POLARISED NEUTRON REFLECTOMETRY FOR GMR SENSORS OPTIMIZATION

M. Pannetier[2], T.D. Doan[2], F. Ott[1], S. Berger[2], N. Persat[3] and C. Fermon[2]

[1]Laboratoire Léon Brillouin (CEA/CNRS), CEA-Saclay, 91191 Gif sur Yvette, France
[2]DSM/DRECAM/SPEC, CEA Saclay, 91191 Gif sur Yvette, France
[3]OnStream MST B.V. Lodewijkstraat 1, 5652 AC Eindhoven, The Netherlands

The optimisation of multilayer stacks for magnetic sensors and more sophisticated spin electronics devices will strongly benefit from the precise knowledge of the magnetic properties of each layer with their behaviour as a function of the applied field. Polarised Neutron Reflectometry (PNR) allows very precise vectorial measurements of magnetic moments but that technique suffers from its relatively low intensity. Polarised neutron reflectometry with polarisation analysis (PNRPA) has proved to be a useful tool to probe in-depth vectorial magnetic profiles [1] and can be used for selective hysteresis loops [2]. We present results obtained on GMR spin valves. We show how PNRPA allows to determine with a high precision, the thickness and magnetic moment configuration and reveals the mechanism of reversal of the soft magnetic layer. This piece of information has permitted the optimisation of very low noise GMR sensors.

GMR sensors description

The studied GMR spin valve has a rather standard composition : SiO2 / Ta(5) / NiFe(3.7) / CoFe(1.2) / Cu(2.4) / CoFe(2.4) / MnPt(35) / Ta(10). The soft layer (NiFe(3.7) / CoFe(1.2)) can rotate in a field of several Oe as the hard layer (CoFe(2.4)/MnPt(35)) is blocked for fields larger than 1T.

The GMR is built with an easy axis of the soft layer (created by an applied external field during the growth) perpendicular to the hard axis. Figure 1 shows SQUID measurements on a 9x10mm square sample. This sample has been chosen among others because it exhibits a larger coercivity of the soft layer and allows us to separate well the two directions of the varying field.

The GMR effect with current flowing parallel to the layer is increased when the thicknesses of the different layers are smaller. However, a too small NiFe layer gives rather bad GMR spin valves [6]. This GMR exhibit a reasonable effect of 9.18% and a very low 1/f noise. 1/f noise of our optimised GMR sensors is lower in the most sensitive part than in previous works [5]. The reason for the good behaviour is the absence of domain formation during reversal process independently of the direction of the hard layer. In the presence of domains, 1/f noise can be several order of magnitude larger.

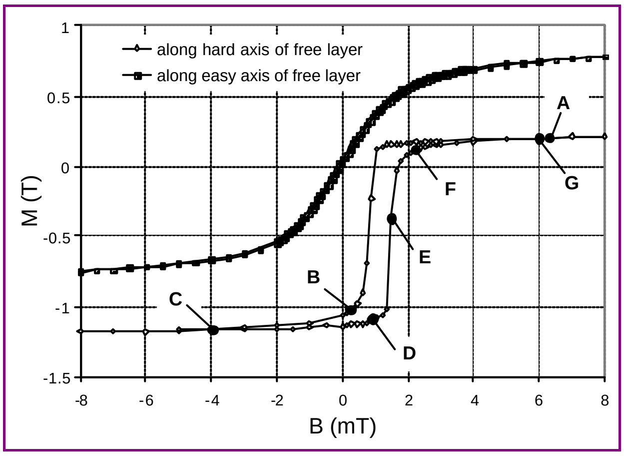


Figure 1. SQUID measurements of the spin-valve GMR01. The anti-ferromagnetic layer is aligned perpendicular to the easy axis of the free layer.

Neutron reflectivity results

In order to follow the magnetic configuration as a function of the magnetic field, we have used the procedure described in reference [2]. A first measurement has been performed in a magnetic saturating field. The hard and soft layers are aligned. Spin-flip reflectivity is then very low due to the absence of non collinear magnetic moments.

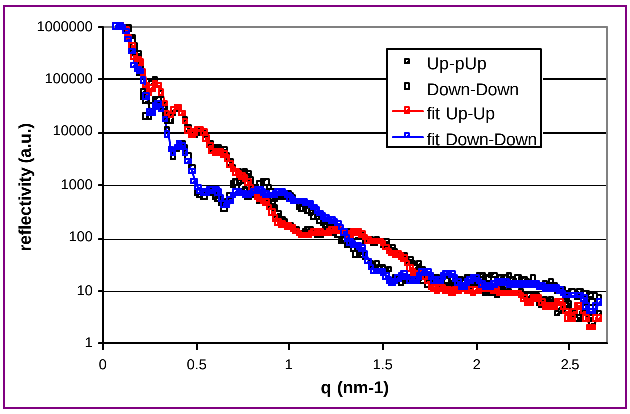
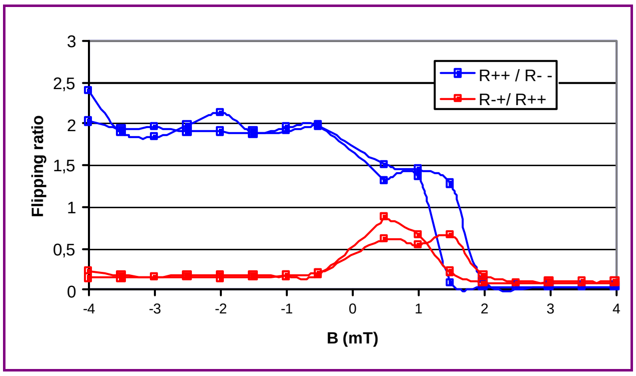


Figure 2. Reflectivity of the system GMR01 in a field of 15mT. The curves given correspond to an anti-ferromagnetic arrangement of the two CoFe layers (point A of figure 1). Black squares : R++, white squares R--, best fit in black line.

The reflectivity of the system in this magnetic state is given in figure 2. Table 1 summarises the parameters obtained from the fitting of the different reflectivity curves. We measure a very low roughness (< 0.5 nm RMS). We have then followed the magnetic configuration as a function of the applied magnetic field. The reflectivities have been measured for a small set of angles as a function of the applied magnetic field (see figure 3a).
Then, using the parameters deduced from the saturated state, these reflectivities have been adjusted by varying a single parameter: the magnetic direction of the soft layer. It appears during the fit that a homogeneous magnetic configuration in the NiFe layer cannot account for the measured reflectivities.



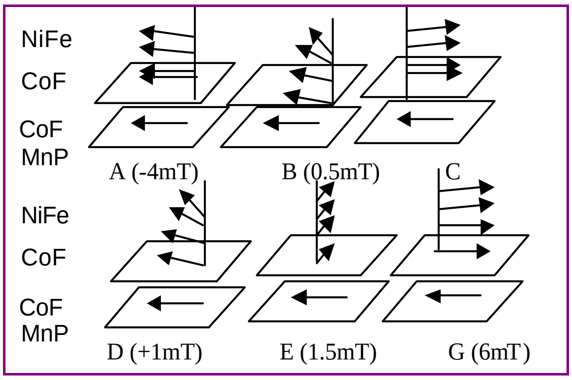


Figure 3 : (a) evolution of the reflectivity R^{++}/R^{--} and R^{+-}/R^{++} (x10) at q=0.53 nm^{-1} as a function of the applied magnetic field; (b) schematics of the evolution of the magnetisation direction of the three magnetic layers as a function of the applied magnetic field. The letters refer to the position on the hysteresis loop (see fig. 1).

One needs to consider that a small magnetisation rotation with respect to the CoFe layer occurs inside the NiFe layer. The fit of the curves have been made by cutting the NiFe layer into 3 homogeneous layers of 1.06 nm. The limited intensity in the neutron experiments does not allow a better precision of the NiFe rotation.
The evolution of the magnetic configuration of the GMR system is given in figure 3b. The small rotation of the NiFe, almost non visible in the magnetisation curve, is clearly revealed by the neutron reflectometry curves.
Even at 8 mT, the free layer appears to be not fully aligned with the external magnetic field. This effect appears clearly on the SQUID measurements under 6mT, (points A and C on figure 1) but after A and C a small rotation still exists which is non detectable by SQUID measurements. The effect of that rotation is to induce a coherent rotation of the free layer, beginning from the bottom (Ta layer) to the top (CoFe layer) during the reversal. This effect avoids any domain formation and therefore leads to low frequency magnetic noise in the sensitive region of the GMR. The maximal angle of rotation of the magnetisation in NiFe is fixed by a competition between the anisotropy and the exchange. This gives a rotation of about 0.5° for 0.1 nm (like in NiFe domain walls) and then about 25° for the total NiFe layer in reasonable agreement with the maximum rotation observed in the layer (30°± 5°). Off-specular neutron scattering did not reveal the presence of magnetic domains. The reflectivity values are also adjusted by using the full nominal moments of the layers suggesting that there is no significant domain formation even in unpatterned layers.

Conclusion

Through the particular case of the optimisation of 1/f noise of GMR sensors by avoiding domain formation, we have shown how precise can be the determination of the magnetic configuration using PNRPA even on present sources. Very small rotations of magnetic moments in a specific layer can be determined allowing an in depth understanding of the magnetic evolution of the system under an applied field. The building of third generation neutron sources like SNS will allow us to gain about two order of magnitude in flux and then achieve depth resolution of about 0.2 nm-0.4 nm even in rather complex system with several magnetic layers.

Acknowledgement
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