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Journal of Magnetism and Magnetic Materials 304 (2006) e62–e64

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The study of exchange coupling in NiFe/Cu/IrMn trilayer structures by MOKE and FMR measurements

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Abstract

The exchange coupling strength of NiFe/Cu/IrMn trilayer films was examined with both a new magneto optical Kerr effect (MOKE) method developed for the exchange coupling field determination and ferromagnetic resonance (FMR) measurements. We found that the value for exchange coupling field obtained by the MOKE technique coincided with FMR result with high accuracy. Other peculiarities of FMR measurements due to interlayer exchange coupling such as angular dependence of resonance field on Cu spacer thickness are also shown in the article.

PACS: 75.70.Cn; 68.55.−a

Keywords: FMR; MOKE; Exchange coupling

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1. Introduction

The exchange coupling between ferromagnet (F) and antiferromagnet (AF) in thin film structure has been intensively studied due to their physical and applicable interest [1]. The exchange coupling strength caused by the interfacial spin configuration of F/AF depends on the thickness of F and AF layers and/or their domain structure [2]. In experiment the magnitude of exchange coupling is commonly represented by hysteresis loop shift (exchange bias), which can be defined as exchange coupling field (H_{ex}) [1]. H_{ex} obtained from hysteresis loop bias, however, exhibits a discrepant value with several different magnetic measurement techniques due to hysteresis loop asymmetry for the sweep field direction [3,4]. The asymmetry comes from the irreversible switching of magnetization to the sweep field direction [5]. The method of ferromagnetic resonance (FMR) represents a powerful tool for studying the magnetic anisotropy. The latter is determined by the intrinsic property of the F layer and/or an exchange coupling in the case of an exchange-coupled thin film [3].

In this work, we report a new magneto optical Kerr effect (MOKE) method for H_{ex} determination to obtain the correct value of H_{ex}. The examined sample was chosen to be the NiFe/Cu/IrMn trilayer structure. The Cu spacer was inserted to control the H_{ex} strength. The measured H_{ex} from MOKE was verified by FMR measurement.

2. Experimental

The exchange-coupled NiFe(5 nm)/Cu(d)/IrMn(10 nm) thin films were fabricated by magnetron sputtering with a seed and a capping layer of Ta(5 nm). The thickness of the Cu spacer was varied from 0.2 to 2 nm. The Cu spacer thickness was carefully controlled by sputter condition and the thickness was confirmed by cross-sectional transmission electron microscopy (TEM) and Auger depth profile. The MOKE measurements were preformed to determine H_{ex}. FMR data were obtained with a laboratory-made

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doi:10.1016/j.jmmm.2006.01.180

spectrometer at 1.687 GHz. The measuring procedure is described elsewhere [6].

3. Results and discussion

Fig. 1 shows the coordinate system in the film plane for our MOKE measurement. $0X$ is the crossing line of incident light flat and magnetic film surface. Lets assume that H_{ex} (and magnetization M) forms a small angle α_0 with the x-axis. The oscillatory (AC) field $h = h_0 \cos \omega t$ and DC field $H_0 = h_0$ of small magnitude h_0 are applied perpendicular to the x-axis (along $0Y$). After applying h and H_0, M forms a small angle α with H_{ex}. Magnetization vector M oscillates in the range from α_0 to $\alpha_0 + \alpha$ because α is time dependent. The oscillation causes the change of magnetic moment to x-axis projection. The MOKE signal can be expressed as follows:

$$\frac{\Delta M}{M}(t) \approx -\frac{h_0 \sin 2\alpha_0}{H_{\mathrm{ex}}} \cos \omega t - \frac{h_0^2 \cos^3 \alpha_0}{4H_{\mathrm{ex}}^2} \cos 2\omega t.$$

Thus, output voltage, which is proportional to $\Delta M/M(t)$, contains two different frequencies: ω and 2ω. Using a selective amplifier, it is possible to distinguish signals on the frequencies ω and 2ω to determine H_{ex} value and direction as described below. Turning the film to determine the easy axis, one can find a position when the signal on the frequency ω is equal to zero. This happens when H_{ex} and M vector coincide with the x-axis, i.e. $\alpha_0 = 0$. To determine H_{ex} value, applying compensation field (DC field H) in the direction opposite to H_{ex} leads to an increase in signal on the frequency 2ω. The signal becomes maximal at the precise compensation, i.e. in the case of $H = H_{\mathrm{ex}}$. This method makes it possible to measure H_{ex} with a high accuracy.

Fig. 2 exhibits the measured H_{ex} data from MOKE and FMR measurements of NiFe(5 nm)/Cu(d)/IrMn(10 nm) thin films with Cu thickness. As shown in Fig. 2, MOKE data coincide well with FMR results. With increase in Cu thickness the H_{ex} value decreased with oscillation, but it was preserved up to 2 nm of Cu thickness. It indicates that the long-range exchange coupling between NiFe and IrM presents through the Cu spacers. The exchange coupling for the thin films with the thin Cu layer inserted could be caused by the possibility of pinhole in their interface. Nevertheless, the oscillatory interaction of H_{ex} values is well exhibited in Fig. 2. According to Ref. [7], the

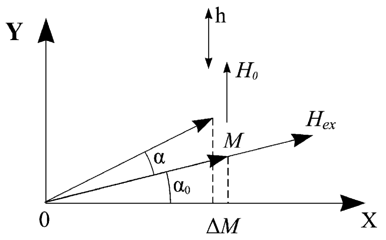

Fig. 1. The rectangular coordinate system in the film plane for MOKE measurement.

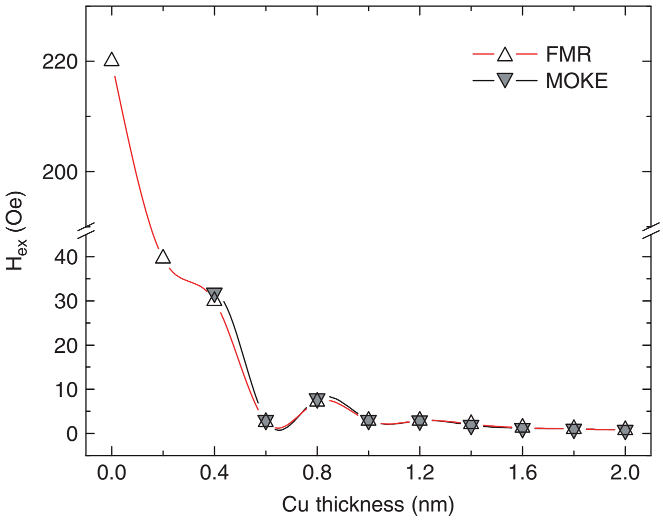

Fig. 2. H_{ex} variation of NiFe/Cu(d)/IrMn thin films with Cu thickness. The up triangle and down triangle indicate the FMR and MOKE measured data, respectively.

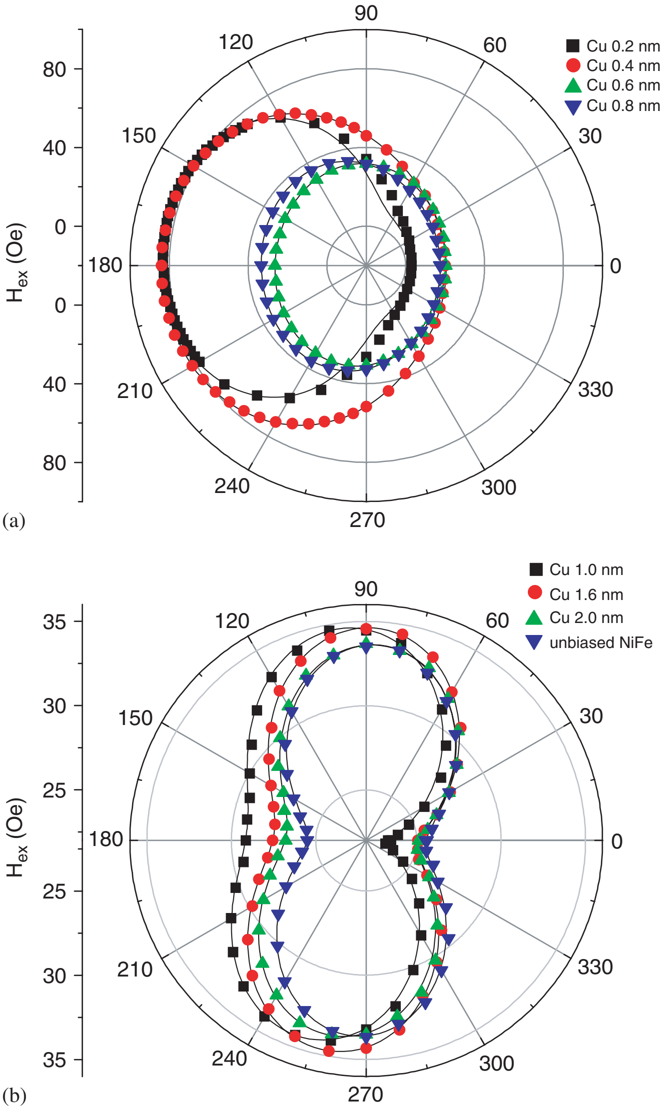

Fig. 3. Polar plot of resonance field for NiFe/Cu(d)/IrMn thin film with Cu thickness. The solid line indicates the fitted data.

oscillatory decrease of H_{ex} was explained by the RKKY-like coupling and interlayer dipolar interaction [7].

Angular dependence of the resonance field (H_r) for the NiFe(5 nm)/Cu(d)/IrMn(10 nm) thin films determined by FMR measurement is shown in Fig. 3. The H_{ex} and a uniaxial anisotropy field (H_k) were extracted using FMR equation, which includes a unidirectional anisotropy term [6]. Fig. 3(a) shows the polar plot of H_r for the thin films with thin Cu layer inserted. The angular variation in H_r indicates a manifest unidirectional behavior as indicating an asymmetric angular curve. The asymmetry reduces with increase in Cu thickness corresponding to decrease in H_{ex} strength. On the other hand, the thin films with thick Cu layer inserted show a small asymmetry and uniaxial shape in the angular curve, as shown in Fig. 3(b). The Cu thickness of the 2-nm sample exhibits a angular shape similar to the unbiased NiFe thin film even though it still remains in exchange-biased state.

4. Conclusion

The exchange-coupling field of NiFe/Cu/IrMn thin films was determined by the new MOKE method for H_{ex} determination and FMR measurement. The MOKE technique was based on reversible measurement unlike hysteresis loop measurement. The measured data from MOKE well agreed with FMR measurement. The angular dependence of the resonance field of FMR well represented unidirectional properties as an asymmetric curve. The thin films with thin Cu layer inserted showed a large asymmetry of angular curve, while the thin films with thick Cu layer inserted showed a mixed curve of unidirectional and uniaxial property.

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