discovered

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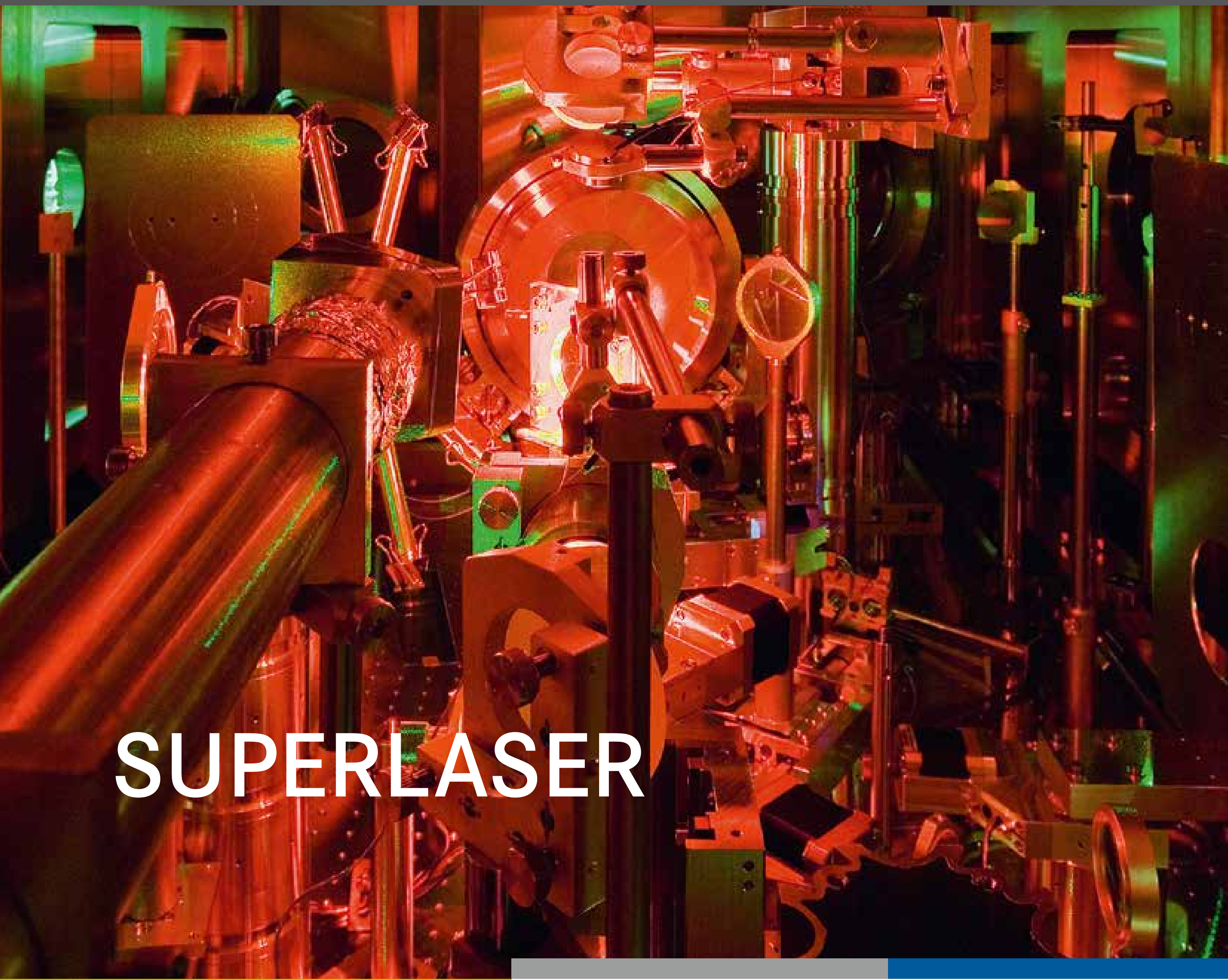

HZDR

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

COVER ILLUSTRATION: Experimental chamber at the high-power laser DRACO.
Photo: Jürgen Lösel

DEAR READERS,

The basic idea behind the **l**ight **a**mplification by **s**timulated **e**mission of **r**adiation = laser goes back to Albert Einstein and, as such, is nearly a hundred years old. The precursor of the laser was the maser – the acronym stands for **m**icrowave **a**mplification by **s**timulated **e**mission of **r**adiation – and it was implemented by Charles H. Townes in the year 1954. Together with Nicolay G. Basov and Alexandr M. Prokhorov, the US-American physicist won the 1964 Nobel Prize in Physics for fundamental work in the field of stimulated emission. The first functional laser was the ruby laser, built by the US-American physicist Theodore Maiman in 1960.

We have the laser to thank for many groundbreaking developments and fascinating discoveries. This current edition of our research magazine "discovered" is not, however, looking to present the vast field of laser technology in its entirety. Rather, we want to introduce you to the lasers in our own Helmholtz Center.

Its name is DRACO – **D**resden **L**aser **A**cceleration **S**ource – and it has just emerged from an elaborate re-tuning. If this short-pulse laser with an output of a good 100 terawatts was already one of the strongest in Europe, its output of one petawatt – that is, a quadrillion watts – has now catapulted it into the international vanguard. But what is this laser power needed for? Readers, who are familiar with HZDR, already know the answer: the power of high-intensity beams can be harnessed to accelerate particles. In the articles "Lasers as Particle Turbos" and "Plasma Flash in the Supercomputer" you can discover more about the state of the art in research and the possible applications for this new accelerator technology.

The two free-electron lasers in HZDR's ELBE Center for High-Power Radiation Sources are also a special type of laser. Here it is electrons that are the active medium while the electron accelerator acts as the pumping mechanism (the illustration on p. 9 demonstrates how a laser functions). In close cooperation with TU Dresden it has been possible to build a so-called near-field microscope at our free-electron laser. This facilitates unique insights into nano worlds at the lowest temperatures.

As always, in the section on "Research", we offer you a potpourri of topics: from the first clinical trials involving a slit camera for high-precision proton therapy, via a type of detector that is tracking down Dark Matter in the underground lab at Gran Sasso in Italy, to heat transfer during boiling and condensation – and linked up with this are issues on safety in nuclear facilities and increasing the efficiency of energy production and cooling systems.

I look forward to receiving your comments and suggestions and hope you enjoy reading this edition of "discovered".

Christine Bohnet
Communications and Media Relations Department at HZDR

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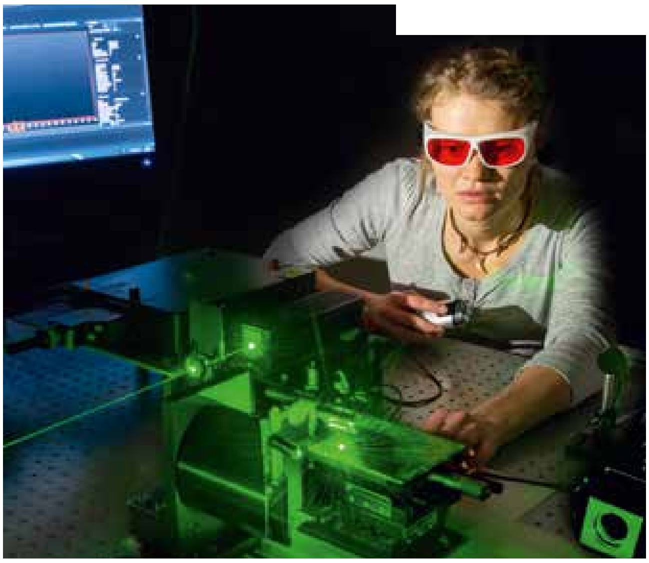


TITLE

Superlaser

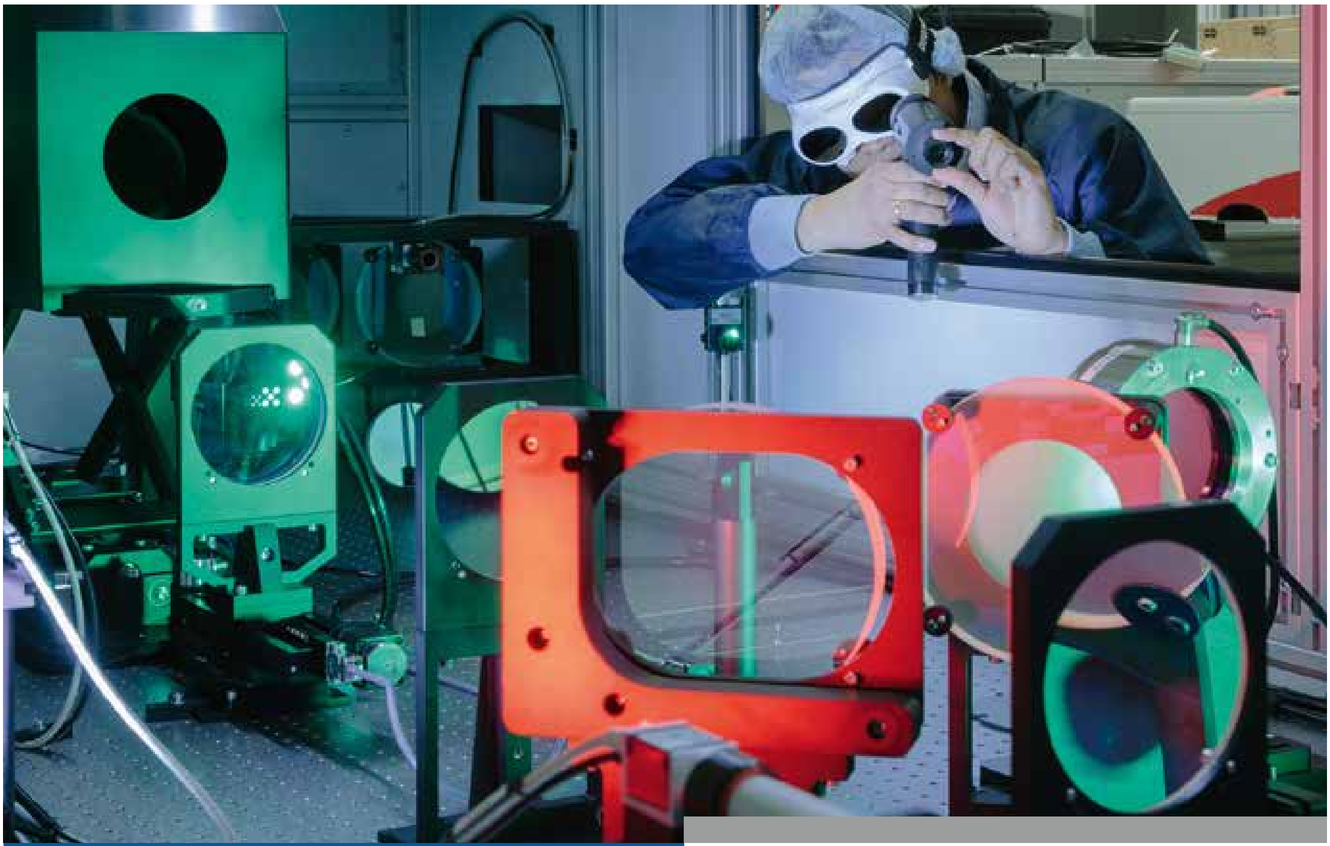
RESEARCH

PORTRAIT

Photo: André Forner

PANORAMA – HZDR NEWS

// HZDR physicists are working on novel acceleration methods for radiation therapy.



MAXIMUM: Laser physicist Arie Irman carefully adjusts the amplifier stages on the DRACO laser to optimize the intensity and profile of the beam. Photo: Oliver Killig

LASERS AS PARTICLE TURBOS

_TEXT . Frank Grotelüschen

Karl Zeil has donned his white coat, changed his shoes and pulled on a mob cap. The physicist explains the reason for the surgical gear: "We are now going into our laser lab, and that's a cleanroom. We have to keep it totally free of dust because dust is the arch-enemy of optics!" Zeil then opens the door and enters a space the size of a classroom crammed full of long tables weighed down with apertures, mirrors and lenses. Just a couple of narrow aisles are left for the staff to move around.

"This is the high-power laser DRACO, our workhorse," Zeil's colleague Arie Irman comments. DRACO stands for Dresden Laser Acceleration Source. The device functions in several phases: a Ti:Sapphire laser, hardly bigger than a shoebox, generates ultra-short, relatively weak infrared pulses. They then pass through several amplifier stages during which special optics form, stretch, expand, compress and bundle them. At the end of the process, the pulses have a billion times more power, up to a petawatt, a quadrillion watts – although only for the extremely short span of just 30 femtoseconds, which is significantly less than one quadrillionth of a second.

The superlaser serves one single purpose: Zeil and Irman are trying to find the most efficient way of accelerating particles almost up to the speed of light. They both head junior research groups at Helmholtz-Zentrum Dresden-Rossendorf. While Irman's team concentrates on electron laser acceleration, Zeil and his colleagues are trying to speed up protons and other ions. Their vision is to create an efficient, relatively compact irradiation facility for modern proton tumor therapy.

Particle accelerators play a prominent role in today's research and applications: In our efforts to investigate the elemental building blocks of matter, a vast facility like LHC (Large →

Hadron Collider) at CERN in Geneva sees hydrogen atoms impacting at record energies. Huge electron accelerators, such as PETRA III at DESY in Hamburg, generate extremely intense X-ray beams which make it possible to scrutinize materials and biomolecules. And in hospitals, accelerators are required for radiation therapy – one of the core methods for treating cancer.

Plasma thrust instead of surfriding

All these facilities are based on acceleration using radio waves: Strong transmitters feed intense radio waves into a resonator – a pipe-like vacuum tube providing ideal conditions in which the waves can spread out. If an electrically-charged particle flies through the resonator, it can ride the waves like a surfer and gather additional momentum.

But the method has its limits: "Particles can only be accelerated up to a certain extent in this way," Arie Irman explains. "You can only feed a certain maximum intensity of radio waves into the resonator, otherwise the field breaks down." This means that in order to reach the energy desired, a series of resonators have to be connected, which can result in extremely large facilities: The accelerator at the European X-Ray Laser Facility (European XFEL), which is scheduled to be completed shortly, will be about 3.4 kilometers long.

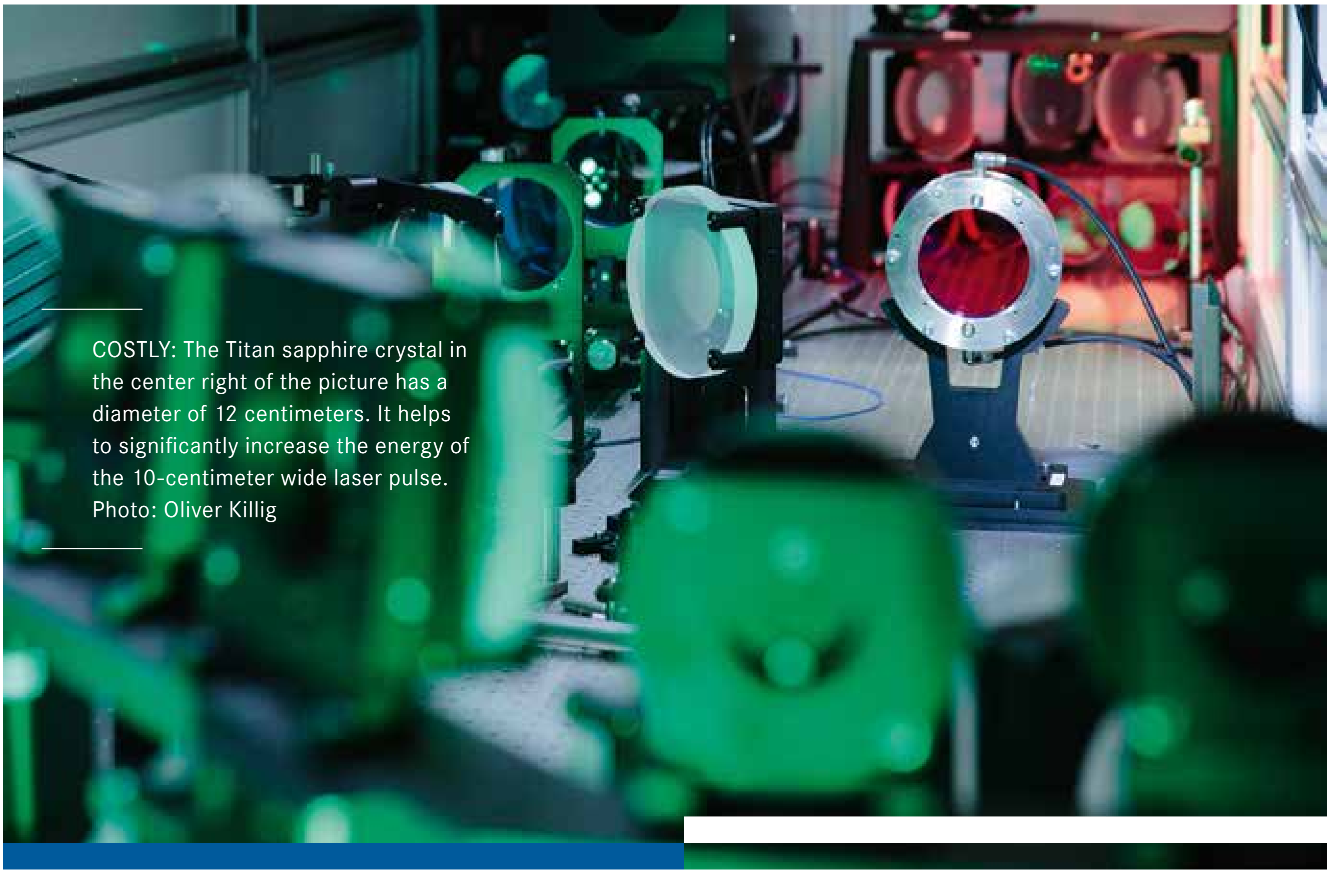
Irman and Zeil are working on an alternative that would take up much less space – laser-plasma acceleration. "It promises to be much more efficient," says Karl Zeil. "It can house acceleration fields that are stronger by orders of magnitude than today's resonators." It works on the principle that ultra-strong laser pulses are fired at matter. The force of the light pulse drives the atoms out of the electrons, creating a plasma – an ionized state of matter that can get exceedingly hot.

By applying a laser pulse, an extremely strong electric field can be generated in the plasma within a tiny fraction of a second. This field can accelerate electrons or ions to nearly the speed of light in next to no time. "The procedure is still new," Irman explains. "It was only in 2004 that experiments in the United States and Europe were able to show that a laser plasma can bring electron packages to energies of several hundred megaelectronvolts (MeV) over a distance of just a few millimeters!"

Electron sprint record

Today, the record stands at 4,000 MeV for an acceleration section of just under seven centimeters. By comparison: In order to reach the same energy, a traditional linear accelerator would have to be several hundred meters long. But the work being undertaken in Dresden is not trying to achieve new energy records. Irman and his team want to produce optimum beam quality – and also the first applications using laser-accelerated electrons.

In his lab, Irman demonstrates the vacuum chamber, a room the size of an office filled with countless stainless steel components. The pulses from the high-power laser DRACO



COSTLY: The Titan sapphire crystal in the center right of the picture has a diameter of 12 centimeters. It helps to significantly increase the energy of the 10-centimeter wide laser pulse. Photo: Oliver Killig

Next Laser Generation

Since the spring of 2015, Karl Zeil and Arie Irman have each been heading a junior research group at HZDR. They belong to that body of highly-qualified junior researchers who are given the opportunity by the Center to take responsibility for their own group of doctoral candidates and students. Although a junior research group usually has a fixed-term of five years, it is quite likely that this will lead to long-term positions at HZDR. "Good prospects for the long run," Zeil enthuses. "A position as a junior research group leader is a good start to a career in research." Currently, there are four junior research groups in Rossendorf. After three years, and again after five years, they are evaluated by a commission composed of HZDR scientists.

Together with one DFG-funded Emmy Noether group and three Helmholtz young investigators groups, eight groups thus offer excellent young scientists a firm foundation for a long and successful career in research.

UPGRADE: In this target chamber the diameter of the beam has already reached 20 centimeters with a power of nearly a petawatt. Junior research group leader Karl Zeil adjusts one of the parabolic mirrors. Photo: Oliver Killig

travel though a pipe into the chamber and are directed to the "target". "That's that little cylinder over there. It's only three millimeters long," the physicist explains. It has helium flowing through it at supersonic speed." The bundled laser pulses hit the gas atoms and immediately ionize them into a plasma. "In this plasma, the laser pulse drags a strong electric field along with it like a bow wave," Arie Irman explains. "Moving at near-light speed, this bow wave can capture electrons and significantly accelerate them."

Using this method, researchers have already accelerated particles to energies of 300 MeV – over a distance of just three millimeters. "Now we want to understand this process better and optimize it," says the physicist. In particular, it is not yet easy to achieve a stable, reliable electron beam – the prerequisite for later applications.

One of the questions to be addressed is how the laser's bow wave can be made to drag along as many electrons as possible. One option would be to inject additional particles into the electrons already existing in the plasma. For this purpose, the experts could utilize the electron beam in the →

neighboring ELBE accelerator. They are currently trying to synchronize the processes in the vacuum chamber so that the plasma really can accelerate the ELBE electron beam yet further.

And what do the Dresden physicists want to do with the fast plasma electrons? "One obvious idea is to produce strong X-radiation with the help of fast electrons," Irman answers. It might then be possible to make the careering electron bundles collide with another laser beam, for example, which would generate extremely bright, short X-ray flashes. Such flashes would be a most valuable research tool for investigating things like the extreme states of matter that exist inside planets and stars and that can already be produced in the lab today, at least very briefly.

Fast particles with healing powers

Karl Zeil is in the process of exploring one practice-related application: He uses DRACO's high-intensity laser pulses to speed up protons and other ions – that is, particles that are significantly heavier than electrons. "Fast protons and carbon-ions help to irradiate patients' tumors effectively and gently," says Zeil. "If we were able to accelerate the particles with laser pulses, future irradiation facilities would be more compact, simpler and cheaper."

Many physicians think particle therapy is more effective and has fewer side-effects than conventional radiation therapy using X-ray light. The principle underlying the therapy is that an accelerator speeds up charged particles – usually protons, but also carbon-ions. Then the particles are fired at the tumor: They penetrate deep into the tissue, releasing most of their energy at a certain point – the tumor. This comes much closer to the goal of radiation therapy: maximum dose in the tumor, minimum dose in the healthy tissue surrounding it.

But there is a snag: The dimensions of the equipment needed for particle therapy are enormous. Up to now, it has required an efficient accelerator that uses radio waves to get the protons up to speed. Bulky magnets keep the particles on the intended path and lead them to the patient. Not least because it is so complex, there are only very few treatment centers in Germany, such as HIT in Heidelberg and the new University Proton Therapy Dresden (UPTD) at the OncoRay Center for Cancer Research.

This is why Zeil and his team are working on a compact and hopefully simpler method: Instead of radio waves, they accelerate the particles with strong laser pulses. In contrast to laser-electron acceleration, however, the ions and protons cannot be kick-started by the bow wave of the laser flash – they are far too heavy and inert. Instead, an indirect effect comes into play: After the laser pulse has transformed the matter into a plasma, it drives the electrons out of the matter into the vacuum and leaves behind positively-charged ions.

This generates an extremely strong electric field – so strong that the ions are literally ripped apart and thus accelerated. "For our experiments we don't use gas like we do for electron acceleration," Karl Zeil explains. "What we use are solid matter targets, such as thin metal foils."

The physicist now heads for his workplace – a lab with direct access to the DRACO laser. In the middle of the room there is a voluminous, stainless steel vacuum chamber containing a wide range of optics and components. Zeil points to one element that is reminiscent of a king-sized shaving mirror. "It bundles the laser pulses on the foil," the physicist explains. "The protons are then accelerated vertically onto the reverse side of the foil." →

PROTON THERAPY: At University Proton Therapy Dresden (UPTD), the charged particles are accelerated in the cyclotron (blue, right) and transported along the beamline where heavy electromagnets (yellow) keep them on track. Part of the beam is diverted into an experimental hall. A second line leads to the gantry (blue, left), a rotatable steel construction with a patient treatment unit in the middle. Diagram: OncoRay

Hope for the superlaser

In order to capture the protons and bundle them into particle pulses, researchers have installed a special magnet at the back of the foil – a magnetic coil with powerful windings through which strong electrical pulses can be unleashed. A magnetic field up to 30 Tesla captures the proton pulses and focuses them in the right direction. Detectors subsequently measure the pulses. In this way, experts can determine how successful an experiment has been.

"We can already demonstrate that the principle works," says Zeil. "We have accelerated protons up to 20 MeV on a distance of no more than just a few micrometers." For use in hospitals, however, ten times the amount of particle energy is required, and in order to achieve this, researchers are trying to improve the method in a number of different ways. It is as yet unclear, for example, what are the most appropriate kinds of targets. Among others, the Dresden researchers are experimenting with plastic-coated metal foils as well as refrigerated "wires" of frozen hydrogen.

But at the heart of the strategy are even stronger laser pulses, which should mean the ions can be accelerated to significantly higher energies. The course has already been set. Karl Zeil enters a room that is nearly twice as large as the DRACO laser lab. It is still fairly empty, but the first components have already been installed. "This is where PENELOPE is being constructed, our new high-power laser," Zeil explains. "It is based on high-power diode laser technology and will generate significantly longer light pulses than DRACO for the same output – 150 femtoseconds instead of 30."

These longer pulses should prove particularly suited to accelerating ions – at least that is what the computer simulations predict. "We want to reach proton energies with PENELOPE which will be relevant for therapies," says Zeil. "In two or three years, we hope to know whether the method will achieve what we want and whether it’s worth building a clinical prototype." They already have a concrete plan: The prototype is supposed to be constructed in the OncoRay Center, a facility run jointly by HZDR, the University Hospital und TU Dresden. In a combined radiation room, the new technology could be directly compared with the old – laser pulses versus radio waves. And the high-power lasers, which currently take up huge spaces, could basically be made much more compact. "This development has only been underway for a short while," Zeil comments. "The potential is enormous."

PENELOPE: HZDR researchers want to use this new laser to accelerate protons to energies that can be used for cancer therapy. It will take several months before the first experiments can be undertaken. Photo: Oliver Killig

PUBLICATIONS:

K. Zeil et al.: "Direct observation of prompt pre-thermal laser ion sheath acceleration", in Nature Communications 2012 (DOI: 10.1038/ncomms1883)

K. Zeil et al.: "Dose-controlled irradiation of cancer cells with laser-accelerated proton pulses", in Applied Physics B – Lasers and Optics 2012 (DOI 10.1007/s00340-012-5275-3)

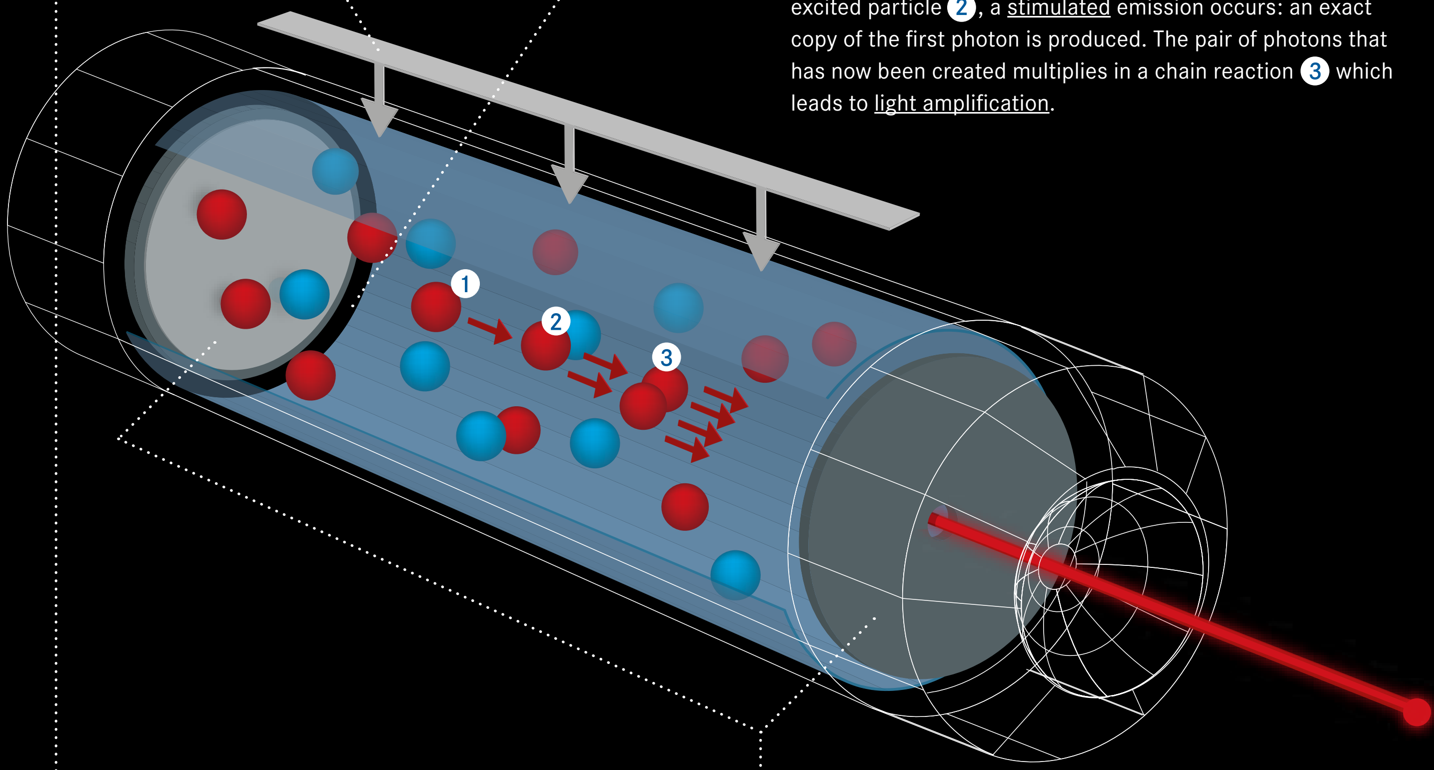
A. Jochmann, A. Irman et al.: "High resolution energy-angle correlation measurement of hard X-rays from laser-Thomson backscattering", in Physical Review Letters 2013 (DOI: 10.1103/PhysRevLett.111.114803)

CONTACT

_Junior Research Group on Laser-electron Acceleration at HZDR
Dr. Arie Irman
a.irman@hzdr.de

_Junior Research Group on Laser-ion Acceleration at HZDR
Dr. Karl Zeil
k.zeil@hzdr.de

L·A·S·E·R Light Amplification by Stimulated Emission of Radiation



THE ACTIVE MEDIUM

The heart of the LASER: This is where the LASER beam is generated. The active medium is composed of many particles (blue and red balls), for example atoms of a gas which are mostly energetically excited (red). The particles can spontaneously discharge this energy (1) by emitting a photon – as the portion of light is known. If the photon meets another excited particle (2), a stimulated emission occurs: an exact copy of the first photon is produced. The pair of photons that has now been created multiplies in a chain reaction (3) which leads to light amplification.

THE PUMPING MECHANISM

The particles in the active medium have to be charged with energy. This can be done by an electrical discharge. What is crucial is that the "pumping" is so strong that more particles are in a charged state (red) than in an uncharged state (blue). This is referred to as population inversion.

THE RESONATOR

Two parallel mirrors ensure that the LASER beam is caught in the active medium. While the light moves back and forth it keeps gaining in strength by stimulated emissions – which is called positive feedback. One of the mirrors is partially light-transmissive: This is where the beam exits the LASER.

// The "DRACO" laser is being substantially upgraded in order to produce even stronger pulses.

EXTREME-TUNING A POWER LASER

_TEXT . Frank Grotelüschen

In order to effectively accelerate particles via laser plasma, you need one thing above all: extremely high-performance lasers. At HZDR, this is DRACO’s job. The acronym stands for "Dresden Laser Acceleration Source". It was launched in 2008 and has since been delivering ultra-short pulses at a power of 100 terawatts (TW). Now, the laser has been fundamentally expanded with additional new components. Thanks to this upgrade, DRACO can now also generate pulses that are ten times stronger, i.e. one petawatt.

DRACO consists of several core components: At the center of it all is a compact titan sapphire laser oscillator, which can produce 78 million ultra-short laser pulses per second. Each of these pulses lasts only about 30 femtoseconds and has an energy of a few nanojoules. For the experiments, energy billions of times stronger is required. This is done with optical amplifiers, which are basically additional laser stages that multiply the number of light particles, thus strengthening the energy of the laser pulses.

The danger with a high-performance laser is that the amplified light pulses can become so strong that they might damage the optical elements. The experts therefore resort to clever tricks: They stretch the pulses spatially, enlarging their diameter from a few millimeters to ten or even 30 centimeters. This spreads their energy over a larger surface and decreases its intensity. Not until the very end, shortly before the experiment, is the beam re-concentrated onto a spot the size of a micrometer.

Yet this spatial enlargement alone is not enough. The pulses also have to be stretched out in time. To do this, the beam is directed through an arrangement of optical gratings. This "expander" stretches the flashes from their original duration of 30 femtoseconds to one nanosecond, which is 30,000 times longer. This distributes the energy over a longer period of time, its intensity decreases. At the end of this expansion chain, the pulses must be compressed back to their original duration of 30 femtoseconds. This happens in large compressor tanks, once again with the help of optical gratings.

Originally, DRACO consisted of a front-end area that generated the pulses and boosted their energy up to one joule. After this, an amplifier increased the power of the flashes to six joules. This was followed by a compressor assembly that compressed the pulses back to their original length. As part of the upgrade, another section was added to this set-up: Now, the beam that exits the front-end area is divided by a beam-splitter. The first section is the final stage of the original 100 TW laser. The second, new section consists of a big optical amplifier as well as a large compressor tank. Since the beam has to be stretched to 30 centimeters instead of ten, this tank is considerably larger than the one in the 100-TW section. This new section boosts the pulses to an energy level of about 40 joules – which, at a pulse duration of 30 femtoseconds, means that its power is in the petawatt range.

One of the challenges in upgrading DRACO was manufacturing the optical elements. Making the twelve-centimeter titan sapphire disks to boost the laser was a particularly difficult task, because amplifying the energy evenly requires extremely high-quality crystals. It has only been in the last few years that industry has even been capable of growing crystals of the desired size and type. So far, there are only a few such crystals in the world – some of which can be found in Dresden.

In addition, the new petawatt section meant the front-end area had to be remodeled as well, because each of the ultra-strong pulses has a sort of vanguard that precedes it. If one were to simply boost the energy of the pulses to the petawatt range, this ‘vanguard’ would be so intense that it would destroy the sample ahead of time. This is why HZDR scientists had to try to weaken the pre-pulse considerably in relation to the actual pulse. They achieved it by adding an additional filter stage that cleans the laser pulses better, keeping the vanguard of pre-pulses small.

The experts want to make sure that once remodeling is completed, both sections can be used simultaneously. They take advantage of the fact that both the petawatt and the 100-TW pulses are fed from the same source. With the smart use of delaying techniques, they can make pulses from both sections meet in the experiment. This makes it possible to conduct pump-probe experiments, for example, whereby the pulse from one section interacts with a material sample, which is immediately afterwards illuminated and analyzed by the pulse from the other section.

The upgrade is a joint development project by HZDR and the French corporation Amplitude Technologies. Work began in 2011 with the expansion of the lab building. In 2015, the facility was completed, followed by initial tests. The next milestone is planned for August when scientific experiments at DRACO will resume.

CONTACT

_ Institute of Radiation Physics at HZDR
Prof. Ulrich Schramm
u.schramm@hzdr.de

// How HZDR theoretician Thomas Kluge uses computers to simulate laser acceleration.

PLASMA FLASH IN THE SUPERCOMPUTER

_TEXT . Frank Grotelüschen

INSIGHT: Physicist Thomas Kluge uses super computers to simulate particle acceleration with high-power lasers. Photo: Oliver Killig

Laser particle acceleration is a highly-complex process: An ultra-short light pulse hits matter and produces a plasma, which catapults electrons to nearly the speed of light in subseconds and accelerates ions. In order to harness this process for applications in fields like tumor therapy, experimental physicists want to make it as effective as possible. They are being supported in their efforts by their theoretical colleagues: With the help of the world's best supercomputers, HZDR physicist Thomas Kluge simulates laser-acceleration and acquires profound insights into the physical events. His findings help to elucidate the experiments and optimize them for future measurements.

"Just imagine bundling all the solar radiation that hits the earth on the tip of a pencil," Thomas Kluge explains. "That's the power of each of our laser pulses – although it only lasts for 30 femtoseconds, that is, for 30 quadrillionths of a second." What happens when these ultra-intense light pulses encounter a solid, such as a thin metal foil? "It's tricky to simulate on a computer," the theoretician answers, "because during the processes a number of extreme events happen all at once."

What this means in practice is that when the light pulse hits the foil, it produces such a high electromagnetic field that the atoms it is composed of are immediately ionized: Within femtoseconds, electrons are swept out of the atomic shell, leaving behind positively-charged ions. A strong electric field is generated that catapults out some of the ions with huge momentum – a highly-effective method of acceleration.

But there is a hitch: During these processes, instabilities occur. For example, the electrons do not usually exit the foil in one homogeneous beam, but in lots of little beams. This, in turn, influences the accelerating field that the ions "see" in the foil. Instead of an even surface, it is deformed to a greater or lesser extent. →

Utilizing irregularities

In their simulations, Kluge and his colleagues try to capture these instabilities as precisely as possible. "Our aim is to minimize the instabilities," the physicist explains. "But in some cases, we actually want to utilize them." Because the researchers have discovered that there are advantages to working with micrometer-sized irregularities in the surface of the foil: It means the laser pulse is presented with a larger contact surface, so the material can absorb more laser energy, which makes the acceleration of the particles up to 50 percent more efficient.

However, the simulations are complex and cannot be done on an ordinary office computer. They need supercomputers. Among others, Kluge and his colleagues use HZDR's high-performance "Hypnos" cluster, but they have also worked in the US with one of the fastest machines in the world, the supercomputer "Titan". Some of the simulations run for several weeks – on thousands of processors simultaneously.

Their findings, incidentally, are also of interest to astrophysicists because conditions inside the planets and stars may be similar to those created by the interaction of laser pulse and foil. "You may get comparable instabilities there, as well," says Thomas Kluge. "The outcomes of our computer simulations may help to develop more precise models of the evolution of planets and stars."

One thing is clear: So far, computer simulations are the only way of looking directly into the plasma and the interplay of laser pulse and matter. All previous experimental methods are at best able to deliver indirect evidence: Detectors, for example, can measure the X-radiation that is generated as a by-product when the laser pulse hits the foil, but the signals can only achieve a resolution of a few micrometers at most. A resolution in the nanometer range is what is needed – this is the scale on which the crucial processes take place.

Kluge and his colleagues are working on a new method that could bring some progress on this front: "We want to work with the extremely strong and short X-ray flashes which the European X-ray Laser is going to start producing in 2017." The European XFEL is currently under construction in Hamburg – a 3.4 km long acceleration facility which will generate the world's strongest X-ray pulses.

Profound insights into plasma

HZDR researchers are planning a spectacular experiment on this giant: A standard laser fires short light pulses onto a sample, such as a foil. On a micrometer-sized spot, a plasma forms which can accelerate particles highly efficiently. As soon as the light pulse has hit the foil, a second pulse arrives – the X-ray flash from the European XFEL. It literally X-rays the events in much the same way as a doctor X-rays patients in hospital. "By varying the time between the laser pulse and the X-ray flash, we can virtually scan the process," Kluge explains. "We then want to combine the images into a film and observe what is really going on." This method is expected to achieve a resolution of just a few nanometers – accurate enough to detect significant instabilities in the plasma.

Being a theoretician, Kluge has already simulated the experiment on the computer. But the decisive question can only be answered by an experiment: When you fire at the hot plasma with an X-ray flash, will the sample really scatter enough of the X-ray signals?

The researchers have been able to test the procedure during a large-scale measuring experiment at what is currently the strongest light source worldwide, the LCLS (Linac Coherent Light Source) in California. The outcome? "We really did observe a scattering image that was just as we had expected," Kluge enthuses. "So we have proved that the procedure is viable." What is more, the physicists have even been able to gain initial physical insights. "Under certain circumstances, shock waves occur which travel across the foil," Kluge continues. "This causes fractures or phase transformations in the material." It emerged that these different areas are strictly demarcated – an important detail when it comes to understanding plasma processes.

The road-map is clear: From 2018 onwards, the researchers want to regularly make their way to Hamburg to conduct experiments at the HIBEF measurement station, which is operated jointly by HZDR and DESY as part of an international collaboration. "Even though I'm a theoretical physicist, I'll certainly be there sometimes, even if it means doing the odd night-shift," Kluge explains, "because this is the very first method that allows you to look directly into plasma, and for us theoreticians, that promises to be a great leap forward in our ability to make predictions."

PUBLICATION:
T. Kluge et al.: "Nanoscale femtosecond imaging of transient hot solid density plasmas with elemental and charge state sensitivity using resonant coherent diffraction", in Physics of Plasmas 2016, online http://arxiv.org/abs/1508.03988, DOI: 10.1063/1.4942786

CONTACT

_Institute of Radiation Physics at HZDR
Dr. Thomas Kluge
t.kluge@hzdr.de

www.hibef.de

// Physicists at TU Dresden and HZDR are bypassing the boundaries of optics with near-field microscopy and demonstrating how a smooth transition from university research to extra-mural science can work.

RECORD-BREAKING: Denny Lang, doctoral candidate at HZDR, adjusts the low-temperature near-field microscope at the Free-Electron Laser FELBE. Photo: Oliver Killig

SHIFTING THE BOUNDARIES IN THE NANO WORLD

_TEXT . Christian Döring

Looking into a microscope always means immersing ourselves into worlds that are usually hidden from us. Miniscule fibers of material, the tiniest bacteria and individual grains of dust suddenly tower up like skyscrapers or planet-like formations. Modern research has long since started using the nanometer range – that is, millionths of a millimeter – for its measurements. But here, classic microscopy soon reaches its absolute boundaries – the so-called Abbe limit. From this point onwards, light diffraction means that individual points can no longer be distinguished.

The highest possible resolution in a traditional optical microscope is roughly half of the wavelength of the light used. Thus even by employing particularly short-wave ultraviolet light it is barely possible to examine details smaller than 200 nanometers. By comparison, the structures of modern microchips are often significantly smaller and many viruses barely exceed 100 nanometers.

Firing infrared radiation at the nanotip

If we want to investigate the nano world with long-wave infrared radiation, this is a serious obstacle, as the physicist Stephan Winnerl of HZDR's Institute of Ion Beam Physics and Materials Research explains: "On the one hand, electromagnetic radiation is very suitable for a lot of physical studies because it can easily penetrate matter and excite oscillations in molecules and solids. On the other hand, with the increasing wavelength, the resolution gets ever worse."

→

A catch-22 that researchers can only solve by employing a trick: Using a particularly small probe they move up to within a few nanometers of the sample – into the near field.

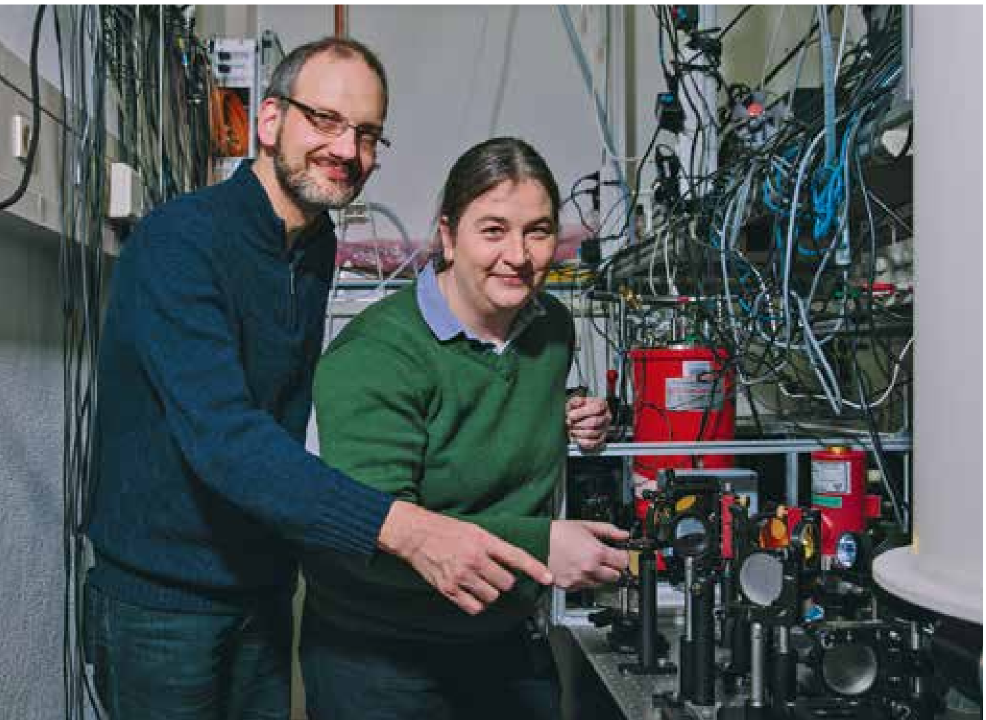
In near-field microscopy, as it is called, only a tiny point directly under the tip of the probe is examined. Thus in order to investigate associated structures, the entire surface of the sample has to be scanned in a pre-defined grid. The free-electron lasers at HZDR's Center for High-Power Radiation Sources, ELBE, deliver precisely the right amount of illumination, Winnerl explains: "We produce an intense infrared beam with an adjustable wavelength that can be directed at the tip." The backscattered light is measured with a detector. It contains optical information about the area of the sample underneath the tip which is not limited by the wavelength.

A lab of their own at ELBE

In order to incorporate all the many pieces of information from the individual points into an image of the sample, the computer puts them together like a mosaic – a principle that has been in use in scanning-force microscopy for some time: Here, too, a tiny needle just a few nanometers long travels across the sample in a fine linear grid. However, only the atomic forces between the tip of the needle and the surface of the sample are evaluated – the tip itself is still blind. "Only when the infrared radiation is measured with near-field microscopy is it also possible to examine the optical properties of the sample using the same linear scanning principle," explains Susanne Kehr, physicist in the Institute of Applied Physics (IAP) at TU Dresden.

Kehr heads a junior research group which focuses on microscopy methods in the department chaired by Lukas Eng; the group are permanent guests at the ELBE center. "In the early years, we still used to pack a small car full of equipment at the university and drive over to Rossendorf. It was a bit like playing Tetris with sensitive microscopy equipment," says Kehr, smiling. Today, the group operates its own optics lab at ELBE where the researchers have permanently installed two near-field microscopes. The special thing about the lab is that the free-electron lasers can be operated in so-called continuous wave mode: "The lasers deliver radiation pulses with a high repetition rate and controllable intensity. That's important because we rely on a continuous signal, and many samples are over-excited by individual strong pulses and can even be destroyed."

Such excellent cooperation between the IAP Group and the scientists at HZDR has already produced striking results. Former HZDR doctoral student Markus Fehrenbacher, for example, developed a superlens in the context of this collaboration which facilitates imaging below the diffraction limit and strengthens optical signals in the sample. "In order to be able to examine lenses like this in detail, you need microscopy technology that is not limited by wavelength," says Winnerl. By using near-field microscopy, researchers have been able to show for the first time how the semiconductor gallium arsenide can be changed into a superlens by additional electrons from intentionally incorporated foreign atoms. By adjusting the concentration of such impurity atoms the lens can even be matched to a desired wavelength. →



COLLEAGUES: Stephan Winnerl of HZDR and Susanne C. Kehr of TU Dresden have been working together successfully for years. Photo: Oliver Killig

SENSITIVE: The near-field microscope ‘T-bone’ is based on a home-constructed atomic force microscope (left). It is illuminated by a parabolic mirror (right). Photo: Oliver Killig

Ambitious search for impurity atoms near to absolute zero

Just how smooth the transition from one research group to another can really be is illustrated by Denny Lang. When he was working on his "Diplom" at TU Dresden, the 27-year-old was supervised by Susanne Kehr; today, he is doing a doctorate at HZDR. "I use the near-field microscope to investigate the spectrum of individual impurity atoms in silicon. If assignment to the respective wavelengths works out, it might be possible to use the impurity atoms to construct quantum computers." A highly-ambitious project because studies of this kind are only viable at low temperatures of under -250 degree Celsius. The group is thus the first in the world to conduct near-field microscopy at such low temperatures. According to Denny Lang, "It’s only near to absolute zero that we can exclude thermic excitement in the material, which would falsify our measurements."

In order to expand the potential of near-field microscopy in the future, the researchers at TU Dresden want to go beyond the infrared range. The goal is to use even longer waves in the terahertz range, which will be available at "TELBE", the new terahertz facility at the ELBE Center, from the second half of 2016. This long-wave, low-frequency radiation could excite many materials during microscopy – another aid to discovering yet more about the nano world.

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CONTACT

_Institute of Applied Physics at TU Dresden
Dr. Susanne Kehr
susanne.kehr@iapp.de

_Institute of Ion Beam Physics and Materials Research at HZDR
Dr. Stephan Winnerl
s.winnerl@hzdr.de

↗ www.iapp.de

// Lasers are also finding their way as research tools into resource exploration. Geographer Margret Fuchs wants to develop a quick, hands-off method of detecting metals while maintaining maximum efficiency. She is getting support from the TU Bergakademie Freiberg.

THE TELLTALE GLOW OF MINERALS

_TEXT . Tina Schulz

Every time Margret Fuchs shuts the heavy metal door to her workplace, she leaves the outside world behind her for several hours. The curly-haired, young HZDR scientist conducts her experiments in almost complete darkness. She enters the darkened lab through a windowless lobby. Once her eyes have accustomed themselves to her surroundings she skillfully circumnavigates the silhouette of an experimental set-up. With the beam of her flashlight she scans the UV laser, drops the switches and sends countless photons off on a laser light mission. A point the size of a grain of sand immediately appears at the end of the course: a miniature crystal the UV laser excites so that it glows.

Photo: Detlev Müller

The phenomenon that certain materials have the property to emit short-lived light as soon as they are exposed to a certain light source is something we often encounter in shopping malls. Cashiers hold bank bills under UV lamps to check whether they are genuine. This works because while they are being manufactured, the real bills are mixed with fluorescent filaments that show up in color under black light. Margret Fuchs, who has been working at HZDR's Helmholtz Institute Freiberg for Resource Technology (HIF) since 2015, wants to apply this physical phenomenon to detecting rare earths. These are a group of 17 metals, such as Cerium, Neodymium and Lanthanum, which are needed to manufacture displays and screens as well as extremely strong magnets. Despite the name, rare earths occur quite frequently in the Earth's crust. But in contrast to other ores, they are usually distributed sparsely and seldom occur in high concentrations, which is why it is often so difficult to find and exploit high-tech metals.

Non-destructive exploration

The basis for this new method of exploration is laser-induced fluorescence spectroscopy (LIF). Margret Fuchs excites minerals with lasers of different wavelengths, from ultraviolet through to the infrared range. Not all minerals are naturally fluorescent. The luminescent effect is usually a result of impurities in the crystal lattice caused by foreign atoms – such as those of rare earths. This is why the fluorescence method is particularly suited to determining the presence of such metals. The moment the laser excites a foreign atom, the electrons it contains start leaping to a higher energy level and back again. This releases light with a characteristic emission spectrum that is measured by a special camera. "It is just as unique as a person's fingerprint," Margret Fuchs explains. In future, a scanner is supposed to be developed that will visualize this fingerprint from the rock surface of drill cores and deposits. In contrast to standard methods of investigation, which usually depend on comprehensive chemical and physical analyses, this should make it possible to detect natural deposits of rare earths non-destructively and thus also more quickly.

LIF research is part of a whole series of "gentle" exploration methods which the Helmholtz institute is involved in developing and implementing. For example, a flying probe that is affixed to the underside of a helicopter sends signals at certain frequencies to the subsoil. There the signals generate electrical fields which the probe subsequently receives. This allows researchers to identify electrical conductivity, which can indicate whether there are ore minerals in the rock. Furthermore, geoscientists are testing how drones can be combined with different aerial survey exploration methods or spectroscopy to produce high-resolution models of the Earth's surface. →

Optimizing exploitation processes in real time

The LIF procedure would not only be useful for specifically detecting rare earths. Exploitation and processing procedures could also benefit from this technology. In order to coordinate the extraction and processing of the ores with their composition, the mined material is constantly tested. At regular intervals, samples are taken and usually subjected to complex, time-consuming lab tests. Scanners that could measure changes – permanently, automatically and basically in real time – would be a great deal more energy- and cost-efficient.

"For the procedure to function properly, we still have many obstacles to overcome, such as transferring lab results to natural conditions," Margret Fuchs warns. It was only recently that the geographer compared the emission spectra of cultured and natural minerals. Unlike cultured samples, the crystal lattice of natural minerals can store a whole smorgasbord of foreign atoms. Thus the fingerprint of two similar minerals can differ considerably. Apart from which, in nature, pure minerals are rare. Instead, they tend to occur in rocks and ores in the form of complex mixtures so that ever more spectra overlay each other. "In order to be able to differentiate these mixed spectra better we have to study the fluorescence properties of the individual minerals," the researcher adds.

To conduct her studies, Margret Fuchs uses the Optical Characterization Lab in the Institute of Applied Physics at TU Bergakademie Freiberg, HIF's most important collaborative partner. Together with scientists at the university, she is investigating the spectra in minerals. She wants to use her data to develop algorithms which will automatically evaluate the emission signals sent and generate whole maps with point measurements. As part of the development team, the Helmholtz Institute has recruited the Freiberg Instruments GmbH, a company that constructs special measuring technology for an international market. The company's task will be to develop and eventually build the LIF-based scanner. But at present, the procedure is still in its infancy. Before it is ready to do its job Margret Fuchs will have to spend many more days in the lab prising out the minerals' glowing secret.

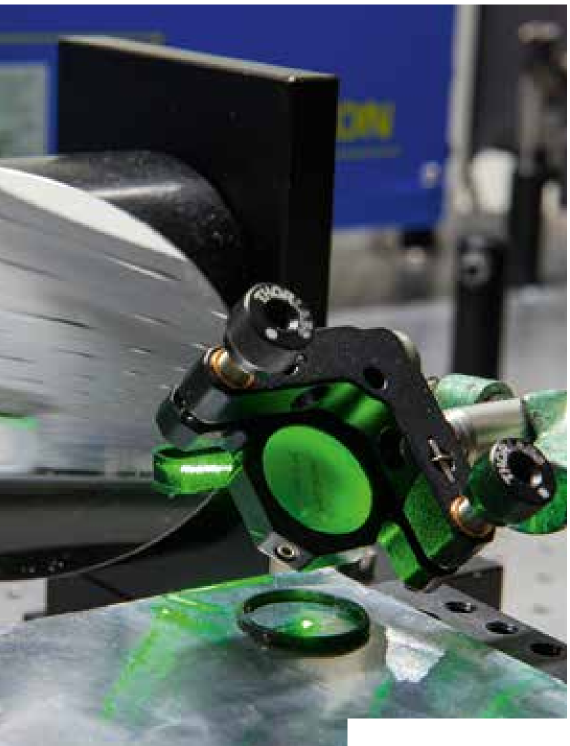
CONTACT

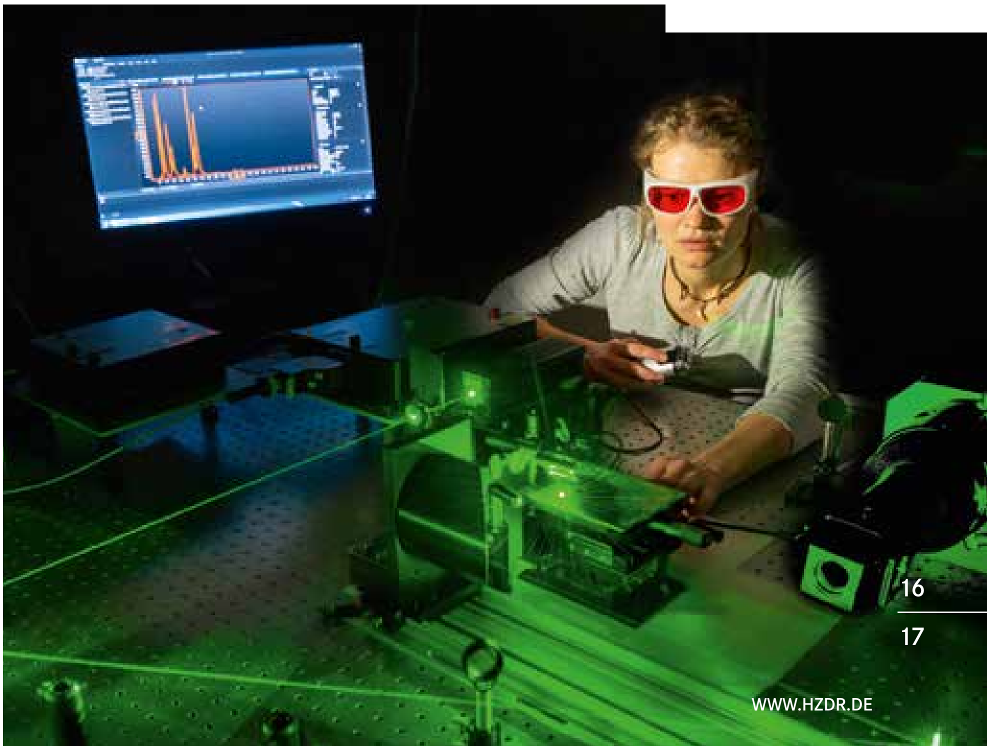
_Helmholtz Institute Freiberg for Resource Technology (HIF) at HZDR
Dr. Margret Fuchs
m.fuchs@hzdr.de

↗ tu-freiberg.de/fakultaet2/angph

EXCITATION: The fluorescent sample contains europium – a rare earth element – in the crystal lattice of an artificial mineral. Photo: Detlev Müller

SIGNATURE: Geographer Margret Fuchs studies the fluorescent properties of minerals. Photo: Detlev Müller





// Fluorescence spectroscopy reveals how radionuclides behave in soils and water.

WHEN URANIUM RESPONDS TO LASER PULSES

_TEXT . Uta Bilow

Hanford in the US State of Washington is one of the most radioactively contaminated places in the world. For around 50 years, the Americans operated nuclear reactors on the high-security site there and produced plutonium for atomic weapons. The last reactor was shut down in 1989. Since then, enormous cleanup efforts have been underway, including decontaminating the extensive grounds. One particularly sensitive aspect are the underground tanks storing many tons of liquid waste from plutonium extraction, which have started showing signs of corrosion. Uranium, plutonium and other radionuclides have already found their way into the earth. Measurements revealed that uranium, in particular, had spread out over a wide area while plutonium and curium only tended to occur in the vicinity of the tanks. Why this is the case is explained by Gerhard Geipel from the Institute of Resource Ecology at HZDR: "Uranium oxidizes in the earth and turns into calcium uranyl carbonate. Uranium in this form is highly-soluble and can easily be transported. Plutonium and curium, on the other hand, occur as compounds which tend to be associated with solid surfaces."

Species analysis is the key term behind these insights. And when it comes to the species analysis of radionuclides, →

EXPERT: With this equipment Gerhard Geipel can capture the characteristic fluorescence at room temperature in less than 100 nanoseconds.
Photo: Oliver Killig

HZDR researchers head the field. Gerhard Geipel and his Biogeochemistry Division study various types – species – of elements, taking account of the type of bonding in which the element occurs and the different stages of oxidization. "Standard methods of analysis usually only verify the overall values of elements," says Geipel. "But in the case of heavy metals like mercury or radioactive elements it is necessary to differentiate the various species – because they have very different properties and behave differently, be it in the metabolism of people and animals or in other biological and geological systems. Thus, the various species also exhibit quite different toxicities."

Tracing the path of radionuclides

Geipel and his colleagues want to use species analysis to help predict the behavior of radionuclides in the biosphere. To this end, the scientists are investigating how uranium and other radionuclides behave in a variety of near-nature model systems and thereby delivering important data for repository research. This is highly relevant because Germany is currently searching for a location for a repository to store radioactive waste from nuclear power plants. Here the disused fuel rods, which are essentially composed of uranium, are supposed to be isolated from the biosphere for a very long period of time. Clay, salt stocks or crystalline rocks are potential geological formations suitable for the purpose as they are considered suitable barriers. But how does the waste react when water penetrates into the repository, the containers corrode and radionuclides are released? The conditions in the rocks differ enormously, starting with possible ligands with which the nuclide can form a chemical bond, via the pH values through to pressure, temperature and, finally, bacteria and fungi that may be present. This complex chemical-physical-biological environment determines which species occur. And this, in turn, dictates whether the radionuclides are easy to transport or tend to be immobile.

The data being collected is not only important for assessing potential depository sites but also for research on former uranium mining areas, such as examining pithead stocks in Saxony to discover how their radioactive components proliferate. The measurements allow scientists to draw up risk assessments for the systems studied. Finally, the investigations provide a pool of data which can be used to better manage nuclear accidents and decontamination work of the type being done in Hanford.

How plants absorb uranium

For more than 20 years, researchers at HZDR have been developing and refining the technology required for conducting species analysis on uranium and other actinides. The most important procedure is laser-induced fluorescence spectroscopy. The institute has a whole arsenal of laser systems for determining the bonds actinides make. Geipel, a chemist, explains the principle of fluorescence spectroscopy: "The energy in the laser light excites the atoms in the sample, causing the electrons in the atomic shell to be raised to a more energy-rich level. When the electrons drop back to their original level, they themselves emit light." This fluorescence is analyzed with a spectrograph and a special, connected camera system. On the basis of the wavelength and the duration of the light emitted, the researchers can determine which species is present and in what concentration.

"The procedure is very good, for example, for determining the various species of tetravalent and hexavalent uranium," says Geipel. Every ion responds to a different excitation wavelength to which the laser can be precisely tuned. "By measuring the fluorescence we can determine in detail how the uranium is bonded." As well as earth and water samples, organic material is also analyzed in Dresden. The researchers came across a plant, for example, that thrives on the pithead stocks in the Johanngeorgenstadt area and contains a high level of uranium. By exposing the plant to fluorescence spectroscopy Geipel and his colleagues discovered how the plant absorbs radionuclides and stores them in its cells.

In the bio- and geospheres, radionuclides often combine with inorganic substance groups like carbonate, phosphate and arsenate, although organic substances such as ligands in the form of components of humus, solvent residues or medical waste are also viable. In order to study these metal-organic complexes the scientists employ so-called femtosecond fluorescence spectroscopy which utilizes an ultrashort laser pulse to excite fluorescence in organic ligands. The radionuclide extinguishes the emission. "By observing the decrease in fluorescence we can calculate the concentration of nuclide and determine the stability constants of the metal-organic complex," Gerhard Geipel explains. To do so, a special camera is used. "The fluorescence disappears very quickly, after as little as ten nanoseconds," the chemist continues. "Therefore we use a camera with an extremely short exposure time. It originated in automotive research where it is used to capture the combustion process in gasoline engines." →

> This knowledge is taken into consideration when designing possible repositories.

Lasers plus acoustics

Not all radionuclides are suitable for fluorescence spectroscopy. Neptunium and plutonium species, for example, do not respond to excitation by producing an emission. For these samples HZDR researchers chose a different procedure: laser-induced photoacoustic spectroscopy. Here, too, a laser pulse is directed at a sample, but the system responds differently. "At the point where the laser pulse impacts, the temperature of the sample increases. It is a tiny effect but we are able to measure this local warming," Geipel explains, "because it creates a pressure wave which we can convert into an electric signal using a piezoceramic sensor." The sample is irradiated with laser pulses of differing wavelengths. If it responds to a certain wavelength, the researchers get a meaningful absorption spectrum. The measuring process is highly sensitive: recently, HZDR analyzed leachate from mining residues in which the scientists identified nuclides at a concentration of less than 2 ppm.

In addition to his lab work, Gerhard Geipel currently has other tasks on his plate as well: he was organizing the international BioMetals Symposium that took place in Dresden in July. This expert conference, which is held every two years, brings together specialists in the interaction of metals in biology. The fact that Dresden has been chosen as the venue for the symposium for the first time, underscores the expertise of the HZDR researchers.

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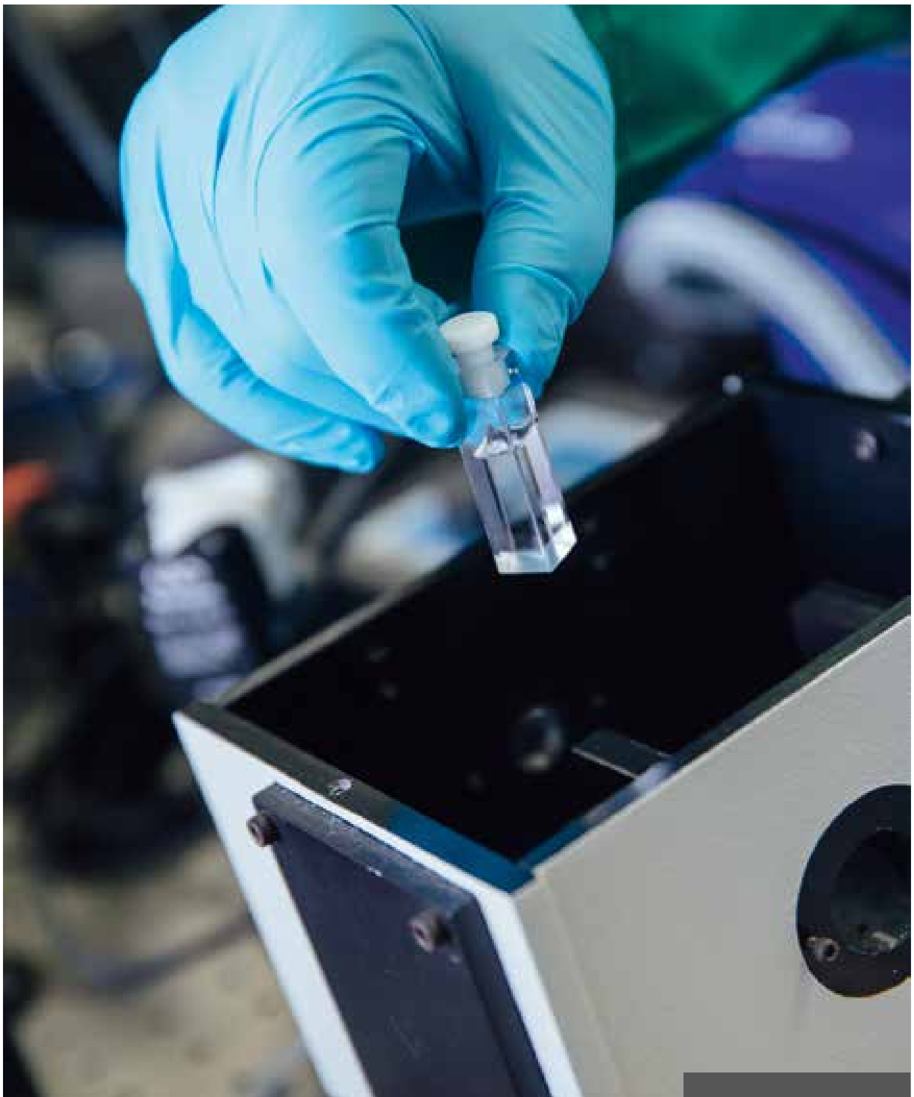

FLUID: The wavelength and the duration of the transmitted light not only reveal which radionuclide is involved but also which species. Photo: Oliver Killig

CONTACT

_Institute of Resource Ecology at HZDR
Dr. Gerhard Geipel
g.geipel@hzdr.de

// For more than half a century, there has been a successful network on flotation, which is a processing method for metal ores and industrial minerals, spanning Australia, Canada, the USA, Brazil, Chile and South Africa – with little European involvement. A new EU project, headed by HZDR, will change this by building a similarly strong network in Europe.

NET-FLOT: Johanna Lippmann-Pipke and Martin Rudolph at a flotation cell in the Freiberg lab. Photo: Detlev Müller

PROCESSING RAW MATERIALS IN EUROPE: STRONGER TOGETHER

_TEXT . Sara Schmiedel

Since January 1st of this year, HZDR scientists have been pooling skills and infrastructures in the field of flotation with thirteen partners from France, the UK, Finland, Poland, Belgium and the Netherlands in a European alliance called NetFlot. Put simply, flotation means finely grinding ores and then mixing them with water and various chemicals. This renders the desired ore particles more hydrophobic, they attach to air bubbles and float to the surface. Now, they can be separated from the other substances in the form of a metal concentrate.

The NetFlot partners are universities, research institutions and corporations – among them global players in ore mining and processing. What they bring to the table are various kinds of equipment, methods and measuring techniques to study, model and perform flotation processes. Once the partners are well connected in the network, these infrastructures will be shared and made available to external interested parties, as well. "To help us build this infrastructure network, we are receiving funding for travel expenditures and a half-time staff position. We are not getting any financial support for research

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ANALYSIS: Doctoral candidate Bent Babel demonstrates current findings at the Raman spectroscope to physicist Johanna Lippmann-Pipke (left) and Heike Hildebrand, manager of the Net-Flot Project. Photo: Detlev Müller

and development as such, we are working with our own resources," says Johanna Lippmann-Pipke, project coordinator and physicist at the HZDR Institute of Resource Ecology.

A central European point of contact

The project is starting out with great momentum: "By the end of the first year, existing infrastructures and models of all scales – from molecular to industrial – must be inventoried and strategically assembled, and our website will go live," says Johanna Lippmann-Pipke. To this end, the partners' individual strengths have to be compiled systematically so that third parties can clearly understand what is available.

As NetFlot's central point of contact, the website will forward any requests, such as reserving testing time, directly to the right project partner. "Our goal is to get as many scientists and corporations as possible to benefit from these expensive facilities and from our partners' valuable expertise. Europe must make progress on this important front," the project coordinator summarizes.

Flotation – an old procedure with room for improvement

Flotation has been used to enrich ore metals since the end of the 19th century. Efforts to make it more economical and efficient are still underway to this day. "The quality of existing ores is dwindling due to massive mining in the past few decades, while demand for raw materials is growing enormously. We need more efficient technologies to make the mining of complex or hard-to-access repositories financially viable," Johanna Lippmann-Pipke explains.

Three HZDR institutes are involved in the project. In addition to the Institute of Resource Ecology, the Institute of Fluid Dynamics and the Helmholtz Institute Freiberg for Resource Technology also contribute their expertise. Lippmann-Pipke: "Even before the call for applications for this particular project, we were toying with the idea of collaborating on experiments and model approaches in the field of flotation." The first call for applications issued by the European Institute of Innovation and Technology (EIT) RawMaterials (see box) suited their purposes perfectly.

A flow of particles and gas bubbles

While geo-ecologist and NetFlot manager Heike Hildebrand from the HZDR Institute of Resource Ecology brings her expertise on the transport behaviours of particles in highly complex systems, the HZDR Institute of Fluid Dynamics clearly excels in fundamental research on multi-phase flows and interactions between gas bubbles and the tiniest particles floating in the liquid. Uwe Hampel and his team of scientists, for instance, are trying to acquire a fundamental understanding of fluid-dynamic transport processes in flotation systems. Building on this insight, the NetFlot partners want to develop flow calculations to increase the efficiency of flotation equipment.

"Flotation has been working for decades, but we don't yet have a clear physical and chemical understanding of it," Martin Rudolph explains. He is a processing expert at the Freiberg institute. "In order to further optimize these processes, you need to understand their basic working principle." Therefore, he and his team are using an atomic force microscope to characterize the minerals that are involved in flotation. Their goal is to increase both yield and purity in ore processing. Their experiments are small- →

OVERSPILL: Experiment in a flotation cell.
Photo: Detlev Müller

scale: "When it comes to upscaling, that means projecting our findings onto industrial scale, we hope to get help from our NetFlot partners," the processing engineer says. Martin Rudolph is convinced that a pan-European effort is the only way to achieve a comprehensive strategy.

CONTACT

_Institute of Resource Ecology at HZDR
Dr. Johanna Lippmann-Pipke | Dr. Heike Hildebrand
netflot@hzdr.de

_Helmholtz Institute Freiberg for Resource Technology at HZDR
Dr. Martin Rudolph
m.rudolph@hzdr.de

_Institute of Fluid Dynamics at HZDR
Prof. Uwe Hampel
u.hampel@hzdr.de

↗ www.net-flot.eu

European Institute of Innovation & Technology

Europe's New Resource Network

In late 2014, the European Institute of Innovation and Technology (EIT) tasked a consortium with establishing a Knowledge and Innovation Community, KIC, for the European raw materials sector. The network, called EIT RawMaterials, currently pools the skills of about 100 partners from 19 European countries, who collaborate to find solutions for a sustainable supply of natural resources. The network supports businesses and researchers in bringing novel products and technologies to market faster, while at the same time encouraging young entrepreneurs. Their goal is to make Europe's raw materials sector more competitive internationally and more appealing to innovative businesses and excellent researchers.

Founded in 2015 and coordinated by HZDR and the Fraunhofer-Gesellschaft, the world's largest raw materials alliance spent most of its first year building its organizational structure. Since the beginning of 2016, EIT RawMaterials GmbH has been an independent corporation. Jens Gutzmer, director at the Helmholtz Institute Freiberg for Resource Technology and interim CEO until the summer of 2015, passed the torch to the new CEO Dr. Ernst Lutz. In addition, all leadership positions in central management and the six co-location centers were filled. The purpose of these regional centers is to thematically organize the regional efforts of EIT RawMaterials, which is headquartered in Berlin.

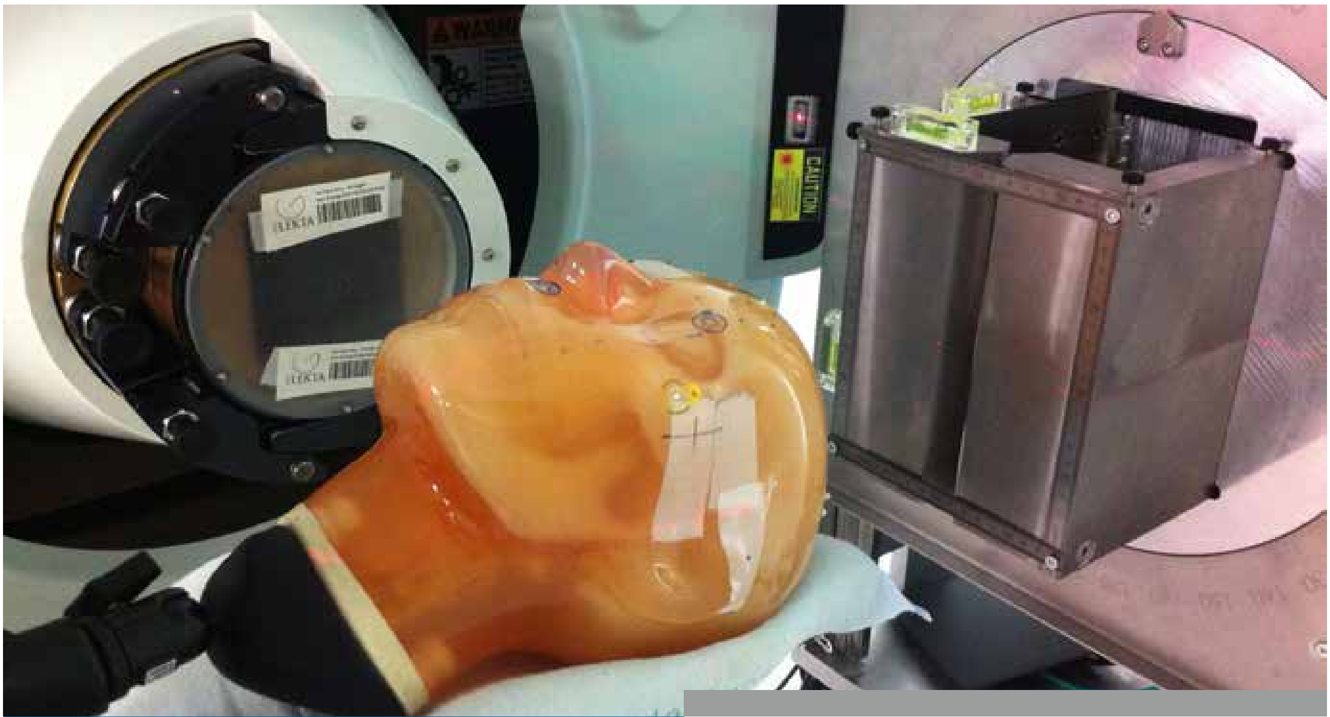
In its first year, EIT RawMaterials defined several support programs to enable its partners to implement technologies in practice, or to network their infrastructures such as labs and equipment. In addition, it has created a transparent assessment procedure to evaluate new project proposals according to strict criteria – such as developing a market-ready recycling process – as well as to monitor ongoing projects. This process is designed to ensure that only the best technologies or products will receive funding. By 2018, EIT RawMaterials plans to be involved in the launch of at least 16 start-ups. By 2022, more than 10,000 new jobs in the raw materials sector will have been created and about 8,000 entrepreneurs will have received certified training. _TS

↗ www.eitrawmaterials.eu

// It used to be impossible to determine how deeply proton beam therapy penetrates the body of a cancer patient. A special camera, developed by Ion Beam Applications (IBA) and clinically tested by a team of Dresden-based researchers, can solve this problem and save healthy tissue from unnecessary radiation.

TRACKING THE PROTON BEAM

_ TEXT . Sascha Karberg



SIMULATION: Final trials using a head phantom prepare the slit camera for work with humans. Photo: OncoRay

When doctors treat cancer patients with proton beams, they use what is considered the most precise radiation technology available to date. In contrast to harsh X-rays, which also harm the healthy tissue in front of, next to and behind a tumor, a proton beam can be directed in such a way that its destructive energy is deposited almost exclusively in the cancerous tissue. This, however, assumes that its range has been calculated correctly, which has so far been impossible to verify during irradiation. A team of researchers at the OncoRay Center Dresden, the company IBA (Ion Beam Applications) and the Helmholtz-Zentrum Dresden-Rossendorf has now solved this problem – with the help of a special device called a prompt gamma camera.

"In the past, we had no means of measuring down to the millimeter how deeply protons penetrate a tumor during irradiation," says Christian Richter, head of the research group "High-Precision Radiotherapy" at OncoRay. While it is possible to pre-calculate the penetration depth of a proton beam in a homogeneous tank of water, "a patient is not a water tank, but consists of tissues of various densities, which will slow down the proton beam at different rates." This has major implications for the clinical application of proton beams. A radiation oncologist who does not know exactly whether the beam will reach the tumor, or perhaps overshoot its target, must irradiate a larger area of tissue as a precaution to ensure that all the cancer cells will be hit. "This uncertainty in range can amount to up to 10 millimeters, even more if the beam has to travel further," says Richter. This forces the doctor to treat areas of up to 10 millimeters larger than the actual tumor – and risk damaging a finger's width of healthy tissue instead of destroying only the cancer cells. "In the past, this uncertainty in range greatly diminished the benefits of proton therapy in clinical applications." →

Protons making waves

Richter's team has now taken a huge step towards solving this problem. Just as a stone thrown into a pond causes waves to ripple across the surface, protons also generate gamma waves, called prompt gamma radiation, around the spot where they "land" in the patient's body and deposit their destructive energy. Researchers capture this radiation with a slit camera – a gamma radiation detector. "The gamma rays tell us where the protons currently are in the human body," says Guntram Pausch, head of the research group "In-vivo Dosimetry" at OncoRay. The gamma rays that are generated by the proton beam are visualized in a detector plane. "This provides information about the edge, i.e. the spot where the gamma radiation suddenly drops because that's where the proton beam stops."

While there are other methods of measuring this "edge", the depth of the proton beam penetration, they are either too slow to yield any results while irradiation is in progress or not developed far enough to be used on human subjects. The slit camera has already passed its first test. In mid-August of 2015, the first measurements were taken during radiation treatment on a patient with a head and neck tumor.

Prior to that, researchers had conducted innumerable experiments on plexiglas and tissue phantoms to prepare the camera for use on human subjects. "Plexiglas consists of carbon, hydrogen and oxygen, which means it's very similar to humans," says Marlen Priegnitz from the Institute of Radiation Physics at HZDR. "You start with cubes, blocks and cylinders, then you go on to tissue-like materials that simulate fat, lung, muscle or brain tissue." By irradiating the phantoms with protons and making targeted modifications, the researchers were able to experimentally prove that the camera can indeed capture the expected variations in range. Only then they did venture to use the detector at the hospital.

Margin of error halved

"The patient knew that the measurement with the slit camera wouldn't harm him, but wouldn't benefit him either, but might help the next generation," Richter emphasizes. The treatment took a little longer, simply because it takes a few minutes to position the slit camera prior to radiotherapy. With the help of the slit camera, we were able to ascertain on different treatment days that the measured range of the proton beam did not vary by more than two millimeters in one area," Richter reports. A significant improvement over the margin of error that radiation therapists currently have to work with. "In the case of this specific patient, the estimated margin of error in the proton range used to be seven millimeters, which means we had to irradiate an area seven millimeters larger than the tumor to make sure we really hit it," Pausch explains. "The camera would allow us to limit this margin to three to four millimeters. Patients would benefit from this."

Even if a few millimeters' difference does not sound as though it justifies that much research effort – in the brain, irradiating an area as thin as orange peel can mean the difference between a brain tumor patient being able to speak after therapy – or not. "The deeper I penetrate into the patient, the greater the uncertainty in range," Richter adds. "When irradiating a prostate, for instance, the proton beam has a range of 25 centimeters, which means a margin of error of more than 10 millimeters." This makes it even more important to continuously measure the range of the proton beam during such multi-week treatments. And the prompt gamma camera, the prototype of which was developed by IBA and tested jointly with the team from Dresden, makes this possible. The OncoRay Center, which is operated jointly be the University Hospital, TU Dresden and HZDR, provides the perfect setting for testing such research projects – where clinical trials meet nuclear physics.

Pausch explains that the goal is to integrate the slit camera into the proton beam equipment. Right now, researchers have to manually position the detector at a right angle to the direction of the proton beam. In the future, the slit camera will automatically transmit its measurement data and interrupt the treatment if the beam penetrates too deeply. "We have a long way to go before that," Pausch says. A realistic short-term success would be to use the slit camera to find out to what extent the theoretical planning of penetration depth matches up with the actual treatment on the patient. "If we could just learn that our calculations match up with the delivered treatment 99.9 per cent of the time, or how we have to modify it, it would help us to avoid having to irradiate so much healthy tissue around the tumor." And the patients would benefit.

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CONTACT

_National Center for Radiation Research in Oncology – OncoRay
High-Precision Radiotherapy
Dr. Christian Richter
christian.richter@oncoray.de

↗ www.oncoray.de

_Institute of Radiooncology at HZDR
In-vivo Dosimetry
Dr. Guntram Pausch
guntram.pausch@oncoray.de

_Institute of Radiation Physics at HZDR
Dr. Marlen Priegnitz
m.priegnitz@hzdr.de

// Dark Matter is everywhere, even though its existence has yet to be demonstrated. According to one popular theory, it might consist of what are called WIMPs. These Weakly Interacting Massive Particles are believed to pass through us unnoticed – millions of times per second.

SLEUTHING WITH A THERMOS

_TEXT . Christine Bohnet

The largest underground astrophysics lab is located in the Gran Sasso d'Italia Mountain in Italy. There, shielded by more than four thousand feet of rock, physicists from around the globe are searching for evidence of this mysterious Dark Matter. The shield of rock is necessary to ensure that the highly sensitive detectors only capture signals from unknown particles. But there is one troublemaker: natural radioactivity.

The chemical element uranium is present in rock anywhere on Earth. Natural uranium is primarily uranium-238, which decays, just like any other isotopes of uranium following a certain temporal scheme. Every decay produces new atoms and particles – uranium-238 decays via what is called the uranium-radium-series, at the end of which is a stable lead isotope. What it is important to realize is that energetic alpha particles are emitted during decay, generating neutrons via nuclear reactions in the rock.

The neutrons deep within the Gran Sasso Massif are partly a remnant of natural radioactivity but they also form in the shielding materials around detectors. So these particles can find their way to the detectors at the Italian National Institute for Nuclear Physics (INFN) and those of its international partners. These include the University of Mainz, which is majorly involved in the development and operation of a new xenon detector. This is a ten meter high tank filled with 3,500 kilograms of the liquid inert gas. Scientists from 21 institutions all over the world are involved in the XENON1T experiment in the Gran Sasso lab.

→

TARGET: The neutron source nELBE enables scientists to find out exactly how neutrons interact with matter. Photo: Oliver Killig

Neutrons or WIMPs – that is the question

When the xenon detector registers an event, it is most likely not a WIMP, but rather a fast neutron. "This is why Uwe Oberlack's group from Mainz has built a small xenon detector for experiments at our neutron source nELBE. We want to figure out how the detector can separate the wheat from the chaff," says HZDR physicist Andreas Wagner.

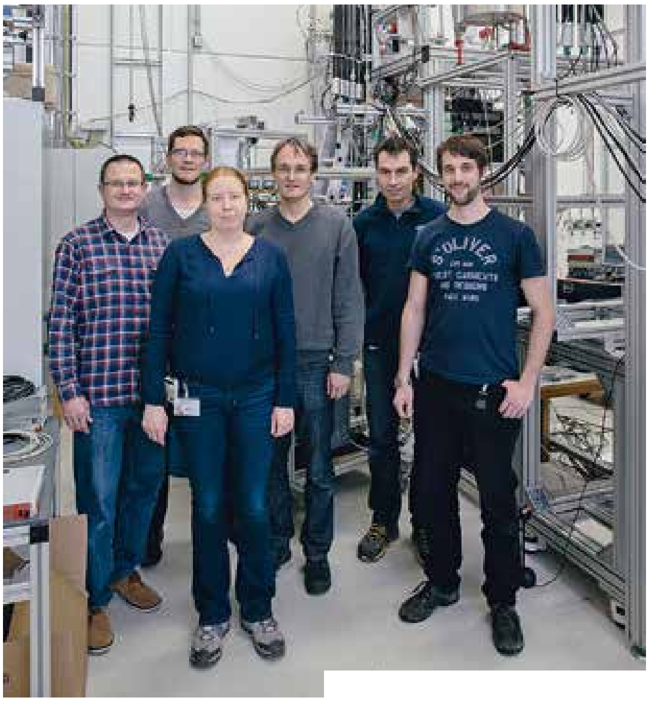
The true-to-scale detector from Mainz looks like a steel thermos bottle, but it works in exactly the same way as its big brother in Italy. Xenon, which is liquid at a temperature of about -170 degrees Celsius emits light as soon as a WIMP or another particle recoils off one of the xenon atoms. To be more precise, an impacting particle energetically excites the xenon atom, which scintillates as it returns to its original state. Several light sensors register and amplify this light. With the help of fast neutrons from the nELBE neutron source, reactions that interfere with the proof of WIMPS in the underground lab can now be closely studied.

Flight duration, energy and angle

nELBE is driven by the ELBE accelerator's intensive electron beam. In the neutron lab, this "beam", which actually consists of a multitude of individual electron packets, impacts with an arrangement of liquid lead. The deceleration of the electrons generates about 100 billions of neutrons per second. The scientist in charge, Arnd Junghans, explains what is special about the nELBE neutron source: "Thanks to the exact timing of the electron pulses, we can precisely measure the flight time of the neutrons, and hence, their speed and energy. Since the parameters of the beam, and thus the neutron flow, can be set as desired, the HZDR neutron source is the perfect tool for detector research."

Fellow physicist Andreas Wagner says: "So as a result, we know the energy-dependent sensitivity of the detector." This knowledge helps the scientists involved in the XENON1T experiment distinguish potential candidates for Dark Matter from fast neutrons.

But there is even more nuclear physics involved here. The light neutrons can make direct impact with the xenon cores, which are about 130 times heavier. When it experiences such a central impact, the neutron transfers a great deal of energy to the nucleus of the atom. When it bounces off to the side, however, the neutron only loses a small amount of energy and flies straight ahead, exiting the detector at a certain angle. "That is why we specifically built ten neutron detectors and arranged them all around the detector with the liquid xenon for the experiment," says Wagner. "This way, we are able to analyze two parameters, the flight time and the angle, which tells us how much energy was transferred to the nucleus." Three doctoral students from Mainz came specially for this multi-week series of experiments.



TOGETHER: Seeking to track down WIMPs (from left to right): Andreas Wagner and Toni Kögler (HZDR), Melanie Scheibelhut (Uni Mainz), Arnd Junghans (HZDR), Uwe Oberlack and Pierre Sissol (Uni Mainz). Photo: Oliver Killig

Many indicators suggest that a major proportion of the matter that surrounds us is Dark Matter. "Let's take the rotational speed of a galaxy, for example. How fast do the arms of the galaxy rotate around its center? Without the existence of Dark Matter, we could not reconcile the calculated speed with the distribution of mass we observe," Andreas Wagner explains.

Thanks to Rossendorf's expertise with regard to particles in general and neutrons in particular, the scientists involved in the XENON1T experiment are now one crucial step nearer to tracking down Dark Matter. Should the theory of weakly interacting particles, WIMPs, be confirmed, the scientists ought to be on the safe side if they erupt in cheers one day, when they detect the first WIMP signals. But since experts only expect two or three such events per year, it could still take a while.

CONTACT

_Institute of Radiation Physics at HZDR
Dr. Andreas Wagner | **Dr. Arnd Junghans**
a.wagner@hzdr.de | a.junghans@hzdr.de

_Johannes Gutenberg-Universität Mainz
Prof. Uwe Gerd Oberlack
oberlack@uni-mainz.de

↗ www.xenon1t.org

// Three young scientists are taking a closer look at heat transfer during boiling and condensation. Their findings might enhance safety in nuclear facilities and increase the efficiency of cooling systems and energy production.

HEDGEHOG: In order to maintain the temperature in fuel rod cooling ponds when accidents occur or the power goes, doctoral candidate Sebastian Unger is focusing on a novel coating. Photo: Oliver Killig

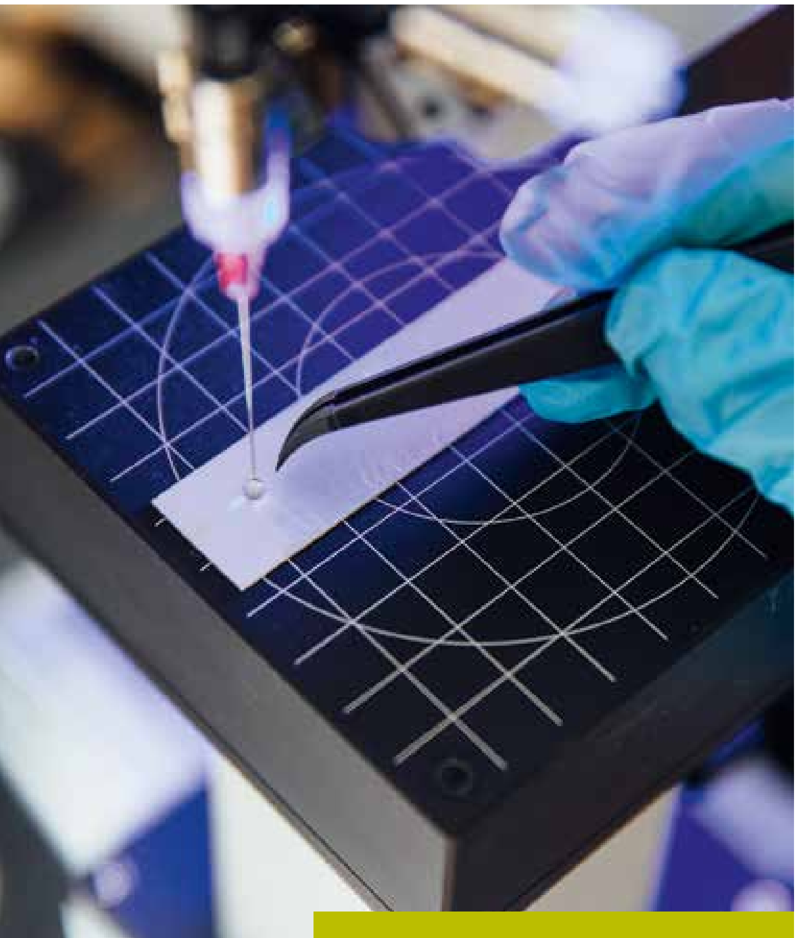
HOT STEAM, COOL DROPLETS

_Text . Inge Gerdes

It is a piece of metal that looks like a small gray hedgehog. It is hollow inside. To Sebastian Unger, the hedgehog is a step towards finding a solution for a more efficient cooling cycle that requires no electricity. This is vital for nuclear power plant safety, but also relevant for many other applications. For a year, the young scientist has been working on his doctorate in "Heat transfer systems for improved passive cooling in nuclear systems", which mainly revolves around cooling fuel element storage pools in the event of an accident or a power outage. "I find it exciting to use my knowledge of engineering to solve process and energy problems," says the 27-year-old, describing his motivation. He studied Energy Technology at TU Dresden with a specialization in thermodynamics.

Heat from nuclear energy is generated by controlled nuclear fission and the radioactive decay in the reactor's fuel elements. Spent fuel elements are replaced, but they continue to release a lot of decay heat, which means they have to be cooled for another five years in a wet storage pool within the plant. If there is a cooling outage, the temperature in this pool will rise rapidly and things can get dangerous. The fuel elements might become so overheated that their cladding would eventually burn and melt and radioactive substances might be released. To prevent this from happening, it is essential that the temperature in the storage pools is maintained. If pumps fail due to a power outage, passive safety systems must take over. →

BASICS: A droplet of water on a coated stainless steel sample is used to measure the wettability between sample and fluid. The aim is to optimize evaporation and condensation processes.
Photo: Oliver Killig



This is where Sebastian Unger's hedgehog comes in. In his quest to optimize the interplay of flow and heat transfer, the Ph.D. candidate is starting with the cooling tubes. The hedgehog is nothing other than an example for an unconventional heat transfer structure. The enlarged exterior surface and a special coating inside the tube are designed to optimize heat transfer efficiency.

Promising coating

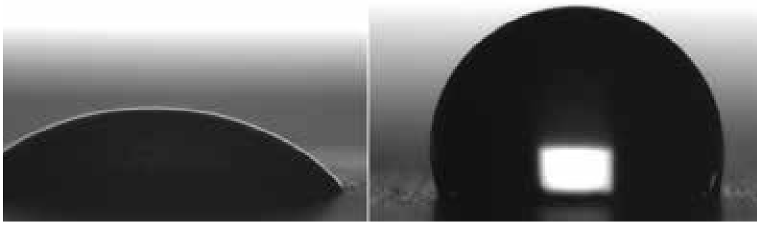
In a passive cooling system, circulation is generated solely by the difference in density of the cooling medium, which is usually water. Hot steam flows into the cooler, condenses along the walls and runs back as water. The smaller the difference in temperature, the smaller the forces propelling the circulation. To make sure that emergency cooling works efficiently nevertheless, it is important to minimize heat resistances and improve condensation. Sebastian Unger has found a promising approach in a thin, hydrophobic coating on the interior of the cooling tube. It will ensure that condensed water droplets will run off quickly rather than forming a film that impedes heat transfer from the inflowing steam to the wall.

In his search for a suitable coating technique, Sebastian Unger turned to a specialist at HZDR, electrochemist Ulrich Harm. He is an expert on wet-chemical processes – a method that lends itself very well to coating the inside of a tube. It harnesses a special property of metals, the fact that they form a thin oxide layer at the surface. If a metal tube is dipped into the coating bath, a single layer of molecules, called a monolayer, will attach to this oxide layer. This kind of coating favours the formation of water droplets, which means that the surface will not get very wet. "It is like the lotus effect," Sebastian Unger explains. "Since the monolayer is between a few ångströms and two nanometers thick, it improves heat transfer during condensation without causing any additional thermal resistance."

To find the right coating, various chemicals and surface structures were tested to achieve the desired wettability and thermal resistance. Previous studies relate to coated copper or gold, which is used at a smaller scale, mainly in electronics. Power plants, however, mainly use steel or aluminium. HZDR researchers are therefore breaking new ground with this hydrophobic coating of steel. Unger is hoping to publish initial results as early as this year.

The printed hedgehog

In a passive cooling system, the only option is often to release heat into the surrounding air. In order to improve the transfer of heat and air circulation, Sebastian Unger developed a special surface design. He coated the outside of the tube with a host of thin spikes, thereby increasing the heat exchange surface.



COATING: Good wettability – on simple steel the droplet "lies flat" on the surface. In the image on the right, by contrast, the surface repels the droplet.

To create his spiky heat-transfer structure, the young researcher chose a novel additive manufacturing method generally known as 3D printing. Since this technology also works for metals, it offers plenty of creative leeway for designing special components at relatively low cost. He was therefore able to calculate the optimum shape and have his little model made at the TU Dresden Institute for Materials Science.

Soon, a foot-long (35 cm) piece of the 'hedgehog rod' will be tested in the flow channel. "I will heat it from the inside and measure heat conductivity," Sebastian Unger says. "I will then be able to compare the results with traditional cooling fins." If the experiments are successful, the cooling design will have to be calculated and adapted to the large scale. →

Research with imaging measurement methods

The young scientist's work is directed by his supervisor Uwe Hampel. He is the head of Experimental Thermal Fluid Dynamics at HZDR and holds the AREVA Endowed Chair of Imaging Techniques in Energy and Process Engineering at TU Dresden. Such fundamental research would not be possible without the kind of state-of-the-art measuring technologies available at HZDR. To study heat transfer processes, the researchers use ultrafast, high-resolution X-ray tomography, high-speed and infrared cameras, 3-D-scans and other measuring methods. Their findings will help improve nuclear safety and increase the efficiency of industrial processes.

Debasish Sarker and Thomas Geißler, who are also Uwe Hampel's doctoral students, are pursuing the same goal. Since mid-2014, both of them have been working on evaporation processes. More specifically, they are studying the formation of steam bubbles and their behavior in a flow.

When the boiling crisis becomes a problem

Boiling and evaporation are powerful cooling mechanisms. In a nuclear power plant, they are used to conduct heat that is released at the fuel elements. The steam drives a turbine; the attached generator converts the motion energy into electrical energy. The fuel rods inside the fuel elements are separated by a grid. To harvest the largest amount of energy, the distance from this grid must be minimal, while still allowing the cooling water to flow freely. Under no circumstances may the fuel rods heat to the point of a boiling crisis.

When a liquid begins to boil, it produces bubbles. The liquid evaporates. If a critical level of heat flux density is surpassed at the heated surface, a film of steam will form, isolating the liquid from the surface and blocking heat transfer. This is called a boiling crisis. Everyone has seen water droplets dancing on a hot stove. The droplet will hover or glide on a cushion of steam, and it will take quite a while before it evaporates. A boiling crisis can occur very fast and cannot be reversed in an operating nuclear reactor. The isolating steam layer keeps the fuel elements from being cooled properly, the fuel rods heat up. In the worst case, entire fuel elements can be damaged.

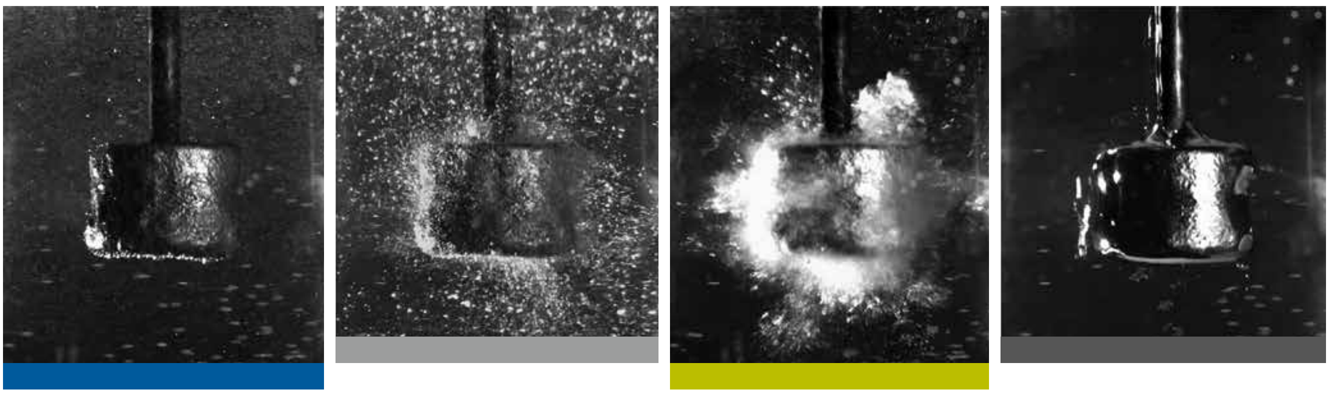
A look inside

The boiling crisis, this sudden transition from regular boiling to what is called film boiling, is the subject of Thomas Geißler's dissertation. At what point does the steam layer form and how does it relate to flow? How can the boiling crisis be delayed? A lot remains to be discovered. To find answers, Geißler, who is a chemical engineer, set up an experiment.

Beneath a protective aluminium cover is a thin titanium rod about 40 centimeters long. Due to its lower boiling point, it is filled with a refrigerant rather than water. It is surrounded by several gold mirrors. When the rod heats up, the young scientist can watch the liquid evaporate.

He uses ultrafast X-ray tomography and an infrared camera for his observations. While the tomograph looks deep into the interior of the rod, the camera captures the temperature fields on the exterior via various mirrors. "With this data, I am able to visualize the formation of steam bubbles and their behavior," he explains. "Some travel along the wall with the flow, others fuse into bigger bubbles."

He then derives new theoretical models from his experimental findings. Such models exist already, but the processes are so complex that none of the models describes them comprehensively. The model must be expressed →



BOILING: How does a copper cylinder respond to increasing surface temperature? (a) convective heat transfer without bubbles, (b) nucleate boiling with just a few bubbles, (c) eruptive boiling, (d) film boiling above the Leidenfrost Point: the cylinder is completely encased in vapor.

HAND IN HAND: Basic experiment, simulation and technology development – the three doctoral candidates Debasish Sarker, Sebastian Unger and Thomas Geißler (from left to right) share ideas in front of the steam drum at the TOPFLOW facility. Photo: Oliver Killig

mathematically to be scalable to larger applications. This is the only way to model complex heat transfer processes in fuel elements under all conceivable circumstances. New experiments are then conducted to validate the findings. "At HZDR, I can combine research and technical applications," the 27-year-old is happy to report.

Better understanding of evaporation processes

Debasish Sarker has a Master's degree in Mechanical Engineering and Energy Systems. Following his studies in Bangladesh and South Korea, he came to HZDR two years ago to pursue his Ph.D. He investigates single steam bubbles, at a scale of less than a millimeter. At his test facility, a high-speed camera provides him with high-resolution images of the evaporation surface and bubble formation. They allow Sarker to observe how steam bubbles form and glide along the wall, as well as to measure their flow speed. He also simulates the bubble formation on the computer.

"I want to contribute to a better understanding of evaporation," the 33-year-old says. He is particularly interested in finding out how to optimize heat transfer at slow flow velocities in small spaces, as is the case, for instance, in tight bundle heat exchangers. This is fundamental knowledge of great importance for passive cooling systems. He is convinced that "if we can make progress here, it will impact the energy efficiency of a lot of large industrial facilities."

Debasish Sarker's research is also of interest to his two colleagues. He examines the evaporation processes on Sebastian Unger's coated samples. And for Thomas Geißler, it is vital to understand what is happening when a steam bubble grows and becomes detached.

Greater safety and energy efficiency

Even though all German nuclear reactors will be off the grid by 2022, research in nuclear power plant safety and safe storage of fuel elements is still needed. Germany will only be able to have a say in future debates about global safety standards and participate in international research projects if it continues to cultivate its own expertise in the field. The three Ph.D. projects under the supervision of Uwe Hampel are partly funded by the Federal Ministry for Economic Affairs and Energy.

Their research outcomes, however, can be applied in many fields. Insight into the boiling crisis is vital to any situation in which vast amounts of heat must be cooled in a small space, which is the case, for example, in certain computer components. Hydrophobic coating, on the other hand, could have an impact in the field of renewable energies. If small differences in temperature can be exploited better using such coatings, it would be possible to increase the efficiency of biogas, geothermal, solar and heat recovery systems.

CONTACT

_Institute of Fluid Dynamics at HZDR
_AREVA Endowed Chair of Imaging Techniques in Energy and Process Engineering at TU Dresden
Prof. Uwe Hampel
u.hampel@hzdr.de

_TU Dresden
Thomas Geißler and Sebastian Unger

_Institute of Fluid Dynamics at HZDR
Debasish Sarker

// Thanks to a Georg Forster Research Fellowship, George Mamatsashvili is spending two years at the HZDR. He is not only building a bridge between Georgia and Germany but also between astrophysics and fluid dynamics.

THE LINK BETWEEN SIMULATION AND EXPERIMENTS

_TEXT . Simon Schmitt

George Mamatsashvili

"Astrophysicists are sometimes a tad skeptical about our experiments," says Frank Stefani, grinning about his experiences with his colleagues. That is one of the reasons why the Dresden researcher is even more delighted that he has been able to welcome an expert in the field to the HZDR Institute of Fluid Dynamics: since the beginning of December 2015, George Mamatsashvili from Tbilisi State University has been in residence thanks to a Georg Forster Research Fellowship awarded by the Alexander von Humboldt Foundation. The Georgian astrophysicist will spend two years at HZDR – bringing the stars to Rossendorf – because he wants to elucidate how stars acquire their mass. Or rather: he is interested in magnetorotational instability (MRI).

This magnetic effect plays an important role both in the formation of stars and planets as well as in the emergence of black holes in the center of galaxies. "MRI describes how magnetic fields can cause turbulence in what are basically stable flows," George Mamatsashvili explains. "And it is precisely this phenomenon that occurs in the universe." Around black holes and young stars, so-called accretion disks orbit – ring-shaped disks of gas and dust. "Because according to Kepler's laws of planetary motion the angular momentum increases towards the periphery, these disks are actually very stable. That is why the particles of matter shouldn't accrete onto black holes or stars."

How do black holes and young stars get their mass?

Only when they are decelerated does the centrifugal force become too weak to keep them in orbit, the Humboldt Fellow explains. "And this is what MRI does. It de-stabilizes the disk and at the same time causes mass to be transported inwards and angular momentum outwards." However, for this, the matter in the disks must at least be able to conduct minimal amounts of electricity. In dead zones or at the outermost edges this is not always the case which is why the effect of standard MRI – with a purely vertical magnetic field being applied – is controversial. One solution was delivered by Frank Stefani and colleagues at HZDR, together with the Leibniz Institute for Astrophysics in Potsdam back in 2006, when they complemented the vertical magnetic field of the standard MRI with a circular one.

By doing so, using even just low magnetic field strength and rotation speeds, researchers were able to create a special variant of the phenomenon in the lab for the first time: helical MRI. "But there is a flaw," Stefani admits. "Helical MRI only destabilizes rotation profiles that drop relatively steeply towards the outside, and this is not initially the case with accretion disks." A couple of years ago, the Dresden researcher managed to rebut this argument with an expanded theory. As he and his colleagues showed, helical MRI can also operate in cases such as this – at least it will, provided that some small part of the circular magnetic field has been generated in the disk itself: which is a perfectly realistic assumption.

Unique opportunities

It was these theories, and especially the experiments, that attracted George Mamatsashvili to Dresden. "Apart from Dresden, there are only a couple of labs in the world that are investigating this phenomenon experimentally and not just numerically." His stay at the Dresden research center →

will therefore be a unique opportunity for the theoretician to build bridges between astrophysics, which tends to use simulations, and experimental fluid dynamics. For this purpose, he wants to investigate MRI under preconditions the theoretical analyses have neglected up to now. "They assume a higher degree of stability," Mamatsashvili explains. "But that doesn't correlate with the actual conditions in the disks, which are presumably much more instable."

Reasearchers most often use the so-called modal approach for studying MRI. "This assumes that in the long run, turbulences will either drop or grow exponentially, but their behavior at the outset is not taken into account. This means that even flows that should really be stable in the long term are instable from the start." For his analysis, George Mamatsashvili therefore wants to use the non-modal approach, which factors in this process. "Various studies have shown that non-modal growth of MRI can be much stronger than the modal one so that the conditions for the formation of turbulences don't have to be as stringent as we had thought so far."

With the help of this alternative technique the impact of MRI on the processes in accretion disks can be investigated in much greater detail, Mamatsashvili is confident. He wants to demonstrate this by testing his theoretical outcomes on PROMISE, the Potsdam Rossendorf Magnetic InStability Experiment, a device on which Frank Stefani also conducted his experiments – thus making the connection between simulation and experiments.

CONTACT

_Institute of Fluid Dynamics at HZDR
Dr. George Mamatsashvili
g.mamatsashvili@hzdr.de

Dr. Frank Stefani
f.stefani@hzdr.de

↗ **www.humboldt-foundation.de**

HZDR Research Award for Controlled Spin Waves

Up to now, the number of transistors per microprocessor has doubled roughly every two years. But the limits of ever smaller processors with ever higher performance are gradually being reached. One of the main reasons is the amount of waste heat generated when yet more circuits are squeezed onto an increasingly small surface.

The Magnonic Junior Research Group around Helmut Schultheiß is trying out a new approach based on spin – the magnetic angular momentum of electrons. In ferromagnetic materials, this makes it possible to generate spin waves, which can transport information like flowing charge carriers, but without the extreme waste heat.

Thomas Sebastian, Andreas Henschke, Helmut Schultheiß (f.l.t.r.; not in the picture: Kai Wagner) receive the 2015 HZDR Research Award from IPP Director Sibylle Günter and HZDR Scientific Director Roland Sauerbrey. Photo: André Forner

For the very first time, Helmut Schultheiß, Andreas Henschke, Thomas Sebastian and Kai Wagner managed to control the emission of spin waves on the nano-scale. To do so, they transmitted a wave through a domain wall – the area where the different magnetic domains meet. For this achievement, they received the HZDR Research Award 2015.

New Helmholtz Young Investigators Group

Dominik Kraus

An international collaboration of researchers recently managed to directly track the transformation of graphite into a special form of diamond for the first time: Lonsdaleite had previously been a matter of speculation. Only formed under very high pressure, this hexagonal diamond structure does not occur on Earth under natural conditions. In order to investigate the formation process of this alien matter, the researchers combined two high-energy lasers with the free-electron laser at the Linear Coherent Light Source in Stanford.

The head of this collaboration, Dominik Kraus, is now joining HZDR, because similar experiments on warm dense matter (WDM) will soon be possible at the Helmholtz International Beamline for Extreme Fields (HIBEF). An international consortium led by HZDR is currently installing these new capabilities at the High Energy Density Facility of the European XFEL. In order to be involved in constructing HIBEF, Kraus has relocated to Dresden. Together with his Helmholtz Young Investigators Group, he wants to explore the fundamental physics of WDM.

// April 1st saw the launch of a new ion implanter under the leadership of physicist Roman Böttger. The equipment will increase the pull of what science and industry already consider a very attractive ion beam center.

YOUNG FACILITY IN YOUNG HANDS

_TEXT . Markus Fehrenbacher

RACETRACKS: Amid the steel pipes that run from the implanter to four experimental stations: Roman Böttger, the physicist responsible for the facility. Photo: Oliver Killig

It is noisy in the sterile little room. So noisy that you can hardly understand Roman Böttger as he explains: "That's the aircon. If the air isn't constantly exchanged and dried, we could end up with lightening-like discharges. We have to prevent that." The head of the "Ion Implantation" group is standing in front of a cube-shaped structure the size of a small automobile. It sits on four black isolators in the middle of the room and is the physicist's pride and joy. After all, he was one of the main forces behind the set-up of the new ion implanter. It is here that ions, that is, electrically-charged atoms, are accelerated to very high speeds with the help of 500 kilovolts – which is roughly 2,000 times the amount that issues from an electrical outlet. "With such enormous voltages we have to take special safety precautions," says Böttger.

Despite his youth, the 29-year-old scientist can look back on a long career in the Ion Beam Center – which is not because he spent such a long time working on his doctorate. On the contrary: Even while he was still at school, the student from the Erzgebirge region laid the foundation stone for his current →

position. Having been successful in the national "Jugend forscht" competition for young researchers in 2005, he was granted a number of awards, including an internship at HZDR. He followed this up with an exemplary performance studying physics in Chemnitz, regularly working as a research assistant at the Ion Beam Center, and completing both his "Diplom" and Ph.D. with outstanding results. So it comes as no surprise that he was given a post of responsibility immediately after his doctorate: With the support of five technical staff he has been in charge of ensuring the smooth running of the user service for nearly two years – and for the launch of the new facility as well.

High speeds and large currents

The new equipment is composed of a whole series of chambers that are available for both internal and external users at the Ion Beam Center. It produces beams of fast ions which can be employed to manipulate and investigate the most diverse materials. As a rule of thumb, the higher the achievable speed of the particles in a device, the fewer the number of particles, that is, the particle current. Two types of facility exist: on the one hand, accelerators the size of an entire manufacturing hall which are required to generate particularly high kinetic energies. They are mostly used for analytical purposes. On the other are ion implanters, which, by contrast, are largely used to modify materials thanks to significantly larger currents. Due to a simpler acceleration principle they are much more compact – at least, compact enough to fit in the little room with the roaring air conditioning.

Unlike the existing 40 kV and 200 kV implanters, the 500 kV implanter delivers a combination of particularly high speeds and ion currents. The modern facility has now replaced its elderly 500 kV predecessor. "The new device has a lot of advantages," Roman Böttger explains. "It is totally computer operated. On the old machine you always had to spend a couple of hours fiddling with the potentiometers to adjust the ion beam. Today you can do it in 15 minutes. Also, it's modular and therefore very easy to maintain." All in all, a big time saving that of course benefits user service. "Another important development is that some types of ion beams can now be generated with much larger currents, enabling us to to conduct certain high-dose experiments."

Usage by science and industry

When you leave the little room through the safety door you encounter a massive steel pipe that channels the accelerated ions into a huge hall. It branches out like tentacles into four smaller pipes through which the charged atoms hurtle towards different set-ups. Here they meet the material of choice. "Every setup is designed and optimized for a certain approach," the physicist explains, pointing to one of the four stations. "This one here, for example, is essentially operated for industrial enterprises to work on wafers, that is, thin slices of semiconductor." Böttger's comment touches on a significant point, which is that materials research using ions is very closely related to applications. The raft of product innovations that have been generated by the Ion Beam Center in the last few years bears witness to the fact. Since 2011, HZDR Innovation GmbH, a successful HZDR spin-off, has regularly been using the facility's ion beam service to implement process steps that can only be carried out here for national and international firms. The ion beam service, for its part, thus enables the Ion Beam Center to finance larger-scale investments such as the new implanter. "So far, this is unique among Helmholtz Centers," Böttger emphasizes.

With approximately 80 percent of beam time, however, the main users are researchers. "No question, science has priority," the scientist stresses. The particular importance of the Ion Beam Center for researchers is certainly the choice of different types of ion on offer. While many ion beam facilities specialize in just a few ion species, normally for processing semiconductors, here all non-radioactive elements can be accelerated. "We can do the whole periodic table," says Böttger.

Multiple options for different users

Ask the physicist about the potential applications of ion implantation and he will be in his element. "It's an absolutely elementary tool in the semiconductor industry. Whether we are talking about cellphone or camera, nothing would otherwise function the way we know it. Even in fields like medicine or space research, this technology is used in manufacturing anti-bacterial surfaces or simulating solar wind."

He would have enough ideas for new experiments – but not enough time to conduct them himself. Doesn't he think that is a pity? "Oh, I can live with it. What I particularly enjoy about my work is the breadth of scientific topics I am able to pursue. The experiments we do here are very varied and individual." Last year alone, nearly 100 applications for ion beam experiments arrived on Roman Böttger's desk and it can be assumed the figures will not drop this year either. Already, users with an eye to the new 500 kV implanter are standing in line. ⊣

CONTACT

_Institute of Ion Beam Physics and Materials Research at HZDR
Dr. Roman Böttger
r.boettger@hzdr.de

↗ www.hzdr.de/ibc

PANORAMA – HZDR NEWS

Sixty Years of Radiopharmacy in Dresden

Sixty years ago, that is, shortly after Rossendorf was established as a research site on January 1, 1956, radioactive substances had started to be developed for use in medicine and business. At that time, there was no clear distinction between radiochemistry and radiopharmacy; instead, attention was focused on producing radionuclides at the research reactor as well as on separating, purifying and handling them. Today's Clinic and Polyclinic for Nuclear Medicine at Dresden University Hospital can also look back on a sixty-year history. The medical use of radionuclides, however, started as early as 1939 with the first application of iodine-131. Today, some 60,000 therapies and more than two million diagnostic examinations take place in nuclear medicine in Germany every year.

Art at the new Center for Radiopharmaceutical Tumor Research – the installation “Strahlen” (rays, beams) by artist Karl-Heinz Adler was officially unveiled on 28 May by Saxon State Minister of Science and the Arts, Dr. Eva-Maria Stange. Photo: André Forner

Between 1959 and 1969, at Rossendorf's Central Institute for Nuclear Research (ZfK), so-called isotope production, that is, the commercial manufacture of radiopharmaceuticals, was developed under the director of the Radiochemistry Section, Kurt Schwabe. Particularly under his successor, Rudolf Münze, production was placed on a scientific footing, modernized and expanded extensively. In particular, this involved the manufacture of fission molybdenum-99/technetium-99m generators (Rossendorf was thus the world's second producer of fission molybdenum). At the same time, ZfK researchers were working on new substances and on how to manufacture them at a high quality level. The iodine-131 therapy was employed in both Eastern and Western Europe. The "Rossendorf Standard", which became a catchword in Central and Eastern Europe, is indicative of the institute's development into one of the leading radiopharmacy research centers.

When the Research Center Rossendorf was founded on 1.1.1992, Bernd Johannsen became the head of the Institute of Radiopharmacy. He focused to a greater extent on the biochemical-medical origins of radiopharmacy and on applied basic research. Thanks to closer academic ties with TU Dresden, the institute became more involved in teaching and doctoral training. In 1995, a cyclotron went into operation with which the radioactive source materials for cancer diagnosis with the aid of Positron Emission Tomography (PET) were produced. This was followed by a full-body PET camera in 1997, the year that also saw the formal inauguration of the PET Center Rossendorf. It is here that the partners HZDR, University Hospital and TU Dresden still cooperate closely for the benefit of cancer patients to this day. For 20 years, until the PET camera was relocated to the University Hospital in 2015, patients came to Rossendorf for their appointments; some 17,000 examinations were conducted.

Fighting cancer with radiation

In order to keep improving cancer cure rates many new approaches are needed. Today's Institute of Radiopharmaceutical Cancer Research favours a combination of imaging techniques on the one hand and endoradionuclide therapy on the other. The latter involves the radiotherapeutic agent killing the cancer cells from within the tumor or the metastases. In order to be successful in this endeavor, close cooperation with medical partners in the context of NCT Dresden (NCT = National Center for Tumor Diseases) is essential. HZDR benefits in any case from decades of expertise in radioactive substances and biochemical competency. Across the world, oncologists and patients are currently pinning their hopes on immunotherapy. How to furnish novel immunotherapeutic agents with an additional radioactive label is a further research area now being explored at HZDR under the leadership of Jörg Steinbach and Michael Bachmann.

Röntgen Medal for Michael Baumann

Röntgen-Museum

Science at the highest level and for the benefit of cancer patients is both an obligation and a personal mission for the director of several Dresden institutions, Michael Baumann. The radiation biologist and radiation therapist heads the OncoRay Center, the Radiation Therapy Unit at Dresden University Hospital, the HZDR Institute of Radiooncology and the NCT partner site in Dresden. On April 23, he was awarded the Röntgen Medal for his outstanding scientific achievements in Wilhelm Conrad Röntgen's birthplace, Remscheid. This honor is conferred on individuals by the Mayor of the city for their exceptional services to advancing and disseminating the discovery made by Röntgen.

EMFL Becomes a Landmark

The European Strategy Forum on Research Infrastructures (ESFRI) has named the European Magnetic Field Laboratory (EMFL) as a Landmark in its new Roadmap. EMFL is one of 29 institutions recognized for enabling European scientists to conduct unique top-level research and thus to sustainably strengthen research in Europe. EMFL amalgamates three European high field magnetic laboratories at four sites in Dresden, Grenoble, Toulouse and Nijmegen, providing the highest pulsed and static fields in Europe for internal as well as external users. Such high magnetic fields are among the most powerful tools available for modifying and studying the properties of matter.

Gold for HZDR Film

At the World Media Festival in Hamburg on May, 11, important film prizes were awarded in the public relations sector. HZDR was among them, winning an "intermedia-globe Gold" in the "Research and Science" category for its film on repository research. The director of the relevant institute Thorsten Stumpf was delighted: "Our Institute of Resource Ecology does basic research on issues relating to the permanent disposal of highly radioactive waste. We wanted to present this important task, which is so important to society, to a broader public. And, of course, film is a particularly suitable medium." The HZDR film scored another strike at the 49th Worldfest International Film Festival in Houston, Texas. Produced by the Dresden company Avanga, it won the Gold Remi Award in the category "Nuclear/Energy Issues".

What's on?

01.09.2016
HZDR Summer Student Program
Presentation of First Results

29.08.-02.09.2016
EUCALL Annual Workshop
HZDR | Institute of Radiation Physics

29.-30.08.2016
Workshop: Targets for Advanced Light Sources
HZDR | Institute of Radiation Physics

19.-20.09.2016
FRIENDS2 Workshop – Framework of Innovation for Engineering of New Durable Solar Surfaces
HZDR | Institute of Ion Beam Physics and Materials Research

10.-12.10.2016
SATIF-13 – 13th Meeting of the Task-Force on Shielding Aspects of Accelerators, Targets and Irradiation Facilities
HZDR | Institute of Radiation Physics

07.-10.11.2016
14th Multiphase Flow Short Course and Conference
HZDR | Institute of Fluid Dynamics

22.-23.11.2016
Helmholtz Open Science Workshop
HZDR | Department of Information Services and Computing

29.-30.11.2016
EERA Meeting – European Energy Research Alliance
HZDR | Institute of Ion Beam Physics and Materials Research

Radiation protection courses at the HZDR research site Leipzig

27.09.2016 | 10.11.2016
Continued education courses

12.-16.09.2016 | 01.-03.11.2016
Technical qualification (Modules GH, OG, GG, FA)

Petrus Peregrinus Medal 2016

That the earth has a magnetic field is no news to anyone. But the fundamental mechanism of how it was formed has only recently been verified in a lab experiment. The name behind the world's first demonstration of this dynamo effect is Agris Gailitis. Since the 1960s, the professor in the Institute of Physics at the University of Latvia in Riga had investigated magnetic self-excitation. It then all happened on 11.11.1999: together with scientists from HZDR, the self-excitation of a magnetic field in a spiral flow of fluid sodium was demonstrated. And, as coincidence would have it, a few days later, the dynamo at what was then the Karlsruhe Research Center "ignited" as well.

For this milestone in magnetohydrodynamics, which also laid important foundations for experiments currently taking place in Cadarache, Maryland, Grenoble, Madison, Zürich and Dresden-Rossendorf, Agris Gailitis has now been honoured. On April 18, he received the 2016 Petrus Peregrinus Medal, which is awarded by the European Geosciences Union (EGU) for outstanding scientific contributions in the field of magnetism and paleomagnetism. Peregrinus was a French scholar and the first to describe the polarity of magnets in his 13th century treatise "Epistola de Magnete".

HZDR physicist Frank Stefani (right) nominated Agris Gailitis (middle) for the award.

In-service Training Attracts Many Teachers

At the annual in-service training for teachers in mid-February, some 130 educationalists from all over Saxony took the opportunity to learn about the most recent scientific findings in astrophysics. At various lectures – dealing with topics like the evolution and influence of cosmic magnetic fields – and during visits to selected labs, the participants grasped the chance to refresh their knowledge. They were even able to acquire information on a hot topic: the first proof of gravitational waves.

The physics educationalist Karl-Heinz Lotze of the University of Jena redesigned his opening lecture at short notice to address this discovery, which was made by the LIGO Collaboration at the beginning of February. For many years now, HZDR has run in-service training sessions for teachers who are also eligible to participate in further offerings of the DeltaX School Lab.

↗ **www.hzdr.de/deltax**
↗ **www.facebook.com/schuelerlabor-deltax**

DeltaX Welcomes the 10,000th Student

April, 26, was a very special day for Matthias Streller and his team at HZDR's own school lab, DeltaX: they welcomed their 10,000th young researcher. The lucky candidate was Aaron Ickert. On this special day, he and his classmates from the Werner-Heisenberg-Gymnasium in Riesa and another advanced course from the Julius-Ambrosius-Hülße-Gymnasium in Dresden conducted experiments on magnetic phenomena. The fact that two classes visited the HZDR lab on the same day is indicative of its popularity. To do their own research-related experiments in a big Helmholtz Center – that catches young people's imagination.

Aaron Ickert from Riesa and the DeltaX team: Matthias Streller, Florian Simon, Nadja Gneist (from left to right)

Photo: Oliver Killig

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Dr Christine Bohnet (editor-in-chief), Simon Schmitt, Jana Grämer (images) |
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EDITORIAL ADVISORY BOARD
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AUTHORS
Dr Uta Bilow | Freelance science journalist, Dresden
Christian Döring | Communications and Media Relations, HZDR
Dr Markus Fehrenbacher | Internship @ Communications and Media Relations, HZDR
Inge Gerdes | Freelance science journalist, Dresden
Frank Grotelüschen | Freelance science journalist, Hamburg
Sascha Karberg | Freelance science journalist, Berlin
Sara Schmiedel | Freelance science journalist, Leipzig
Tina Schulz | Communications officer at Helmholtz Institute Freiberg for Resource Technology, HZDR

TRANSLATION
Dr Lynda Lich-Knight | ResearchComm Ltd

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CONTACT / ORDER (free of charge)
Helmholtz-Zentrum Dresden-Rossendorf
Communications and Media Relations
Dr Christine Bohnet
PO Box 51 01 19 | 01314 Dresden
Phone +49 (0)351 260 2450
Email: c.bohnet@hzdr.de

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TRACE METALS

for Industry

HIGHTECH METALS ● facilitating the energy transition

RAW MATERIALS ● exploring domestic resource potential

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This tiny rock sample is composed of spherical crystals of copper arsenate on a fluorite cube. Scanning electron microscopy reveals exactly how these minerals are associated.

Scientists at Helmholtz Institute Freiberg for Resource Technology use the information they glean from this method to improve the mechanical processing of mineral and metallic raw materials.

Helmholtz Institute Freiberg for Resource Technology

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Chemnitzer Straße 40 | 09599 Freiberg