Chiral domain walls in thin magnetic films

Magnetic domain walls are the transition regions between two magnetic domains with different magnetization directions. In ultra-thin films of a magnetic metal such as cobalt, having magnetization perpendicular to the film plane, the domain walls can be very narrow: 5 - 20 nm. Such domain walls can be moved at speeds faster than 400 m/s by in-plane current pulses and could be used as carriers of binary information in future high-density magnetic storage devices. These high speeds are possible because the magnetic configuration within the domain walls has definite "chirality": the magnetization rotates in the same direction in every wall in the cobalt layer.

The first observations of high-speed domain wall movement driven by an electrical current were made by Spintec Laboratory, Grenoble, in collaboration with the Institut NÉEL. This was in 0.6 nm (2 - 3 atomic layers) cobalt films sandwiched between a thicker layer of the non-magnetic metal platinum and an insulating layer of aluminium oxide (AlO_x). Following that discovery, it was proposed (Thiaville *et al.* EPL 2012) that two effects induced by the Pt/Co interface could explain such high propagation speeds.

First, the combination of a strong spin-orbit interaction in platinum and the breaking of the structural inversion symmetry by the interfaces can lead to a type of exchange interaction, called the Dzyaloshinskii-Moriya (DM) interaction, that favours a tilted alignment between neighbouring Co spins. This interaction can lead to domain walls where the magnetization rotates progressively in a plane perpendicular to the wall (see Fig. 1). This type of domain wall is well known (such walls are called Néel domain walls after Louis Néel) but in this system they have a special property: the sense of rotation is not random but is imposed by the sign of the DM exchange interaction, and is the same for all domain walls in the Co film. Hence the label "chiral domain walls".

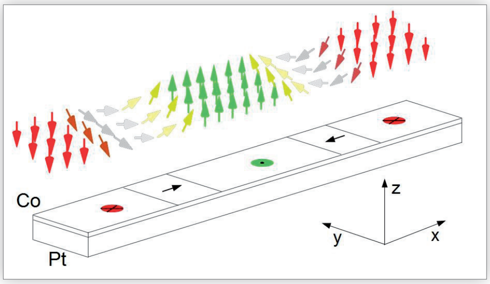

Fig. 1: *Two Néel domain walls with fixed left-handed chirality in a thin Co layer having perpendicular magnetization along z. The magnetization rotates to the left (anticlockwise around y) in both walls. Thus, the mean magnetization has opposite directions along x in the two successive domain walls.*

In this scenario, the second ingredient needed for efficient wall motion is a phenomenon called the Spin Hall effect that produces a spin-polarized electron current flowing from the Pt to the Co layer when an electrical current passes through the Pt layer. This spin current flow generates a strong torque that moves all the chiral walls *in the same direction* through the cobalt layer.

Fig. 1 illustrates the expected magnetization configuration of Néel walls with left-handed chirality. Notice in particular that the magnetization direction at the center of each domain wall is horizontal and opposite within the two, consecutive walls that separate down/up and up/down domains. We can make use of this property to prove that the domain walls are indeed chiral, by applying an in-plane magnetic field B_x: the energy of these walls will differ according to whether their mean magnetization is parallel or anti-parallel to B_x.

Fig. 2 shows images we have obtained using Kerr microscopy (magnetic microscopy with polarized light) for a rectangular $Pt/Co/AlO_x$ microstructure. The magnetization of the cobalt is first saturated in the up direction. A magnetic field pulse is then applied in the down direction. With zero in-plane field (Fig. 2a), reversal of the cobalt's magnetization starts at a defect in the centre of the film. However, in the presence of an in-plane field B_x, nucleation starts either at the left edge (Fig. 2b) or at the right edge (Fig. 2c) of the structure, depending on the direction of B_x.

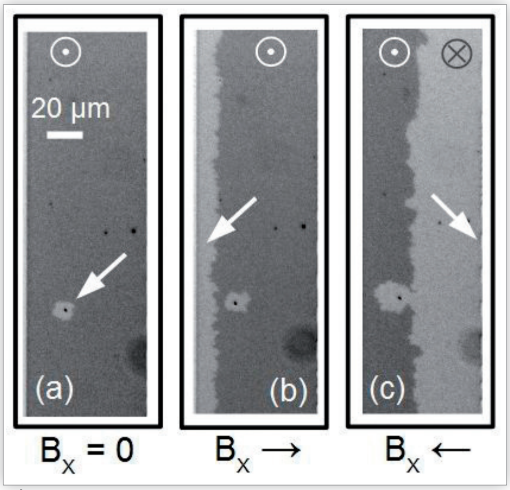

Fig. 2: *Kerr-microscopy demonstration of the left-handed chiral nature of Néel domain walls in a $Pt/Co(0.6nm)/AlO_x$ microstructure. A small, perpendicular, magnetic field pulse B_z is applied in the down direction to a layer that had been initially magnetized in the up direction (dark grey). In* ***(a)****, with no in-plane field (B_x), a small domain with down magnetization (light grey) nucleates at a defect. With an in-plane field 260 mT directed right in* ***(b)****, or left in* ***(c)****, magnetization reversal starts along the left or right edge respectively, and spreads rapidly.*

These results confirm the presence of chiral Néel domain walls. By geometry, chiral walls created on the opposite edges have opposite in-plane magnetization (see Fig. 1). The nucleation takes place at the side where the domain wall's energy is lower, *i.e.* where its mean magnetization is parallel to B_x. A left-handed chirality (like in Fig. 1) can then be deduced from our measurements for the domains walls in the Pt/Co system.

The perpendicular field needed for nucleating an edge domain, *i.e.* to trigger reversal of the magnetization, depends strongly on the strength of B_x. By modelling this dependence we could obtain the strength of the Dzyaloshinskii-Moriya interaction in this system, which is D = 2.2 mJ/m^2. This is a high value and leads to a high stability of the domain walls in Pt/Co heterostructures, which is essential for high velocity propagation, making them a promising system for binary storage applications.

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FURTHER READING

"Chirality-induced asymmetric magnetic nucleation in $Pt/Co/AlO_x$ ultrathin microstructures"

S. Pizzini, J. Vogel, S. Rohart, L. Buda-Prejbeanu, E. Jué, O. Boulle, I.M. Miron, C.K. Safeer, S. Auffret, G. Gaudin, A. Thiaville

Phys. Rev. Lett. 113, 047203 (2014).