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THE INFLUENCE OF INTERFACE HALL PONTENTIAL BARRIER ON MAGNETORESISTANCE OF MULTILAYERS

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Abstract-Using Boltzmaan equation by introducing the potential barrier scattering which built by Hall-effect , a possible origin of giant magnetoresistance in multilayers is proposed. The calculated results may be well explain the giant magnetoresistance observed in multilayers

I INTRODUCTION

Transport properties of magnetic multilayered thin films have aroused a great deal of attention due to their novel properties. among these are the exisitence of giant magnetoresistance (GMR) effect [1] [2] and oscillation in the coupling of adjacent ferromagnetic layer [3]. In these experiments, that the multilayers superlattice exhibit an antiferromagnetic ordering of the magnetic moments of the ferromagnetic layers an applied field Hs is needed to overcome the interlayer coupling and to align the moments . And the resistivity strongly decreases during the magnetization process and then, for H>Hs, is practically constant. This GMR has been described by baibich et al. to spin dependent interface scattering . Calmley and Barnas[4] and Levy [5] have worked out theory models in which introduce different interface scattering rates for the spin up and spin down conduction electron.

A lot of experiments evidence shown that GMR properties are quit sensitive to changes in magnetic state. In this paper we turn our attention to the Hall-efficet. To determine the electrical transport properties and study the giant magnetoresistance of the multilayers structured, we, using Boltzmaan equation, by consider the diffusive scattering electrons due to Hall effect which built potential barrier in the interface and propose a possible orign of the giant magnetoresistance. The calculated results can well explain the giant magnetoresistance observed in multilayered structures.

II HALL-EFFECT IN MULTILAYERS

We now pay attention to the Hall-effect. The Hall resistivity of a magnetic material is given by

$$\rho_H = tV_H/I = R_o[H+4\pi M(1-N)]+R_S 4\pi M, \quad (1)$$

here R_0 and R_s are the ordinary and spontaneous Hall coefficienects , V_H is the Hall voltage, I is the sample current , H is the magnetic field applied to the films, M is the magnetization of the films, N is the demagnetization factor. This means that the magnetization of the films will produec a Hall voltage even H=0.

As we know, when a magnetic field is applied at right angle to the direction of current flow an electric field is set up in a direction perpendicular to both direction of current and of the magnetic field. This can be seen as the result of the lorentz force on the free electrons in the solid. as in Fig.1.

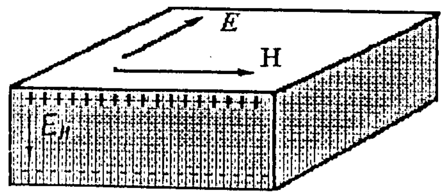

Fig. 1 The Heaa-effect in solid material

when a magnetic field is applied as shown there is initially a transient, transverse electric current, as the electrons, are deflected to the edge of the sample. Since they are mutually repulsive, not all of the electron can be deflected to the extremities and in the steady state the transverse electric field produced by their concentration gradient exactly opposes further deflection. Consequencely, once the transient have diminished to zero

the lines of current flow are again parallel to the longitudinal axis. But there is a transverse concentration gradient electrons with its attendant electric field.

There we analyze the multilayered thin films by introduce the Hall-effect. Consider a layered structure consisted of multi-identical ferromagnetic layers, magnetization in the film plane and separated from one another by a nonmagnetic spacer, as shown schematically in Fig.2-a. The corresponding film thickness are d and d_0 for the ferromagnetic films and nonmagnetic interlayer respectively. If there is an antiferromagnetic exchange coupling between the layers across the interlayer then the magnetization will be anti-parallel . If the magnetic films are exchange decoupled and having different coercive fields then the antiparalled alignment can be obtained by applying a proper external field. When the magnetic fields are coupled by an antiferromagnetic exchange interaction then the magnetization of both layers are not spatially uniform in the general case, the uniform state occurs only in zero magnetic field, with strictly antiparallel alignment or in a sufficiently strong magnetic field that force the uniform parallel alignment. In our considerations, however, we neglect this

small nonuniformity. We assume a uniform magnetization in each layer at arbitrary magnetic field. If the quantum corrections to the conductivity are negligible. The electron transport in multilayered films can be described.
In the multilayer filme, with an antiferromagnetic exchange coupling between the layers across the interlayer, some situation as below have been considered:

1 The Hall-effect by the antiferromagntic coupling

First let consider the ferromagnetic layers with antiferromagnetic coupling. Only the effective internal field built by coupling have an influence on the electrons transport. (The orientation of the magnetization is in plane and antiferromagnetically couple with another magnetic layer). For the first magnetic layer, when an electric field is applied to the multilayers the electros will be deflected to bottom interface by the Hall effect because of the internal magnetic field produced by coupling. And for the second magnetic layer, the electrons will be deflected to top interface by Hall effect. In the metal the electrons is it inerant, so the electrons will tend to gather in the first nonmagnetic layer. In the same consideration the third magnetic layer will deflect to the bottom of the layer. So the electron in the second nonmagnetic layer will be deflected away. These cause the nonuniform distribution of the electron. As the concequence, internal potential barrier··has been set up at the interface, which are show in Fig.2-b. This will result in the strong scattering of electrons in the multilayer films. The resistance of the film is higher in this situation.

2 Multilayered thin films with external magnetic field

When the external field increase from the zero ,the magnetic moment begin to align along the direction of the field. If the field is along the axis x, we see that the magnetic moment of the antiparallel to the external field will rotation to the direction of the field. The effective field in this direction will reduce. It also reduce the force of deflection to electron. This result in the reduction of electron concentrition in the interface. The potential barrier which is set up by the Hall effect will reduce as shown in fig.2-c. This make electrons distribution more uniform and reduce the nonuniform distribution scattering. As the external field increase, the potential of the internal will becom lower and lower, and finally disappear. When the external field is large enough to saturate the multilayer films, all magnetization is aligned in the same direction. In this case the distribution of the electron is uniform in the film, and there is no interface potential been set up. The Hall effect only deflect electron into surface of the multilayer, which is show in the Fig.2-d. The influence of the Hall effect on the resistance is very small. The scattering of electron in the film is much small than that of no external field, and so the resistance of the film is lower.

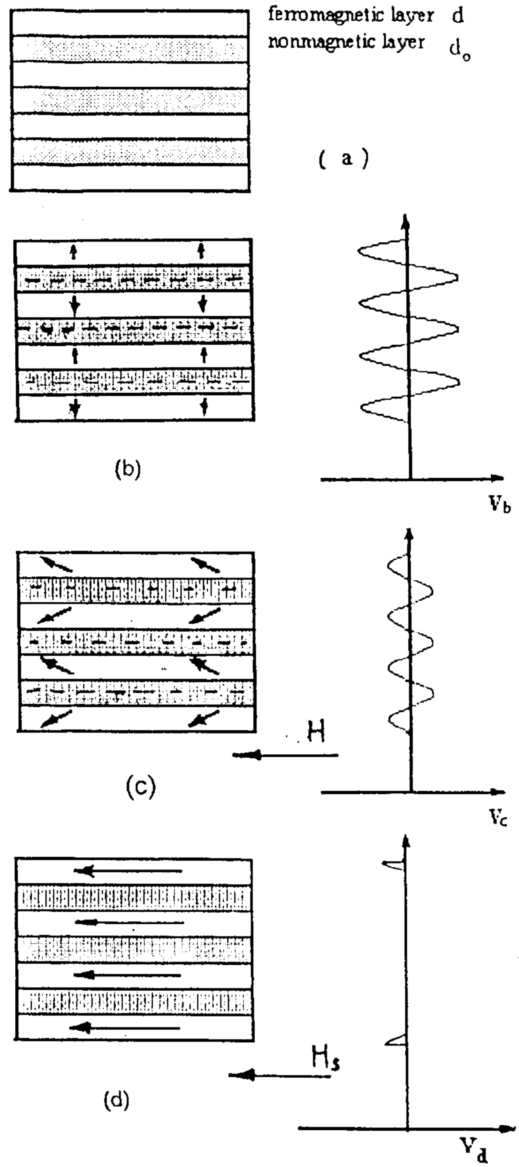

FIG. 2 schematic cross section showing several possible magnetic ordering and Hall-effect potential barrier configurations. All shaded areas represent nonmagnetic spacer layers. The shaded area with dashed lines denote spacer layers between antiparallel magnetic layers.
(b) have M=0 but has potential barrier between antiparallel layers , so therefore has higher than (c) and (d) resistance.
(c) have $0<M<M_s$ has a lower potential barrier between antiparallel layers , so therefore has a higher resistance.
(d) have $M=M_s$ has a no potential barrier between antiparallel layers , so therefore has a lower resistance.

III The calculated of resistivity in multilayered films

The resistivity of multilayered films has been treated in by solving the Boltzmann equation with respect to appropriate boundary. Within this framework the influence of the interface is introduced by interface pontential built by Hall-effect.

IN the multilayer film, when the magnetization is antiparallel, there exist the potential barrier introduced by the Hall-effect. So there is a addition of scattering rates proportional to $1/\lambda$= 1/mean free path arising from boundary beyween antiparallel layer in magnetization. Approximation can be made for the multilayer film. The electrons in a multilayer form a degenerate electron gas whose properties are severely limited by the Pauli exclusion principle where as we have so far been concerned with scattering of particles into final states that were assumed always to be empty. The ions in a host multilayer produce their own periodic potential, which do produce the elastic scattering but nocontribution to the resistance. The scattering due to the internal potential arises from Hall effect is not elastic scattering and cause the increase of the resistance. When the electrons are scattered by the internal potential, the state of the electrons will change from **k** to **k**' in the Fermi space, and loss their energy. It can be show by a proper averaging over all directions that with a spherical Fermi surface and transition probability **P** from **k** to **k**'. The relaxation time at all point in the Fermi surface is given by

$$\lambda=1/\tau=\oint P\,ds \qquad (2)$$

This result can be expressed in terms of the differential cross section for scattering $d\sigma/d\omega$ by using the relationship

$$P=Vd\sigma/d\omega \qquad (3)$$

The σ of total cross section is:

$$\sigma=\pi r^2(V/E_F)^2 \qquad (4)$$

This is a very simple and useful for order of magnitude purpose. It says that the effective cross sectional area of the potential barrier in the internal interface is roughly the geometrical area of cross section πr^2 multiplied by the square of the ratio of the hight of the potential to the Fermi energy of the conduction electros.

Because the internal potential **V** which is produced by Hall-effect is proportional to the change of the magnetization of the magnetic layer. To thein the monolayer is magnetic coupling, so the $\mathbf{m}_l$ is shown as below

$$\mathbf{m}_l=ng_jJ_{uB}B_j(y) \qquad (5)$$

For the multilayer the neighbouring magnetic layer is antiparallel coupling, so the total magnetic moment is show as

$$\mathbf{M}=\Sigma\mathbf{m}_l(\mathbf{H}) \qquad (6)$$

here $\mathbf{m}_l(\mathbf{H})$ is the unit magnetic moment in the each layer. The potential in the interface is proportional to **M** as follow:

$$V\sim A\exp(-c\mathbf{M}) \qquad (7)$$

We compute the conductivity of the multilayer films by the Boltzmann equatio and consider the influence of the interface potential barrier built by Hall-effect.

The Boltzmann equation for the electrons is:

$$(e/m)\mathbf{E}\,\mathbf{grad}_v[f^0(\mathbf{v})]=(1/\tau)\,g(\mathbf{v},\mathbf{r})+\mathbf{v}\,\mathrm{grad}_r[g(\mathbf{v},\mathbf{r})] \qquad (8)$$

where g is the departure of the distribution function of the electron gas $f(\mathbf{v},\mathbf{r})$ from the Fermi-Dirac equilibrium distribution, i.e

$$g(\mathbf{v},\mathbf{r})=f(\mathbf{v},\mathbf{r})-f^0(\mathbf{v}) \qquad (9)$$

with

$$f^0(\mathbf{v})=1/[\exp\{(\varepsilon_V-\varepsilon_F)/K_BT+1]$$

$$\varepsilon_V=1/2mv^2$$

E is the electric field and τ is the relaxation time supposed to be a function of v only. Eq. mean that the change of $g(\mathbf{v},\mathbf{r})$ due to the acceleration of the electrons by the electric field **E** is balanced by the change due to scattering expressed by the term g/τ and the change due to the diffusion which tends to make the distribution uniform. For a bulk metal, g is uniform, $\mathrm{grad}_r[g]=0$and the standard solution is

$$g_B(\mathbf{v})=e\tau\mathbf{E}.\mathbf{grad}_v[(\mathbf{v})]/m=e\tau\mathbf{E}.\mathbf{v}\,\partial f^0/\partial\varepsilon_V \qquad (10)$$

The above equation means that the Fermi surface is shifted in k-space $eE\tau(V_f)$ in the opposite direction to E. The current density is proportional to this shift,

$$j=-ne^2\tau\varepsilon_V\mathbf{E}/m \qquad (11)$$

. The simple assumption for the boundary conditions is to suppose that the scattering at the interface is entirely diffuse, because the potential barrier. The distribution of electrons leaving a surface must be independen of the direction of **v**. Eq.9 shows that this can be satisfied only if we choose F(v) so that $g(\mathbf{v},0)=0$ for all **v** having $v_z>0$ and $g(\mathbf{v},d)=0$ for all **v** having $v_z<0$. there are therefore two function g: g^+ for electrons with $v_z>0$ and g^- for electrons with $v_z<0$:

$$g^+(\mathbf{v},z)=e\tau\mathbf{E}.\mathbf{v}\,\partial f^0(\mathbf{v})/\partial\varepsilon_V[1-\exp(-z/\tau)] \qquad (12)$$

$$g^-(\mathbf{v},z)=e\tau\mathbf{E}.\mathbf{v}\,\partial f^0(\mathbf{v})/\partial\varepsilon_V[1-\exp((d-z)/\tau)]$$

The current carried by the multilayered films is given by an expression of the form

$$J \sim e v_x\, g(v,z) d^3 v dz \qquad (13)$$

to be compared to the current in an equivalent slab of the bulk metal :

$$J_o \sim e v_x\, g_B(v) d^3 v dz \qquad (14)$$

where g_B is expressed by Eq.10
Resorting to polar coordinates

$$v_z = v\cos\Phi, \quad v_x = v \sin\Phi\cos\Phi$$
$$d^3v = (v/m) d\varepsilon_V \sin\Phi d\Phi d\phi$$

After calculated one obtain

$$\sigma/\sigma_o = 1 - 3/(2k) \int_0^{\infty} \{(1/t^3 - 1/t^5)(1-\exp(-kt))\} dt \qquad (15)$$

where $\lambda = 1/\cos\emptyset$, $k = d/\lambda$ = thickness /mean free path, where the λ is given by Eq2. Approximations can be made for large and small k

$$\sigma/\sigma_o = 1 - (3/8k) \qquad \text{for } k >> 1 \qquad (16)$$
$$\sigma/\sigma_o = (3k/4)[\mathrm{Ln}(1/k) + 0.423] \quad k << 1$$

We use above equation and make a numerical calculation. The result is shown in the Fig. 3 From this fig. we can clear see that the change of MR with the magnetic field is approximately agree with experiments result.

In conclusion, the giant magnetoreisitance is caused by the potential at the interface produced by Hall effect. By making use of the Boltzmann equation and the simple models the difference between the resistivity of the multilayer with ferromagnetic and antiferromagnetic coupling of the adjacent magnetic layers has been calculated. The results explain the giant MR observed.

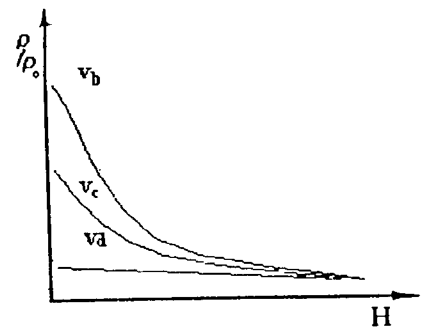

Fig . 3 The interface Hall-effect potential **V** contribution to the GMR in multilayers vs magnetic field **H**, with different potential **V**

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