INFLUENCE OF SURFACE ROUGHNESS ON THE AMPLITUDE OF GIANT MAGNETORESISTANCE EFFECT IN MULTILAYERED THIN FILMS

A. Melikadze[1,a], L. Kalandadze[1,b], N. Gomidze[1,c]

[1] *Department of Physics, Batumi Shota Rustaveli State University, Georgia*

[a]aleksander.melikadze@gmail.com, [b] lali.kalandadze@bsu.edu.ge , [c] gomidze@bsu.edu.ge

Since the discovery of one of the most engrossing advances in solid state physics occurred, the discovery of the giant magnetoresistance effect (GMR) by Grünberg and Fert in 1988 the theoretical treatment of this effect became the subject of much attention [1-6]. It is considered that the effect of giant magnetoresistance is due to the spin-dependent scattering of charge carriers in the volume of magnetic layers and at their boundaries, and its amplitude depends on the degree of roughness of the outer and interlayer boundaries. Nevertheless, when it comes to detail, discrepancies between experimental observations and theoretical models can arise: a realistic theoretical description of electron scattering at lattice discontinuities, disorder or defects is still a crucial factor [6,7]. Despite a large number of both experimental and theoretical works, in which the influence of the state of outer boundaries and interfaces on the magnitude of the giant magnetoresistance was studied, conclusions do not coincide [1-6]. The need to resolve these contradictions should be carried out within the framework of an extended theoretical study of the giant magnetoresistance effect using more complex models for describing the interaction of charge carriers with the structure and interlayer boundaries. This was the subject of our study. As an example, we considered a three-layer film (fig.1) consisting of ferromagnetic metal layers of different thicknesses separated by a nonmagnetic ultrafine metal layer (sandwich).

Fig.1 Model of the three-layer sandwich

The giant magnetoresistance effect is the change of the electrical resistance in a system of layers when an external magnetic field changes the magnetization of the ferromagnetic layers relative to each other. A parallel orientation is characterized by an electrical state of low resistance, while an antiparallel orientation is a state of high resistance. The effect size is defined as:

$$\delta = \frac{R_H - R_0}{R_0} = \frac{(R_\uparrow - R_\downarrow)^2}{4R_\uparrow R_\downarrow} = \frac{(J_\uparrow - j_\downarrow)^2}{4J_\uparrow J_\downarrow} \qquad (1)$$

where, $J_{\uparrow\downarrow} = eq_{\uparrow\downarrow}\langle V_{\uparrow\downarrow}\rangle$ is the current density; $q_{\uparrow\downarrow}$, is the density of electrons with spin projections on the z axis equal to +1/2 and -1/2, $q = n_\uparrow + n_\downarrow$ is the total electron density, $\langle V_{\uparrow\downarrow}\rangle$ is the average velocity of electrons with corresponding spin projections.

The longitudinal conductivity σ of a magnetic sandwich is calculated using the semi-classical Boltzmann kinetic equation for the boundary conditions to describe the transport of electrons in metals, according to which [1]:

$$\sigma_{\uparrow\downarrow} = \sum_{s=\pm} \sum_{j\neq n=1}^{2} \sigma_j^{(n-j)s} = \frac{1}{d} \sum_{s=\pm} \sum_{j\neq n=1}^{2} d_j\, \sigma_{0j}^{(n-j)s} \Phi_J^{(n-j)s} \qquad (2)$$

$\Phi_J^{(n-j)s}$ Dimensional functions that determine the effect of layer sizes for the samples with constant roughness amplitude [1,6]. For $\delta_{\uparrow\uparrow}$, when magnetization of adjacent ferromagnetic layers is in a parallel:

$$\sigma_{\uparrow\uparrow} = \sum_{s=\pm} \sum_{j=1}^{2} \sigma^s_{\uparrow\uparrow\, j} = \frac{1}{d} \sum_{s=\pm} \sum_{j=1}^{2} d_j\, \sigma^s_{0\, j} \Phi^s_{\uparrow\uparrow j} \qquad (3)$$

For numerical calculations, it was assumed that the magnetic anisotropy is relatively small and can be neglected. It is convenient to write delta in the following form:

$$\delta_{\uparrow\downarrow} = \frac{\sum_{j\neq n=1}^{2} (d_{j,n}\, \sigma^-_{0j,n})^{j-1} (\Phi^-_{\uparrow\uparrow,j} + \alpha_{b.j} \Phi^+_{\uparrow\uparrow,j})}{\sum_{j\neq n=1}^{2} (d_{j,n}\, \sigma^+_{0j,n})^{j-1} (\Phi^-_{\uparrow\downarrow,j} + \alpha_{b.j} \Phi^+_{\uparrow\downarrow,j})} - 1 \qquad (4)$$

$\alpha_{b,j}$ determines the spin asymmetry $\alpha_{b,j} = \frac{\sigma_{0,j}^{+}}{\sigma_{0,j}^{-}}$.

We performed calculations for a classical Fe/Gr/Fe sandwich, for which the velocities of charge-carrying particles are known, $v_j^+ = 7{,}1 \times 10^5$ m/s და $v_j^- = 8{,}51 \times 10^5$ m/s;

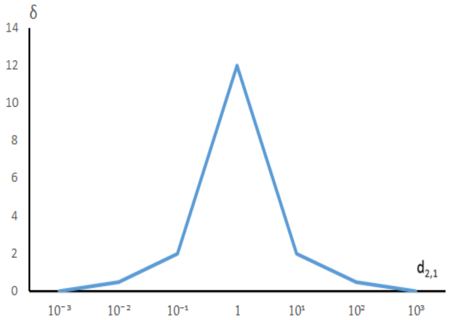

Fig.2. Dependence of the change in electrical Conductivity δ on the ratio of the layer thicknesses $d_{2,1} = d_2/d_1$

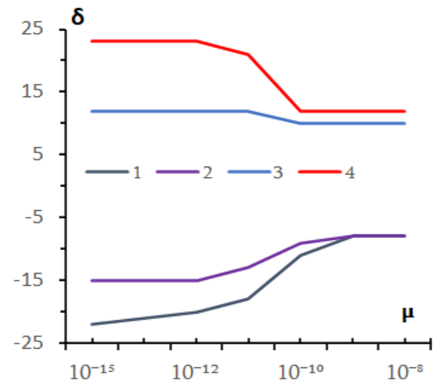

Fig.3. Dependences of the change in conductivity δ on the magnitude of the roughness μ of the interlayer and outer boundaries for Fe/Gr/Fe

Fig.2 presents that if the thickness of the ferromagnetic conducting layers is of the same order $d_{2.1} = d_2/d_1 \sim 1$, then the graph will show the maximum conductivity value, which is due to the spin scattering of bulk and interface electrons of the sample. From the Fig.3 we can conclude that the specular scattering of charge carriers by the interlayer and outer boundaries increases the amplitude of the giant magnetoresistance effect due to the fact that they do not lose their spin information when reflected from the surface. However, it should be noted that in the case when scattering centers are concentrated at the interlayer boundary, this leads to screening of charge carriers and, accordingly, to a decrease in the effect.

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