Structural analysis and magnetic properties of Fe/Bi system

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Abstract

We have investigated the structure and magnetic properties of Fe/Bi multilayers and trilayers by RHEED, XRD,XRR,XPS and SQUID. The samples were grown by molecular beam epitaxy method. It was found that the synthesis of the multiplayer is very difficult. However, we successfully grown Fe/Bi trilayers by adopting the appropriate growth conditions.

Key words: magnetic multiplayer; MBE; Magnetization; X-ray reflectivity

It has been known that Fe-based intermetallic compounds show a variety of magnetic properties. Many kinds of magnetism such as Ferromagnetism, Antiferromagnetism and itinerant metamagnetism have been observed, depending on the constituent elements and crystal structures. In case of Fe monopnictides, FeP and FeAs show spiral magnetic states, and FeSb antiferromagnetism. However, there has been no report on FeBi, because Fe and Bi are immiscible in the equilibrium states and neither alloy nor intermetallic compound exists in the binary system[1]. It is considered to be very difficult to make Fe-Bi compounds. However, immiscible systems such as Au and Fe may compose an excellent artificial lattice and exotic magnetic properties, when they are grown in the form of membrain or multiplayer[2]. In stead of bulk form, the artificial lattice is of interest from the basic research for strongly electron correlation.

Only a few studies have been reported for Fe/Bi film systems. The crystal structure of both metals differ from each other so markedly, that polycrystalline and amorphous Fe/Bi multilayers have been grown onto cooled substrate. Thickness dependence of saturation magnetization has been studied[3]. For Sb that is the same semimetal as Bi, on the other hand, Fe/Sb multilayers with rhombohedral metastable Fe phase exhibited ferromagnetic behavior[4]. We think that Fe/Bi systems remain many problems (*i.e.* crystalline multilayers and conducting properties). We have tried to make both multilayers and trilayers of Fe/Bi system. In this paper, we will report the results of the structural analysis and magnetic properties.

Samples were prepared by alternate deposition of Fe and Bi on $SrTiO_3(100)$ STO substrates in an ultrahigh vacuum, which is order of 10^{-9} Torr. The substrate temperature was varied in wide temperature range from room temperature up to 523K. Multilayered films were prepared with a fixed Fe layer thickness, *i.e.*, STO/[Fe(50Å)/Bi(t_{Bi})]*20 (t_{Bi} = 5, 10, 20, 36 and 60Å). The top Bi layer was deposited as cover layer to prevent oxidation. The first Fe layer was deposited as a buffer. On the other hand, trilayered samples were prepared; fixed Fe layer thickness, STO/Fe(500Å)/Bi(t_{Bi})/Fe(500Å) (t_{Bi} = 50, 150, and 300Å). Total thickness of Fe was fixed to be 1000Å. The crystallographic structures of the prepared samples were characterized by X-ray diffraction using CuKα radiation with the scattering vector perpendicular to the film plane. Magnetization measurements were performed by a SQUID magnetometer.

At first, we prepared Fe/Bi multilayers. High-angle X-ray pattern shows clear Bragg reflections of the Bi(012) and Fe(200). However, the low-angle reflected pattern and satellite peaks from the multilayerdd

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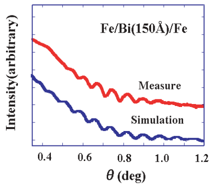

Fig. 1. The low-angle X-ray pattern for trilayered film, together with the fitting curve performed by XRR.

structure were not be observed. Therefore, we did not obtain a clear evidence for the layer structure of the film. This results indicate that it is hard to grow up Fe/Bi multilayers. This result is ascribed to the fact that Bi works as surfactant for metallic and semi-conductor films[5]. If it is really so, the alternative stacking of Fe and Bi will have a large problem.

In order to check this point, we studied trilayered films. The growth structure during the deposition was observed by RHEED. A clear streaked pattern waonserbeds observed during the first Fe deposition. The orientation of Fe is (100). The streaked pattern disappeared after the deposition of several Bi layers. It suggests that the Bi was neither grown layer by layer nor has epitaxial relation with Fe layer. When the second Fe layer starts to be deposited, a streaked pattern revives again.

From the X-ray analysis, all the films were observed strong Fe and Bi Brag peaks. The quality of the films strongly depends on the growth condition. In particular, The substrate temperature is relevant. Figure 1 shows the low-angle X-ray pattern for Fe/Bi(150Å)/Fe films, at substrate temperature of $T = 473$K. An oscillation due to reflected intensity was observed. This confirms a good quality in the interface structure of Fe and Bi. Most of films under other growth condition, however, do not show such nice low-angle fringe pattern. The structural parameters (*i.e.*, film thickness, density and surface roughness) could be evaluated by the reflectivity curve, which is listed in Table 1. The fitting performed by XRR (X-Ray Reflectivity) program using GA (Genetic Algorithm) and LM (Levenberg-Marquart) method[6]. The evaluated total thickness is consistent with the nominal value within the accuracy of 3%. The density of this film is slightly small of 5%, compared to the bulk.

Figure 2 shows $M(H)$ curves for Fe/Bi(50Å)/Fe measured at $T = 10$K in the magnetic fields both parallel and perpendicular to the film plane. Magnetic anisotropy and a clear kink as indicated by arrows were found. This kink and anisotropy were observed all films prepared at $T = 473$K. This behavior looks very similar to that of Cu/Co/Cu/NiFe reported before[7]. The magnetization indicates the magnetic easy direction to be parallel to the substrate. For the sake of check, we studied the Fe film without Bi layer. It shows an isotropic magnetization, which means that Bi layer is responsible for the anisotropic behavior in the trilayer. It is considered that the anisotropy and kink originate from the adjacent Fe layer coupling through the spacer Bi layer.

Table 1
The structural parameters evaluated by XRR program.

	Thickness (Å)	Roughness (Å)	Density (g/cm^3)
FeO	27.89	2.86	4.10
Fe	489.96	9.20	6.69
Bi	126.70	12.34	9.70
Fe	497.24	19.24	7.82
STO		30.06	

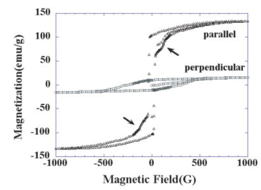

Fig. 2. The magnetization curves for Fe/Bi(150Å)/Fe measured at $T = 10$K in the magnetic field both parallel and perpendicular to the film plane.

In this work, we studied the structural and magnetic properties of Fe/Bi systems grown on STO(100) substrates. The results of the trilayered system strongly indicate that that a layered structure can be realized in Fe/Bi systems with appropriate film thickness and substrate temperature.

$M(H)$ curves exhibit a clear kink and remarkable anisotropy indicating the presence of the magnetic interaction between Fe and Bi. The observed anisotropy in the magnetization supports the correlation between Fe and Bi in the layered structure. This study suggested the possibility to grow up a Fe/Bi multilayer; neither amorphous nor polycrystalline.

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