Structural Study of Fe/Al MLS as a Function of Fe Film Thickness

R. Brajpuriya

Amity Institute of Nanotechnology, Amity University Haryana, Gurgaon, India

Abstract: The paper presents surface and interface structural study of electron beam evaporated \([\text{Fe} \,(40\,\text{Å} -10\,\text{Å})/\text{Al} \,(10\,\text{Å})]_{\times15}\) thin multilayer structures (MLS). The structural studies show significant amount of intermixing between the layers during growth for lower thickness of Fe layer (\(<20\,\text{Å}\) ), indicating the loss of periodicity at these thicknesses i.e. the prepared layers are not continuous and they are far away from the percolation threshold. These structures appear like a composite film consisting of Fe and Al matrix. However, at higher Fe layer thickness (\(\geq30\,\text{Å}\) ), the presence of first order Bragg diffraction in reflectivity patterns demonstrates the evaluation of a better-MLS as compared to lower Fe layer thickness. AFM and resistivity measurements also support the above results.

Keywords: Fe/Al multilayers GIXRD; GIXRR; AFM; Thickness

1. Introduction

Metallic multilayer films with manufactured periodicity obtained by alternate deposition of ferromagnetic and non-magnetic films show an improvement of magnetic properties, most suitable for high density magnetic recording [1, 2]. Among many MLS, Fe/Al bilayer and ML systems also have the potential to be used as thin film magnetic head for recording media, and it has been shown to possess excellent soft magnetic properties required for such use [3, 4]. However, the fundamental magnetic properties of these MLS are largely different from their bulks. It has been observed that the structural parameters such as thickness, periodicity and the nature of interfaces formed during deposition greatly affect these interesting properties [5-7]. In various cases, it is found that reaction and interdiffusion phenomena at interfaces during growth cause a loss of periodicity below a certain thickness, which severely modifies the structural and magnetic properties of these multilayers. Under such conditions, one needs a careful characterization of these structures in order to understand the role played by various micro-structural parameters, and in interpreting the different properties displayed by them. Therefore, in the present paper we have systematically carried out the structural and morphological studies of Fe/Al bilayers (BL) and multilayers (ML). The combination of distinct non-destructive techniques such as grazing incidence x-ray diffraction (GIXRD), x-ray reflectivity (GIXRR), atomic force microscopy (AFM), and four-probe resistivity were used to characterize the same.

2. Experimental Details

For the present study e-beam evaporation method is used to deposit \([\text{Fe} \,(40\,\text{Å} -10\,\text{Å})/\text{Al} \,(10\,\text{Å})]_{\times15}\) MLS. The samples were prepared at RT under UHV conditions keeping 0.1 Å/s deposition rate for both layers of Fe and Al. A capping layer of Al (25 Å) was deposited on top to avoid oxidation of MLS. All ML and bilayer (BL) samples were synthesized in a single run. GIXRD, GIXRR and AFM techniques were used to obtain the micro-structural and morphological information of the samples. The GIXRD and GIXRR measurements were carried out at a wavelength (\(\lambda\)) of 1.542 Å, operated at 40 KV and 30 mA. Morphological (AFM) measurements (Digital Instruments Nanoscope III) were carried out on bilayer samples in the contact mode. To save the samples from the contaminations the images were collected just after the samples were taken out from the synthesis chamber. The four probe method is employed to obtain the resistivity data.

3. Results and Discussion

Figure. 1 depicts the thickness (Fe) dependent GIXRD patterns of pristine \([\text{Fe}/\text{Al}]_{\times15}\) MLS. Diffraction patterns show that in all the cases samples was textured along Fe (110) direction. One can also notice that no peaks corresponding to Al were found proving that the prepared Al layer (10Å) is amorphous or nanocrystalline in nature. In case of \([\text{Fe} \,(40\,\text{Å})/\text{Al} \,(10\,\text{Å})]_{\times15}\) MLS, the 2θ (44.62°) value of Fe (110) peak is found to be close to bulk Fe (44.67°) [8]. However, as the thickness of Fe layer decreases the peak intensity as well as 20 values decreases i.e. the peak shifts towards lower 20 values. It is also found that peaks broaden with decrease in Fe layer thickness. The variation in the peak position and shape can be interpreted as follows: (i) increase in interplanar spacing ‘d’ due to large internal stress in the Fe layers introduced by adjacent Al layers, and their (ii) intermixing at the interface during growth resulting iron aluminate phase formation. Grain size of Fe crystallites is a critical structural parameter to modify the magnetic properties, together with the grain orientation, which controls the magnetic anisotropy. Therefore, using Scherrer formula we have determined the average particle size from the recorded GIXRD patterns as shown in table 1. It is found that the average particle size decreases linearly with decreasing Fe layer thickness. This indicates that large and more oriented crystallites of Fe were grown in case of MLS with greater \(d_F\).

However, for lower Fe layer thickness it is appeared to be composed of nano-crystallites Fe and Al grains, leading to a distorted Fe lattice structure. Table 1 also shows the measured d spacing value as a function of Fe layer thickness.

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One can clearly see that d spacing value decreases with increase in layer thickness of Fe. As the Fe layer thickness increases to 40Å the d value moving towards the bulk d value of Fe. The variation in d spacing values with Fe layer thickness indicates that the stresses were present in the prepared MLS, which released as Fe layer thickness increase to form more continuous and ordered layers.

Table 1: Values obtained from GIXRD, GIXRR, AFM and resistivity measurements as a function of $d_{Fe}$.

<table>
<thead>
<tr>
<th>$d_{Fe}$ (Å)</th>
<th>$L$ (Å)</th>
<th>$D_0$ (Å)</th>
<th>$\sigma$ (Å)</th>
<th>$\rho$(µΩcm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>75</td>
<td>2.05</td>
<td>13.5</td>
<td>127</td>
</tr>
<tr>
<td>20</td>
<td>82</td>
<td>2.04</td>
<td>22.9</td>
<td>91</td>
</tr>
<tr>
<td>30</td>
<td>86</td>
<td>2.03</td>
<td>18.6</td>
<td>34</td>
</tr>
<tr>
<td>40</td>
<td>97</td>
<td>2.03</td>
<td>16.2</td>
<td>20</td>
</tr>
</tbody>
</table>

Figure 2 depicts the GIXRR patterns of the as prepared [Fe($d_{Fe}$/Al(10Å))]$_{15}$ MLS. The rms roughness has been calculated by taking the average over at least 5 regions of area $1 \times 1$ μm. As the thickness of Fe layer increases, surface roughness increases to a particular layer thickness and thereafter decreases, and has maximum roughness for $d_{Fe}=20$ Å. The average roughness found to be in this case is 22.9 Å. So one can understand the obtained reflectivity patterns by seeing the above AFM images why a well-defined MLS is not observed at lower Fe layer thicknesses. However, as the Fe layer thickness is increased further to ≥30 Å, the separation of these features decreases and show the formation of more continuous and denser layers compared to the above-mentioned cases and as a result the value of surface roughness decreases to 16.2 Å. This is in correlation with the reflectivity patterns which also shows the formation of a better layered structure at these thicknesses. Hence, these images provide us more clear information about different stages of growth as the thickness of Fe layer is increases from 10 Å to 40 Å.

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Table 1 displays the thickness dependent variation in resistivity value. It is clear from the table that the resistivity decreases rapidly as the Fe layer thickness increases. This is similar to what happen in case of a single layered metallic film [9]. Thus, from the resistivity measurements it is possible to derive the structure of each layer in the prepared MLS. The table also informed that resistivity is maximum for a lower Fe layer thickness, implying that the prepared layers are not continuous and looks like a composite single layer structure consisting of Fe clusters embedded in a matrix of an Al.

4. Conclusion

The paper shows the effect of Fe layer thickness on the surface and interface structural properties of Fe/Al MLS keeping Al layer thickness constant. At lower \( d_{Fe} \), the structural and morphological measurements showed significant amount of intermixing due to discontinuous growth of Fe and Al layers and interdiffusion at the interface during growth. At lower Fe layer thicknesses, the prepared layers are not continuous and looks like a composite single layer structure consisting of Fe clusters embedded in a matrix of an Al.

References

[8] JCPDS file No 4-787 and 6-696.