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MAGNETO-DEFORMATION EFFECT IN THIN METAL FILMS

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Question about dependence of the strain sensitivity factor of metal films versus the value of magnetic field induction (the magneto-deformation effect) is examined. The so-called magnetic coefficient of the strain sensitivity factor is a quantitative characteristic of this effect and describes change of the film electric resistance under its deformation in the external magnetic field.

Keywords: *MAGNETO-DEFORMATION EFFECT, MAGNETIC COEFFICIENT OF THE STRAIN SENSITIVITY FACTOR, DEFORMATION OF THE FILM SAMPLE, TEMPERATURE DEPENDENCE OF THE STRAIN SENSITIVITY FACTOR, MAGNETIC FIELD INDUCTION.*

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Question about dependence of the strain sensitivity factor (SSF) of film and bulk materials versus the value of magnetic field (the magneto-deformation effect), as a question about its temperature dependence [1, 2], is among the little-studied ones, though it is a subject of current interest. Thus, the authors of [3] carried out the investigations of magnetic field influence on the SST of amorphous metal alloys on Fe and B basis and determined its very essential influence on the value of longitudinal SST both towards the increase in comparison with the SST value under a field absence (relatively weak fields) and towards the SST value decrease (relatively strong fields). Authors explain the obtained results by the Young modulus change under magnetic field action (the so-called ΔE - effect).

The authors of [4] carried out theoretical and experimental study of the magneto-deformation effect on the example of diamond films with *p*-type conduction. It was established that in the range of deformation $\Delta\varepsilon = 2{\cdot}10^{-5}$-$10^{-4}$ in magnetic field $B = 3$ T the value of SST decreases to 10% that is connected with the deformation-induced change of valence band and with the influence of magneto-resistance effect.

Analysis of publications about the magneto-deformation effect points out that the magnetic coefficient of the strain sensitivity factor (MCSSF) can be its quantitative characteristic, the methodological basis of which introduction can be the same as for the thermal strain sensitivity factor (TSSF) [1], that is

$$\beta_{\gamma lB} = \frac{1}{\gamma_l}\left(\frac{\partial \gamma_l}{\partial B}\right)_{\varepsilon l}, \quad \beta_{\gamma tB} = \frac{1}{\gamma_t}\left(\frac{\partial \gamma_t}{\partial B}\right)_{\varepsilon t}, \qquad (1)$$

where indexes l and t denote the longitudinal and the transverse strain sensitivities, respectively; γ_l and γ_t are the values of SSF at the corresponding deformation direction, which are expressed in the terms of film resistance.

Using relations for γ_l and γ_t in the most general form [1]

$$\gamma_l = \frac{1}{\rho}\frac{\partial\rho}{\partial\varepsilon_l} + 1 + 2\mu_f, \quad \gamma_t = \frac{1}{\rho}\frac{\partial\rho}{\partial\varepsilon_t} - 1, \qquad (2)$$

where ρ is the resistivity, μ_f is the Poisson ratio for a film, we can write

$$\beta_{\gamma lB} = \frac{1}{\gamma_l}\frac{\partial}{\partial B}\left(\frac{1}{\rho}\frac{\partial\rho}{\partial\varepsilon_l} + 1 + 2\mu_f\right) = \frac{1}{\gamma_l}\left(-\frac{1}{\rho^2}\frac{\partial\rho}{\partial B}\cdot\frac{\partial\rho}{\partial\varepsilon_l} + \frac{1}{\rho}\frac{\partial^2\rho}{\partial\varepsilon_l\partial B}\right),$$

$$\beta_{\gamma tB} = \frac{1}{\gamma_t}\frac{\partial}{\partial B}\left(\frac{1}{\rho}\frac{\partial\rho}{\partial\varepsilon_t} - 1\right) = \frac{1}{\gamma_t}\left(-\frac{1}{\rho^2}\frac{\partial\rho}{\partial B}\cdot\frac{\partial\rho}{\partial\varepsilon_t} + \frac{1}{\rho}\frac{\partial^2\rho}{\partial\varepsilon_t\partial B}\right). \qquad (3)$$

We assume that in film samples the weak magnetostriction effect takes place, and therefore μ_f does not practically depend on magnetic field.

Relation (3) is transformed to the following form:

$$\beta_{\gamma lB} = \frac{1}{\gamma_l}\left(-\beta_B\cdot\frac{1}{\rho}\frac{\partial\rho}{\partial\varepsilon_l} + \frac{1}{\rho}\frac{\partial^2\rho}{\partial\varepsilon_l\partial B}\right) = \frac{\gamma_l - 1 - 2\mu_f}{\gamma_l}\left(-\beta_B + \frac{1}{\gamma_l - 1 - 2\mu_f}\cdot\frac{1}{\rho}\frac{\partial^2\rho}{\partial\varepsilon_l\partial B}\right),$$

$$\beta_{\gamma tB} = \frac{1}{\gamma_t}\left(-\beta_B\cdot\frac{1}{\rho}\frac{\partial\rho}{\partial\varepsilon_t} + \frac{1}{\rho}\frac{\partial^2\rho}{\partial\varepsilon_t\partial B}\right) = \frac{\gamma_t + 1}{\gamma_t}\left(-\beta_B + \frac{1}{\gamma_t + 1}\cdot\frac{1}{\rho}\frac{\partial^2\rho}{\partial\varepsilon_t\partial B}\right), \qquad (4)$$

where we took into account relation (2), and $\beta_B = (1/\rho)(\delta\rho/\delta B)$ is the magnetic resistance coefficient.

Subject to γ_l and $\gamma_t \geq 10$ equations (4) are reduced to

$$\beta_{\gamma lB} \cong -\beta_B + \frac{1}{\gamma_l\rho}\cdot\frac{\partial^2\rho}{\partial\varepsilon_l\partial B}, \quad \beta_{\gamma tB} \cong -\beta_{\mathbf{B}} + \frac{1}{\gamma_t\rho}\cdot\frac{\partial^2\rho}{\partial\varepsilon_t\partial B}, \qquad (5)$$

that allows to easily define the very important tensometric characteristic $\delta^2\rho/\delta\varepsilon\delta B$, which characterizes behavior of the strain-gauge sensing element in conditions of deformation and magnetic field simultaneous action. Simplified relations (4) allow to qualitatively analyze the field dependence of γ_l and γ_t.

At first we consider the more typical case for metal materials when $\beta_B < 0$ [3, 5] and $\delta^2\rho/\delta\varepsilon\delta B$ can be less or more than zero depending on the sensitivity to deformation ($\delta\rho/\delta\varepsilon$) or to field ($\delta\rho/\delta B$). Then $\beta_{\gamma lB}$ and $\beta_{\gamma tB}$ will be more than zero (γ_l and γ_t increase in magnetic field), if $\delta^2\rho/\delta\varepsilon_{l,t}\delta B > 0$. The same situation will take place in the case when $\delta\rho/\delta\varepsilon > |\delta\rho/\delta B|$, i.e., resistivity increase under deformation should exceed its decrease in magnetic field. Probably, this case takes place in double-layer films on Cr and Fe basis, for which the value of γ_l in magnetic field by 3-6% more than 0,1 T.

If resistivity decrease in magnetic field will exceed the effect of increase due to the deformation processes, $\beta_{\gamma B}$ will be more than zero even under condition $|\delta^2\rho/\delta\varepsilon_{l,t}\delta B| < |\beta_B|$. With the opposite sign of inequality the values of

γ_l and γ_t will decrease in external magnetic field, as it takes place in diamond films [4] or amorphous metal alloys [3] under relatively strong fields.

In another case, when $\beta_B > 0$, the value of $\beta_{\gamma B}$ will be more than zero under condition $\delta^2\rho/\delta\varepsilon\delta B < 0$ or $|\beta_B| > |\delta^2\rho/\delta\varepsilon\delta B|$ independently of the second derivative sign. At the same time under condition $\delta^2\rho/\delta\varepsilon\delta B > 0$ and $> |\beta_B|$ the values of γ_l and γ_t will increase in external magnetic field. But we do not know the experimental results corresponding to the second case.

As we have pointed out, using relations (4) it is possible to estimate the value of $\delta^2\rho/\delta\varepsilon\delta B$. According to the data [5] in the case of Cr(30 nm)/Fe(70 nm) film system $\delta^2\rho/\delta\varepsilon\delta B \cong -4\cdot10^{-5}$ Ohm·m·T^{-1}.

CONCLUSIONS

We can state conclusions of the present work as follows.

Within the phenomenological approach we propose the theoretical relations for magnetic coefficients of the longitudinal and transverse strain sensitivities of metal films, on the basis of which the qualitative analysis of the possible dependence of the SSF versus the value of external magnetic field induction is carried out. Obtained relations allow to calculate the important tensometric characteristic $\delta^2\rho/\delta\varepsilon\delta B$, which describes the resistivity change of the strain-gauge sensing element under its deformation in magnetic field. Similarly to the TSSF [1], which is determined by the temperature and deformation dependences of the electron mean free path, of the specular reflection coefficient of outer surfaces, and of the transmission coefficients of grain boundaries and different layer interfaces, the MCSSF should be defined by the deformation and magnetic field influence on the specified electro-transport parameters as well.

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