ORIGINAL PAPER

MAGNETORESISTANCE-TEMPERATURE RELATIONSHIP: CALCULUS OF VARIATION APPROACH

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Abstract. *To account for the varied index of power law T^n for temperature (T) dependence of giant magnetoresistance (GMR); an exponential model is developed through calculus of variation. The model yields temperature coefficient α, that is strongly dependent on the system involved and plays the role of performance index. For instance, for Fe(1nm)/ITO(3nm) [1] and Co(3nm)/ITO(1.76nm) [2],* $\alpha = -3.90\times10^{-3}$ *and* $-1.05\times10^{-3}\ K^{-1}$ *respectively with corresponding predicted GMR of 6.46% and 2.62% at 1K. The model fits all experiment data considered.*

Keywords: *GMR, multilayer, temperature.*

1. INTRODUCTION

Several factors affect the giant magnetoresistance, GMR among which is temperature. In layered structures, the temperature response has been modeled by power law T^n. In Fe/ITO the response is fitted by T^2 [1] and similar response obtains for Fe/Cr at temperatures below 100k [2]. For Co/Cu studied by Saito et al [3] it showed linear variation of form T^1 whereas in Co-Cu/Cu it fits to T^2 [4]. Also linear response was observed for current in plane MR of Fe/Cr and Co/Cu up to 300k; whereas the current perpendicular to plane MR of both can best by described by a polynomial function [5, 6].

Irrespective of the power law index, GMR generally reduces with increasing temperature, so there is a negative temperature coefficient associated with a magnetoresistive structure. Hence it is possible to have a model in terms of this coefficient rather than power law; in which case the coefficient will be a characteristic feature or property of a particular structure.

This paper presents such general model. In section 2, we describe the model and apply it, in section 3, to a number of experimental data to determine the corresponding coefficients of the systems involved.

Description of model

Given the standard equation for MR

$$R = 1 - \frac{\rho^{\uparrow\uparrow}}{\rho^{\uparrow\downarrow}} \tag{1}$$

where the symbols have their usual meanings. Then

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$$\ln\left(1-\frac{\rho^{\uparrow\uparrow}}{\rho^{\uparrow\downarrow}}\right)=a_1z+a_2z^2+a_3z^3+\cdots \tag{2}$$

where $a_i(i=1,2,\ldots)$ are constants and $z=-\rho^{\uparrow\uparrow}/\rho^{\uparrow\downarrow}$. As (2) applies to a number z in the range $|z|\leq 1$ [6] and $z^i\to 0$ as $i\to\infty$; $\ln\left(1-\rho^{\uparrow\uparrow}/\rho^{\uparrow\downarrow}\right)$ may be approximated to linear function over the range of magnetic field B. Consequently similar approximation can be made, for fixed B, over a range of temperature, T.

Therefore, if $P(T_0,R(T_0))$ and $Q(T,R(T))$ are points in lnR-T plane, the element of curve linking them

$$ds=(1+y'^2)^{1/2}dT \tag{3}$$

where $y=lnR$ and $y'=dy/dT$.

Applying Euler-Lagrange method [7] we have

$$R(T)=A\exp(aT) \tag{4}$$

with initial condition $R(T_0)=R_0$

$$R(T)=R_0\exp\alpha(T-T_0) \tag{5}$$

where α is temperature coefficient. It characterizes a given multilayer and thus is structure dependent. We have extended “structure” to include techniques of preparation since it is well known that the latter affects properties of materials. So various α of a multilayer prepared by different techniques, serve to determine best preparation technique for anticipated performance in particular range of temperatures.

The model (5) accounts for any index of the power law T^n and is solved analytically or numerically with regards to degree of accuracy required.

2. APPLICATION TO EXPERIMENT

We applied the model to a number of multilayers in current in plane, CIP and current perpendicular to plane, CPP geometries. As-deduced temperature coefficients are listed in table 1. For the Co/ITO, the very close values of α for $t_{ITO}=1.32, 1.76\mathrm{nm}$ indicates weak dependence on layer thickness

Table 1. Comparison of temperature coefficient of magnetoresistive structures prepared.

Structure	Geometry	α (k^{-1})
DC magnetron sputtered [2]:		
$Co(3nm)/ITO(1.32nm)\|_{40}$	CIP	$9.39x10^{-4}$
$Co(3nm)/ITO(1.76nm)\|_{40}$	CIP	$-1.05x10^{-3}$
DC magnetron sputtered [1]:		
$Fe(1nm)/ITO(3nm)\|_{30}$	CIP	$-3.90x10^{-3}$
****Molecular beam epitaxy [5]:***		
$Co(1.2nm)/Cu(1.1nm)\|_{180}$	CPP	$-1.88x10^{-3}$
****Vacuum sputtered [5]:***		
$Fe(3nm)/Cr(1nm)\|_{100}$	CPP	$-7.17x10^{-3}$
Epitaxial[8]:		
$Fe(120Å)/Cr(10Å)\|_{4}Fe$	CIP	$-5.95x10^{-3}$
**original data in [6]*		

However a strong dependence on structure is very evident. A prediction of MR can then be made. As instance, magnetron sputtered Fe(1nm)/ITO(3nm) [3] and Co(3nm)/ITO(1.76nm) [1] have GMR of about 6.46% and 2.62% respectively at 1K.

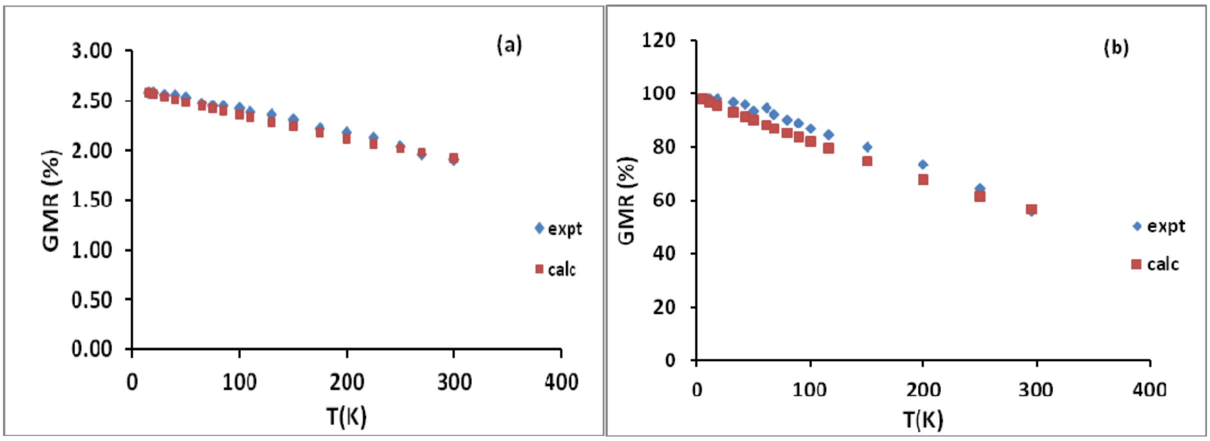

Fig. 1. GMR as function of temperature for magnetron sputtered (a) $Co(3nm)/ITO(1.76nm)|_{40}$ in CIP geometry and (b) $Co(1.2nm)/Cu(1.1nm)|_{180}$ in CPP geometry ◆ experiment. ■ Calculated. (experiment data after [2, 5]).

Fig. 1 illustrates experimental and analytical values of GMR of two of the structures investigated. Similar trend holds for other structures. The discrepancy in values is due to inherent error in evaluating the exponential function. Though better accuracy is achieved with numerical solutions, the trend of response remains the same. The temperature coefficient being structure-dependent, suggests possible influence by: (i) exchange coupling, in coupled systems like Fe/Cr, (ii) heat capacity of structure and (iii) interface properties. These possible factors are planned to be investigated in future.

3. CONCLUSION

A general model for response of GMR to temperature in layered structures is developed. The temperature coefficient is found to be a characterizing parameter and strongly dependent on the magnetoresistive structure involved.

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