ESRF	**Experiment title: Time-resolved magnetic microscopy of domain wall resonances in magnetic nanowires**	**Experiment number**: **HE-2699**
Beamline:	**Date of experiment**: from: 19/05/2008 to: 28/05/2008	**Date of report**: 21 August 2008
Shifts:	**Local contact(s)**: Dr. Carsten Tieg	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

Jan Vogel*, Stefania Pizzini*, Vojtech Uhlir*, Nicolas Rougemaille*, *Institut Néel (CNRS), 25 rue des martyrs, 38042 Grenoble, France*

Julio Camarero*, Erica Jimenez* *Dpto. Física de la Materia Condensada, Universidad Autónoma de Madrid Cantoblanco sn, 28049 Madrid Spain*

Vincent Cros*, Sana Laribi, Frédéric Petroff *Unité Mixte de Physique CNRS/Thales, Route départementale 128, 91767 Palaiseau cedex, France*

Report:

This proposal is part of an ambitious work that we have carried out since October 2006 at Institut Néel in Grenoble, in collaboration with Unité Mixte CNRS-Thales at Palaiseau and ID08 staff at ESRF. The final aim of this work is to study, by time-resolved XMCD-PEEM microscopy, the current-induced dynamics of a domain wall (DW) propagating in a spin-valve nanowire, due to the so-called "spin torque" effect. Presently this is one of the hottest topics in spintronics.

The important experimental difficulties that we had to face during the previous runs on ID08 can be found in our experimental reports. Many improvements carried out in the last year both on the "nanowires+contacts" design and on the "UHV chamber+sample holder" set-up, have allowed the experiments in the May 2008 run to be successful. **Nevertheless, the objectives of proposal HE2699 were only partially achieved.**

Samples of excellent quality have been fabricated both at Nanofab facility in Grenoble and at LPN in Marcoussis. The samples studied in May 2008 are **spin-valve-like 400 nm wide FeNi (5 nm)/Cu (8 nm)/Co (7 nm)/CoO (3 nm) nanostripes**. The nanostripes were processed from film stacks grown by sputtering on high resistivity Si substrates, combining electron beam lithography and lift-off technique. They were patterned in zigzag shapes with angles of 90° and 120° (see in **Fig. 1a** the topographic image of one of the zigzag nanostripes with 90° angles). Contact electrodes made of Ti/Au were subsequently deposited using evaporation and lift-off technique.

The samples were mounted on a home-made new sample holder that allows both *magnetic field pulses* and *electrical current pulses* to be applied. For field pulses, we used a combination of double stripline-like microcoils and a home-made pulsed current supply. Magnetic field pulses with amplitude up to 60 mT and a duration of some tens of nanoseconds could be applied in the plane of the stripes, perpendicular to the long axis of the zigzag, as indicated in **Fig 1b**. Current pulses were injected into the nanostripes using a standard pulse generator providing voltage pulses with 4 ns risetime and tunable length.

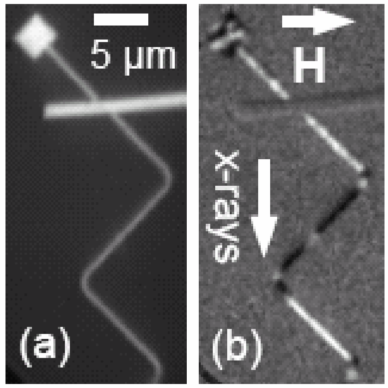

Figure 1

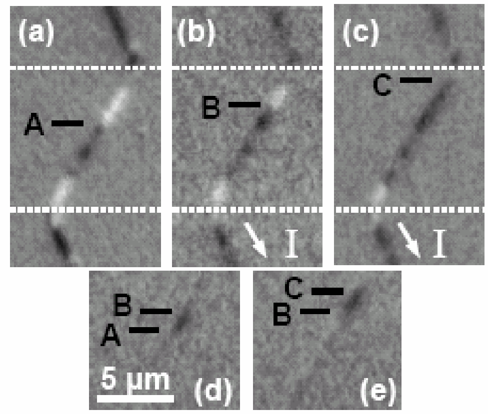

Figure 2

In order to avoid discharges from the objective lens of our Focus IS-PEEM, which is at a distance of 2 mm from the sample, **the voltage on the objective lens was kept low** (up to 4.2 keV), therefore limiting the spatial resolution to about 0.7 μm. XMCD-PEEM images of the magnetic domain structure in the FeNi layer were obtained by tuning the x-ray energy to the Ni L_3 edge.

The magnetic domain structure obtained for a 90° angle, 400 nm wide, zigzag line after application of a strong external magnetic field in the direction perpendicular to the line long direction is shown in **Fig. 1b**. It consists of several magnetic domains (white or black) separated by domain walls. The contrast is given by the projection of the magnetization on the beam direction, i.e., white (black) domains have their magnetization pointing downwards (upwards), along the stripes. The magnetization is nearly saturated in the straight sections, but a **black-white-black-white contrast** is visible at the bends. This magnetic contrast is due to strong **magnetostatic effects** induced by the presence of a DW in the Co layer in the same location, which induce a local antiparallel alignment between Co and FeNi magnetisation in the vicinity of the Co DW.

During the May 2008 run, we have clearly observed that the magnetostatic interactions due to the presence of a DW in the buried Co layer prevent domain wall motion in FeNi across the bends, but do not hinder DW motion away from the bends.

In **Fig. 2**, we show an example of current-induced DW motion in a 400 nm wide stripe with zigzag angles of 120°. The initial domain structure was induced by a strong static magnetic field applied perpendicular to the long axis of the zigzag. This particular geometry is at the origin of the multidomain structure found for this sample This allowed us studying domain walls with different pinning barriers.

The domain structure in **Fig. 2a** could be obtained reproducibly by applying 50 ns long magnetic field pulses with an amplitude of 50 mT. Starting from this initial state, we applied **current pulses with different amplitudes and lengths**, in order to determine the **DW velocity and the threshold current**.

Fig. 2b shows the domain structure obtained after applying one 100 ns long current pulse with amplitude of +2 mA, a value below which no DW motion was detected for these relatively short pulses. This **threshold current pulse** causes a displacement of the domain wall from position A to position B in the images. A consecutive pulse with the same amplitude and length induces a further movement of the same domain wall in the same direction, from B to C (**Fig. 2c**). Note that in these images **only one DW moves** for the applied amplitude of the current, showing that the **pinning strengths can strongly differ at different positions** in the nanostripe. This pinning can be due to topographic features in the nanostripe, but also to domain walls in the Co layer.
The free motion of the FeNi domain wall over section A-C in Fig. 2 suggests that no Co DW is present in this sample section. Our attempts to prove this statement by carrying out Co L_3 edge measurement of the Co

magnetic structure failed, as the escape depth of the secondary photoelectrons is too short compared with the thickness of the trilayer structure.

Domain wall movements in the FeNi layer are more clearly shown in the bottom part of **Fig 2**, where we show the differences between Fig. 2a and Fig. 2b (Fig. 2d) and between Fig. 2b and Fig. 2c (Fig. 2e). The first pulse causes a current-induced DW motion of (1.75± 0.2) μm, the second pulse (1.92 ± 0.2) μm, resulting in a domain wall velocity of about (18 ± 2) m/s for +2 mA pulses. The corresponding current density in the FeNi layer is 2×10^{11} A/m^2 if we consider a uniform current distribution through the trilayer stack and 4×10^{10} A/m^2 if we suppose that the current density is proportional to the conductivity in each layer.
The value of 2×10^{11} A/m^2 gives thus an upper bound for the current density in the FeNi layer. This domain wall moves at a velocity comparable with those found for single FeNi layers, for current amplitudes that are at least an order of magnitude smaller. Measurements using **current pulses with the maximum available amplitude of 5 mA** (corresponding to a current density of 5×10^{11} A/m^2 in the FeNi layer, or 1×10^{11} A/m^2 for non-uniform current distribution) and lengths between 5 and 20 ns showed DW velocities of **(175 ± 10) m/s. This result clearly shows that for this trilayer system the current-induced domain wall velocities are well above literature values for single FeNi layers (about 1 to 150 m/s) , for current densities that are at least a factor two smaller.** The interpretation of this result is under way, probably implying an amplification of the spin-torque yield in these trilayers due to an important current flux in the direction perpendicular to the plane. **Our direct observation of high velocity current-induced DW motion shows the potential of these trilayer systems for applications in DW-based magnetic memories and logic devices.**

The first direct, time-resolved measurements of current-induced domain wall motion were performed in the last night of our May 08 beamtime. Though the first analysis of these data indicates that stroboscopic measurements were successfully performed, the quality of these first data is not sufficiently good for publication. **However, the already obtained results with quasi-static measurements at ID08 are very important and the dynamic measurements could have worked with some more shifts. We therefore hope that we can continue the experimental plan of May 2008 in the near future at ID08.**

The results of this work have been submitted to Appl. Phys. Lett. on August, 20th, 2008.

High domain wall velocity at zero magnetic field induced by low current densities in spin valve nanostripes

S. Pizzini, V. Uhlíř,* N. Rougemaille, E. Bonet, M. Bonfim,† and J. Vogel
Institut Néel, CNRS and UJF, B.P.166, 38042 Grenoble, France

S. Laribi,‡ V. Cros, R. Mattana, C. Deranlot, F. Petroff, and A. Fert
Unité Mixte de Physique CNRS/Thales and Université Paris Sud 11, 91767 Palaiseau, France

E. Jiménez and J. Camarero
Dpto. Física de la Materia Condensada, Universidad Autónoma de Madrid and IMDEA-NANO, 28049 Madrid, Spain

C. Ulysse and G. Faini
CNRS, PhyNano Team, Laboratoire de Photonique et de Nanostructures, route de Nozay, F-91460 Marcoussis, France

C. Tieg
ESRF, rue Jules Horowitz, BP200, 38043 Grenoble, France

Current-induced magnetic domain wall motion at zero magnetic field is observed in the permalloy layer of a spin-valve-based nanostripe using photoemission electron microscopy. High domain wall velocities (exceeding 150 m/s) are obtained for low current densities (ca. 10^{11} A/m^2). These values are beyond the expectations of conventional models describing the interaction between spin-polarized currents and domain walls.