MODIFYING INTERLAYER COUPLING IN CoFe/Bi/Co TRILAYER JUNCTION BY POST-ANNEALING TREATMENTS

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Introduction

The discovery of interlayer coupling between two ferromagnetic (FM) layers separated by a nonmagnetic spacer has aroused strong interest among the international scientific community, because such coupling has great potential to be used in various applications. The variation in the coupling strength with the thickness of the spacer layer and the oscillatory behavior of interlayer coupling makes this field even more interesting. In our earlier studies [1], interlayer coupling with a very long range was found to be present in a trilayer system with Bi as the spacer. Additionally, the interlayer coupling exhibits an unique dependence on temperature. No exact theory is available that explains satisfactorily the special characteristics of interlayer coupling in the system described herein. To investigate the dependence of interlayer coupling on the interface structure could increase our understanding of this issue. Changing the interlayer coupling strength following sample preparation is normally non-trivial. However, the low melting point of Bi enables thermal annealing to be easily used to modify the layer structures, to enable the variation in the interlayer coupling with interface structure to be observed.

Experiments

Trilayer structures CoFe/Bi/Co with a magnetic layer with a thickness of 60nm and a bismuth layer with a thickness from 1nm to 60nm were prepared by dc sputtering through various masks at room temperature. The standard structures of the trilayer junction comprise two perpendicular ferromagnetic stripes with a length of 1cm, separated by a circular spacer with a diameter of 0.3 cm. Samples prepared at room temperature were annealed at various temperatures from 50°C to 250°C for 30 minutes in each run respectively. The crystalline structure of the as-prepared and annealed samples was checked by X-ray diffraction. TEM cross-sections were examined to characterize the microstructures of the as-deposited and annealed samples. Magnetization loops associated with as-prepared and annealed samples were obtained using a vibrating sample magnetometer (VSM) and a magnetic field was applied parallel to both Co and CoFe stripes respectively.

Results and discussion

The diffraction patterns of as-prepared samples reveal that major observed diffraction peaks are from Bi because Bi has a larger scattering factor than Co or CoFe, although the Bi spacer in general is much thinner than Co or CoFe. However, the thin samples annealed up to 100°C exhibited less intense peaks, indicating that annealing process promotes the mobility of Bi atoms. However, the intensity gradually increases as the annealing temperature is further increased. Above 200°C, a larger number of diffuse peaks appear with reduced

intensity; these peaks are broader than those of the as-made samples. The broadening of the peaks and the loss of high-order peaks are characteristic of increased layer roughness. Therefore, the roughness increases with the annealing temperature above 200°, leading to less intense and broader reflections. These changes can be interpreted as associated with an initial sharpening of the interface or a decrease in its roughness, followed by the onset of de-stratification. However for a thick Bi spacer, the intensity of the peaks remains approximately constant and the X-ray diffraction pattern does not change much. Fig. 1 reveals that the saturation field, H_s , varies in a complex way with the thickness of the spacer layer. The as-made samples exhibit an oscillating interlayer coupling over a long period of oscillation, with a period of about 18 nm; the coupling is oscillating between AFM as well as FM orderings and has a long range of up to 50 nm [1]. Samples annealed at 50°C exhibit the same behavior but samples annealed at a higher temperature exhibit different behaviors. The samples annealed at 100°C exhibit a different dependence on Bi thickness and large reduction of H_s for $t_{Bi} \leq 20nm$. The original AFM coupling even becomes FM coupling and vice versa. At $t_{Bi} > 20nm$, very little change was observed, except when H_s was reduced for all samples in this category. Further increasing the annealing temperature to 200°C did not cause the shapes of the curves to change as H_s was increased with higher annealing temperatures. When the annealing temperature reached 250°C - close to the melting temperature of Bi, which is approximately 271°C - the variation in H_s with the nominal thickness of Bi was similar to that of as-made samples. The cross-section TEM images indicate that the as-made samples had clear three-layer structures with thickness of bismuth spacer layer close to the nominal value. Besides, all three layers were crystalline. Annealing below 100°C yielded rougher interfaces than those of as-made sample. As the annealing temperature was increased, the interface became smoother because the atoms diffused in the plane of the interface, smoothing it out. However, as the annealing temperature reached 250°C, interdiffusion of Bi and Co layers also occurs, causing the spacer layer to behave like a ferromagnet with thin spacers. No clear boundary was easily identified. The correlation of interface parameters with interlayer coupling will be analyzed and reported in this presentation.

Fig. 1. Variation of H_s with thickness of Bi spacer for different samples annealed at various temperatures

Reference

[1] Jen-Hwa Hsu and D. Sahu, submitted to Appl. Phys. Lett..