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Spin wave resonance in CoCr/Cu/CoCr sandwiches

Q.Y. Jin [c,*], H.R. Zhai [a,b], Y.B. Xu [a,b], Q.S. Bie [a,b], M. Lu [a,b], Y.H. Shen [c]

[a] Center of Materials Analysis and National Laboratory of Solid State Microstructure, Nanjing University, Nanjing 210008, China
[b] Center for Advanced Studies in Science and Technology of Microstructure, Nanjing 210093, China
[c] T.D. Lee Physics Laboratory and Department of Physics, Fudan University, Shanghai 200433, China

Abstract

Sandwich structures CoCr/Cu/CoCr with varying thickness of Cu spacer from 0 to 40 Å were investigated by ferromagnetic resonance (FMR). Spin waves with odd modes were observed in perpendicular geometry, which suggested the interlayer coupling between two ferromagnetic CoCr layers through nonmagnetic Cu layer. The effective exchange constant showed a monotonous decrease with increasing thickness of Cu.

In recent years, the coupling of the ferromagnetic layers in multilayer, sandwich films through the nonmagnetic metallic layer has attracted considerable interest [1–3]. Various experimental methods have been used to study the behavior and the related phenomena of interlayer coupling. Ferromagnetic resonance (FMR) may be an efficient technique since it can provide information about the magnetic exchange interaction in magnetically ordered materials. It has been reported a lot in Fe/Cu, Pd, Cr/Fe, FeNi/Ag/Ni sandwiches [4–7] and in Fe/Cu, Fe, Co/Pt multilayers [8–10].

Our present study of CoCr/Cu/CoCr sandwiches with thick CoCr layers showed the excitation of standing spin waves in perpendicular geometry for all samples with the thickness of intervening Cu layer varying from 0 to 40 Å, and the effective exchange constant decreased while the thickness of Cu increased.

The CoCr/Cu/CoCr sandwiches were prepared by rf sputtering onto water cooled silicon substrates with a base pressure of 3×10^{-6} Torr. An argon gas pressure of 5 mTorr was used during deposition. A composite target was used for CoCr with the atomic concentration in the films of about $Co_{85}Cr_{15}$ determined by the electron microprobe. In these films, a Cu spacer of various thicknesses of $d_{Cu} = 8$, 12, 16, 26, 30, 40 Å was sandwiched between two thick CoCr layers of 600 Å. The deposition rates of CoCr and Cu were 1.5 and 1.0 Å/s, respectively.

For the FMR measurements, the sample was mounted inside an X-band cavity (9.778 GHz) of a commercial EPR spectrometer of model ER200D-SRC. The FMR was conducted at room temperature with the external magnetic field applied at various orientations with respect to film normal. The measurement of the magnetization was carried out by a vibrating-sample magnetometer (VSM) with applied field of 2 T parallel to the film plane.

In the FMR with the magnetic field parallel to the film plane, only one resonance maximum corresponding to the uniform mode in which all magnetizations are parallel during precession was observed for all samples. When the direction of the static magnetic field changed from in-plane towards the plane normal, the resonance field increased according to the behavior of uniform mode. At a certain angle multiple resonance maxima began to appear. For perpendicular geometry the FMR spectra consisted of several resonant peaks. Fig. 1 shows a typical spectrum of the sample with $d_{Cu} = 8$ Å, in which four resonance modes appear. When the static field turned out of the normal, the resonance modes at low field side became weaker rapidly and disappeared at a critical angle of a few less than 90°. The mode at highest resonance field did not have its intensity significantly decreased when the orientation of

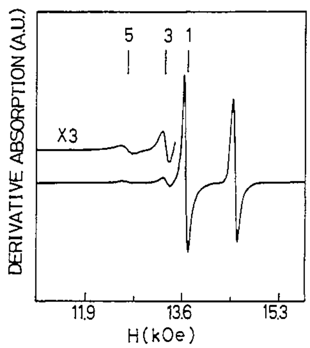

Fig. 1. Spin wave resonance spectrum of CoCr(600 Å)/Cu(8 Å)/CoCr(600 Å) sandwich in perpendicular geometry.

* Corresponding author. Fax: +86-21-5493232; email: yhshen@fudan.ihep.ac.cn.

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the external field changed apart from 90°, but showed an angular dependence different from that of the low field modes. It disappeared at a critical angle of about 85°. From the angular dependence of the resonance modes, we concluded that none of the multiple resonance maxima in perpendicular (⊥) geometry was due to the stratification in the layers and they were certain modes of non-uniform procession.

We suppose the well-known resonance condition for single layer film with ⊥ geometry can be applied to the sandwich structure,

$$\omega/\gamma = H_{res} - 4\pi M_{eff} + (2A/M_s)k^2 \quad (1)$$

where ω is the microwave frequency, γ the gyromagnetic ratio defined by $g\mu_B/\hbar$ with the Landé g factor and the Bohr magneton μ_B, $4\pi M_{eff}$ the effective magnetization including the saturation magnetization $4\pi M_s$ and the anisotropy field $2K/M_s$. The last term represents the exchange field when standing spin wave is excited. $k = n\pi/L$ is the wave number with L the thickness of the film sustaining the standing spin waves and n the mode number.

In the model of homogeneous magnetization and entire surface pinning, only an odd number of spin wave modes could be excited [11]. For the samples with $d_{Cu} = 8$ and 12 Å, H_{res} of spin waves exhibited a linear relation with respect to n^2 as shown in Fig. 2 if $n = 1$, 3, 5 were assigned. The extrapolation of the straight line in Fig. 2 to $n = 0$ gives the $k = 0$ uniform-mode resonance field. From the slope of the lines, the effective exchange constant A could be obtained and its relation with the thickness of Cu layer is shown in Fig. 3, in which the data for $d_{Cu} = 0$ was taken from the spectrum of single layer CoCr film of thickness 1200 Å. The exchange constant A showed a monotonous decrease with increasing d_{Cu} and it approached a constant value when d_{Cu} was larger than 20 Å.

Finally, we would like to mention a few words about the resonance modes at highest field. The spacing between the H_{res} of this mode and $n = 1$ spin wave mode was not sensitive to d_{Cu} and it appeared only when the field orientation was near to the normal. Thus it might be thought also as a kind of non-uniformed mode, such as a surface mode. To identify it, more work is needed.

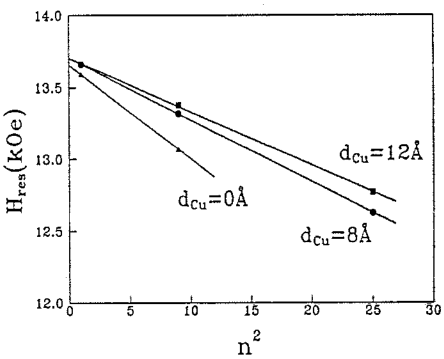

Fig. 2. Resonance field H_{res} at the perpendicular orientation versus n^2 for samples with $d_{Cu} = 0$, 8, 12 Å, where n is the number of the spin wave modes.

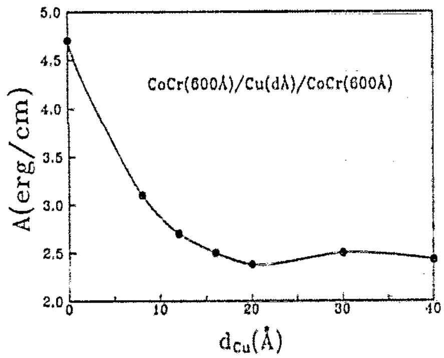

Fig. 3. Effective exchange constant A as a function of the thickness of Cu layer.

In conclusion, the multimodes of spin waves in perpendicular FMR spectra have been found in CoCr/Cu/CoCr sandwich structures with various thickness of Cu spacer, which suggests exchange coupling between two CoCr layers across the Cu layer. The effective exchange constant decreased monotonously when the thickness of Cu increased and approached a small value while $d_{Cu} \geq 20$ Å showing a nearly magnetic decoupled state, together with a significant weak strength of spin-wave resonance peaks with $d_{Cu} \geq 20$ Å. The observation of only odd spin wave modes and the obeyance of the resonance field with the n^2 law implies a homogeneous structure of sandwiches and nearly pinning at the surfaces.

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