MAGNETO-DEFORMATION EFFECT IN DOUBLE-LAYER NANODIMENTIONAL FILM SYSTEMS

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ABSTRACT

For the first time theoretical study of magneto-deformation effect (MDE) in double-layer film materials, taking into account previous results obtained for single-layer films. When creating the elementary theory used well known correlation coefficient for longitudinal gauge factor (GF, γ) double-layer film system type "biplate", without taking into account the possible processes of mutual diffusion of atoms. Quantitative characteristic MDE is magnetic coefficient of the GF – $\beta_{\gamma B} = (1/\gamma)\cdot(\partial\gamma/\partial B)$, which describes change of the film electric resistance under its deformation in the external magnetic field. In the finite ratio for MDE considered by the appropriate index to three possible orientation of the magnetic field relative to the direction of flow of electric current, which coincides with direction at the longitudinal GF. To the right part consists of the following values us $\beta_{\gamma B}$, γ, ρ (resistivity), $\beta_{\rho B}$ (magnetic coefficient ρ) and two derivative of the resistivity on deformation and magnetic field, which not calculated from first principles, as measured experimentally. Analyzed the ratio of limiting cases for $\beta_{\gamma B}$, when $d_1 \gg d_2$ and $d_1 \ll d_2$. These basic and limiting ratio can be used to forecast depends on the size of GF magnetic field.

Keywords: longitudinal deformation, magneto-deformation effect, magnetic coefficient of the resistivity, magnetic coefficient of the gauge factor, magnetic field.

INTRODUCTION

Efficacy of nanodimention thin film materials as the sensitive elements of temperature sensors, pressure, strain, magnetic field and others (see, [1]) allows the author [2] to develop the concept design of multifunctional sensors.

The aim of our work is to use a phenomenological theoretical model of magneto-strain effect in double-layer film systems, which may be methodological basis of a multifunctional sensor strain and magnetic field. The model is phenomenological approach developed in [3], where was proposed within the phenomenological approach to the theoretical correlation coefficient of longitudinal magnetic GF, which is expressed in terms of resistance to single-layer metal films. They allow qualitative analysis of the possible dependence of

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GF on the magnitude of induction of external magnetic field – magneto-deformation effect (MDE). Quantitative characteristic effect is the so-called magnetic coefficient GF, which describes the change in electrical resistance of the film during its deformation in the external magnetic field $\beta_{\gamma B} = (1/\gamma)\cdot(\partial\gamma/\partial B)$.

THEORETICAL ANALYS

The analysis conducted in [3] on the magneto-strain effect in a single layer metal films can be transferred to the case of two-layer film systems, and what was the purpose of our work. When using the elementary theory we have used correlation between GF two-layer film, satisfying the condition "biplate" [4]:

$$\gamma = \gamma_1 + \gamma_2 - \frac{d_1\mu_1 + d_2\mu_2}{d_1 + d_2} - \frac{\gamma_1\rho_1 d_2 - \rho_1 d_2\mu_2 + \gamma_2\rho_2 d_1 - \rho_2 d_1\mu_1}{\rho_1 d_2 + \rho_2 d_1} \qquad (1)$$

where d_i, μ_i and ρ_i - the thickness, Poisson 's ratio and resistivity of *i*-layer (*i*=1,2). After differentiation ratio (1) to obtain the magnetic field induction ratio for $\beta^k_{\gamma B}$ that is not taken into account the terms proportional to the size of magnetostriction $M_i^k = d\,ln d_i/dB$, where upper index *k* corresponds to the longitudinal, transverse or perpendicular geometry measuring:

$$\begin{aligned}\beta^k_{\gamma B} &= \beta^k_{\gamma_1 B}\cdot\gamma_1 + \beta^k_{\gamma_2 B}\cdot\gamma_2 - \frac{\gamma_1\rho_1 d_2\left(\beta_{\gamma_1 B} + \beta_{\rho_1 B}\right) + \gamma_2\rho_2 d_1\left(\beta_{\gamma_2 B} + \beta_{\rho_2 B}\right)}{\left(\rho_1 d_2 + \rho_2 d_1\right)} + \\ &+ \frac{\beta_{\rho_1 B}\rho_1 d_2\mu_2 + \beta_{\rho_2 B}\rho_2 d_1\mu_1}{\left(\rho_1 d_2 + \rho_2 d_1\right)} + \frac{\left(\beta_{\rho_1 B}\rho_1 d_2 + \beta_{\rho_1 B}\rho_2 d_1\right)\left(\gamma_2\rho_2 d_1 + \gamma_2\rho_2 d_1\right)}{\left(\rho_1 d_2 + \rho_2 d_1\right)^2} - \\ &- \frac{\left(\beta_{\rho_1 B}\rho_1 d_2 + \beta_{\rho_2 B}\rho_2 d_1\right)\left(\rho_1 d_2\mu_2 + \rho_2 d_1\mu_1\right)}{\left(\rho_1 d_2 + \rho_2 d_1\right)^2}\end{aligned} \qquad (2)$$

Value for $\beta_{\gamma B}$ single-layer film was previously obtained by the author [1] and it is the following:

$$\beta^k_{\gamma B} = \frac{1}{\gamma_R}\left(-\beta^k_B\cdot\frac{1}{\rho}\frac{\partial\rho}{\partial\varepsilon} + \frac{1}{\rho}\frac{\partial^2\rho}{\partial\varepsilon\partial B}\right) = \frac{\gamma_R - 1 - 2\mu_f}{\gamma_R}\left(-\beta^k_B + \frac{1}{\gamma_R - 1 - 2\mu_f}\cdot\frac{1}{\rho}\frac{\partial^2\rho}{\partial\varepsilon\,\partial B}\right) \qquad (3)$$

where γ_R - value GF, which is expressed in terms of electrical resistance; β^k_B - magnetic coefficient of resistivity (see more details [3], where the theory for the magnetic coefficient for one-layer films is presented) and ε - the longitudinal deformation.

LIMITING CASES

Equation (2) greatly simplifies in two limiting cases:

at the $d_2 << d_1$ $\beta^k_{\gamma B} \cong \beta^k_{\gamma_1 B}\gamma_1 + \beta^k_{\rho_2 B}\mu_1$; (2')

at the $d_2 >> d_1$ $\beta^k_{\gamma B} \cong \beta^k_{\gamma_2 B}\gamma_2 + \beta^k_{\rho_1 B}\mu_2$ (2")

Note that the comparison ratio (2) and its limiting cases of the experimental results relatively easily if γ >>1, when equation (3) simplified to the form:

$$\beta^k_{\gamma B} \cong -\beta^k_B + \frac{1}{\gamma\rho}\cdot\frac{\partial^2\rho}{\partial\varepsilon\partial B}. \quad (3')$$

Especially emphasize that because the value of GF significantly decreases with increasing thickness of the one carried a film, then on the settlement of relations for the limiting cases of formula (2) must use the relation (3) or (3') for a thick or thin film, respectively. Also specify that the ratio (2) - (2"), (3) and (3') to qualitatively predict the field dependence of double-layer GF film system. In particular, if (2') the value of double-layer GF film will increase with increasing external magnetic field under the conditions:

if $\beta^k_{\gamma_1 B}$>0 and $\beta^k_{\rho_2 B}$>0 or $\beta^k_{\gamma_1 B}$>0, then $\beta^k_{\rho_2 B}$<0, but $\beta^k_{\gamma_1 B} > \left|\beta^k_{\rho_2 B}\right|$;

if $\beta^k_{\gamma_1 B}$<0 and necessarily the condition $\beta^k_{\gamma_1 B}$>0 and $\beta^k_{\rho_2 B} > \left|\beta^k_{\gamma_1 B}\right|$.

Similar conditions occur in case (2"). If, $d_1 \cong d_2$ as $\gamma_{1,2}$~ 1, then the analysis should make calculation for the ratio (2) taking into account of the ratio (3) the possible options of the sign $\beta^k_{\gamma B}$ and $\beta^k_{\rho B}$. Based on the forecasted values to estimate the sensitivity to strain and magnetic field sensitive element of a multisensor.

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