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

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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

$$E = \sum_i [-J_i \cos(\theta_i - \theta_{i+1}) - K_i t_i \cos^2\theta_i - \mathbf{H}\mathbf{M}_i t_i], \quad (1)$$

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

The IEC, J_{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_{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_{ex} is more abrupt, which is likely due to structural disorder damping magnetic moments correlations.

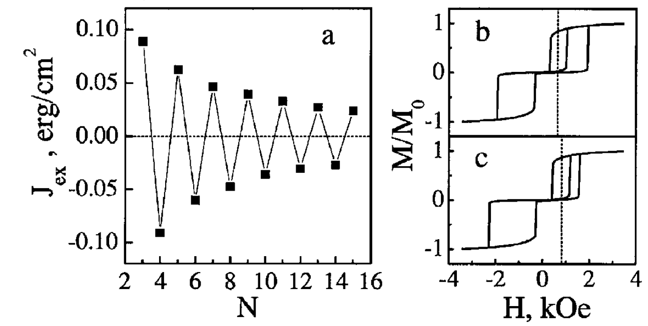

FIG. 1. (a) Interlayer exchange coupling as a function of the number of NiO (111) MLs, N, for $J_{Co/NiO} = 0.3\ \mathrm{erg/cm^2}$. (b) Magnetization versus applied field for $N = 4$. (c) Same as (b) in the presence of bias field in the bottom film.

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 $\mathbf{H}_a\mathbf{M}_i t_i$ 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.

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