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Electrophysical properties of Ni/V and Cr/Fe multilayer films

L. Odnodvorets, S. Protsenko, O. Synashenko, D. Velykodnyi, and I. Protsenko*

Sumy State University, R.-Korsakova Str. 2, Sumy 40007, Ukraine

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Results of experimental researches of electrophysical properties of Multilayer film systems Ni/V, and Cr/Fe which was formed on the basis of nanocrystals (V, Cr and Fe) and high dispersed Ni films are presented. It is carried out comparisons of experimental and calculated on the basis ratio for films alloy (Cr/Fe) and semiphenomenological model (Ni/V) results.

1 Introduction

Electrophysical properties of film materials (resistivity, thermal coefficient of resistance, gauge factor (GF)) significantly differ from analogical ones for bulk samples (wires, plates, foils), as it is connected with their thickness, crystal structure, element composition, concentration and defects type, etc. Electrophysical properties are very sensitive to change of film thickness and size of grains, concentration of impurity atoms and defects of crystal structure, influence of external fields (deformation, magnetic field, temperature, etc.). As it is known, influence of them mentioned factors stipulates a number of effects including structure, size phase and concentration effects. The effect of strain deformation appears when bulk or film sample is compressed or stretched [1,2]. The matter of physical processes as to tensoresistive effect is conditioned by changes on the microscopic levels (decrease or increase of lattice parameter) or macroscopic and microscopic level on the grain boundary or interface (rotation and change of size of grains, appearance of local energy levels, change of concentration and defects type, dependence on deformation [3] of specularity parameter, reflection coefficient at the grain boundary, scattering (transition) coefficient at the grain boundary and transmission through interface).

The significant contribution to study of strain deformation of bulk and film materials in 1950-70-th was done by G. Kuzinsky (1950-th), A. Kolumbani (1960), P. Ture (1961), R. Parker and A. Krynsky (1963), Z. Meiksin and R. Hudzinsky (1967), G. Witt and T. Couts (1970-th), B. Verma (1970-th), et al. All these investigations, except works of Z. Meiksin et al., had the experimental character and applied directivity. The end of 1970-th and 1980-th was marked by intensive theoretical investigations of size effect (SE) for gauge factor of one-layer metal films in the works of F. Warkusz [4], and C. Tellier, C. Pichard and A. Tosser [5], the start of analogical investigations for two-layer films in the works of F. Khater and M. El-Hiti [6-8]. The resulting data of carried out testing of these theoretical models are given in our work [9]. In addition the development of much more perfect experimental methods for GF measurements [10] helped to obtain much more correct results for one- and two-layer film systems.

Transition from two-layer film system to three-layer and multilayer film system from the point of view of experiment has not any difficulties of methodical character, but from the point of view of developmend of theoretical semiclassical models similar to introduced in [4-6]; this transition stipulates some difficulties, which have not been solved up to nowadays.

* Corresponding author: e-mail: protsenko@aph.sumdu.edu.ua

Starting from the end of 1980-th the intensive experimental investigations of electrophysical properties of multilayer film system of general type (below will be called multilayer film system) and the one of periodical type (below will be called superlattices, multilayers) have been carried out. In connection with some difficulties of testing SE for GF of semiclassical models, we have introduced our macroscopic and semiphenomenological models, which allow us to realize the interpretation of experimental results. The latest our works, in which semiclassical models for the thermal coefficient of resistance (TCR) and GF of multilayers is introduced, open the perspective for the creation of much more correct theoretical model for calculation of GF of multilayers.

The purpose of this work is to describe the solution of such problems:

- studying electrophysical properties of film systems on the basis of nanocrystals (V, Cr and Fe) and high dispersed Ni films, which have wide application in some areas of micro- and nanoelectronics;
- testing of macroscopic and semiphenomenological theoretical models of GF of multilayer film systems.

2 Technique of experiment

The films samples at the condensation on technical vacuum 10^{-4} Pa at the temperature of substrate 300 K method of resistivity evaporation (Ni and Cr) and electron beam evaporation (V and Fe) were obtained. The substrates cleared up by ultrasound treatment, and before condensation of film – by heating 100 W galogen lamp.

To obtain dependences of TCR on thickness of one-layer films we used glass plates with fused molybdenum electrodes (which withstand temperature up to 700 K) or sital plates with contacts preliminary coated with copper (which withstand temperature up to 900 K) as substrate. Annealing of samples with the purpose of recrystallization and termostabilization of electrophysical properties was spent according to scheme "heating-cooling" with constant rate (3-5 K/mines) during three-four cycles from 300 to 800 K. Film resistance was measured by universal multimeter UT70D with accuracy ±0.01 Ohm under the double-point scheme. The temperature of the samples was measured during annealing process by multimeter UT70B using graduated chromel-alumel thermocouple.

At research of GF effect we used substrates of teflon, which have satisfactory elastic properties, suitable to anneal films within the range of temperatures 300-500K and satisfy with the following requirements: thermal stability, absence of chemical interaction with material of the film and limit of elasticity up to 1 %. For GF measuring of one- or multilayer films we used specially developed device (Fig. 1a.), which allowed to deform film and simultaneously to measure its resistance in the vacuum chamber.

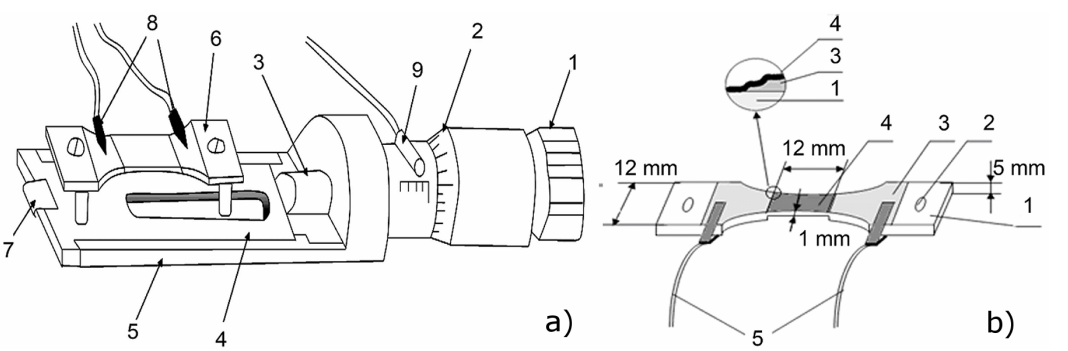

Fig. 1 Device for studying electrophysical properties of thin-film samples during deformation (a) and scheme of substrate (S) (b): 1 - microscrew, 2 - scale of the microscrew, 3 - mobile rod, 4 - sliding part of the deforming device, 5 - directing rails, 6 - teflon substrate, 7 - rotating mechanism, 8 - clamping contacts, 9 - light source (a); 1 - teflon substrate, 2 - fastening apertures, 3 - copper step-like contact platforms, 4 - film or film system, 5 – terminals of clamping contacts (b).

When turning the microscrew (1) the rod (3) moves and shifts the sliding part (4) of the deforming device along the directing rails (5). Teflon substrate is longitudinally deformed as a result of moving of the rod (3) as one end of it is immovably fixed and opposite one is fixed on the sliding part (4) of the device. To measure TCR of the films at ε_1=0 and ε_2=const we used two substrates (deformed and not deformed), which were

parallel one to another. Fabrication of substrate with low resistance contact platforms (3) is an important methodical problem to measure γ_l (Fig.1b). Contact platforms were formed on teflon substrate by condensation of copper layer. Their step-like geometry was formed by means of micromovings of special masks during condensation. Contact platforms were annealed at temperature 400 K during 2-3 minutes for improvement of adhesion. The film samples were longitudinally deformed up to 1 % of their length with a step of deformation equal to 0.05 % that conforms with the shift of the to moving rod at 0.02 mm. To calculate GF of the film we carried out 4 – 5 "loading-unloading" deformation cycles, then $\Delta R/R(\varepsilon)$ dependence was plotted and γ_l value was obtained using angular factor. As it was necessary to measure TCR and GF under the same experimental conditions we used halogen lamp.

To study crystal structure, phase and element composition we used methods of transmission electron microscopy (TEM) and electron diffraction (ED) (apparatus TEM-125K) and secondary ion mass-spectrometry (SIMS) (apparatus MS-7201M). We measured thickness with accuracy ±1 nm by means of method of quartz resonator.

3 Theoretical models for multilayer film system

Systematic theoretical investigations of SE for electrophysical properties of two-layer film systems were started in the works of F. Warkusz and R. Dimmich [4, 11]. Concerning strain deformation, the effect was analysed for the first time in studies [6-8], where two-layer monocrystalline films were taken as example. The similar result was obtained for the monocrystalline one-layer films, i.e. with the increase of k_1, when the value of k_2 is fixed, ($k_i=d_i/\lambda_{0i}$, where d_i - is thickness of i layer, λ_{0i} - is mean free path (MFP) of electron in the bulk) the longitudinal GF (γ_l) asymptotically approaches to γ_{0l} bulk monocrystal and inversely. The authors [12] then considered that two-layer film can be simulated by the parallel connection of conductors with point contact. The fact that all theoretical models for both GF and TCR make a good accordance with the experimental results evidences about accordance of real film sample to the condition of parallel connection. Thus, according to [6-8,11,13], we can write:

$$\frac{1}{R}=\frac{a}{l}[\sigma_{01}F_1\left(d_1,\lambda_{01},p_1,r_1\right)d_1+\sigma_{02}F_2\left(d_2,\lambda_{02},p_2,r_2\right)d_2], \tag{1}$$

where F_i - is Fuchs's function, p – is effective specularity parameter; r – is transmission coefficient at the grain boundary; σ_0 – is conductivity of bulk samples; l and a – are length and width of samples.

Having taken logarithmical differential from the left and right parts of the correlation (1), we obtain:

$$\frac{dR}{R}=-\left(d\ln d_1+d\ln\sigma_{01}+d\ln F_1\right)A_1-\left(d\ln d_2+d\ln\sigma_{01}+d\ln F_2\right)A_2-\left(\ln a-d\ln l\right),$$

where $A_i=d_i\sigma_{0i}F_i/(d_1\sigma_{01}F_1+d_2\sigma_{02}F_2)$.

Considering that $d\varepsilon=d\ln l$ (longitudinal deformation), $\mu_f=-d\ln a/d\ln l$ (Poisson's ratio), $\mu'=\mu_f(1-\mu_s)/(1-\mu_f)$ (reduced Poisson's ratio) and $\gamma_l=d\ln R/d\ln l$, and making the similar assumption as in [4-8], but in contrast to [3], that p_i and r_i don't depend on deformation, $-d\ln\sigma_0/d\ln l=1+\eta_{\lambda 0l}$ ($\eta_{\lambda 0l}$ - deformation coefficient of MFP of electrons) and $d\ln F_i/d\ln k=1-\beta_i/\beta_{0i}$, $d\ln k_i/d\ln k_k=\beta_{0i}/\beta_{0k}$ (β – is TCR; i, k=1, 2 and $i\neq k$), we obtain the following formula:

$$\gamma_l=A_1\left\{\left(\gamma_{01l}+\mu_1'\right)+\left(1-\frac{\beta_1}{\beta_{01}}\right)\left[(1-\gamma_{01l}^{\rho}+\mu_1')+(1-\gamma_{02l}^{\rho}+\mu_2')\frac{\beta_{01}}{\beta_{02}}\right]\right\}+$$

$$A_2\left\{\left(\gamma_{02l}+\mu_2'\right)+\left(1-\frac{\beta_2}{\beta_{02}}\right)\left[(1-\gamma_{02l}^{\rho}+\mu_2')+(1-\gamma_{01l}^{\rho}+\mu_1')\frac{\beta_{02}}{\beta_{01}}\right]\right\}+1+\mu_s. \tag{2}$$

We adapted formula (2) for the case of polycrystalline films. The idea was to use Mayadas's correlation for σ_i in the multipliers for A_1 and A_2. This procedure appeared to be ineffective as correspondence of the data obtained using correlation (2) with the experimental results was poor. We can suppose that the authors [14] in addition to the derivatives $d\ln F_i/d\ln k_i$, had to apply derivatives $d\ln F_i/d\ln m$ also, where $m_i=L_i/\lambda_{0i}$ – is the reduced value of mean size of grains. Significant experimental material having been collected (its generalization was done in the paper [15]), the development of the semiphenomenological model [14], which improved the

adapted model, became possible. In this case the Fuchs's function depends not only on *k, p* and *r*, but on *m* and the coefficient of interface transmission (*Q)*.

The authors of [3] obtained the correlation for γ_l of film system with any number of layers, which allow for the surface and grain boundary scattering of electrons more reasonably. At the case when the electrical properties of *i*-layer are stipulated by electrons of *i*-layer and neighboring layers (*i*±1), that is possible at realization of conditions: $\lambda_{01}\approx d_1+d_2$, $\lambda_{02}\approx d_2+(d_1+d_2)/2$ and $\lambda_{03}\approx d_3+d_2$, correlation for γ_l of three-layer film may be written in the following form:

$$\gamma_l = A_1\left\{\left(\gamma_{01l}^{\rho}+\mu_1'\right)-\left(1-\frac{\beta_1}{\beta_{01}}\right)\left[\left(2\gamma_{01l}^{\rho}-1-\mu_1'-\eta_{p1l}\frac{d\ln k_1}{d\ln p_1}-\eta_{Q1l}\frac{d\ln k_1}{d\ln Q_1}-\eta_{r1l}\frac{d\ln m_1}{d\ln r_1}\right)+\right.\right.$$
$$\left.\left.\left(\gamma_{02l}^{\rho}-1-\mu_2'-\eta_{p2l}\frac{d\ln k_2}{d\ln p_2}-\eta_{Q2l}\frac{d\ln k_2}{d\ln Q_2}-\eta_{r2l}\frac{d\ln m_2}{d\ln r_2}\right)\frac{\beta_{01}}{\beta_{02}}\right]\right\}+$$
$$A_2\left\{\left(\gamma_{02l}^{\rho}+\mu_1'\right)-\left(1-\frac{\beta_2}{\beta_{02}}\right)\left[\left(2\gamma_{02l}^{\rho}-1-\mu_2'-\eta_{p2l}\frac{d\ln k_2}{d\ln p_2}-\eta_{Q2l}\frac{d\ln k_2}{d\ln Q_2}-\eta_{r2l}\frac{d\ln m_2}{d\ln r_2}\right)+\right.\right.$$
$$A_2\left\{\left(\gamma_{02l}^{\rho}+\mu_1'\right)-\left(1-\frac{\beta_2}{\beta_{02}}\right)\left[\left(2\gamma_{02l}^{\rho}-1-\mu_2'-\eta_{p2l}\frac{d\ln k_2}{d\ln p_2}-\eta_{Q2l}\frac{d\ln k_2}{d\ln Q_2}-\eta_{r2l}\frac{d\ln m_2}{d\ln r_2}\right)+\right.\right.$$
$$\left.\left.\left(\gamma_{03l}^{\rho}-1-\mu_3'-\eta_{p3l}\frac{d\ln k_3}{d\ln p_3}-\eta_{Q3l}\frac{d\ln k_3}{d\ln Q_3}-\eta_{r3l}\frac{d\ln m_3}{d\ln r_3}\right)\frac{\beta_{02}}{\beta_{03}}\right]\right\}+$$
$$A_3\left\{\left(\gamma_{03l}^{\rho}+\mu_3'\right)-\left(1-\frac{\beta_3}{\beta_{03}}\right)\left[\left(2\gamma_{03l}^{\rho}-1-\mu_3'-\eta_{p3l}\frac{d\ln k_3}{d\ln p_3}-\eta_{Q3l}\frac{d\ln k_3}{d\ln Q_3}-\eta_{r3l}\frac{d\ln m_1}{d\ln r_3}\right)+\right.\right.$$
$$\left.\left.\left(\gamma_{02l}^{\rho}-1-\mu_2'-\eta_{p2l}\frac{d\ln k_2}{d\ln p_2}-\eta_{Q2l}\frac{d\ln k_2}{d\ln Q_2}-\eta_{r2l}\frac{d\ln m_2}{d\ln r_2}\right)\frac{\beta_{03}}{\beta_{02}}\right]\right\}+1+\mu_s\,, \qquad (3)$$

where it is allowed that $Q_1=Q_{12}=Q_{21}$, $Q_2=Q_{21}=Q_{23}$ and $Q_3=Q_{32}=Q_{23}$; $Q_{13}=(Q_{12}+Q_{23})/2$ and $Q_{31}=(Q_{12}+Q_{23})/2$.

It must be noted that terms with the index *i* allow for the electrical properties of this layer, and with the indices *i*±1 – the influence of neighboring layers on these properties. At the case when there are inequalities $\lambda_{0l}\geq d_1+1/2(d_2-d_3)$ and $\lambda_{03}\geq d_3+1/2(d_2+d_1)$, corresponding terms with multipliers β_{01}/β_{03} and β_{02}/β_{03} will appear in the correlation (3). This ratio may be prevalente on film systems with arbitrary quantity layers. The γ_l ratio from (3) can be rather easy compared it with the experimental data, because the right part of the correlation includes such values and parameters, which can be calculated on the basis of experimental results for the one-layer films. But theoretical problem concerning efficiency of interface transmission, i.e. concerning the part of electrons from the neighboring layers, which have an influence on electrophysical properties of this layer, is difficult. In other words the question is: which correcting coefficient must be used to multiply the multipliers β_{01}/β_{02}, β_{02}/β_{01}, β_{02}/β_{03} and β_{03}/β_{01}.

4 Experimental results and testing

Structure and phase composition of samples The investigations of structure and phase composition Cr/Fe film systems by TEM and ED method show that it is solid solution (s.s.) with BCC- lattice (Fig. 2 and Table 1); and phase composition of Ni/V film system is two-layer BCC-V + FCC-Ni (Fig. 3).

Thus we come to the conclusion, that testing of theoretical model (3) can be carried out using the film system of Ni/V as the example, at the same time we can compare the results of testing for Cr/Fe film system with the ratio for film alloys, which is similar, which presented in work [16], but more exact, as takes into account an addition in GF, related to the change of concentration of atoms during deformation:

According to these data γ_l value monotonously decrease with increase of thickness or number of a deformation cycle, tending to the some asymptotic value. Received results for Cr and Ti films well agree with the data received earlier [17], and in case of Fe films it is possible to carry out comparison only with data for

bulk Fe wires, in which $\gamma_{0l} \cong 2$ [18]. For this purpose it is necessary to reconstruct dimensional dependence in $\gamma_l - d^{-1}$ coordinates and to extrapolate to zero that will give value $\gamma_{\infty l} \cong 2.2$ and well agree with [18]. The results of the γ_l ratio testing for film alloys (4) are represented in table 3.

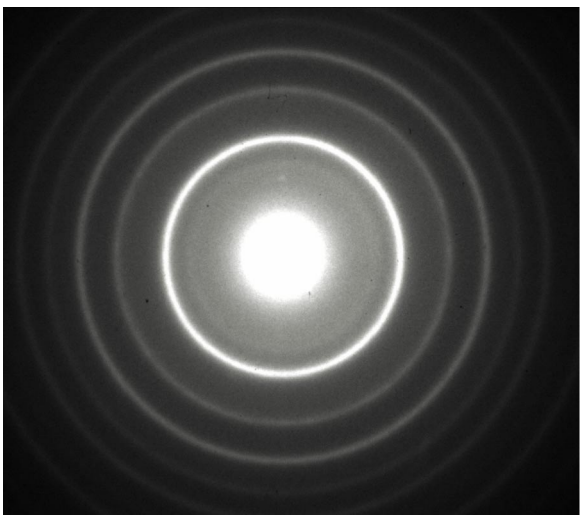

Fig. 2 Diffraction pattern of Cr(30)/Fe(30)/S film system.

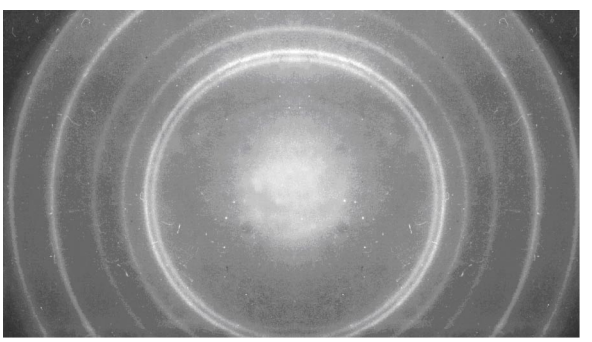

Fig. 3 Diffraction pattern of Ni(35)/V(45)/S film system.

Table 1 Calculation of diffraction pattern of Cr(30)/Fe(30)/S films system.

№	I, a.u.	d, nm	hkl	a, nm	Phase composition
1	V.H.	0.205	110	0.289	s.s.(α-Fe,Cr)
2	m.	0.145	200	0.290	-"-
3	m.	0.180	211	0.289	-"-
4	l.	0.102	220	0.288	-"-
5	l.	0.091	310	0.288	-"-
6	l.	0.077	321	0.289	-"-

V.H. – very high, m. – middle, l. – low, $\bar{a}$ (α-Fe,Cr)=0.289 nm, a_0 (Cr) = 0.288 nm, a_0 (α-Fe) = 0.287 nm, a_0 – lattice parameter of bulk sumples

Table 2 Dependence of GF on number of a deformation cycle.

Film (d, nm)	GF number of a cycle		Film (d, nm)	GF number of a cycle	
	I	IV		I	IV
V(45)	9.60	4.60	Fe(30)	4.41	4.20
V(60)	4.70	1.10	Fe(50)	4.38	3.95
V(120)	1.60	0.60	Fe(100)	3.21	2.82
Cr(20)	23.20	8.30	Ni(25)	19.20	8.60
Cr(60)	16.60	4.20	Ni(56)	18.40	8.20
Cr(100)	12.20	2.30	Ni(90)	17.80	7.20

Table 3 Comparison of experimental results and calculated according to (4) data for longitudinal GF

Film (d, nm)	$\gamma_{l\,exp}$	$\gamma_{l\,cal1}$	$(\gamma_{l\,exp} - \gamma_{l\,cal})/\gamma_{lexp}$, %
Ni(25)/V(25)/ S	13.10	17.06	30.2
$[Ni(25)/V(25))]_2$/S	24.70	32.36	31.0
$[Ni(25)/V(25)]_3$/S	30.90	39.21	26.9

Testing of macroscopic model The previous researches specify that the values of gauge factor depend on the following parameters: film thickness, number of a deformation cycle, quantity of layers and the order of their alternation. Experimental results (Table 2) enable to track the dependences of GF on thickness and number of a deformation cycle.

Testing of semiphenomenological model In spite of complication of the correlation (3), its results can be relative easy compared with the experimental results. This phenomenon can be explained by the fact that all physical quantities, which are in it, can be obtained either experimentally or by these data proper processing. Let us consider the procedure of obtaining of transport parameters, and, in particular, η_{pl}, η_{rl} and η_{Ql} deformation ratios and evaluation of $d\ln k/d\ln p = pdk/kdp$ derivatives, $d\ln m/d\ln r = rdm/mdr$ and $d\ln k/d\ln Q = Qdk/kdQ$, i.e. the values connected with p, r and Q changing during the deformation of film.

The results was calculated based on linearized and isotropic models [5] of two size dependences: β versus d (Fig. 4 a,b):

$$\beta d \cong \beta_g d - \beta_g \lambda_0 (1-p) H(\alpha), \quad \frac{R}{1-R} \cong 0{,}97 \ln\left(\frac{1}{r}\right), \quad \beta_g \beta_0^{-1} \cong \left[1 + 1{,}45 \cdot L^{-1} \lambda_0 \ln\left(\frac{1}{r}\right)\right]^{-1}, \tag{5}$$

measured before deformation of the film i.e. when ε_1=0, and after the certain static deformation ε_2.

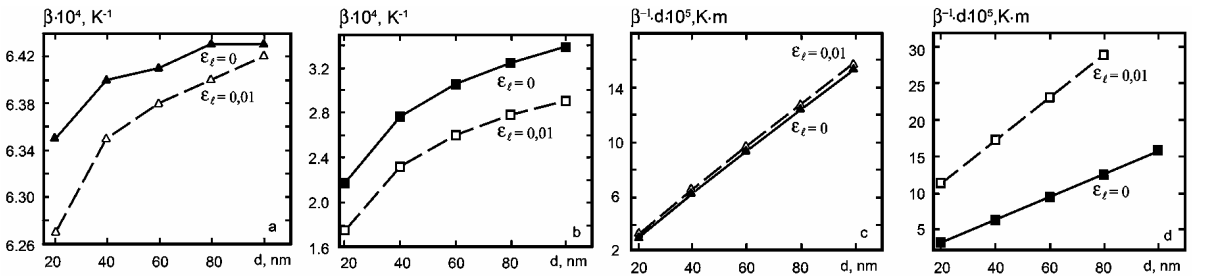

Fig. 4 Dependence versus in different coordinates for not deformed and deformed films V (a, **c**) and Ni (**b**, d).

Experimental results having been reconstructed in the coordinates, which express dependence of βd on d, or of $\beta^{-1}d$ on d (Fig. 4 c,d), we can obtain two groups of values: $\lambda_0(0)$, $p(0)$ and $r(0)$ under the condition that ε_1=0, as well as $\lambda_0(\varepsilon_2)$, p (ε_2) and $r(\varepsilon_2)$ under the condition that ε_2=const. The obtained values in turn give us opportunity to determine all terms in the right part of the correlation (3). The obtained values of p and r are used for the calculation of deformation ratios η_{pl} and η_{rl} by the correlation:

$$\eta_{pl} = -\frac{1}{p(0)} \frac{p(\varepsilon) - p(0)}{\varepsilon_l} \text{ and } \eta_{rl} = -\frac{1}{r(0)} \frac{r(\varepsilon) - r(0)}{\varepsilon_l}.$$

We also consider the assumption about the equality of the coefficients of grain boundary transmission and surface transmission ($\eta_{Ql} \cong \eta_{rl}$), as far as firstly it is rather difficult to determine the value of Q, and secondly these boundaries from the point of view of scattering processes, can be considered as identical relaxation centers for conductivity electrons. The values $\eta_{\lambda 0l}$, η_{pl} and η_{rl} can be calculated as by the correlation for the deformation ratio of mean free path:

$$\eta_{\lambda_0 l} = -\frac{1}{\lambda_0(0)} \frac{\lambda_0(\varepsilon_l) - \lambda_0(0)}{\varepsilon_l}, \text{ where } \eta_{\lambda_{01}} = -\gamma_{01}^{\rho} - 1.$$

Thus the procedure used by us allows calculating the following transport parameters: p, r, λ_0, $\eta_{\lambda 0}$, η_{pl}, η_{rl} and $d\ln k/d\ln p$ and $d\ln r/\ln m$ derivatives (Fig. 5). It must be underlined that $d\ln k/d\ln p$ derivative doesn't depend on thickness as reduced thickness isn't determined by mean free path in film sample λ_g (as λ_g/λ_0 and β_g/β_0 are equal $f(\alpha)$), but it is determined by λ_0 for bulk sample. In case when $d\ln k/d\ln p$, the above mentioned assumption doesn't fundamental, but if we consider values of r, η_{rl} and $d\ln m/d\ln r$ we must take into account that mean size of grains (L) depends on thickness (here we omit basic statement of theoretical model concerning the assumption that L = const. and L doesn't depend on thickness, as it is practically impossible to realize it in the specified experimental situation), and r in turn depends on L. All above mentioned here have stipulated the necessity to calculate the size dependence of the mentioned values on film thickness (Fig. 5). Thus this necessity is caused by the reasons of ease, as the dependences r, η_{rl} and $\ln m/d\ln r$ on L have a direct physical meaning.

Experimental values of γ_l and TCR for one-layer films later will be used for testing of theoretical models. Thus we shall especially emphasize, that for semiphenomenological model testing it is necessary to receive

dependences for TCR with two static deformations (Example of such dependences in different coordinates are presented in figure 4.).

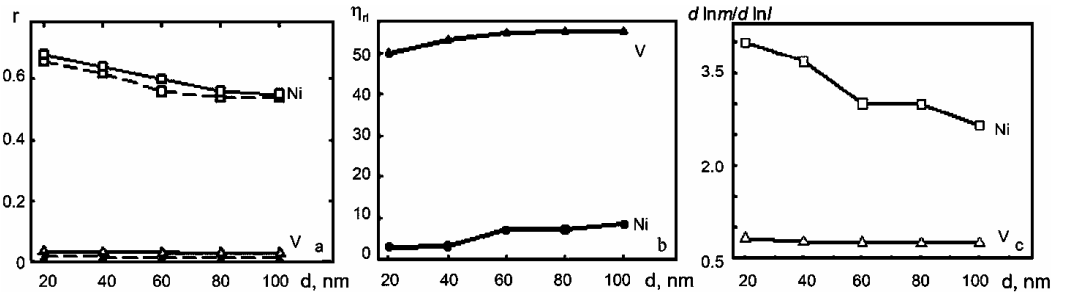

Fig. 5 Size dependences of (a), (b) and (c) for V and Ni films: – before deformation; --- after deformation.

At this conjuncture it is obligatory to carry out the investigations of one-layer samples also, as γ^{ρ}_{0il} or γ^{ρ}_{il} terms, which can be obtained from the linearized correlation (5), are the terms of the correlation (3).

The results of tensosensitivity of one-layer and multilayer films were obtained for model (3) testing. GF (γ_l) was calculated using deformation dependences, the examples of which are presented in figure 6 a, c. Values of γ_l obtained experimentally were compared with proper calculated values (see Fig. 6 b, d).

The results of testing are presented in table 4. These data show evidently good agreement of semiphenomenological model and experimentally obtained results.

Table 4 Comparison of experimentally obtained results and data calculated according to correlation (3) for longitudinal GF.

Film (d, nm)	$\gamma_{l\,exp}$	$\gamma_{l\,cal2}$	$(\gamma_{l\,exp} - \gamma_{l\,cal\,2})/\gamma_{l\,exp}$, %
Ni(25)/V(25)/S	13.10	17.06	25.1
$[Ni(25)/V(25)]_2$/S	24.70	32.64	22.0
$[Ni(25)/V(25)]_3$/S	30.90	36.37	21.4

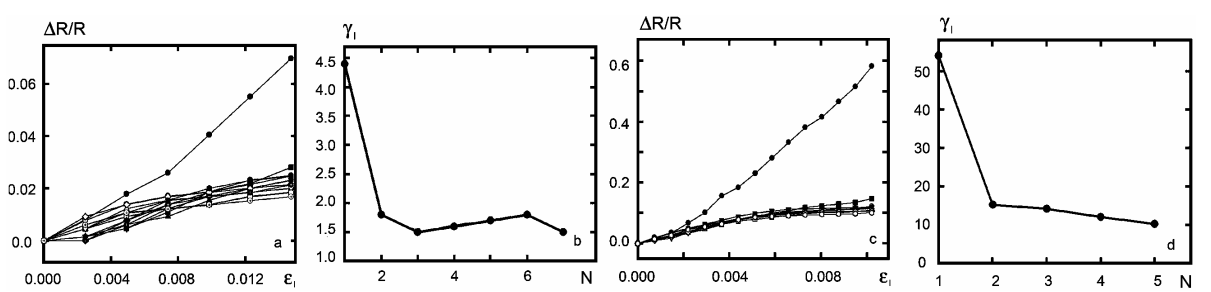

Fig. 6 Deformation dependences (a, b) and dependences of γ_l. on number of deformation cycle (c, d) for Ni(40)/V(80)/S (a, b) and Ni (25)/V(25)/Ni(25)/V(25)/S (c, d) film systems.

5 Conclusion

In this work the new experimentally obtained results regarding tensosensitivity of Fe, Cr, Cr/Fe and Ni, V, Ni/V films are presented. It is stated, that longitudinal gauge factor of multilayer film systems in general has greater meaning in comparison with one-layer films and this fact is connected with the additional scattering mechanism on interfaces. The carried out testing of macroscopical and semiphenomenological models evidently shows better agreement with experimentally obtained data for the semiphenomenological model because this model includes such transport parameters as mean free path, specularity parameter, transmission coefficient at the grain boundary. On the basis of the experimental data we obtained important strain deformation characteristics for the following one-layer films: $\eta_{\lambda 0l}$, η_{pl}, η_{rl} and $d\ln k/d\ln p$ and $d\ln m/d\ln r$ derivatives.

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References

[1] Z. G. Meiksin, "Nesploshnye i kermetnye pljonki / Phizika tonkih pljonok", Moskva: Mir 106, 1978. (in Russian)
[2] N. P. Klokova, „Tenzometrija", Moskva: Mashinostroenie 224, 1990. (in Russian)
[3] S. I. Protsenko and A. M. Chornous, Metallophiz. Noveishie Technol. **5**, 587 (2003) (in Russian)
[4] F. Warkusz, Progr. Surface Sci. **10**, 287 (1980).
[5] C. R. Tellier and A. J. Tosser, „Size effects in thin films", Amsterdam-Oxford-New York: Elsevier Scientific Publ. Company 309, 1982.
[6] F. Khater and M. El-Hiti, phys. stat. sol. (a) **108**, 241 (1988).
[7] F. Khater and M. El-Hiti, phys. stat. sol. (a) **109**, 517 (1988).
[8] M. El-Hiti, phys. stat. sol. (a) **155**, 185 (1989).
[9] A. M. Chornous, N. M. Opanasyuk, A. D. Pogrebnjak, and I. Yu. Protsenko, Jpn. J. Appl. Phys. **39**, L1320 (2000).
[10] Ye. O. Zabila and I. Yu. Protsenko, Ukr. J. Phys. **50**, 729 (2005).
[11] R. Dimmich, Thin Solid Films **158**, 13 (1988).
[12] L. Dekhtyaruk, I. Protsenko, A. Chornous, and M. Marzalek, Cryst. Res. Technol. **41**, 388 (2006).
[13] L. V. Dekhtyaruk, S. I. Protsenko, and A. M. Chornous, Ukr. J. Phys. **49**, 587 (2004).
[14] O. Lasyuchenko, L. Odnodvoretz, and I. Protsenko, Cryst. Res. Technol. **35**, 329 (2000).
[15] I. Protsenko, L. Odnodvoretz, and A. Chornous, Metallophiz. Noveishie Technol. **20**, 36 (1998).
[16] A. Chornous, I. Protsenko, and I. Shpetnyi, Cryst. Res. Technol. **39**, 602 (2004).
[17] Yu. M. Ovcharenko, Yu. Protsenko, O. V. Shovkopljas, and N. M. Opanasyuk, Ukr. J. Phys. **42,** 826 (1997). (in Ukrainian).
[18] G. C. G. C. Kuczynski, Phys. Rev. **94**, 61 (1954).

