ESRF	Experiment title: Magnetization dynamics in spin valves induced by spin-polarized currents: a micro-scopic and layer-selective study using PhotoEmission Electron Microscopy	Experiment number: HE-2376
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Shifts:	**Local contact(s)**: Dr. Carsten Tieg	*Received at ESRF:*

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Report:

During the May 2007 beamtime we made our second attempt to observe current-induced domain wall movement in spin-valve nanowires using time-resolved photoelectron emission microscopy combined with x-ray magnetic circular dichroism (XMCD-PEEM).

Until now, ***all observations of domain wall displacement using spin-polarised current have been carried out using static measurements,*** *looking at the shape and position of the domain wall after the application of a current pulse. For a better theoretical and experimental understanding of the interaction between currents and domain walls* ***it is crucial to observe directly, during the displacement, the domain wall position and shape.*** *Time-resolved XMCD-PEEM in pump-probe mode is a tool of choice for this direct observation, combining element-selectivity and a good temporal resolution with an excellent spatial resolution.*

In the first beamtime allocated in May 2006, we successfully tested the complicated timing scheme required for the pump-probe measurements. Current and magnetic field pulses are synchronized with the x-ray pulses, while one out of two photon pulses is suppressed by applying a negative pulse to a grid placed in front of the imaging module (microchannelplate + CCD camera) (see previous report).

On the other hand, **technical problems** associated with the samples extreme sensitivity to electrical discharges **did not allow us to acquire any XMCD-PEEM image of the samples' domain structure**. Let us recall that in order to obtain high-resolution PEEM images, a tension of around 10 kV has to be applied between the sample and the objective lens, which is placed only 2 mm from the sample surface. The sample and its surrounding area should therefore be as flat as possible in order to avoid field emission and discharge effects, and should not show any trace of the insulating resist used for e-beam lithography fabrication. In May 2006, the architecture of the samples was such that the electrical contacts for the application of current pulses were too close to the objective lens and moreover some resist was left after patterning process. Discharges took place between the objective lens and either the contacts or the residual resist, systematically destroying the samples mounted in the PEEM.

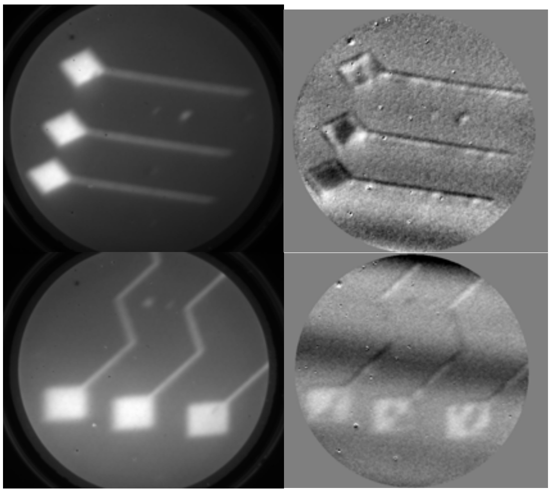

Figure 1

A new series of patterned samples (both with and without contact lines) **has been fabricated at the Institut Néel for the May 2007 beamtime.**

Figure 1 shows the Ni L_3 edge XMCD-PEEM images obtained for straight and zigzag 500nm wide spin-valve Co/Cu/FeNi nanowires (left) as well as the **magnetic domain structure** obtained by subtracting images measured with right and left circular polarization (right). **These new samples are less sensitive to electrical discharges and could be maintained, without deterioration, in the microscope with an extractor potential of 6 kV.**

The **domain structure of a 500nm zigzag spin-valve nanowire with electrical contacts** could also be investigated by PEEM (Figure 2a,b). In order to avoid the major problems found in May 2006, long contact lines have been designed, so that the electrical wires bonded to the contacts are far away from the magnetic pattern (actually hidden under the microcoil double stripline) and therefore from the objective lens. No electrical discharges occurred between the sample and the objective, up to an extractor potential of 6 kV.

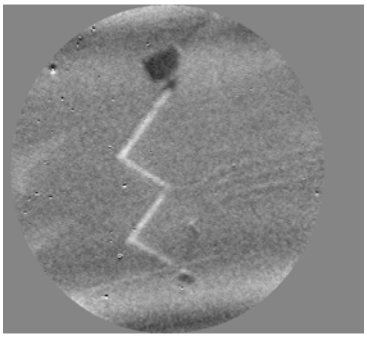

Figure 2a

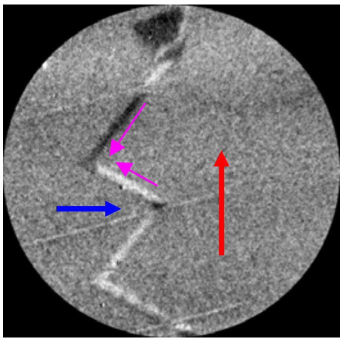

Figure 2b

Figure 2 illustrates the domain structure of a 500nm wide zigzag pattern, before and after the application of 30mT-100ns long field pulses in the direction perpendicular to the line. In Figure 2a the magnetic contrast indicates that the line magnetization in each of the zigzag branches has the same projection with respect to the x-ray direction – the magnetization direction is imposed by shape anisotropy and 'follows' the main line direction. After application of magnetic pulses in the direction perpendicular to the line (blue arrow), a domain structure is created within the line (black/white contrast indicating opposite magnetization direction with respect to x-ray direction - in red in Figure 2b) with a domain wall situated in the corner of the upper branch.

Using this domain structure as « initial state » our following objective has been to induce domain wall movement with field and/or current pulses. Our task has been particularly difficult due to the strong deterioration of the contrast as a function of time. After a period of about 12 hours, the overall intensity of the electrons emitted by the samples had strongly decreased and made magnetic contrast much less clear. After 24 hours the contrast had practically disappeared. We attribute this deterioration to the formation of an insulating layer (probably carbon) within the area exposed to x-rays. The region of the sample corresponding to the impact of the x-ray beam could be clearly visualised using a Hg lamp as a source of chemical contrast.

We have nevertheless succeeded to induce domain wall movement by combining current and field pulses. Due to the radiation damage described before, the quality of the images was however not good enough to be presented here. **The experimental conditions were therefore unfavorable to proceed to the next step of our project – follow domain wall movement by time-resolved PEEM.**

In summary, the beamtime on ID8 in May 2007 was from our point of view successful since we managed to address and solve the problems which made the previous beamtime unsuccessful:

- we succeeded in fabricating good quality nanopatterned spin valve samples. The residual resist on the samples studied in 2006 turned out to be partly responsible for large difficulties we met in the May 2006 beamtime.
- we displaced the electrical contacts with respect to the pattern position, so that we have now much less risk of discharges between them and the objective lens.
- we clearly observed domain structures in 500 nm wide lines and less clearly domain wall movement induced by field and current.
- the remaining problem which made it difficult for us to observe domain wall movement in pump-probe mode – contrast deterioration due to radiation damage, caused by unsufficient vacuum – is presently being solved.

We are now convinced that, with some experimental improvements, we should be able to reach the aims of our project during the next (un-official) beamtime – between 11 and 16 of October 2007

- the carbon layer deposited on the exposed area is certainly linked to the vacuum quality in the chamber (presently of the order of 4 x 10-8 torr) ; we have worked to identify and eliminate all sources of minor leaks (one of such leaks has been shown to be due to the flat cable which powers the microcoil, which is being rebuilt). This problem, which has not occurred during our previous time-resolved XMCD-PEEM experiments at BESSY, is probably due related to the much higher photon flux at ESRF.

- all the image optimisation steps will be carried out using the Hg lamp rather than x-rays. This will increase the lifetime of the patterns.

- narrower (200-300nm) lines have been constructed, in order to favour domain wall movement by current only. The magnetic properties of the domain patterns - in particular the field needed to produce a regular domain structure within the lines, as well as the current density needed to displace the domain walls - are being characterised using a high-resolution magneto-optical microscope. These last steps could not be carried out on the samples used for the May 2007 beamtime, due to the fact that samples fabrication and optimisation by 2-step e-beam lithography was delicate and extremely time-consuming (good samples were ready the week preceeding the beamtime).

For all these reasons, we have very strong hopes to succeed in our ambitious project during the October 2007 beamtime.