Disentangling the magnetoresistance response through the magnetization reversal in magnetic multilayers

C. Rodrigo[1,2], P. Perna[1], M. Muñoz[3,4], J. L. Prieto[4], A. Bollero[1], J. L. F. Cuñado[2], M. Romera[4], J. Akermann[4] , E. Jiménez[2], N. Mikuszeit[1,2], V. Cros[5], J. Camarero[1,2] and R. Miranda[1,2]

[1]Instituto Madrileño de Estudios Avanzados en Nanociencia IMDEA-Nanociencia, Campus Universidad Autónoma de Madrid, 28049 Madrid, Spain
[2]Departamento de Física de la Materia Condensada and Instituto "Nicolás Cabrera", Universidad Autónoma de Madrid, 28049 Madrid, Spain
[3]Instituto de Física Aplicada, CSIC, 28006 Madrid, Spain
[4]Instituto de Sistemas Optoelectrónicos y Microtecnología (ISOM), Universidad Politécnica de Madrid, 28040 Madrid, Spain
[5]Unité Mixte de Physique CNRS/Thales and Université Paris Sud 11, 91767 Palaiseau, France

cecilia.rodrigo@uam.es

Artificial magnetic nanostructures have aroused great interest in the last years. Advances in fabrication of nanostructures and new experimental techniques have led to the discovery of new materials and new properties which take place only in systems with dimensions at the nanoscale [1]. Electronic phenomena governed by spin have given place to the birth of a new branch of electronics called *Spintronics* or *Magnetoelectronics* [2]. For instance, magnetoresistive effects and related phenomena in magnetic nanostructures have found widespread applications in magnetic sensing and recording technologies.

Large magnetoresistance (MR) effects observed in ferromagnetic (FM) layers separated by non-magnetic (NM) spacers have attracted sustained interest over the past decades for both fundamental and technological reasons [3]. The effect could originate from several contributions of spin-dependent scattering processes of the electrons travelling across a multilayered structure with different relative magnetization orientation between adjacent FM layers [4]. In order to observe large MR responses one has to reorient the magnetization of the FM layers relative to one another, either by applying external magnetic fields (i.e., direct magnetic torque on the local magnetization) [3, 4], or by injecting spin polarized currents (i.e., via transfer of angular momentum between the spin polarized conduction electrons and the local magnetization) [5]. The maximum MR value is expected when the magnetic configuration of the FM layers reorients from a fully parallel (P) to a fully antiparallel (AP) configuration.

Even though it is commonly assumed that the MR depends on the magnetic anisotropy of multilayer structures, a comprehensive description of the magnetoresistive behavior related to the magnetization reversal is still lacking. In this work, we show that both amplitudes and shapes of the MR curves of a spin-valve structure depend on the orientation of the applied magnetic field and are directly related to the magnetization reversal processes. In particular, we advance towards a microscopic understanding of the MR properties by showing that their angular dependence leaves distinct fingerprints, which are directly related to their magnetization reversal processes.

We have employed a new MagnetoResistance-Optical Kerr Effect [M(R)-OKE] setup that allows us to determine simultaneously magnetoresistive responses and magnetization reversal processes. The M(R)-OKE set-up and the spin-valve structure used in this study are schematically shown in Figure 1. The layer sequence $Ni_{80}Fe_{20}$(9nm)/Cu(2nm)/$Ni_{80}Fe_{20}$(9nm)/FeMn(15nm) was grown at room temperature (RT) by sputtering on an oxidized Si substrate pre-covered with a 2 nm thick Ta buffer layer [6]. Magnetization reversal processes and magnetoresistive properties were studied at RT by measuring simultaneously in-plane vectorial-resolved magnetization hysteresis loops and the corresponding resistance changes by employing a four probe ac technique with the applied current flowing parallel to the easy axis of the system. The magnetization loops were measured by high resolution vectorial-Kerr magnetometry by using *p*-polarized light focussed between the inner electric probes and analyzing the two orthogonal components of the reflected light. This provides the (additional) simultaneous determination of the hysteresis loops of both in-plane parallel, $M_{||}$, and transverse, $M_{\perp}$, magnetization components as a function of the applied magnetic field [7]. The angular-dependent study has been performed as a function of the sample in-plane angular rotation angle α_H , keeping fixed the external magnetic field direction. The whole angular range was probed every 1.8, with 0.5 angular resolution.

The capability of the M(R)-OKE setup is shown in Figure 2. Both magnetization $M_{||}$, $M_{\perp}$ and MR are acquired simultaneously at the easy-axis (e.a.) and hard-axis (h.a.) direction. At a first glance, different magnetization reversal and MR responses are clearly distinguished when the angle of the applied field is changed from the e.a. to h.a. direction. The correlation between both magnetization reversal and MR responses has been observed in the whole angular range, which indicates their direct relationship. For instance, reversible and irreversible transitions are similar in both MR and vectorial-resolved magnetization curves. Well-defined MR-plateaus are observed around the e.a. direction whereas just reversible MR transitions are found around the h.a. direction. The MR plateau value decreases as the magnetic field is misaligned with respect to the e.a. and the maximum of MR decreases approaching the h.a., where it presents the lowest resistivity changes, one order of magnitude lower than those at the e.a. direction. Our results directly show that the different magnetoresistive behaviors originate from the magnetic anisotropy of the structure and ultimately depend on the relative magnetization orientation of the FM layers.

References

[1] S. D. Bader, Rev. Mod. Phys. **78** (2006), 1.
[2] G. Prinz, Science, **282** (1998), 1660.
[3] M. N. Baibich, Phys. Rev. Lett. **61** (1988), 2472
[4] A. Fert, Angew. Chem. Int. Ed. **47** (2008), 5956
[5] J. Grollier, Appl. Phys. Lett. **78** (2001), 3663.
[6] M. Romera, J. Appl. Phys. **106** (2009), 023922.
[7] J. Camarero, Phys. Rev. Lett. **95** (2005), 057204.

Figures

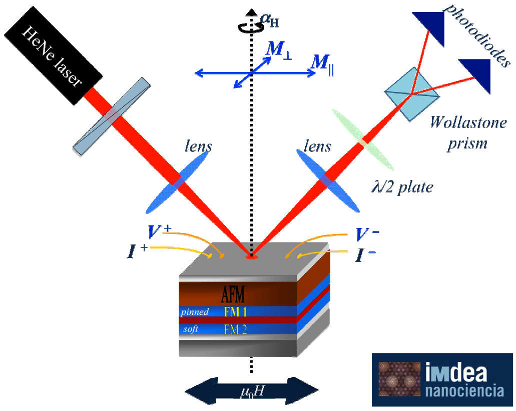

Figure 1: Scheme of the experimental M(R)-OKE setup combining simultaneous vectorial-Kerr and magnetoresistance capabilities and the spin-valve structure investigated.

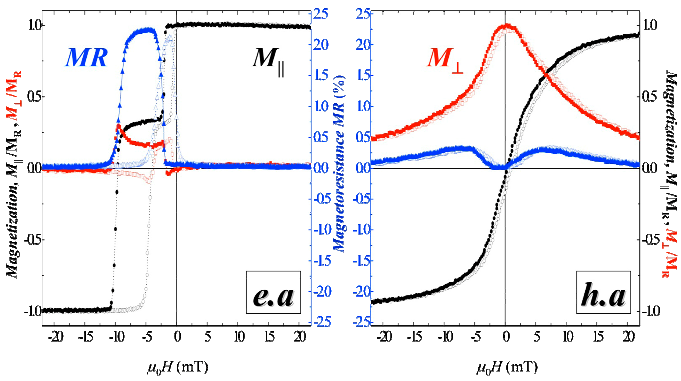

Figure 2: Characteristic in-plane hysteresis and MR curves of the spin-valve structure, at e.a. (left graph) and h.a. (right) directions. The experimental $M_{||}(H;\ \alpha_H)$, $M_\perp(H;\ \alpha_H)$ and $MR(H;\ \alpha_H)$ loops are represented by circles, squares and triangles, respectively. The corresponding ascending (descending) branches are displayed with filled (open) symbols.