

Microstructure and magnetic properties of Co/Os/Co and Fe/Os/Fe thin films

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Abstract

The Co/Os/Co and Fe/Os/Fe thin films were deposited on natural oxidized Si (100) substrates at room temperature by magnetron sputtering. The thickness was kept at 100 Å for all the magnetic layers, and was varied between 3 and 20 Å for the Os layer. Effects of the Os layer thickness and microstructure on the magnetic properties of the film were investigated. The results showed that the antiferromagnetic coupling occurred for the Co/Os/Co thin films with the Os thickness between 7 and 13 Å. Due to the mismatch of Fe and Os, pinholes in the Os layer could be observed. The presence of interface roughness and pinholes reduces the antiferromagnetic interlayer exchange coupling strength and affect the dependence of the interlayer exchange coupling on the Os layer thickness. From the magnetoresistance (ΔMR) study, the largest ΔMR ratio arising from antiferromagnetic coupling for Co/Os/Co and Fe/Os/Fe thin films are about 0.45% and 0.07% respectively. The small ΔMR in Fe/Os/Fe system is explained by the large interface roughness and lattice mismatch effect.

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Antiferromagnetic interlayer exchange coupling due to indirect exchange of ferromagnetic films across interlayer was observed in Fe/Cr/Fe multilayer in 1986 [1]. Thereafter, it has been shown to have an important influence on the electrical properties of the multilayer film. Large change in resistance with magnetic field was discovered in Fe/Cr superlattice [2]. This discovery led to an intensive research in the past few years due to its potential in commercial applications. It has been shown that the synthetic antiferromagnet structure is an important component in MRAM device [3–5]. A synthetic antiferromagnet is a structure where two ferromagnetic layers are antiferromagnetically coupled through a thin nonmagnetic spacer. So, it is important to understand the mechanism of interlayer exchange coupling by studying the magnetization process of two magnetic layers separated by the nonmagnetic layer. In this work, we investigate the

microstructure and magnetic properties of Co/Os/Co and Fe/Os/Fe thin films of the Os thin films inserted in Co or Fe magnetic layers.

The Co/Os/Co and Fe/Os/Fe thin films were deposited on natural-oxidized Si (100) substrates at room temperature by DC-magnetron sputtering with a base pressure less than 1×10^{-8} Torr. The thickness was kept at 100 Å for all the magnetic layers, and was varied between 3 and 20 Å for the Os layer. The microstructure of the film was investigated by high-resolution transmission electron microscopy (HRTEM). Magnetic properties of the films were measured by a vibrating sample magnetometer (VSM) at room temperature. The magnetic field was applied in the film plane. The magnetoresistance was measured with a standard DC four-probe technique.

Fig. 1a shows the HRTEM image of the as-deposited Si//Co/Os/Co thin film. The Os thickness is 9 Å. The clear contrast difference between the Co and Os layers resulting from the scattering and absorption effects for different atoms could be observed. Besides, it can be seen that the Os

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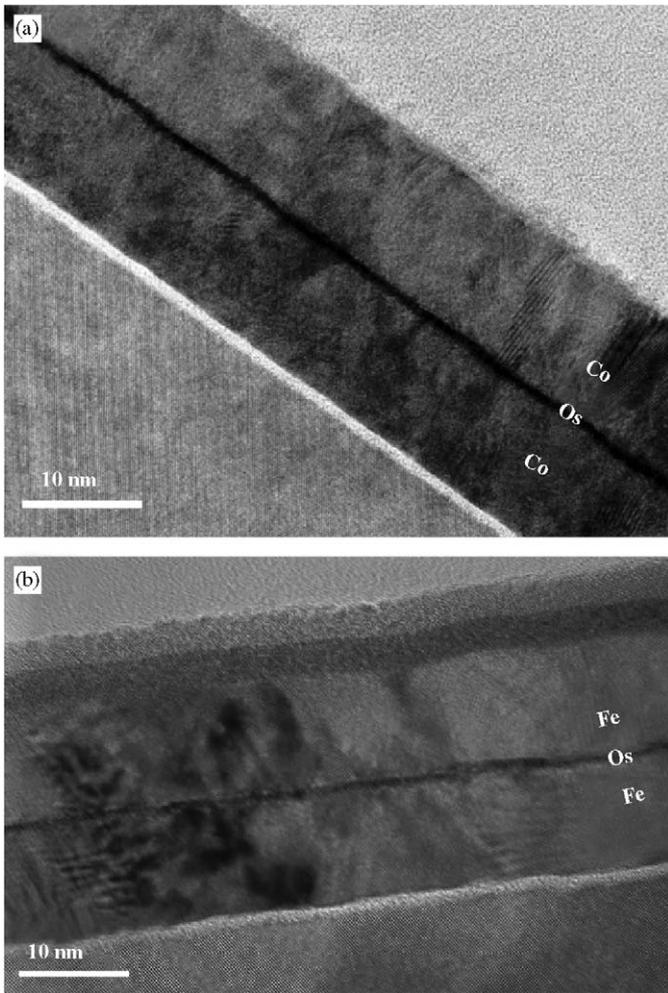


Fig. 1. Cross-sectional HRTEM image of as-deposited (a) Si//Co/Os/Co and (b) Si//Fe/Os/Fe thin film.

layer was grown continually between Co layers. From the high-magnification cross-sectional image (not shown), we did observe polycrystalline structures in the Os layer, and the lattice image of Os could be clearly observed from the lower interface to upper interface. The HRTEM image also shows that the crystalline structure is continuous throughout the multilayer. Fig. 1b shows the HRTEM image of the as-deposited Si//Fe/Os/Fe thin film. The Os thickness is 9 Å. It can be observed that the Os layer is crystalline and the interface between Fe and Os layers were relatively rough. The thickness fluctuations at the interfaces will affect the interlayer coupling. Besides, a discontinuity in the Os layer was some times existed with a Fe columnar grain. These discontinuities could be distinguished even if the TEM image is in out of focus conditions to enhance the Fresnel contrast [6]. These discontinuous pinholes could be related to the mismatch between Fe and Os. The presence of interface roughness and pinholes will reduce the antiferromagnetic coupling strength and will result in the biquadratic coupling or the orange peel coupling [7–9], which tends to the parallel alignment of the ferromagnetic layers magnetizations.

Fig. 2 shows the M–H loops of as-deposited Si//Co/Os/Co thin films with various Os thickness. The thickness was varied between 3 and 20 Å for the Os layer. Nonrectangular M–H loop was observed for samples with the Os thickness between 7 and 13 Å, which indicated that the antiferromagnetic coupling occurred for these samples. It can be seen that the relatively large saturation field occurred for samples roughly with the Os thickness between 7 and 11 Å. It can be observed that the ferromagnetic coupling occurred in samples with Os layer thickness less than 5 Å or between 15 and 20 Å. In plane squareness ($S_{||}$) of

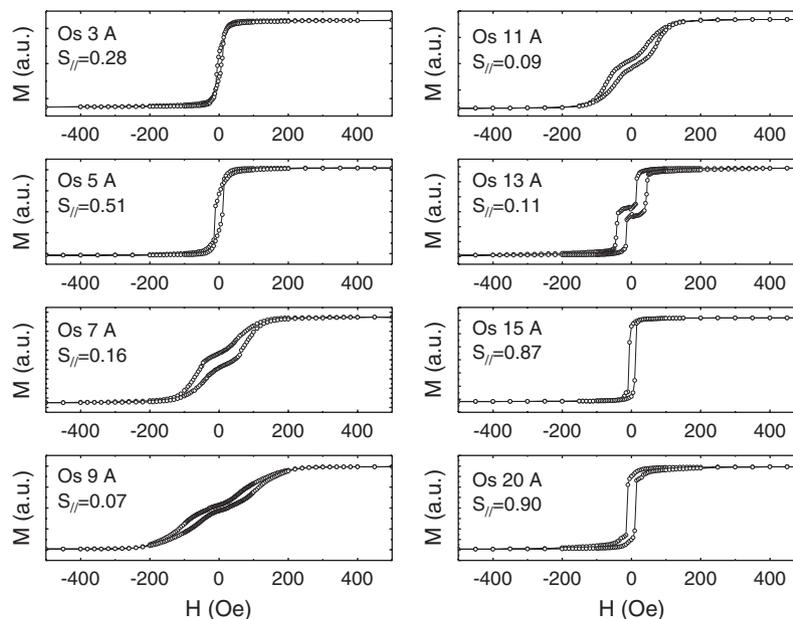


Fig. 2. M–H loops of as-deposited Si//Co/Os/Co thin films with various Os thickness.

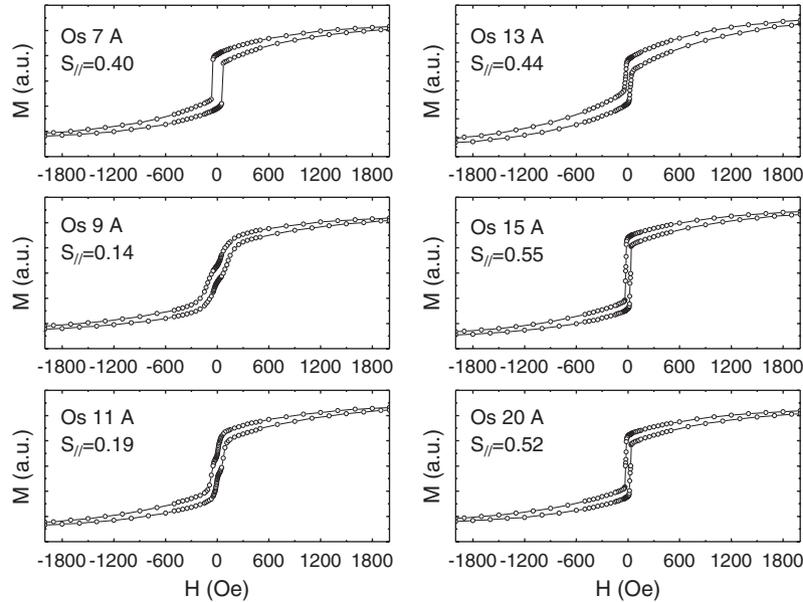


Fig. 3. M–H loops of as-deposited Si//Fe/Os/Fe thin films with various Os thickness.

magnetization curves were indicated in each M–H loop, respectively. The smallest $S_{||}$ of about 0.07 occurred in sample with Os thickness of 9 Å, which is related to the antiferromagnetic coupling for samples with the Os thickness between 7 and 11 Å.

Fig. 3 shows the M–H loops of as-deposited Si//Fe/Os/Fe thin films with various Os thickness. The thickness was varied between 7 and 20 Å for the Os layer. The antiferromagnetic coupling occurred for samples with the Os thickness of 9 and 11 Å. The M–H loop exhibits ferromagnetic exchange coupling for sample with the Os thickness of 7 Å and between 13 and 20 Å. The rougher interface and pinholes as discussed from the TEM results suggest that ferromagnetic coupling may occur easily in Fe/Os/Fe than Co/Os/Co. Large remanent magnetization and squareness are observed for samples with ferromagnetic coupling, the value of $S_{||}$ is roughly between 0.4 and 0.6. The smallest $S_{||}$ of about 0.14 occur for the sample with the Os thickness of 9 Å.

The anisotropic magnetoresistance (AMR) has always existed in both trilayer systems, even for samples with the Os thickness of 9 Å, i.e. for sample with strongest antiferromagnetic coupling. Fig. 4 shows the variations of the $\Delta MR\%$ with Os layer thickness of the Co/Os/Co and Fe/Os/Fe thin films. The measurements have been made with the magnetic field in the film plane and parallel to the current direction. The ΔMR was defined as shown in the inset figure ($\Delta MR = 100(R_p - R_0)/R_0$), that R_p is the peak value of resistance due to interlayer exchange coupling. The maximum ΔMR as shown in Fig. 2 is roughly 0.45% and 0.07% for Co/Os/Co and Fe/Os/Fe systems, respectively. This is related to the rougher interface of Fe/Os/Fe system.

In conclusion, the Co/Os/Co and Fe/Os/Fe thin films with Os layer varied between 3 and 20 Å were investigated.

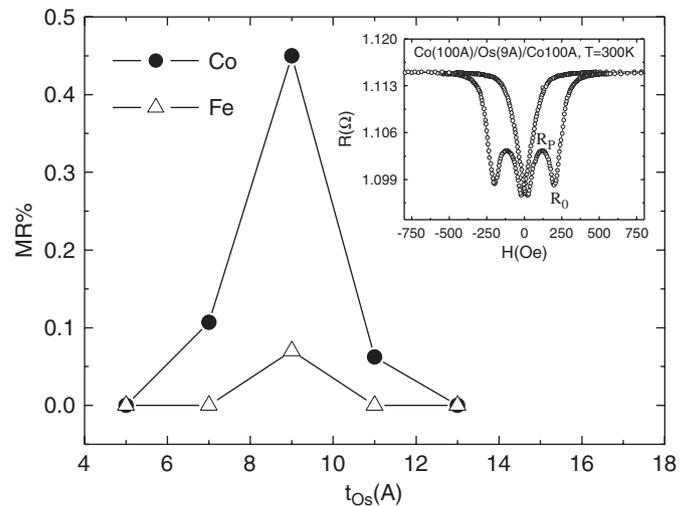


Fig. 4. Relationship between $\Delta MR\%$ and Os thickness of Si//Co/Os/Co and Si//Fe/Os/Fe thin film.

The results showed that the antiferromagnetic coupling occurred for the Co/Os/Co thin films with the Os thickness between 7 and 13 Å. Due to the mismatch of Fe and Os, pinholes in the Os layer could be observed. The presence of interface roughness and pinholes reduces the antiferromagnetic interlayer exchange coupling strength and affects the dependence of the interlayer exchange coupling on the Os layer thickness. From the magnetoresistance (ΔMR) study, the largest ΔMR ratio arising from antiferromagnetic coupling for Co/Os/Co and Fe/Os/Fe thin films are about 0.45% and 0.07%, respectively. The small ΔMR in Fe/Os/Fe system is explained by the large interface roughness and lattice mismatch effect.

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