ESRF	**Experiment title:** Domain-wall resonances in spin-valve nanowires studied by time-resolved XMCD-PEEM	**Experiment number:** HE2999
Beamline: ID08	**Date of experiment:** from: 13 May 2009 to: 27 May 2009	**Date of report:** 31 August 2009
Shifts: 24	**Local contact(s):** Carsten Tieg	*Received at ESRF:*

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Report:

Moving magnetic domain walls using electric currents via spin-torque effects rather than using a magnetic field is one of the recent exciting developments in spintronics. Besides fundamental investigations, the use of domain walls in logic and memory [1] devices has already been proposed. Low current densities and high domain wall (DW) velocities at zero magnetic field are required for future applications. Our results obtained at the ESRF in May 2008 have been reported in a previous report (HE2699), an ESRF highlight (2008, page 89) and a publication [2]. Using spin-valve-like (NiFe/Cu/Co) trilayered nanostructures, we obtained domain wall velocities up to 200 m/s for current densities as low as 5 x 10^{11} A/m^2, almost an order of magnitude lower than for simple NiFe, showing that part of the requirements needed for applications of spin torque can be reached using these systems. However, these velocities were reached for only very few domain walls, due to strong domain wall pinning in our nanostructures. In our most recent experiments at the ESRF (May2009), we performed measurements on NiFe/Cu/Co trilayers with smoother interfaces, obtained using ion-beam assisted deposition. We also studied CoFeB/Cu/Co trilayers with an amorphous CoFeB layer instead of NiFe, in order to reduce domain wall pinning by grain boundaries and, especially, we performed the first time-resolved measurements *during* the application of current pulses.

We found that the domain wall pinning fields are indeed lower for the NiFe/Cu/Co trilayers with smoother interfaces than for the previous samples. Separate images of the NiFe and Co layers show that domain walls in the Co layer are not the main origin of NiFe domain wall pinning, and that the Co domain walls are not displaced by the applied current pulses.

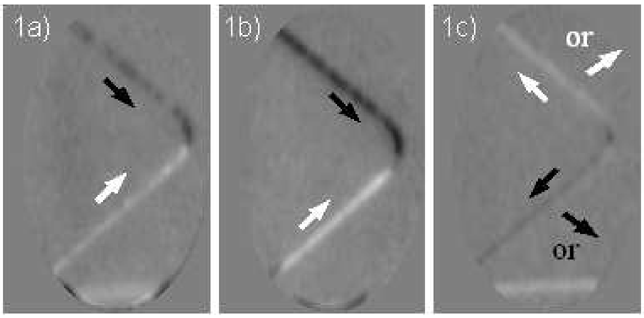

Figure 1 shows the first *time-resolved* images obtained at the ESRF, combining magnetic and current pulses, on the CoFeB/Cu/Co trilayers. The magnetic and current pulses were synchronized with the photon pulses (using 1 bunch out of 2 in the ESRF 4-bunch mode, with a repetition rate of 714 kHz). The acquisition time for each image is about 1 minute, averaging over about 40×10^6 magnetic and current pulses. Figs. 1(a)-(c) show the domain structure in FeNi before, after and during 20 nanosecond current pulses. Fig. 1(a) shows that a domain wall is positioned in the corner of our L-shaped structure after each magnetic field pulse. Fig. 1(b) shows that the domain wall moves over about 2 μm during the current pulses. In the image taken during the current pulses (Fig. 1(c)), the contrast is reversed with respect to Fig. 1(a), for both branches of the nanostructure. This could mean that the magnetization in both branches has completely reversed, corresponding to the motion of a domain wall from outside the field of view into the corner of our structure. However, this would mean that the domain wall should move back to outside the field of view after the pulse [Fig. 1(b)], which is not compatible with our current understanding of CIDM. The other, more likely, explanation involves a rotation by about 90° of the magnetization in both branches. Since XMCD-PEEM shows the projection of the magnetization direction on the incoming photon direction, which is vertical in these images, and since the branches make an angle of 45° with respect to this photon direction, a rotation of 90° in the right direction would reverse the contrast. Such a rotation of the magnetization can be explained when taking into account the current flowing in the Cu and Co layers below the NiFe layer, creating an Oersted magnetic field perpendicular to the stripes. The sense of rotation should depend on the current direction, as we recently confirmed with time-resolved measurements at SOLEIL. The presence of this Oersted field during the current pulses - whose influence on magnetization is shown in these experiments for the first time - should have an important impact on the current-induced domain wall motion, an impact that we want to further explore in the new proposal submitted together with this report. In our recent experiments at SOLEIL we could observe many interesting effects induced by the Oersted field, like magnetization precession in the nanostructures. These results are the subject of a manuscript that will be submitted to a high-impact journal, since they provide the first direct observation of this kind of effects during current pulses in spin-torque devices.

[1] S. S. P. Parkin, M. Hayashi, and L. Thomas, Science **320**, 190 (2008). [2] S. Pizzini, V. Uhlíř, J. Vogel, N. Rougemaille, S. Laribi, V. Cros, E. Jiménez, J. Camarero, C. Tieg, E. Bonet, M. Bonfim, R. Mattana, C. Deranlot, F. Petroff, C. Ulysse, G. Faini and A. Fert, Appl. Phys. Express **2**, 023003 (2009).