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Effect of interface number on giant magnetoresistance

S.M.S.I. Dulal [a,*], E.A. Charles [b]

[a] Department of Materials Science and Engineering, University of Rajshahi, Rajshahi 6205, Bangladesh
[b] School of Chemical Engineering and Advanced Materials, University of Newcastle upon Tyne, Newcastle upon Tyne NE1 7RU, United Kingdom

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ABSTRACT

Ni(Cu)/Cu, Co(Cu)/Cu, and Ni–Co(Cu)/Cu multilayers with a varied number of interfaces (i.e. bi-layers) were electrodeposited on gold coated quartz discs in a flow channel cell by a potentiostatic dual-pulse plating method. It was found that the giant magnetoresistance of these multilayers increased almost linearly with increase in the number of interfaces. This result confirms that the interfaces play a dominating role in giant magnetoresistance. Comparable samples of these three types of multilayers were prepared under identical electrochemical conditions from appropriate baths. The result showed that Ni–Co(Cu)/Cu multilayers exhibited much higher giant magnetoresistance than Ni(Cu)/Cu, and Co(Cu)/Cu multilayers, which was possibly due to the structural differences between the multilayers.

1. Introduction

Nanostructured multilayers consisting of alternate layers of ferromagnetic and nonmagnetic materials exhibit giant magnetoresistance (GMR) [1,2], which has applications in electronic data storage. There are many factors, which affect the magnitude of GMR. It was reported that GMR of multilayers changes periodically with the thickness of nonmagnetic layer [3,4]. GMR also varies with the thickness of the ferromagnetic layer [5]. Increased GMR has been found in multilayers electrodeposited from an electrolyte of very low pH [6]. The electrochemical parameters such as electrodeposition technique [7], pulse waveform [8], etc., also have some effect on the GMR. It is thought that GMR is attributed due to the spin dependence electron scattering in the multilayers, but a controversy exists concerning whether the scattering occurs within the layers or predominantly at the interface [9]. However, Parkin's experiments suggest that interface scattering is important in GMR [10]. Therefore, it is envisaged that interface number should have some effect on the magnitude of GMR. Hence, the present study was undertaken to observe the effect of interface number on GMR of Ni(Cu)/Cu, Co(Cu)/Cu, and Ni–Co(Cu)/Cu multilayers prepared by electrodeposition method. A comparison among these multilayers has been made in terms of their GMR properties and structural stability.

2. Experimental

Ni(Cu)/Cu, Co(Cu)/Cu, and Ni–Co(Cu)/Cu multilayers with varied number of bi-layers (i.e. interfaces) were electrodeposited from citrate electrolytes in a flow channel cell by a potentiostatic dual-pulse plating method. Tri-sodium citrate was chosen because it was non-toxic and had brightening, levelling and buffering actions. Moreover, citrate electrolyte has recently been used for precision electrodeposition [11–14]. The bath compositions are shown in Table 1. The electrolytes were prepared by dissolving appropriate amount of the chemicals in de-ionized water. The pH of the electrolytes was adjusted to 6 by the addition of dilute NaOH. The flow rate of the electrolyte was 40 $cm^3 s^{-1}$. The nonmagnetic and ferromagnetic layers were plated by alternate application of a low pulse at −0.6 V vs. Cu and a high pulse at −2.0 V vs. Cu, respectively. Details of the experimental procedure for pulse plating of multilayers in a flow channel cell were reported previously [15,16]. Deposition was carried out at room temperature. The nominal thickness of nonmagnetic and ferromagnetic layers of all plated multilayers were 2 nm. Bi-layer number was varied between 50 and 400.

The magnetoresistance was measured on as-deposited samples in the current-in-plane (CIP) configuration at four-points-in-line. The longitudinal magnetoresistance (LMR) was obtained when the relative directions of the magnetic field and the electric current were parallel and the transverse magnetoresistance (TMR) was obtained when the magnetic field and electric current were perpendicular to each other. The magnetoresistance ratio (MR) was calculated using the following formula:

$$MR = (R_H - R_0)/R_0$$

where, R_H is the sample's resistance in the magnetic field H and R_0 is the sample's resistance when H=0.

* Corresponding author. Tel.: +88 0721 750041x4156; fax: +88 0721 750064.
E-mail address: dulal_smsi@yahoo.com (S.M.S.I. Dulal).

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Table 1
Bath compositions.

Multilayer type	Bath composition
Ni(Cu)/Cu	0.600 M $NiSO_4$, 0.025 M $CuSO_4$, and 0.265 M $Na_3C_6H_5O_7$
Co(Cu)/Cu	0.600 M $CoSO_4$, 0.025 M $CuSO_4$, and 0.265 M $Na_3C_6H_5O_7$
Ni–Co(Cu)/Cu	0.500 M $NiSO_4$, 0.100 M $CoSO_4$, 0.025 M $CuSO_4$, and 0.265 M $Na_3C_6H_5O_7$

3. Results and discussion

Typical magnetoresistance curves for Ni(Cu)/Cu, Co(Cu)/Cu, and Ni–Co(Cu)/Cu multilayers are shown in Fig. 1. The figure shows the variation of magnetoresistance with applied magnetic field, which is due to the change in the relative alignment of the magnetization vectors of the successive ferromagnetic layers. Both the longitudinal and transverse components show similar behaviour.

Plots of GMR, measured at 8 kOe magnetic field, of the three types of multilayers as a function of bi-layer number are shown in Fig. 2. In these plots the absolute values of magnetoresistance has been presented. The figure shows that GMRs of these multilayers increase strongly with increasing number of bi-layers. The shapes of plots of GMR vs. bi-layer number of Ni(Cu)/Cu (Fig. 2a), and Co(Cu)/Cu (Fig. 2b) multilayers are curved, whereas GMR of Ni-(Co)/Cu (Fig. 2c) multilayers seems to increase linearly with the number of bi-layers up to 400. Multilayers of more than 400 bi-layers were also prepared but the deposits were very brittle and peeled from the substrate within a few hours after deposition. These samples were not suitable for GMR measurements.

The results suggest that giant magnetoresistances of Ni(Cu)/Cu, Co(Cu)/Cu, and Ni–Co(Cu)/Cu multilayers are strongly dependent on the number of interfaces. The reason of this dependence of GMR on interface number, however, is not clear. The multilayers were plated on metallic substrates (gold) and the magnetoresistance measurements were carried out on the 'as-deposited' samples. Therefore, it was thought, in the first instant, that the increase in GMR with increasing number of interfaces (increasing overall thickness) might be due to the decreasing shunting effect of the metallic substrate [17]. The addition of more bi-layers decreases the total resistance but increases the importance of spin-dependent scattering in the film over spin-independent scattering in the substrate and thus, increases the magnetoresistance. However, Fig. 2b shows that GMR becomes almost double when the number of bi-layers is doubled. Thus, the magnitude of this increase in GMR with bi-layer or interface number is greater than that might be assigned to a shunting effect and so eliminates the possibility. Moreover, Cyrille et al. [18] sputter deposited Fe/Cr multilayers on silicon (no metallic substrate) and found an enhanced GMR with increasing bi-layer number. Their studies also show that the interface roughness of each layer is the same and that the cumulative roughness increases with the increase of bi-layer number. Therefore, the increase in magnitude of GMR with bi-layer number may be due to the overall increase of coherent interface roughness as speculated in Ref. [18]. The interface roughness of each multilayer has not been studied in the present work, but it is understandable that the coherent roughness could increase with the increase of the number of bi-layers. Although it is not clear whether GMR is attributed due to the scattering within the layers or predominantly at the interfaces, Parkin's [10] experiments suggest that interface scattering is important in GMR. Our results also strongly support the importance of scattering at interfaces.

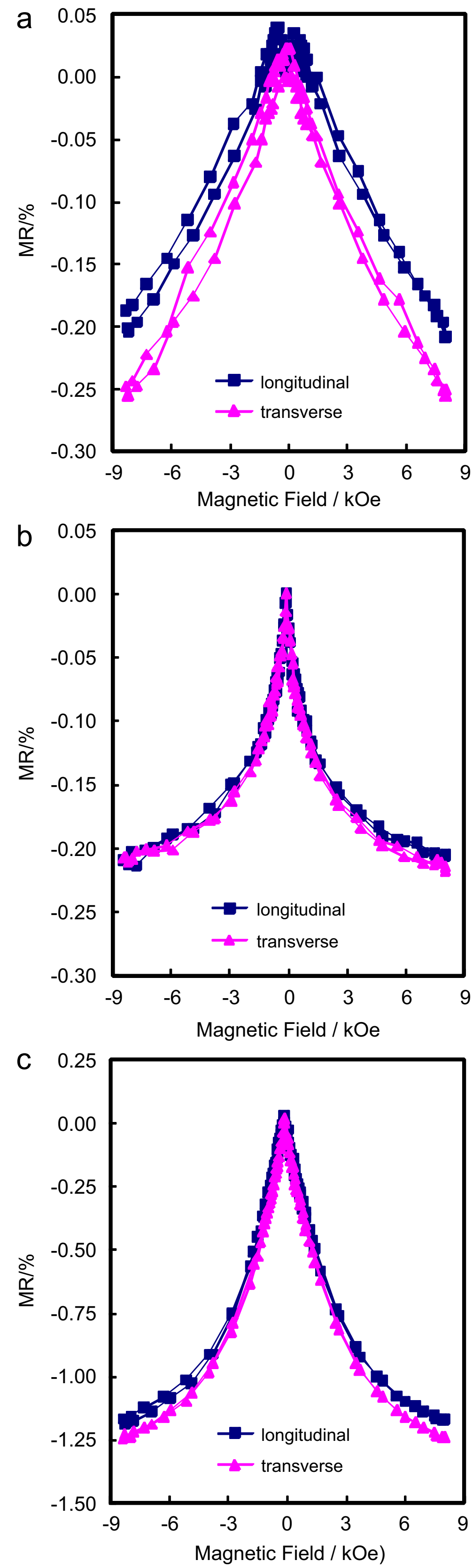

Fig. 1. Typical magnetoresistance curves for (a) 100 × Ni(Cu)(2 nm)/Cu(2 nm), (b) 100 × Co(Cu)(2 nm)/Cu(2 nm), and (c) 100 × Ni–Co(Cu)(2 nm)/Cu(2 nm) multilayers.