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Microstructure and magnetoresistance of MgO thin film with CoFeB and CoFeC underlayers

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Abstract

The MgO thin films were deposited on CoFeB and CoFeC magnetic underlayers at room temperature by magnetron sputtering. The microstructures of the MgO films were investigated by high-resolution transmission electron microscopy (TEM). The results showed that the atomically resolved MgO (0 0 1) lattice planes were parallel to the film plane for MgO layers with CoFeB and CoFeC underlayers. Besides, the X-ray diffraction analyses indicated that the intensity of MgO (0 0 2) diffraction peak was enhanced as the MgO layer was deposited on the CoFeC underlayer. The relatively large tunnelling magnetoresistance ratio for the as-deposited film was obtained at room temperature as the MgO layer was deposited on the CoFeC underlayer. The larger tunnelling magnetoresistance ratio in as-deposited CoFeC/MgO/CoFe magnetic tunnel junction may be related to the higher (0 0 1) texture of the MgO barrier.

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Keywords: Microstructure; MgO films; Tunnel magnetoresistance

Magnetic tunnel junctions have attracted much attention due to its potential for applications in spintronic devices. The large MR ratio is beneficial for devices applications. Giant tunneling magnetoresistance (TMR) ratio based on (0 0 1) oriented MgO tunnel barrier has recently been demonstrated [1,2]. The TMR effect has been observed in a wide variety of structures and materials. The MR ratio of magnetic tunnel junctions depends critically on materials and the microstructure characteristics of the FM electrode and insulating layer. In this work, we investigated the microstructure and magnetoresistance of MgO thin films with CoFeB and CoFeC magnetic underlayers.

All the samples were deposited on thermally oxidized Si (0 0 1) substrates at room temperature by magnetron sputtering with a base pressure less than 1×10^{-8} Torr. The MgO layer was deposited by RF sputtering from a sintered MgO target. The CoFeB, CoFeC, and CoFe layers were deposited by DC sputtering from $Co_{60}Fe_{20}B_{20}$, $Co_{60}Fe_{20}C_{20}$, and $Co_{90}Fe_{10}$ alloy targets, respectively. Specimens for cross-section transmission electron microscopy (TEM) observation were prepared by mechanical grinding to a thickness of about 15 μm, followed by appropriate ion milling. The microstructure and crystal structure of the film were investigated by JEOL JEM-2100 field emission transmission electron microscope and thin-film X-ray diffractometer (XRD) with CuK_α radiation. The junction geometry for magnetotransport properties measurement was patterned by e-beam lithography and Ar ion milling with a junction size of 2×1 μm. The electrical resistivity was measured with a standard DC four-probe technique.

Fig. 1(a) and (b) show the high-resolution transmission electron microscopy (HRTEM) images of the as-deposited CoFeB/MgO and CoFeC/MgO thin films, respectively. It can be seen that the CoFeB and CoFeC underlayer are amorphous and the polycrystalline MgO layer was deposited on the amorphous underlayer. As shown in Fig. 1(a) and (b), the MgO (0 0 1) lattice planes were parallel to the film plane and the atomic layers were grown continuously from the initial stage of the film growth. The selected area diffraction (SAD) pattern of the

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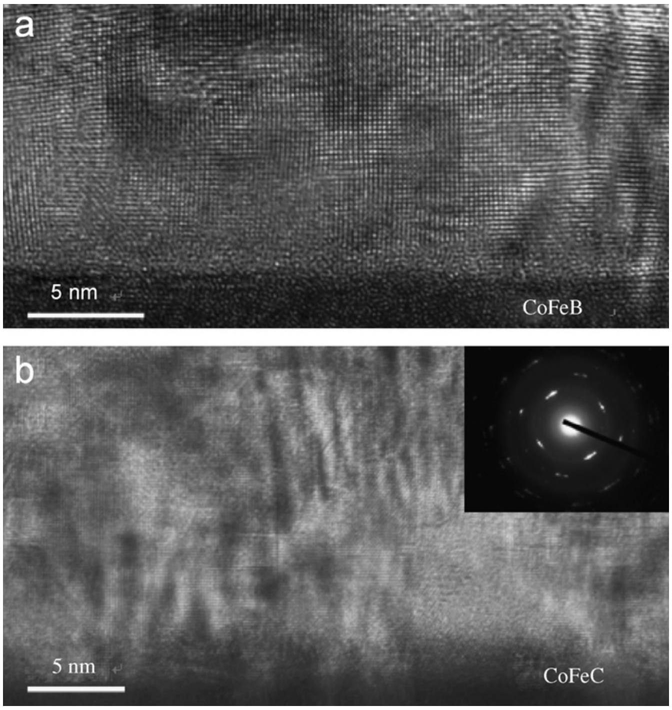

Fig. 1. Cross-sectional HRTEM images of as-deposited (a) CoFeB/MgO and (b) CoFeC/MgO thin films. The SAD pattern of the CoFeC/MgO film is shown in the inset of Fig. 1(b).

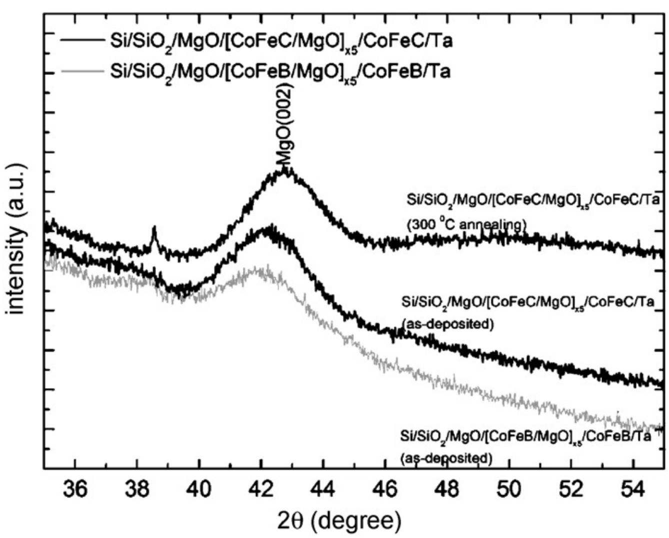

Fig. 2. X-ray diffraction patterns of the MgO/[CoFeB/MgO]$_{x5}$/CoFeB/Ta and MgO/[CoFeC/MgO]$_{x5}$/CoFeC/Ta thin films.

as-deposited CoFeC/MgO film is shown in the inset of Fig. 1(b). The (0 0 1) textured pattern could be observed obviously. This highly (0 0 1) oriented MgO thin film combined with the CoFeC or CoFeB soft magnetic underlayer can be applied to the underlayer of double-layered perpendicular recording medium [3]. However, some crystal defects, such as dislocations and stacking faults, could be observed in MgO thin films for both underlayers.

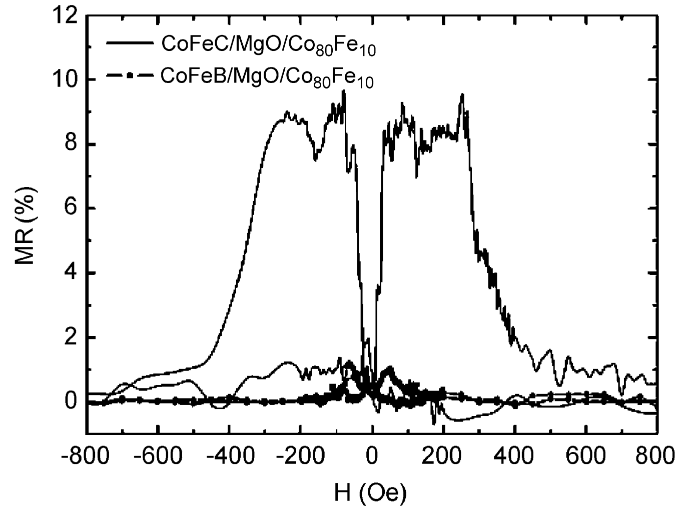

Fig. 3. The MR curves of CoFeB/MgO/CoFe and CoFeC/MgO/CoFe magnetic tunnel junctions.

Fig. 2 shows the X-ray diffraction patterns of the Si/SiO_2 MgO 5 nm/[CoFeB 3 nm/MgO 3 nm]$_{x5}$/CoFeB 3 nm/Ta and Si/SiO_2/MgO 5 nm/[CoFeC 3 nm/MgO 3 nm]$_{x5}$/CoFeC 3 nm/Ta multilayer films. Since the MgO layers are usually much thinner in magnetic tunnel junction structures, X-ray measurements were carried out in these specially prepared multilayer samples. No sharp X-ray diffraction peak is observed for the as-deposited film. However, it is observed that the intensity of MgO (0 0 2) diffraction peak was enhanced as the MgO layer was deposited on the CoFeC underlayer. This suggested that the relatively higher (0 0 1)-oriented MgO film was formed by using the amorphous CoFeC underlayer. It has been known that the carbon atoms are easily bonded with iron atoms to form the iron carbide [4]. Therefore, it is expected that some Fe and C atoms are close and then forming the clusters or nano-sized Fe_xC phase in the as-deposited CoFeC film. The localized clusters or nano-sized Fe_xC phase may improve the (0 0 1) texture of the MgO film. It has been known that the (0 0 1)-oriented MgO crystalline film is beneficial to obtain the large TMR ratio [5]. Because the high TMR ratio is usually achieved with high-temperature post annealing [1,5], we did annealing experiments on CoFeC multilayer sample at 300 °C for 30 min. The broad peak is still observed when the annealing temperature is increased to 300 °C. Besides, the (0 0 2) peak intensity does not change significantly after annealing. Therefore, we expect that the texture of sputtering-deposited MgO films depend critically on the deposition condition. It can also be seen that the broad peak shifts to its typical peak position after annealing. According to the Bragg's law [6], this means that the lattice constant is reduced after 300 °C annealing. Therefore, the MgO film became dense after 300 °C annealing. It can be related to stress relief, which is caused by the elimination of defects in the MgO film to reduce the Gibbs free energy.

Fig. 3 shows the MR curves of the as-deposited Os/CoFeB(6 nm)/MgO(2.5 nm)/CoFe(3 nm)/Ta and Os/CoFeC(6 nm)/MgO(2.5 nm)/CoFe(3 nm)/Ta thin films. The MR ratio of about 9% is obtained at room temperature for the CoFeC/MgO/CoFe junction. However, the MR ratio is about 1% for the CoFeC/MgO/CoFe junction. As discussed above, the higher (0 0 1) texture could be obtained by using the amorphous CoFeC underlayer. So, the relatively large TMR ratio for the as-deposited CoFeC/MgO/CoFe junction may be related to the higher (0 0 1) texture of the MgO barrier.

References

[1] S.S.P. Parkin, et al., Nat. Mater. 3 (2004) 862.
[2] S. Yuasa, et al., Nat. Mater. 3 (2004) 868.
[3] K. Tsunekawa, et al., Appl. Phys. Lett. 87 (2005) 072503.
[4] R.E. Reed-Hill, et al., Physical Metallurgy Principles, third ed., Thomson-Engineering, 1992.
[5] D.D. Djayaprawira, et al., Appl. Phys. Lett. 86 (2005) 092502.
[6] B.D. Cullity, Element of X-Ray Diffraction, Second ed., Addison-Wesley, Massachusetts, 1978.