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Effect of Ni substitution on the microstructure and giant magnetoresistance in nano-granular Fe-Ag thin films

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1. Introduction

Giant magnetoresistance (GMR) in heterogeneous granular alloy films has stimulated a great deal of research activities due to challenges in understanding of the fundamental physics involved in their unusual magnetotransport properties and to its applications for magnetoresistive read-heads and sensors [1-4]. Granular magnetic thin films are characterized by nanometer-sized magnetic particles embedded in an immiscible nonmagnetic matrix. We have studied ternary granular Fe-Ni-Ag alloy film, where Ni is systematically substituted to the Fe-Ag nano-granular system. The motivation for substituting Ni came from the fact that Ni is not miscible to the matrix Ag in the Fe-Ag granular film. A homogeneous meta-stable $Fe_xAg_yNi_z$ alloys can be made with sputter deposition, although the ternary system of Fe-Ag-Ni do not make intermetallic compounds or alloys.

2. Experiment

The seven series of $Fe_xAg_yNi_z$ granular films were prepared by DC magnetron sputtering. The targets was 75 mm diameter and they consisted of semicircular split-targets of one half Fe and the other half Ag. The substrates of ~ 10 mm width were kept in a linear array perpendicular to the FeNi/Ag joint. A linear change in the compositions of Fe, Ag and Ni were observed with respect to the position of substrates. Compositions of the samples were determined from the data obtained by Energy dispersive analysis by X-rays (EDAX). The structure and microstructure of the samples were studied using X-ray diffraction (XRD) and transmission electron microscopy (TEM) on the $Fe_xAg_yNi_z$ samples. Atomic force microscopy was used to see the surface morphology of the $Fe_xAg_yNi_z$ nano-granular film. The magnetoresistance (MR) of the samples of all the series were measured at room temperature using a conventional four probe method. The in-plane magnetic field was used up to 20 kOe. The MR ratio reported in this article is defined as $\Delta R/R$ = [R(20 kOe)-R(0)]/R(0), where R(0) and R(20 kOe) are resistances at zero and 20 kOe, respectively.

3. Results

The concentration of Fe, Ag and Ni varies linearly as a function of substrate position. The concentration of Ni increases gradually from zero while that of Fe decreases when we go from series 1 to series 7. Structural studies carried out by XRD exhibit only one (111) peak from the Ag grains for each sample. In this ternary alloy system, any crystallographic evidences of either bcc Fe or fcc Ni were not observed due to the metastable state which has very fine dispersion of

Fe and Ni in Ag matrix. Due to partial substitution of Ag atoms by the smaller Fe or Ni atoms, Ag (111) peak position shifts to a higher angle as compared to standard peak position of pure Ag. In addition, the peak intensity of Ag (111) decreases and the width broadens as the Fe concentration increases because of the Fe-Ni-Ag alloying [5-7]. Transmission electron microscopy (TEM) studies for the sample exhibiting the highest magnetoresistance shows the Ag grains with differential crystal orientation. By fitting the log-normal distribution to micrograph of Ag grains, we concluded that the average particle diameters are 46 ±14 Å [25]. The rms roughness of the film surface is about ~ 10 Å, obtained from the AFM image. The peak value of the MR lies between 3.8% and 5.7% indicating that the MR has not been significantly affected by the large addition fo Ni in the parent Fe-Ag film.

4. Discuss

In our FexAgyNiz films, the Ag lattice acts as the nonmagnetic spacer that separatesthe magnetic Fe/Ni grain. The shift of the d_{111}^{Ag} to the smaller d-value indicated that the partial intermixing had been taken place between Ag and magnetic entities. The peak value of MR in each series was not significantly affected by the large amounts of Ni impurities in the Ag lattice, since the interface scattering plays a key role in the granular systems due to the enhanced surface to volume ratio of the magnetic grains. As the GMR in granular films is mostly from the interfaces, the detriment of spin flip scattering from the Ni impurities in the Ag lattice does not appear to play a significant role.

5. Conclusion

The observed smaller d-values for the Ag (111) planes are due to partial intermixing of smaller Fe/Ni atoms in the Ag grains. The absence of Fe and Ni peaks in XRD is due to dilution of magnetic entities in Ag matrix. The average diameter of the polycrystalline Ag grains was 46±14 Å. The surface roughness of the selected sample was ~10 Å indicating a smooth morphology at nanometer scale. In each series of samples, the magnetoresistance curves showed a maximum around certain composition.

6. References

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