Journal of Magnetics 4(4), 128-130 (1999)

The Effect of Ni Atoms Inserted in Ag Spacer on the Magnetic Property of Ni/Ag(Ni at %)/Ni Trilayered Films

S. J. Lee

Kyungdong University, Goseonggun, Toseongmyun, Bongpori, San 91-1, Kangwondo, Korea

(Received 15 September 1999)

We have measured the magnetization of Ni/Ag(Ni at %)/Ni (50 Å/30 Å/50 Å) trilayered films including Ni atoms inserted in non-magnetic Ag spacer. The magnetization as a function of applied field at 5 K and as a function of temperature at 100 Oe were investigated respectively using SQUID magnetometer. In these measurements peaks of magnetization at some critical temperatures were observed in all the samples. The antiferromagnetic coupling energy between neighboring Ni layers showed oscillatory behaviors according to the amounts of the Ni atoms inserted in Ag spacer. Loose spin model suggested by slonczewski was used to explain such results.

1. Introduction

It has been reported that loose spins in non-magnetic spacer of magnetic multilayer may create the biquadratic (BQ) coupling phenomena [1]. The basic idea of this model is that the loose spins in non-magnetic layer is polarized by neighboring magnetic layers, inducing the resultant 90° coupling between the spins of the magnetic layers. The loose spins can be intrinsically formed in the depositing process of the multilayers. Hence, the BQ coupling phenomena could be found in some multilayers. To test the model, as suggested in the paper, the magnetic atoms were inserted in non-magnetic spacer [2]. In this case the magnetic atoms play a role of loose spins to yield a BQ coupling between magnetic layers. However, in that work the inserted atoms are arranged to form a line in parallel with the film plane. Actually it is hard to assume that the loose spin atoms line up in non-magnetic layer. To simulate the real circumstances, therefore, co-sputtering of magnetic and nonmagnetic materials can be performed in depositing the spacer layer. The amounts of magnetic atoms in the spacer can be controled by varying the sputtering rate of magnetic material

In this paper we report that the magnetic atoms inserted using co-sputtering technique in non-magnetic layer of the trilayered films affect the couplings between neighboring magnetic layers. As a result the coupling can be one of antiferromagnetic (AFM), ferromagnetic (FM), and BQ coupling types.

2. Experimental

In fabricating the samples we used the sputtering unit equipped with two DC magnetron sputtering guns. The 30 Å thick Ag buffer layer was deposited on the polished silicon (100) substrate. On this buffer layer Ni/Ag(Ni at %)/Ni (50 Å/30 Å/50 Å) trilayer was deposited subsequently. In depositing Ag spacer Ni atoms were inserted using co-sputtering the two materials. The Ni impurity concentrations were 0, 0.5, 1, 1.5, and 2%. Also 30 Å thick Ag overlayer was finally deposited on the trilayers. The base vacuum was 2×10^{-8} Torr before admitting ultra pure argon gas into sputtering chamber. In depositing the films the argon pressure was 10 mTorr.

The magnetization of the samples was measured using a SQUID magnetometer. The applied field was always parallel to the film planes.

3. Results and Discussion

Fig. 1 shows the magnetization curves as a function of temperature for all the samples. As the temperature increases from 5 K to 400 K the magnetization measured at 100 Oe exhibits a broad peak behavior. The occurrence of peaks, as we have suggested in the papers [3], implies that the magnetic state of these trilayer films varies to FM state from AFM state with increasing temperature. At low temperature region below peak temperature (T_p) the magnetization increases with increasing temperature reaching 25~35 emu/g that is almost ~90% of saturation magnetization at 5 K. At high temperature region above T_p it decreases all the way with increasing temperature, which is a typical FM magnetization curve. This peak behavior may be interpreted as the magnetic property of a spin glass material. However, usually the magnetization of spin glass can not be saturated under such low magnetic field (100 Oe). Therefore, it is

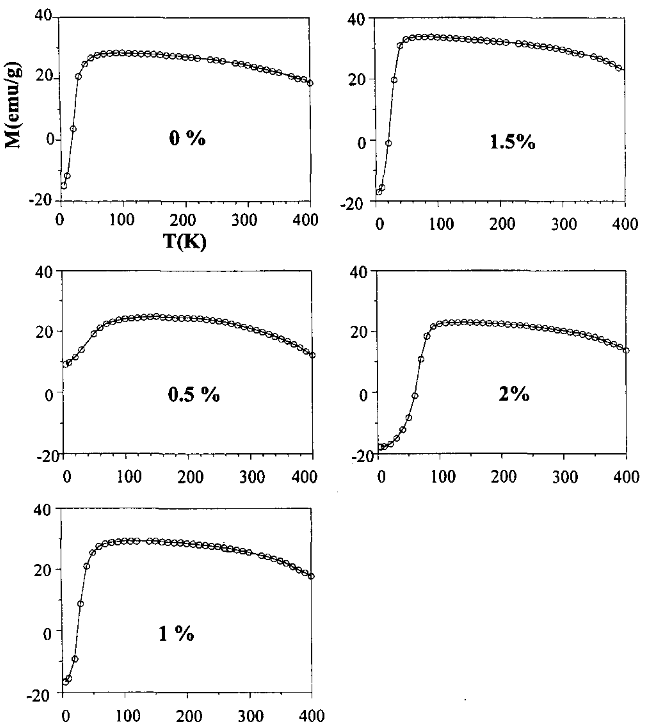

Fig. 1. The magnetization versus temperature of Ni/Ag(Ni at %)/Ni (50 Å/30 Å/50 Å) trilayers at 100 Oe.

considered that in low temperature region the magnetization of the samples increases because the AFM coupling between magnetic layers becomes weak due to increasing temperature.

Fig. 2 shows that the T_p's varies with the amounts of Ni atoms in the Ag spacer. This indicates that the magnetic state of the Ni/Ag(Ni at %)/Ni trilayered films is very sensitive to the amounts of magnetic atoms(Ni) inserted in Ag spacer. According to Slonczewski's theory the spins of magnetic atoms in non-magnetic spacer interacts with the spins of near magnetic layers, which leads to a given coupling state formed between neighboring magnetic layers. Thereby, the coupling state could be one of FM, BQ and AFM types.

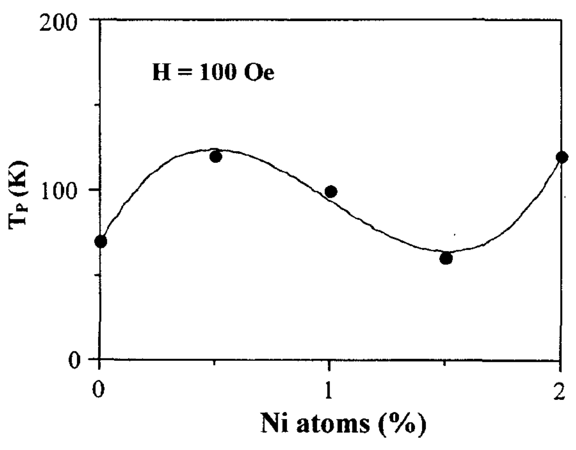

Fig. 2. The peak temperatures (T_p) of magnetization measured at 100 Oe in Ni/Ag(Ni at %)/Ni (50 Å/30 Å/50 Å) trilayers.

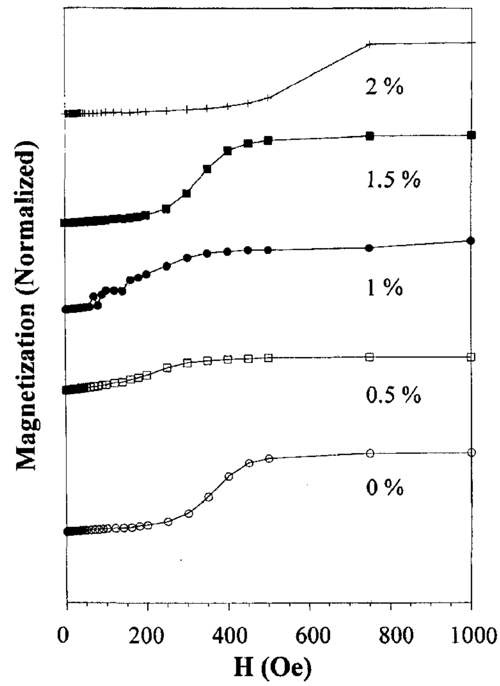

Fig. 3. The magnetization (M) versus the applied magnetic field (H) measured at 5 K for Ni/Ag(Ni at %)/Ni (50 Å/30 Å/50 Å) trilayers.

Considering that the AFM coupling strength depends on the T_p, it is noted that the sample of 2% Ni atoms has the biggest strength among all the samples [4].

Fig. 3 shows the magnetization curves at 5 K for all the samples. As we mentioned in our previous paper the S-like magnetization curves indicate that the magnetic state of the samples is AFM. For 0%, 1.5%, and 2% Ni atoms in the Ag spacer the magnetization curves clearly show S-like shape. Therefore, the magnetic state for Ni/Ag/Ni samples are strongly AFM at those compositions. For 0.5% and 1% Ni atoms, however, the magnetization curve shapes are not clear S-like type. Hence, the magnetic state of these two samples are weakly AFM. This proves that the magnetic state of these samples can be easily changed by varying the amounts of magnetic atoms in the non-magnetic spacer.

The AFM coupling energies at 5 K for each samples were calculated by the equation $J = -M_s t_M H_s/4$ [5], where M_s is the saturation magnetization and t_M is the thickness of the ferromagnetic layer and H_s is the saturation field, and plotted in Fig. 4. The J's oscillate as a function of the amounts of Ni atoms in the Ag spacer. In this data the AFM coupling, as mentioned above, are comparably strong at 0%, 1.5%, and 2% and weak at 0.5% and 1% compositions.

Any feature of BQ coupling was not detected in our samples. As the properties of BQ coupling the first order transition in magnetization (M) versus temperature (T) curves [6] and the intermediate plateau of magnetization in M versus magnetic field (H) curves [7] must be observed. However, we expect that it is possible to obtain the BQ coupling state if the amounts of Ni atoms in the Ag spacer are minutely controled.

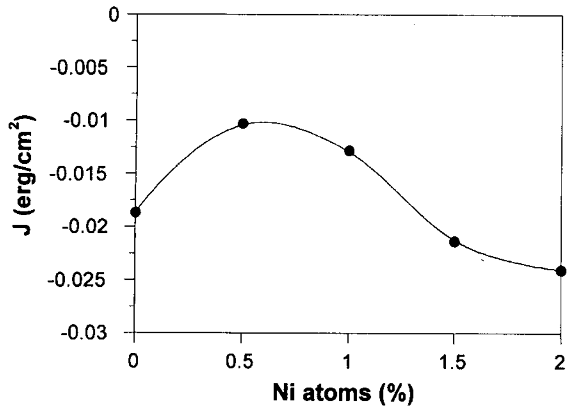

Fig. 4. The AFM coupling energies (J) of Ni/Ag(Ni at %)/Ni (50 Å/30 Å/50 Å) trilayers at 5 K.

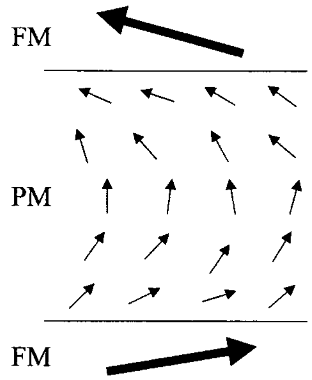

Fig. 5. The spin orientations of FM/PM/FM trilayers. The small arrows are the spins of ferromagnetic (FM) atoms inserted in the paramagnetic (PM) layer and the two large arrows are the spins of each ferromagnetic layers.

The giant magnetoresistance (GMR) effect, which has been found in many magnetic multilayer films, are explained by spin dependent scattering of conduction electrons at interface of film layer [8]. In order to confirm the fact it is needed to measure the MR values for various spin configurations of neighboring magnetic layers. Inserting magnetic atoms in the non-magnetic spacer affects the spin orientations of near magnetic layers as shown in Fig. 5. Accordingly the coupling state of magnetic layers can be determined by the magnetic atoms in the non-magnetic spacer. Basically the magnetic state of FM/PM/FM trilayered films can be changed by inserting the FM atoms in paramagnetic (PM) layer. For fixed each layer thicknesses the FM atoms may be inserted in a thin layer form at a proper position within PM layer. In this case we can expect the magnetic state depends mainly on the position and thickness of inserted FM layer. Actually, the Fe/Cu(Fe at%)/Fe trilayer films show such results [2]. The BQ coupling was detected for those samples. Also, multiple FM thin layers can be inserted in the PM spacer. Although this case has not been investigated experimentally it is easily expected to be able to make a various magnetic states by simply controling the positions and thicknesses of the FM layers in the PM layer. This makes it possible to obtain known magnetic properties of magnetic multilayered films. In comparison with the fabrication of multilayered films, the fabrication of trilayer films inserting FM atoms in PM spacer is much easier in controling the fabrication conditions and analyzing the results of measurements of magnetic properties.

4. Conclusions

In this study we found that the magnetic state of Ni/Ag(Ni at%)/Ni trilayered films varies depending on the amounts of Ni atoms within the Ag spacer. For 0%, 1.5%, and 2% Ni atoms in the Ag spacer layer the magnetic state are strongly AFM at 5 K and for 0.5%, 1% atoms it is weak AFM. The coupling energy at 5 K has the largest value (~–0.024 erg/cm^2) for the sample of 2 % Ni atoms. As the temperature increases from 5 K the magnetization measured at 100 Oe increases up to peak temperature T_p and it decreases thereafter shaping a typical ferromagnetic curve. This fact means that in the low temperature region below T_p the magnetic state of the samples is predominant AFM and above T_p it is FM.

Any feature of BQ coupling phenomena was not detected for all the samples. However, if the amounts of Ni atoms can be minutely controled it is predicted that the BQ coupling could be formed between neighboring magnetic layers. Since inserting the FM atoms in the PM spacer of FM/PM/FM trilayered films makes it possible to have various couplings between FM layers we expect that any important properties such as a GMR can be found in this type of samples.

Acknowledgement

Funding for this research provided by Kyungdong University in 1999 is gratefully acknowledged.

Reference

[1] J. C. Slonczewski, J. Appl. Phys., **73**, 5957 (1993).
[2] B. Heinrich, Z. Celinski, L. X. Liao, M. From, and J. F. Cochran J. Appl. Phys., **75**, 6187 (1994).
[3] S. J. Lee, J. S. Baek, Y. Y. Kim, W. Y. Lim, and W. Abdul-Razzaq, IEEE Trans. Magn., **32**(5), 3398 (1996).
[4] S. J. Lee, J. S. Baek, Y. Y. Kim, W. Y. Lim, and W. Abdul-Razzaq, J. Magnetics, **2**, 93 (1997).
[5] A. Barthélémy, A. Fert, M. N. Baibich, S. Hadjoudj, F. Petroff, P. Etienne, R. Cabanel, S. Lequien, F. Nguyen Van Dau, and G. Creuzet, J. Appl. Phys., **67**, 5908 (1990).
[6] M. E. Filipkowski, C. J. Gutierrez, J. J. Krebs, and G. A. Prinz, J. Appl. Phys., **73**, 5963 (1993).
[7] M. Rührig, R. Schafer, A. Hubert, R. Mosler, J. A. Wolf, S. Demokritov, and P. Grünberg, Phys. Stat. Sol. (a) 125, 635 (1991).
[8] G. Binasch, P. Grünberg, F. Saurenbach, and W. Zinn, Phys. Rev., **B39**, 4828 (1989).