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A study of interlayer coupling of Fe/Ti multilayers

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Magnetic properties of Fe/Ti multilayer films, prepared by DC triode sputtering, have been studied by vibrating sample magnetometer and ferromagnetic resonance (FMR). Spin-wave resonances were observed in Fe/Ti multilayer films in FMR experiments and the spin wave was found to be sustained by both the whole films. Estimated small interlayer coupling constant shows weak exchange coupling effect between Fe layers across Ti spacers. The FMR linewidth, in parallel geometry, of the uniform mode was found to increase with decreasing Fe thickness (20Å ≤ t_{Fe} ≤ 60Å) indicating that it corresponds to an interfacial effect.

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1. Introduction

Nanoscale metallic multilayers containing alternating ferromagnetic and nonmagnetic layers show dazzling magnetic and transport properties such as giant magnetoresistance, which is of great interest for applications in the field of mass storage technology, sensor development, and magnetoelectronics [1-4]. It was observed that the coupling of ferromagnetic layers through nonmagnetic layer in multilayers has an important influence on the magnetic and electric properties of these layered systems. Ferromagnetic resonance is a powerful technique and some important information about the interlayer coupling in multilayers can be shown in FMR spectrum [5-8]. In this work, we report some results on Fe/Ti multilayers. Magnetization and ferromagnetic resonance measurements were used to investigate the magnetic properties of this multilayer system.

2. Experimental details

Fe/Ti multilayers were prepared by DC triode sputtering, using high purity Fe and Ti targets. The initial pressure in the chamber, before the deposition, was roughly at 10^{-7} Torr, while the sputter gas (ultra high purity argon - 5 nines) pressure was kept constant at 7×10^{-4} Torr. Film deposition was done onto a water-cooled glass substrate, being kept at a room temperature. The Fe/Ti multilayers were prepared with Fe layer thickness (t_{Fe}) varying from 20 Å to 60 Å while the Ti thickness (t_{Ti}) was in the range 10-20 Å. The number of periods N varied from 10 to 30. In all cases the first and the last layer was Ti. Low angle X-ray diffraction studies were made to check the periodic structure. Magnetization measurements were done with a vibrating sample magnetometer. The ferromagnetic resonance measurements were performed using a Bruker EPR spectrometer with X-band microwave frequency of 9.8 GHz.

3. Results and discussion

The magnetic properties of the multilayer films were found to be very dependent on t_{Fe}. The magnetization decreases strongly with a decrease in Fe layer thickness. This could be explained in terms of a magnetically dead layer of Fe at each interface due to alloying effects. The thickness of such a dead layer can be estimated as shown in Fig. 1, where we have plotted the product $M_S \times t_{Fe}$ as a function of t_{Fe} at 300K. The slope which corresponds to the magnetization yields 1700 emu/cm^3 at 300 K. The extrapolated Fe dead layer thickness is 12Å at 300K.

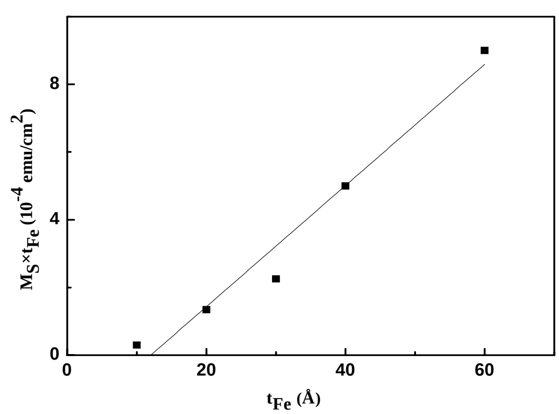

Fig. 1. Variation of the product $M_S \times t_{Fe}$ versus t_{Fe} at 300K.

In FMR measurement, we observed spin wave modes suggesting the interlayer coupling between Fe layers. The multilayer becomes a single coupled system, the spin waves may propagate through the nonmagnetic layers and the standing spin-wave modes are sustained by the whole film. The observed spin wave field positions for the sample are plotted versus n^2 in Fig. 2. The presence of even and odd spin wave resonance modes implies an inhomogeneous distribution of magnetization perpendicular to the film plane, and an asymmetrical spin pinning at the two surfaces and interfaces of the Fe layer [8,9].

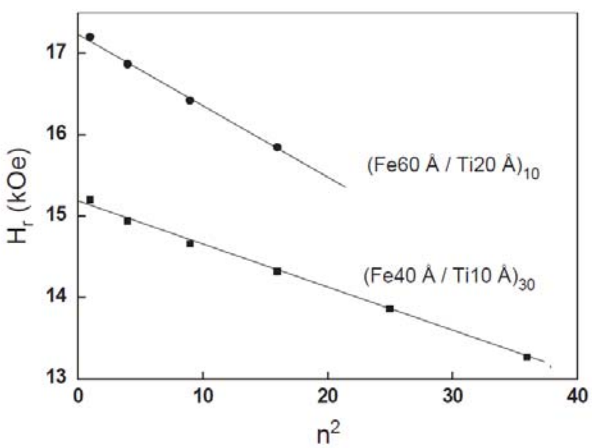

Fig. 2. Resonance field H_r in perpendicular geometry versus n^2 at 300K.

A model for spin waves in ferromagnetic/weak ferromagnetic multilayer proposed by van Staple et al. [10] was extended to the case of ferromagnetic/nonmagnetic multilayers by Wang et al. [11]. In perpendicular geometry, for a single magnetic layer in multilayers, the spin wave dispersion relation can be expressed as:

$$\frac{\omega}{\gamma} = H_{res}^{\perp} - 4\pi M_{eff} + \frac{2Ak^2}{M_S}, \qquad (1)$$

where H_{res} is the resonance magnetic field, $4\pi M_{eff}$ is the effective magnetization, A is the exchange coupling constant in the magnetic layer and k is the spin wave number ($k=n\pi/L$). L and integer n, are the total thickness of the magnetic film sustaining the spin waves and the spin wave mode number, respectively. When the magnetic layers couple to each other, by interlayer exchange interactions, a collective spin wave mode may appear with overall wave vector K. K and k are related by the dispersion relation [10]

$$\cos(kt_{Fe}) = \cos(Kt_{Fe}) + \left[\frac{A}{t_{Fe}A_g}\right] kt_{Fe}\sin(kt_{Fe}), \qquad (2)$$

where t_{Fe} is the thickness of a single magnetic layer and A_g is the interlayer exchange coupling constant per unit area. Within the approximation for small kt_{Fe} and Kt_{Fe}, we have

$$K = k\sqrt{1+\left(\frac{2A}{t_{Fe}A_g}\right)}, \qquad (3)$$

Then, the spin wave dispersion relation of the multilayer film can be expressed by:

$$\frac{\omega}{\gamma} = H_{res}^{\perp} - 4\pi M_{eff} + \frac{2A}{M_S}\left[\frac{1}{\left(1+\frac{2A}{t_{Fe}A_g}\right)}\right]K^2, \qquad (4)$$

K depends on the boundary conditions. For an ideal pinning boundary condition and for an ideal free boundary, $NKt_{Fe} = m\pi$, where m is also an integer. Thus the spin wave spectra should satisfy a n^2 law. In addition, we can estimate the interlayer coupling A_g by analyzing the experimental results shown in Fig. 2 with Eq. (4). In order to determine the interlayer exchange coupling constant A_g, we assumed that the bcc-Fe layers in multilayers have the same exchange coupling constant as a bcc-Fe single layer film ($A = 2\times10^{-6}$ erg/cm). Using this value, we obtained the interlayer coupling constants $A_g \approx$ 3.24 and 0.9 erg/cm^2 for $(Fe_{40Å}/Ti_{10Å})_{30}$ and $(Fe_{60Å}/Ti_{20Å})_{10}$, respectively. A positive sign of A_g means ferromagnetic coupling.

The FMR linewidth $\Delta H_{\parallel}$ is the sum [12] of two contributions: an inhomogeneous width corresponding to a distribution of H_{res} and an homogeneous width associated to the intrinsic relaxation rate of the magnetization vector. The parallel geometry linewidth $\Delta H_{\parallel}$ reflects essentially the intrinsic damping of the magnetic layer. For the Fe/Ti multilayers a linear variation with t_{Fe}^{-1} of the linewidth $\Delta H_{\parallel}$ is observed in (Fig. 3) indicating that it corresponds to an interfacial effect. The physical origin of the interfacial increase of the magnetic layer damping can be associated to the contribution due to the spin-lattice relaxation of the conduction electrons in the Ti and Fe layers.

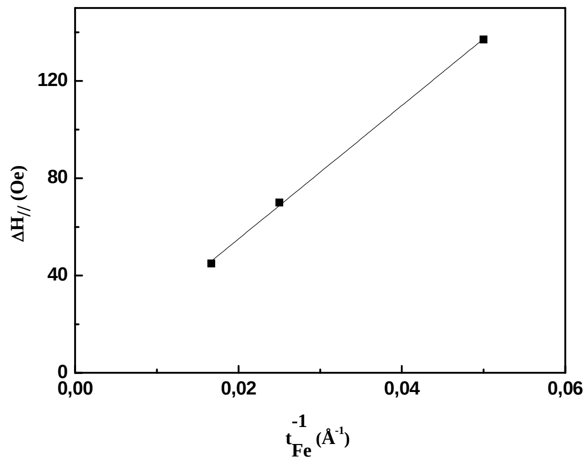

Fig. 3. The t_{Fe}^{-1} dependence of the $\Delta H_{//}$ at 300K.

4. Conclusion

In conclusion, we have studied Fe/Ti multilayers prepared by DC triode sputtering. The magnetizations of Fe/Ti multilayer films are found to decrease with decreasing Fe layer thickness. The spin-waves resonance modes were observed in perpendicular geometry and the interlayer exchange constant was determined. The resonance linewidth $\Delta H_{||}$ are found to increase with decreasing Fe layer thickness.

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