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# Temperature and Concentration Dependences of Anisotropic Magnetoresistance Film Materials

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In framework the phenomenological approach the question of the temperature dependence of anisotropic magnetoresistance (AMR) at the fixed value inducing an external magnetic field (B) and the concentration dependence of AMR at the fixed B and T were analyzes. The obtained ratio to assess and predict the magnitude of thermal and concentration coefficients of AMR, virtually can not be done in the classical model, since it allows complex ratio with many uncertain parameters.

**Keywords:** AMR, Thermal coefficient of AMR, Concentration coefficient of AMR, Solid solution.

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## 1. INTRODUCTION

A lot of experimental studies of magnetoresistive properties film materials devoted to the investigated of anisotropic magnetoresistance (AMR) (see., for example, [1, 2]).

This increased interest in the phenomenon AMR connected with using the so-called AMR sensors on the sensor technique. Because the most basic parameters influence the effect of AMO is magnetic induction (B), temperature (T) and the concentration of atoms of magnetic components (C), the purpose of work was to study on the phenomenological level of influence temperature and concentration on value AMR.

The quantitative characteristics will perform thermal ($\beta_T^{AMR}$) and concentration ($\beta_C^{AMR}$) coefficients of AMR. Note that in previous works [3] (see also [4] and [5]) within the phenomenological model was analyzed question about the effect of the temperature dependence of giant magnetoresistance (GMR) in multilayers and the field dependence In the thermal coefficient of resistance (TCR) of granulated alloy films accordingly.

Such a phenomenological approach we used in works [6, 7] at the analytical solution of the problem of strain effect in granular film materials. In all these cases, obtained the simplicity of the theoretical model, we received a that allow to analyze the possible temperature dependence of GMR [3, 4], field and deformation dependences of TCR [5] or resistivity (ρ) [6, 7].

## 2. ELEMENTARY THEORY

### 2.1 Temperature coefficient of AMR

According to the definition (see., for example, [4]) value AMR expressed through the electrical resistance (R) or resistivity such a relation:

$$AMR = \frac{3\Delta R}{\left(R_{II} + 2R_{+}\right)} = \frac{3\Delta\rho}{\left(\rho_{II} + 2\rho_{+}\right)}, \qquad (1)$$

where $\Delta R = \left(R_{II} - R_{+}\right)$, $\Delta\rho = \left(\rho_{II} - \rho_{+}\right)$; index «*II*» and «+»meaning that the magnetization vectors $\vec{M}$ (or induction $\vec{B}$) and current density $\vec{j}$ lying in the film plane and directed parallel (*II*) or a cross (+) to each other.

Without limiting the generality of the analysis, we can assume $\rho = \rho\left(T, B = const, C = const\right)$. That if expression of the most general form can be represented as follows:

$$\beta_T^{AMR} = \frac{1}{AMR\left(T, B = const\right)} \frac{\partial AMR\left(T, B = const\right)}{\partial T}. \qquad (2)$$

After substituting (1) into (2) we obtain

$$\beta_T^{AMR} = \left(\frac{\left[\left(\rho_{II} - \rho_{II}\right)\right]}{\left[\rho_{II} + 2\rho_{+}\right]}\right)^{-1} \cdot \frac{\left[\frac{\partial\rho_{II}}{\partial T} - \frac{\partial\rho_{+}}{\partial T}\right]\cdot\left[\rho_{II} + 2\rho_{+}\right]}{\left[\rho_{II} + 2\rho_{+}\right]^2} - \\ - \frac{\left[\rho_{II} - \rho_{+}\right]\cdot\left[\frac{\partial\rho_{II}}{\partial T} + 2\frac{\partial\rho_{+}}{\partial T}\right]}{\left[\rho_{II} + 2\rho_{+}\right]^2}. \qquad (3)$$

Multiplying and dividing derivatives $\frac{\partial\rho_{II}}{\partial T}$ and $\frac{\partial\rho_{+}}{\partial T}$, respectively, $\rho_{II}$ and $\rho_{+}$ and relation (3) can be represented as follows:

$$\beta_T^{AMR} = \frac{\left[\beta_{II}\rho_{II} - \beta_{+}\rho_{+}\right]\cdot\left[\rho_{II} + 2\rho_{+}\right] - \left[\beta_{II}\rho_{II} + 2\beta_{+}\rho_{+}\right]}{\left[\rho_{II} + \rho_{+}\right]\cdot\left[\rho_{II} + 2\rho_{+}\right]}, \qquad (4)$$

which simplifies to the form:

$$\beta_T^{AMR} = \frac{\rho_{II}\rho_{+}\left(\beta_T^{II} + \beta_T^{+}\right)}{\left(\rho_{II}^2 - \rho_{+}^2\right) + \rho_{+}\left(\rho_{II} - \rho_{+}\right)}. \qquad (5)$$

If you take the default $\rho_{II}$, $\rho_{+}$, $\beta_T^{II}$ and $\beta_T^{+}$, and it can be estimated by the ratio (5) value $\beta_T^{AMR}$. In cases where $\rho_{II} \square \rho_{+}$, value $\beta_T^{AMR}$ is the order of $10^{-3}$ K$^{-1}$. If the difference ~ $10^{-8}$ Om.m, the ~$10^{-2}$ K$^{-1}$, which suggests a relatively high sensitivity to temperature sensitive element AMR sensor in the second case.

### 2.2 The concentration AMR dependence of film solid solutions

The research of magnetoresistive properties for film solid solutions (s.s.) indicate that at relatively high concentrations of atoms of magnetic components can be stabilized spin-dependent electron scattering that causes the effect of GMR (see more detailed in [8]). At the same time, at relatively low concentrations are stabilized only disordered or ordered solid solutions, in which there is the effect AMR. The phenomenological approach to determining $\beta_C^{AMR}$ similar to what was used in the analysis of the temperature dependence of AMR. Based on the conditions $\rho = \rho(C, T = const, B = const)$, we write the basic equation as follows:

$$\beta_C^{AMR} = \frac{1}{AMR}\frac{\partial AMR}{\partial C} = \left(\frac{3(\rho_{II} - \rho_+)}{(\rho_{II} + 2\rho_+)}\right)^{-1} \cdot \frac{\partial}{\partial C}\left(\frac{3(\rho_{II} - \rho_+)}{\rho_{II} + 2\rho_+}\right). \quad (6)$$

After differentiation and some transformations we obtain:

$$\beta_C^{AMR} = \frac{\rho_{II}\rho^+\left(\beta_C^{II} + \beta_C^+\right)}{\left(\rho_{II}^2 - \rho_+^2\right) + \rho_+\left(\rho_{II} - \rho_+\right)}, \quad (7)$$

where the concentration ratios in general can be represented as follows:

$$\beta_C = \frac{1}{\rho(C)}\frac{\partial \rho(C)}{\partial C}.$$

In turn $\rho(C) = C_1\rho_1 + (1 - C_1)\rho_2$, , where the indices 1 and 2 denote the components of the solid solution. As in the case $\beta_T^{AMR}$, the value $\beta_C^{AMR}$ is defined as the $\beta_C$ separate component, and the difference $(\rho_{II} - \rho_+)^2$. In the case $(\rho_{II} - \rho_+) \cong 10^{-8}$ Om·m value $\beta_C^{AMR}$ will be ten times more $\beta_C^{II}$ and $\beta_C^+$.

## 3. CONCLUSIONS

The proposed phenomenological approach analyse of temperature and concentration dependence of AMR allows relatively easy to predict the values $\beta_T^{AMR}$ and $\beta_C^{AMR}$. This is some of the advantages of this approach compared to the classical theory of magnetoresistance (see., for example, [10]), in which obtained very difficult ratio for $\sigma_{II}$ and $\sigma_+$ (σ - conductivity) with a lot of number of uncertain parameters based on may be ratio for AMR. Difficulty to ratio for $\sigma_{II}$ and $\sigma_+$ associated with the fact that the authors [10] in its theoretical model included not only the surface (theory by Fuch), but grain boundary (the effect Mayadas-Shatkes) scattering of electrons.

In result the model for magnetoresistance [10] allows to analyze the physical side effects, but the prognoses of the value AMR better be based on the phenomenological approach. Note also that on the basis of ratio (3) and (5) can expect a family of curves for different values of B (ratio (3)), under changing temperatures and $B$ = const variables or when $B$ at $T \cong$ const.

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