Oscillatory behavior of coercivity in Bi/Co bilayers

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Abstract

The Bi/Co bilayers on the glass substrate with various thicknesses of Bi underlayer were prepared by DC sputtering method. A remarkable enhancement of the coercivity H_c of sputtered thin Co films was observed. Besides, its coercivity at room temperature was found to oscillate as a function of Bi thickness with a period of about 22 nm. The range of oscillation was observed at least up to 80 nm. The origin of the oscillation in the coercivity of cobalt film was thought to arise from the specific 3D growing mechanism of bismuth layer.

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Ferromagnetic bilayer with a non-magnetic underlayer was intensely studied in recent years driven by the intriguing physics such as magnetic anisotropy, exchange bias and the variation of coercivity. As is well known, the magnetic properties of bilayer thin films are strongly influenced by microstructure such as interface roughness and crystallinity. In the past, the studies were limited to the metal underlayers [1] and semiconductor underlayers [2]. In this investigation, the semi-metallic Bi was chosen as the underlayer material. The low melting point of Bi enables the layer structures to be easily modified and to enable the variation in the magnetic behaviors with interfacial structure to be observed. A large enhancement and oscillatory behavior in the coercivity H_c of sputtered thin Co films with a Bi underlayer was found.

The Bi/Co bilayers were prepared by the DC sputtering method. The 7059 corning glass was used as the substrate. Herein, the thickness of Co layer was kept at 6 nm, while the thickness t of Bi underlayer was varied from 1 to 100 nm.

The crystalline structure was investigated by the X-ray diffraction (XRD) using CuK_α radiation. The surface morphology was examined by the atomic force microscopy (AFM). The magnetic loops were obtained from the vibrating sample magnetometer (VSM).

The XRD results indicated that only the rhombohedral phase of bismuth was present. No diffraction peaks corresponding to Co were found due to larger scattering factor of Bi. Besides, no additional phase other than Bi has been detected. Fig. 1 displayed the AFM images for the Bi/Co bilayers. The AFM measurements revealed that large clusters with the size of about 330 nm were randomly distributed as shown in Fig. 1(a). The clusters seem to connect with each other. In contrast as shown in Fig. 1(b), the small granules have higher density and tend to be aligned. Besides, deep narrow valleys are observed.

The representative $M-H$ loops at room temperature were plotted in Fig. 2. It is noted that the shape of the loops does not change with the thickness of Bi but is significantly different from that of single Co layer. Besides, the width of the loop varies with t , but it does not increase steadily. For example, the loop for $t = 18$ nm was narrower than those for both $t = 4$ nm and $t = 27$ nm.

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The coercivity of glass/Bi(*t*)/Co bilayers at room temperature was found to oscillates as a function of Bi thickness with a period of about 22 nm and the range of

Fig. 1. Representative AFM micrographs of the surface of glass/Bi(*t*)/Co films: (a) *t* = 18 nm and (b) *t* = 27 nm.

Fig. 2. Representative magnetization loops for the samples with applied field along the sample plane.

Fig. 3. Coercivity as a function of increasing Bi underlayer thickness.

oscillation was extended at least up to 80 nm as shown in Fig. 3. This type of oscillation was not detected in glass/Ag(*t*)/Co bilayer system [3]. The small H_c is associated with a smoother surface while the high H_c is found for the rougher films as shown in Figs. 1(a) and (b). The origin of the oscillation in the coercivity of cobalt film was thought to come from the growing mechanism of bismuth. And the oscillation in H_c of Co films is not caused by the coupling effect because the oscillation in H_c disappears if the Bi film is deposited on the Co film instead. According to Stranski–Krastanov model [4] for epitaxy, islands form during film deposition in addition to layer-by-layer accumulation. By means of AFM observation, the Bi surface was found to be significantly rough made of many steep islands. The schematic pictures were given in Fig. 4 to explain the possible epitaxy process of the Bi film. Steep islands form in the course of deposition, and narrow, deep valleys develop between these islands as shown in Fig. 4(a). However, the heights of these islands are impossible to unlimitedly increase. When the islands become high enough, the higher islands collapse and the valleys are filled with collapsing atoms at the same time. Wider and smoother valleys form as shown in Fig. 4(b). As continuing on the growth process, once again the islands gradually grow higher, steeper, and the valleys become narrower as shown in Fig. 4(c). The whole process continues. Therefore, in the course of the Bi layer deposition, the aspect ratio (vertical length)/(lateral length) of the interface roughness varies with Bi thickness

Fig. 4. Epitaxy process of bismuth and cobalt films. (a) steep islands form in the course of epitaxy, and narrow network of cobalt develops surrounding the islands, (b) smooth islands form, and wide network of cobalt develops surrounding the islands, and (c) steep islands form, and narrow network of cobalt develops surrounding the islands.

periodically. After the completion of Bi film growth, the Co film of 6 nm thickness was deposited thereon. Co network structure forms in the valleys surrounding the Bi islands. In Fig. 4(a), the width of the Co network is very small because the Bi valleys are very narrow and steep. However in Fig. 4(b) wider Co networks have formed because of the smoother Bi valleys. Along with the periodically high and low islands in Bi deposition process, the width of the Co network forming in the Bi valleys also exhibits the periodic variation. The coercivity of a narrower network is higher than that of a wider network [5], so the oscillation in the coercivity of Co film with Bi thickness is expected. Furthermore, the uniaxial magnetic anisotropy was found for the films with high H_c .

In summary the oscillation behavior in H_c was observed in glass/Bi/Co bilyer system, which was believed due to the periodic variation of interface structure.

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