XMCD-PEEM magnetic imaging beyond domains: internal degree of freedom in domain walls.

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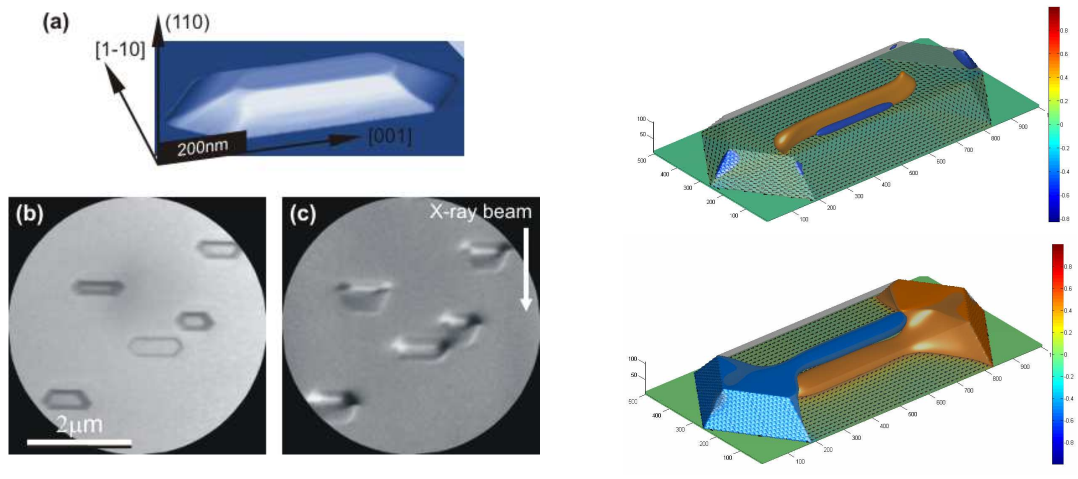
Nanomagnetism and spintronics have been receiving an ever increasing attention over the past two decades. New fundamental effects have been demonstrated at an incredible pace: inter-layer exchange coupling in thin films (1986), giant magneto-resistance (GMR, 1988), tunelling magneto-resistance (TMR, 1995), precessional switching of magnetization (1998), spin torque effects (predicted in 1996, unubiquitous demonstration in 2000). This new golden area of magnetism, having its roots in the co-discovery of GMR by the groups of A. Fert in Orsay and P. Grünberg in Jülich, was recognized by the Nobel prize 2007 awarded to the two inventors.

Fundamental research in the field has been driven by the prospect of products with improved performances or even ground-breaking new concepts. The former includes high-sensitivity magnetic sensors and hard-disks, whose products presently on the market have already integrated most of the above-mentioned phenomena. The latter, still underdevelopment, may concern non-volatile Magnetic MRAM memories as a low-consumption alternative to conventional MRAM, or memory and logic devices based on the movement of domain walls in networks of sub-micrometer-sized magnetic stripes.

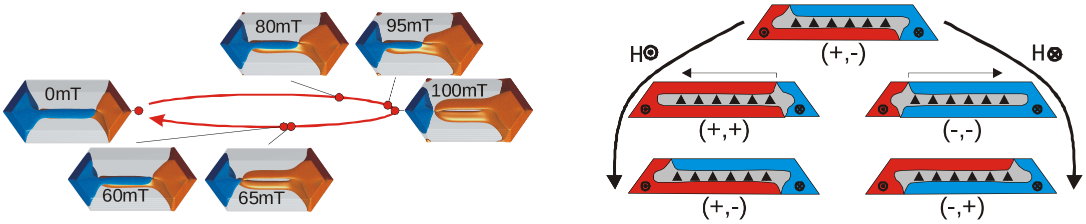
Therefore, since a few years an increasing number of studies have been focusing on magnetic domain walls (DW's) as objects that can be moved by a magnetic field or a spin-polarized current. Beyond the sole movement of these objects, reports about the manipulation of the internal configuration of DW's are only emerging. They concern so far magnetic vortices occurring in lithographically-defined magnetic dots, i.e. the one-dimensional equivalent of the usually-2D domain walls. The vortex core, of diameter 20nm, can be reversed by static fields [1], and as shown recently with more versatility using nanosecond pulsed-fields [2] or spin-polarized currents [3]. These studies proved that two degrees of freedom can be manipulated independently in the so-called vortex flux-closure state: 1. the in-plane chirality of magnetization 2. the polarization of the vortex core. We went one step further and demonstrated the manipulation of a third degree of freedom in one single dot: we could switch the direction of magnetization of the so-called Néel caps (NC's), 50-nm wide magnetic surface features occurring atop and below the Bloch wall of the flux-closure state of elongated dots. Epitaxial micron-sized self-assembled Fe(110) dots grown under ultra-high vacuum by Pulsed Laser Deposition have been used as a model system for this purpose (FIG.1a-b).

The magnetic switching of the Néel caps can be achieved by applying a magnetic field in-the-plane along the short axis of the dots, i.e. parallel to the magnetization vector inside the two Néel caps. As the two Néel caps are naturally antiparallel at remanence, this process allows us to switch between the two essentially-equivalent states that could be labeled (-,+) and (+,-) according to the polarity of the bottom and top Néel caps (FIG.2b). The statistics of switching of NC's following the application of this transverse field has been observed using the Soleil X-ray Magnetic Circular Dichroism PhotoElectron Emission Microscope (XMCD-PEEM) setup currently operated at the Nanospectroscopy beamline at Elettra (Italy) (FIG.1c), before its final installation at Soleil, scheduled 2011. Images of several tens of dots were done after ex situ application of a transverse field with a given magnitude. More than 90% of NC’s have switched under application of 150mT, with a mean reversal field of 125mT. This result is confirmed quantitatively by micromagnetic simulations [2] (FIG.1d-e, FIG.2). Upon application of a positive (resp. negative) transverse field the initial state of the Néel caps becomes (+,+) [resp. (-,-)]. Upon decreasing the field it is always the top Néel cap that switches back, probably in relation with the tilted facets. This drives the dot to a (+,-) [resp. (-,+)] state at remanence. The simulations predict that the switching field reaches a maximum for a height of 90nm, cancels around 25nm on the lower side, and slowly decreases for larger thicknesses. This dependence may be used experimentally to tailor the value of the switching field.



(a-c) **(d-e)**

FIG.1. Typical (a) AFM, (b) LEEM and (c) XMCD-PEEM views of self-assembled Fe(110) dots. In (c) the top Néel caps appear as a thin line along the dots, here all aligned along the same direction (appearing white) after a magnetization procedure. (d) Micromagnetic simulation of the flux-closure state of a dot of size 1000x500x200nm, under zero external field. The color codes the magnitude of one component of magnetization In (d) only the volumes with perpendicular magnetization are shown (Mz>0.5), highlighting the core of the longitudinal Bloch wall. In (e) only the volumes with transverse magnetization are shown, highlighting the arrow-ended domains as well as the two Néel caps with opposite directions, found atop and below the Bloch domain wall.



(a) **(b)**

FIG.2. (a) Micromagnetic simulations of the hysteresis under a magnetic field applied transverse to the dot. Only the transverse component of magnetization is shown, highlighting the Néel caps. (b) Schematic illustration of how the set of Néel caps, antiparallel at remanence, can be switched depending on the sign of the applied field.

Our references

- F. Cheynis, A. Masseboeuf, O. Fruchart, J.C. Toussaint, N. Rougemaille, R. Belkhou, P. Bayle-Guillemaud, A. Marty[2], *Controlled switching of Néel caps in flux-closure magnetic dots*, Phys. Rev. Lett March 2009.
- F. Cheynis, N. Rougemaille, R. Belkhou, J.-C. Toussaint and O. Fruchart, *XMCD-PEEM investigation of size effects on field-induced Néel-cap reversal*, J. App. Phys. **103** (2008) 07D915.
- R. Hertel, O. Fruchart, S. Cherifi, P.-O. Jubert, S. Heun, A. Locatelli & J. Kirschner, *Three-dimensional magnetic flux-closure patterns in mesoscopic Fe islands*, Phys. Rev. **B** 72, 214409 (2005)
- F. Cheynis *et al.,* arXiv:0712.3834v1

Other references

[1] T. Okuno, K. Shigeto, T. Ono, K. Mibu & T. Shinjo, MFM study of magnetic vortex cores in circular permalloy dots: behavior in external field, J. Magn. Magn. Mater. 240, 1-6 (2002)

[2] B. Van Waeyenberg et al., Magnetic vortex core reversal by excitation with short bursts of an alternating field, Nature, 444, 461-464 (2006).

[3] K. Yamada, S. Kasai, Y. Nakatani, K. Kobayashi & T. Ono, Switching magnetic vortex core by a single nanosecond current pulse, Appl. Phys. Lett. 93, 152502 (2008)