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ELECTROPHYSICAL PROPERTIES OF Ge/Cr THIN FILMS

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Electrophysical properties of the two-layer film systems based on Ge and Cr as two-layer film a-Ge/Cr/S or over Ge/Cr/S are studied. It is found that at a limited thickness of $d_{Ge} \cong$ 10-15 *nm there is an inversion of sign value of* $\Delta R/R = [R(Ge/Cr) - R(Cr)]/R(Cr)$ *from* $\Delta R/R < 0$ *(for* $d_{Ge} <$ 10-15 *nm) to* $\Delta R/R > 0$ *(for* $d_{Ge} >$ 10-15 *nm). This result is explained by the formation of excitons of Wannier-Mott type that leads to a decrease in the concentration of free-carriers and, as a result of it, to the increase in the value of* $\Delta R/R$.

Keywords: *Cr, Ge, TWO-LAYER FILM, CONDUCTIVITY, ELECTROPHYSICAL PROPERTIES, EXCITON OF WANNIER-MOTT.*

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1. INTRODUCTION

Interest in thin film systems based on metals and semiconductors (two-layer films or film with coating) [1-3] is connected with the fact that the semiconductor atoms can diffuse along the metal film grain boundary [4] or through the interface and thus changing the electrical transport parameters and electrophysical properties. The authors [2] while studying the electrical conductivity of Cr films with a thin coating of Ge (over Ge/Cr/S) (S - substrate) with a thickness from 2.8 to 11.6 nm or two-layer films Ge/Cr/S with a thickness of Ge layer from 18.5 to 44.0 nm observed a decrease in the resistivity of Ge/Cr/S relative to the film Cr. The film thickness of Ge, where the two-layer system belongs to the category of over Ge/Cr/S or Ge/Cr/S, was gotten by taking into account the fact that the radius of the Wanner-Mott (W-M) exciton is about 10 nm. According to [2] the value of $\Delta R/R = [R(Ge/Cr) - R(Cr)]/R(Cr)$ is within the range of – 0.11 to – 0.40 (over Ge/Cr/S) or from – 0.04 to – 0.11 (Ge/Cr/S). The authors of Ref. [2] proposed five mechanisms of film conductivity to explain for a decrease in the resistivity:

- The system Ge/Cr/S is a parallel connection of two conductors;
- Formation of intermediate phases at the interface based on Ge and Cr, which has less resistance relative to the films Ge and Cr;
- A change in the magnetic structure of the Cr film, which in our view is unlikely;

- Peculiarity of the interface scattering and transmission of holes at the interfaces;
- Appearance of the exciton mechanism in film's conductivity.

Although the situation that is analyzed permits, in principle, the formation of two types of excitons, notably, the W-M excitons and in the form of Cooper electron-hole pairs (since the formation of Frenkel excitons is possible only in molecular crystals), we conjecture that the formation of excitons is most probably W-M type. In this regard, the aim of our work was to study the electrophysical properties of the two-layer film systems a-Ge/Cr/S with Ge thicknesses over 10 nm, at which W-M excitons can be formed, whereas at lower thickness Cooper pairs can be formed.

1. EXPERIMENTAL METHOD

To prepare the samples, we used standard vacuum chamber with the pressure of residual gas at $5 \cdot 10^{-4}$ Pa. Cr and Ge films were grown by the method of thermal evaporation and their thickness were measured using an interferometer. A gas analyzer was used to control the residual atmosphere at any stage of the condensation of film. The crystal structure and phase composition of the films were analyzed by the methods of TEM and electron diffraction. Elemental composition was investigated by the method of SIMS at the etching of primary ion beam of Ar at a rate 2-5 nm/min. Mass spectra of secondary ions from the boundary of the Ge- film/vacuum (Fig. 1) and from the boundary Cr-film/substrate indicate the formation of a small amount of oxides CrO and GeO, although in the volume of samples these are absent.

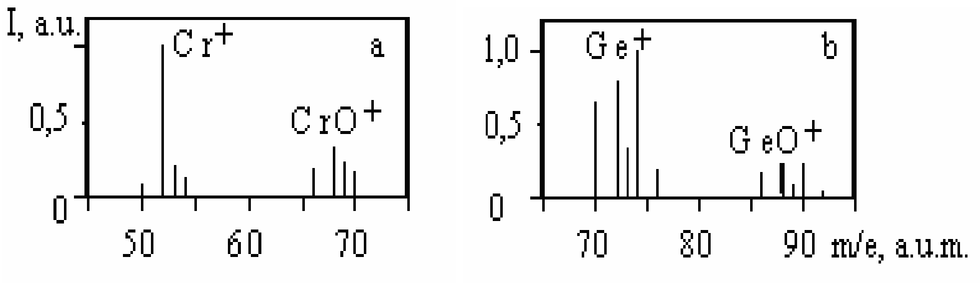

***Fig. 1** – Mass spectrum of secondary ions films (a) Cr and (b) Ge of the side vacuum*

Diffraction studies showed that Ge films are in amorphous state and at the annealing to 430 K they crystallize. For the study of electrophysical properties a two-point probe is used to measure the resistance of two-layer samples, which was from 102 to 103 Ohm. The films were deposited on a polished glass plate with molybdenum rods-electrodes. A special mask was allowed to maintain the geometry of the samples in all experiments.

2. EXPERIMENTAL RESULTS AND DISSCUSIONS

Table 1 presents the results obtained by the authors of Ref. [2].

Table 1 *– Illustration of the influence of Ge films on electrical properties of the two-layer film systems Ge/Cr/S*

Film systems	Ge		Cr		Ge/Cr		
	d, nm	$\rho\cdot 10^6$, Ohm·m	d, nm	ρ, Ohm·m	$\Delta\rho/\rho$	$\Delta R/R$	$\Delta R/R$ [2]
Ge(20)/Cr(30)	20	0.10	30	2.40	–0.35	–0.015	–
Ge(20)/Cr(50)	20	0.10	50	2.70	–0.22	–0.080	–
Ge(20)/Cr(130)	20	0.10	130	5.00	–0.15	≤0	–
Ge(10)/Cr(60)	10	0.10	60	4.70	–0.18	≥0	–
Ge(2,8)/Cr(2,8)	2.8		2.8	1.20	–	–	0.34
Ge(10,8)/Cr(11,6)	11.6		10.8	0.89	–	–	0.04
Ge(11,6)/Cr(11,0)	11.0		11.6	0.56	–	–	0.08
Ge(12)/Cr(33)	33		12.0	0.45	–	–	0.10
Ge(14,6)/Cr(22)	22		14.6	0.35	–	–	0.04
Ge(14,8)/Cr(44)	44		14.8	0.67	–	–	0.06

The analysis of these results leads to the conclusion that for thickness of Ge and Cr films, $d \leq 10$ nm, the formation of W-M excitons is practically impossible, as in this case a hole must be localized on an interface and an electron has to be scattered on a boundary film/substrate and film/vacuum. In Fig. 2 such a type of exciton is marked as number 1. But in transition to the two-layer film system it is possible for the formations of excitons, which are marked as numbers 2 and 3.

Starting from the model presented in Fig. 2, it is possible to estimate the contribution of W-M excitons to the resistance of the two-layer film systems. The resistivity can be calculated by:

$$\rho_{\mathrm{II}} = \frac{\rho_1\rho_2}{\left(d_1 + d_2\right)\left[\rho_1/d_2 + \rho_2/d_1\right]}, \tag{1}$$

where ρ_1 and ρ_2 are given by,

$$\sigma_1 \equiv \frac{1}{\rho_1} = \frac{n_1 e^2 \lambda_0}{2m\tilde{v}} \text{ and } \sigma_2 \equiv \frac{1}{\rho_2} = en_1\left(\mu_e + \mu_h\right) \tag{2}$$

where n_1 and n_2 – are the concentration carriers in the films Cr and Ge ($n_2 = n_e = n_h$), respectively, μ_e and μ_h are the mobility of the electrical charge carriers. If we take experimental values of $n_1 \cong 10^{29}\,\mathrm{m}^{-3}$, σ_2 (300 K) $\cong$ 10 Ohm^{-1}m^{-1} (for $d_2 \cong 20$ nm), $\mu_e \cong 0.40$ and $\mu_h \cong 0.20$ m^{2}V$^{-1}s^{-1}$, then we get $n_2 \cong 10^{20}\,m^{-3}$. Thus the increase in the concentration from n_1 to n'_1 leads to an insignificant formation of excitons and thus will not influence the resistivity. If we consider the three-layered film system (Fig. 2), then the resistivity can be calculated by:

$$\rho_{\mathrm{III}} = \frac{\rho_1 \rho_2' \rho_2}{\left(d_1 + d_2' + d_2''\right)\left[\rho_2' \rho_2 / d_1 + \rho_1 \rho_2 / d_2' + \rho_1 \rho_2' / d_2''\right]} \tag{3}$$

where $\rho_1 \cong 2\rho_2$.

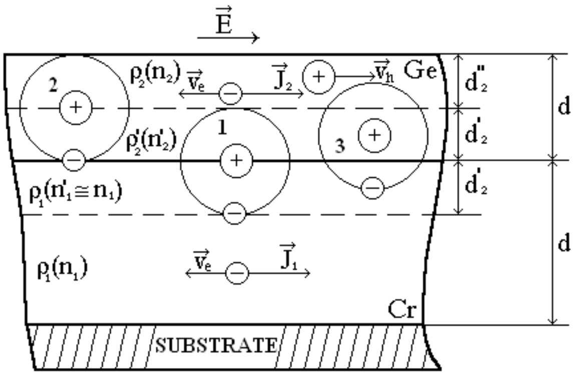

Fig. 2 – *Possible variants of formation of Wannier-Mott excitons in the two-layer film system Ge/Cr/S*

The calculations on the basis of Eqs. (1) and (3) show that $\rho_{\mathrm{III}}/\rho_{\mathrm{II}} \cong 1.02$. It means that the increase of resistivity of the film system Ge/Cr/S is the result of formation of excitons around 2%, as their formation increased the number of free-carriers. If we compare ρ_{II} and ρ_{III} with the experimental value of ρ, then it appears that this contribution is $\rho/\rho_{\mathrm{II}} \cong 0.90$ and $\rho/\rho_{\mathrm{III}} \cong 0.88$. Possibly, that this result is related both to mistake of calculations ρ_{II} and ρ_{III} with influence of other factors, indicated in [2], such as a mutual and mixing of atoms, formation of compound Cr and Ge, size effects, etc. From the results presented in Table 1 we conclude that the thickness of Ge film, $d \cong 10\text{-}15$ nm, is an original limiting value, and an inversion of sign of $\Delta R/R$ is due to the formation of W-M excitons.

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REFERENCES

1. D.M. Zehner, D.W. Goodman, *Physical and Chemical Properties of Thin Metal Overlayers and Alloy Surface* (Pitsburg, USA: Materials research Society: 1987).
2. K. Schroder, L. Walsh, *J. Vac. Sci. Technol.* **A9,** 577 (1991).
3. K. Schroder, I. Zhang, *phys. stat. sol.* **B183,** K5 (1994).
4. T. Hovorun, A. Chornous, *Cryst. Res. Technol.* **41,** 458 (2006).