PROGRAMMA SHORT TERM MOBILITY – ANNO 2008

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***Titolo del programma*: EFFETTO DELLA TAGLIA SU BILAYER MAGNETICI CON EXCHANGE BIAS**

Final Report

The Exchange Bias (EB) phenomenon discovered by Meiklejohn and Bean in 1956 has been extensively revisited during the last decades, due to the large interest in both fundamental studies and technological applications. This phenomenon is present in systems characterized by the interface exchange coupling between a ferromagnetic (FM) and an antiferromagnetic (AFM) material (exchange anisotropy). A shift of the hysteresis loop (exchange bias field, H_E) is observed when the sample is cooled in a magnetic field through the Néel temperature of the AFM material. This was explained asdue to an induced unidirectional anisotropy arising from the direct exchange coupling at the FM/AFM interface. The exchange coupling usually leads also to an increase in coercivity (Hc), as observed in both nanoparticles and bilayer EB systems.

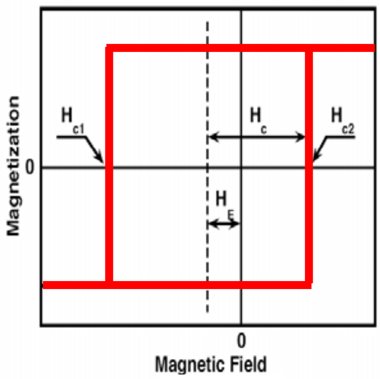


Fig. 1

Despite the large use of EB systems in technological applications (spin-valve systems, including GMR read heads) there are still many controversial issues especially concerning size effects that can be observed when going from the continuous down to the nanometre scale.

The interest in the study of finite size effects, on networks of nanostructures (down to characteristic dimensions of the order of 100 nm) based on the exchange coupling FM/AFM, is thus partially technological. From a fundamental point of view, patterning EB materials at a length scale comparable with characteristic dimensions (for instance domain size in the FM as well as in the AFM materials) should make possible to better understand the mechanisms associated with the phenomenon of exchange anisotropy whose comprehension is still not complete.

In the framework of this project, a continuous fcc-CoPt/NiO exchange bias bilayer (sample A) was fabricated by Pulsed Laser Deposition (***ISM-CNR, Rome***) and characterized by a SQUID magnetometer (***IN, CNRS, Grenoble***). From the same continuous bilayer was then obtained a patterned dot array (sample B) by combining e-beam lithography with ion-etching process (IN***, CNRS, Grenoble***). The sample was constituted by an array of rectangular dots with dimensions of 120x360 nm (with an interdot distance of 240 nm along the short direction and 120 nm along the long direction). A second sample was deposited (in the same deposition conditions), (***ISM-CNR, Rome***) using a pre-patterned mask (dots of 30X90 nm) and a lift-off procedure was then used in order to remove the photoresist (***IN, CNRS, Grenoble***).

Samples are summarized in the table below:

sample	***typology***	***lateral dimension***
A	Continuous	macroscopic
B	patterned from sample A *(E-BEAM+ION ETCHING)*	120 nm x 360 nm rods
C	deposited on a pre-patterned mask *(E-BEAM+LIFT OFF)*	30 nm x 90 nm rods

Results

Sample A : a preliminar magnetic characterization has been performed on the continuous sample in order to correlate its properties to the ones of the patterned samples.

The measurements were performed by cooling the sample from 350K directly down to 5K (with an applied field of 1T) and by measuring the hysteresis loops with increasing temperature. This method was used due to the low training effect observed in this system. Indeed, a significant difference between the first (I) and the second loop (II) has been observed (in shape and coercive field), and for this reason at the lowest temperature (5 K) the loop has been recorded twice. In figure 2b the coercive field (Hc) and Exchange bias field (Hex) is reported as a function of temperature.

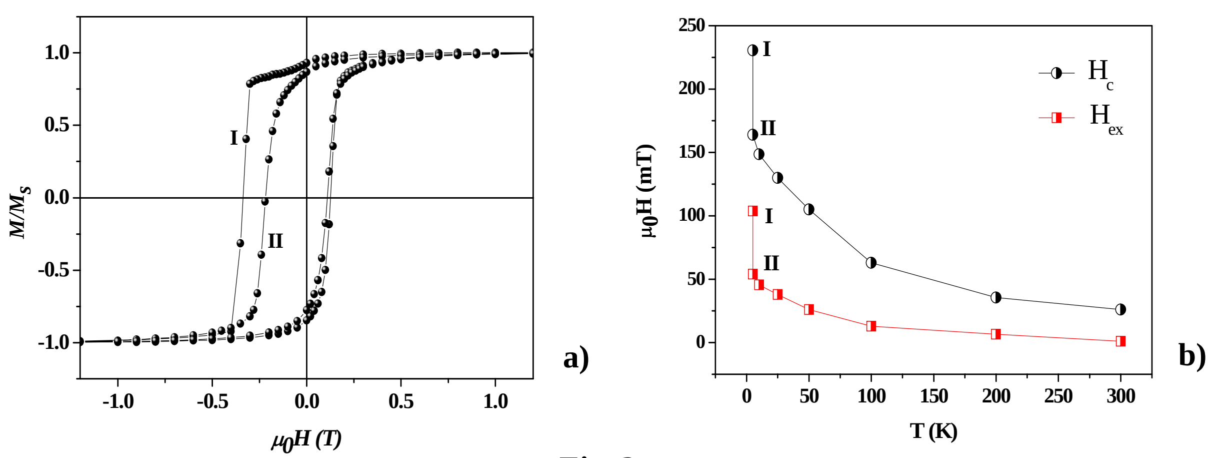


Fig. 2

Sample B :

Starting from the continuous CoPt/NiO bilayer, a patterned sample (on a 3x3 mm^2 total patterned area) has been obtained by e-beam lithography combined with the ion-etching process. Sample B was characterized by an array of rectangular rods, whose typical dimension was 120 X 360 nm^2. The rectangular shape was chosen in order to ensure a preferential direction for the magnetization of each individual dot; moreover, the distance between rods was large enough to minimize the dipolar interactions between neighbouring dots (240 nm along the short direction and 120 nm along the long direction).

The same field cooling procedure used for sample A was performed before measuring the hysteresis loop at increasing temperatures.

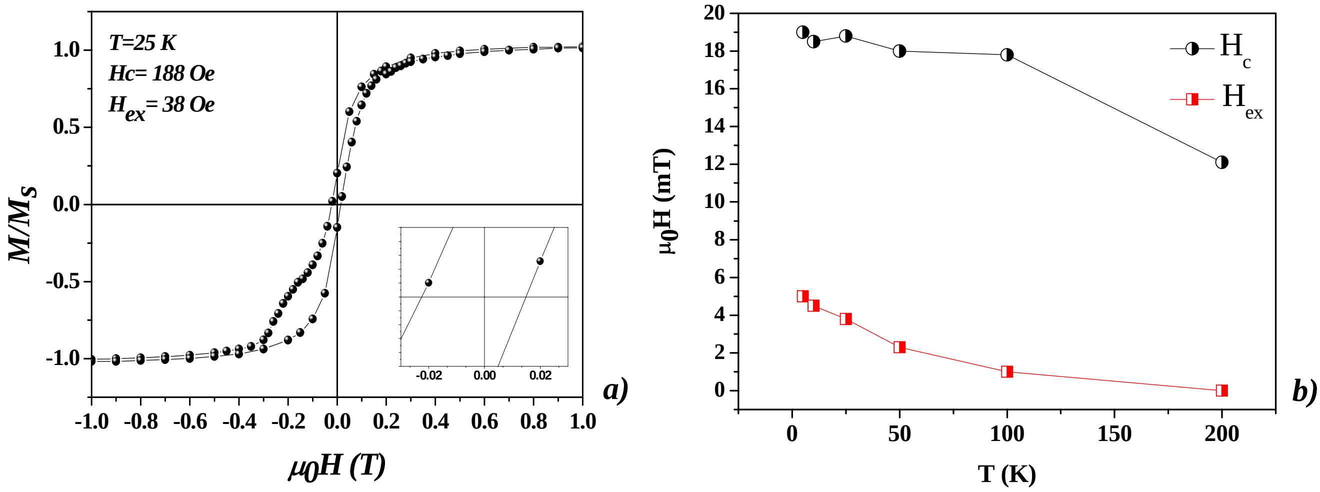


Fig.3

As shown in fig. 3a a drastic change in the loop shape was observed after the lithographic process. Indeed, a strong reduction of the loop squareness (Mr/Ms<0.2) as well as a decrease of both coercivity (Hc) and exchange bias field (Hex) resulted from the comparison with the continuous bilayer (sample A). Moreover, the EB blocking temperature in the nanostructured sample was reduced of about 100K. The double contribution to the magnetization reversal observed in the first branch of the hysteresis loop could be due to residual material (portion of continuous film) not removed by the fabrication process. This hypothesis is supported by the comparison between the field cooling hysteresis loop at 5K for continuous (A) and patterned (B) samples (fig. 4). As evidenced by the loop derivative (first branch) of the two samples, reported in the inset of fig. 4, the high field reversal in the patterned sample (red) occurred at the same switching field of the continuous film (blue).

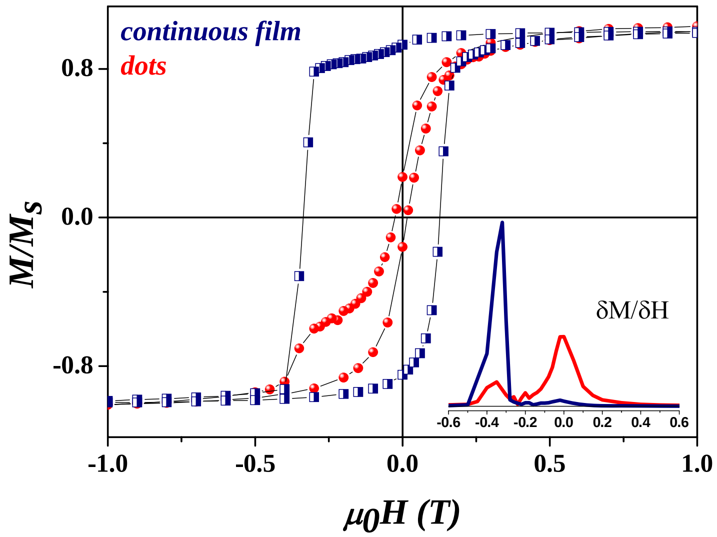
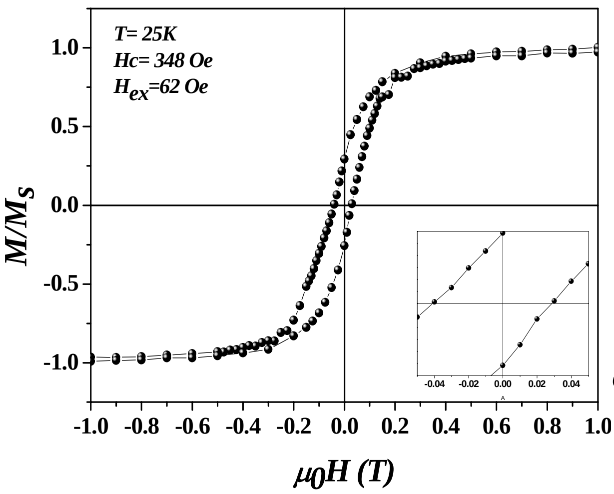


Fig. 4

Sample C

Patterning on sample C was realized by electron-beam lithography on a photoresist-covered Si substrate. After the CoPt/NiO deposition on such a pre-patterned sample (in the same deposition conditions as sample A), a lift-off procedure was used in order to remove the resist. It has to be noticed that the bilayer was deposited through a mask to obtain a deposition confined to the patterned area only; this procedure was used in order to avoid eventual parasitic signals coming from material deposited outside the patterned area.

Sample C was characterized by an array of rectangular rods, whose typical dimension was 30 X 90 nm^2.



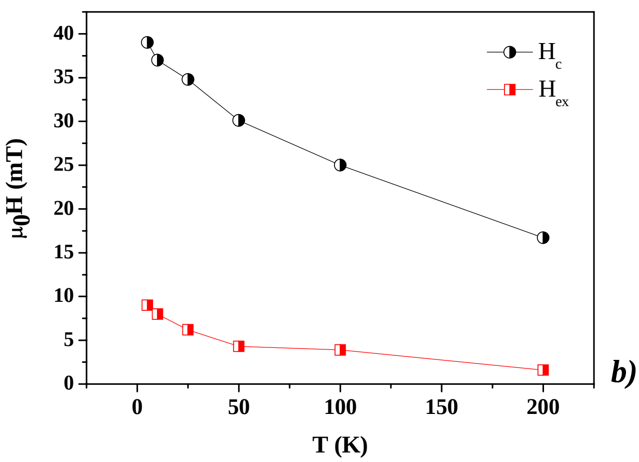


Fig. 5

Also in sample C the loop shape was very different from what observed in the continuous sample (fig. 5a).

In this case, the loop squareness deduced from the field cooling hysteresis loop at 25K was less than 0.3. The coercive field (H_c) and exchange bias field (H_{ex}) were strongly reduced if compared with the continuous film even if almost doubled values were found with respect to sample B.

The interesting results obtained during this activity indicated that a drastic change in the magnetic behaviour are observed when passing from a continuous film down to the nanometre scale. Indeed, for rod dimensions below the micrometer range (as in sample B and C), a single domain structure of the AFM layer can be hypothesized, due to the low anisotropy of NiO phase characterized by a large characteristic dimension of the domain wall.

Further investigation should be performed to study patterned samples with larger lateral dimension (in the micrometer scale) in order to study the magnetic properties of the CoPt/NiO when passing from a multi-domain to a single-domain state.