INJECTION-CONTACT PHENOMENA IN SINGLE CRYSTALS OF InSe, GaSe AND GaS

Yu.G. NURULLAYEV
Baku State University,
370148, Baku, Z. Chalilov st., 23

The current - voltage (I-U) characteristics of high - resistivity InSe, GaSe and GaS crystals have been investigated. The observed peculiarities of the I-U characteristics are interpreted using the space-charge-limited current (SCLC) theory and the two-barrier model. It has been shown that the barriers considerably affect the charge carrier transport process only at relatively low temperatures and voltages. With increasing temperature or injection level, due to increase of free charge carrier concentration, the above barriers are gradually eliminated leading to the quasi-uniform state of the samples.

In this paper the results of studying the infection-contact phenomena - the space-charge-limited, currents (SCLC) in the single crystals of A_3B_6 compounds, i.e. indium and gallium selenides and gallium sulphide, have been presented.

The current-voltage (I-U) characteristics of high-resistance InSe, GaSe and GaS single crystals with the resistivity of 10^5-10^{11} Ohm·cm were investigated. The samples studied were of a sandwich-type structure, i.e. a single-crystalline layer of a semiconductor with thickness of 0.03 - 0.20 mm between two indium metallic contacts deposited so that the current passed along the "c" axis perpendicular to the natural cleavage planes of crystals. To obtain the reproducible data the I-U characteristics were taken after establishing of the steady-state values of current.

The I-U characteristics of InSe (curve 1), GaSe (curve 2) and GaS (curve 3) crystals at 77 K are shown in Fig 1. The current through the samples initially increase according to the exponential law and further the power sections $J{\sim}U$ with n=1.0; n=2.0; n=m>2 for InSe, GaSe and n=1.0; n=2.0; n=m>2 for GaS are observed.

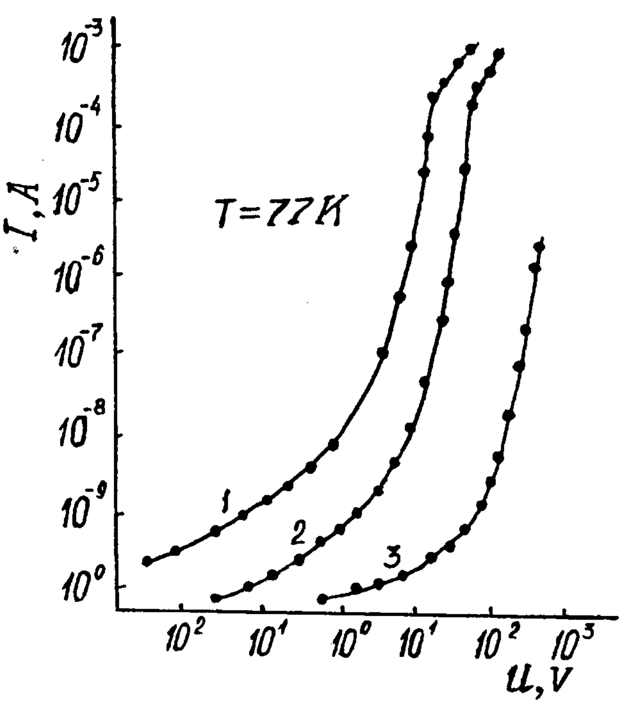

Fig. 1. Current -voltage characteristics of InSe (1), GaSe (2) and GaS (3) crystals. T=77 K.

Such a dependences are evident for the fact that the space - charge - limited currents place main role in charge transfer.

Based on the Lampert's theory for the SCLC [1], the concentration (N_t) and the depth (ε_t) of trapping levels as well as the density (n_0) and the mobility (μ) of the charge carriers were estimated from the power regions of the I-U characteristics. It turned out that although the values of N_t, n_0 and μ at $T \geq 200$ K obtained in such a manner are in good agreement with those obtained from the Hall measurements, the discrepancy between them becomes greater with the temperature decrease. At T<120 K the values of N_t obtained from the SCLC some times proved to be equal to $\sim 10^{23}$ cm^{-3} and even more that arouses great doubts. This fact allows to assume that at relatively high temperatures in samples studied the charge carrier transport is determined by SCLC at a monopolar injection. With decreasing temperature in addition to SCLC, the other competitive mechanisms, which in the final analysis become predominant are assumed to affect the charge carrier transport process.

When extending the regions of a sharp increase in the I-U characteristics for different temperatures, they must intersect in a single point with the coordinates:

$$J_t = N_v \mu e \frac{V_t}{d} \quad (1)$$

$$U_t = N_t e \frac{d^2}{\varepsilon} \quad (2)$$

where N_v is the density of states in valence band, d - is a distance between the contacts, ε is a dielectric constant of a semiconductor. As a result, the values obtained from (1) and (2) are N_t=7.5·10^{19}cm^{-3};$N_v\mu$=1.6·10^{10} (cm·V·s)$^{-1}$;$N_v\mu$=3·10^{17}cm^{-3}.

The investigation of temperature dependence of the current density at different voltages has shown that the course of the $J(T)$ dependence is considerably defined by the U value (Fig. 2). At $U<U_{1-2}$, where $J(U)$ obeys the exponential law, the dependence of $lg\ J$ on $10^3/T$ consists of two straight-line parts. The activation energies determined from the slope of the initial low-temperature regions are 0.07; 0.06; 0.05 eV and about 0.02; 0.36; 0.56 eV for InSe, GaSe and GaS, respectively. With increasing U in InSe crystals the first region disappears gradually and the dependence of lgJ on $10^3/T$ is a

GaSe and GaS as the U value increases the (T) dependence in a low-temperature region becomes more and more less pronounced and the slope of the dependence of lgJ on $10^3/T$ in a high-temperature region remains nearly unchangeable.

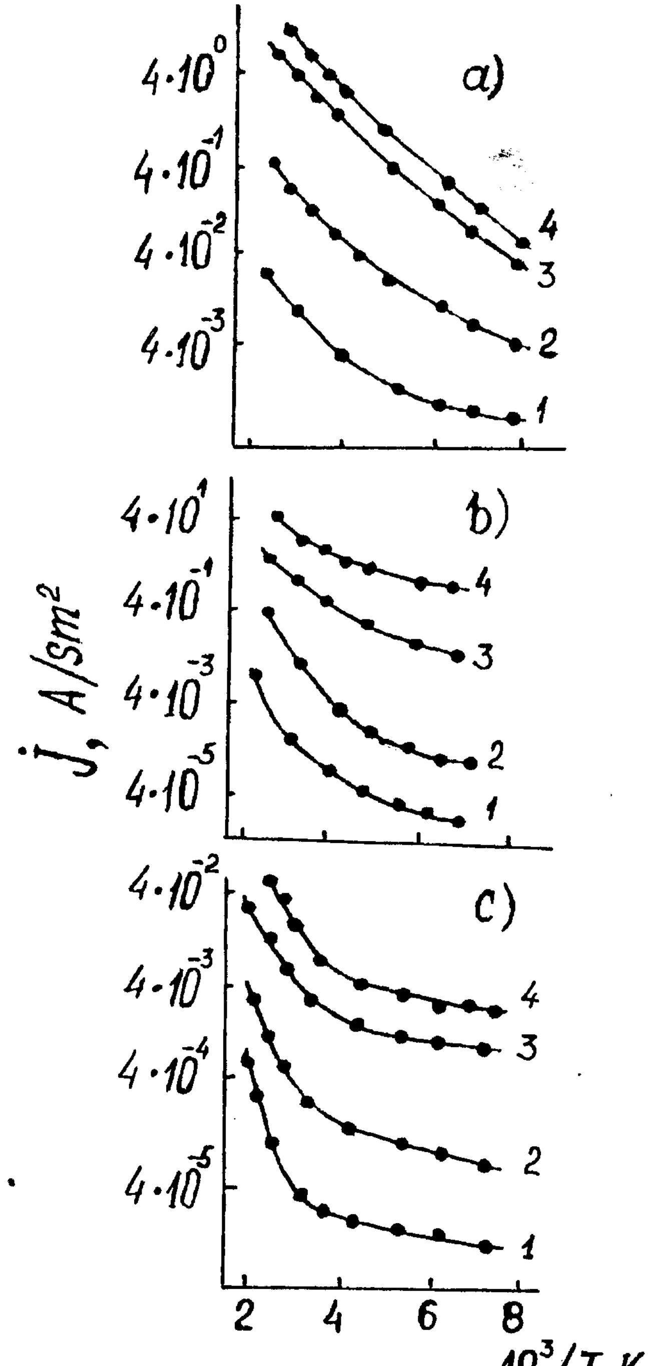

Fig. 2. Temperature dependence of the current density in InSe (a), GaSe (b) and GaS (c) single crystals. U, V: (a) 1 - 0.2; 2 - 1.0; 3 - 10; 4 – 20; (b) 1 - 0.1; 2 - 1.0; 3 - 4.0; 4 – 10; (c) 1 - 5.0; 2 - 20; 3 - 100; 4 - 150.

A correlation of results obtained from photoelectric, Hall measurements and the I-U characteristics for one and the same sample allows to conclude that the observed dependences of lgJ on $10^3/T$ and the I-U peculiarities in high-resistance InSe, GaSe and GaS crystals can be interpreted only by the use of the SCLC theory and two-barrier model developed for macro-inhomogeneous semiconductors. According to this model high-resistivity crystals as whole consist of low-resistivity (LR) matrix with in a random way distributed high-resistivity (HR) inclusions, and in their interface potential barriers ($e\varphi_r$) of recombination type exist. Also in HR regions the potential barriers of drift type create due to overlapping of the space charge of the adjacent LR regions. At the same time shallow, α- and β-trapping levels, as well as fast S- and slow r-centres of recombination exist in the forbidden bands of these crystals. In so doing S-centres and α-trapping levels are localized in LR, and r-centers and β-trapping levels are placed in HR inclusions. In particular, it is assumed that at low temperatures, when $U<U_{1-2}$, the current density is $J \sim exp\left(-\frac{e\varphi}{kT}\right)$, where $e\varphi$ is the effective height of the drift barrier equal to the activation energy of the current determined from a low-temperature part of the dependence of lgJ on $10^3/T$. With increasing temperature due to increase of majority charge carrier concentration, the height of the barrier, $e\varphi$, and decreases and at relatively high temperatures the drift barriers disappear, i.e. the condition characteristed of quasi-homogeneous semiconductor is provided. Under the given conditions, in this part of the $J(T)$ dependence the current through the sample is determined by the impurity conductivity. The impurity activation energy values determined from the slope of the $J(T)$ dependence curves for InSe, GaSe and GaS are 0.20; 0.36 and 0.56 eV, respectively. But in InSe crystals the equilibrium charge carrier concentration (n_0) is high, (10^{14}-10^{15} cm^{-3}). Therefore, in the given conditions, the current through the samples of InSe crystals is mainly determined by these carriers and the $J(T)$ dependence is described by a single straight line with a slope equal to the activation energy of impurity levels. In GaSe and GaS crystals at $U>U_{1-2}$ the drift barriers become negligible. However, in this case, the $J(T)$ dependence consists of two parts, i.e. the low- and the high-temperature regions. In a low-temperature region the J depends on T much weaker, while in a high-temperature region with increasing T it also increases and the activation energy is equal to 0.36 and 0.56 eV for GaSe and GaS, respectively. This situation is probably due to the fact that at relatively high temperatures the equilibrium charges carrier concentration increases and considerably exceeds the injected carrier concentration. Therefore these carriers and increases with temperature [2] mainly determine a total current density.

As at low T some part of the charge carriers the concentration of which has been determined from the Hall measurements, n_H, is localized in high-resistance regions and is almost not involved in the charge carrier transfer in the SCLC conditions, the concentration n_0 determined from the SCLC theory will be less than n_H. With increasing T the barriers at the boundaries of low- and high-resistance regions "disappear" and hence the discrepancy between n_H and n_0 decreases. Within the framework of the suggested model at relatively low temperatures $\mu = \frac{n_0}{n_H}\mu_H$; $\mu_H<\mu$ and with increase of T, n_0 approaches n_H and the discrepancy between μ and μ_H also disappears.

The drift barriers considerably effect the charge carrier transport process only at relatively low temperatures and applied voltages. With increasing temperature or the infection plied voltages. With increasing temperature or the infection level (as the applied voltage increases), due to increase of free charge carrier concentration, these barriers gradually disappear. As a result, the sample converts to electrically quasi-uniform state [3, 4].

Based on the above considerations. It is assumed that the discrepancy between the values of N_t, μ and n_0 determined from SCLC at low rather attributed to a spatial non-uniformity crystals studied.

[1] *A. Lampert, P. Mark.* Injection currents in solids. Moscow, 1973, p.416.

[2] *A.Sh. Abdinov, A.G. Kyazim-zade, A.A. Ahmedov.* FTP. 1976. v.10. p. 2299.

[3] *A.Sh. Abdinov, A.G. Kyazim-zade, N.M. Mehdiyev, M.D. Khomutova, A.G.Sharipov.* FTP, 1974, v.8. p. 2283.

[4] *A.G. Akhundov, A.Sh. Abdinov, N.M. Mehdiyev, A.G. Kyazim-zade.* Problems of dielectric electronics. Tashkent, 1974, p. 127.

Y.Q. Nurullayev

InSe, GaSe VƏ GaS MONOKRİSTALINDA İNJEKSİYA - KONTAKT HADİSƏLƏRİ

İşdə yüksək omlu InSe, GaSe və GaS kristalların volt-amper xarakteristikaları (VAX) öyrənilmişdir. Alınan nəticələr həcmi yüklərlə məhdudlaşmış cərəyan nəzəriyyəsi və ikiqat çəpər modelinin köməyi ilə izah olunur.

Müəyyən olunmuşdur ki, çəpərlər yalnız aşağı temperatur və gərginliyin kiçik qiymətlərində keçiriciliyə nəzərə alınacağı dərəcədə tə'sir göstərir. Temperatur və ya injeksiya artdıqca yükdaşıyıcıların konsentrasiyasının artması nəticəsində bu çəpər tədricən yox olur və nümunə kvazibircins hala keçir.

Ю.Г. Нуруллаев

ИНЖЕКЦИОННО-КОНТАКТНЫЕ ЯВЛЕНИЯ В МОНОКРИСТАЛЛАХ InSe, GaSe И GaS

Исследованы статические вольт-амперные характеристики высокоомных кристаллов InSe, GaSe и GaS. Наблюдаемые особенности вольт-амперных характеристик интерпретированы с привлечением теории ТООЗ и двухбарьерной модели. Показано, что барьеры оказывают значительное влияние на процесс токопрохождения лишь при относительно низких температурах и напряжениях. С ростом температуры или уровня инжекции из-за увеличения концентрации свободных носителей заряда эти барьеры постепенно снимаются, в результате чего образцы переходят в квазиоднородное состояние.

Дата поступления: 22.06.98

Редактор: Б.Г. Тагиев