5-28-2004

Exchange Model for Oscillatory Interlayer Coupling and Induced Unidirectional Anisotropy in $[\text{Pt/Co}]_3/\text{NiO}/[\text{Pt/Co}]_3$ Multilayers

Mikhail Ye Zhuravlev
*University of Nebraska-Lincoln*, myezhur@gmail.com

Evgeny Y. Tsymbal
*University of Nebraska-Lincoln*, tsymbal@unl.edu

Sitaram Jaswal
*University of Nebraska*, sjaswal1@unl.edu

Follow this and additional works at: [http://digitalcommons.unl.edu/mrseccapubs](http://digitalcommons.unl.edu/mrseccapubs)

Part of the [Materials Science and Engineering Commons](http://digitalcommons.unl.edu/mrseccapubs)

Zhuravlev, Mikhail Ye; Tsymbal, Evgeny Y.; and Jaswal, Sitaram, "Exchange Model for Oscillatory Interlayer Coupling and Induced Unidirectional Anisotropy in $[\text{Pt/Co}]_3/\text{NiO}/[\text{Pt/Co}]_3$ Multilayers" (2004). Faculty Publications: Materials Research Science and Engineering Center. 6.
[http://digitalcommons.unl.edu/mrseccapubs/6](http://digitalcommons.unl.edu/mrseccapubs/6)

This Article is brought to you for free and open access by the Materials Research Science and Engineering Center at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Faculty Publications: Materials Research Science and Engineering Center by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.
Exchange Model for Oscillatory Interlayer Coupling and Induced Unidirectional Anisotropy in [Pt/Co]_3/NiO/[Pt/Co]_3 Multilayers

In a recent Letter [1] Liu and Adenwalla found an interesting oscillatory behavior of the interlayer exchange coupling (IEC) through an insulating NiO (111) layer with a period of 2 monolayers (ML). They interpreted this phenomenon in terms of multiple reflections of electronic waves from a periodic atomic potential in the spirit of the model of Ref. [2]. However, this interpretation is not consistent with the tunneling mechanism used by the authors which would result in a modulated exponential decrease of the IEC but no periodic change in sign. In this Comment we show that the observed oscillatory IEC can be explained quantitatively by the exchange interaction at the interfaces and in the bulk of the antiferromagnetic NiO film.

NiO is an antiferromagnet with antiparallel-aligned magnetic moments in the adjacent Ni (111) planes. If a NiO (111) film is placed between two ferromagnetic layers their magnetic moments tend to align parallel (antiparallel) to the magnetic moments of the top and bottom Ni MLs in the NiO due to a ferromagnetic (antiferromagnetic) exchange coupling at the interface. Hence, the magnetic moments of the two ferromagnetic layers tend to align parallel for the odd number of NiO MLs and antiparallel for the even number of NiO MLs. This simple argument explains qualitatively the 2 ML oscillations in the IEC found in Ref. [1].

To make this argument quantitative we have modeled the [Pt/Co]_3/NiO/[Pt/Co]_3 multilayer using a simple one-dimensional model. Within this model the total energy of the multilayer per unit area is given by

\[ E = \sum_i \left[-J_i \cos(\theta_i - \theta_{i+1}) - K_i \cos^2 \theta_i - H \mathbf{M}_i \mathbf{t}_i \right], \tag{1} \]

where \( t_i \) is the thickness of ML \( i \), \( \mathbf{M}_i \) is the magnetization of ML \( i \) (Co in Co/Pt or Ni in NiO), \( J_i \) is the exchange coupling between MLs \( i \) and \( i + 1 \), \( \theta_i \) is the angle of \( \mathbf{M}_i \) with respect to the plane, \( K_i \) is layer-dependent anisotropy constant, and \( H \) is an applied magnetic field. In our calculations we used parameters \( J_{\text{Co/Pt}} = 85 \text{ erg/cm}^2 \), \( J_{\text{NiO}} = 55 \text{ erg/cm}^2 \), \( J_{\text{NiO}} = -30 \text{ erg/cm}^2 \), and \( K_{\text{NiO}} = 1 \times 10^6 \text{ erg/cm}^3 \) taken from the experiments [3]. Anisotropies of the top and bottom Co/Pt layers were assumed to be \( K_{\text{top}} = -1.5 \times 10^6 \text{ erg/cm}^3 \) and \( K_{\text{bot}} = -2.4 \times 10^6 \text{ erg/cm}^3 \) to provide agreement in the coercive fields with the experiments of Ref. [1]. The exchange coupling at the interface, \( J_{\text{Co/NiO}} \), was considered as a parameter.

The IEC, \( J_{\text{ex}} \), was found from a shift of the minor hysteresis loops, i.e., using the same method as in Ref. [1]. As seen from Fig. 1(b), the calculated hysteresis curve displays a striking resemblance to the experimental curve (compare to Fig. 1(a) in Ref. [1]). \( J_{\text{ex}} \) oscillates with a 2 ML period and decreases with NiO layer thickness as \( 1/N \) that is typical for the domain wall energy [Fig. 1(a)]. The experimentally observed decrease of \( J_{\text{ex}} \) is more abrupt, which is likely due to structural disorder damping magnetic moments correlations.

Because of the IEC an exchange-bias field in the one ferromagnetic film induces a unidirectional anisotropy in the other ferromagnetic film. We simulated the exchange-bias field in the bottom Co/Pt film by adding a \( H_a \mathbf{M}_i \mathbf{t}_i \) term in Eq. (1) for a ML of Co and a ML of Ni at the bottom interface. We found that this induces a shift in the minor hysteresis loop of the top film, which reflects the induced unidirectional anisotropy [see Fig. 1(c)]. In particular, for such a value of \( H_a \) that provides the exchange anisotropy field of 0.35 kOe the induced unidirectional anisotropy field is 0.15 kOe. This fact indicates that in the exchange-coupled [Pt/Co]_3/NiO/[Pt/Co]_3 multilayer the exchange biasing of the top and bottom ferromagnets is not independent.

We thank our colleagues Shireen Adenwalla and Zhongyuan Liu for valuable discussions. This research is supported by NSF (DMR-0203359), NSF-MRSEC (DMR-0213808), and the W. M. Keck Foundation.

Department of Physics and Astronomy, Center for Materials Research and Analysis, University of Nebraska
Lincoln, Nebraska 68588, USA

Received 10 October 2003; published 26 May 2004
DOI: 10.1103/PhysRevLett.92.219703
PACS numbers: 75.70.Cn, 75.30.Gw, 75.70.Ak