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Short Communication

Drude Formalism Study of The Giant Magnetoresistance in Fe(t)/Cu/Fe Trilayers

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Abstract

The recently developed Drude-like model for resistivity in metallic multilayers is applied to Fe(t)/Cu(10A)/Fe(10A) trilayer systems. The basic GMR characteristics deduced conform qualitatively to reports communicated in literature. Our analyses show that the Fuchs-Sondheimer theory of thin film resistivity is not valid for layered structures and spin-dependent scattering in the bulk is the dominant mechanism for GMR in the investigated systems.

Keywords: GMR, relaxation time, trilayer.

Introduction

Two decades after its discovery in Fe-Cr trilayers[1,2], the giant magnetoresistance still attracts growing number of theoretical and experimental studies. Several of these investigations seek better GMR materials[3–5] while more in depth understanding of the spin-dependent transport is the focus of most theoretical studies[6–7]. Some of the influencing factors like pressure and temperature have been investigated as well[8–11].

The theoretical models developed over the years to interpret GMR, consists of two main approaches: quasiclassical[12,13] and quantum methods[14,15], both evaluate resistivity on per-layer basis. However Camblong[16] in his Kubo formalism approach demonstrated the equivalence of both methods. A generalized proof of this has been developed recently[17].

With regards to metallic structures, it is well known that in the homogenous limit $l_{j,\alpha} \gg a_j$ (l is mean free path, j = sublayer index, α = ↑, ↓ spin and a_j = thickness of j^{th} sublayer) an electron probes all scattering within a mean free path which includes several layers and thus averages all sorts of scattering medium[16]. It is then conceivable to have a model that yields the global resistivity of a structure on a non per-layer basis. In this respect, a Drude-like model was recently developed[17] in the framework of piece-wise constant potentials. The present contribution centers on the application of the model to the GMR of Fe(t)/Cu(10A)/Fe(10A) trilayer systems. Section II presents a brief description of the model and in section III we present results of the numerical analyses.

Material and Methods

Resistivity of either spin channel is given by

$$\rho^\alpha = \frac{M^\alpha}{n^\alpha e^2 \tau^\alpha} \quad (1)$$

where the parameters have the same meanings as in the conventional Drude model but now with respect to spin α. Also the relaxation time τ^α is dependent on the magnetic state (antiparallel and parallel alignments) of the system. The spin channel density and fermi velocity are respectively given by

$$n^\alpha = \frac{(M^\alpha V_F^\alpha)^3}{6\pi^2\hbar^3} \quad (2)$$

And,

$$V_F^\alpha = \left[\frac{2(E_F - u^\alpha)}{M^\alpha}\right]^{\frac{1}{2}} \quad (3)$$

Where u^α denotes total spin-dependent potential of the system and consists of the bulk potential, potential step at interfaces and s-d scattering potential introduced by interface roughness. E_F is the adjustable fermi level. Equation 1 is solved for both magnetic states and the global resistivity evaluated using the two current model.

Results and Discussion

From what has been shown, resistivity is dependent on the magnetic states through relaxation time. To characterize the basic features, we adopt bulk potentials of the constituent layers as given in[12] and assume effective mass $M^\uparrow = M^\downarrow$ = 4× free electron mass.

We analyse numerically, five trilayers of Fe(t)/Cu (10Å) /Fe(10Å) where t = 5 – 25Å in steps of 5Å. Our results compare positively with what has been reported about GMR in experiments and theoretical models. The MR shows decreasing trend with increasing structure thickness as illustrated in figure 1. This is due to increasing t_{Fe}; a well known fact[15] that is explicitly shown in figure 2a.

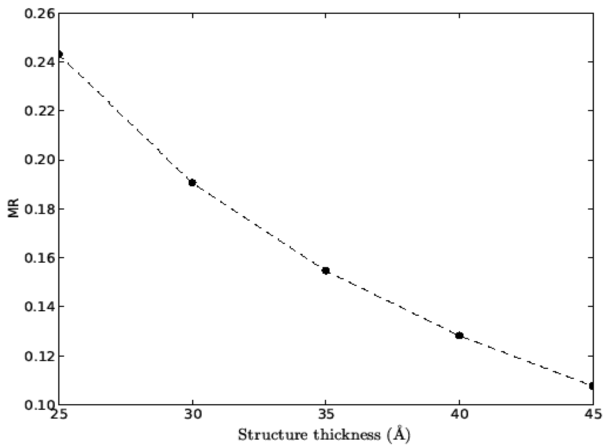
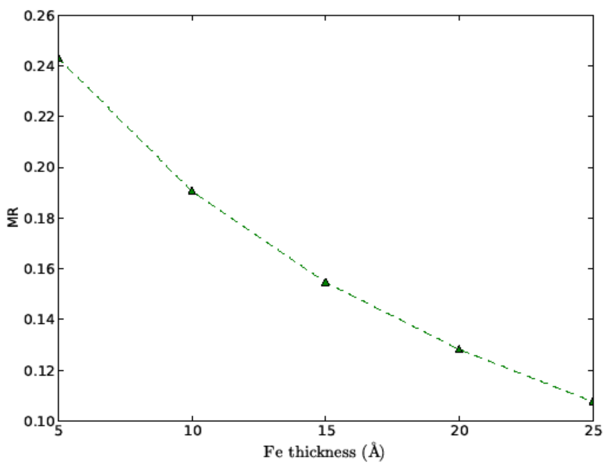
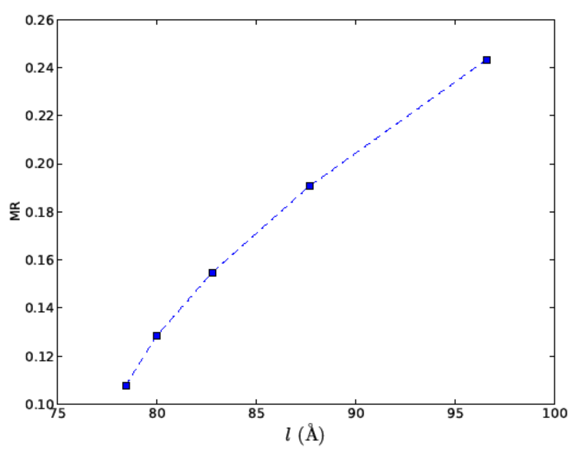


Figure-1
GMR as function of thickness of structure



(a)



(b)

Figure-2
(a) GMR as function of Fe thickness for t_{Fe} = 5, 10, 15, 20, 25Å. (b) GMR as function of mean free path calculated for $l = (l^{\uparrow} + l^{\downarrow})/2$ in parallel alignment

As expected, the MR maximizes in the limit $L, t_{Fe} \ll l$ [15] as demonstrated in figure 2b, where l is arithmetic mean of the mean free paths of the two spin channels in the trilayers. It is observed from figure 1 – 2b that MR_{max} of 0.24 occurred at L = 25Å, t_{Fe} = 5Å and l = 97Å.

In comparison, figure 2b is qualitatively analogous to those of Fe-Cr structures of unit specularity factor at outer boundaries[13]. This inherent unit specularity is a natural consequence of confining conduction electrons within piece-wise potential environment as adopted in our model. The Fuchs-Sondheimer theory[18,19] had predicted resistivities of thin and thick films as decreasing functions of thickness due to decreasing surface effect. However resistivities shown in figure 3 contradict this theory as is the case in reference 15 and 18.

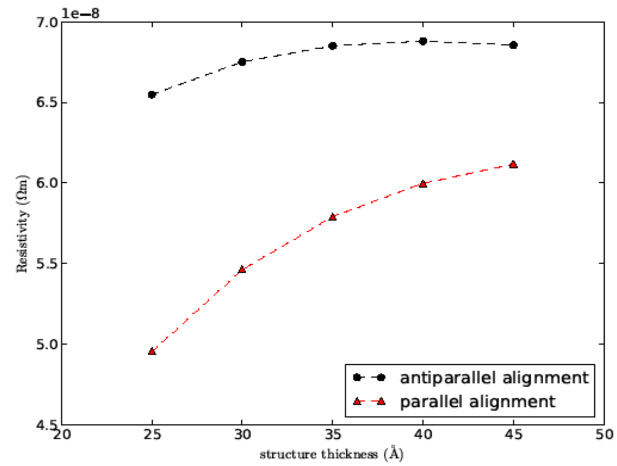


Figure-3
Antiparallel and parallel alignment resistivities as function of structure thickness

One can then infer that dominant contribution to GMR in the present case comes from bulk effects.

Conclusion

We have successfully applied a drude-like model to Fe/Cu/Fe trilayer system. The qualitative agreement of the derived basic characteristics of GMR with those already communicated in many experimental and theoretical reports give credibility to the model. The model emphasizes the role of relaxation time and has the merit of straight forward evaluation of resistivities on a non-per-layer basis and as such is computationally less demanding unlike other models.

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