Magnetic properties and interlayer coupling in Co/V multilayers

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Abstract: The magnetic properties of evaporated Co/V multilayer films have been studied by superconducting quantum interference device magnetometer and ferromagnetic-resonance (FMR). FMR has been used to study the interlayer exchange coupling and the FMR linewidth in Co/V multilayers at room temperature. Spin-waves resonance modes were observed in some Co/V multilayers and the relation of resonant field H_{res} with the mode number n obeys the so-called n^2 law. The interlayer coupling constant was determined. The FMR linewidth, in parallel geometry, of the uniform mode was found to increase with decreasing Co thickness (10Å ≤ t_{Co} ≤ 45Å) indicating that it corresponds to an interfacial effect.
Keywords: Co/V multilayers; Spin wave excitations; Interlayer coupling.

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I. Introduction

Magnetic multilayers with suitable magnetic properties would offer improvements over conventional magnetic materials for applications in high density magnetic recording, both as recording media [1] and as heads [2]. One of the main requirements for perpendicular recording and magneto-optic recording is a high perpendicular magnetic anisotropy, which can be achieved in Co-alloy films or magnetic multilayers.
The magnetic properties of multilayers are strongly dependent on their detailed structure and composition, which are determined by the growth conditions used during fabrication [3, 4]. For example, the degree of mixing between adjacent layers determines the amount of Co able to contribute to the magnetic properties of the film, and the degree of crystallographic texture within the layers, combined with any surface anisotropy present determines the overall anisotropy of the multilayers.
It has been reported that the magnetization of several Co multilayer films decreases as the layer becomes thinner [5-8]. As possible reasons one can mention, (1) the unique properties of thinner film, (2) the change in crystal structure, and (3) the change in the electronic state by interaction between Co and the substrate atoms, although more detailed work is required for clarification.
Research on interlayer exchange coupling of magnetic multilayers and double layers is becoming active, and many characteristic of interlayer coupling have been discovered, such as antiferromagnetic, ferromagnetic, and oscillating exchange couplings [9,10].
In this work we describe the ferromagnetic resonance properties for some Co/V multilayers at 300K. FMR studies are particularly suitable for providing information on interlayer exchange coupling of multilayers.

II. Experiment

Co/V multilayers were prepared by sequential evaporation of Co and V using two e-guns installed in ultra high vacuum chamber. Pressure during deposition was in the range 2-5 10^{-9} Torr. The deposition rates of Co and V were variable in the range of 0.2-0.3 Å/s, and the thicknesses are controlled using a quartz oscillator. First a vanadium buffer layer 100Å thick was deposited on glass substrates and it was annealed at 200°C for 2 hours. The magnetic layer thickness t_{Co} was varied in the range of 10 to 45 Å while the V layer t_V was constant at 15 Å. The V top layer in all the samples was 20 Å thick. The number of bilayers N was in the range of 9 to 15. Prior to the growth of the films, about 100 Å of V was deposited as a buffer layer. The magnetization M was measured using the supraconducting quantum interference device (SQUID) magnetmeter in the temperature range 5-300 K. The ferromagnetic resonance was observed at 9.8 GHz with static magnetic field applied both parallel ($H_{//}$) and perpendicular ($H_\perp$) to the film plane at 300K.

III. Results and discussion

The magnetization expressed in terms of total volume of Co decreases from 1050 emu/cm^3 for t_{Co}=45 Å to 940 emu/cm^3 for t_{Co}=10 Å. An effect that is typically encountered in metallic hetero-structures is a change of the magnetic moment in the magnetic layers or an induced magnetic moment in the non-magnetic layers, either due to hybridization of the electronic bands or due to the reduced coordination at the interface (or both). In Co/V multilayers the V layers close to the interface carry an induced magnetic moment which oriented antiparallel to the Co moment, thus leading to an apparent reduction of the total magnetization.

The thickness of the magnetic layers in the multilayers is usually less than 50Å. Thus, for standing spin waves localized within the individual magnetic layers, the wavelength is of the order of tens of angstroms, and the exchange field is so high that the microwave frequency needed to excite the spin-wave modes is much higher than the microwave frequency usually used for FMR, say 9.8 GHz. However, when interlayer coupling occurs, and the multilayer becomes a single coupled system, the spin waves may propagate through the non-magnetic layers, and the standing spin-wave modes are sustained by the whole film. Thus, the wavelength of the spin wave can be increased by one or two orders of magnitude, and the spin-wave resonance may be excited and observed.

The typical FMR spectra for $(Co_{25Å}/V_{15Å})_9$ multilayer are shown in Figs. 1a and 1b, respectively, with the external magnetic field parallel and perpendicular to the film plane. In FMR measurement, we observed spin wave modes suggesting the interlayer coupling between Co 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 (SWR) 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 Co layer [11].

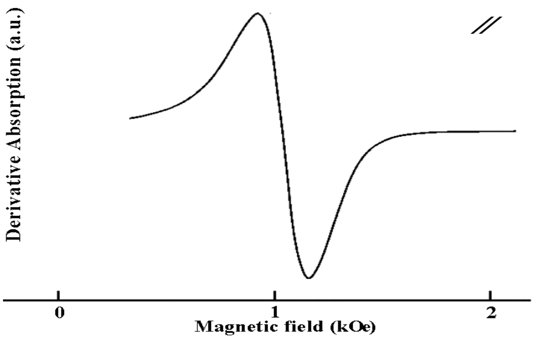

Fig.1a

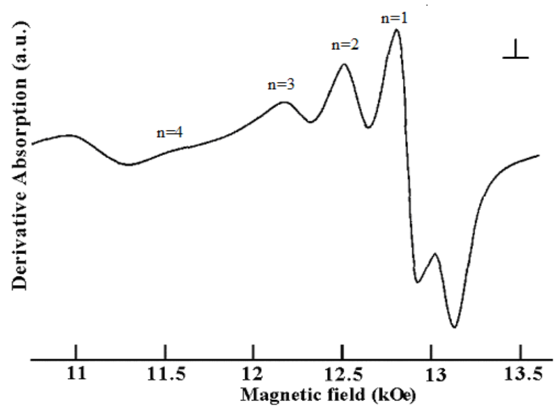

Fig.1b

Fig. 1. FMR spectra for $(Co_{25Å}/V_{15Å})_9$ multilayer in parallel (//) and perpendicular geometry (⊥) at 300K.

A model for spin waves in ferromagnetic/weak ferromagnetic multilayer proposed by van Staple et al. [12] was extended to the case of ferromagnetic/nonmagnetic multilayers by Wang et al. [13]. In perpendicular geometry, for a single magnetic layer in multilayers, the spin wave dispersion relation can be expressed by:

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

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=nπ/L). L is the total thickness of the magnetic film sustaining the spin waves and the integer n is the spin wave mode number. 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 [12]

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

where t_{Co} is the thickness of a single magnetic layer and A_g is the interlayer exchange coupling constant (per area). In the approximation for small kt_{Co} and Kt_{Co},

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

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

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

K depends on the boundary conditions. For an ideal pinning boundary condition and for an ideal free boundary, $NKt_{Co} = m\pi$, m is also an integer. Thus the spin wave spectra should satisfy a n^2 law.

Then 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 fcc Co layers in multilayers have the same exchange coupling constant as a fcc Co single layer film ($A = 1.3\times10^{-6}$ erg/cm) [14, 15]. Using this value, we obtained the interlayer coupling constants $J=A_g/N= 0.015$ and 0.018 erg/cm^2 for $(Co_{10Å}/V_{15Å})_{15}$ and $(Co_{25Å}/V_{15Å})_9$, respectively. These values are much smaller than the interlayer coupling constant in $(Co_{50Å}/Cu_{4Å})_{20}$ multilayer system, J=0.79 erg/cm^2 [13]. A positive sign of J means ferromagnetic coupling and agrees with our expectation.

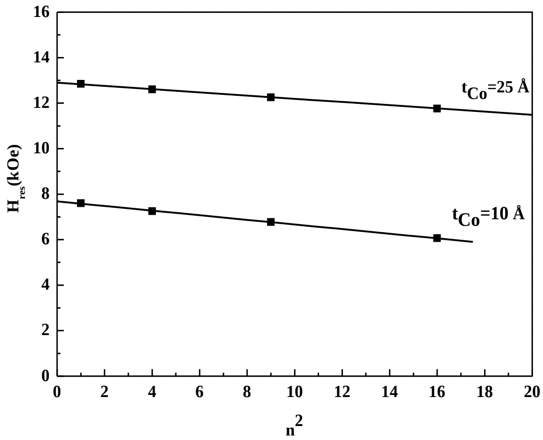

Fig. 2. n^2-dependence of the resonance fields H_{res} (perpendicular configuration) of the spin-wave modes for Co/V multilayers (with t_{Co} = 10 and 25Å) at 300K.

The FMR linewidth $\Delta H_{||}$ is the sum [16] 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 $\Delta H_{||}$ reflects essentially the intrinsic damping of the magnetic layer. For the Co/V multilayers a linear variation with t_{Co}^{-1} of the linewidth $\Delta H_{||}$ is observed (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 V and Co layers.

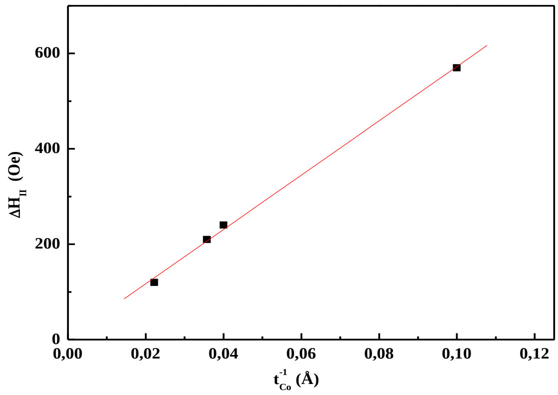

Fig. 3. The t_{Co}^{-1} dependence of the $\Delta H_{//}$ at 300K.

Conclusions

In conclusion, we have studied Co/V multilayers prepared by evaporation in ultra-high-vacuum. The spin-wave modes were analyzed with the existing spin wave resonance theory of multilayers and the interlayer coupling constants were calculated. The resonance linewidth $\Delta H_{||}$ are found to increase with decreasing Co layer thickness.

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References

[1] N. Sato, K. Habu and T. Oyama, IEEE Trans. Magn. MAG-23 (1987) 2614.
[2] F.W.A. Dirne, J.A.M. Tolboom, H.J. de Wit and C.H.M. Witmer, J. Appl. Phys. 66 (1989) 748.
[3] H. Salhi, K. Chafai, O. Msieh, H. Lassri, K. Benkirane, M. Abid, L. Bessais, E.K. Hlil; J Supercond Nov Magn 24 (2011) 1375.
[4] G. Garreau, M. Farle, E. Beaurepaire, K. Baberschke, Phys. Rev. B55 (1997) 330.
[5] H. Salhi, K. Chafai, H. Lassri, M. Abid, E.K. Hlil; J Supercond Nov Magn 24 (2011) 1735.
[6] P.E. Wigen, Z. Zhang, S. Iwata, T. Suzuki, J. Magn. Soc. Jpn 15 (1991) 33; P.E. Wigen, Z. Zhang, Braz. J. Phys. 22 (1992) 267.
[7] D.H. Mosca, F. Petroff, A. Fert, P.A. Schoeder, W.P. Pratt, R. Laloee and S. Lequien, J. Magn. Magn. Mater. 94 (1991) L1.
[8] M. Lassri, H. Hamouda, M. Abid, M. Omri, R. Krishnan, J. Magn. Magn. Mater. 271 (2004) 307.
[9] P. Gruberg, J. Barnas, F. Saurenbach, J. A. Fuss, A. Wolf, and M. Vohl, J. Magn. Magn. Mater. 93

(1991) 58.
[10] S.S.P. Parkin, R. Bhadra, and K.P. Roche, Phys. Rev. Lett. 66 (1991) 2152.
[11] H. Puszkarski, Progr. Surface Science 9 (1979) 191.
[12] R.P. van Stapele, F.J.A.M. Greidanus, and J.W. Smits, J. Appl. Phys. 57 (1985) 1282.
[13] Z.J. Wang, S. Mitsudo, K. Watanabe, S. Awaji, K. Saito, H. Fujimori, and M. Motokawa, J. Magn. Magn. Mater. 17 (1997) 127.
[14] Z. Frait, D. Fraitova, in: A.S. Borovik-Romanov, S.K Sinha (Eds.) Spin wave and magnetic excitations, North-Holland, Amsterdam, 1988, and references therein.
[15] F. Schreiber, Z. Frait, Phys. Rev. B 54 (1996) 6473.
[16] H. Hurdequint, J. Magn. Magn. Mater. 310 (2007) 2061.

