ORIGINAL PAPER

ON THE MAGNETORESISTANCE OF COBALT BASED MAGNETORESISTIVE STRUCTURES

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Abstract. *We characterize Co-based metallic multilayers by an exponential model of response of magnetoresistance to applied magnetic field. The magnetic coefficient (k) is found to be dependent on interface roughness and is (tesla)-1 for Co(10Å)/Cu(10Å)|15 at 2GPa pressure [9] and Co(2nm)/Cu(1nm)|300 [16]. Our analysis attributes this to influence of pressure on the microstructure of interfaces.*

Keywords: *Metallic multilayer, cobalt, magnetic coefficient.*

1. INTRODUCTION

Magnetoresistance (MR) has been studied in several metallic and metal/semiconductor systems, comprising 3d metals among which are predominantly Fe and Co [1-6].

The magnetoresistance is most frequently measured in the current in plane geometry and much theoretical models were developed to study the phenomenon; whose mechanism in metallic structures is accepted to be spin-dependant scattering [7, 8]. Established theories can only calculate MR at given magnetic fields (B) without explicit form for the variation over the range of B. This variation is however, a primary study in experiments. Explicit relation for this variation would be a means of characterizing different magnetoresistive structures. The importance of this, is obvious from the varied MR responses of even same materials fabricated in different methods. The ion-beam sputtered Co/Cu [9] had MR of 54% whereas electrodeposited Co/Cu [4] showed maximum effect of 10%. This sort of differences can easily be accounted for by a characterization parameter. Assuming the generally accepted interface scattering [2,7,8,10] as the mechanism; we observe that differences in MR such as mentioned above, is determined by the quality of an interface which in turn is affected by method of fabrication. Hence, the complexity in accounting for such differences, (thereby characterizing a multilayer), using any of the quasiclassical or quantum theories of MR [11-15] is very much obvious.

Recently, however, a functional form for MR variation with B was developed within the framework of calculus of variation; in which the variation coefficient (referred herein as "magnetic coefficient") is a characterization parameter. That is, it is determined by the materials and techniques of preparation involved. In this paper we characterize, in terms of this coefficient, certain Co-based metallic structures. We present a brief description of our

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model in section II. Section III is the application to some case studies and explanation of the import.

2. DESCRIPTION OF THE MODEL

The logarithm of the standard equation for magnetoresistance can be given as

$$y = \ln\left(1 - \frac{\rho^{\uparrow\uparrow}}{\rho^{\uparrow\downarrow}}\right), \tag{1}$$

With $\rho^{\uparrow\uparrow}$ and $\rho^{\uparrow\downarrow}$ having their usual meaning. Series expansion of Eq. (1) may be approximated to first order since $|x| = \left|\rho^{\uparrow\uparrow}/\rho^{\uparrow\downarrow}\right| \le 1$. Thus, Eq. (1) is linear over the range of B.

Then it is easy to show, via variation calculus [9] that,

$$R(B) = R_0 \exp\Big[\big(\big(k|B - B_0|\big)\big]\Big), \tag{2}$$

where R denotes MR and R_0 MR at reference field B_0. This is the explicit form of MR variation with B, where k is the magnetic coefficient. Note that Eq. (2) can be in perturbation form

$$R(B) = R_0 + \sum_{n=1}^{\infty} a_n \left(B - B_0\right)^n, \tag{3}$$

where $a_n = (n!)^{-1} \lim_{x\to\infty} d^{\,nR(B_0)}/dB^n$.

Eqs. (2) and (3) do not evaluate discrete values of MR in the conventional methodologies of other MR models. But says that if R_0 and k known, MR at any other B can be predicted. Though R_0 may be calculated by any of the quasiclassical or quantum models of MR; k happens to be empirical and as such depends on materials, method of preparation and geometry of measurement (current in plane (CIP), current perpendicular to plane (CPP) and current at angle to plane (CAP)).

3. APPLICATION TO EXPERIMENT

We consider three Co-based multilayers: (i) electrodeposited Co(2nm)/Cu(tCunm)|300 where tCu= 1, 3.2nm [16], (ii) Co(12Å)/Ag(174Å)/NiFe(12Å)/Ag(174Å) deposited on V-groove substrate where MR was observed in the CIP and CAP geometries [17] and (iii) ion beam sputtered Co(10Å)/Cu(10Å)|15 where MR was observed at different pressures [9]. The respective k deduced by using Eq. (2) are listed in table 1. We also calculated numerically, using Eq. (3), the MR of Co(2nm)/Cu(tCunm)|300. Comparison with experiment is illustrated in Fig. 1.0 which shows reasonable agreement of both.

Table 1. Magnetic coefficient (k) of Cobalt based multilayers.

Multilayer	k (Tesla)-1	Geometry
Electrodeposited [17] Co(2nm)/Cu(tCu)|300	-3.50 (tCu = 1.0nm)	CIP
	-5.00 (tCu = 3.2nm)	CIP
V-groove substrate [18] Co/Ag/NiFe/Ag	-8.93	CIP
	-10.50	CAP
Ion beam sputtering [9] Co(10Å)/Cu(10Å)|15	-2.91 (at 0GPa)	CIP
	-3.50 (at 2GPa)	CIP

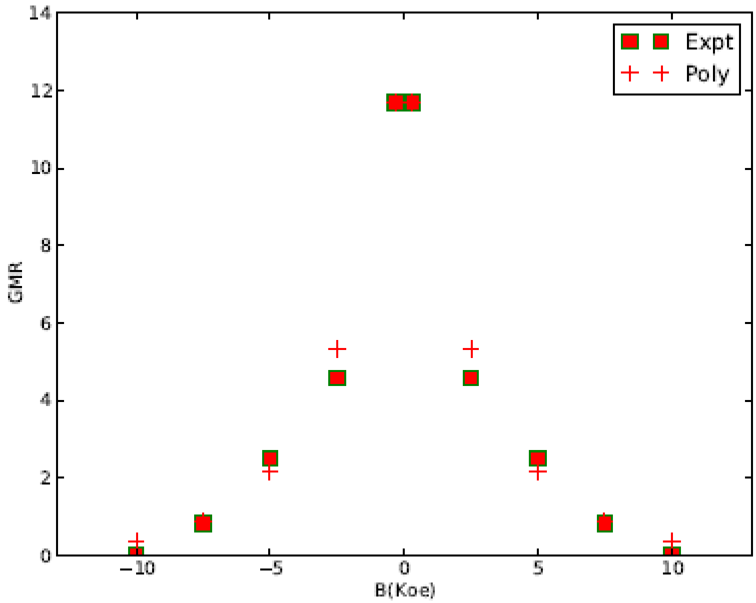

Fig. 1. Experimental and numerical GMR of Co(2nm)/Cu(1nm)|300 [17]. Numerical evaluation was done with Eq. (3). ■ Experiment. + calculated.

4. DISCUSSIONS

Spin dependent scattering in the bulk and at interfaces of layers are the mechanisms of magnetoresistance in multilayers. Though bulk scattering plays major role in certain conditions [10], scattering at interface is generally taken to dominate [2, 7, 8, 10]. We assume the latter in the present work.

The negative sign on k shows eq. (2) to be specifically a decay function, which agrees with experimental observation of MR response to increasing B. In general large $|k|$ entails rapid decay of MR over the range of B. With regards to geometry of measurement we see that for Co/Ag/NiFe/Ag there is a large difference in $|k|$ for CAP and CIP. This is reflected in the rapid reduction of CAP MR, though its value is larger than the CIP MR for the same range of B as shown in [18]. The same trend obtains for the other multilayers with regards to the respective parameters: pressure and thickness.

It can be noted from table 1.0 that *k* is sensitive to pressure. This is attributed to suppression of spin dependent scattering at the interface by pressure [9]. Moreover, we note that k is the same for $Co/Cu|_{15}$ at 2GPa and $Co/Cu(1nm)|_{300}$; at 10KOe (1 tesla) the latter had MR of zero and that of the former is approximately the same. (see the respective literature). This is explained by alteration of microstructure of an interface by pressure [9]. It is suggested then, that the alteration does not influence compositional alloying and atomic defects (dislocations, interstitial atoms etc) which are subject to methods of deposition and thickness of layers but rather the geometric roughness. Hence the suppression of scattering mentioned above can only be for diffusive scattering. Within the two current series resistor model [13], this suppression will hamper the short-circuit effect between the majority and minority spin channels and results to reduced MR as can be observed in [9] for $Co/Cu|_{15}$ and similar MR for this structure and $Co/Cu(1nm)|_{300}$ at 1 tesla. Also it is noted from table 1.0 that k is sensitive to methods of deposition and it is well known that deposition method influences quality of interface.

So we see that *k* is strongly dependent on interface roughness and indirectly dependent on parameters and conditions that affect interface quality.

5. CONCLUSIONS

We have characterized Co-based metallic multilayers in terms of magnetic coefficient (k). k is found to depend on interface roughness and permits evaluation of MR of a multilayer in any range of B.

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