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Conductivity of the $Bi_{12}SiO_{20}$ thin films

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The results of the conductivity examination in the $Bi_{12}SiO_{20}$ thin films prepared using the sol-gel method are presented. The conductivity was investigated in the 300–550 K temperature and up to 100 V/cm field ranges. It was observed that the charge carrier transfer at the flow level, situated in the tail of the density of states into the forbidden band is dominant for the investigated sample at $T > 500$ K. The obtained results are explained in terms of the highly compensated doped semiconductor model.

Key words: *bismuth sillenite, thin film, sol-gel method, conductivity*

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Bismuth sillenite $Bi_{12}SiO_{20}$ (BSO) is an attractive material for active optical devices. Most of these devices were made with the BSO single crystals. But it is desirable to make BSO thin films both for optical processing devices and for scientific investigations, for example for the optical absorption edge investigation. Among various techniques of dielectric thin film preparation the sol-gel processing is one of the most promising. In this paper the results of the conductivity examination in the BSO thin films prepared by sol-gel method are presented.

BSO thin films were obtained from the fresh precursor prepared by dispersing the starting materials (Bi_2O_3, SiO_2) in an organic solvent. The silicon plane-parallel plates with platinum coverage were used as the substrates. In order to obtain the films of the desired thickness, several layers were deposited and each layer was heated at 673 K in the air. Film thickness was evaluated by weighing and its value was $\sim 10^{-5}$ cm for each layer. Annealing at 923 K during 1 hour was carried out for BSO crystal structure fabrication of the film. The film conductivity σ in the temperature range 300–550 K at E = 100 V/cm in the direction of the perpendicular to the film plate was investigated. The VK 2-16 voltmeter (I < 10^{-8}A) and microampermeter (I > 10^{-8}A) were used for the current measurements. Platinum electrode on the substrate was the anode.

Temperature dependence of the BSO film conductivity is given in figure 1. At room temperature σ is $\sim 10^{-10}$ $\mathrm{Om}^{-1}\mathrm{cm}^{-1}$. The obtained results strongly differ from

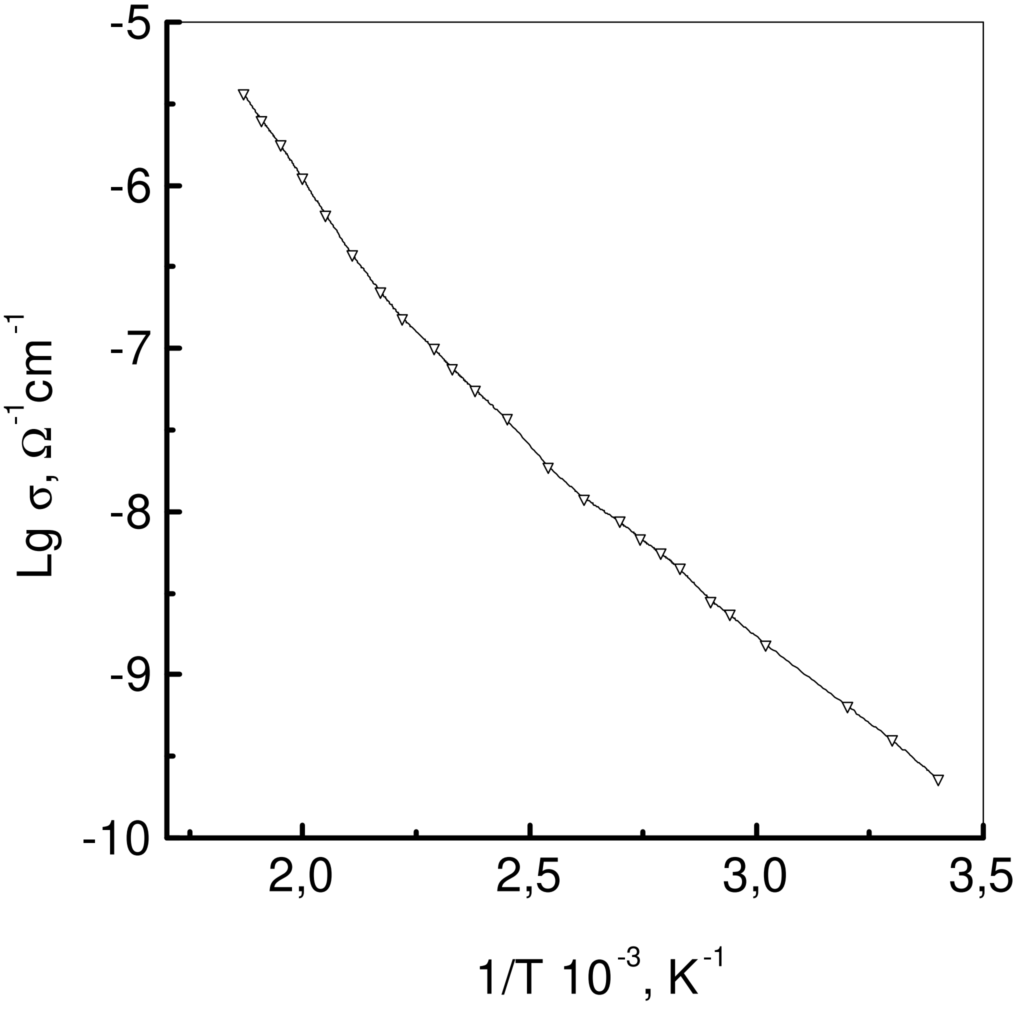

Figure 1. Temperature dependence of the conductivity of the $Bi_{12}SiO_{20}$ thin films.

the data in [1] where σ is $\sim 10^{-14}$ $Om^{-1}cm^{-1}$ (T = 300 K). In the latter case, BSO thin films have been prepared on the glass substrates by ECR plasma sputtering with aluminum electrodes. The σ distinction is possibly connected with the technology of the film preparation. As may be seen from figure 1, the conductivity increases with the temperature. The curve slope on the plot is not constant, the activation energy E_a increases from 0.44 eV to 0.83 eV. Above 500 K, the E_a remains constant with the value 0.83 eV.

The current-voltage (C-V) characteristics have got some special features (figure 2).

1. There are several sub-regions on the $I \sim U^{\alpha}$ dependence: ohmic, square-law regions and the region of the abrupt rise in current.

2. On the region of the abrupt rise in current the α value changes from 2 to 8. The transition from the σ ohmic dependence to the quadratic one is continuous.

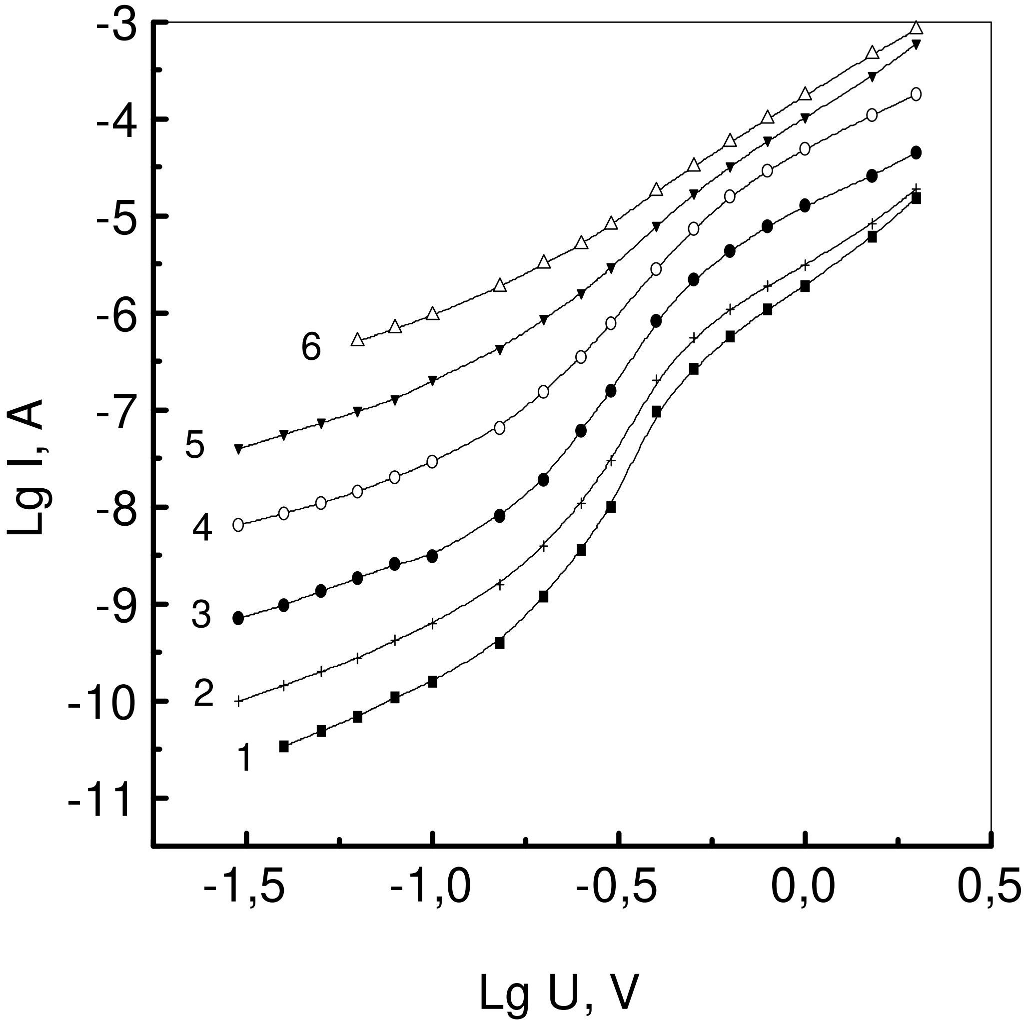

Figure 2. Current-voltage curves of the $Bi_{12}SiO_{20}$ thin films at temperatures: 1 – 293 K; 2 – 323 K; 3 – 373 K; 4 – 423 K; 5 – 473 K; 6 – 523 K.

3. There is a region of the C-V dependence where α remains constant with the value 1.9–2.4.

The described peculiarities of the C-V characteristics can be connected both with the film bulk features and with the contact effects, for example the Schottky emission. In order to choose the mechanism type, the $\log I = f(U^{1/2})$ curve was investigated which should be a straight line if the current is conditioned by Schottky emission [2]. In our case, such a curve was not straight. We may say that C-V curves are defined in general by the film bulk properties in the investigated temperature and field ranges. As it was noted above, several coatings were deposited one upon the other to obtain the films of the thickness desired. So the "barrier" mechanism of conductivity can be one of the possible mechanisms. Then the sample total resistance is determined by the sum of the barrier resistance formed on the coating boundaries and of the resistance of coatings successively joined. In the latter case, the activation energy is the linear function of the applied voltage and it

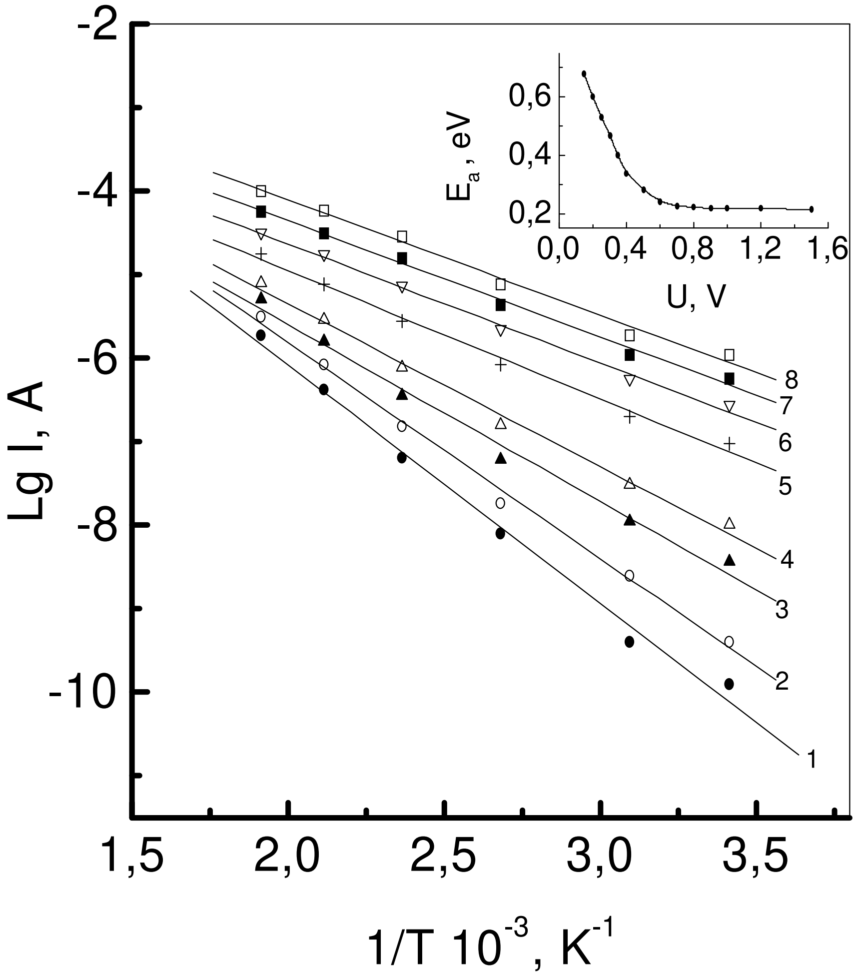

Figure 3. Temperature dependence of the current in $Bi_{12}SiO_{20}$ thin films subjected to different voltages U(V): (1) 0.4; (2) 0.5; (3) 0.6; (4) 0.7; (5) 0.8; (6) 1.0; (7) 1.2; (8) 1.5. The inset shows the activation energy of conduction E_a plotted as function of the voltage U.

should decrease with the voltage increasing [3]. The temperature dependence of the conductivity at different voltage values is presented in figure 3. These curves were obtained from the C-V characteristic measurements. As may be seen in figure 3, the slope of the curves decreases with the increasing voltage. The E_a values calculated are given in figure 3. The E_a value decreases from 0.7 eV (ohmic region) to 0.22 eV. The E_a does not decrease for higher voltages. Such $E_a(U)$ dependence is in contradiction with [3]. So we assume that "barrier" effects are not determinative in the conductivity mechanism of the obtained films.

Thus C-V characteristics and $E_a(U)$ curves permit us to say that the deep traps control the current across a given structure. According to [4], the form of the $E_a(U)$ curves (figure 1 and 3) can be observed when the traps distribution is Gaussian. In this case, the hopping charge transport mechanism may take place. The charge carrier jumps may be realized on the flow level, at the state of density maximum as well as at the states near Fermi level. The variable jump length is typical of the transfer at the states near Fermi level. But we did not observe such cases. The activation energy depends on the applied voltage for hops on the maximum of the state density. The E_a decreases as the result of the local state filling due to injection. The Fermi level shifts to the larger density of the local states. This corresponds to the E_a decrease and to the conductivity increase. In the case of the injection ability limited, the E_a does not depend on voltage. The conductivity has the variable E_a with the increasing temperature. In our case, such a dependence is observed at $T < 500$ K. The activation energy constant at a different voltage and the high effective mobility are the characteristic peculiarities of the transfer at the flow level in the "tail" part of the state density. Starting from the C-V curves and time-of-flight investigations at $t > 500$ K, the effective mobility is about $10^{-2}\mathrm{cm}^2\mathrm{V}^{-1}\mathrm{c}^{-1}$. Thus the charge carrier transfer at the flow level, situated in the tail of the density of states into a forbidden band is dominated for the sample investigated at $T > 500$ K. These states emerge due to the disorder distribution of the impurities of the doped materials at a strong compensation.

The results obtained in this work agree with those of the investigation of transfer mechanism in $Bi_{12}SiO_{20}$ single crystals well [5,6]. The different conductivity and activation energy values for films and single crystals may most probably be caused both by various concentrations of the local states and by the different power of the compensation in the crystals and in the films.

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Провідність тонких плівок $Bi_{12}SiO_{20}$

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Тонкі плівки сіленіту вісмуту були отримані золь-гель методом. У широкому діапазоні полів та температур були досліджені вольт-амперні характеристики та електропровідність. Знайдено, що перенесення носіїв заряду в тонких плівках при $T > 500$ K здійснюється по рівню протікання, розташованому у хвості густини локалізованих станів. Отримані результати обговорюються у рамках моделі легованих компенсованих напівпровідників.

Ключові слова: *електропровідність, вольт-амперна характеристика, енергія активації, густина локалізованих станів*

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