Spintronic magnetic memory devices

Tomáš Jungwirth
Institute of Physics, Czech Academy of Sciences and University of Nottingham, United Kingdom
* jungw@fzu.cz

Recording technologies come and go, but magnetic recording is a keeper. The magnetic wire recorder was conceived in 1878, a year after Thomas Edison's invention of the phonograph, and was realized two decades later. It evolved into the tape recorder and hard disk drive. It also led to magnetic core memory, whose run as the main type of random access storage lasted from the mid 1950s to the mid 1970s and whose resistance to radiation damage made it vital for space exploration and the shuttle program. All those devices relied on 19th-century physics: Maxwell's equations.

Nowadays magnetic recording enables an hour of video to be uploaded onto the internet every second of every day, and few of us worry about the physical limits of data storage. In the lecture we will discuss how for today's magnetic recording needs, 20th-century spintronics is essential. It helps readout in a decisive way via giant magnetoresistance and tunneling magnetoresistance spin-dependent phenomena found in structures of alternating ferromagnetic and nonmagnetic conducting or insulating layers. Thanks to those phenomena, read heads are more sensitive and more information can be packed onto hard drives. They also paved the way for a transition from solid state core memories with macroscopic magnetic bits to microelectronic magnetic random access memory (MRAM) chips. For writing, hard drives and first-generation commercial MRAMs still rely on 19th-century physics involving the coupling between an electromagnet used for writing and a permanent magnet that provides storage. Revisiting the means of writing magnetic information on MRAMs had to wait for the 21st century, when researchers began to explore the possibility of using a scalable spintronic approach rather than relying on an external magnetic field. While some variants of this approach have already made it to the second-generation MRAMs, others are a subject of current frontier spintronics research. Latest scientific developments in this area include the utility of relativistic spin-orbit coupling phenomena and the materials basis has expanded from ferromagnets to include also antiferromagnets. As a result, terahertz writing speeds have been experimentally demonstrated and magnetic memories are now also considered as building blocks of artificial neural networks.

Lecture topics:

1. Magnetic recording overview
2. Anisotropic and giant magnetoresistance readout
    a. Hard-drive
    b. Magnetic random access memory
3. Spin-torque writing
    a. Spin-transfer-torque MRAM
    b. Spin-orbit-torque MRAM
4. Advanced spintronics concepts
    a. Ultra-fast devices
    b. Neuromorphics

Recommended reading:

[1] Chappert, Claude, A. Fert, and Frederic Nguyen Van Dau (2007), “The emergence of spin electronics in data storage.” Nature Materials 6 (11), 813–23.

[2] Kent, Andrew D, and Daniel C Worledge (2015), “A new spin on magnetic memories,” Nature Nanotechnology 10 (3), 187–191.

[3] Sinova, Jairo, and Tomas Jungwirth (2017), “Surprises from the spin Hall effect,” Physics Today 70, 38.