Magnetostrictive Characteristics of Fe-IIIB Alloy Thin Film by Ion-Plating Process

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In previous works, supersaturated magnetostrictive Fe-Al alloys were prepared by ion plating (IP) process. Ion-plating process is expected to form supersaturated solid solution of Fe-In of immiscible system in equilibrium thin film. In this study, Fe-III B supersaturated thin films were prepared by ion plating process of the dual vapor source and magnetostrictive characteristics of thin films were discussed. IP system was used for film preparation. Dense plasma flux (~2.5 A) of source material can be dosed and deposited on a substrate. The flux of the source vapor is ionized by thermal electrons accelerated from molten pool to an electrode called “probe”. All sample films showed bcc structure. This may be caused by non-equilibrium condition as plasma-solid quenching peculiar of the IP. The sample of Fe-17 at%Ga and Fe-1.5 at%In showed maximum value of magnetostriction is about 200 ppm and 80 ppm at 1200 kA/m, respectively. [DOI: 10.1380/ejssnt.2009.801]

Keywords: Ion bombardment; Metastable states; Indium; Gallium; Magnetic films; Ion plating; Supersaturated solid solution; Vegard’s law

I. INTRODUCTION

Giant magnetostrictive materials (GMM) have been investigated as potential materials for actuator of micro electro mechanical systems (MEMS). We recently have studied magnetostrictive thin films prepared by various preparation processes [1, 2]. Rare earth transition metal alloys as giant magnetostrictive materials show brittle and corrosive. Contrary alloy of Fe-III B was excellent in toughness and corrosion resistance. Recently, Clark et al. have reported that a Fe-17at%Ga alloy single crystal showed magnetostriction of about 300 ppm at 16kA/m [3, 4]. In previous works, Matsuoka et al. have reported Fe-21at%Ga alloy thin film prepared by magnetron sputtering (MS) showed maximum value of magnetostriction of 180 ppm at 1200 kA/m [5]. Moreover supersaturated Fe-Al alloys thin films prepared by IP process showed maximum value of magnetostriction 150 ppm at 1200 kA/m [1, 2].

In contrast, Fe and In are immiscible system in equilibrium [6]. Ion-plating process are expected to form supersaturated solid solution of Fe-In thin film. In this study, Fe-III B (Ga, In) supersaturated thin films were prepared by ion plating process, their nanostructure and magnetostrictive characteristics of thin films were discussed.

II. EXPERIMENTAL

A. Ion Plating System

Figure 1 shows the schematic diagram of the ion plating (IP) system of dual vapor source with electron beam and resistance-heating used for the film preparation. The film characteristics prepared by IP process show wide variation with dense plasma flux (~2.5 A) of ionized source materials can be dosed and deposited on a substrate. In this type ion plating system, the flux of the source vapor is ionized by thermal electrons accelerated from molten pool to an electrode so called “probe” [6]. Since the vapor pressure of Ga and In is much higher than Fe, Fe and III B group metal (Ga or In) were evaporated by electron beam and resistance heating, respectively. Composition of films was controlled by ratio of Fe and In or Ga deposition rate. Deposition rate of Fe and IIIB group metals measured by crystal oscillator of “ULVAC CRTM-5000” individually.

B. Sample Analysis

The composition of the film samples was measured by using energy dispersive X-ray spectroscopy (EDX). The film nanostructures were analyzed by X-ray diffraction.
III. RESULTS AND DISCUSSION

A. Nanostructure of film samples

XRD patterns of Fe-Ga film samples are shown in Fig. 2. Fe-Ga sample films showed b.c.c structure. Diffraction peaks shifted lower side of diffraction angle with increasing Ga content. It was known that the solubility limit of Ga is only about 10 at% in Fe at equilibrium [7]. So these analyses showed the Ga was supersaturated solid solution in Fe by using ion-plating process. This may be caused by non-equilibrium condition as plasma-solid quenching peculiar of the IP. Diffraction peaks shifted lower side of diffraction angle with increasing In content.

Figure 3 shows X-ray diffraction patterns of the film samples for Fe, Fe-1.5 at%In, Fe-2.6 at%In, Fe-9.5 at%In and Fe-17 at%In prepared by IP process. It was found that the 0 to 17 at%In film had b.c.c structure, although Fe-In system is immiscible in room temperature. These results are attributed unrecognized nonequilibrium phase was formed by non-equilibrium condition as plasma-solid quenching peculiar of the IP.

Table I shows a dependence of the Ga content to magnetostriction at 1200 kA/m. In the composition below Fe-17 at%Ga, the magnetostriction of film samples increased with increasing of Ga concentration. This result was caused by substitution of Ga and In into Fe (bcc) lattice. Because Ga and In atomic radius is larger than Fe atomic radius. These samples other than Fe-24 at%Ga are guessed that Ga and In is random substitution into Fe lattice because increasing lattice parameter was lined up on Vegard’s law. It is attributed that increasing lattice parameter was affected impeding energy of evaporation particles on IP process [8].

B. Magnetostrictive and Magnetic Properties

Table II shows a dependence of the In content to magnetostriction at 1200 kA/m. In the composition below Fe-17 at%Ga, the magnetostriction of film samples increased with increasing of Ga concentration. This result was caused by lattice instability due to increasing lattice parameter.

TABLE I: Maximum value of magnetostriction of Fe-Ga.

<table>
<thead>
<tr>
<th>Film composition</th>
<th>Magnetostrictive (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe-8at%Ga</td>
<td>90</td>
</tr>
<tr>
<td>Fe-17at%Ga</td>
<td>200</td>
</tr>
<tr>
<td>Fe-24at%Ga</td>
<td>75</td>
</tr>
</tbody>
</table>

TABLE II: Maximum value of magnetostriction of Fe-In.

<table>
<thead>
<tr>
<th>Film composition</th>
<th>Magnetostrictive (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe-1.5at%In</td>
<td>80</td>
</tr>
<tr>
<td>Fe-2.6at%In</td>
<td>20</td>
</tr>
<tr>
<td>Fe-9.5at%In</td>
<td>0</td>
</tr>
<tr>
<td>Fe-17at%In</td>
<td>0</td>
</tr>
</tbody>
</table>
tostriction. Fe-1.5 at%In shows maximum value of magnetostriction. In composition more than Fe-1.5 at%In, the magnetostriction of Fe-In film samples decreased with increasing of In concentration.

IV. CONCLUSION

In this study, supersaturated solid solution of Fe-III B thin films were prepared by the ion plating process and discussed with their nanostructure and magnetostrictive characteristics. It was found that Fe-17at% In film had b.c.c structure although Fe and In are immiscible system. These shows nonequilibrium phase was formed by IP. In the Fe-0 to 24 at% Ga had b.c.c structure. So it found that the Ga and In was supersaturated solid solution in Fe by using ion-plating process. The sample of Fe-17 at%Ga and Fe-1.5 at%In showed maximum value of magnetostriction is about 200 ppm and 80 ppm at 1200 kA/m, respectively.

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