

Electric field trapping of a magnetic domain wall

In spintronics applications such as magnetic memories, information is written to and read from magnetic metals using electric currents. In contrast, electric fields, used extensively to control the state of semiconductor transistors, have not yet been exploited in spintronics despite the lower power consumption expected as compared to current-based devices. We have made an important step in this direction with the demonstration of electric-field control of magnetization.

Until recently, the influence of an electric field on magnetic properties was considered negligible in ferromagnetic metals. Indeed, an electric field cannot penetrate into a metal as it is screened at the surface by charges that accumulate on the topmost few atomic layers. However, in the case of an ultra-thin film of 1 nm thickness or less, this surface charge can influence the properties of the whole film.

At Institut NEEL, in collaboration with Spintec Laboratory (Grenoble), we have realized an ultra-thin, 0.6 nm film of the magnetic metal cobalt, which is sandwiched between a layer of the nonmagnetic metal platinum and a dielectric layer of alumina (Al_2O_3). The ultra-thin magnetic film, only a few atoms thick, possesses a strong magnetic anisotropy: it is energetically more favorable for the magnetization to align perpendicular to the plane than in the plane.

We have carried out the following experiment: the magnetization of the sample is visualized with a microscope in polarized light (Kerr microscopy). We obtain grey-contrast images where bright regions correspond to magnetization directed down and dark regions to magnetization directed up. We apply an electric field using a patterned electrode made of a transparent material (Indium Tin Oxide ITO), see (Fig.1(a)), which allows us to visualize the magnetization under the electrode. Reversal of the magnetization is investigated thus: Initially we apply a magnetic field to magnetize the sample in one direction, then we reverse the magnetic field and record images of the magnetization reversal as a function of time. The following reversal process is observed in the cobalt layer.

A small region with opposite magnetization is first created near a defect (nucleation) and this region then grows.

Our sample can therefore present a region with "up" magnetization and another with "down" magnetization. The frontier between those two regions is called a magnetic domain wall and within the wall the magnetisation rotates progressively to minimize the energy Fig. (1a). We have demonstrated that when the electric field is switched on, the domain wall is pinned when it reaches the edge of the electrode leaving the magnetization unreversed below the electrode while the rest of the sample is reversed, see Fig. 1(a), and Fig. 1(b) at times t_1 - t_4 . When the electrode voltage is switched off the domain wall is released and the magnetization reverses everywhere (Fig. 1(b) t_5 - t_6).

What is the origin of this domain wall trapping? The magnetization is the sum of the cobalt atom spins, aligned parallel to each other. Below the ITO electrode, the electron clouds of the interfacial cobalt atoms are deformed by the electric field. This deformation affects the magnetic properties: the magnetic anisotropy (the energy barrier to reversal of the magnetization) is enhanced. The movement of domain walls becomes more difficult in the high anisotropy region below the electrode and a domain wall arriving from outside the electrode is blocked at the edge of the electrode.

This demonstration opens the way to controlled domain-wall propagation, which is required for the development of domain-wall based magnetic logic or magnetic memory components, such as domain wall based Magnetic Random Access Memories.

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FURTHER READING

ELECTRIC-FIELD CONTROL OF DOMAIN WALL NUCLEATION AND PINNING IN A METALLIC FERROMAGNET
A. Bernard-Mantel et al.
Appl. Phys. Lett. 102, 122406 (2013)

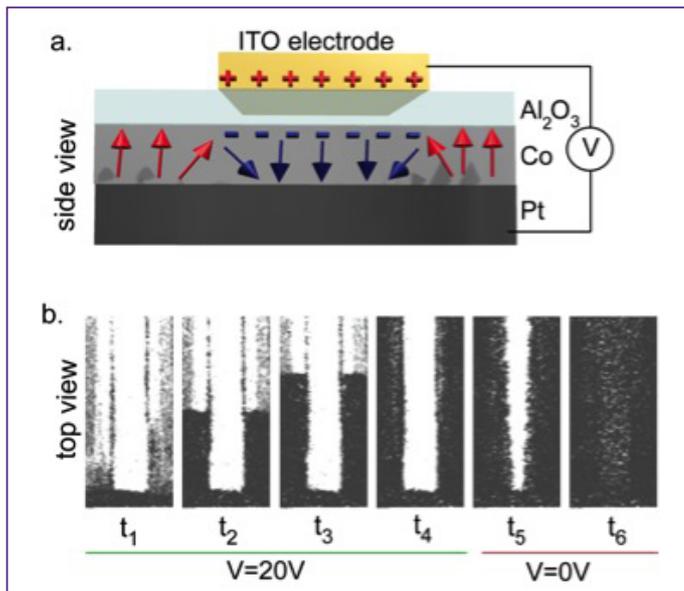


Fig. 1(a): Side view of the Platinum/ 0.6 nm Cobalt/ Al_2O_3 layer structure under a transparent Indium Tin Oxide electrode.

Fig. 1(b): Top view of the structure : Kerr reflection microscopy images recorded as a function of time in an applied magnetic field which is reversing the magnetization in the cobalt layer from "down" (white) to "up" (black). While the electric field is held on (times t_1 to t_4), the region below the electrode stays magnetized "down" (white) because the electric field blocks the domain-wall propagation. When the electric field is switched off the domain wall is released and the magnetization is reversed over the whole area (times t_5 to t_6).