Exchange bias and coercivity fields as a function of the antiferromagnetic layer thickness in bi- and tri-layered thin-films based on IrMn and NiFe

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Abstract

The exchange bias phenomenon in bilayered and trilayered thin films, based on NiFe and IrMn, was studied. The exchange bias and coercivity fields dependences on the antiferromagnetic layer thickness were obtained. It was shown that 6 nm of IrMn is a critical thickness for the exchange bias appearance. Largest value of the exchange bias is found to be for NiFe/IrMn/NiFe sample with 10 nm thickness of antiferromagnetic layer.

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1. Introduction

Nowadays the exchange bias phenomenon is a hot topic of both fundamental and experimental researches (van den Brink et al. (2016), Savin et al. (2016), Li et al. (2016), Vafaee et al. (2016), Chang et al. (2016)). This high

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scientific interest was induced thanks to very wide applications of this phenomenon in spintronics, magnetic
sensorics, MRAM (for example, Da Silva et al. (2009), Zdravkov et al. (2013)).

The exchange bias is a shift of a hysteresis loop along the field axis (Meiklejohn W. H. et al. (1956)), revealing an
exchange coupling between ferromagnetic (F) and antiferromagnetic (AF) materials at their interface. Nowadays, the
exchange bias is very often investigated in thin films as a function of thickness of film's layers, roughness of
surfaces, composition of materials etc. Each parameter has influence on both the exchange bias value and coercive
force, that is shown in many papers (Fleischmann et al. (2010), Mishra et al. (2009), Ledue et al. (2012), Zhang and
Dressel (2009), O’Grady et al. (2010), Kanak et al. (2008), Nascimento et al. (2008) etc.). However, despite a large
volume of the experimental data, there is still a lacking consistency between them and no widely accepted
mechanisms worked out of the influence of above-mentioned parameters on the magnetic properties, including
exchange bias. This motivates our investigation of the coercivity and the exchange bias fields as a function of AF-
layer thickness and layers deposition sequence. Below we present some of the results of our study.

2. Experimental techniques

As our study we have prepared three series of thin films with the following orders of layers deposition: F/AF,
AF/F and F/AF/F. Thus, we have had two series of bilayered structures in which the thickness of AF-layer was
varied from 4 to 10 nm, and one series of trilayered films with thickness of AF-layer (t(AF)) from 2 to 10 nm. These
thickness ranges were chosen in correlation with our previous experiments with similar structures (Dzhun et al.
(2015), Gritsenko K. et al. (2015)), where it is shown that the critical changes of the exchange bias occur at IrMn
layer thickness thinner than 10 nm.

All thin films were deposited by magnetron sputtering onto 450 μm Si (100) substrate with 10 nm of Ni75Fe25 as
the ferromagnetic layers, obtained by co-deposition from two targets – Ni and Fe, 30 nm of Ta as seed and capping
layers and Ir45Mn55 as the antiferromagnetic layer. Thus, we obtained the following structures: Si/Ta/NiFe/IrMn/Ta,
Si/Ta/IrMn/NiFe/Ta and Si/Ta/NiFe/IrMn/NiFe/Ta.

During the magnetron sputtering the pressure of Ar was 3*10⁻³ Torr. A magnetic field of 395 Oe was applied in
plane of the substrate to saturate the growing AF layer.

The Lake Shore setup of vibrating sample magnetometry (VSM) was used to study the magnetic properties of our
samples. Magnetic moment of each sample was measured in parallel and perpendicular directions of VSM external
magnetic field with respect to the sample's magnetization easy axis (MEA).

3. Results and discussion

The dependences of the samples magnetic moments on the external magnetic field for two directions of MEA
with respect to the direction of the magnetic field are shown in the figure 1 for bilayered and trilayered samples with
t(AF)=8 nm and trilayered sample with t(AF)=4 nm. As it can be seen, the hysteresis loops for bilayered samples
with different sequence of deposition look different: for IrMn/NiFe sample coercivity and exchange bias is a few
times larger. Furthermore, for trilayered samples, two-regions hysteresis loops appear when exchange bias emerges
in the sample: for sample with t (AF) =4 nm there are non-shifted hysteresis loops while for t(AF)=8 nm two-region
hysteresis loop is observed. Each part of this type hysteresis loop corresponds to magnetization reversal of top or
bottom FM. This form of hysteresis loop is typical for F/AF/F trilayers (for example, Nascimento et al. (2008),
Sankaranarayanan et al (2005), Bolon et al. (2007)). Comparing the exchange bias and coercive force values in bi-
and trilayered structures we can conclude that top part of trilayer’s hysteresis loop corresponds to the bottom NiFe
layer in the structure and demonstrates exchange bias at F/AF interface and bottom part corresponds to the top NiFe
layer. Also it can be noted that the magnetization reversal goes very fast with some kind of jump and after that the
saturation magnetization is quickly achieved.

The exchange biases dependences on the AF-layer thickness are presented in Figure 2. In our case the critical
thickness of IrMn layer for the appearance of the exchange bias is 6 nm. The exchange biases in our structures is
near zero at smaller values of AF-layer thickness. With increase of AF layer thickness the exchange bias of bottom
part of the trilayer hysteresis loop monotonically increases. The same behavior of exchange bias vs AF-layer
thickness dependence was observed in the case of AF/F structures but exchange bias value remains lower than
mentioned above. For top part of hysteresis loop of trilayered samples and for F/AF samples exchange bias value
remains near zero in all thicknesses in the range, except for the bilayer with t(AF)=8nm and the trilayer with t(AF)=6nm. This result is surprising because earlier the exchange bias up to 60 Oe was observed at same AF layer thicknesses (Devasahayam et al. (1998), Queste et al. (2005)). Probably, the exchange bias is diminished due to a high roughness of F layer that leads to disorder of AF magnetic moments and to a weak AF magnetic anisotropy especially at low AF layer thicknesses (Dzhun et al. (2015), Kuncer et al. (2008)). However it is still open to debate and further microstructure investigations by AFM and TEM techniques are required.

Figure 1: Hysteresis loops of samples for two directions of MEA to the external magnetic field for samples (perpendicular - red, parallel - black curves):
   a) IrMn/NiFe at t(AF)=8 nm; b) NiFe/IrMn at t(AF)=8 nm;
   c) NiFe/IrMn/NiFe at t(AF)=4 nm and d) NiFe/IrMn/NiFe at t(AF)=8 nm.

Figure 2: The exchange bias dependence on the AF-layer thickness for bilayered and trilayered samples.
One can see that the largest shifts were reached in bottom loops of the trilayered samples and the exchange bias maximum value reached 75 Oe for the trilayer with $t_{\text{AF}} = 10$ nm. The larger shift of the bottom parts of loops, corresponding to the top Fe layer, is larger than that in the top parts of the loops, responsible for the bottom Fe layer in the trilayered structure. The effect has been observed before, see for example, Gritsenko K. et al. (2015), Rodionova et al. (2015), Malinowski G. et al. (2003)), and, presumably, can be related either to a different roughness of AF/F and F/AF interfaces in trilayered structures, or to magnetic interactions between two F layers through AF layer, or to different domain patterns of antiferromagnetic layer at the bottom and the top interfaces, as suggested by Malinowski G. et al. (2003).

Figure 3 shows the coercivity dependence on the IrMn layer thickness. One can see a rapid increase of coercive force in the IrMn/NiFe sample, while a low coercive force in the NiFe/IrMn samples does not significantly change. Coercive force of top and bottom part of hysteresis loop in the NiFe/IrMn/NiFe samples increases and then slightly decreases with AF layer thickness increasing. The bottom part of hysteresis loop is characterized by higher coercive field values than top part for all AF thickness in the investigated range.

Thus, it can be concluded, that the magnetic properties in the studied structures depend not only on the thickness of AF-layer, but also on the sequence of layers deposition, because, at the same value of antiferromagnetic layer thickness, we obtained different values of the exchange bias and coercivity fields (Kuncer et al (2008), Shanova et al (2014), Rodionova et al (2015)). Thus, it can be supposed, that the difference in magnetic properties of the samples with alternative order of the layer deposition are in a direct dependence on the structural characteristics of thin films such as roughness, texture and grain size, that leads to a different configuration of magnetic moments at F/AF and AF/F interfaces.

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References


Chang Ch.Hs.T., Chang Sh.Ch., Tsay J. Sh., 2016, Variation of blocking temperatures for exchange biased CoO/Co/Ge(100) films, AIP Advances 6, 056101


Devasahayam, A. J., Sides, P. J., Kryder, M. H., 1998, Magnetic, temperature, and corrosion properties of the NiFe/IrMn exchange couple,
Dzhun I., Chechenin N., Chichay K., Rodionova V., 2015, Dependence of Exchange Bias Field on Thickness of Antiferromagnetic Layer in NiFe/IrMn Structures, ACTA PHYSICA POLONICA, Vol. 127


Gritsenko K., Dzhun I., Chechenin N., Babaytsev G., Rodionova V., 2015, Dependence of the exchange bias on the thickness of antiferromagnetic layer in the trilayered NiFe/IrMn/NiFe thin-films, Physics Procedia, V. 75, pp. 1066–1071


Malinowski G., Henn M., Robert S., Lenoble O. and Schulz A., 2003, Magnetic origin of enhanced top exchange biasing in Py/IrMn/Py multilayers, PHYSICAL REVIEW B68, 184404


Mishra S. K., Radu F., Durr H. A. and Eberhardt W., 2009, Training-Induced Positive Exchange Bias in NiFe/IrMn Bilayers, PHYSICAL REVIEW LETTERS, 102, 177208


Rodionova V., Dzhun I., Chichay K., Shevyrtalov S., Chechenin N., 2015, Enhancement of exchange bias in NiFe/IrMn, IrMn/NiFe and NiFe/IrMn/NiFe structures with different thickness of antiferromagnetic layer, Solid State Phenomena, vol. 233, pp. 427–430


Shevyrtalov S., Dzhun I., Chechenin N., 2015, Influence of surface roughness and deposition order on exchange bias in bilayer structures NiFe/IrMn, EPJ Web of Conferences, vol. 75, p. 05010

Zdravkov V. I., Lenk D., Morari R. et al., 2013, Memory effect and triplet pairing generation in the superconducting exchange biased Co/CoOx/Cu41Ni59/Nb/Cu41Ni59 layered heterostructure, Appl. Phys. Lett. 103, 062604

Zhang T. and Dressel M., 2009, Grain-size effects on the charge ordering and exchange bias in Pr0.5Ca0.5MnO3: The role of spin configuration, PHYSICAL REVIEW B80, 014435


Van den Brink A. et al., 2016, Field-free magnetization reversal by spin-Hall effect and exchange bias, Nature Communications 7, 10854