The **Spin Doctor**

This physicist changed our world: It was **Stuart Parkin**'s developments in spintronics that first made Facebook and Google possible, as well as many other computer applications without which our everyday lives are now barely conceivable. Parkin has been Director at the **Max Planck Institute of Microstructure Physics** in Halle for one year now. For his colleagues there, his energy is impressive and challenging in equal measure.

TEXT **PETER HERGERSBERG**

The profession of physicist isn't generally regarded as physical labor. Still, Stuart Parkin doesn't need sports for recreation – he's almost constantly in motion. Like when, in May 2014, the Technology Academy Finland awarded him the Millennium Technology Prize – the world's highest-endowed technology prize, worth one million euros – and Parkin gave a speech for the occasion. He impressed the audience not only with his innovations for memory storage technology, but also with the route he took to get on stage: ceaselessly taking a couple steps forward, a couple steps back, then a slight detour to the table with the water glass, and onward again.

His hands, too, are always in motion. Sometimes one hand is making drawings in the air of the layer materials he developed, sometimes the other hand uses sweeping gestures to point to an image in his slides or to a particularly important statement, and sometimes both hands appear to be pulling down on a non-existent rope. As spry as he is, the gaunt figure is no surprise – he could also pass for a long-distance runner.

When Parkin spoke in Helsinki, he had been Director at the Max Planck Institute of Microstructure Physics and a professor at Martin Luther University of Halle-Wittenberg for a good month. Today, he can already look back on numerous scientific and technological successes. It is thanks to his discoveries that we can now store ever increasing amounts of information in an ever smaller space. "This makes it possible for us to use Facebook and Google," says the physicist. "Big data, too, is possible only because we can now store large amounts of data on relatively cheap devices."

Before Parkin explains in greater detail what he contributed to today's high-performance computers, he briefly outlines his background and shows some photos of the most important stages: "As a child, I always wanted to go to Cambridge, because of Isaac Newton – you've probably heard of him," says the Brit, who was born in Watford,

Dynamic – this is one characteristic Max Planck Director Claudia Felser uses to describe her husband Stuart Parkin. Even for a photo shoot, he hardly stands still.

Lively: The Construction Commission discusses the progress of the remodeling of the lab and workspaces in Stuart Parkin's Department.

not far from London. "Newton was both a student and a fellow at Trinity College – as was I."

After that, Parkin worked at the Paris-Sud University on organic superconductors. These are carbon-based materials that conduct electricity without resistance. Initially, he continued this research in 1982, after relocating to IBM's Almaden Research Center in San José, California. Since then, he has not only been appointed to various honorary and visiting professorships, but also as a consulting professor at Stanford University and as an IBM Fellow.

And now Halle an der Saale. Before presenting a photo of the Max Planck Institute of Microstructure Physics, he shows one of himself with his then fiancée – now wife – who is almost completely hidden behind a lavish bouquet of various orange-colored blossoms: Claudia Felser, Director at the Max Planck Institute for the Chemical Physics of Solids. "We're both very interested in materials," says Parkin. "She's the reason I'm going to Germany."

This is not something to be taken for granted – Claudia Felser characterizes him with these words: "Stuart is energetic and dynamic, and his first priority is science." She has no problem with this – on the contrary: it simplifies a lot of things, as she is quite similar. The liaison was thus initially also a professional one before it became a private one. Claudia Felser researches magnetic materials that could be used for Stuart Parkin's developments in electronics, or more accurately, in spintronics.

THE SPIN VALVE AS A SENSITIVE MAGNETIC SENSOR

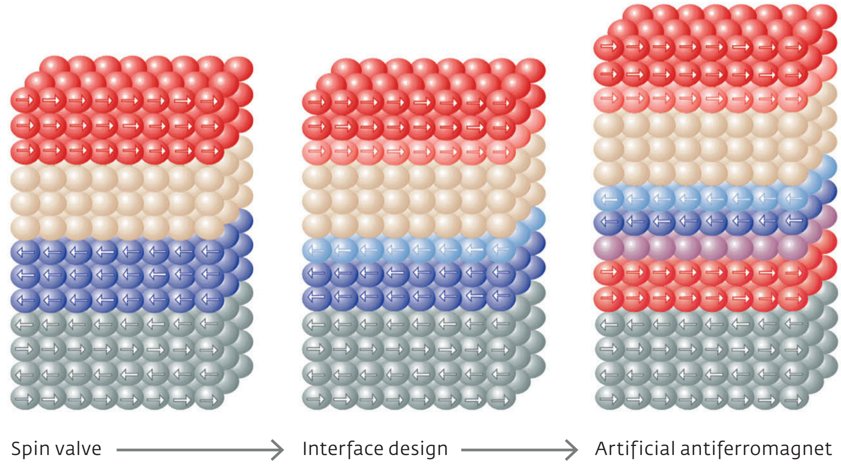
Spintronics takes advantage of not only the charge of electrons, but also their spin. The spin is a quantum mechanical property of electrons that turns each of these elementary particles into a tiny bar magnet. It can take on only two directions. In fact, it is due to the spins of countless electrons in a bar magnet – like those we know from physics lessons – that its ends can be only north or south poles. But the orientation of the spins also determines which data bit is stored in a magnetic islet that serves as the memory point on a hard drive.

Parkin is considered to be one of the pioneers of spintronics, not least due to what is perhaps his most relevant development to date: the spin valve, which is used in every hard drive today to read data.

In order to then also be able to decipher a data bit on a hard drive when the magnetic islands of individual memory points and thus their fields are extremely tiny, a particularly sensitive sensor is needed. This is precisely what the spin valve provides. The giant magnetoresistance that this magnetic sensor uses was discovered by Peter Grünberg and Albert Fert, who were awarded the Nobel Prize in Physics for it in 2007.

Grünberg and Fert noticed that the electrical resistance of sandwiches in which magnetic and non-magnetic materials are layered alternately drops dramatically when the sandwich is exposed to a strong magnetic field. "It wasn't immediately clear whether it

Photo: Sven Döring



Stacked: A spin valve consists of two magnetic cobalt layers (red and blue) and a non-magnetic copper layer (beige). An antiferromagnetic substrate (gray) serves to fix the polarity of the one cobalt layer. (The arrows symbolize the spin directions of the atoms.) But it is only through careful design of the interfaces (light red and light blue) and an artificial antiferromagnet that the spin valve becomes useful as the read head for hard drives. The artificial antiferromagnet is created by feeding one or two atomic layers of ruthenium (pink) into the bottom cobalt layer. The artificial antiferromagnet prevents antiferromagnetic coupling with the top cobalt layer.

Graphic: Parkin et al., Phys. Rev. Lett. (1990), Phys. Rev. B (1991) Parkin, US Patent (1993)

would be possible to use the effect in technology," says Parkin.

Grünberg and Fert first observed giant magnetoresistance only in a layered material of iron and chrome that they produced using a rather exotic and elaborate technique. Moreover, the resistance changed most dramatically at low temperatures and very high magnetic fields. Thus, the phenomenon wasn't yet suitable for practical application. "The suggestions Peter Grünberg and Albert Fert made for a read head didn't work," says Parkin. He stepped up to change that.

In his lab at IBM's Almaden Research Center in San José, he discovered that the effect also occurs in other metal compositions, for instance in sandwiches composed of cobalt and copper. And that this was also true if the metals are produced using the more practical technique of sputter deposition. This discovery was spawned by necessity: "When I was there, IBM built an expensive molecular beam epitaxy facility like the one Grünberg and Fert used," says the physicist. "But the facility came with a new colleague, and then that was his equipment, so for me there was only enough money left for a small sputter system."

Of course sputter deposition doesn't create such beautiful crystalline structures, but that doesn't diminish the effect at all. And above all, this method is suitable for mass production of layer materials because it's much faster and it's very easy to layer different materials on top of one another.

But that was just one of the discoveries that helped put giant magnetoresistance in today's hard drives. Since the material sandwiches could now be produced so easily, Parkin tested all possible material combinations. And lo and behold, with a combination of cobalt and copper instead of iron and chrome, the effect also occurs at room temperature – a mandatory requirement for use in PCs.

95 PERCENT OF THE WORLD'S KNOWLEDGE IS STORED DIGITALLY

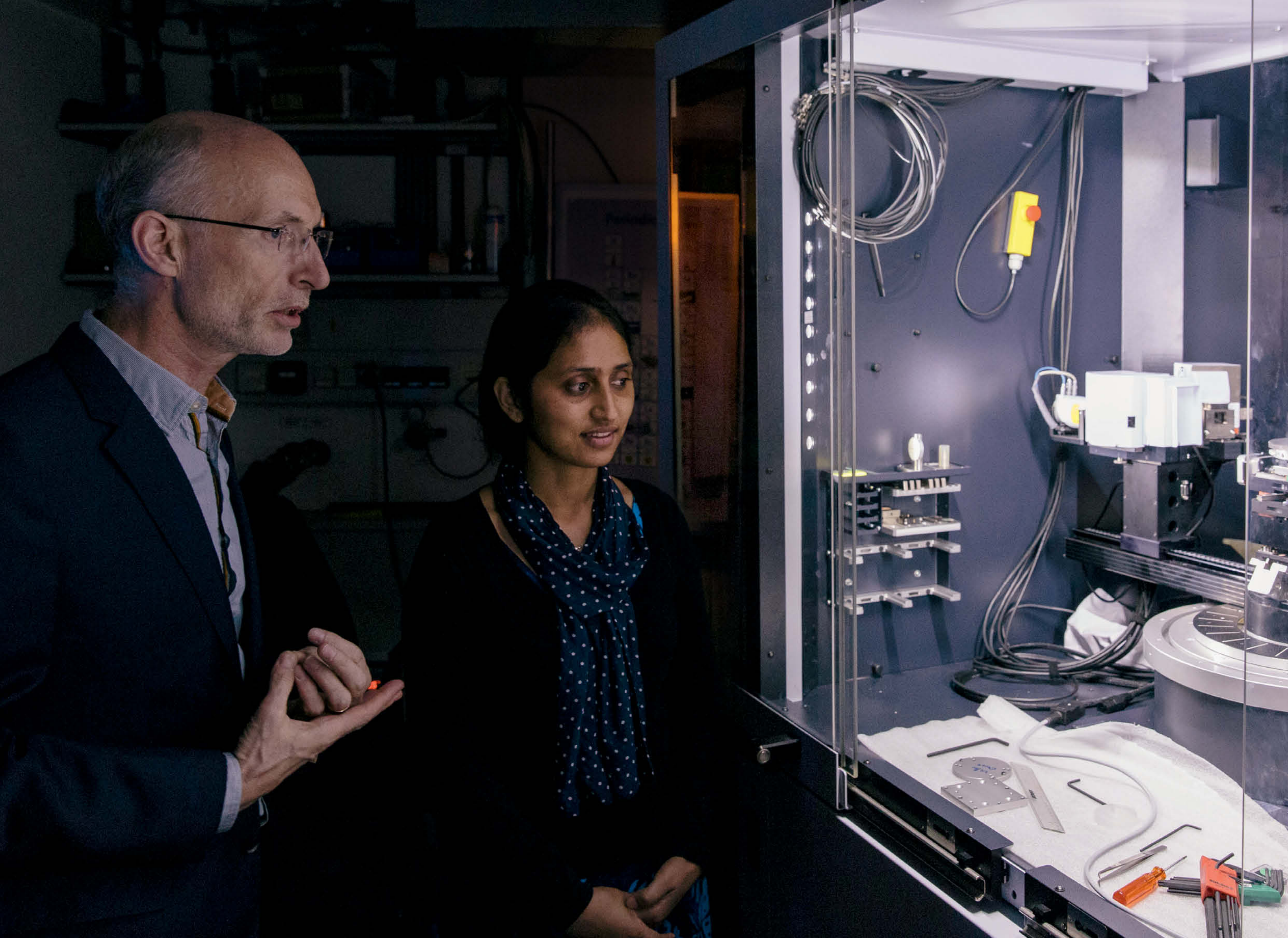
In addition, Parkin downsized the stack of numerous alternating magnetic and non-magnetic layers to a sandwich comprising just two magnetic cobalt layers and a non-magnetic copper layer. This is what led him to the spin valve. Although its resistance doesn't change as much in a magnetic field as a stack of many layers, this is compensated for by the fact that it changes even in magnetic fields 10,000 times weaker than those that Grünberg and Fert had to apply.

But even in this form, the spin valve still isn't suitable as the read head of a hard drive. In a spin valve that is small enough to scan the tiny memory points on a hard drive, the magnetic layers are so sensitive to each other that, again, they react only to very large external magnetic fields. The magnetic islands on a hard drive can't make a mark here. But Parkin discovered further idiosyncrasies in the interaction between magnetic and non-magnetic layers with a thickness of just a few atomic layers. Using these effects, it is possible to sensitize even an atomically thin spin valve to tiny magnetic fields. And it's far from trivial that giant magnetoresistance is effected at the interfaces between the magnetic and non-magnetic layers of the material and not in the interior of the layers.

"So I made the discoveries that make giant magnetoresistance useful," says Parkin confidently. "Our spin valve reacts to such weak magnetic fields that the magnetic regions on a hard drive could be made 1,000 times smaller." It is due in no small part to the fact that this increased storage density considerably that 95 percent of the world's knowledge today is stored digitally. Twenty years ago, it wasn't even 5 percent.

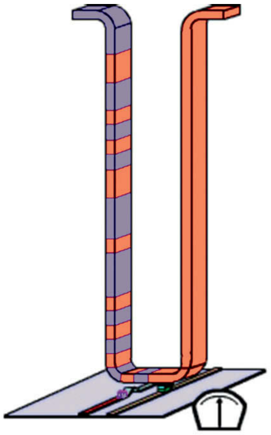
But that's still not enough for Stuart Parkin. During the past several years, he was already working at IBM on the next innovations, not only for increasing storage density, but also for making the information more quickly accessible than is the case with today's hard drives.

That is the aim of so-called racetrack memory. With this, a read head no longer speeds across the magnetic memory points. Instead, the magnetic regions



Above: Stuart Parkin and Kumari Gaurav Rana discuss analyses obtained from an X-ray diffractometer. This instrument can be used to analyze the detailed structure of material layers such as those that Stuart Parkin will also be researching in Halle.

Below: In racetrack memory, short current surges push magnetic regions (red and blue zones) through a nanowire to a read head at a fixed location. Since this memory principle requires no moving mechanical parts, it permits faster data readout.



move at speeds of several hundred meters per second through nanowires to a fixed read head. Since there are no longer any moving mechanics, in terms of speed, racetrack memory would beat today's hard drives by a long shot. However, there are still too many defective components being produced today in the manufacture of these delicate magnetic structures. "But all the major computer companies are working on this type of memory," says Stuart Parkin. They could be ready for market in a few years.

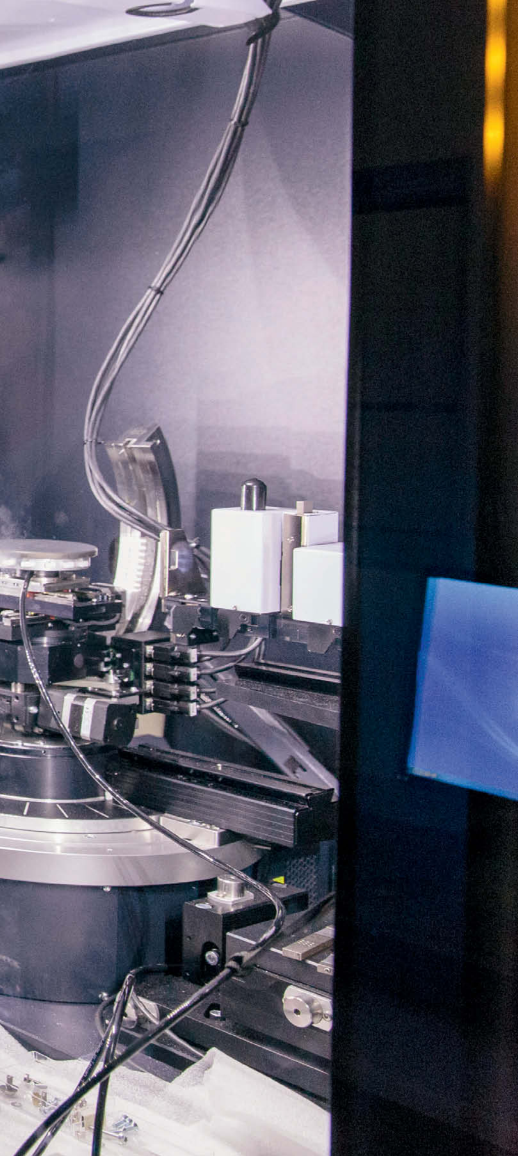
In Halle, Parkin will continue to pursue some of the latest concepts that he already developed while at IBM, but there will be room to develop new ideas, too. He brings the spirit of Silicon Valley to Saxony-Anhalt, says Claudia Felser. But nearly one year later, this inventive spirit is still commuting back and forth between San José and Halle approximately every two weeks. And you can tell that from looking at him this morning, after his return the previous day. "Nice to see you," he says by way of greeting, and adds, with a mixture of impatience and openness: "What are we doing now?"

"IF A PAINTING APPEALS TO ME, I BUY IT"

At this point, he has no time to chat. He hurries to his office; he has various meetings scheduled for this morning, some of which were arranged spontaneously, disrupting his original schedule.

Parkin's office is dominated by a conference table that seats ten. In the background stands a desk, next to which hangs a poster-sized painting of a Buddha's face. He likes art, but has no preference for a specific artist or epoch. "When I see a painting that appeals to me, I buy it," he says. That's why he sometimes takes advantage of his conference trips throughout the world to visit galleries.

Photo: Sven Döring; graphic: Stuart Parkin



Even if he already has a painting to adorn his office in Halle, he can't conduct his research here yet. Various modifications and new construction, as well as some renovations, must be completed first in order to equip the lab in Parkin's Department to meet his expectations. The Construction Commission is meeting to discuss the current planning status. It quickly becomes clear that they're pretty far behind schedule. Parkin is sorry to hear this and says: "I want to start now!" But many building measures can't be carried out as originally planned. In addition, new requirements have been added. With their combined English skills, the construction experts try to explain the problems to Parkin.

Parkin sits up very straight, elbows resting on the table, his ankles crossed under his chair. One foot bounces with a frequency approaching a CPU clock speed. A long time is spent discussing a new water supply, as the cooling water for experiments with magnetic materials can't be contaminated with iron.

Stuart Parkin is becoming familiar with German fire safety regulations and local construction law. When the discussion turns to getting a construction permit from the City of Halle, he interjects jokingly: That won't be a problem, he met the mayor yesterday, he'll take care of that. But of course he knows it's not that simple. For someone who really wants nothing more than to pursue his research ideas, that must be annoying. "But if that's how the rules are, you just have to accept it," he says after the meeting. As high as his standards are for his lab facilities, and as much as he would like to have his department completely set up already, he is also pragmatic.

And when the initial difficulties have been overcome, it should be possible to conduct research with even greater freedom at a Max Planck Institute than in the company lab. "At IBM, you get promoted from one day to the next, and in order to hire additional doctoral students or postdocs, you need funding from other sources that are becoming increasingly difficult to access," he says. "At the Max Planck Institute, I can employ more scientists and engage in more projects." Moreover, the Max Planck Society offers funding and freedom for long-term projects.

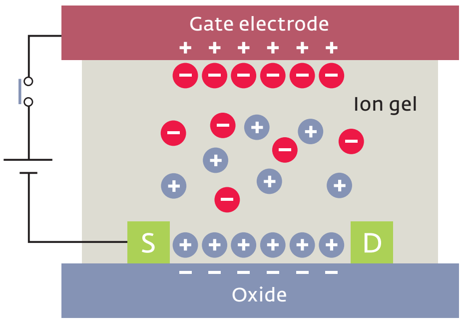
After the Construction Commission has headed home again, taking many unresolved questions with it, it's time for a photo shoot. When Parkin steps out of his office into the institute foyer, he points to the plain gray interior with hanging steel lamps of the same color: "Isn't it ugly?" When no answer is immediately forthcoming, he provides it himself and proclaims, laughing, that he will change a few things here, too. As one who appreciates art, he has high standards for his working environment, not only in terms of practicality, but also with regard to his personal sense of aesthetics.

After a few more meetings in late afternoon, it's time for the conversation for this article. Parkin is supposed to talk about the motivation for his tireless research activities, explain a few more details about his previous work, and outline what his plans are for his new research facility. And because the photographer still doesn't have enough photos, the interview takes place while we take a walk to the river Saale, which runs near the institute.

"THE DETERIORATION IS WHAT GIVES HALLE ITS CHARM"

"Wow, isn't it beautiful here!" Parkin exclaims repeatedly on the walk across Peißnitz Island. And he becomes even more enthusiastic when he realizes that he will cross this park when he makes his way from his future home to the institute on foot or by bicycle. The house he and Claudia Felser are building will be just three kilometers away, on the bank of the Saale. "We agreed that Claudia would move from Dresden to Halle if I come all the way here from California," he says in response to the question of whether Dresden wouldn't also have been an attractive place for the scientist couple to live. But as this walk showed, if it wasn't clear before, Halle, too, has some highly appealing aspects.

During the walk along the Saale, Parkin is particularly taken with the café in Peißnitzhaus, which also lures visitors on this mild April day with a beer garden. Like many of the older buildings in Halle, this small castle, built in the late 19th century, has acquired a patina. That's what Parkin likes: "The certain degree of deterioration one sees here is what gives Halle its charm, I think." >



Information processing like in the human brain: In a transistor that, like neurons, is switched using ions, a small voltage applied to the gate electrode causes ions from an ion gel to be deposited on the gate electrode and on an oxide layer lying opposite. Oxide ions are then released from the oxide, making this layer conductive and allowing a current to flow between the source (S) and drain (D) electrodes.

But as appealing as Halle is, that is, of course, not the reason why he's coming here. Here, he finds the conditions he needs to pursue his many ideas, and not only in spintronics. He wants to develop computers that compute in a similar way to how we think. And that means, above all, as energy efficiently. "The brain of a rat works about as quickly and with the same memory capacity as the supercomputer Blue Gene/L, but needs only one ten-millionth of the energy."

This efficiency can't be achieved with either conventional electronics or spintronics. The former always operates with losses that drive up the power demand. The latter is even more inefficient, since the spin currents used here first have to be produced from charge currents. Furthermore, there is, as yet, no functioning concept for not only storing, but also processing information in the form of electronic spins.

So Parkin wants to do it in a manner similar to human neurons, which exchange information by taking up and releasing ions. And he already has a concept for doing this, which he developed with some preliminary work at IBM. He found a way to charge an electrical insulator with ions from an ionic liquid, thus switching it, or in other words, bringing it from an electrically insulating state to a conductive one. "We noticed that we need only tiny amounts of ions for this," he explains. So such a transistor would work much more efficiently than those currently in use. Today, the smallest computing elements of a processor operate in that electrons are pumped into or suctioned out of a semiconductor. That costs more energy than directing a relatively small amount of ions on a surface.

ON VACATION, WORK WILL BE DONE ONLY DURING THE DAY

"We're still at the very beginning with these liquid electronics," says the scientist. Particularly for these kinds of projects, which still have a long way to go before they can be used in applications, IBM lacks the patience. To come up with such a fundamentally new approach to new computer technology, Parkin and his staff must, of course, constantly search for radically new physical effects. However, Parkin isn't interested in these effects for their own sake. "The principles are interesting, but for me, it's important that they offer a potential application in the long run."

Thus, in Halle, he wants to prepare the way for computers to one day be capable of computing as energy efficiently as the brain of a human or a rat. The fact that the 60-year-old will soon reach the retirement age of an ordinary employee should present no obstacle. His contract in Halle already runs until he turns 70, and there is an option for him to renew until the age of 75. In any case, it's difficult to imagine him retiring – he already has a hard enough time taking a vacation. Therefore, for their honeymoon, which he and his wife plan to spend in Scotland, the couple agreed on a compromise: they will work during the day and take the evenings off.

Part-time vacation – Claudia Felser calls it a nano-honeymoon – seems to be the best solution, following their initial experiences with short getaways. As she explains, they stopped in the Fiji Islands for two days on their way from a conference in the US to a conference in Australia. "When we weren't able to depart after the second day, he got so jittery that he could hardly manage the third day." ◂

GLOSSARY

Big data: Thanks to digital technologies, today it is possible to record and process far larger amounts of data than just 20 years ago. This facilitates new approaches in science, but it is also exploited in business and by secret services.

Molecular beam epitaxy: This method also makes it possible to produce very thin layers, albeit in the form of a single crystal. For this, a substance is evaporated and applied to a substrate in the form of a directed beam. This method is slow and requires a very high vacuum.

Sputter deposition: A method for producing thin material layers. For this, a beam of charged noble gas atoms is used to knock atoms out of a material. These atoms are then deposited in individual layers on a substrate. This method produces thin layers faster than molecular beam epitaxy and doesn't require as high a vacuum, making it more versatile and suitable for mass production.

Graphic: Stuart Parkin