Available online at www.sciencedirect.com
SCIENCE DIRECT
Journal of Magnetism and Magnetic Materials 304 (2006) e103–e105
Journal of magnetism and magnetic materials
www.elsevier.com/locate/jmmm

Microstructure and morphology of MgO thin film with different magnetic underlayers

C.Y. Chou[a,*], Y.D. Yao[b], P.C. Kuo[a], K.W. Cheng[b], C. Yu[b]

[a]Institute of Materials Science and Engineering, National Taiwan University, Taipei 106, Taiwan
[b]Institute of Physics, Academia Sinica, Nankang 115 Taipei, Taiwan

Available online 6 March 2006

Abstract

The MgO thin films were deposited on various magnetic layers at room temperature by magnetron sputtering. The microstructure and surface morphology of the MgO films were investigated by high-resolution transmission electron microscopy. The results showed that bottom ferromagnetic layer and the MgO thickness are essential factors affecting the quality of the MgO layer. The surface roughness increases with the thickness of the MgO layer. Highly (0 0 1) oriented MgO crystalline films were grown on CoFeB and CoFeC underlayers. On the contrary, the crystallinity of the MgO layer is relatively poor and it shows a wavy interface as the MgO layer was deposited on the Co underlayer.

PACS: 68.37.Lp; 68.35.Ct; 73.40.GK

Keywords: MgO films; Microstructure; Tunnel magnetoresistance

Magnesium oxide (MgO) has attracted much attention due to its potential for applications in spintronic devices [1–3] and magnetic recording media [4]. Tunnel magnetoresistance ratio of up to 260% at room temperature based on MgO tunnel barrier has recently been demonstrated [5]. The result was related to the (0 0 1) oriented state of the MgO thin film. Besides, the MgO intermediate layer is employed to induce (0 0 1) texture of FePt film for perpendicular recording [6]. Since the microstructure strongly influences the properties of these materials, it is necessary to study the detailed microstructure of the multilayer films. In this work, we investigate the microstructure and morphology of MgO thin films with different magnetic layers.

All the samples were deposited on 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 conventional magnetron sputtering gun from MgO target. The annealing condition was at 300 °C in vacuum below 1×10^{-5} torr for 30 min. Specimens for cross-section transmission electron microscopy (TEM) observation were prepared by mechanical grinding to a thickness 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 operated at 200 kV. The junction geometry for magnetotransport properties measurement was patterned by e-beam lithography and ion-milling with a junction size of 3 μm × 1 μm. The electrical resistivity was measured with a standard dc four-probe technique.

First, we investigated the microstructure and morphology of MgO thin films inserted in two magnetic layers as functions of the thickness of MgO layer. Fig. 1(a)–(c) shows the high-resolution transmission electron microscopy (HRTEM) images of the as-deposited Co/MgO/NiFe thin films. All the films were deposited at a pressure of 5 mtorr in an Ar atmosphere. The MgO thickness of Fig. 1(a)–(c) are 5, 20 and 35 nm, respectively. It was observed that the structure of the MgO layer is composed of mixing phases of polycrystalline grains and amorphous. Random-oriented MgO grains were observed for various MgO thicknesses. Besides, it was observed that the MgO film roughens considerably as its thickness increases. The

*Corresponding author. Tel.: +886 2 23648881; fax: +886 2 23634562.
E-mail address: a3150@ms3.hinet.net (C.Y. Chou).

0304-8853/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.jmmm.2006.01.192

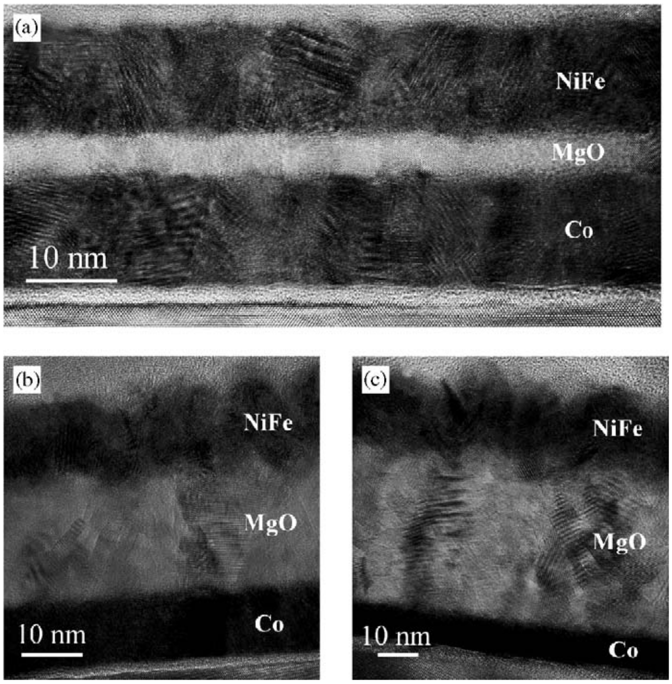

Fig. 1. Cross-sectional HRTEM images of as-deposited Co/MgO/NiFe thin films with the MgO thickness of (a) 5 nm, (b) 20 nm and (c) 35 nm.

increase in interface roughness between the MgO and NiFe layers causes the deterioration of the growth of NiFe layer. The small islands were formed obviously as the MgO film thickness increases. The increase of the strain energy with thickness may lead to the 3D crystals growth. However, the interface roughness is important. It is well known that the magnetoresistance effect in magnetic multilayer was affected by the interface roughness. The obviously geometrical rough interface is detrimental. Reduction of interface roughness is desirable for practical applications.

Fig. 2(a)–(c) shows the HRTEM images of the as-deposited CoFeB/MgO/Co thin films, where the MgO layers were deposited at 5, 10 and 100 mtorr in an Ar atmosphere. The CoFeB thin film was deposited using $Co_{60}Fe_{20}B_{20}$ alloy target. It can be seen that the CoFeB underlayer is amorphous. The interfaces of the MgO layer were very sharp and smooth as the MgO layer was deposited at 5 and 10 mtorr. It can be seen that the atomically resolved MgO (0 0 1) lattice planes were parallel to the film plane. This highly (0 0 1) oriented MgO thin film combined with the soft magnetic underlayer can be applied to the underlayer of double-layered perpendicular recording medium [4]. However, it was observed that the crystallinity of the MgO layer is poor and the interface is rough as the MgO layer was deposited at 100 mtorr. The (0 0 1) texture could be also obtained by using the CoFeC underlayer. The CoFeC thin film was deposited using $Co_{60}Fe_{20}C_{20}$ alloy target. The HRTEM image of the as-deposited CoFeC/MgO/Co thin film is shown in Fig. 2(d). We can see that the interfaces of the MgO layer were very smooth. So, we believed that the MgO layer with random-

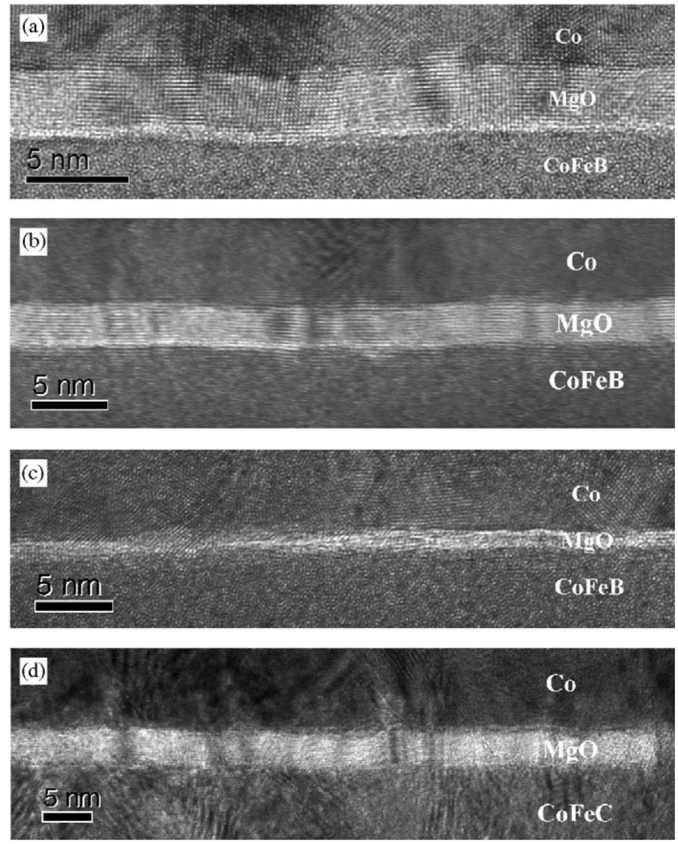

Fig. 2. (a)–(c) Cross-sectional HRTEM images of as-deposited CoFeB/MgO/Co thin films. (d) Cross-sectional HRTEM image of as-deposited CoFeC/MgO/Co thin film.

oriented grains and the poor crystallinity observed by using the Co underlayer is due to the relatively rough surface of Co underlayer and the difference of the texture between Co and MgO layer. Therefore, we expect that the texture of sputtering deposited MgO films is a nucleation controlled process. The growth orientation of the MgO film is determined by the lowest surface energy of the crystal structure. The inappropriate underlayer will affect the crystal growth of the MgO thin film.

As shown in Fig. 3, we have also observed the crystal growth of the CoFeB/MgO bilayer as the MgO thickness increased to about 10 nm. We can see that the atomic layers were grown continuously from the initial stage of the film growth. The atomically resolved MgO (0 0 1) lattice planes were parallel to the film plane. However, the rough surface was still observed by using the smooth CoFeB underlayer. So, the MgO film seems like to grow as the Stranski–Krastanov (SK) growth mode (uniform crystalline film was formed first, followed by 3D crystallite growth). The increase of the strain energy with thickness may lead to the 3D crystals growth.

Fig. 4(a) shows the MR curve of the Os/CoFeB(5 nm)/MgO(2.5 nm)/CoFe(5 nm) thin film after 300 °C annealing. The postannealing time is 30 min. For annealing sample, the 20 Å Os layer was used as a buffer layer. The Osmium

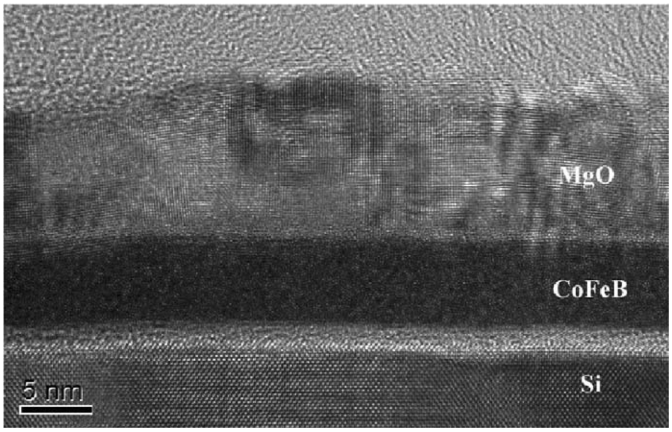

Fig. 3. Cross-sectional HRTEM image of as-deposited CoFeB/MgO thin film.

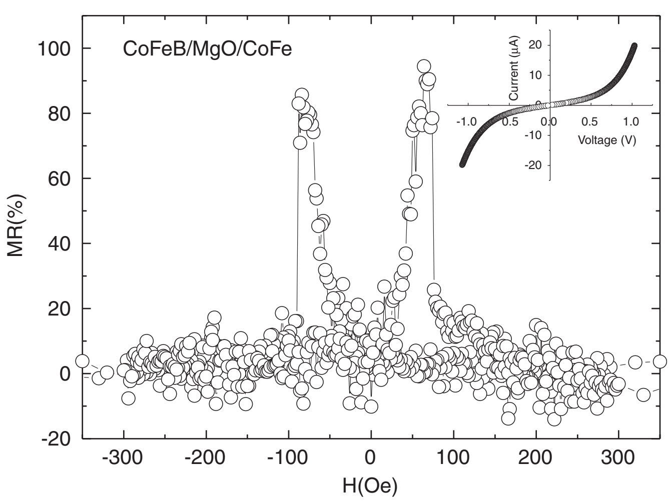

Fig. 4. The MR curve of CoFeB/MgO/CoFe magnetic tunnel junction.

layer, served as the diffusion barrier, was adopted due to its high melting temperature (~3000 °C). The MR ratio of about 90% is obtained at room temperature for the CoFeB/MgO/CoFe junction. The current (I) versus voltage (V) curve of this magnetic tunnel junction is shown in the inset of Fig. 4. The I–V curve shows nonlinear relationship. This non-ohmic behavior of the I–V curve suggests that the MR mechanism in this sample is the spin-polarized tunneling effect.

References

[1] S.S.P. Parkin, C. Kaiser, A. Panchula, P.M. Rice, B. Hughes, M. Samant, S.H. Yang, Nat. Mater. 3 (2004) 862.
[2] S. Yuasa, T. Nagahama, A. Fukushima, Y. Suzuki, K. Ando, Nat. Mater. 3 (2004) 868.
[3] K. Tsunekawa, D.D. Djayaprawira, M. Nagai, H. Maehara, S. Yamagata, N. Watanabe, S. Yuasa, Y. Suzuki, K. Ando, Appl. Phys. Lett. 87 (2005) 072503.
[4] T. Suzuki, T. Takanori, N. Honda, K. Ouchi, IEEE Trans. Magn. 36 (2000) 2417.
[5] J. Hayakawa, S. Ikeda, F. Matsukura, H. Takahashi, H. Ohno, Japan J. Appl. Phys. 44 (2005) L587.
[6] Z.G. Zhang, K. Kang, T. Suzuki, Appl. Phys. Lett. 83 (2003) 1785.