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EFFECT OF PULSE TIME AND EXTERNAL MAGNETIC FIELD ON GIANT MAGNETORESISTANCE (GMR) EFFECT OF ELECTRODEPOSITED MULTILAYER Co/Cu

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SUMMARY

Influences of pulse time and external magnetic on Giant Magnetoresistance (GMR) effect of multilayer Co/Cu were investigated. Results showed that by changing pulse deposition time ($t_{Co,}$ t_{Cu}), the MR ratio of the electrodeposited multilayers varied from 0 to 2.70%. The maximum value of MR ratio (2.70%) was achieved with deposition time (t_{Co} = 2s, t_{Cu} = 5s), corresponding to the thickness (δ_{Co} = 2.1 nm, δ_{Cu}= 7.0 nm). The presence of external magnetic field H_{ext} during electrodeposition enhanced the amount of deposited Cu on one hand, and increased the (200) texture of the deposited films on the other hand. As a result, the MR ratio of the obtained multilayers increased slightly from 2.70% (H_{ext}= 0) to 2.74% (H_{ext}= 600 mT).

I - INTRODUCTION

Magnetic multilayers have attracted considerable attention in magnetic sensor research due to their giant magnetoresistance (GMR) effect, which are characterized by changes of electrical resistance when magnetic field is applied [1, 2]. Usually, the multilayer materials are prepared by means of vapour deposition techniques, which are suitable for the controlled preparation of structures on atomic scales. Electrodeposition meanwhile is a promising technique for practical purpose due to its efficiency and simplicity of the required equipment [3 - 7]. In the previous studies, we have shown that the multilayers Co/Cu can be produced by electrodeposition routine [5, 6]. However, the GMR effect, which is mainly related to microstructure as well as microscopic growth process and electric transport inside the multilayers, is influenced by structure and magnetic properties of components and therefore decided by electrodeposition parameters.

In this paper, the results on study influences of pulse deposition time and external magnetic field during electrodeposition on GMR effect of the electrodeposited multilayer Co/Cu will be presented.

II - EXPERIMENTAL

Electrodeposition of Co/Cu multilayers was performed in a citrate electrolyte containing 0.5 M $CoSO_4$, 0.05 M $CuSO_4$, 0.035 M NaCl and 0.2 M Na-citrate, pH 4 and at room temperature. The substrate used in the experiments is Si (111) coated by 10 nm film of Au (denoted as Si/Au) with resistively of 0.05 Ω.cm. Prior to each experiment the Si/Au samples were sequentially ultrasonically cleaned in acetone, ethanol and water for 10 minutes. An ohmic contact was formed on the back side of the samples by applying InGa eutectic after treatment in 48% HF 1 min.

The electrodeposition experiments were carried out in a conventional three electrode electrochemical cell with Pt counter electrode and saturated calomel electrode (SCE) connected to potentiostat Autolab (EcoChemie). The electrodeposition of Co/Cu was carried out by the pulse technique with E_{Co} = -0.8 V, E_{Cu} = -0.15 V and varied t_{Co} and t_{Cu} (Fig. 1a). The thicknesses of the deposited Cu and Co films can be calculated from the intergration of the current-time curve (Fig. 1b) and the equation (2) [7].

$$\delta_{Me} = \frac{Q^{Me}_{diss}}{nF}.\frac{M_{Me}}{S.D} \quad (1)$$

where deposition charge $Q^{Me}_{dep} = \int_{t_1}^{t_2} Idt$ with I: recorded current response (A), δ: thickness of the deposited metal (cm), n: number of electron, F: Faraday constant (C/mol), M: atomic weight, S: electrode surface (cm^2), D: density (g/cm^3). Since the obtained multilayers practically consist of Cu and Co-Cu alloy components (Co-Cu/Cu), the thickness of Co layer was calculated with the approximation that M, D values of the Co-Cu component were taken from Co element (M_{Co} = 59, D_{Co} = 8.8 g/cm^3).

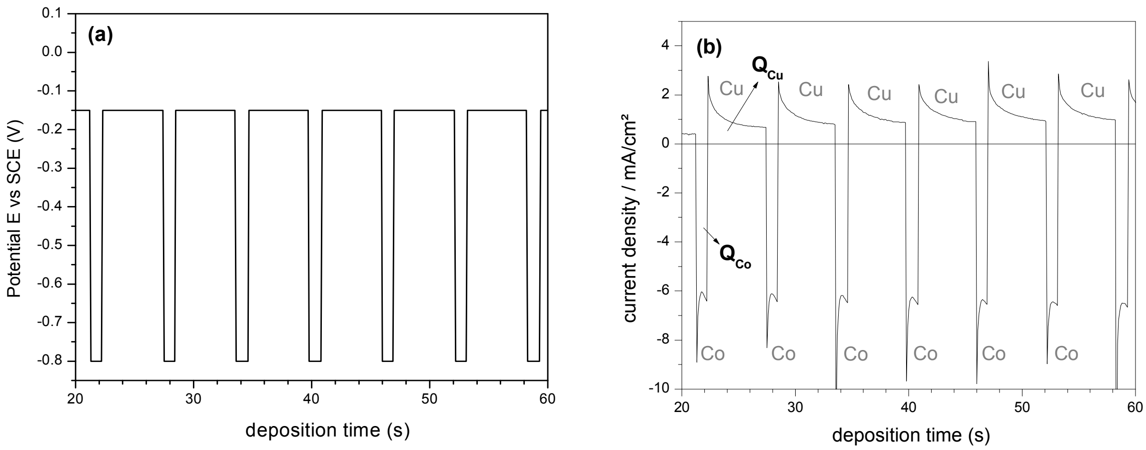

Figure 1: (a) Potential pulse program for the electrodeposition, and (b) Current response for the electrodeposition of Cu/Co multilayer (t_{Co} = 2s, t_{Cu} = 5s)

In order to investigate the effect of external magnetic fields during the deposition process, uniform magnetic fields of up to 600 mT generated by an electromagnet were applied parallel to the electrode's surface. The GMR effect was characterized by a four-point in-plane resistance measurement varying the field strength up to 250 Oe. The magneto resistance (MR) ratio is determined by equation:

$$MR = \frac{\Delta R}{R} \quad (2)$$

where R is electrical resistance at zero magnetic field (H = 0), ΔR is change of electrical resistance as external magnetic field H = 0. The crystal structure of the deposited Co/Cu was analyzed by X-ray diffraction with Co-K_α using a Philips diffractometer.

III- RESULTS AND DISCUSSION

1. Influence of pulse deposition time (t_{Co}, t_{Cu})

In order to investigate the influence of pulse time (t_{Co}, t_{Cu}) on the GMR effect of the multilayer, the pulse time (t_{Cu}, t_{Co}) was varied and MR curves of the obtained multilayer were recorded. It should be noted that the pulse potential time (t_{Co}=2s; t_{Cu}=5s) (corresponding to (δ_{Co} = 2.1 nm, δ_{Cu} = 7.0 nm)) was chosen as the origin value, since with these thickness the theoretically calculated MR-ratio owned the highest value [2]. Figure 2 shows MR curves of the multilayers deposited at different pulse time (t_{Co}, t_{Cu}) and the corresponding MR ratios of multilayers with different (t_{Co}, t_{Cu}) are summarized in table 1. Results show that the maximum value of MR ratio is obtained with (t_{Co} = 2s, t_{Cu} = 5s), corresponding to the thicknesses (δ_{Co}= 2.1 nm, δ_{Cu} = 7.0 nm). This result confirms the theoretical calculations, which indicated that with thickness δ_{Co} = 2 nm and δ_{Cu} = 7 nm, the highest MR ratio of the multilayer can be obtained due to the optimal magnetic and electric transports between layers [2].

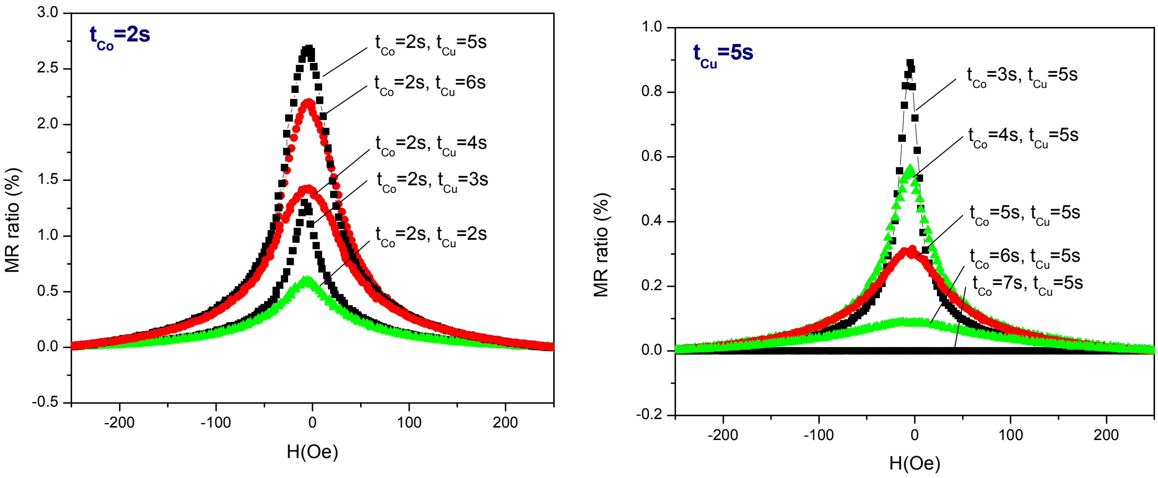

Figure 2: MR curves of multilayers Co/Cu electrodeposited with different pulse time (t_{Co}; t_{Cu})

Table 1: Magnetoresistance ratio (MR) of multilayers Co/Cu deposited with different pulse time

Pulse deposition time	δ_{Co}, nm	δ_{Cu}, nm	MR, %
t_{Co} = 2s			
t_{Co} = 2s; t_{Cu} = 2s	2.0	3.0	0.56
t_{Co} = 2s; t_{Cu} = 3s	2.0	3.7	1.29
t_{Co} = 2s; t_{Cu} = 4s	2.0	5.6	1.42
t_{Co} = 2s; t_{Cu} = 5s	2.1	7.0	2.71
t_{Co} = 2s; t_{Cu} = 6s	2.2	7.5	2.23
t_{Cu} = 5s			
t_{Cu} = 5s; t_{Co} = 3s	5.2	2.4	0.91
t_{Cu} = 5s; t_{Co} = 4s	5.3	3.1	0.56
t_{Cu} = 5s; t_{Co} = 5s	5.3	4.5	0.29
t_{Cu} = 5s; t_{Co} = 6s	5.2	6.0	0.08
t_{Cu} = 5s; t_{Co} = 7s	5.1	6.9	0.00

2. Influence of external magnetic field H_{ext}

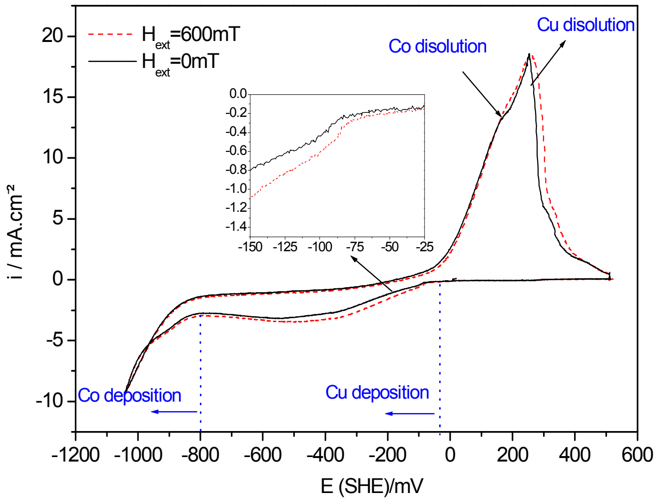

Figure 3: Cyclic Voltammetric curves without external magnetic field (solid curve) and with external magnetic field $H_{ext} = 600$ T (dash curve)

Figure 3 displays the cyclovoltammogram of the substrate Si/Au without magnetic field (solid line) and with external magnetic field H_{ext} = 600 mT (dashed line). A slight increase of the current density in the Cu deposition region in the presence of external magnetic field H_{ext} can be observed in the magnified part of the polarization curve (inset in Fig. 3). In the back scan, Co dissolution peaks of both curves are nearly overlapped, while the amount of Cu dissolution is higher for the curve with external magnetic field (Fig. 3). This effect can be explained by the so-called magneto-hydrodynamic effects (MHD) caused by a high convection in the electrolyte as a result of the Lorentz force [8]. Thus, the external magnetic field increases the amount of Cu deposition and affects only slightly on the deposition of Co.

XRD pattern of the electrodeposited multilayers without magnetic field and with H_{ext} = 600 mT is shown in Fig. 4. It can be observed that the electrodeposited multilayers consist of fcc phases ((111) and (100) textures) and bcc phase ((200) texture). However, the (200) texture of the multilayer deposited under external magnetic field is higher than that of the multilayer deposited without external magnetic filed H_{ext}. Since the (200) texture enhances the magnetic properties of the Co components, it is expected that the GMR effect of the multilayer increases clearly as electrodeposition is carried out under external magnetic field [9]. However, the MR ratio increases only slightly when external magnetic field is applied during electrodeposition i.e $MR_{(Hext=0)}$ = 2.70 and $MR_{(Hext=600mT)}$ = 2.74 as shown in figure 5. This can be explained by the fact that the MR ratio in this case is mainly decided by the thickness of the Co and Cu layers. As shown in Fig. 3, the presence of H_{ext} accelerates the deposition of Cu and thereby increases the thickness of Cu layers.

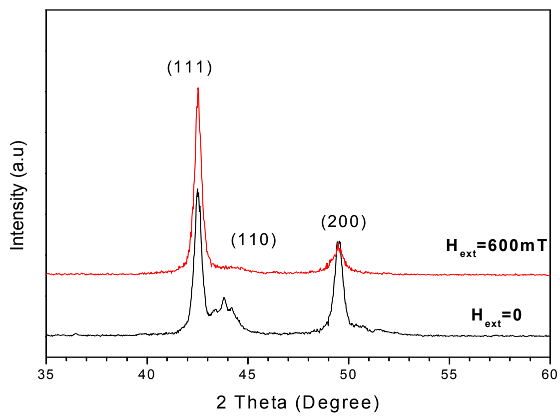

Figure 4: XRD pattern of the electrodeposited multilayers Co(2.1 nm)/Cu(7.0 nm) (t_{Co} = 2s; t_{Cu} = 5 s) with superimposed magnetic field H = 0 and H = 600 T

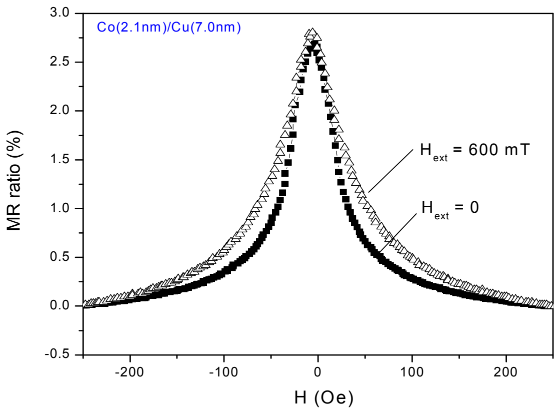

Figure 5: MR curves of the electrodeposited multilayer Co(2.1 nm)/Cu(7.0 nm) (t_{Co} = 2s; t_{Cu} = 5s) with external magnetic field H = 0 and H = 600 T

Therefore, the effect of increasing Cu thickness is dominated comparing with the increase of the (111) texture and only small change of the MR ratio is obtained as a result when external magnetic field is applied during electro-deposition.

IV- CONCLUSIONS

Giant Magnetoresistance (GMR) effect of the multilayer Co/Cu is influenced by pulse deposition time (t_{Co},t_{Cu}) and external magnetic field during electrodeposition. By changing pulse deposition time (t_{Co},t_{Cu}), the MR ratio of the electrodeposited multilayers varied from 0 to 2.70%. The maximum value of MR ratio (2.70%) is achieved with deposition time (t_{Co} = 2s, t_{Cu} = 5s), corresponding to the thickness (δ_{Co} = 2.1 nm, δ_{Cu} = 7.0 nm). The presence of external magnetic field H_{ext} during electrodeposition enhances the amount of deposited Cu on one hand, and increases the (200) texture of the deposited films on the other hand. As a result, the MR ratio of the obtained multilayers increases slightly from 2.70% (H_{ext} = 0) to 2.74% (H_{ext} = 600 mT).

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REFERENCES

1. M. N. Baibich, J. M. Broto, A. Fert, Nguyen Van Dau, R. F Petroff, P. Eitenne, G. Creuzet, A. Freiderich and J. Chazelas. Phys. Rev. Lett., 61, P. 2472 - 2479 (1988).
2. M. Villeret, J. Mathon. Phys. Rev. B, 57(6), P. 3474 - 3477 (1998).
3. M. Schlesinger. Scripta Met et Mat., 33, P. 643 - 646 (1995).
4. K. Bird, M. Schlesinger. J. Electrochem. Soc., 142(1), P. 64 - 72 (1995).
5. Mai Thanh Tung, Nguyen Hoang Nghi, J. W. Schultze. Journal of Chemistry, 6, P. 764 - 767 (2005).
6. Mai Thanh Tung, Chu Van Thuan, Nguyen Hoang Nghi. Proceedings of 12th Regional Symposium of Chemical Engineering (RSCE), P. 216 - 219 (2005).
7. Tran Minh Hoang. Handbook of Electroplating Engineering, Science and Technology, Publishers, Hanoi (2000).
8. T. Z. Fahidy. Modern Aspects of Electrochemistry, No. 32 (edited by B.E. Conway), Kluwer Academic Plenum Publisher, NY (1999).
9. Q. Huang, D. P. Young, J. Y. Chan, E. J. Podlaha. J. Electrochem. Soc., 149(6), P. 349 - 354 (2002).