

ELECTROLUMINESCENCE OF LAYERED MONOCRYSTALS OF $A_3B_6<RE>$

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The brightness characteristics and spectral distribution of an electroluminescence, and also its dependence on the temperature, prehistory and initial dark resistivity of a sample, on the frequency and duration of a pulse field in specially not alloyed and alloyed by rare-earth elements as gadolinium, holmium and dysprosium with various percentage $N_{RE} \approx 10^{-5} \div 10^{-1}$ at. % in layered monocrystals of InSe and GaSe are investigated at various temperatures (from 77 K) in a wide range of constant, sine wave and pulse electric fields of applied intensity. It is established, that at $T \leq 100$ K brightness of electroluminescence (B_e) does not depend almost on the temperature, and further with increasing of T sharply decreases (exponentially). At $T \approx 200$ K and 160 K the luminescence absolutely disappears in crystals p -GaSe and n -InSe - there is a temperature suppression of an electroluminescence. With increasing of N_{RE} brightness of a luminescence firstly (at $N_{RE} \leq 10^{-4}$ at. %) decreases a little, and further increases (in crystals not alloyed specially). Thus non-monotone dependence B_e on prehistory of a sample varies also. It is established, that the structure of spectral distribution of B_e does not depend almost on the N_{RE} . With change N_{RE} brightness of separate strips of radiation only varies. Change of the chemical nature of the entered impurity in investigated crystals does not influence an electroluminescence.

It is shown, that the most stable values of electroluminescent parameters are provided in crystals with $N_{RE} \approx 10^{-2} \div 10^{-1}$ at. %.

It is supposed, that dependence of an electroluminescence on the doping level by rare-earth elements is caused by change of interlaminar connections depending on the N_{RE} in investigated crystals.

The electroluminescence in layered crystals of A_3B_6 is found out enough for a long time [1, 2]. However by present time some interesting its aspects (dependence of brightness on the temperature, initial dark resistivity and prehistory of sample, and also dependence of radiation spectrum on the direction concerning a «C» axis of crystal) are not investigated almost. Influence of alloying by rare-earth elements (RE) as gadolinium (Gd), holmium (Ho) and dysprosium (Dy) on an electroluminescence of crystals GaSe and InSe which considerably changes their photoelectric and photoluminescent properties [3–5] is not investigated also.

The present work is devoted to complex investigation of the above-stated questions.

Investigated samples with thickness of $0.100 \leq d \leq 1.000$ mm and cross-section size of $(2 \div 3) \times (4 \div 6) \text{ mm}^2$ were cut off from large monocrystals of InSe and GaSe, grown by a method of slow cooling at a constant gradient of temperature along ingot [6]. Current contacts have been created by soldering metals as In, Ga, Sn, or drawing of silver paste in open air on fresh-chipped surfaces of samples. Measurements were carried out in the temperature range of $(77 \leq T \leq 300) \text{ K}$ under action of an electric voltage of various types (sinusoidal-variable and rectangular-impact) with a various voltage, frequency and duration (up to 350 V, $5 \cdot 10^4 \text{ Hz}$ и $10 \mu\text{s}$ respectively). The spectral distributions of an electroluminescence and photoconductivity, dependence of brightness of electroluminescence (B_e) and photocurrent (I_{ph}) on the temperature, the dark volt -ampere characteristic and the volt - brightness characteristic of an electroluminescence, and also dependence of brightness of an electroluminescence on frequency and duration of a stimulating electric voltage were removed on the same sample under various conditions. Samples with various percentage of entered impurity $N_{RE} \approx 0; 10^{-5}; 10^{-4}; 5 \cdot 10^{-4}; 10^{-3}; 5 \cdot 10^{-3}; 10^{-2}; 10^{-1}$ at. % were used.

It is established as a result of the measurements carried out by us, that electroluminescence (EL) as in specially not alloyed, in alloyed by Gd, Ho and Dy with $N_{RE} \approx 10^{-5} \div 10^{-1}$ at.% crystals p -GaSe and n -InSe is raised at rather low temperatures ($T_i \leq 200 \text{ K}$ for $T_i \leq 160 \text{ K}$ for GaSe and InSe, respectively) under action of an electric current of the various

type (unidirectional pulse and sinusoidal-variable) with intensity, the greater some E_z . The value of E_z under other identical conditions depends on temperature (T), initial dark resistivity (ρ_{TO}) and prehistory of a sample, and also on the doping level (N_{RE}).

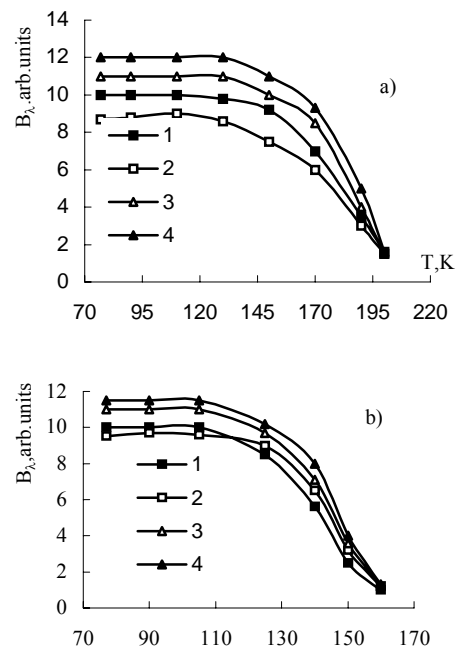


Fig. 1. Temperature dependence of brightness of an electroluminescence in not alloyed specially (1), and also alloyed by RE (2, 3) crystals p -GaSe (a) and n -InSe (b). N_{RE} , at. %: (a) 1 - 0; 2 - 10^{-5} ; 3 - 10^{-2} , (b) 1 - 0; 2 - 10^{-4} ; 3 - 10^{-1}

The value of E_z increases with increasing of ρ_{TO} and T and with increasing of N_{RE} varies non-monotone. In particular, the value of E_z with increasing of N_{RE} firstly (at $N_{RE} \leq 10^{-4}$ at.%) increases a little, and then (at $10^{-4} < N_{RE} \leq 10^{-1}$ at.%) decreasing comes nearer to value having places in not alloyed specially

low-ohmic crystals ($\sim 5 \cdot 10^2$ and 10^2 V/cm at 77 K for p -GaSe and n -InSe, accordingly). With increasing of N_{RE} dependence of parameters and characteristics of an electroluminescence on ρ_{TO} and prehistory of a sample, firstly ($N_{RE} \leq 10^{-4}$ at.%) amplifies a little, and brightness of luminescence (B_l) - is weakened concerning initial. Further (at $10^{-4} < N_{RE} \leq 10^{-1}$ at.%) with increasing of N_{RE} besides a degree of stability of electroluminescent characteristics and the parameters, appreciable image increases also B_l . The electroluminescent radiation in crystals p -GaSe<RE> and n -InSe<RE> with $N_{RE} \approx 10^{-2} \div 10^{-1}$ at.% is characterized with the greatest brightness, and also the highest degree of stability and reproducibility of parameters and characteristics.

The electroluminescence with the least E_z and the greatest B_l is observed at 77K in specially not alloyed crystals. With the further increase of temperature firstly (at $T \leq 100$ K) brightness of a luminescence does not vary (fig. 1, curve 1), and further exponentially decreases sharply and at $T \approx 200$ K and $T \approx 160$ K for p -GaSe and n -InSe accordingly there is a temperature suppression of electroluminescent radiation.

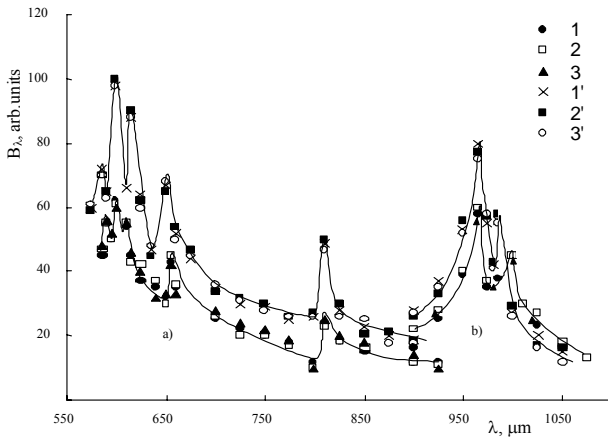


Fig.2. Spectral distribution of brightness of an electroluminescence in crystals p -GaSe<RE> (a) and n -InSe<RE> (b) at the various chemical nature of the entered impurity. N_{RE} , at. % : 1, 2, 3 - 10^{-4} ; 1', 2', 3' - 10^{-1} . RE: 1, 1' - Gd; 2, 2' - Ho; 3, 3' - Dy.

In both groups of crystals at rather small N_{RE} with increasing of temperature B_l all over again (up to 100 K) increases concerning having a place at 77K, and further a little as well as in a case of specially not alloyed crystals decreases exponentially (fig.2, curve 2).

It is established, that spectral distribution of brightness of electroluminescent radiation in p -GaSe has more complex structure, than in n -InSe. In particular, on EL spectrum of crystals p -GaSe besides the bright basic, a number of weaker maximums is observed also. Besides in both materials the EL spectrum at excitation along layers almost on ~ 0.1 eV is displaced aside longer waves concerning a spectrum corresponding to a case of excitation to perpendicularly natural layers. However at increase of N_{RE} this displacement gradually decreases and at $10^{-2} \div 10^{-1}$ at.% sometimes becomes not appreciable. For both semiconductors the structure of $B_l(\lambda)$ curves does not depend almost on the doping. With increasing of N_{RE} only on EL spectrum of crystals p -GaSe additional strips of radiation are shown by more clearer - their contrast increases. It is necessary to note, that at all us

the considered conditions electroluminescent properties of investigated crystals appeared dependent only from percentage of the entered impurity, and their dependence on the chemical nature of an impurity is not found out almost (fig.2).

Also it is established, that as in crystals not alloyed specially, in p -GaSe<RE> and n -InSe<RE> too dependence of $B_l(U)$ has sedate, and dependence $B_l(I)$ - linear character. The energy determined on the basic maximum of the electroluminescence spectrum, allows telling, that process of radiation thus is caused by recombination of injected no basic current carriers through the slow r -centers of recombination [7].

It is shown, that the range of temperature EL suppression in samples investigated by us well coincides with a range of temperature clearing own photoconductivity, and also with a temperature range of supervision of negative photoconductivity and IR clearing of intrinsic photoconductivity. If at excitation modes of an electroluminescence simultaneously to illuminate a sample also with light, creating negative photoconductivity, or IR clearing of intrinsic photoconductivity then EL radiations it is not observed. With change N_{RE} though non-monotone, but weak displacement of red border of EL nevertheless is observed, that most likely, can is caused by influence of doping on the energetic depth (ϵ_r) of bedding of the r -centers. These results too testify that the electroluminescence in investigated crystals is directly caused by recombination of no basic carriers of a current through the r -centers of slow recombination.

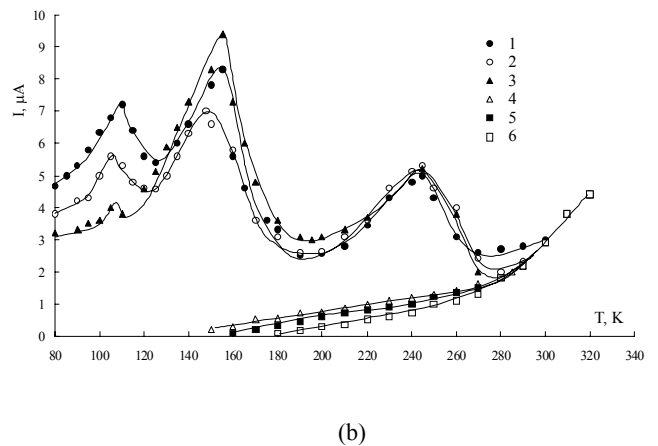
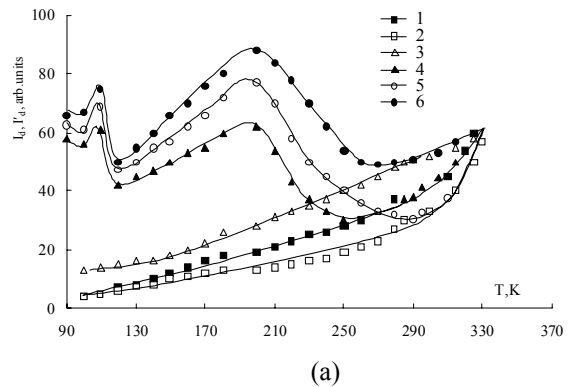


Fig. 3. Temperature dependence of dark (1-3) and quasidark (4-6) conductivity in crystals p -GaSe<RE> (a) and n -InSe<RE> (b). N_{RE} , at. % : 1, 4- 0; 2, 5 - 10^{-4} ; 3, 6 - 10^{-1} .

The uniform positions of dependences of EL on the ρ_{TO} , prehistory of a sample, temperatures, and doping level is possible to explain in view of partial disorder of crystals GaSe and InSe [7]. Apparently, thus existing recombination barriers interfere the recombination of no basic carriers through located in high-resistance inclusions of the slow r -centers of recombination.

Within the framework of this model, dependence of an electroluminescence on the RE doping level can speak dependence of a degree of disorder of investigated samples on the N_{RE} [3-5].

As to displacement of spectral distribution B , aside longer waves of a spectrum at excitation in a direction of natural layers, most likely, it is caused with presence of potential barrier $\Delta\phi_c \approx 0.1\text{eV}$ between next natural layers [8]. It is

supposed, that at RE doping because of growth of number covalent connections of RE ions taking place in the next layers, the general share ionic-covalent connections concerning weak molecular between natural layers [9] increases also. Therefore with increasing N_{RE} the value of $\Delta\phi_c$ and the found out displacement of spectral distribution decreases is weakened.

The thermostimulated conductivity measurement carried out by us (fig.3) testify that entered RE impurity enter into investigated crystals as levels of sticking for the basic carriers instead of as the r -centers of slow recombination. As to influence of these impurity on energetic depth of the r -centers it is possible to assume, that it is appears by change of donor-acceptor interaction pairs that sometimes appears appreciable in investigated semiconductors.

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LAYLI A_3B_6 <NTE> MONOKRİSTALLARINDA ELEKTROLÜMINESSENSİYA

Qadolinium, holmium və disprozium tipli, nadir torpaq elementləri ilə aşqarlanmış indium və qallium selen monokristallarında elektrolüminessensiya tədqiq edilmişdir. Müəyyənləşdirilmişdir ki, $T \leq 100\text{K}$ olduqda şüalanmanın parlaqlığı (B) temperaturdan asılı deyil, sonra isə temperaturun artması ilə eksponensial qanunla azalır. $T \approx 200\text{K}$ və 160K -də uyğun olaraq p -GaSe □ə n -InSe kristallarında elektrolüminessensiyanın temperatur sönməsi baş verir. N_{NTE} -nin artması ilə əvvəlcə ($N_{NTE} \leq 10^{-4}$ at. % olduqda) işıqlanmanın parlaqlığı bir qədər azalır, sonra isə artır. N_{NTE} -nin dəyişməsi ilə ayrı-ayrı şüalanma zolaqlarının parlaqlığı da dəyişir. Daxil edilən aşqarın kimyəvi təbiətinin dəyişməsi isə elektrolüminessensiyaya təsir göstərmir. $N_{NTE} \approx 10^{-2} \div 10^{-1}$ at. % olduqda elektrolüminessensiya parametrləri ən stabil qiymətlərini alır.

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ЭЛЕКТРОЛЮМИНЕСЦЕНЦИЯ СЛОИСТЫХ МОНОКРИСТАЛЛОВ A_3B_6 <PЗЭ>

Исследована электролюминесценция в легированных редкоземельными элементами типа гадолиния, гольмия и disproзия, кристаллах моноселенида индия и галлия. Установлено, что при $T \leq 100\text{K}$ яркость электролюминесценции (B) почти не зависит от температуры, а далее с ростом T уменьшается. При $T \approx 200\text{K}$ и 160K в кристаллах селенида индия и галлия соответственно, свечение совсем исчезает - происходит температурное тушение электролюминесценции. С ростом $N_{PЗЭ}$ яркость свечения сначала (при $N_{PЗЭ} \leq 10^{-4}$ ат.%) несколько уменьшается, а далее увеличивается относительно исходного. С изменением $N_{PЗЭ}$ меняется также яркость отдельных полос излучения. Изменение химической природы введенной примеси на электролюминесценцию в изучаемых кристаллах не влияет. При $N_{PЗЭ} \approx 10^{-2} \div 10^{-1}$ ат. % обеспечиваются самые стабильные значения электролюминесцентных параметров.

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