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Magnetic and magneto-optical properties of Co/Cu multilayers

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Abstract

Co/Cu multilayers made by rf sputtering were studied with a vibrating sample magnetometer (VSM), ferromagnetic resonance (FMR) and magneto-optical (MO) spectra. The magnetization increases with decreasing thickness of Cu, which was attributed to the joint effect of interlayer coupling and 2D magnetism. Spin polarization of Cu related to interlayer coupling was indicated from the data of VSM and FMR measurements. The different feature of the experimental and calculated MO spectra further suggested that the Cu is spin polarized and gives an additional MO activity.

Magnetic/nonmagnetic multilayers has attracted much attention recently [1]. The giant magneto-resistance, perpendicular anisotropy and magneto-optical effect etc. have been studied extensively. We have also investigated Fe/Cu [2], Fe/Ag [3], Co/Cu and Co/Al multilayers with static magnetic measurement, magnetic resonance and magnet-optical spectra. Our main interest is the possible spin polarization of the nonmagnetic layers in the multilayers. We tried to get some insight into this question from magnetic and magneto-optical measurements. In this paper, some results of our studies of Cu/Cu multilayers are presented.

The samples were prepared by rf sputtering onto water cooled glass substrates. The base pressure is 3×10^{-6} Torr, and the argon gas pressure is 5×10^{-3} Torr during deposition. The deposition rates of cobalt and copper are 1.7 Å/s and 1.0 Å/s, respectively. Low angle X-ray diffraction pattern showed that the multilayers are well periodically layered. The difference between the nominal period and that obtained from X-ray diffraction is about only 3%. Large X-ray diffraction pattern of the samples showed a strong diffraction peak located at the middle between Cu(111) and Co(111). This suggested that the Co and Cu layers almost have fcc structure. For the FMR experiments, the samples were mounted inside an X-band cavity (9.7 GHz) of a commercial EPR spectrometer. The magneto-optical Kerr rotation was measured with a Faraday-modulated MO spectrometer. The magnetization of the samples was measured with VSM at room temperature with an applied magnetic field upto 22 kOe.

Fig. 1(a) shows the saturation magnetization M_{VSM} of $[Co(22\ Å)/Cu(d_{Cu}\ Å)]_{50}$ multilayers measured with VSM. With decreasing d_{Cu}, M_{VSM} increases monotonously and approaches the bulk value for $d_{Cu} = 6$ Å. It is well known that when the thickness of the magnetic layers is small, two dimensional magnetism may appear. The magnetic moment decreases more rapidly with raising temperature than that of bulk materials. Thus for larger d_{Cu}, a reduction of magnetization at room temperature is due to this dimensional effect. However, when d_{Cu} decreases, the interlayer coupling between neighbouring Co layers appears and gets stronger with the decrease of d_{Cu}. As a result of the increasing coupling strength, the multilayers behave more and more three dimensionally [4]. Thus the

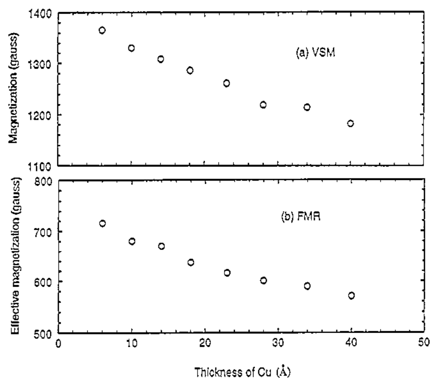

Fig. 1. Magnetization M_{VSM} (a) and effective magnetization M_{eff} (b) of $[Co(22\ Å)/Cu(d_{Cu}\ Å)]_{50}$ multilayers measured with VSM at room temperature.

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magnetization measured at room increases with decreasing d_{Cu}.

Fig. 1(b) shows the effective magnetization M_{eff} of the Co/Cu multilayers obtained from FMR measurements. M_{eff} also increases with decreasing d_{Cu}. $4\pi M_{eff}$ is determined by both the demagnetization field $4\pi M_{Co}$ and the anisotropy field H_k of the Co sublayers, that is:

$$4\pi M_{eff} = 4\pi M_{Co} - H_k. \quad (1)$$

As the thickness of the Co layers is kept unchanged, we supposed that H_k is approximately constant for all the samples. The change of M_{eff} for different d_{Cu} is due to the change of the magnetization M_{Co} of Co layers. Again, we think that the increase of M_{eff} is caused by the joint effect of interlayer coupling and 2D magnetism.

Recently, X-ray dichroism and spin-polarized photoemission [5] studies of Co/Cu showed that Cu is spin polarized. After a careful comprision of Figs. 1(a) and (b) we noticed that the increase of M_{VSM} is faster than that of M_{eff} with decreasing d_{Cu}. As a possible mechanism, we suppose that Cu layers in our Co/Cu multilayers are also spin polarized for smaller d_{Cu}. M_{VSM} is contributed by the magnetization of both Co (M_{Co}) and Cu (M_{Cu}) sublayers, that is

$$M_{VSM} = M_{Co} + (d_{Cu}/d_{Co})M_{Cu}. \quad (2)$$

Thus the difference of M_{VSM} and M_{eff} can be expressed as

$$M_{VSM} - M_{eff} = (d_{Cu}/d_{Co})M_{Cu} - H_k/4\pi. \quad (3)$$

To estimate the magnitude of M_{Cu}, we assume that (i) The anisotropy field is constant for all the samples. (ii) For $d_{Cu} = 40$ Å, there is no spin polarization ($M_{Cu} = 0$) and the difference is the anisotropy field. Fig. 2 is the magnetization M_{Cu} of Cu calculated from Eq. (3). It decreases rapidly with increasing d_{Cu} with about d_{Cu}^{-2}. It is interesting to note that the relation of interlayer coupling constant with the thickness of nonmagnetic layer is also d^{-2} [6]. This correlation may indicate that the interlayer exchange coupling between adjacent ferromagnetic layers in the multilayers is transmitted by the spin polarization in the nonmagnetic layers, as recently shown by spin polarized photoemission [5] and NMR [2]. The magnetization of Cu

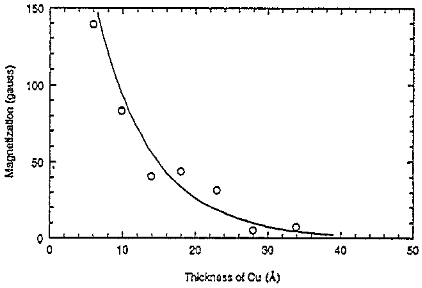

Fig. 2. Magnetization of Cu layers in [Co(22 Å)/Cu(d_{Cu} Å)]$_{50}$ multilayers.

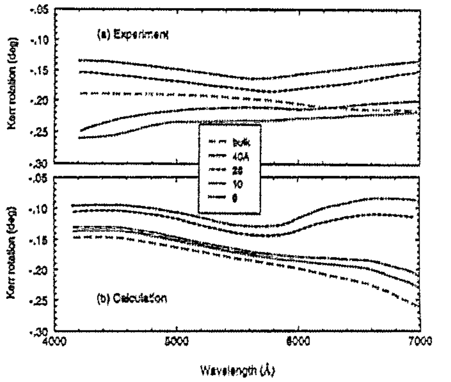

Fig. 3. Experimental (a) and calculated (b) Kerr rotation spectra of [Cu(22 Å)/Cu(d_{Cu} Å)]$_{50}$ multilayers.

is about $0.09\mu_B$ for $d_{Cu} = 10$ Å, which is of the same order of magnitude of the theoretical prediction (0.03–$0.08\mu_B$) made by Fu et al. [7].

Fig. 3 is the Kerr rotation Θ_k spectra of Co/Cu multilayers for different d_{Cu}. For $d_{Cu} = 24$ and 40 Å, the experimental results are in coincidence with that of calculations. However, for $d_{Cu} = 6$ and 10 Å, the experimental and calculated MO spectra show different features. With the decrease of the wavelength, the experimental Θ_k increases, but the calculated Θ_k decreases. In Fe/Ag multilayers, we found that the average direction of the magnetization of Ag is opposite to that of Fe, which leads to an increase of MO effect at long wavelength side. Here, in Co/Cu multilayers, the additional MO activity leads to an increase of MO effect at short wavelength side. We suppose that the Cu is also spin polarized but with average direction parallel to that of Co, which is in agreement with the result of magnetic measurements given above.

In summary, the magnetic and magneto-optical properties of Co/Cu multilayers were measured with VSM, FMR and MO spectrometer. From these properties, the spin polarization of Cu was indicated. At last, we would like to note that, spin polarisation of nonmagnetic layers in multilayers is an interesting but difficult question to investigate. Further studies are needed to testify the preliminary results obtained in this paper.

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