Study of domain wall propagation in nanostructured CoPt multilayers by using antisymmetric magnetoresistance

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Abstract. Domain wall propagation has been studied in perpendicular anisotropy CoPt multilayers patterned by e-beam lithography into 5 µm wide wires. Positive and negative peaks appear in time resolved magnetoresistance curves, associated to the different directions of domain wall propagation along the wires. The field dependence of domain wall velocity is well described by a creep model of a 1D wall in the presence of weak disorder with critical exponent $\mu=1/4$.

1. Introduction
The study of domain wall (DW) propagation in magnetic nanostructures is a subject of great current interest due to its possible applications for magnetic memory and logic devices [1-2]. Also, from a fundamental point of view, magnetic domain walls are a good model system to study the physics of elastic interfaces in the presence of random or controlled pinning potentials [3-7]. Thus, different techniques have been used to detect domain wall propagation, based in many cases in time resolved microscopy measurements such as Magnetic Force Microscopy [8] or Kerr microscopy [3,9]. In particular, magnetic nanowires provide a very controlled geometry for DW propagation experiments and, in certain cases, allow for magnetotransport measurements in which DW motion gives rise to a voltage signal variation using for example giant magnetoresistance effect (GMR) in a spin valves geometry [10] or extraordinary Hall effect (EHE) [5]. Magnetoresistance contributions related to individual domain walls have also been reported, for instance, in FePd nanostructures [11] and in perpendicular anisotropy Co/Pt multilayers [12]. In this last case, the DW contribution to the magnetoresistance has been found to be antisymmetric depending on the direction of magnetization rotation when the DW is perpendicular both to the current and the magnetization at the domains.

In this work, we have analyzed domain wall motion in perpendicular anisotropy Co/Pt wires by magnetotransport measurements. Forward and backward DW propagation can be detected by the presence of positive/negative peaks in the time resolved magnetoresistance curves with a probability that depends on wire geometry (position of nucleation pads and continuous vs interrupted wire).
2. Experimental

Epitaxial Pt(3nm)/[Co(0.6nm)/Pt(1nm)]/Pt(3nm) multilayers with high perpendicular anisotropy have been grown by sputtering on Si substrates [13]. The samples have been patterned into 5 µm wide wires by a combination of e-beam lithography and an etching process through Ar+ milling, as shown in Fig. 1. A large DW nucleation pad is attached to the left side of the wire, and three Hall crosses are defined along the wire with a 20 µm spacing to perform the DW velocity measurements. Two different kinds of wires have been used in this study: either a continuous wire (Fig. 1(a)) or a wire interrupted on its left half by a 3 µm triangular hole (Fig. 1(b)) intended to provide an effective pinning site for DWs coming from left to right (Forward propagation in the following). Non magnetic Al electrical contacts were fabricated by means of optical lithography and a lift-off process.

Time resolved magnetotransport measurements were performed using a lock-in detection technique similarly to that used by Cayssol et al [5] with frequency 613 Hz at room temperature and fields up to 4 kOe applied perpendicular to the sample plane. In these high quality epitaxial multilayers magnetization reversal takes place by domain wall motion following rare nucleation events [5,14], resulting in a very square hysteresis loop with a full remanence. Fig. 2 shows a typical EHE hysteresis loop measured across V1 and V3 in the continuous wire which exhibits a coercive field HC = 288 Oe.

![Fig. 1: Micrographs of the 5 µm wide CoPt patterned bridges for magnetoresistance measurements: (a) Continuous wire; (b) Wire interrupted by a triangular hole on right portion. Contact pads used for current and voltage leads are also indicated. Inset is a zoom on the triangular hole.](image)

![Fig. 2: Normalized Extraordinary Hall effect hysteresis loop of the continuous CoPt bridge measured across voltage leads V1 and V3.](image)
3. Results and Discussion

Fig. 3 shows the time resolved magnetoresistance curves measured across in the right half of the continuous (Fig. 3(a)) and interrupted (Fig. 3(b)) wires (i.e. across $V_1$ and $V_2$). The field vs. time $H(t)$ used in the measurements (red lines) consists of a short triangular ramp in which $H$ varies continuously from 800 Oe to -800 Oe (to bring the sample from positive to negative saturation) followed by a period of constant magnetic field $H = 242$ Oe, slightly below coercivity, during which DWs propagate along the wire at constant magnetic field to reverse the entire wire. For the continuous wire a series of positive peaks appear in the magnetoresistance curve, at every constant field period, in a similar way as observed in [5] but with a rounder peak shape that can be attributed to the larger width of the Hall crosses used here (5 µm here in comparison with 1.5 µm in [5]). For the interrupted wire, a qualitative difference appears: both positive and negative peaks are observed in random order. Even, there are periods for which the signal follows a positive/negative ripple (see last period in Fig. 3(b)) that could be a combination of two close peaks of different sign. A similar behavior is obtained for different values of the constant field varying from 220 Oe to 260 Oe, which is summarized in the histograms shown in Figs. 3(c) and (d): only positive peaks appear for the continuous CoPt wire, whereas positive and negative peaks appear with equal probability for the interrupted wire.

Peak widths $\Delta t$ correspond to the time spent by the DW to travel along the 20 µm distance between contacts and can be converted into DW speed as $v = 20 \mu$m/$\Delta t$. For a fixed field, average $v$ is independent on peak polarity and, as a function of $H$, $v$ increases steeply following an exponential law $v = v_0 \exp[-(H_{eff}/H)^{1/4}]$, characteristic of 1D domain wall creep in a 2D geometry [4], and already observed in other works on CoPt multilayers [3,5,7]. Therefore, both the positive and negative peaks in the time resolved magnetoresistance curves can be associated to DW propagation along the wire. The different signs observed could be related with an antisymmetric EHE contribution around the
DW, in a similar way as reported by Cheng et al [12] in Pt/Co/Pt trilayers, that changes sign depending on whether the reversed domain is located at the left or at the right of the DW (see sketch in Fig.4). Thus, in the present geometry, a positive/negative $\Delta V_R$ peak would correspond to forward/backward wall propagation. Forward DW motion would be the preferred reversal mode for the continuous wire with a large nucleation pad at the left. In the interrupted wire, the probability of forward wall propagation decreases due to the pinning effect of the hole in the left side of the wire. Thus, it becomes possible to detect DWs moving backwards after nucleation on the smaller right pad.

4. Conclusions
In summary, positive and negative peaks have been observed in the time resolved magnetoresistance curves of CoPt wires that can be associated to forward/backward DW motion along the wires with a different probability depending on the wire geometry (position of larger nucleation pad, continuous or interrupted wires). Thus, this kind of measurements can be a very useful tool to obtain not only DW speeds but, also, of the sense of DW propagation along the magnetic wires.

Acknowledgements
Work supported by Spanish MICINN (grants NAN2004-09087 and FIS2008-06249), by Principado de Asturias FICYT (PCTI IB08-106) and by European Community (MERG-CT-2004-513625).

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