Journal of Korean Magnetics Society, Volume 5, Number 5, October 1995

THE EFFECT OF OVER AND UNDERLAYER ON THE MAGNETORESISTANCE IN Co-Ag NANO-GRANULAR ALLOY FILMS

Yonghyuk Kim and Seong-Rae Lee
Department of Metallurgical Engineering
Korea University, Seoul, 136-701, Korea

Abstract-The composition and thickness dependence and the ferromagnetic under- and overlayer effect on the magnetoresistance ratio and saturation field of the Co-Ag nano-granular films were investigated. The maximum magnetoresistance (23% at R.T.) in the as-deposited state was obtained in the 3000Å $Co_{30}Ag_{70}$ bare alloy film. As the thickness of the alloy films decreased below 500Å, the MR ratio decreased because of the resistivity increase and the non-uniform film formation. We showed that the ferromagnetic over- and underlayer could reduce the saturation field of the nano-granular films via exchange coupling effect. The magnetoresistance and the saturation field of the 100Å alloy film were 3.65 % and 2.85 kOe respectively and those of the under- and overlayered alloy films with 200Å Fe were 3.3 % and 1.23 kOe respectively.

I. INTRODUCTION

Since giant magnetoresistance (GMR) was observed in Fe/Cr[1] multilayer, much interest has been drawn into the scientific understanding and practical application. It has been believed that the GMR originates from spin dependent scattering in the magnetic layer and/or non-magnetic layer interfaces.[2] GMR materials have much practical applicability in various magnetic sensors and a magnetic reading head. Soft magnetic properties such as low coercivity and low saturation field are essential for the application. Many efforts to reduce the saturation field in multilayer have been done by various methods. Magnetic softening[3] , buffer layer effect[4], uncoupled spin valve structure[5] and exchange-biased spin valve structure[6] were the good examples of the efforts. The remarkable reduction of the saturation field could be achieved in uncoupled and exchange-biased scheme with magnetic softening.

Recently, the GMR phenomena observed in the immiscible granular alloy systems such as Cu-Co[7] and Ag-Co[8] have widened the understanding of the GMR effect and stimulated the related research areas. GMR in granular alloy films is believed to be mainly due to the interface spin dependent scattering.[9] Granular alloy system gives some advantage over multilayer system in terms of easy fabrication and structural tunability. However, its high saturation field which is due to the single domain behavior of nano-granular particles is the shortcoming for the practical application. The efforts to reduce the saturation field in nano-granular alloy system are not satisfactory yet. The saturation field of nano-granular alloy films could be reduced by structural modification via heat treatment[10], magnetic softening of magnetic particles or possibly exchange coupled layer effect.

In this report, we have investigated the effect of exchange coupled ferromagnetic over- and underlayer in the MR and the saturation field of Ag-Co nano-granular alloy films.

II. EXPERIMENTAL PROCEDURE

Co-Ag nano-granular alloy films were deposited by the thermal co-evaporation method on to the Corning 2948 glass substrate at the room temperature. The background pressure was 5×10^{-7} Torr. During the deposition, 3×10^{-6} Torr was maintained. The deposition rate of each source and film thickness were controlled independently by the Leybold Inficon XTCs. The composition of the nano-granular alloy films was changed from 20 to 55 at.% Co. The thickness of the films was varied from 100 to 3000 Å. The exchange coupled ferromagnetic over- and underlayer materials were Co, Fe and $Ni_{81}Fe_{19}$ and their thickness was varied from 50 to 200Å. The deposition rate of over- and underlayer was 0.5Å/sec. The magnetoresistance were measured at the room temperature by four probe methods, applying 1 mA current and 10 kOe magnetic field parallel to film plane and current direction. The MR measurement and data acquisition were performed automatically by the personal computer linked with IEEE488 interface. The magnetic properties were measured using the DMS VSM 880, applying 10 kOe magnetic field parallel to the film plane. The saturation fields were measured at the field of 50 % of the total MR change. Annealing was performed in Ar atmosphere at 200℃ for various time.

III. RESULTS AND DISCUSSION

Fig. 1 shows the variation of room temperature resistivity(ρ), resistivity change($\Delta\rho$), magnetoresistance(MR) ratio and saturation field(H_s) of the as-deposited Co-Ag nano-granular films as a function of the Co composition. According to the structural analysis

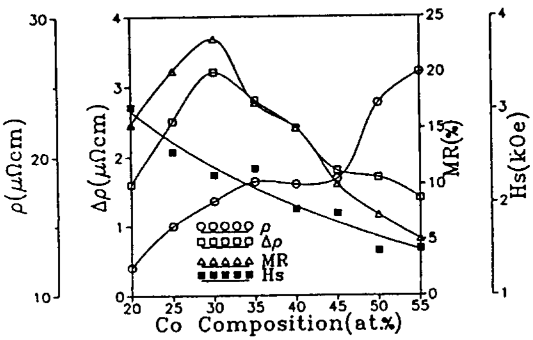

Fig. 1 The ρ, $\Delta\rho$, MR and Hs variation as a function of Co composition

[11], high Co content films had smaller grain sizes and more point defects, which increased the resistivity of the film. The $\Delta\rho$ represented the difference of ρ between the magnetically saturated and the demagnetized state of the films. The maximum $\Delta\rho$ was obtained at the 30 at.% Co composition film. This result was supposed to be obtained because of its optimum Co cluster size and size distribution for spin dependent scattering. As the Co content increased, the surface to volume ratio of the Co clusters in Ag matrix decreased due to the growth of the Co clusters. The maximum MR ratio(23%) at the room temperature was obtained in the as-deposited 30 at.% Co film. The saturation field of the 20 at.% Co film was 3.03 kOe. It decreased monotonically with the Co content. This result was obtained because the Co cluster behaved more ferromagnetically as the Co content increased. The saturation field of 55 at.% Co film was 1.5 kOe.

The ρ, $\Delta\rho$, MR ratio, M_s and H_s of the bare $Co_{30}Ag_{70}$ alloy film as a function of the alloy film thickness were plotted in Fig. 2. The ρ increased rapidly below 200Å thickness because of the size effect and the non-uniform film formation. The $\Delta\rho$ also decreased significantly below 500Å thickness and was saturated to a 3.5$\mu\Omega$cm at 2000Å. The magnitude of the $\Delta\rho$ could be varied by intensity of applied field, size of the magnetic cluster and measuring temperature.[12] The $\Delta\rho$ could be maximized

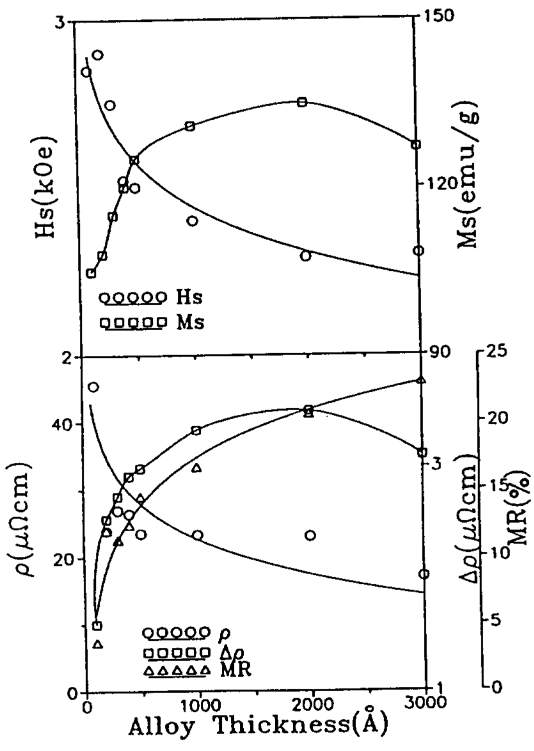

Fig. 2 The ρ, $\Delta\rho$, MR, Hs and Ms variation of $Co_{30}Ag_{70}$ alloy film as a function of alloy thickness

when the measuring temperature is low enough and the magnetic field is strong enough to saturate the small superparamagnetic clusters which have the maximum surface to volume ratio. For example, Yu et al[13] have reported that the $\Delta\rho$ increased as the film thickness decreased in Fe-Ag system. They measured the magnetoresistance at 1.5 K and the magnetic field of 60 kOe. Therefore, small magnetic clusters could be sufficiently magnetized and they had large S/V ratio which could enlarge the interface spin dependent scattering. But in this experiment of which the applying field is 10 kOe and the measuring temperature is room temperature, the clusters which are larger than a superparamagnetic critical size could be contributed to the $\Delta\rho$.[9] The number of clusters in the alloy film which could be contributed to the MR within 10 kOe decreased as the film thickness decreased. Especially, the non-uniform film formation in the 100Å film hampered the conduction electrons flow. Therefore, the MR ratios of the 100 Å and the 3000 Å alloy film were 3.65 % and 23 % respectively.

The M_s behavior resembled the behavior of the $\Delta\rho$. There might be three possible reasons which cause the M_s reduction resulting from the reduction of the alloy thickness. They are Co size reduction, non-uniform film formation and Co concentration in Co cluster and Ag matrix. The non-uniform film formation and the Co cluster size variation were confirmed by the TEM and the annealing experiment. The H_s of 100 Å and 3000 Å film was 2.85 kO_e and 2.3 kO_e respectively.

The ρ, $\Delta\rho$ and MR ratio variation as a function of the under/overlayer thickness were summarized in Fig. 3. The $\Delta\rho$ decreased as the Co under/overlayer thickness increased. There may be two major reasons which cause the $\Delta\rho$ decrease in this trilayered system. Firstly, 3 dimensionally random oriented magnetic moments of the Co clusters in the alloy layer were aligned to 2 dimensionally random oriented state due to the exchange coupling between the Co clusters and the under/overlayer. As a result, the spin orientation difference between the saturated and the demagnetized state was reduced. Therefore, the probability of the spin dependent scattering decreased. Secondly, the structure of the underlayered alloy films could be altered. The Co cluster size could be changed especially when the alloy film is under/overlayered. It appeared that the Co cluster size of the under/overlayered alloy films became smaller than that of the bare alloy film. This hypothesis was confirmed by the annealing experiment. When the bare alloy film was annealed at 200℃, the $\Delta\rho$ decreased continuously. This result was consistent with the result of Lee et al.[11] However, the $\Delta\rho$ of the trilayered film increased initially but decreased after long time annealing. This means that the Co cluster size of the underlayered alloy films

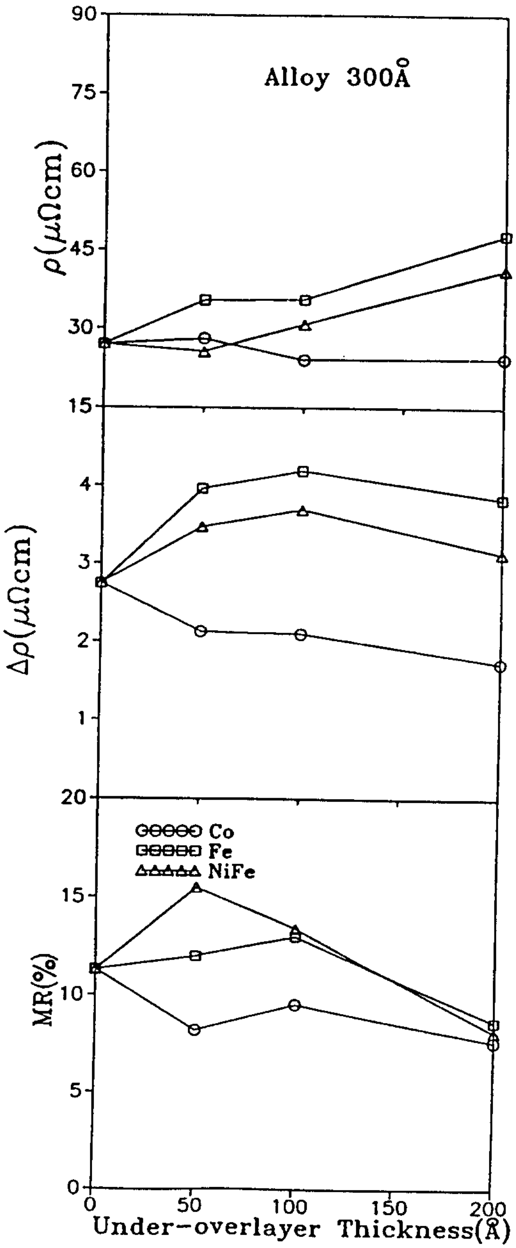

Fig. 3 The effect of under-overlayer thickness on the magnetoresistance of 300Å $Co_{30}Ag_{70}$ alloy film

was smaller than that of the bare alloy films. Therefore the $\Delta\rho$ and MR ratio decreased as the thickness of Co over/underlayer increased.

The ρ increased as the thickness of Fe and $Ni_{81}Fe_{19}$ under/overlayer increased. These phenomena resulted not only from the interface scattering but also from high ρ of the Fe and $Ni_{81}Fe_{19}$ under/overlayer. The resistivities of the 400 Å Fe and $Ni_{81}Fe_{19}$ films were 125 and 134 $\mu\Omega$cm respectively. So, higher resistivity of the trilayered film than that of the bare alloy film was mainly due to the under/overlayer deposition. The $\Delta\rho$ increased when Fe or $Ni_{81}Fe_{19}$ layer was deposited. This result was opposite to the Co under/overlayered film. The result was obtained because Co has larger exchange integral than Fe and $Ni_{81}Fe_{19}$.[14] And the high resistivity of the Fe and $Ni_{81}Fe_{19}$ layer helped the conduction electrons to move through the alloy layer. As a result, the probability of the interface spin dependent scattering at the Co clusters increased. However, the MR ratio decreased because the increase of ρ was more than that of $\Delta\rho$. Fig. 4 shows the variation of H_s as a function of under/overlayer thickness in the 100 and 500 Å alloy film. The thinner the alloy film thickness, the more reduction of H_s was achieved because of the limitation of the effective exchange coupling depth. The H_s of 100 Å alloy film under/overlayered with Fe 200 Å was 1.23 kOe. But the 500 Å thick film had no reduction of the saturation field. In Co/Ag multilayer system, Lee[15] have reported that 60 Å of Ag decoupled the adjacent Co layers. The effective exchange coupling thickness between the under-overlayer and the Co clusters could be extended because the Ag matrix contained ferromagnetic Co clusters in the granular system. But we thought that it couldn't exceed 300 Å. Therefore, the exchange coupled ferromagnetic under/overlayers would be effective to reduce the saturation field when the thickness of the alloy film is thinner than about 300 Å.

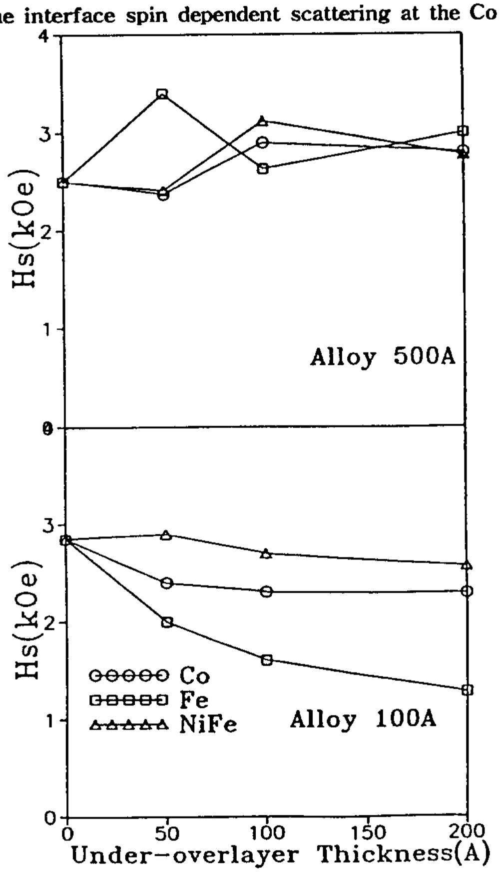

Fig. 4 The effect of under-overlayer thickness on the Hs of 100 and 500 Å alloy film

IV. CONCLUSIONS

1. Maximum magnetoresistance ratio (23%) was observed at 30 at.%Co alloy film whose film thickness was 3000 Å and its saturation field was 2.3 kOe.
2. As the film thickness decreased, the resistivity increased due to the size effect and film structure. The $\Delta\rho$ and MR ratio decreased because the Co size decreased. The MR ratio of 100 Å alloy film was 3.65% and its saturation field was 2.85 kOe.
3. The MR ratio of the Co under/overlayered film decreased because the magnetic spin configuration was changed. And the Co cluster size in the alloy film decreased when the Co under/overlayer was deposited. But the reduction of the saturation field was obtained due to the exchange coupling.
4. The reduction of the saturation field was achieved in the 100 Å alloy film under/overlayered with the 200 Å Fe. The MR ratio was 3.3 % and the saturation field was 1.23 kOe in the trilayered sample.

ACKNOWLEDGEMENT

This paper was supported in part by NON DIRECTED RESEARCH FUND, Korean Research Foundation, in 1993.

REFERENCES

[1] M. N. Baibich, J. M. Broto, A. Fert, F. Nguyen Van Dau, F. Petroff, P. Etienne, G. Creuzet, A. Friederich and J. Chazelas, Phys. Rev. Lett. **61**, 2472 (1988)

[2] S. Zhang, Appl. Phys. Lett. **61**, 1855 (1992)

[3] M. Jimbo, J. Appl. Phys. **74**, 3341 (1993)

[4] S. S. P. Parkin, Appl. Phys. Lett., **60**, 512 (1992)

[5] T. Shinjo and H. Yamamoto, Jpn. J. Phys. Soc. **59**, 3061 (1990)

[6] B. Dieny, V. S. Speriou, S. S. P. Parkin, B. A. Gurney, D. Mauri, Phys. Rev. **B43**, 1297 (1991);K. Hoshino, S. Noguchi, R. Nakatani, H. Hoshiya and Y. Sugita, Jpn. J. Appl. Phys. **33**, 1327 (1994)

[7] J. Q. Xiao, J. S. Jiang and C. L. Chien, Phys. Rev. Lett. **68**, 3749 (1992)

[8] M. B. Stearns and Y. Cheng, J. Appl. Phys. **75**, 6894 (1994)

[9] S. Zhang and P. M. Levy, J. Appl. Phys. **73**, 5315 (1993)

[10] S. R. Lee, Y. J. Oh and Y. H. Kim, J. Kor. Inst. Met. Mat. in Press, (1995)

[11] S. Y. Lee and S. R. Lee, J. Kor. Mag. Soc. 5, 48 (1995)

[12] J. S. Jiang, J. Q. Xiao and C. L. Chien, Appl. Phys. Lett. **61**, 2363 (1992)

[13] C. Yu et al. J. Appl. Phys. **76**, 6487 (1994)

[14] B. D. Cullity, Introduction to Magnetic Materials, Addison-Wesley, (1972) pp134

[15] Y. K. Lee, MS Thesis, Korea University (1995)