Current-Driven Magnetic Domain Wall Motion in Nanowires

A Step Toward Magnetic Data Storage without Rotating Disk

MSD researcher Peter Fischer (Center for X-ray Optics), in collaboration with Guido Meier (University of Hamburg, Germany) and Dong-Hyun Kim (Chungbuk University, Korea), has used the CXRO x-ray microscope XM-1 at the Advanced Light Source to demonstrate that magnetic domain walls in nanowires can be moved at high speed by injecting nanosecond pulses of spin-polarized currents into the wires. This discovery could have a significant impact on the development of novel magnetic storage devices in which data is moved electronically rather than mechanically as it is in today's computer disk drives. The technique also provides an accurate experimental tool for testing theoretical models of current-induced phenomena in magnetic materials at the nanoscale.

The quest to increase both computer data storage density and the read/write speed continues unabated. One novel concept involves the use of a local electric current to move information–carrying magnetic domain walls along a thin nanowire. The physical effect is based on the fact that a "spin torque" is exerted on the magnetic moments in the wire by the spin-polarized electrons of the applied current. This torque rotates the moments so that the domain walls move. In contrast to today's magnetic hard drives in which a disk spins to bring the data to the fixed readhead, here the current would move the domain walls (which represent the bits) electronically to the head.

This "racetrack memory," patented in 2004 by Stuart Parkin (IBM Almaden) would combine the advantages of solid-state and magnetic memory devices. However, before devices using the concept can be produced, a better understanding of the physics involved (including how to boost the readout speed) is required. These recent results from Fischer and his colleagues have yielded important insights into the fundamental processes of spin-torque-driven motion of domain walls in curved ferromagnetic permalloy ($Ni_{80}Fe_{20}$) wires, a widely used material in disk drives.

In their experiments, high current density pulses of nanosecond duration were injected to drive the motion of a single domain wall along the nanowire. Polarized x-ray images taken with XM-1 before and after the current pulse was injected, allowed the researchers to track the movement of the domain wall with 25-nanometer spatial resolution. The results showed that the magnetic domain walls moved at 110 meters per second, 100 times faster than earlier reported, and in accord with theory.

Although this is encouraging news for technological development, repetitive pulse experiments showed that many of the pulses gave slower speeds or no movement at all. This suggests that the current-driven motion follows a statistical distribution comparable to the so-called "Barkhausen jumps" seen when domain motion is driven by an applied magnetic field. Since domain-wall pinning associated with disorder plays a significant role in magnetic field driven motion, one can assume a similar mechanism in the case of current-driven motion. It is believed that the shorter pulses reduce the chances that a wall would be pinned by imperfections in the crystalline structure, thereby explaining the faster speeds. However, the random nature of the domain wall jumps makes reliable reading and writing a challenge. This might be minimized by controlling the preparation of the materials to minimize the effect of inhibiting defects (perhaps by changing the wire geometry).

The ability to characterize the dynamics of this system through high-resolution soft x-ray microscopy–with a 10-nm spatial resolution, ultrafast time resolution in the femtosecond regime and sufficient intensity for snapshot imaging–will be a powerful analytical tool to study the effect and allow accurate testing of theoretical models.

P. Fischer (510-486-7052), Center for X-ray Optics, Materials Sciences Division (510-486-4755), Berkeley Lab.

Guido Meier, Markus Bolte, René Eiselt, Benjamin Krüger, Dong-Hyun Kim, and Peter Fischer, "Direct Imaging of Stochastic Domain-Wall Motion Driven by Nanosecond Current Pulses", *Phys. Rev. Lett.* **98**, 187202 (2007

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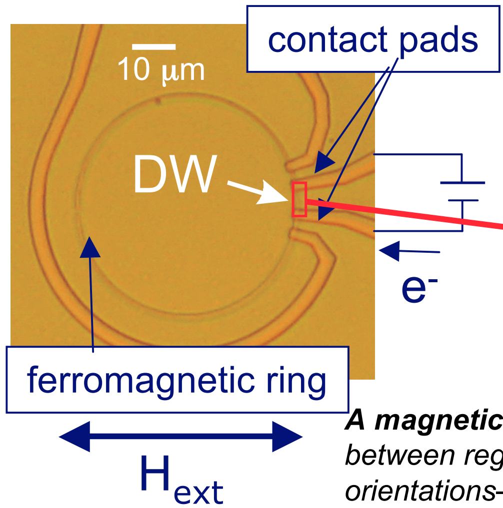
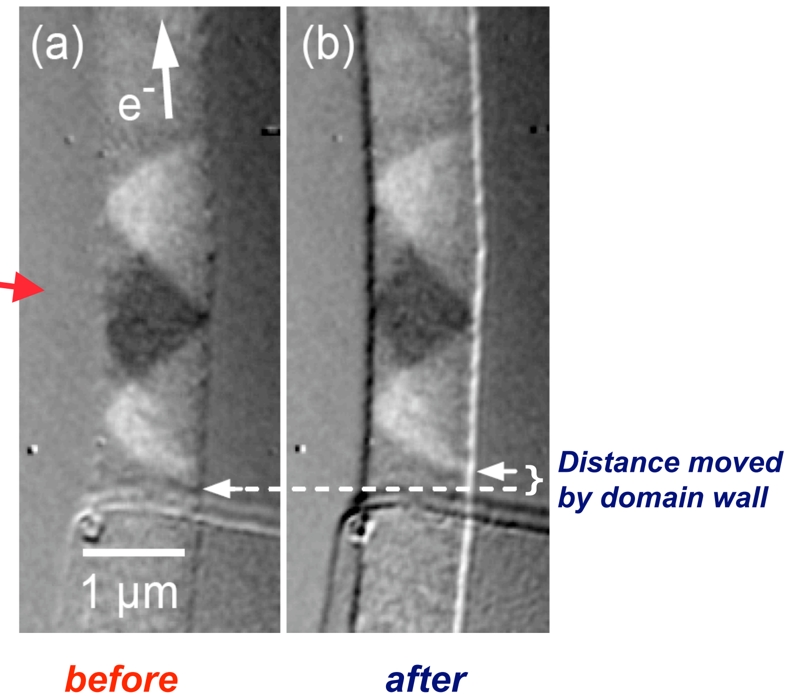
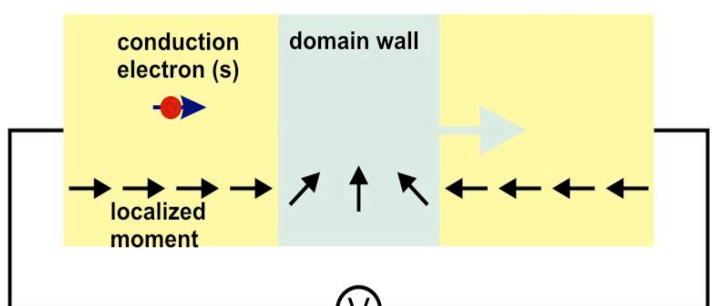


***A magnetic domain wall** (DW)—the boundary between regions of different magnetic orientations—is created in a 20nm x 1000nm ferromagnetic permalloy ($Ni_{80}Fe_{20}$) ring through the application of a magnetic field (H_{ext}) between two contact pads. One nanosecond short pulses are injected into the ring to move the DW.*



***Magnetic soft x-ray microscopy** using the CXRO XM-1 x-ray microscope allows the imaging of domain wall motion with a spatial resolution as high as 15 nm. Images captured before (a) and after (b) the current pulse injection are used the measure the speed of the motion, which was 110m/s, in agreement with theoretical estimates.*



***A "spin torque"** exerted by the current pulse pushes the domain wall along the wire.*

P. Fischer (CXRO, ALS) 07-2