Effect of Composition near the Layer Boundary on GMR for Co/Cu, Ag Multilayers Electrodeposited by Pulse Method

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The effect of the compositional modulation and the structure near the layer boundary between ferromagnetic and nonmagnetic metals, on magnetoresistance (MR) in the Co/Cu and Co/Ag multilayers produced by pulse electrodeposition method has been investigated. It was possible to control the film thickness in the range of 4.5-39 Å by electrodeposition. From the experiments on the films with composition modulation near the layer boundary between ferromagnetic Co-rich layer and nonmagnetic Cu layer, it is observed that the MR ratio strongly depends on the thickness of the ferromagnetic layer rather than the change of the composition near the interface between magnetic and nonmagnetic layers.

Key words: giant magnetoresistance, Co/Cu multilayer, Co/Ag multilayer, electrodeposition, pulse method, compositional modulation

1. Introduction

The studies on the physical properties of metallic multilayers prepared on the atomic scale have attracted attention in view of the fundamental physics and applications. Recent studies on giant magnetoresistance (GMR) in thin films are based on films grown mainly from the vapor phase, and the phenomenon exhibits different properties depending on their production methods. The reason seems to be that the state of the crystallinity in the ferromagnetic and non-magnetic layers and smoothness of the interface are different depending on the production method. And consequently, magnetic coupling interaction between the ferromagnetic layers adjacent to the non-magnetic layers has a different value depending on the structure.

Electrodeposition is one of the advantageous method for producing the thin film on the atomic order scale. We have already reported that electrodeposited Co/Cu alloy films and pulse electrodeposited multilayer films exhibit GMR %. The pulse electrodeposition method has a merit that it is possible to control the composition and the film thickness in atomic scale by varying the electrode potential wave.

In this report, we have investigated the effect of the compositional modulation and the structure near the layer boundary between ferromagnetic and nonmagnetic metals, on the magnetoresistance in the Co/Cu and Co/Ag multilayers produced by pulse electrodeposition method.

2. Experimental

The electrolytic bath for Co/Cu multilayer deposition was composed of CoSO₄·7H₂O, CuSO₄·5H₂O, Na₂C₂H₃O₂·2H₂O, NaCl and for Co/Ag multilayer deposition was composed of CoSO₄·7H₂O, Ag₂SO₄, Na₂C₂H₃O₂·2H₂O, Na₂SO₄·10H₂O. The substrates for electrodeposition were copper thin films vapor deposited on glass plates. Electrodeposition was carried out with a square wave and a trapezium wave of 0.1-20 mA/cm². The composition of the deposited films was determined by x-ray fluorescence spectroscopy and atomic absorption spectroscopy. The MR ratio was calculated as |Δ R/R₀|, where Δ R is the change in resistance due to the applied magnetic field and R₀ is the maximum resistance near zero magnetic field. The MR was measured at room temperature (300K) and 5K. The magnetic properties were investigated using a VSM and magnetic balance.

3. Results and discussion

Fig. 1 shows the concentration of Co in the electrodeposited films as a function of the deposition current density. The precipitation of Co from Co/Cu solution is higher than that from Co-Ag solution above the current density of 1 mA/cm². But, the precipitation of Co from Co-Cu solution is smaller below the current density of 1 mA/cm².

Fig. 2 shows the Cu layer thickness dependence of MR ratio for the various concentrations of Co in the alloy layer. The MR ratio has a maximum value of 16% (Cu=14 Å, room temperature, 21kOe) at the Co concentration of 86 at%. When the temperature is decreased to 5K, the MR value increases to about 24%. The 1st and 2nd peaks of MR ratio against the Cu layer thickness are observed at the thickness of 10-18 Å and

Fig. 1 Composition of Co in electrodeposited films as a function of the deposition current density (bath composition for Co/Cu deposition is Co₉₆Cu₄, and for Co/Ag deposition is Co₈₆Ag₁₄).

Fig. 2 Cu layer thickness dependence of the MR ratio for the various concentrations of Co in the alloy layer. Broken line is the MR ratio measured at 5K for the 86at%Co concentration in the alloy layers.

Fig. 3 Magnetic field for maximum resistance in the field dependence of MR against the Cu layer thickness for the films with 86at%Co concentration in the alloy layer. Inset shows the magnetic field dependence of the films.

about 35 Å, respectively. The thickness at which the first peak occurs shifts to the thicker side of the Cu layer with increasing Co concentration in Co-rich layer. The reason seems to be that Cu concentration in the vicinity of the layer boundary between Cu and Co increases with decreasing Co concentration in the ferromagnetic Co-rich layer, and the true Cu thickness becomes thick.

Fig. 3 shows the peak-to-peak width (=H_{peak}) in the field dependence of the ΔR/R_o of the film against the layer thickness of Cu for the films with 86 at%Co. H_{peak} increases monotonically with increasing the Cu layer thickness. H_{peak} does not always correspond to the MR ratio. However, this result indicate chronological formation of the films.

Fig. 4 shows the Ag-rich layer thickness dependence of MR ratio measured at 300 and 5K for [Co_{50}Ag_{50} 8 Å /Ag_{50}Co_{9} 1 Å]_{15} multilayer films. The MR ratio of the films measured at room temperature shows a maximum of 8.7% at a Ag-rich layer thickness of 12 Å. When measured at a temperature of 5K, the MR ratio increases to about 13%.

Fig. 5 shows the MR ratio for the Co-rich films deposited with a trapezium shaped pulse against the gradient of the trapezium pulse (i.e. sweep time). Broken line is the MR ratio measured at 5K for the 9 Å thick Co-rich layer films.
Fig. 6 shows the comparison between the magnetic field dependence of $\Delta R/R_0$ and the magnetization curve. $\Delta R/R_0$ at low magnetic field corresponds to magnetization, but such a correspondence was not always observed at high magnetic field.

4. Conclusion

It was possible to control the film thickness in the range of 4.5-39 Å by electrodeposition. Maximum MR ratio (room temperature, 21kOe) of 16% and 8.7% was observed for [Co-rich 9 Å Cu 14 Å]$_{50}$ and [Co-rich 8 Å Ag-rich 12 Å]$_{50}$ multilayer, respectively. The MR ratio of the Co/Cu and Co/Ag multilayers increases when measured at a low temperature(5K), and the values were 24% and 13%, respectively. From the experiments on the films with composition modulation near the layer boundary between ferromagnetic Co-rich layer and nonmagnetic Cu layer, it is observed that the MR ratio strongly depends on the thickness of the ferromagnetic layers rather than the change of the composition near the interface between magnetic and nonmagnetic layer. $\Delta R/R_0$ at low magnetic field corresponds to magnetization, but such a correspondence was not always observed at high magnetic field.

References