THE INTERLAYER ENERGY BARRIER IN THE ANISOTROPIC $TlB^{III}C_2^{VI}$ MONOCRYSTALS

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The temperature dependence of the anisotropy degree of the conductivity of the $TlInS_2$, $TlGaS_2$ and $TlGaSe_2$ layered monocrystals has been investigated. It is established, that $TlGaSe_2$ monocrystals have the most anisotropy degree, and $TlInS_2$ has the less anisotropy degree. The values of the interlayer energy barrier $\Delta\varphi$, eV in the $TlInS_2$ (0.04), $TlGaS_2$ (0.17) and $TlGaSe_2$ (0.3) crystals are obtained.

The $TlGaSe_2$, $TlGaS_2$ and $TlInS_2$ monocrystals are representatives of the layered materials of the group $T1B^{III}C_2^{VI}$. They are characterized by the strong anisotropic physical properties, caused mainly by the fact, that charge carriers can move freely inside the layers in them, and between the layers its movement is limited because of the interaction of the layers by the Van der Waals type and the small overlapping of the wave functions of the neighboring layers. The important parameter of the layered compounds is anisotropy of the electric conduction:

$$N = \sigma_{\perp C} / \sigma_{||C} \quad , \qquad (1)$$

where $\sigma_{||C}$ and $\sigma_{\perp C}$ is the electric conduction in the parallel and perpendicular directions of the crystallographic crystal *C* axis (*C* axis is perpendicular to the plane of the crystal layers) correspondingly.

It is need to note, that anisotropy degree of the layer crystals can be increased because of their intercalation, i.e. because of the introducing of the foreign ions, atoms or the molecules in the interlayer Van der Waals spaces. So, in the ref. [1] it was shown, that the anisotropy degree of the conductivity increased in 2-2,5 times because of the decrease in the similar times of the conductivity transversally to the layers at the intercalation of $T1B^{III}C_2^{VI}$ crystals by the lithium ions, whereas the crystal conduction was almost changeless along the layers.

The aim of the present paper is the investigation of the anisotropy degree of the conductivity of the layer semiconductors $TlInS_2$, $TlGaS_2$ and $TlGaSe_2$ in the dependence on the temperature and the finding of the energy barrier value between the layers.

The results of the conductivity investigation of the given layer monocrystals in the constant electric field are given below. The indium was used in the capacity of the contact material, which was melted in the monocrystals and it creates the ohmic contacts. The samples for the measurements have the thickness about 80÷130 mkm and were prepared as in the planar-, so in the sandwich-variant. For the samples in the planar variant, the indium contacts were carried on the lateral terminate edges so, that the electric current was directed along the natural layers of the monocrystal, i.e. perpendicularly to monocrystal *C* axis ($\sigma_{\perp C}$). In the samples, prepared in the sandwich-variant, the electric current was directed transversally to the natural layers, i.e. along the monocrystal *C* axis ($\sigma_{||C}$). The amplitude of the constant electric field, applied to the samples ($F=10^2 \div 10^3$V/cm) corresponded to the ohmic region of VAC. During the measurements the samples were established in the cryostat of the "Utrex" mark with the system of the temperature stabilization (the accuracy of the stabilization was 0,02 K).

The measurement results of the temperature dependence of the anisotropy electric conduction for the $TlInS_2$ monocrystals (curve 1), $TlGaS_2$ (curve 2) and $TlGaSe_2$ (3) in the temperature region, at which the jump conductivity takes place in these crystals are given on the fig.1 [2,3]. From the fig.1 it is seen, that *lgN* increases for all three crystals with the temperature decrease.

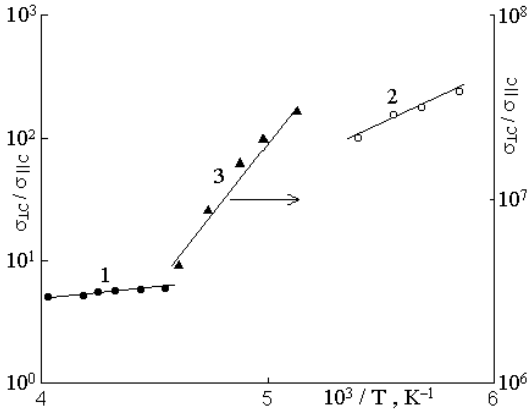

Fig.1. The temperature dependences of the anisotropy degree of the electric conduction of $TlInS_2$, $TlGaS_2$ and $TlGaSe_2$ monocrystals in the region of the low temperatures.

The energy barrier $\Delta\varphi$ between the layers can be valued because of the jump conductivity in the given crystals along *C* axis by the relation:

$$\sigma_{\perp C} / \sigma_{||C} \sim exp(\Delta\varphi / kT). \qquad (2)$$

From all three investigated crystals, the $TlGaSe_2$ monocrystals had the most energy barrier between the layers: $\Delta\varphi$=0.30 eV. In the $TlGaS_2$ $\Delta\varphi$=0.17 eV, and in $TlInS_2$ the value $\Delta\varphi$ was the less: 0.04eV.

According to these $\Delta\varphi$ values, the most anisotropy degree of the conductivity was in the $TlGaSe_2$ monocrystals, and the less one in the $TlInS_2$.

The dependence of the anisotropy degree of conductivity at the fixed temperature (*T*=232K) on the value of the interlayer energy barrier in the crystals $TlInS_2$, $TlGaS_2$ and $TlGaSe_2$ is given for the comparison on the fig.2. As it is seen from the fig.2, the experimentally obtained dependence *lgN* on $\Delta\varphi$ is linear that is in the agreement with the formula (2).

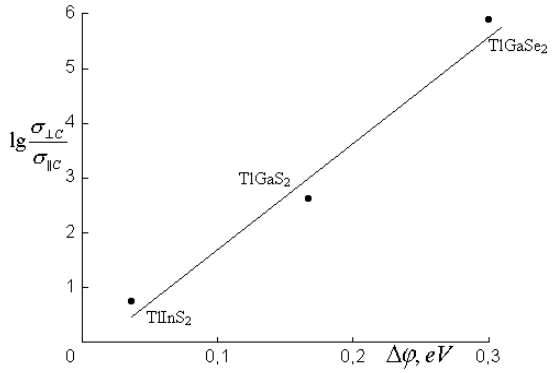

Fig.2. The dependence of the anisotropy degree of the conductivity on the value of the interlayer energy barrier in $TlInS_2$, $TlGaS_2$ and $TlGaSe_2$ monocrystals.

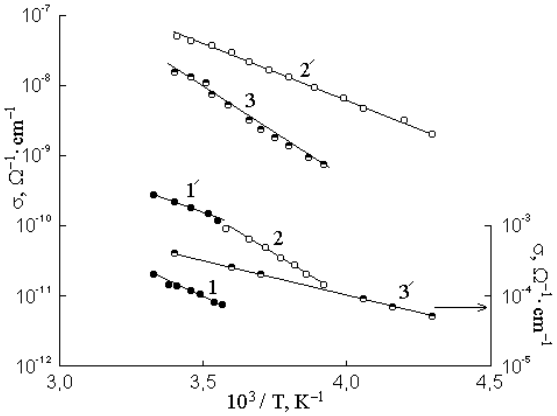

Fig.3. The temperature dependences of the conductivity of $TlInS_2$ (curve 1; 1'), $TlGaS_2$ (2; 2') and $TlGaSe_2$ (3; 3') monocrystals transversally and along to the layers near 300 K.

The value of the interlayer energy barrier can be estimated also by the difference of the activation energies of the conductivity transversally and along the layers, i.e. as follows:

$$\Delta E = E_{\sigma\parallel C} - E_{\sigma\perp C}. \qquad (3)$$

The temperature dependences of the conductivity of $TlInS_2$ (curve 1; 1'), $TlGaS_2$ (2; 2') and $TlGaSe_2$ (3; 3') monocrystals in the temperature interval near 300 K along and transversally to layers are given on the fig.3.

The obtained values of the activation energies of the conductivity from the fig.3 are given in the table, where the values $\Delta\varphi$ and ΔE are given for comparison also.

Table.

The electrical parameters of $TlInS_2$, $TlGaS_2$ and $TlGaSe_2$ monocrystals.

Monocrystal	Δφ, eV	$E_{\sigma\parallel C}$, eV	$E_{\sigma\perp C}$, eV	ΔE, eV
$TlInS_2$	0.04	0.39	0.34	0.05
$TlGaS_2$	0.17	0.50	0.31	0.19
$TlGaSe_2$	0.30	0.54	0.20	0.34

As it is seen from the table, the $\Delta\varphi$ and ΔE values well agree with each other in the limits of the experiment fault for all investigated monocrystals. Moreover, the ΔE value was a little bit bigger, than $\Delta\varphi$ in all three cases.

Thus, the values of the interlayer energy barrier, well-agreed with each other, in the $TlInS_2$, $TlGaS_2$ and $TlGaSe_2$ monocrystals are obtained by two independent methods.

[1] *S.N. Mustafaeva, V.A. Ramazanzade, M.M. Asadov.* Materials Chemistry and Physics. 1995, v.40, n.2, p. 142–145.

[2] *S.N. Mustafaeva, V.A. Aliev, M.M. Asadov.* FTT, 1998, t.40, n1, s. 48–51.(in Russian).

[3] *S.N. Mustafaeva, V.A. Aliev, M.M. Asadov.* FTT, 1998, t.40, n4. s. 612–615. (in Russian).

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$TlB^{III}C^{VI}_2$ ANİZOTROP MONOKRİSTALLARINDA LAYLAR ARASINDAKI ENERJİ MANEƏLƏRİNİN TƏYİNİ

$TlInS_2$, $TlGaS_2$, $TlGaSe_2$ laylı monokristallarda keçiriciliyin anizotropiya dərəcəsinin temperaturdan asılılıqıarı tədqiq edilmiş və müəyyən olunmuşdur ki, $TlGaSe_2$ ən çox, $TlInS_2$ isə ən az anizotropiya dərəcəsinə malikdir. $TlB^{111}C^{V1}_2$ monokristallarında laylararası enerji maneələrinin qiymətləri tapılmışdır ($\Delta\varphi$, eV): 0,04 ($TlInS_2$), 0,17 ($TlGaS_2$) və 0,3 ($TlGaSe_2$).

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ОПРЕДЕЛЕНИЕ МЕЖСЛОЕВОГО ЭНЕРГЕТИЧЕСКОГО БАРЬЕРА В АНИЗОТРОПНЫХ МОНОКРИСТАЛЛАХ $TlB^{III}C_2^{VI}$

Изучена температурная зависимость степени анизотропии проводимости слоистых монокристаллов $TlInS_2$, $TlGaS_2$ и $TlGaSe_2$. Установлено, что наибольшую степень анизотропии имеют монокристаллы $TlGaSe_2$, а наименьшую – $TlInS_2$. Определены величины межслоевого энергетического барьера $\Delta\varphi$, эВ в кристаллах: $TlInS_2$ (0.04), $TlGaS_2$ (0.17) и $TlGaSe_2$ (0.3).

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