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Phenomenological Theory of Strain Effect in Granular Film Alloys

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The elementary theory tensoresistive effect in granular thin film materials was proposed. Analyzed limiting cases of large, small and normal concentration of magnetic granules. It is concluded that in all three cases, the strain coefficient is defined tensoresistive properties of the matrix solid solution film samples as granules sold ballistic electrocarry charge.

Keywords: Granular alloy, Strain coefficient, Solid solution, Granule, Ballistic electrocarry charge.

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1. INTRODUCTION

Opening the effect of a giant magnetic seasons in granular thin film alloys [1] has stimulated studies of their other properties, including electrophysical (resistivity, thermal coefficient of resistance (TCR), magnetoresistance). In work [2] we made an attempt to develop the elementary theory about the effects of external magnetic field on the value of TCR granular alloy. In particular, the ratio obtained which allow sections s contribution to the TCR process of electron scattering in the matrix of the solid solution (s.s.) and ferromagnetic metal granules.

The aim of this work is further to study the electrical properties of the film are granulated alloys. It is about the development of the elementary theory strain effect for the purpose of establishing the role of scattering processes of conduction electrons in a volume including and ferromagnetic granules, but, unlike [2], in the absence of spin-dependent scattering of electrons.

2. ELEMENTARY THEORY

The basis of the theoretical model we taken the ratio of the general form for the resistivity (ρ) of the sample as a granular solid solution, which is modeled as a layered structure (Fig. 1) with a parallel connection of individual layers (for more details see [3]):

$$\rho = 4{,}65(2+\alpha)\cdot\rho_{ss}\cdot\left(4+\frac{4{,}65\pi l\rho_{ss}}{r_0 n\left(\rho_g+\alpha\rho_{ss}\right)}\right)^{-1} = A\left(2+\alpha\right)\rho_{ss}\cdot\left(4+\frac{B\rho_{ss}}{\rho_g+\alpha\rho_{ss}}\right)^{-1} \quad (1)$$

where $A = 4{,}65$ and $B = 4{,}65\pi$ – the parameters of form sample; ρ_{ss} and ρ_g – resistivity of s.s. and granule material; Δl_{ss} and r_0 – average length fragment of s.s. in the tube current and the average radius of the granules ($\frac{\Delta l_{ss}}{r_0}=\alpha$ – coefficient of granularity);

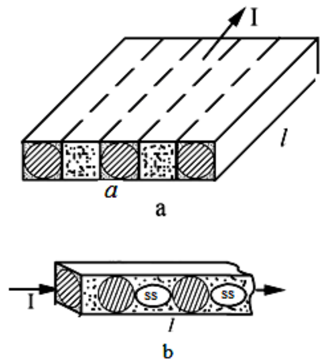

Fig. 1 – Schematic illustration of a single layer (a) and tube current (b) layered structure. I – current intensity; l and a – length and width of film sample

n – linear concentration of fragments s.s. or granules. In (1) taking into account that $n = l / r_0$.

Note that in [3] considered spherical granules, although, for example, in [4], they simulated a cubic or nearest to cubic form.

After differentiation on longitudinal strain (ε_l) of formula (1) we obtain the general form of correlation coefficient for longitudinal strain coefficient (SC) γ_l^{ρ}, where the index "ρ" indicates that SC is expressed through resistivity:

$$\gamma_l^{\rho} = \frac{d\ln\rho}{d\varepsilon_l} = \frac{d\ln(2+\alpha)}{d\varepsilon_l} + \frac{d\ln\rho_{ss}}{d\varepsilon_l} - \frac{B\cdot\dfrac{\rho_{ss}\gamma_l^{\rho_{ss}}\left(\rho_g+\alpha\rho_{ss}\right)-\rho_{ss}\cdot\gamma_l^{\rho_g}\left(\dfrac{\partial\alpha}{\partial\varepsilon_l}\rho_{ss}+\alpha\cdot\gamma_l^{\rho_{ss}}\cdot\rho_{ss}\right)}{\left(\rho_g+\alpha\rho_{ss}\right)^2}}{4+\dfrac{B\cdot\rho_{ss}}{\left(\rho_g+\alpha\rho_{ss}\right)}}. \quad (2)$$

Ratio (2) is somewhat simplified if we consider that α is independent from deformation:

$$\frac{d\alpha}{d\varepsilon_l} = \frac{d}{d\varepsilon_l}\left(\frac{\Delta l_{ss}}{r_0}\right) = \frac{1}{r_0}\left(-\mu_{ss}\cdot\Delta l_{ss}+\mu_g\cdot\Delta l_{ss}\right)\cong 0,$$

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Since Poisson's coefficients for s.s. and granules material about an only son (it is known that metals $\mu = 0{,}25\text{-}0{,}35$ [5]):

$$\gamma_l^{\rho} = \gamma_l^{\rho_{ss}} - \frac{\rho_{ss}\gamma_l^{\rho_{ss}}\left[\rho_g + \alpha\rho_{ss}\left(1-\gamma_l^{\rho_{ss}}\right)\right]}{\left(\rho_g + \alpha\rho_{ss}\right)^2\left(4 + \dfrac{B\cdot\rho_{ss}}{\rho_g + \alpha\rho_{ss}}\right)} \qquad (2')$$

In the analysis (2′), as in [2], we consider three limiting cases: $\alpha >> 1$, $\alpha \cong 1$ and $\alpha << 1$.

In the first case the relation (2′) is simplified to the form:

$$\gamma_l^{\rho} = \gamma_l^{\rho_{ss}} - \left(1 - \frac{\alpha\cdot\left(1-\gamma_l^{\rho_{ss}}\right)}{4\alpha + B}\right) \cong \begin{cases}\gamma_l^{\rho_{ss}} \text{ at the } \gamma_l^{\rho_g} \cong 1;\\ 1{,}3\gamma_l^{\rho_{ss}} \text{ at the } \gamma_l^{\rho_g} \cong 2,\end{cases} \qquad (3)$$

i.e. when $\alpha >> 1$ γ_l^{ρ} is almost completely determined by the properties tensoresistive s.s., because the default value $\gamma_l^{\rho_g} = 1-2$.

In the second limiting case ($\alpha \cong 1$) ratio (2′) is:

$$\gamma_l^{\rho} \cong \gamma_l^{\rho_{ss}} - \frac{\rho_{ss}\gamma_l^{\rho_{ss}}\left[\rho_g + \rho_{ss}\left(1-\gamma_l^{\rho_g}\right)\right]}{\left(\rho_g + \alpha\rho_{ss}\right)^2\left(4 + \dfrac{B\cdot\rho_{ss}}{\rho_g + \alpha\rho_{ss}}\right)} \cong \begin{cases}\gamma_l^{\rho_{ss}} \text{ at the } \gamma_l^{\rho_g} \cong 1;\\ \gamma_l^{\rho_{ss}} \text{ at the } \gamma_l^{\rho_g} \cong 2,\end{cases} \qquad (4)$$

that come to the event, a similar case at the $\alpha >> 1$.
In the case $\alpha << 1$, we arrive at the same conclusions:

$$\gamma_l^{\rho} = \gamma_l^{\rho_{ss}} - \frac{\rho_{ss}\rho_g\gamma_l^{\rho_{ss}}}{\rho_g^2(4) + B} \cong \begin{cases}\gamma_l^{\rho_{ss}} \text{ at the } \gamma_l^{\rho_g} \cong 1;\\ 0{,}9\gamma_l^{\rho_{ss}} \text{ at the } \gamma_l^{\rho_g} \cong 2.\end{cases} \qquad (5)$$

Conclusion of the major contributors to the overall vemask SC only s.s., how granular matrix system can be qualitatively explained on the basis of the concept [6] and the ideas of ballistic charge transfer (see, eg, [7]). According to [6], the strain resistor in which the role of the leading phase are the metal particles, for example, in a dielectric matrix effect is implemented to strain effect the mean free path of electrons (λ_0). As the grain size will always be less λ_0 ($r_0 / \lambda_0 < 1$), we conclusion what in inside the granules sold ballistic mechanism electrocarry was realized and $\gamma_l^{\lambda_0} = -\dfrac{1}{\lambda_0}\dfrac{\partial\lambda_0}{\partial\varepsilon_l} = 0$. At the same time in the localization s.s. routine mechanism implemented conductivity, which gives the main contribution to the overall value of SC.

Accordingly to the literature data for strain effect in film systems with different concentration of ferromagnetic components (see, for example, [8]), we can find evidence of ours conclusions. In particular, the film system Fe(4 nm) / Pt(18 nm) / S (concentration $c_{Fe} = 22$ at. %), which is formed diluted s.s. with the possible stabilization elements granular state (i.e. $\alpha >> 1$), the value of SC in the elastic deformation is $\gamma_l^{\rho} \cong 2{,}5$ units. At the transition to greater concentration $c_{Fe} \cong 61$ at. % (system Fe(22 nm) / Pt(18 nm) / S) value does not change, although the number of atoms of Fe can provide condition $\alpha \geq 1$. Even at concentrations $c_{Fe} \cong 71$ at. %, where we can talk about the condition $\alpha >> 1$, tha value γ_l^{ρ} increases by 0.7 units.

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