The model of a giant magnetoresistance, built taking into account the bulk scattering of spins of conducting electrons

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INTRODUCTION

The first theory explaining the giant magnetoresistance effect is based on the two-channel conduction model proposed by Mott. A key aspect of this model is the assumption that the conductivity and other kinetic properties of charge carriers (electrons) depend on one of two values of its spin. Therefore, it is possible to replace the three-layer structure "ferromagnetic-nonmagnetic metal-ferromagnetic", which includes a ferromagnetic, with two equivalent electrical circuits for the parallel and antiparallel directions of magnetization of the ferromagnetic. This model is adequate for current perpendicular to plain geometry.

METHODS

In the work, a study of the two-channel model of the spin-valve three-layer structure is carried out, without taking into account the probability of electron transitions between channels (spin mixing). Unlike the classical Mott model, the effect of asymmetric scattering of electrons on the surfaces of the ferromagnetic-nonmagnetic metal transition is taken into account. The equivalent electric circuit of the spin-valve structure is shown in Figures 1a and 1b for parallel and antiparallel alignment, respectively. Numerical parameters of the model developed are listed in Table 1.

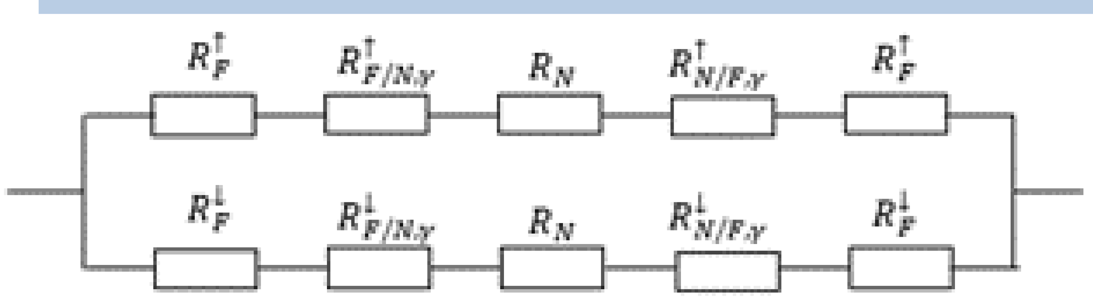

Fig. 1a

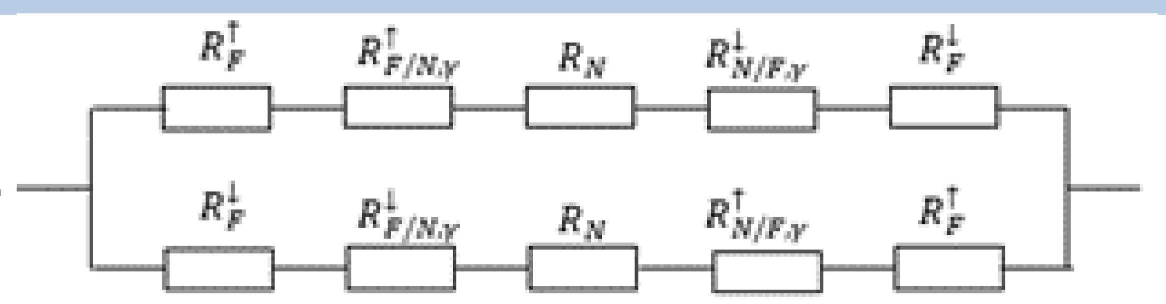

Fig. 1b

$$R_P = \frac{\left(R_{F1}^{\uparrow} + 2\cdot R_{F/N}^{\uparrow} + R_N + R_{F2}^{\uparrow}\right)\cdot\left(R_{F1}^{\downarrow} + 2\cdot R_{F/N}^{\downarrow} + R_N + R_{F2}^{\downarrow}\right)}{R_{F1}^{\uparrow} + R_{F1}^{\downarrow} + 2\cdot\left(R_{F/N}^{\uparrow} + R_N + R_{F/N}^{\downarrow}\right) + R_{F2}^{\uparrow} + R_{F2}^{\downarrow}}$$

$$R_{AP} = \frac{\left(R_{F1}^{\uparrow} + R_{F/N}^{\uparrow} + R_N + R_{F/N}^{\downarrow} + R_{F2}^{\downarrow}\right)\cdot\left(R_{F1}^{\downarrow} + R_{F/N}^{\uparrow} + R_N + R_{F/N}^{\downarrow} + R_{F2}^{\uparrow}\right)}{R_{F1}^{\uparrow} + R_{F1}^{\downarrow} + 2\cdot\left(R_{F/N}^{\uparrow} + R_N + R_{F/N}^{\downarrow}\right) + R_{F2}^{\uparrow} + R_{F2}^{\downarrow}}$$

$$GMR = \frac{R_{AP} - R_P}{R_{AP}}$$

Table 1. Electrophysical parameters of the model developed[1]

Bulk scattering asymmetry model	Scattering on the surface asymmetry model	Table values of parameters used in the model	
		Copper $\rho_{Cu} = 6\cdot10^{-9}\ \Omega m$	
$\beta_{F1,2} = (\rho_{F1,2}^{\downarrow} - \rho_{F1,2}^{\uparrow})/(\rho_{F1,2}^{\downarrow} + \rho_{F1,2}^{\uparrow})$	$\gamma_{F1,2/N} = (AR_{F1,2/N}^{\downarrow} - AR_{F1,2/N}^{\uparrow})/(AR_{F1,2/N}^{\downarrow} + AR_{F1,2/N}^{\uparrow})$	**Cobalt (scattering)**	**Permalloy ($Ni_{80}Fe_{20}$) (scattering)**
$\rho_{F1,2}^{*} = (\rho_{F1,2}^{\downarrow} + \rho_{F1,2}^{\uparrow})/4$	$AR_{F1,2/N}^{*} = (AR_{F1,2/N}^{\downarrow} + AR_{F1,2/N}^{\uparrow})/4$	$\varrho_{Co}^{*} = 7.5\cdot10^{-8}\ \Omega m$	$\varrho_{Py}^{*} = 2.9\cdot10^{-7}\ \Omega m$
$\rho_{F1,2}^{\downarrow} = 2\rho_{F1,2}^{*}(1+\beta_{F1,2})$	$AR_{F1,2/N}^{\downarrow} = 2AR_{F1,2/N}^{*}(1+\gamma_{F1,2/N})$	$\beta_{Co} = 0.46$	$\beta_{Py} = 0.76$
$\rho_{F1,2}^{\uparrow} = 2\rho_{F1,2}^{*}(1-\beta_{F1,2})$	$AR_{F1,2/N}^{\uparrow} = 2AR_{F1,2/N}^{*}(1-\gamma_{F1,2/N})$	$\gamma_{Co/Cu} = 0.77$	$\gamma_{Py/Cu} = 0.7$
$R_{F1,2}^{\uparrow} = d_{F1,2}\cdot\rho_{F1,2}^{\uparrow}$	$R_{N,F1,2}^{\uparrow} = AR_{F1,2/N}^{\uparrow}/S$	$2AR_{Co/Cu}^{*} = 10^{-15}\ \Omega m^2$	$2AR_{Py/Cu}^{*} = 10^{-15}\ \Omega m^2$
$R_{F1,2}^{\downarrow} = d_{F1,2}\cdot\rho_{F1,2}^{\downarrow}$	$R_{N,F1,2}^{\downarrow} = AR_{F1,2/N}^{\downarrow}/S$	$l_{sf}^{Co} = 4\cdot10^{-8}\ m$	$l_{sf}^{Py} = 5.5\cdot10^{-9}\ m$
$R_N = d_N\cdot\rho_N$		**Cobalt (no scattering)**	
$d_{N,F1,2}$ – layers thickness; S – area of the structure; ρ – specific resistivity R – resistivity		$\rho^{\uparrow} = 32\cdot10^{-8}\ \Omega m$	
		$\rho^{\downarrow} = 141\cdot10^{-8}\ \Omega m$	

REZULTS

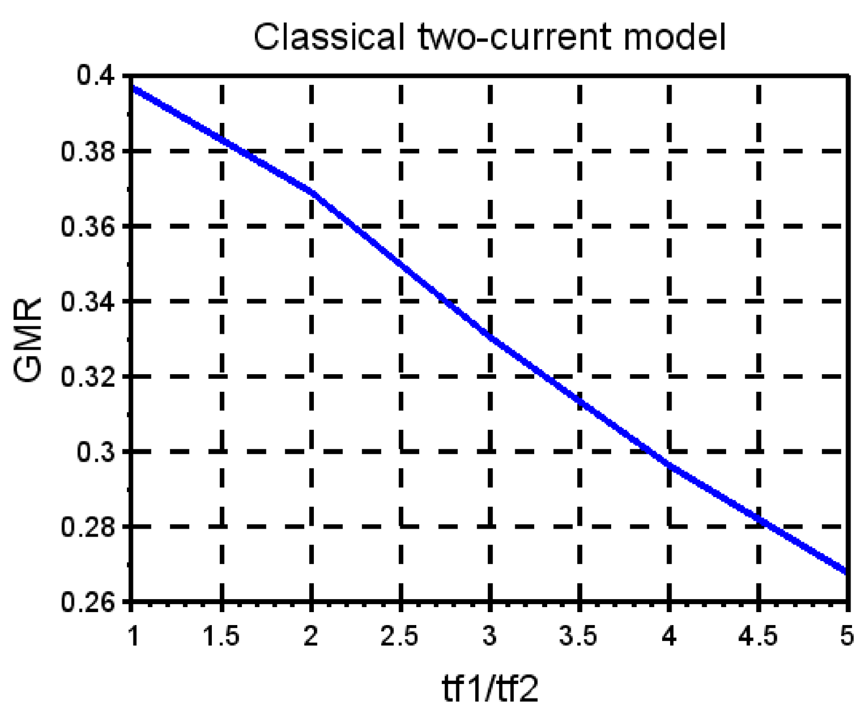

Fig. 2a

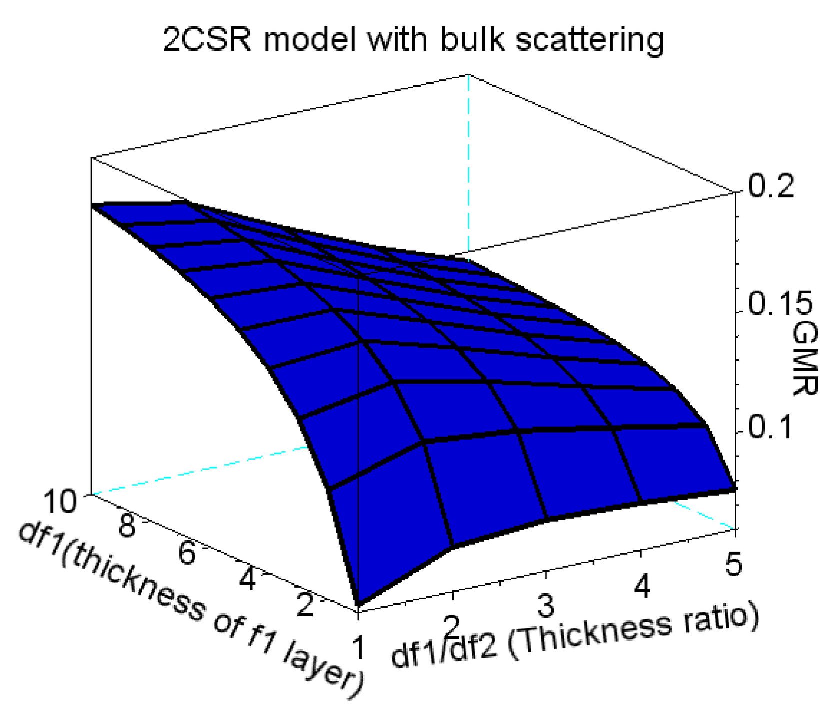

Fig. 2b

The results of a comparison of two-channel conductivity models [2] with series-connected resistances without taking into account scattering (Fig. 2a), with bulk scattering (Figs. 2b) and surface scattering when the thickness of the layers is smaller than the spin diffusion length are given. If the thickness of the magnetic layers does not exceed the spin diffusion length, then the GMR value does not depend on the geometric dimensions and is 0.59.

CONCLUSIONS

The paper developed a model of a giant magnetoresistance, which clarifies the well-known model of two-channel conductivity. On the basis of this model, the geometric dimensions of the spin valve (thickness of layers, area of device) made of the given material could be specified.

REFERENCES

1.Xiaoguang Zhang and William Butler, Theory of Giant Magnetoresistance and Tunneling Magnetoresistance, Handbook of Spintronics, pp. 5-59, 2016.

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