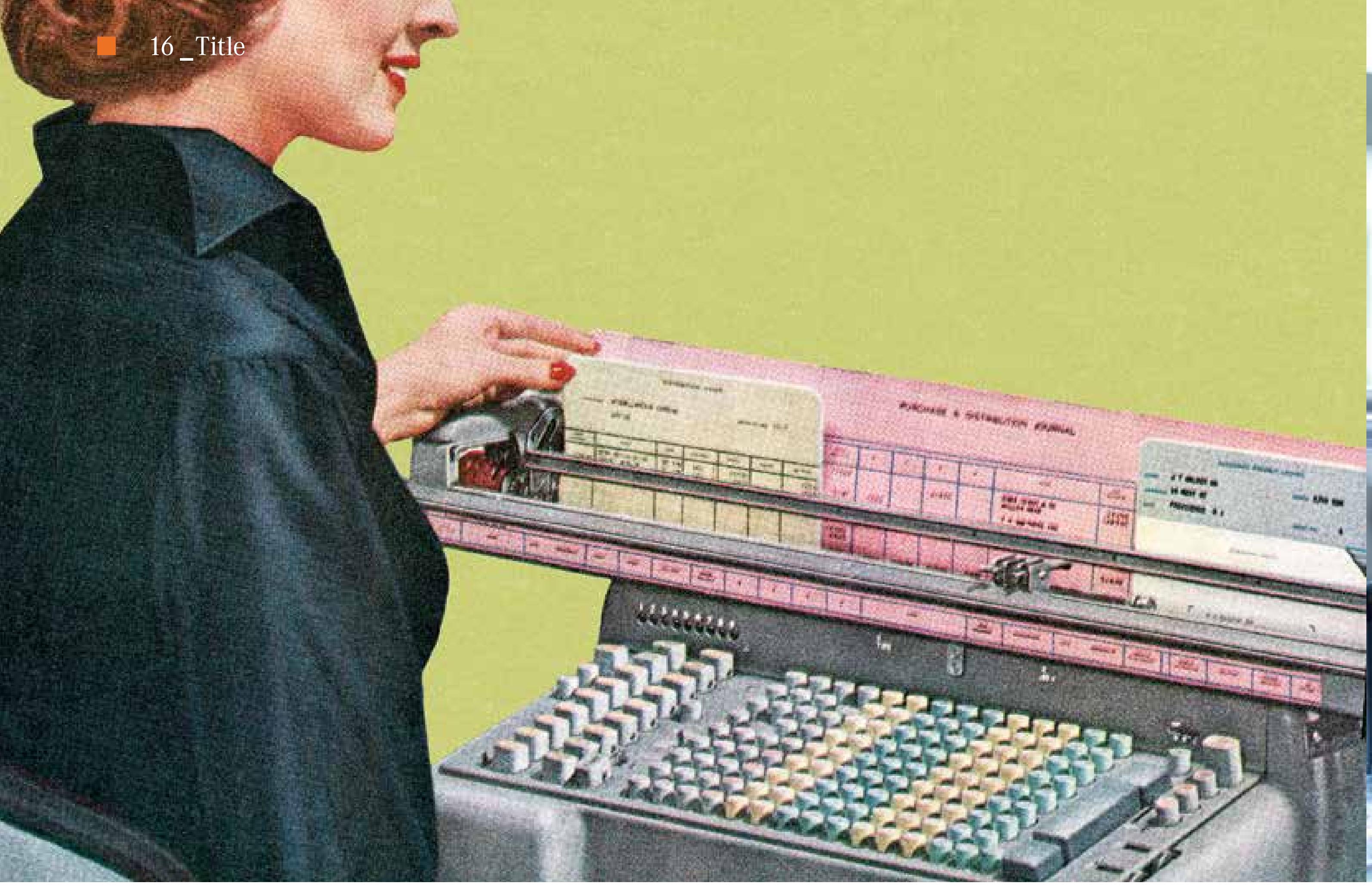


Since the inception of mechanical data storage – originally still using punch cards – storage technologies have downsized rapidly. Today, researchers like Miriam Lenz work on magnetic nanostructures in thin-film systems. Source: istock.com, CSA Images, Color Printstock Collection (left) / A. Wirsig (right)

From nanomagnets to storage giants

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

_Text . Kai Dürfeld

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

“Since 1956, the storage density of hard disks has grown by nine orders of magnitude,” says Olav Hellwig. “On the same surface you can now fit a billion times more data.” Hellwig is a physicist, head of HZDR’s research group on Magnetic Functional Materials and holder of a professorship of the same topic at Chemnitz University of Technology. “By optimizing traditional hard-disk technologies, we might be able to increase storage density by another order of magnitude. Then the magnetic units will be so small that they simply won’t be stable at room temperature even if we use the hardest magnets known to man.”

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

Nano format magnetic islands

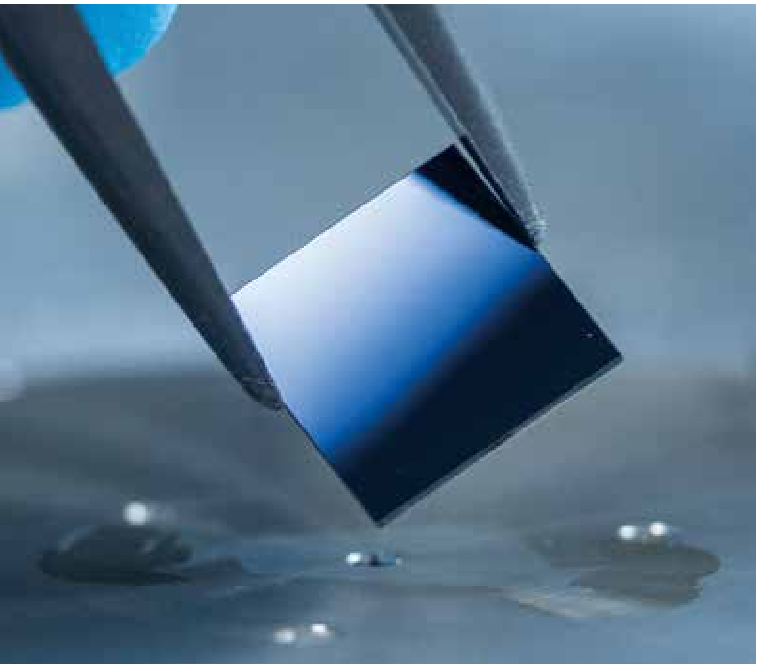
Standardized size, huge storage capacity, unbeatable price: since the first hard disk saw the light of day, they have become the backbone of modern IT systems. Inside are rotating platters made of inert material with a wafer-thin coating of cobalt, chromium and platinum. A read-and-write head hovers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

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

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

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

›



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

How can the hunger for energy be abated?

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

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

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

From short-term to long-term memory

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

A combination of both technologies with their respective benefits would be an enormous step. And it has actually been taken already. Magnetoresistive random access memory, MRAM for short, is a technology that does not store data electrically, but magnetically, also drawing on spin-polarized currents. MRAM modules can be written on and deleted any number of times and are just as fast as modern RAMs without being volatile. In the layered storage modules, magnetic films just a few nanometers thick alternate with even thinner, non-magnetic layers. MRAM modules are already on the market, but their applications are limited due to their high price. They can be found, for example, in aerospace, as data buffers in server systems and industrial plants, where the loss of data caused by a power cut is more serious than the extra expense of the memories.

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

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

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

Publications:

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

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

Contact

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