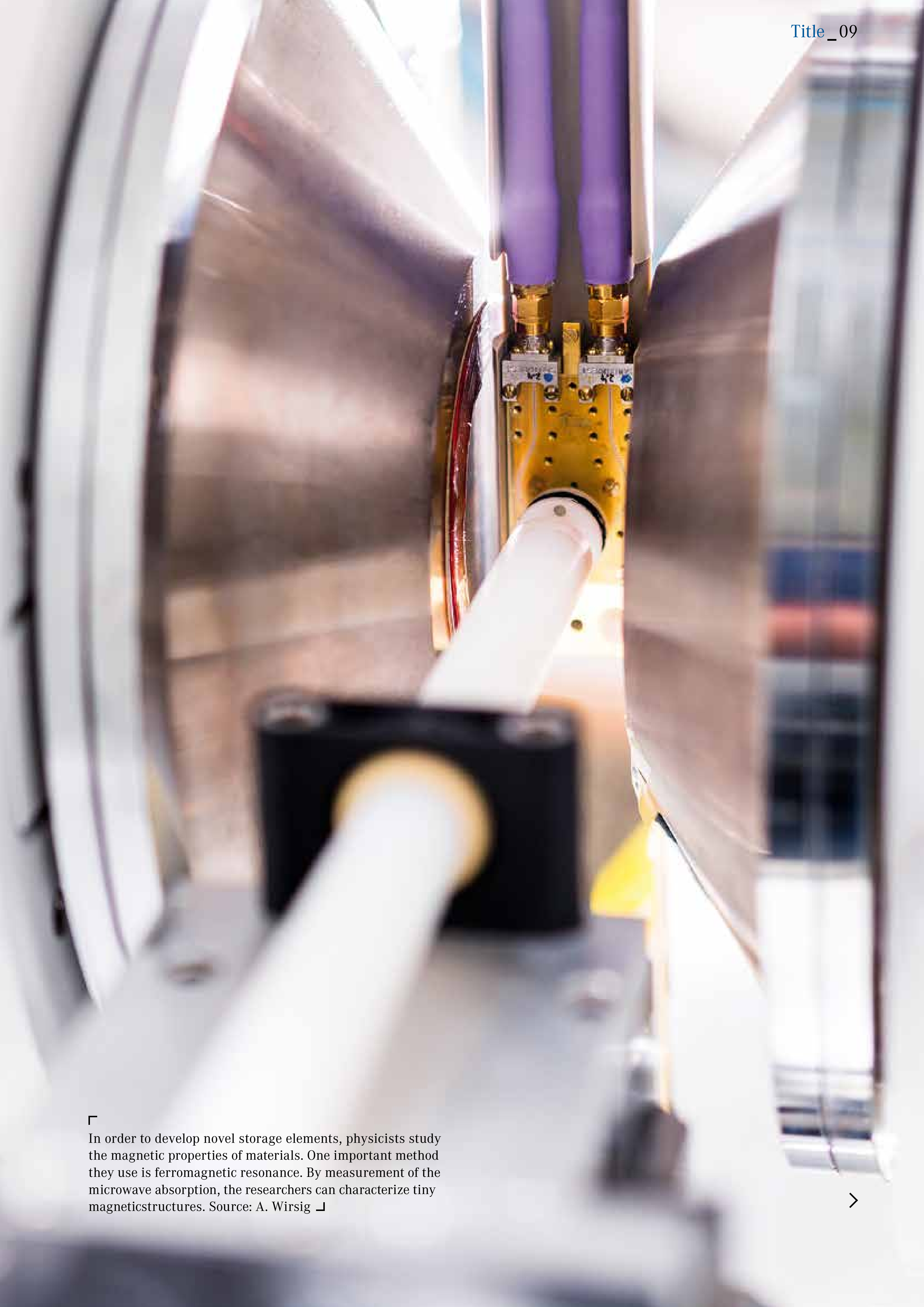
Best of all: what is used to transport and store data, is the electron’s magnetic moment, aka the spin. In the process, it is only the information that is transferred, there is no flow of electrons. “This facilitates low-loss applications and expands the possibilities for processing and storing information very considerably,” emphasizes Jürgen Lindner, head of HZDR’s Department of Magnetism. The research field of nanomagnetism has been making headway for the last ten to twenty years. At HZDR, physicists are working on new concepts for magnetic data storage, on components for so-called spintronics, which are seen as a potential successor technology in electronics, and on magnonic materials that are supposed to make this all possible.

Amazing effects in nanostructures

We have long been familiar with ferromagnetic materials such as iron and nickel. Their ability to act as permanent magnets or compass needles is based on a special property: the spins of their electrons are aligned in parallel, and thus, produce a noticeable magnetic moment. On the nanoscale, however, these metals are full of surprises. In 1988, for example, Peter Grünberg and Albert Fert both independently discovered the giant magnetoresistance (GMR), which is based on multilayer structures in nanometer dimensions, and very quickly found applications in hard disk read heads. In 2007, the two researchers were awarded the Nobel Prize in Physics for their discovery.

One of the keys to progress in this extremely exciting research area are highly-sensitive analytical methods, which are the precondition for embarking on a fundamental examination of magnetic nanostructures. HZDR’s Kilian Lenz is a specialist for measurements of this kind. With his research group on Magnetization Dynamics he has perfected a technique that uncovers important details of nanomagnetism: ferromagnetic resonance, or FMR.

This measuring technique is related to magnetic resonance imaging, which is widely used in diagnostics. With FMR, scientists can probe the magnetic properties of ferromagnetic samples. To this end, the material is placed in a constant magnetic field and then swept with an alternating electromagnetic field on the microwave scale, that is, with a frequency of approximately one to 300 gigahertz, and then the absorption is measured. Microwaves can, after all, excite the sample's spin like in a spinning top. In the process, the rotational axis gyrates as though it were off balance and



In order to develop novel storage elements, physicists study the magnetic properties of materials. One important method they use is ferromagnetic resonance. By measurement of the microwave absorption, the researchers can characterize tiny magneticstructures. Source: A. Wirsig consequently describes a cone – the spins are precessing, as the experts say. And this happens at a certain resonance frequency, as Kilian Lenz explains: “It’s like a swing. If you push a child on a swing and keep the rhythm going, it will continue to swing at the same rate. It’s the same in the sample. Because of the microwaves, you can keep the precession movement going.”

Microresonators for tiny samples

The FMR technique, however, is not particularly sensitive, as the physicist knows: “Typically, you need 10^{11} spins in order to be able to measure any signal at all.” 10^{11}, that is, 100,000,000,000 – which sounds like a pretty big figure. But in the world of atoms it only equates to a tiny amount of material – and in the nano cosmos the portions are yet smaller still. An iron cube with a 40 nanometer edge length has just 10^{6} spins, 100,000 times fewer than are really needed for measurements. That is why Lenz and his staff have developed special microresonators for FMR, which enable the technique to grow to new dimensions.

Using this device, the technology becomes much more sensitive. You can measure the tiny samples and discover interesting phenomena, Kilian Lenz explains: “In large samples I can only see the so-called uniform mode, which means all the spins precess in the same phase.” Figuratively speaking, all rotations are in sync and rotate in perfect harmony. In this case, the FMR spectrum precisely registers a signal, as Lenz continues: “It gets really exciting in small dimensions because there, there are other excitation options, namely spin waves.” In a spin wave, the orientation of the magnetic moment constantly changes along the sample. Just imagine a number of spinning tops all revolving in a slightly different phase from their neighbors so that each one has already turned a bit further. Seen as a whole, a wave is produced, which propagates through the material. With FMR it becomes possible to measure these spin waves.

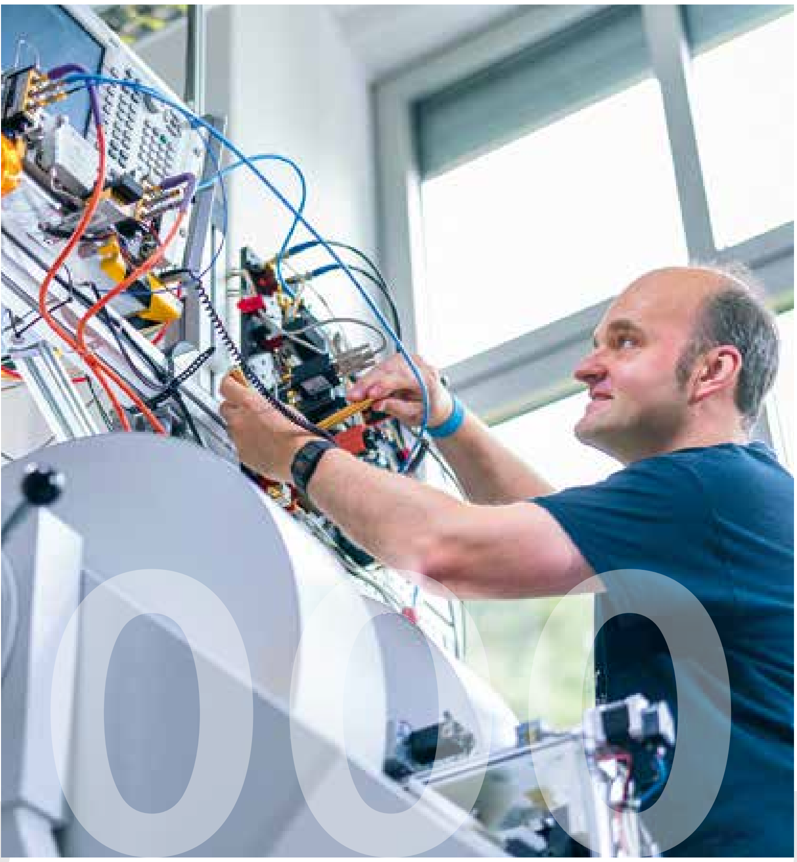
Researchers hope that these spin waves will herald major progress in digital technology because they allow signals to be transmitted highly efficiently without heating up the components as is currently the case with electronics. And ferromagnetic materials on the nanometer scale impose special properties on the spin waves, Jürgen Lindner explains: “The edge of a thin layer quite naturally delivers potential for spin waves. Here you can find magnetic potential that is only ten to twenty nanometers wide.” It is only at this edge that the spin waves form, not on the rest of the sample, so almost of its own accord the perfect propagation pathway for spin waves is created.

The reason for this behavior is that spins at the edge of a material sample do not have any neighbors. “It’s like a water wave,” says Jürgen Lindner. “It behaves differently on an open stretch of water than it does at the coast.” Specialists refer to these special spin waves that develop at the rim of a material sample and which Kilian Lenz can detect with FMR, as edge modes. Moreover, this analytical method also delivers details about magnetization dynamics, that is, the speed at which the magnetic properties of a nanostructure can be excited. “We look to see how quickly the precession diminishes after excitation, that is, how strongly the spin wave is damped. And we measure how easily the magnetization in a sample can be turned in a certain direction,” Lenz notes.

An ion microscope for exact edges

For investigations of this kind, objects with perfect edges are extremely important. “Our samples initially have slightly rough edges,” Kilian Lenz explains, “because we produce them using electron beam lithography. The exposure process involving an electron beam might be compared to using a sort of coarse serrated knife.” The edge is then trimmed with a special ion microscope. Because the beam that is composed of neon

With the help of a helium ion microscope, physicist Gregor Hlawacek can trim nanometer-sized samples into the desired form. Source: A. Wirsig



Kilian Lenz prepares a sample to investigate its magnetic properties using ferromagnetic resonance. Source: A. Wirsig

ions is extremely focused, the cut-off edge can be made particularly sharp – as though it had been cut with a scalpel.

“It’s a big advantage for us to be able to use this equipment here on the spot in the Ion Beam Center,” says Jürgen Lindner. “The nanostructures are produced, trimmed and subsequently analyzed in one and the same place – thanks to the unique combination of high-tech devices.” When it comes to FMR, this is why the Dresden researchers are in the international vanguard, Lindner believes, instancing: “We have specialized in this technology that can be used for quantitative measurements. These methods are incredibly interesting for our understanding of nanomagnetic phenomena. They are often rather overshadowed, but they are extremely important and the basis for successful developments.”

Micromagnetic simulations, with which the FMR measurement results can be compared, play a crucial role for Lenz and his colleagues. Here, physicists are also working on further developing existing software themselves because the simulation programs sometimes lag behind the scientists’ aspirations, as Kilian Lenz explains. “In order to do the modelling the objects have to be divided up into small elements. Many programs insist on a cube shape. But if I have a cylinder, for example, with a curved surface, I can’t describe it properly with cubes. And that can lead to wrong results, for instance at the edge modes.” Consequently, the HZDR scientists have written their own programs, which allow the objects to be broken down into whatever tiny geometrical form they need.

Simulations of this kind make it possible, on the one hand, to transfer the absorption signals that have been measured onto an image that visualizes spin distribution and direction. On the other, these programs can be used for predictions, as Kilian Lenz explains: “The parameters in the programs can be played with. Thus, it can be calculated where the spin-wave modes will move if the sample is half as wide or twice as long, or if I use a different material.”

Many investigations are done using permalloy, a nickel-iron alloy with the formula $Ni80Fe20$. “It’s the drosophila of magnetism research,” Kilian Lenz jokes, referring to the common fruit fly, Drosophila melanogaster, which is the model organism of choice in genetics. Conveniently, the alloy is easy to use, has been a known entity for a long time and is well characterized. But in the FMR device he also examines other substances that could be of particular interest to technical applications, such as alloys of cobalt, iron and boron, or what are known as Heusler compounds, which are being investigated for high-frequency applications.

At present, it is still unclear what future generations of processors and storages will look like, which building blocks and physical phenomena will lay the foundations for their architecture. But the HZDR scientists are working hard to make nanomagnetic structures fit for purpose in information processing.

Publications:

H. Cansever, R. Narkowicz, K. Lenz, C. Fowley, L. Ramasubramanian, O. Yildirim, A. Niesen, T. Huebner, G. Reiss, J. Lindner, J. Fassbender, A.M. Deac: Investigating spin-transfer torques induced by thermal gradients in magnetic tunnel junctions by using micro-cavity ferromagnetic resonance, in Journal of Physics D: Applied Physics, 2018 (DOI: 10.1088/1361-6463/aac03d)

R.A. Gallardo, T. Schneider, A. Roldán-Molina, M. Langer, A.S. Núñez, K. Lenz, J. Lindner, P. Landeros: Symmetries and localization properties of defect modes in metamaterial magnonic superlattices, in Physical Review B, 2018 (DOI: 10.1103/PhysRevB.97.174404)

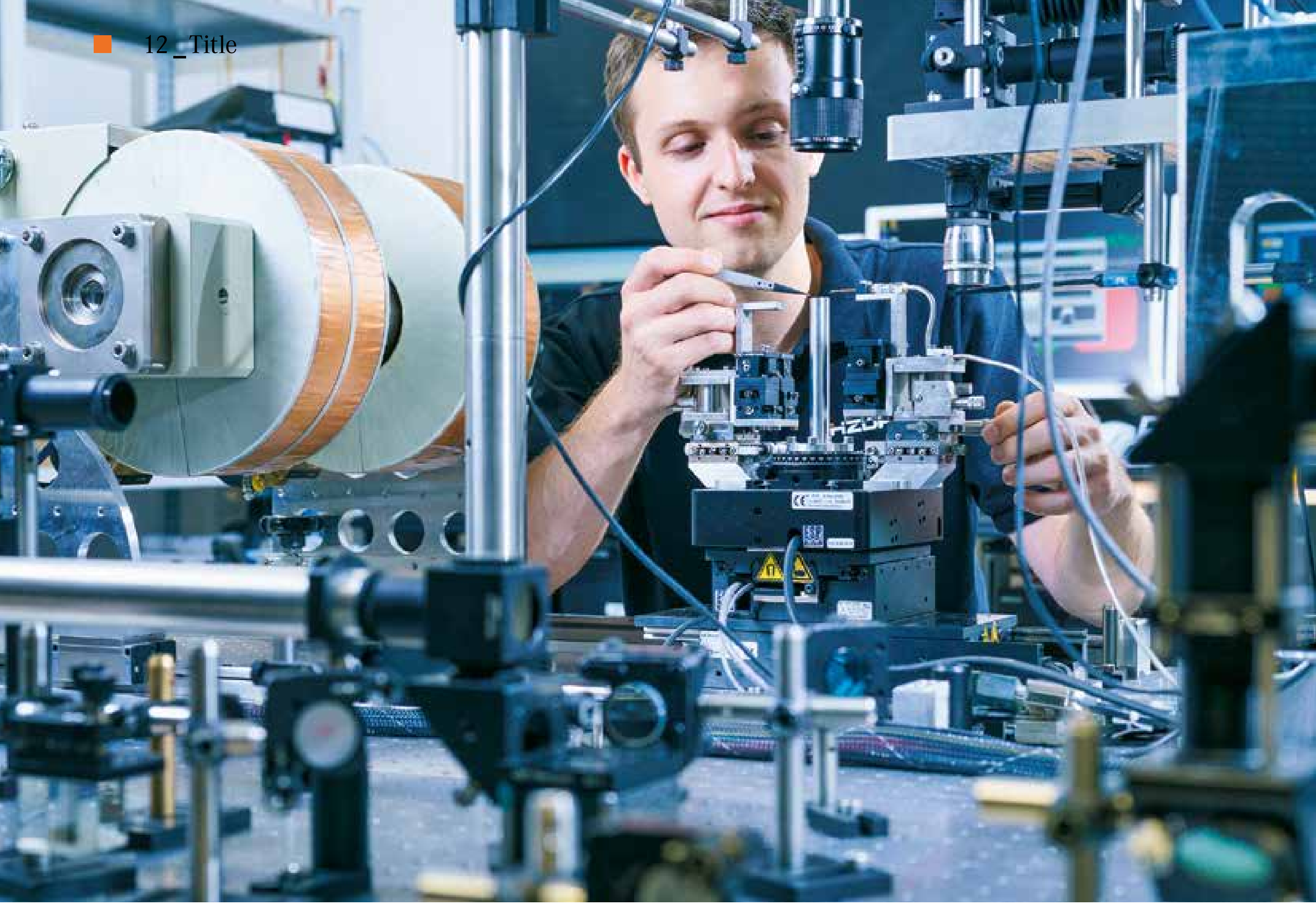
R.A. Gallardo, T. Schneider, A. Roldan-Molina, M. Langer, J. Fassbender, K. Lenz, J. Lindner, P. Landeros: Dipolar interaction induced band gaps and flat modes in surface-modulated magnonic crystals, in Physical Review B, 2018 (DOI: 10.1103/PhysRevB.97.144405)

Contact

_Institute of Ion Beam Physics and Materials Research at HZDR
Dr. Kilian Lenz
k.lenz@hzdr.de

Dr. Jürgen Lindner
j.lindner@hzdr.de

Dr. Gregor Hlawacek
g.hlawacek@hzdr.de



Using a laser scanning microscope, doctoral candidate Tobias Hula can study the dynamics of magnetic microstructures, such as spin waves. Source: A. Wirsig

The magnetic wave

Gradually, microelectronics reach their physical limits. Across the world, researchers are working on alternatives. At HZDR, experts are banking on a very special phenomenon: that by utilizing spin waves, you can compute without any electrical charges or currents flowing.

_ Text . Frank Grotelüschen

"Here are our toys." Alina Deac has opened the door to her lab. Now she points to various pieces of apparatus: metal frames full of electronic measuring equipment, test stands with massive magnetic coils and microscopes you can use to precisely position the finest contact wires. This is the high-tech arsenal used by Deac's team to examine sensitive samples. "In our experiments we have to pass relatively strong currents through these tiny samples," the HZDR researcher explains. "Sometimes one of them melts." Nevertheless all their efforts could prove worthwhile because the materials the research group is tinkering with could potentially change wireless communication fundamentally: they hold the promise of transmitting a hundred times more data than today – thus enabling mobile and WLAN networks.

What this is based on is a particular property of the electron – its spin. Figuratively speaking, what the tiny particle does is to continually rotate around itself. As, by definition, it carries an electric charge, according to the laws of physics, this self-spinning generates a weak magnetic moment. "In principle, the electron spin is the basis of most magnetic phenomena," explains Jürgen Linder, head of the Department of Magnetism at HZDR's Institute of Ion Beam Physics and Materials Research. "Among other things, it's the reason why a piece of iron is magnetic, and you can store data on a hard disk."

For some time now, researchers around the globe have been trying to do more with the electron spin than just store information. Their aim is to achieve faster computers and data transmission, as well as computer systems that mimic the functioning of the human brain. In this respect, scientists have been working on the fundamentals of "spintronics" for the last couple of decades, but recently, they have made promising progress – with the prospect of applications becoming much more concrete.

In Dresden, researchers concentrate on a phenomenon called spin waves. Unlike today's electronic components, they do not have electrons flowing through a metal or semiconductor. Instead, the fundamental materials are specific magnets in which the electrons themselves stay where they are and only pass on their magnetic moment. All electrons spin simultaneously in exactly the same way, like one spinning top. But if you apply short electrical pulses, for instance, to force some of the electrons out of sync, this disturbance can move through the material via the neighboring electrons – a spin wave races through the crystal lattice.

Chain instead of messenger

In these waves, information can be coded and transmitted, somewhat like a messenger running with an express parcel from the sorting office to the addressee. The spin waves, on the other hand, are more like a human chain, passing the parcel from one person to the next. In electronics, this could ameliorate a problem that is becoming ever more stringent. "Today's computer chips have electrons flowing through them," Jürgen Lindner explains. "On the way they encounter electrical resistance and heat up the chip."

As manufacturers are developing chips with ever narrower conductor paths, this heating up is becoming an ever-greater problem – it makes it impossible to increase the speed of the components. This shortcoming could be avoided with spin waves. As they manage without charge transport, they would use less electricity. Smartphones, laptops and tablets would not have to be plugged in so often, large computer farms would consume less energy. And there is another perspective, too: In suitable magnetic materials, spin waves can propagate at much lower wavelengths – which, in itself, promises higher speeds and thus more efficient processors than we have today.

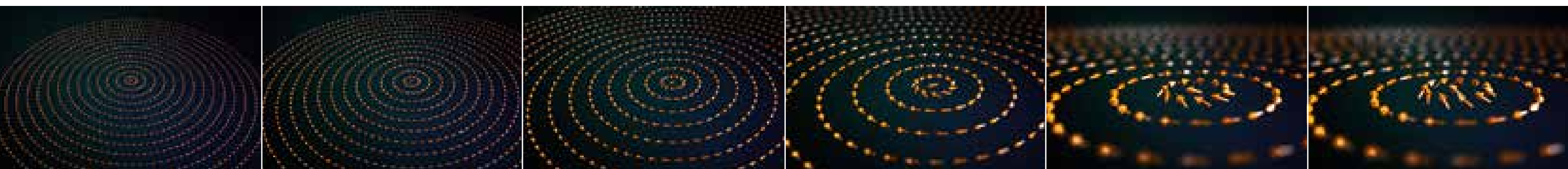
The core of the vortex

Although the requisite research is still in its infancy, experts have now managed to master the core challenges: They can generate spin waves in a very defined way, which then can be directed precisely through materials and get reliably detected. In the field of generation, a team around physicist Sebastian Wintz recently achieved a breakthrough. "We used to generate a spin wave in a tiny antenna made of gold or copper which we mounted on a thin magnetic film," explains Wintz, who is currently working at the Paul Scherrer Institute in Switzerland. "If you shot alternating current into this narrow layer it could trigger a spin wave in the magnet."

Using this method, it is, however, very difficult to excite spin waves with wavelengths of less than a micrometer, which would be an advantage for many purposes. And in order to access the nanoscale, the physicists had to come up with completely different ideas: "Instead of artificial antennas we use ones that generate themselves," Wintz explains. "To do this, we pre-structure our magnetic layers by imprinting micrometer-sized disks into them. As a result, miniscule magnetic vortices are formed with out-of-plane oriented magnetic moments at their cores."

These vortex cores have a diameter of just ten nanometers and, in magnetic terms, are highly stable. If these tiny devices are subjected to an alternating field, the vortices start to rotate – and thus excite a spin wave inside the material. "We have already used this method to generate wavelengths under 100 nanometers," Wintz reports. "Using special X-ray

By imprinting micrometer-sized disks on magnetic layers, HZDR physicists can create tiny magnetic vortices which excite extremely short-wave spin waves (below).
Source: AVANGA



microscopes, we've been able to observe how these spin waves spread – which is very similar to water waves."

Spin wave channels

But how can the propagation be controlled? How can the spin waves be precisely steered and maneuvered around bends and corners? On this point, the scientists are pursuing an original strategy: they create structures in the material itself that act as crash barriers for spin waves. These "domain walls" divide the areas of differing magnetization. The crucial point is that the spin waves are caught between these domain walls and can only propagate in the direction specified – like a roaring mountain stream in a narrow, straightened channel.

"Using domain walls like this we can steer the spin waves precisely," says Helmut Schultheiß, head of the Magnonics Group at HZDR. "And with the aid of magnetic fields we can more or less push these walls back and forth at will." The result is that unlike today's microprocessors, a chip based on spin waves would not have an architecture defined at manufacture but could be changed subsequently and thus adapted to new challenges.

And this is an aspect that makes the researcher's heart beat faster. "It would facilitate a whole new way of computing," Schultheiß speculates, turning his attention to the "neuromorphic computer" which would consist of artificial neurons, nerve pathways and synapses and would recreate the functioning of a biological brain. "My vision is to achieve this using spin waves," says Schultheiß. "The advantage is that you could accommodate all the components in a single material."

For example: Ring-shaped domain walls could act as neurons and store spin waves. They would be connected with other artificial neurons via a system of channels. If a certain threshold was reached in one of the neuron rings it would trigger spin waves and thus activate other neurons – a process similar to what takes place in the brain. "Systems like this could play to their strengths in image and speech recognition, which would be useful for things like autonomous driving," Helmut Schultheiß believes. "And if you allow these neural networks to modify themselves, they would even be capable of learning."

Probing by laser

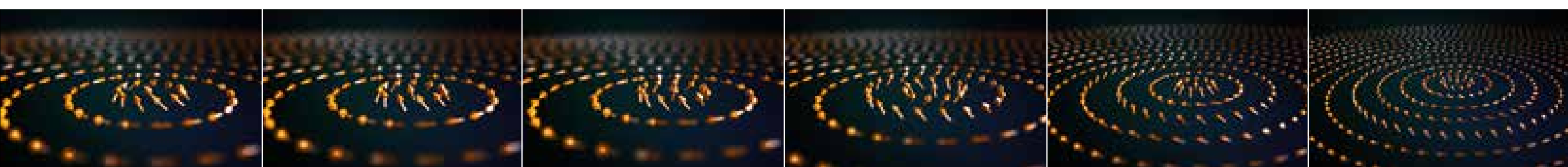
A bold vision requiring one precondition to be fulfilled: it is not enough to be able to precisely generate and manipulate spin waves, you have to be able to absorb and detect them, as well. Here, too, HZDR experts have had some success. Among other things, they studied thin layers of platinum attached to magnetic materials. If a spin wave now propagates through the material, thanks to scattering processes in the platinum layer, it produces a small, but measurable flow of current that can be detected with sensitive electronic measuring equipment.

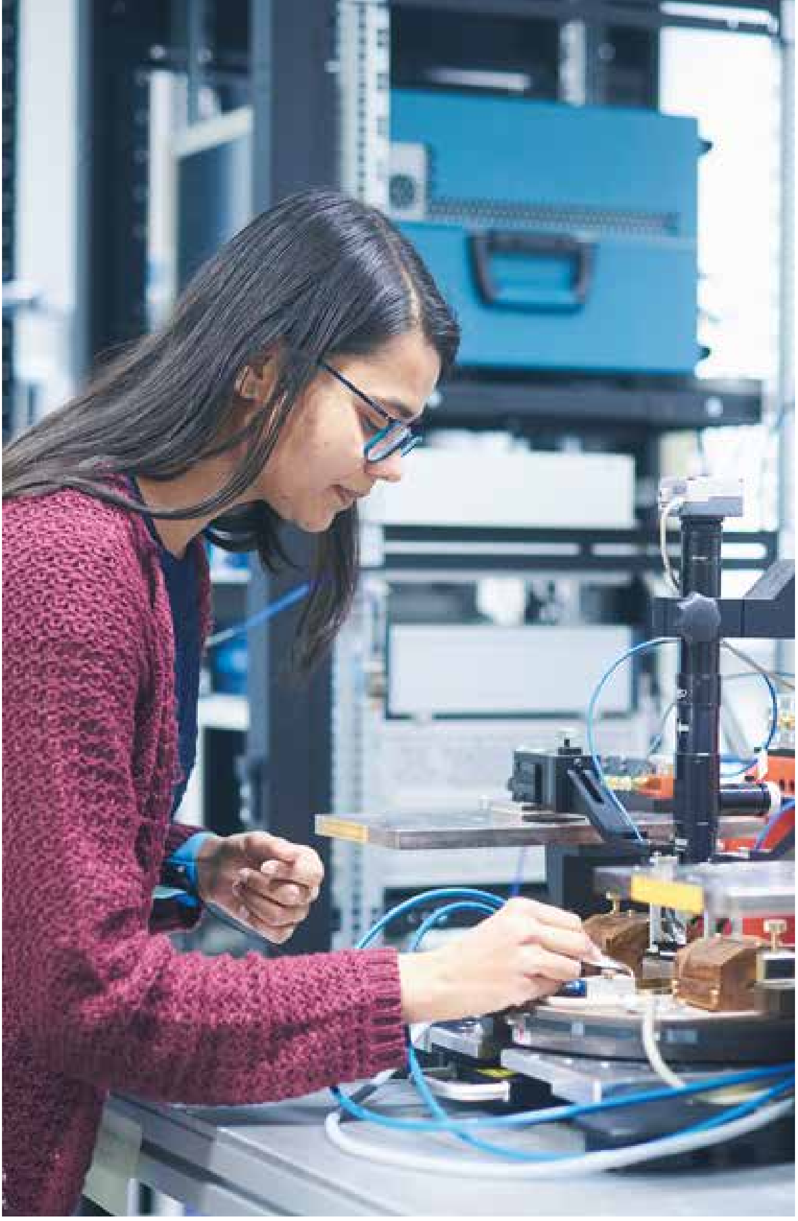
It is, however, also possible to use lasers for detection – whereby you can essentially listen in to the spin waves. It works on the principle that if you direct a light pulse at the spin wave, the spin wave will modify it by changing its polarization – the oscillation direction of the light. With the aid of optical sensors, this, in turn, can be analyzed precisely. This method promises to significantly speed up data retrieval which, among other things, would be relevant for fast communication between two spin wave computers.

High data rates are also one of the issues that Alina Deac focuses on. She is working on the WLAN of the future. In order to expedite wireless communication, higher transmission frequencies are required. In our current networks, they range from two to five gigahertz. Deac, who heads HZDR's Spintronics Group, is aiming for 300 gigahertz. "Transmission rates like this could be especially useful in the health sector," the physicist believes, "for example, when sensors on a patient's body are continually monitoring their state of health and sending enormous volumes of data to the hospital." For chip-to-chip communication and the broadening of the internet of things ultrafast wireless connection will be an absolute requirement.

Ultrafast WLAN

Deac's work is based on special manganese-gallium compounds that have only been developed in the last few years. In these materials, electron spins rotate at enormous speeds – the precondition for generating high frequencies.





Doctoral candidate Lakshmi Ramasubramanian prepares a sample to measure the oscillating electromagnetic signal. The finest probe tips must be used to pass the current through the device and detect the emitted oscillating voltage. (left)
Source: S. Floss

In order to trigger the rotation, researchers exposed their samples to terahertz pulses from HZDR's accelerator ELBE. What they discovered was that the spins, as hoped, gyrate at a frequency of approximately 350 gigahertz.

The team also managed to integrate the new materials in thin multilayered stacks, i.e. complex sandwich structures, which effectively are the first precursors for wireless transmitters working at such high frequencies. "Our goal is to apply electrical currents to a component like this to excite the rotation of the electron spin," Alina Deac explains. "This rotation should then generate high-frequency electromagnetic waves that we will detect with suitable antennas." A milestone scientists hope to achieve by 2020, which is when the EU project TRANSPIRE, in which HZDR is cooperating with partners from Ireland, Norway and Switzerland, comes to an end.

Whatever the case, work on spin waves is definitely reaching a new level. "In the lab we can already reliably generate, manipulate and detect them," says Jürgen Lindner. "Now we have to bring these three components together and I believe we'll manage this in the next couple of years." So functioning laboratory prototypes for simple spin wave computers and the like would seem to be within reach.

Before the new concept can be transferred to industry, however, one hurdle still has to be taken: "So far, we work with exotic materials like yttrium iron garnet and monocrystalline iron," Lindner emphasizes. "They work well enough in the lab, but for industry they would be much too expensive and intricate." What is required, therefore, is a good portion of materials research: a new generation of materials is needed in which spin waves can propagate under ideal conditions and which are also suitable for low-cost mass production.

Publications:

S. Wintz, V. Tiberkevich, M. Weigand, J. Raabe, J. Lindner, A. Erbe, A. Slavin, J. Fassbender: Magnetic vortex cores as tunable spin-wave emitters, in Nature Nanotechnology, 2016 (DOI: 10.1038/NNANO.2016.117)

K. Wagner, A. Kákay, K. Schultheiss, A. Henschke, T. Sebastian, H. Schultheiss: Magnetic domain walls as reconfigurable spin-wave nanochannels, in Nature Nanotechnology, 2016 (DOI: 10.1038/NNANO.2015.339)

L. Yang, R. Verba, V. Tiberkevich, T. Schneider, A. Smith, Z. Duan, B. Youngblood, K. Lenz, J. Lindner, A.N. Slavin, I.N. Krivorotov: Reduction of phase noise in nanowire spin orbit torque oscillators, in Scientific Reports, 2015 (DOI: 10.1038/srep16942)

Z. Duan, A. Smith, L. Yang, B. Youngblood, J. Lindner, V.E. Demidov, S.O. Demokritov, I.N. Krivorotov: Nanowire spin torque oscillator driven by spin orbit torques, in Nature Communications, 2014 (DOI: 10.1038/ncomms6616)

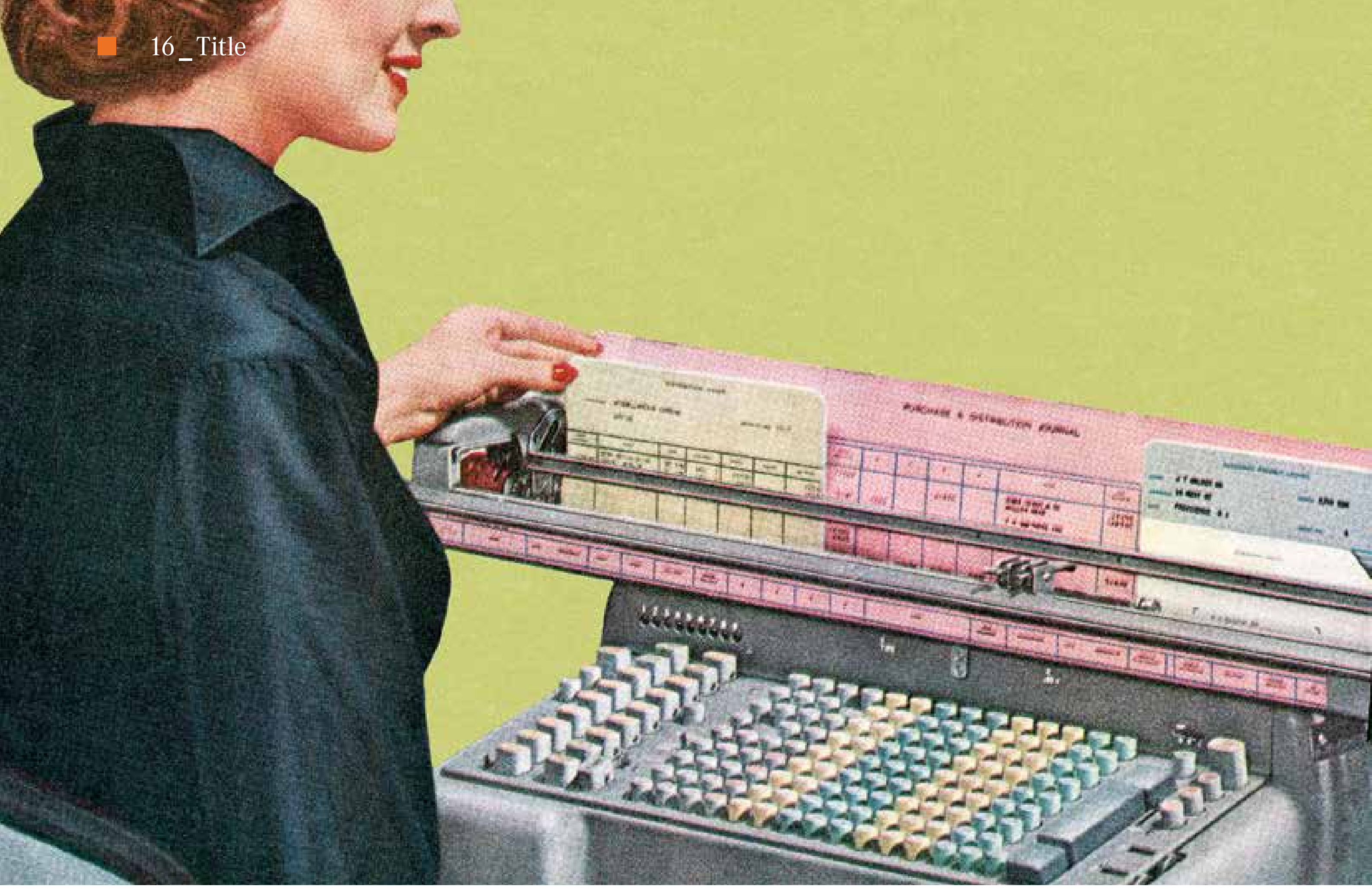
Contact

_Institute of Ion Beam Physics and Materials Research at HZDR
Dr. Jürgen Lindner
j.lindner@hzdr.de

Dr. Helmut Schultheiß
h.schultheiss@hzdr.de

Dr. Alina Deac
a.deac@hzdr.de

_Paul Scherrer Institute / Institute of Ion Beam Physics and Materials Research at HZDR
Dr. Sebastian Wintz
s.wintz@hzdr.de



From nanomagnets to storage giants

In order to store information, scientists and engineers have long since advanced into the realms of minuteness. Interactions on the nanoscale pose a number of challenges, but also offer unimaginable opportunities for future data storage.

_ Text . Kai Dürfeld

Data are the resource of the 21st century. While in 2002, 100 gigabytes were generated around the world every second, you can multiply this figure by 500 today. And the trend is upward. Smart factories produce data, as do highly-automated vehicles, earth observation satellites and particle accelerators. Creative video-makers, social media users and supermarket checkouts can be added to the list that could be extended *ad infinitum*. By 2020, every person will generate an average of approximately 1.5 gigabytes every single day. Computer manufacturers and scientists are faced with the enormous challenge of storing this flood of data – safely and, above all, affordably.

“Since 1956, the storage density of hard disks has grown by nine orders of magnitude,” says Olav Hellwig. “On the same surface you can now fit a billion times more data.” Hellwig is a physicist, head of HZDR’s research group on Magnetic Functional Materials and holder of a professorship of the same topic at Chemnitz University of Technology. “By optimizing traditional hard-disk technologies, we might

Since the inception of mechanical data storage – originally still using punch cards – storage technologies have downsized rapidly. Today, researchers like Miriam Lenz work on magnetic nanostructures in thin-film systems. Source: istock.com, CSA Images, Color Printstock Collection (left) / A. Wirsig (right)

be able to increase storage density by another order of magnitude. Then the magnetic units will be so small that they simply won't be stable at room temperature even if we use the hardest magnets known to man."

Hellwig spent nearly 14 years working for major hard-disk producers in Silicon Valley, seeking to get as much as was physically possible out of established materials and to find new ways of storing data. In Dresden and Chemnitz, he is now continuing this activity and working with colleagues to lay the foundations for the next storage generation and the one after that.

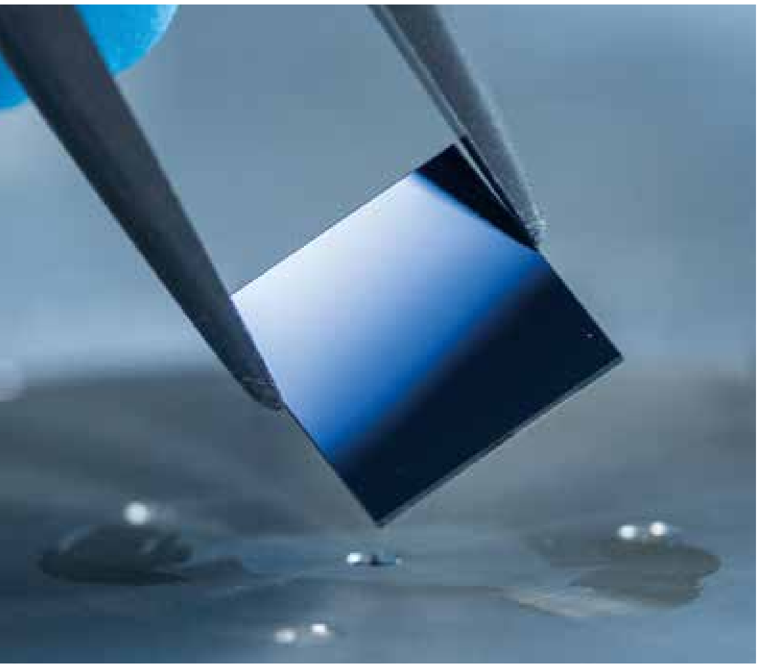
Magnetic islands in nano format

Standardized size, huge storage capacity, unbeatable price: since the first hard disk saw the light of day, they have become the backbone of modern IT systems. Inside are rotating platters made of inert material with a wafer-thin coating of cobalt, chromium and platinum. A read-and-write head hovers over the surface at a distance of roughly three nanometers and, as it records, it defines the so-called bit-cells in a data track. Up to now, these layers have been granular, that is, made up of grains. In the early days, a storage cell was composed of several hundred grains with a diameter in the micrometer range. Today, there are fewer than 20 grains per bit with an average diameter of just approximately eight nanometers.

If more storage cells are to be accommodated on a standard disk, the grains will have to shrink. Current technology has arrived at seven to eight nanometers, meaning it has nearly reached its tweaking limit, because when the grains get smaller, the superparamagnetic effect causes a drop in thermal stability. The magnetism can spontaneously change its direction, making the stored data disappear. One solution could be HAMR – heat-assisted magnetic recording. It is based on particularly magnetically-hard layers of a chemically ordered iron-platinum alloy. Even tiny three-nanometer diameter grains are stable under these conditions.

In order to save data in them, however, the surface has to be locally heated. This is the task of an in-built laser, which projects its energy onto the surface with nanometer precision while the write head magnetizes the storage cell. The data can then be stored and read out in a cold state. Back in the days when he was employed by the big players in hard disk manufacturing, Hellwig worked on HAMR technology. At HZDR, he and his colleagues are now expanding the knowledge of ultrathin storage layers and their characteristic properties.

Instead of granular structures, tiny, ordered, magnetically-homogenous islands are another option for increasing the storage capacity of hard disks. Each one equals one bit and is either generated lithographically or by self-organization, or by



a combination of both. Bit patterned media (BPM) is the name of this technology. Being larger, the advantage is that the “magnetic islands in nano format” are thermally more stable than the many little magnetic grains in conventional storage cells. So, in the storage density department, BPM still has upside potential.

How can the hunger for energy be abated?

There is another aspect, however, that is even more urgent than increased storage density. “The major cost factor for today’s data centers,” Hellwig explains, “is generating the necessary energy to operate the memories and processors, especially for cooling” – because electronics are based on the flow of electrons. But in the process, a large share of the electrical power is converted into heat. The closer the storage cells and processor units are packed together, the more difficult it becomes to discharge this heat.

“Nowadays, data processing and storage takes place at such density that we have long since advanced into the nanoscale,” Hellwig continues. “But the magnetic interactions on the nanometer scale are much more diverse than on the macroscopic level. Most of them only occur in nanomagnetism, with an effective length of under one micrometer. Take spin-polarized currents, for example. These electrical currents carry a magnetic moment, so are magnetic themselves. But this effect can only be utilized in the nanoscale.”

With a magnetometer, researchers can precisely analyze the magnetic switching behavior of pieces of coated silicon wafer. Source: A. Wirsig

For tomorrow’s memories, new interactions on the nanometer scale without charge transfer, such as spin waves (magnons) or pure spin currents could prove to be a blessing, because they have one advantage: In the absence of Ohmic heat, energy requirements drop and the problem of heating up is avoided.

From short-term to long-term memory

Today, there are indeed already storage elements that utilize spin-polarized currents and, quite incidentally, transform a computer’s short-term memory into a long-term memory. To temporarily store information for the next work steps is the task of random access memory, or RAM. Semiconductor memories based on silicon are the current state of technology. They read and write data exceptionally fast, but they cannot conserve the data without being connected to external power. In terms of speed, by contrast, non-volatile semiconductor memories like USB sticks are not a patch on RAMs. Apart from which, every deletion process causes a certain amount of damage to the device.

A combination of both technologies with their respective benefits would be an enormous step. And it has actually been taken already. Magnetoresistive random access memory, MRAM for short, is a technology that does not store data electrically, but magnetically, also drawing on spin-polarized currents. MRAM modules can be written on and deleted any number of times and are just as fast as modern RAMs without being volatile. In the layered storage modules, magnetic films

Dresden researchers work on novel magnetic functional materials. To do so, they apply thin coats of metal to pieces of silicon wafer. The different sequence of layers produces different magnetic functionalities.
Source: A. Wirsig

just a few nanometers thick alternate with even thinner, non-magnetic layers. MRAM modules are already on the market, but their applications are limited due to their high price. They can be found, for example, in aerospace, as data buffers in server systems and industrial plants, where the loss of data caused by a power cut is more serious than the extra expense of the memories.

This is, incidentally, one thing all new storage technologies have in common: "I don't think that any one technology will sweep away everything that has been created so far," Hellwig believes. "Apart from technical viability, the cost is going to determine whether, how quickly and how sustainably a new technology can establish itself." He knows from his own experience that the first priority of industrial storage research is to see its results reflected in sales statistics. And even contract research at many universities, he estimates, is becoming ever more like product development. "That's why HZDR is a very special place for someone like me. Here we can focus completely on basic research and create the foundations for the storage technologies of tomorrow."

Publications:

T.R. Albrecht, H. Arora, V. Ayanoor-Vitikkate, J. Beaujour, D. Bedau, D. Berman, A.L. Bogdanov, Y. Chapuis, J. Cushen, E.E. Dobisz, G. Doerk, H. Gao, M. Grobis, B. Gurney, W. Hanson, O. Hellwig, T. Hirano, J. Lille, P. Jubert, D. Kercher, Z. Liu, C.M. Mate, I. Oboukhov, K.C. Patel, K. Rubin, R. Ruiz, M. Schabes, L. Wan, D. Weller, T. Wu, E. Yang: Bit-patterned magnetic recording: Theory, media fabrication, and recording performance, in IEEE Transactions on Magnetics, 2015 (DOI: 10.1109/TMAG.2015.2397880)

B.C. Stipe, T. Strand, C. Poon, H. Balamane, T. Boone, J. Katine, J-L Li, V. Rawat, H. Nemoto, A. Hirotsune, O. Hellwig, R. Ruiz, E. Dobisz, N. Robertson, T. Albrecht, B.D. Terris: Magnetic recording at 1.5 Pb m-2 using an integrated plasmonic antenna, in Nature Photonics, 2010 (DOI: 10.1038/nphoton.2010.90)

Contact

_Institute of Ion Beam Physics and Materials Research at HZDR / TU Chemnitz
Prof. Olav Hellwig
o.hellwig@hzdr.de

Dresden's dynamo

Inside our planet, a layer of liquid metal swooshes around a solid iron core. Its movements trigger an electric current, which in turn generates the Earth's vital magnetic field that protects us from solar winds. The exact workings of this geo-dynamo are as yet unclear. HZDR researchers now want to solve the mystery with a unique experiment.

— Text . Simon Schmitt / Illustration . Juniks Marketing /Picture . iStock – Yuri_Arcurs

At first sight, the facility built on seven reinforced concrete columns that descend 22 meters into the granite below looks like a very futuristic telescope. Yet this giant contraption is not designed to gaze into the expanses of the universe, but rather the opposite: It will simulate a glimpse into the inner workings of the Earth. Researchers at HZDR's Institute of Fluid Dynamics plan to study the processes that occur inside the planet's core in order to test a theory on the formation of the Earth's magnetic field.

According to numerous experts, Earth's precession could be a complementary energy source of the geo-dynamo, as project coordinator Frank Stefani explains: "The term precession describes a movement similar to that of a child's tilting, spinning top. That's how Earth is reeling through space because its rotational axis is tilted by about 23 degrees in relation to its orbital plane." The Dresden researchers hope their experiments will show that the Earth's precession is enough of a natural flow generator to produce a magnetic field.

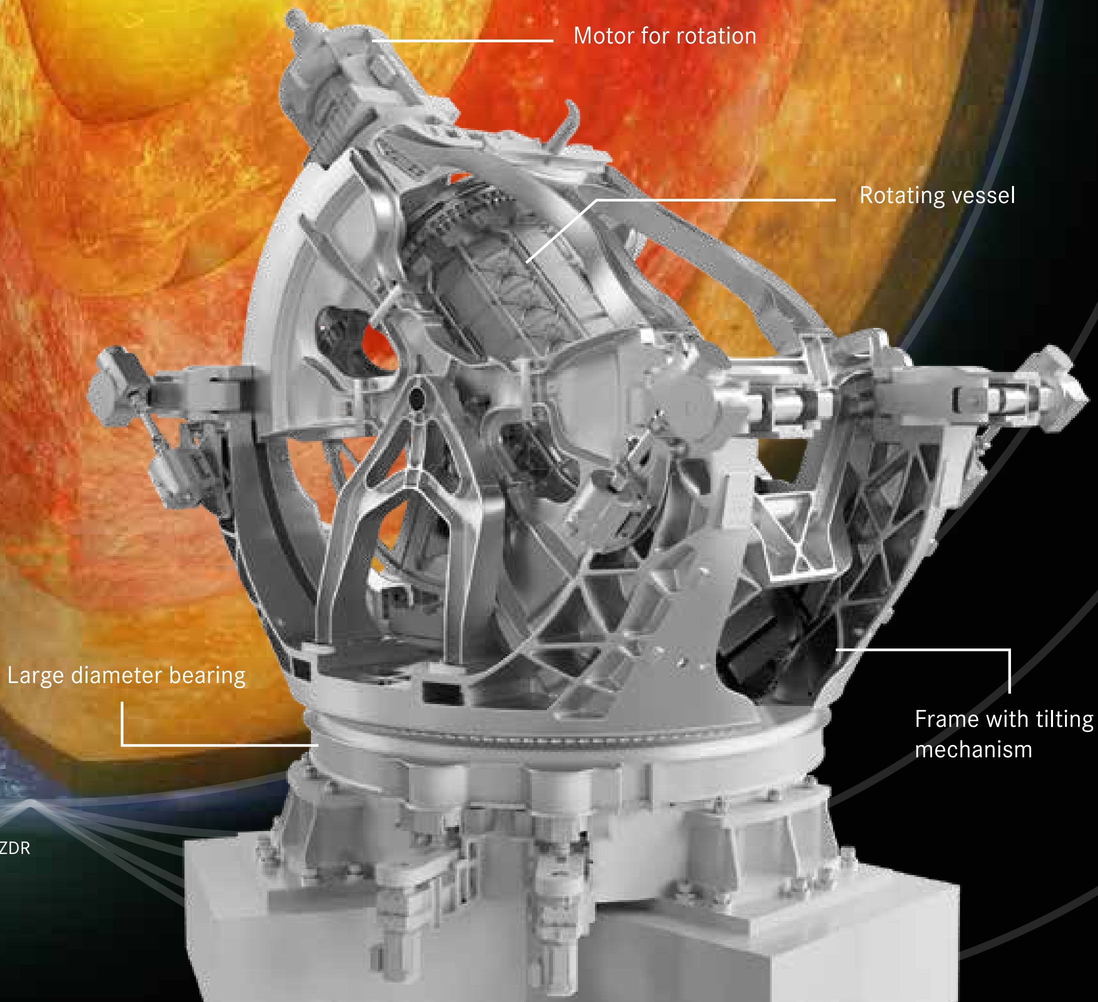
The project involves filling eight tons of liquid sodium into a giant steel drum, which is encased in a massive frame in the middle of the facility. "Similar to liquid iron, liquid sodium is a great electric conductor and therefore highly suitable for our studies," Stefani describes. "During the experiment, the drum will rotate around its own longitudinal axis while the giant plate on which it is mounted revolves around its own axis. This generates a precession flow in the sodium comparable to the one inside the Earth."

The double rotation exposes the facility to an extreme gyroscopic force that can reach up to eight million newton-meters. "It's as if 400 tons were pulling up on my right arm and 400 tons were pulling down on my left," says Stefani, describing the forces that will reign during the experiment. "This is why we need this massive foundation – to ensure that our construction will withstand such forces." It will likely be another year before the project can start. Test runs with water will verify whether the mechanics work as planned. But after that Dresden's dynamo might provide new insights into an ancient phenomenon.

European Research Council provides 2.5 million euros

The formation of Earth's magnetic field is just one of many magnetic phenomena explored on the experimental platform DRESDYN (DREsden Sodium facility for DYNamo and thermohydraulic studies). Researchers also plan to use additional experimental setups to find out how stars are formed out of giant gas disks and how currents impact the functioning of novel liquid metal batteries. Liquid sodium is used in all these experiments. In April 2018, the European Research Council (ERC) awarded an ERC Advanced Grant to Frank Stefani to promote this research. Over the next five years, the physicist will receive a total of 2.5 million euros for his magneto-hydrodynamic studies.

Source: D. Müller



Contact

_Institute of Fluid Dynamics at HZDR
Dr. Frank Stefani
f.stefani@hzdr.de

Source: istock.com, andrei_r

The long journey from lab to clinic

It is difficult to miss all the hype about immune therapies against cancer. But their initial success has been accompanied by considerable costs and risks. A team of researchers around Michael Bachmann has developed approaches to minimizing both. The first patient trials began this year. One important milestone has been reached – after some thirty years of research shaped by successes and setbacks.

_ Text . Marcus Anhäuser

If you want to meet a happy man, you should visit Michael Bachmann. The 61-year-old professor of Translational Radiopharmacology at TU Dresden has notched up a number of achievements during his scientific career. Currently, he is the Executive Director of the Institute of Radiopharmaceutical Cancer Research at the Helmholtz-Zentrum Dresden-Rossendorf: Ph.D. in record time at 24, habilitation as one of the youngest researchers in Germany. His publication list boasts more than 800 scientific titles, he has received diverse awards and honors and he recently even set up a company together with the former Director of Hematology at Dresden University Hospital, Gerhard Ehninger.

But what makes Bachmann happiest of all is a wish fulfilled: “That some of the scientific ideas one once had actually reach the patient.” For him, an expert on the “causes, treatment and diagnosis of tumors and autoimmune diseases”, it is even more than happiness: “It’s what every scientist dreams of.” And it is the next big step in the development of a cancer therapy: the leap from bench to clinic.

The research Bachmann and his colleagues are doing has reached the stage when they can risk trying it out on patients. “In June, we started treating our very first patient with a therapy we developed here to cure a form of leukemia,” Bachmann explains. The second trials will probably begin at the end of the year when a patient with a prostate tumor will be treated for the first time with a similar drug, also developed in Dresden.

Making tumors identifiable

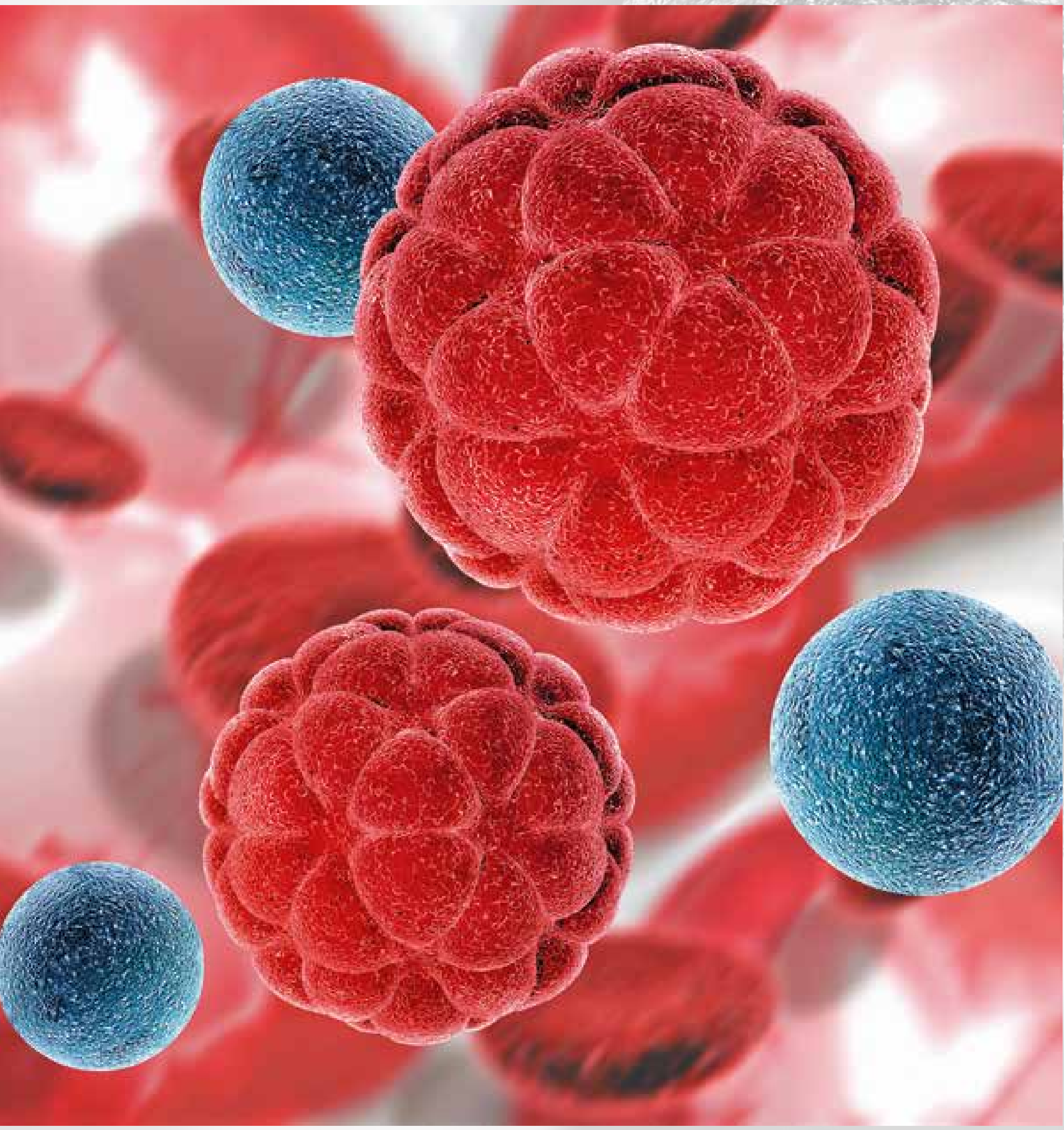
Both approaches are variations on and developments of the immune therapies that have been enjoying increasing success in the last few years. What happens here is that the patient's immune system is supported using molecular biological and, not least, molecular engineering methods to specifically fight the cancer – because the immune system has problems with tumors: cancer cells are hard to differentiate from healthy tissue because they are not foreign invaders like bacteria or viruses. Immune therapies help the immune system to recognize the enemy and take up the battle.

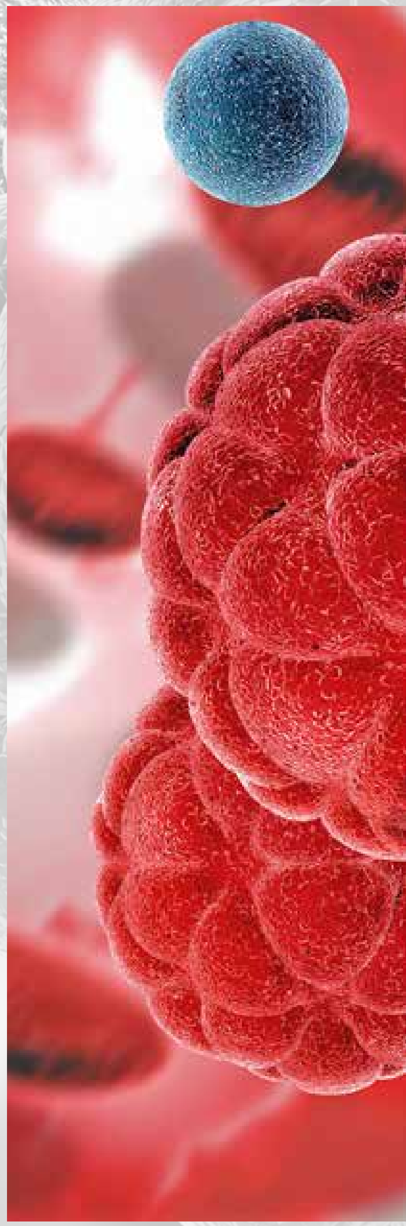
Two terms are used for the Dresden scientists' therapeutic methods, real tongue-twisters that sound positively cryptic to the lay person: bispecific antibodies and universal chimeric antigen receptors, or UniCAR. They are the product of years of work from the initial idea to the final concept: "All in all, it's been about thirty years," Bachmann concludes. And he makes it sound as though it were nothing, although it equates to half a lifetime, during which there were no guarantees that it would work. The journey to the patient, developing a new approach to treating the most serious diseases like cancer, is seldom rewarded with success. But Bachmann has embraced this insight into how medicine and science function and almost turned it into a mantra: "Usually, it's a case of one step forward and ten back, combined with a lot of frustration. Ninety-five percent failure." The art, he emphasizes, is to be so fascinated by the other five percent that they keep you going for an entire lifetime.

The thought that marked the beginning of these developments was originally expressed by the famous medical researcher Paul Ehrlich: "Our immune system ought to be able to recognize tumors." The only problem is that tumors and the body's own tissue are very similar, so the immune system finds it difficult to tell the one from the other. But there is one area where we can perhaps learn from the immune system, according to Bachmann, and that is when it is not really functioning properly: systemic autoimmune diseases like *lupus erythematosus* and *rheumatoid arthritis* where our immune system attacks our bodies. "Our idea was that if we understand how these autoimmune diseases function, how these autoimmune reactions can develop, then we could perhaps use these mechanisms and materials to help an intact immune system recognize and thus attack the very closely related tumor tissue."

Throughout the decades, the object of Bachmann's and his colleagues' research, whether in the nineties in Mainz, in Oklahoma City around the turn of the century or since 2002 in Dresden, has always been a central class of immunological molecules: antibodies. They are the immune system's scouts and guards. They recognize and mark the pathogens by docking on to certain receptors – the antigens. This connection then makes the pathogen, for example, "tasty" for phagocytes which engulf and absorb it.

Stefanie Koristka from the Institute of Radiopharmaceutical Cancer Research prepares a tumor cell culture for examination. Source: F. Bierstedt



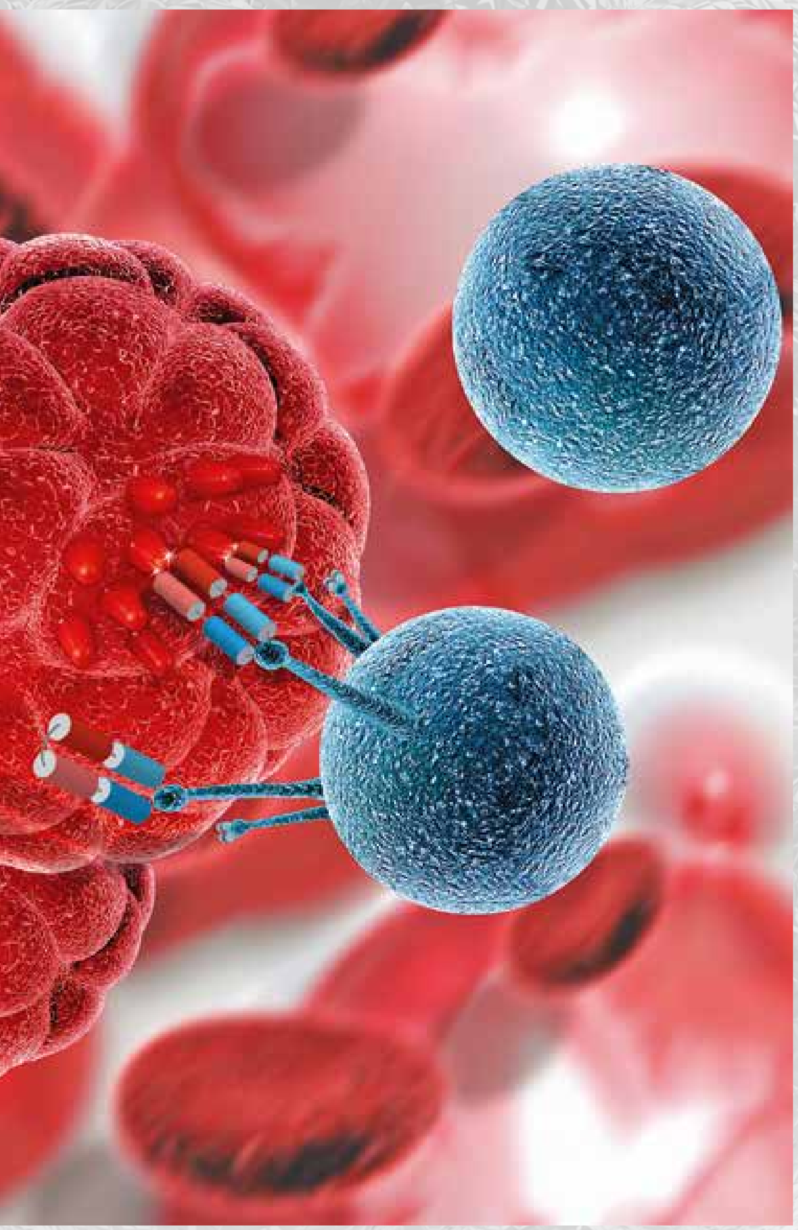


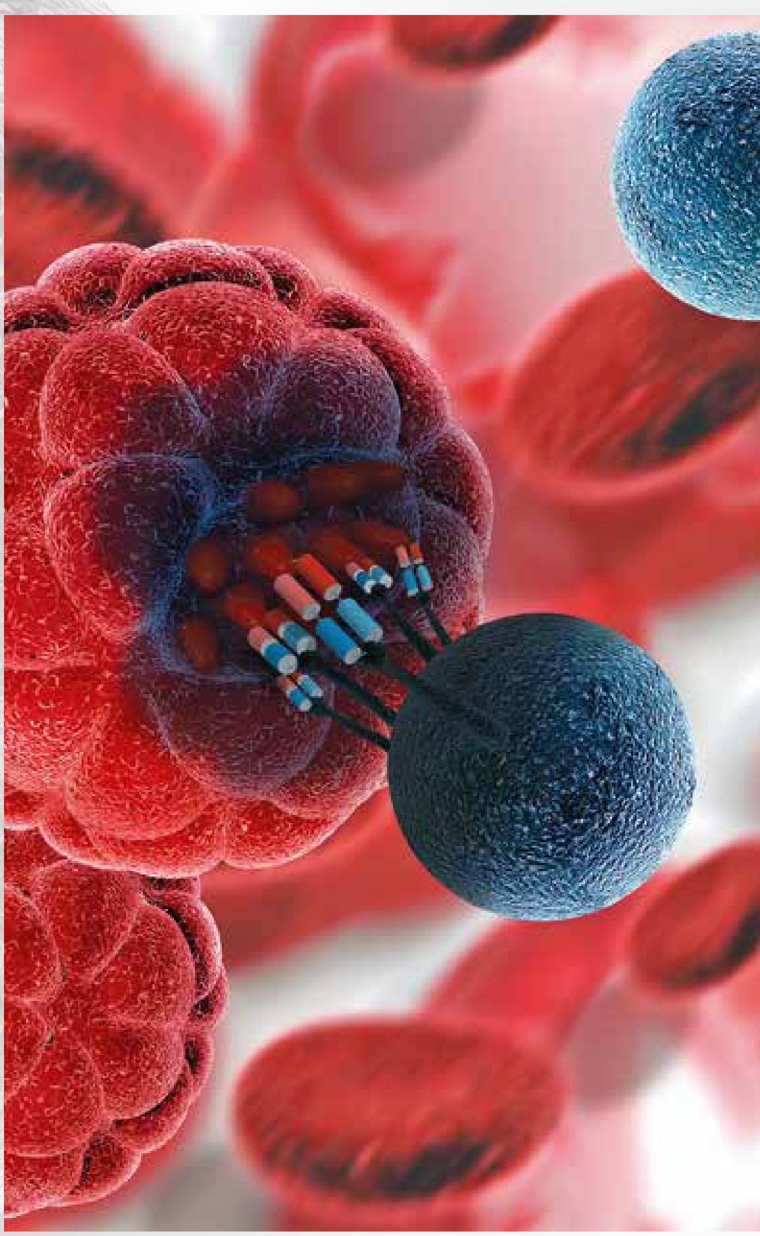
All the cells in our body have protein molecules on their surface. Via these structures, the immune system can recognize what is happening inside the cell. In cancer diseases, however, the immune system usually fails because the molecules hardly differ from healthy structures.

Euphoria and disillusion

At a very early stage back in Mainz, Bachmann and his colleagues managed to produce their first, monoclonal antibodies using a technology developed by Georges Köhler in the 1970s that earned him the Nobel Prize in 1984. You might call them test-tube antibodies. The research community started hoping they could be used to target any disease. But after the initial euphoria, disillusion set in. While these “artificial” antibodies had been traded and hailed as “magic bullets”, it soon became clear that the jubilation was premature.

The magic shots proved to be rubber bullets that only proved effective against tumors in very few cases. “They were, after all, murine antibodies, which means they were produced in mice. And we researchers hadn’t really understood what that would mean for their effectiveness in humans,” Bachmann remembers. As expected murine antibodies do adhere to structures on the target cell but the interaction with human immune cells does not work well, or not at all. The desired immune reaction fails to kick in or is much weaker than anticipated. In some cases, the human immune system even attacks the murine antibodies because it categorizes them as foreign matter.



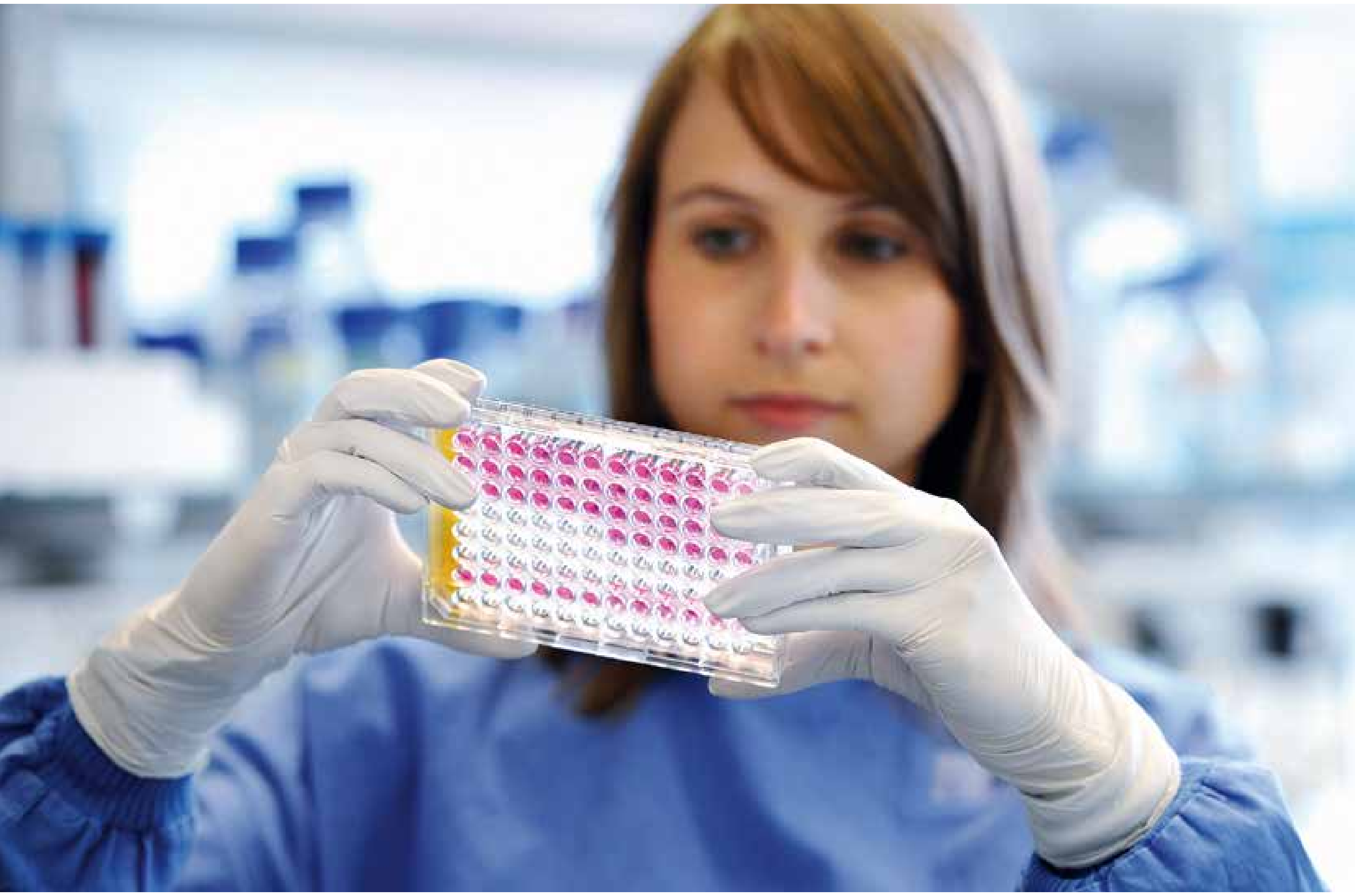


Bispecific antibodies are supposed to give the immune system a helping hand. These artificially manufactured proteins dock onto special structures on the surface of the immune cells. The other end of the antibody then bonds with the cancer cell and thus directs the previously inactive immune system to target the tumor.

Via the connection built by the antibody, toxins leave the immune cell and enter the cancer cell, which destroys it. Source: HZDR / Sahneweiß / Kjpargeter, Freepik (all images)

But in science, setbacks are always also a challenge, which led to the idea not just to specifically engineer the one end of the antibody, but the effector side as well, that is, the side that connects with the human immune system. So, this receptor was produced with a second antibody that could bond just as precisely as the antibody on the target side. The antibody had become bispecific, two-fold specific. In the beginning, two antibodies were coupled for the purpose by means of a chemical reaction.

However, this bonding led to new problems. It was impossible to control at which point the chemical bonding between the molecules occurred. The researchers got a mixture of thousands of totally different substances, some effective, some not, some more, some less. It was almost impossible to predict: “Of course, you can’t do anything with something like that. Above all, no regulatory authority would approve it,” Bachmann explains. “But it was at least a proof of concept that you can produce such functional bispecific antibodies.”



The characterization and production of antibodies for cancer research is a specialty of HZDR researchers like Claudia Arndt. Source: F. Bierstedt

A doctoral student's chutzpah

Over the years, Bachmann developed a whole menagerie of antibodies and extended his understanding of the mechanisms in these important molecules, both in the antibodies and in the auto-antibodies that were involved in autoimmune diseases. When he moved to the Immunology Department at TU Dresden he was able to combine this arsenal with the antibody ensemble of the then head, Ernst Peter Rieber, to create an impressively comprehensive catalog. "This was the foundation for producing antibodies with the two-fold specificity we wanted," says Bachmann. The situation became somewhat easier by the fact that now the spectrum of molecular biological techniques was much larger than it had been in the nineties. And when a doctoral student had the chutzpah to develop one of these bispecific antibodies in his thesis, it marked the beginning of serial production of modular antibodies in the Dresden Immunology Department.

But, of course, this was not a straightforward success story either. There were always disappointments. Especially in the early years, developing bispecific antibodies was a complicated matter. It always took several years for an idea to become a finished molecule, to put it all together, even if the antibody already existed, Bachmann explains: "At the beginning, you never knew whether you would end up with something that worked. We sometimes spent two or three years on development and then got to the point where the bispecific antibody should, in principle, have functioned only to find it didn't in practice." This is a problem that can still occur today, although improved methods and accrued knowledge mean development cycles are much shorter.

The uncertainties of the initial years annoyed the researchers in Bachmann's orbit and they began to consider how they could gain greater control over the development of their antibodies. This finally led to a special extension of one of the most hyped cancer immune therapies of the moment, CAR technology. Here it is not the antibodies but the T cells, that is, the immune system's white blood cells that are furnished with artificial receptors enabling them to recognize tumors, dock on to them and thus induce their destruction. In certain types of cancer there have already been some impressive results. But this achievement goes hand in hand with enormous costs, and the approach is not without potentially sizable dangers.

The costs and risks of a hype

Bachmann was skeptical ten or fifteen years ago – and despite the current euphoria, he still is: “When you transfer cells that have been manipulated like this to patients, then they are inside them. And I can’t control their behavior, I can’t switch them on and off. That’s not ideal to put it mildly.” If something goes wrong inside a patient’s body, it can have devastating side effects, and may even be fatal. “This was a risk I personally felt was too great to take,” says the pharmacist and immunologist. Apart from which, you need to be able to visualize the course of therapy. The requisite technologies are one of HZDR’s specialties because this is where the necessary radioactively marked molecules, so-called tracers, are developed, something only undertaken by a few institutes around the world. Consequently, some six years ago, Bachmann moved to HZDR’s Institute of Radiopharmaceutical Cancer Research.

In order to take control of the modified T cells, the Dresden researchers soon started to try and develop controllable CARs, which they called UniCARs. This is a system – the researchers speak of a platform – whereby the T cells do not recognize the tumor cells directly, as they do in CARs, but through a universal link, a peptide. And this bonds with an antibody, the target module, which, in its turn, docks on to the tumor cell – effectively, a combination of bispecific antibodies and CAR technology. And this is where Bachmann’s research comes full circle back to the ideas that were circulating at the time of his habilitation – because the universal link has elements that he and his colleagues were familiar with from research on autoimmune diseases. Thanks to this link, they can therapeutically control UniCAR T cells at last and, if necessary, switch “the drug” on and off. By coupling with suitable radionuclides, it is also possible to make the tumor inside the patient visible, as well.

Whether all this will now produce a successful therapy is still uncertain because this will only become clear when the first patients are treated: “Of course, we’re convinced that the therapy will be successful. But even if it weren’t, to have got this far is already a major stage victory,” Bachmann concludes. Patient trials will probably begin at the end of the year. Clinicians usually refer to them as Phase 1 clinical trials. Two further phases will follow involving increasing numbers of patients. Only when they have been completed successfully will the authorities license the drug.

As can be seen, it takes many years for the ideas, successes and defeats to actually become a drug that can help people safely. By the time it is licensed as a drug, Bachmann will probably already be emeritus. Nevertheless, he is optimistic about the future: “I’m just pleased that we have got to this point and have created at least an opportunity for others to further improve the whole thing – if necessary.”

Publications:

A. Krackhardt, B. Anliker, M. Hildebrandt, M.P. Bachmann, S.B. Eichmüller, D. Nettelbeck, M. Renner, L. Uharek, G. Willimsky, M. Schmitt, W.S. Wels, M. Schüssler-Lenz: Clinical translation and regulatory aspects of CAR/TCR-based adoptive cell therapies – the German Cancer Consortium approach, in Cancer Immunology, Immunotherapy, 2018 (DOI: 10.1007/s00262-018-2119-y)

R. Aliperta, P.B. Welzel, R. Bergmann, U. Freudenberg, N. Berndt, A. Feldmann, C. Arndt, S. Koristka, M. Stanzione, M. Cartellieri, A. Ehninger, G. Ehninger, C. Werner, J. Pietzsch, J. Steinbach, M. Bornhauser, M.P. Bachmann: Cryogel-supported stem cell factory for customized sustained release of bispecific antibodies for cancer immunotherapy, in Scientific Reports, 2017 (DOI: 10.1038/srep42855)

M. Cartellieri, A. Feldmann, S. Koristka, C. Arndt, S. Loff, A. Ehninger, M. von Bonin, E.P. Bejestani, G. Ehninger, M.P. Bachmann: Switching CAR T cells on and off: a novel modular platform for retargeting of T cells to AML blasts, in Blood Cancer Journal, 2016 (DOI: 10.1038/bcj.2016.61)

R. Aliperta, M. Cartellieri, A. Feldmann, C. Arndt, S. Koristka, I. Michalk, M. von Bonin, A. Ehninger, J. Bachmann, G. Ehninger, M. Bornhäuser, M.P. Bachmann: Bispecific antibody releasing-mesenchymal stromal cell machinery for retargeting T cells towards acute myeloid leukemia blasts, in Blood Cancer Journal, 2015 (DOI: 10.1038/bcj.2015.73)

Contact

_Institute of Radiopharmaceutical Cancer Research at HZDR / Carl Gustav Carus University Hospital Dresden / TU Dresden
Prof. Michael Bachmann
m.bachmann@hzdr.de

Gazing into the stars with powerful lasers

What goes on inside a planet? What happens in the crust of a star? To answer questions like these, Katerina Falk generates an unusual state of matter using ultra-strong lasers. Since March, the physicist has had her own research group at HZDR.

_ Text . Frank Grotelüschen

The lab, which Katerina Falk uses, is not all that small, but it's still pretty crowded: in the middle of the room there is a massive vacuum chamber the physicist has to squeeze past. Then she looks inside the stainless-steel cover and points to a special mirror: "It bundles a strong laser beam with a diameter of several centimeters onto a micrometer-sized spot," she explains. "We can use it to generate and observe a special state of matter – warm dense matter."

"If you want to take a photo of a moving bullet, you need a high-speed camera with extremely short frames," Falk explains. "It's just like that in our experiments: the laser pulses we use to examine our samples are just 30 femtoseconds long. You need that to be able to observe the extremely fast processes inside the warm dense matter."

> Warm dense matter – as dense as a metal, but simultaneously so hot that it is ionized.

Dresden is the new scientific home of Katerina Falk. In March 2018, the Czech researcher became head of a new Helmholtz Young Investigators Group. She is exploring a state of matter which can only exist under extreme conditions – at pressures and temperatures that can be found inside planets and the crust of stars. "You can compare warm dense matter to a hot lead brick," Falk explains. "This matter is just as tightly packed as in a crystal but nearly as energy-rich as a plasma, that is, an electrically-charged, extremely hot fluid."

By generating warm dense matter in the lab, it becomes possible to simulate the inner life of planets and stars. To do so, huge laser facilities are needed to bombard material samples with ultra-strong light pulses. The flashes heat and compress the samples so strongly that they become warm and dense – if only for fragments of a second. During this short period of time, highly-sophisticated measuring techniques try to gather as much information as possible about the exotic form of matter.

Back to Europe from the States

Katerina Falk chose her current research field while she was still at school. "When I was 16 or 17, I read a book by the German astrophysicist Rudolf Kippenhahn about the structure of the Sun. And I thought, that's fascinating – that's what I want to do." Falk decided to study physics in London and took her Ph.D. at Oxford University. In her doctoral thesis she worked at what were then the largest laser facilities in the world. Giants like the National Ignition Facility (NIF) in California are supposed to show, among other things, that you can induce nuclear fusion reactions in frozen pellets of heavy and superheavy hydrogen with laser light.

"On its path to implosion, the fuel passes through the state of warm dense matter," Katerina Falk explains. "In my thesis, I discovered that heavy hydrogen can't be compressed as much as originally hoped." For the US scientists this was a rather sobering result – nonetheless, they offered the physicist a job >

Katerina Falk heads a new Helmholtz Young Investigators Group. Source: A. Wirsig

at the Los Alamos National Lab. She stayed for nearly three years, but then gravitated back to Europe.

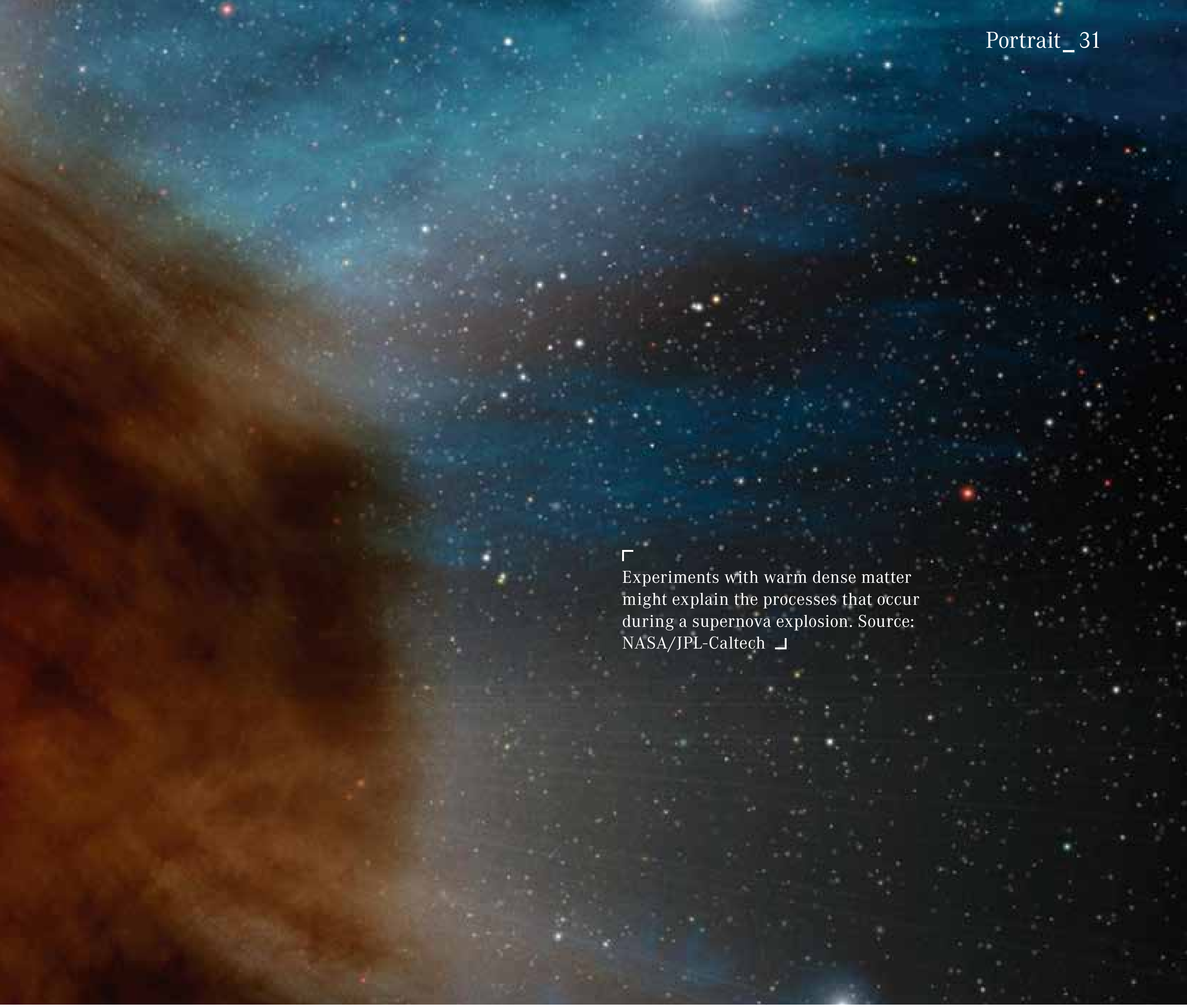
“At Los Alamos I would have had to work on developing nuclear weapons at some stage,” says Falk, “but I didn’t want to. I’m much happier with basic research and astrophysics.” So, she went to Prague to help develop a new European superlaser, the Extreme Light Infrastructure (ELI). And then she was offered the chance to move to Dresden together with her Swedish husband and small daughter to build her own research team. “The perfect place at the perfect time for a young physicist like me,” Katerina Falk enthuses. “I have a lot of freedom here, I can teach at TU Dresden and the conditions for research are excellent.”

Strong pulses for small samples

By that she means the high-performance laser DRACO. With its ultra-short, extremely strong pulses it can both generate and observe warm dense matter. In the coming years, Falk and her team want to use the facility to discover how well the strange state of matter conducts electricity and how radiation and particles propagate through it. “By studying these transport phenomena, we can better understand, for example, how the interior of planets is structured.”

Does a gas giant like Jupiter have a solid core? How could a planet like Neptune produce a magnetic field? What happens when stars are developing and what goes on during a supernova explosion? A deeper understanding of warm dense matter could also be useful in laser fusion. “When ultra-strong laser beams compress and heat a frozen fuel pellet, they are forced to adopt this state of matter,” Falk explains. “So, you have to understand it as precisely as possible if you want to achieve nuclear fusion.”

Apart from working at her “own” DRACO, the junior research group leader is planning excursions to other giant lasers, including PHELIX in Darmstadt, ELI in Prague and the European XFEL in Hamburg where HZDR is currently building the Helmholtz International Beamline for Extreme Fields (HIBEF). And in Dresden, too, there will soon be a new laser:



Experiments with warm dense matter might explain the processes that occur during a supernova explosion. Source: NASA/JPL-Caltech

PENELOPE is a petawatt laser under construction at HZDR with pulses that will have considerably more power than DRACO. “The more lasers we can use for our experiments, the more properties we can measure,” says a visibly pleased Falk.

As well as conducting research, she also finds time to communicate her enthusiasm for astrophysics to the public at large. She talks in schools and has just published a popular science book on physics. “I like passing on interesting scientific results,” says Falk – and laughs. “Only when I can explain a complex physical relationship to a five-year-old child can I be certain that I have really understood it myself.”

Publications:

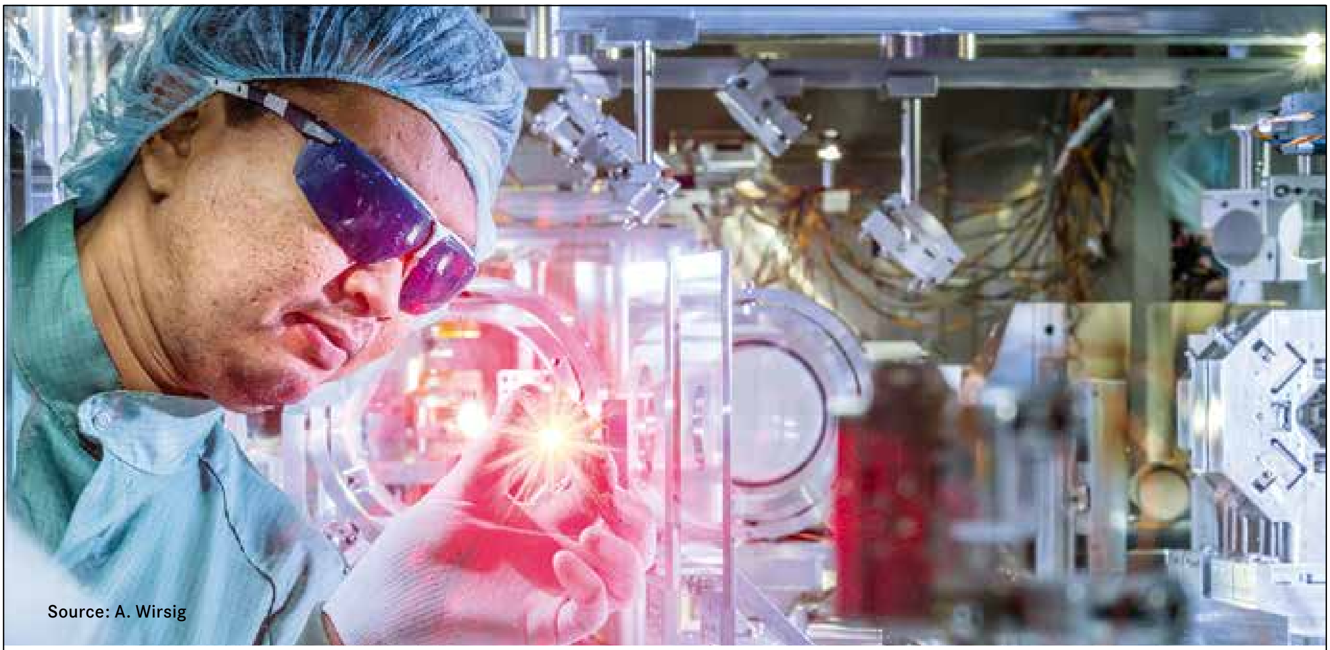
K. Falk, M. Holec, C.J. Fontes, C.L. Fryer, C.W. Greeff, H.M. Johns, D.S. Montgomery, D.W. Schmidt, M. Šmíd: Measurement of preheat due to nonlocal electron transport in warm dense matter, in Physical Review Letters, 2018 (DOI: 10.1103/PhysRevLett.120.025002)

M. Šmíd, I. Gallardo González, H. Ekerfelt, J. Björklund Svensson, M. Hansson, J.C. Wood, A. Persson, S.P.D. Mangles, O. Lundh, K. Falk: Highly efficient angularly resolving x-ray spectrometer optimized for absorption measurements with collimated sources, in Review of Scientific Instruments, 2017 (DOI: 10.1063/1.4986464)

K. Falk, E.J. Gamboa, G. Kagan, D.S. Montgomery, B. Srinivasan, P. Tzeferacos, J.F. Benage: Equation of state measurements of warm dense carbon using laser driven shock-and-release, in Physical Review Letters, 2014 (DOI: 10.1103/PhysRevLett.112.155003)

Contact

_Institute of Radiation Physics at HZDR
Helmholtz Young Investigators Group “Development of Novel Laser Wakefield Sources for Plasma Physics”
Dr. Katerina Falk
k.falk@hzdr.de



Source: A. Wirsig

FUNDED

Joining forces – nationally …

The Helmholtz Association is providing almost 30 million euros to support the research platform ATHENA ("Accelerator Technology HElmholtz iNfrAstructure"). Six centers belonging to Germany's largest research organization are joining forces in this project to develop new accelerator technologies. Specifically, they are planning two new facilities for plasma-based particle acceleration and modern laser technology: a hadron accelerator at HZDR and an electron accelerator at the German Electron Synchrotron DESY in Hamburg. The project partners plan to use these facilities to explore various fields of application, ranging from compact free electron lasers via medical applications to nuclear and particle physics. In addition to HZDR and DESY, the Forschungszentrum Jülich, the Helmholtz Zentrum Berlin, Karlsruhe Institute of Technology and the GSI Helmholtz Centre for Heavy Ion Research are partners in the project.

… and internationally

The Helmholtz Association and the Russian Science Foundation (RSF) have accepted two HZDR research groups in their German-Russian grant program. Over the next three years, Frank Stefani's team at the Institute of Fluid Dynamics as well as Tino Gottschall's group at the Dresden High Magnetic Field Laboratory will receive a total of 390,000 euros each from the Helmholtz Association's Initiative and Networking Fund and a matching grant from RSF. Partnering with researchers from Perm and Moscow, Stefani plans to study current instabilities which occur both in novel liquid metal batteries and in the magnetic field of the sun. Tino Gottschall aims to establish a new, more efficient method to liquefy gas: magnetic cooling. To accomplish this, he and his partners in Darmstadt and Chelyabinsk plan to develop novel magnetic materials and study them in high magnetic fields.

AMAZED

Where robots dance and frying pans hover

Approximately 2,500 guests visited the Open Lab Day at Campus Rossendorf in early June to find out more about the world of modern research. At over 150 stations, scientists and staff from HZDR, VKTA – Radiation Protection, Analytics and Disposal as well as ROTOP Pharmaka GmbH displayed their research topics and questions. Visitors learned about the entire range of research at Rossendorf: energy-saving electronic materials for storage and computing technologies, innovative ways of exploring and mining raw materials, approaches to safe nuclear waste storage, unique concepts for particle accelerators and lasers through to the development of radioactive cancer medications.

Source: F. Zadnicek

WON

Everyone loves the police

In mid-May, Nicola Mitwasi won the audience award at the national finals of “FameLab”, a competition for science communication that was held in Bielefeld. Mitwasi, a Ph.D. candidate at the Institute of Radiopharmaceutical Cancer Research, was able to explain to the audience in a mere 180 seconds how HZDR researchers train immune cells to fight tumors, comparing the body’s immune system to a police patrol that is taken straight to the diseased cells via chemical structures. At “FameLab”, which is run by the British Council, young STEM researchers and medical scientists present their research to a lay audience.

WHAT’S ON

26 September 2018, 5 pm
Scientific Sightseeing Tour on the DRESDEN-concept tram
Plauen Nöthnitzer Straße tram stop

17 October 2018
Groundbreaking ceremony for the technical center
Helmholtz Institute Freiberg for Resource Technology

30 October 2018
DeltaX School Lab, opening of the new building
Helmholtz-Zentrum Dresden-Rossendorf

12-16 November 2018
16^{th} Multiphase Flow Short Course and Conference
Institute of Fluid Dynamics at HZDR

26-28 November 2018
MHD Days
Institute of Fluid Dynamics at HZDR

RECOGNIZED

Sustainable award

The HZDR short film “Nanoelectronics - Highly Efficient Structures for Tomorrow’s Information Technology” won a Golden Trophy at the Deauville Green Awards in the category “Innovations and Technological Leaps” in mid-June. In the film, HZDR physicists use vivid animations to explain how spintronic components could power a whole new class of information processing technologies. This is precisely the kind of innovative approach that the Green Awards seek to honor. Held since 2011 in Deauville, France, by the organization “Un Ecran pour la Planète” (“A screen for the planet”), the festival aims to generate publicity for short films and documentaries on the topics of “sustainability” and “social justice”.

↗ **https://www.youtube.com/user/FZDresden**

REJOICED

2,000 m² for cancer research

In mid-April, after only eleven months of construction, guests from politics, research, and industry celebrated the topping out ceremony for the newly-built National Center for Tumor Diseases (NCT) in Dresden. The event marked the completion of the shell of the four-storey building, which, from 2020, will be the new home of combined cancer research and patient care on the premises of Carl Gustav Carus University Hospital. The new building will include the “surgery room of the future”, laboratories, areas for patient studies as well as rooms for drug therapy. Dresden was designated as a partner site of NCT Heidelberg in 2014.

IMPRINT

PUBLISHED BY
Prof. Dr. Dr. h. c. Roland Sauerbrey and Dr. Ulrich Breuer,
Board of Directors Helmholtz-Zentrum Dresden-Rossendorf (HZDR)

DATE OF PUBLICATION
September 2018
ISSN: 2194-5713 // Issue 01.2018

CONCEPTION AND EDITING
Simon Schmitt (editor-in-chief), Dr. Christine Bohnet,
Jana Grämer (images) | Communications and Media Relations at HZDR

Editorial Advisory Board:
Energy – Dr. Harald Foerstendorf, Dr. Frank Stefani
Health – Dr. Fabian Lohaus, Dr. Holger Stephan
Matter – Dr. Stefan Facsko, Dr. Andreas Wagner

AUTHORS
Marcus Anhäuser | Freelance science journalist, Dresden
Dr. Uta Bilow | Freelance science journalist, Dresden
Kai Dürfeld | Freelance science journalist, Leipzig
Frank Grotelüschen | Freelance science journalist, Hamburg

PICTURE CREDITS
HZDR staff, unless stated otherwise

LAYOUT
WERKSTATT X . Michael Voigt
www.werkstatt-x.de

TRANSLATION
Dr. Lynda Lich-Knight,
ResearchComm Ltd

PRINTING
Druckerei Mißbach
www.missbach.de

CIRCULATION
1,500 // Printed on Circlesilk (cover) and Circleoffset (content),
FSC certified and awarded with the EU Ecolabel

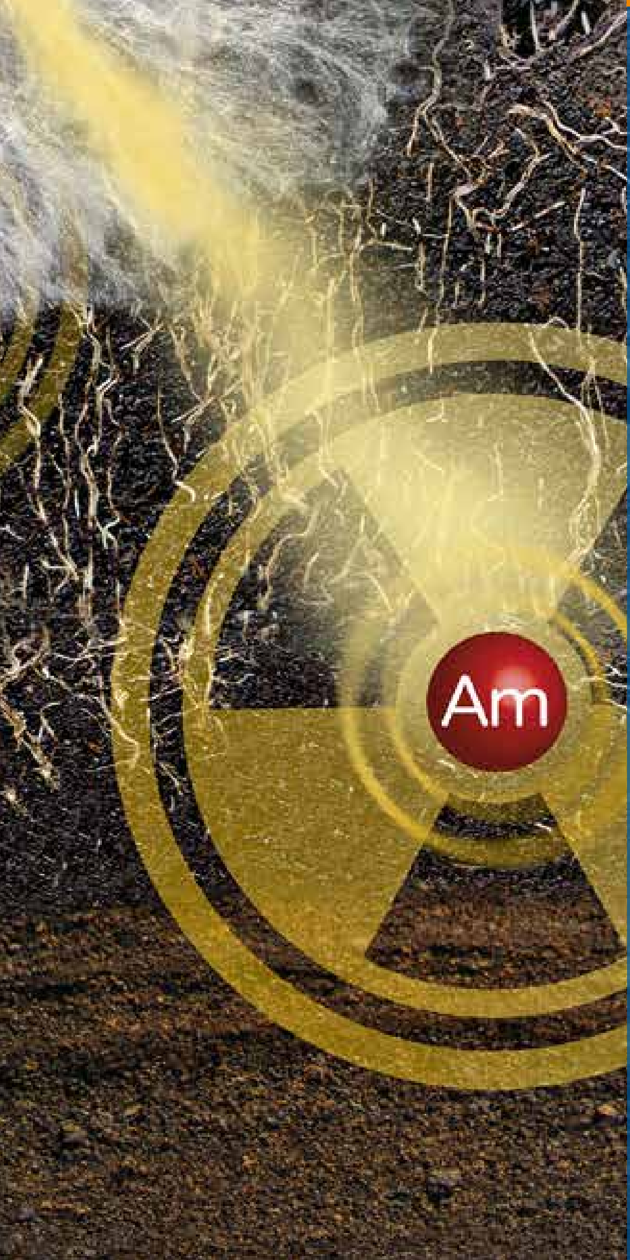
CONTACT/ORDER (free of charge)
Helmholtz-Zentrum Dresden-Rossendorf
Communications and Media Relations
Dr. Christine Bohnet
Phone: +49 (0) 351 260 2450
Email: c.bohnet@hzdr.de

The HZDR research magazine “discovered” appears twice a year, also in German titled “entdeckt”. All print editions can be found in ePaper format on the HZDR website.

↗ **www.hzdr.de**

HZDR on YouTube and Twitter:
↗ **www.youtube.com/user/FZDresden**
↗ **www.twitter.com/hzdr_dresden**

Source: Sahneweiß | shutterstock.com, ER_09, nednapa



The fungi cleaning squad

At first sight, the field looks like any other herb garden, a little untended perhaps. Fungi are growing in the soil under the plants. Only one thing disturbs this apparently idyllic scene: the “gardeners” are wearing white protective clothing – because the ground is contaminated with radioactive isotopes. And the fungi did not sprout there on their own, they were planted deliberately to do a specific job. The mycelia – string-like webs underneath the fruiting body – are supposed to absorb and restrain the radioactive substances. This could be a decontamination concept for the future – according to Johannes Raff. The microbiologist at HZDR’s Institute of Resource Ecology is currently working with partners at the universities of Jena and Hannover to explore these capabilities in the *Schizophyllum commune* and *Leucoagaricus naucinus* fungi. But before they can be deployed as soil cleaners in a “real” field, a few questions need to be clarified in the lab. The fact that fungi can absorb harmful substances has been known for some time. What remains unclear is the exact process behind it. This is why the researchers primarily want to decode the molecular processes – the absorption of radionuclides into the cells – as well as the transport within the organism. Depending on the results, fungi might one day help transform contaminated soils back into thriving gardens.

Source: D. Müller

DeltaX School Lab

More opportunities in the new school year: HZDR's DeltaX School Lab now has more space for new experiments in physics, chemistry and biology.

www.hzdr.de/deltaX

HZDR

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF