Incoherent Magnetization Reversal Process in Discontinuous $Fe_{50}Co_{50}$/Ag Multilayer Thin Films

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Abstract—**The possibility of incoherent magnetization reversal process in annealed $Fe_{50}Co_{50}$/Ag multilayer thin films has been studied. Small magnetoresistance was measured in as-deposited films; however, after annealing above 150°C, the highly mobile Ag atoms form bridges between the Ag layers, and the magnetoresistance increases. For example, after annealing at 225°C for 30 minutes, the TEM photographs show clearly the crosssection of a discontinuous multilayer structure, the coercivity is relatively small, and the magnetoresistance reaches its largest value. This is explained by the formation of elongated clusters of disk-like ferromagnetic FeCo particles, the exchange coupling between these particles is weak due to the presence of Ag layer between them. In this case, an incoherent magnetization reversal process is assumed to be dominant. For samples annealed above 250 °C, these disk-like ferromagnetic particles within a column grow larger due to diffusion. The exchange interaction increase due to the Ag atoms migrating to the bridges between the columns and decreasing the distance between disk-like ferromagnetic particles. The coercivity of the film then increases, and a coherent magnetization reversal process is assumed to become dominant.**

Index Terms-multilayer, magnetic, magnetoresistance.

I. INTRODUCTION

In recent years considerable attention has been drawn to giant magnetoresistance (GMR) in various magnetic multilayers and granular systems [1-6]. The GMR is important not only for basic research but also from the viewpoint of application, such as magnetic sensors, GMR heads for high density magnetic recording etc.

Discontinuous multilayers discovered by Hylton et al [7] exhibit fairly large room temperature GMR in very low applied fields. This film is produced by first sputtering multilayer films and then annealing the as-sputtered films at high temperatures. The annealing breaks up the magnetic layers into islands or discs with interlayer material between the them. Micromagnetic computation of the GMR effect in discontinuous multilayer films has been published by Oti et al [8]. The annealing effect is assumed to change the average inter-island spacing. According to this model, the GMR increases as a function of the layer thickness, at first sharply, and then it gradually decreases.

In this article, we report on observation of an possibly incoherent magnetization reversal process in $Fe_{50}Co_{50}$/Ag multilayer thin films after different annealing processes.

Manuscript received October, 15, 1997.
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This work was sponsored in part by the National Science Council of the R.O. C. under Grant Nos. NSC86-2216-E-002-029 and NSC86-2112-M001-020.

II. EXPERIMENTAL CONSIDERATIONS

$[Fe_{50}Co_{50}/Ag]_N$ multilayer films were fabricated on oxidized silicon wafers by rf magnetron sputtering. The vacuum system had a base pressure of $1x10^{-6}$ Torr., and argon pressure of $5x10^{-3}$ Torr was maintained during deposition. The thickness of the SiO_2 buffer layer on Si wafer was about 200 Å, and the number N of the multilayer was varied between 4 and 20; the thickness of Ag layers was varied between 7 and 47 Å. The films were subsequently heat-treated of temperatures between 150 and 300 °C in order to improve the discontinuous multilayer structure. X-ray diffractometry analysis was performed to study the interface and the variation of the layers. A SQUID magnetometer was used to measure the magnetic properties of the $Fe_{50}Co_{50}$/Ag multilayer films with various $Fe_{50}Co_{50}$ and Ag thickness; The films were annealed at various temperatures for 30 minutes. The MR at room temperature was measured with both the current and the applied magnetic field in the film plane.

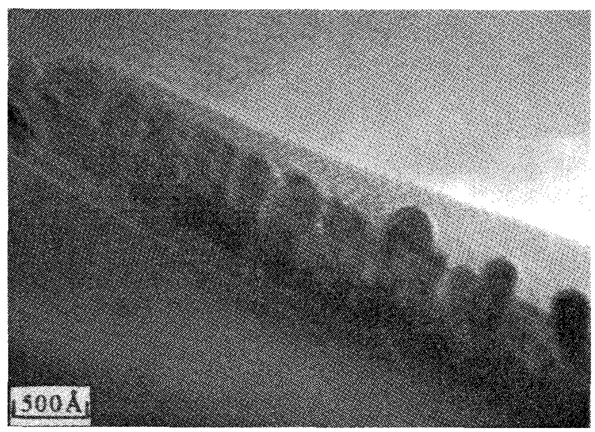

Fig. 1 TEM crosssection image of an $[Fe_{50}Co_{50}(15Å)/Ag(37Å)]_{12}$ film annealed at 200 °C.

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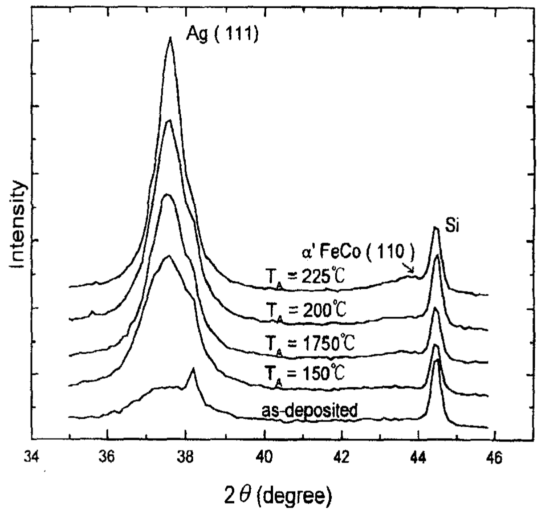

Fig. 2 X-ray diffraction patterns for $[Fe_{50}Co_{50}(15Å)/Ag(37Å)]_{12}$ multilayer samples.

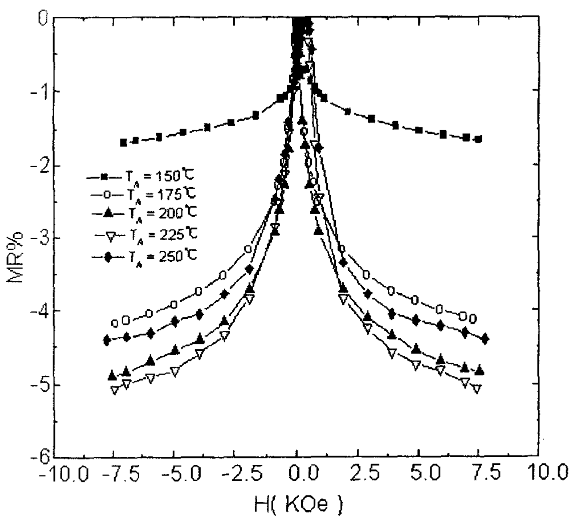

Fig. 3 The MR curves for $[Fe_{50}Co_{50}(15Å)/Ag(22Å)]_{12}$ multilayer samples annealed between 150 and 250 °C.

III. RESULTS AND DISCUSSION

The x-ray diffraction pattern confirms the multilayer structure of the samples. The annealing process is assumed to break up the magnetic layers into islands or discs with Ag bridges between them and this picture has been verified by high resolution electron microscopy.

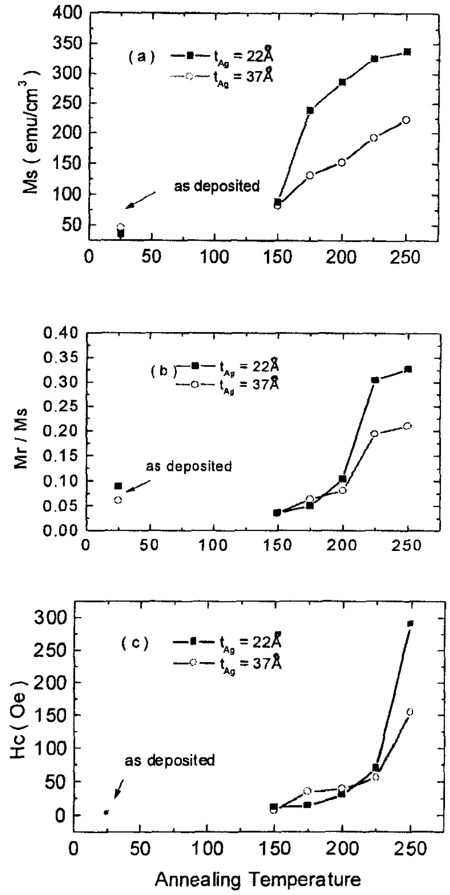

Fig. 4 M_s, M_r/M_s, and H_c for $[Fe_{50}Co_{50}(15Å)/Ag(t_{Ag}Å)]_{12}$ multilayer samples versus annealing temperature. The thickness of Ag layers t_{ag} is 22 and 37 Å.

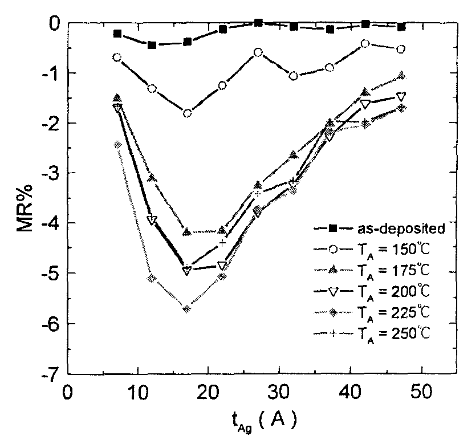

Fig. 5 The MR ratio of $[Fe_{50}Co_{50}(15Å)/Ag(t_{Ag}Å)]_{12}$ multilayer samples as a function of the thickness of the Ag layers. The annealing temperature was varied between 150 and 250 °C.

The behavior of the annealed film is like that of a granular film but where the islands are not sufficiently large as to increase the coercivity of the film. This means that the GMR peak is very narrow. Small values of magnetoresistance were observed in as-deposited films; however, the magnetoresistance increases significantly after annealing above 150°C this is due to the highly mobile Ag atoms forming bridges between the Ag layers. Fig. 1 shows the TEM crosssectional image of the $[Fe_{50}Co_{50}(15Å)/Ag(37Å)]_{12}$ film annealed at 200 °C for 30 minutes. This TEM photograph clearly shows the discontinuous multilayer structure. Fig. 2 shows the x-ray diffraction pattern of the as-deposited samples and of samples annealed below 225 °C. The peaks of the x-ray pattern for the as-deposited sample are relatively low, but they increase slowly after annealing. After annealing at 225 °C, the FeCo peak gradually formes near 44 degrees. The Ag peak near 37 degrees is slightly shifted to lower angles with annealing.

The typical variation of the MR ratio with magnetic field is plotted in Fig. 3 for the $[Fe_{50}Co_{50}(15 Å)/Ag(22Å)]_{12}$ multilayer samples. The MR ratio for the as-deposited film was very small and is not shown in the figure; after annealing, however, it increased to 1.75 and 5.3 % for anneals at 150 and 225 °C for 30 minutes, respectively. On the other hand, at annealing temperatures above 250 °C the MR ratio decreased rapidly and became 4.4% at 250 C. Fig. 4 shows the saturation magnetization M_s, the normalized remanance M_r/M_s, and the coercivity H_c for $[Fe_{50}Co_{50}(15Å)/Ag(t_{Ag}Å)]_{12}$ multilayer samples as functions of the annealing temperature below 250°C. The thickness of Ag layers was 22 and 37 Å. It is clear that the magnetic properties are very poor for samples annealed below 150 °C. The figures show that the saturation magnetization increases smoothly above 150 °C; and that, the coercivity increases slowly below roughly 225 °C, and rapidly above 225 °C. We speculate that an incoherent magnetization reversal process[9,10] is dominant near the annealing temperature of 225 °C; the high MR ratio and low coercivity can then be explained by the formation of elongated clusters of disk-like ferromagnetic FeCo particles with weak exchange coupling due to the presence of Ag layer between them.

In samples annealed above 250 °C, the disk-like ferromagnetic particles within a column grew larger due to diffusion and their separation decreased. This increased the exchange interaction between the particles; their coercivity, as shown in Fig. 4(c), was therefore relatively large. This suggests that here the coherent magnetization reversal process is dominant.

Fig. 5 shows the relation between MR and the Ag layer thickness t_{Ag}, at a given annealing temperature T_A. We found that the MR ratio of the $Fe_{50}Co_{50}/Ag$ multilayer films depends on both the annealing temperature and the Ag spacer thickness in the samples. The MR ratio for the as-deposited film was below 1%. However the MR ratio oscillates as a function of the Ag layer thickness for samples annealed below 150 °C. For all samples annealed above 175 °C, however the MR ratio showed a sharp peak at the Ag layer thickness of roughly 17 Å. The highest MR value found in this study was about 6.0% for samples with T_s = 225 °C and t_{Ag} = 17 Å.

IV. CONCLUSIONS

In conclusion, the possibility of incoherent magnetization reversal process in annealed $Fe_{50}Co_{50}/Ag$ multilayer thin films has been studied. In general, all studied samples exhibited increasing magnetoresistance on annealing between 150 and 225 °C, Crosssection TEM photograph clearly shows discontinuous multilayer structure. The coercivity of these annealed films was relatively small, and their magnetoresistance relatively large. This behavior was explained by the formation of elongated clusters of disk-like ferromagnetic FeCo particles, the exchange coupling between these particles is weak due to the presence of the Ag layer between them. In this case, the incoherent and coherent magnetization reversal processes were speculated.

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