Current-Voltage Characteristic of Bridgeman-Stockbarger $InGaSe_2$ thin films

ABSTRACT

The monocrystals $InGaSe_2$ were grown by Bridgeman-Stockbarger **method**. The current-voltage characteristic was studied in the rectangular form samples of sizes $7x1x1mm^3$. In and Cu served as contacts. The current supplying the ends of rectangular samples is oriented so that the current flows through the sample along the axis $\vec{c}$ of the monocrystal $InGaSe_2$. The current-voltage characteristic was investigated on direct current in static mode. Investigations of luminescence properties of the compound $InGaSe_2$ were carried out by means of spectrofluormeter Cary Eslipse, the production of the firm Varian. Statistical current-voltage characteristic of $InGaSe_2$ at different temperatures, temperature change of samples in the domain of negative incremental resistance, dependence of threshold voltage on temperature were studied. It was revealed that the given phase possesses switching properties, with memory and with decreasing the temperature, the value of the threshold voltage increases, and as a result, the S-shaped characteristic becomes strongly-pronounced. Change of the threshold voltage due to temperature change was analyzed. The spectrum of fluorescence of the compound $InGaSe_2$ in the interval of wavelength 300-600nm was studied, and it was revealed that given material is widely used in multifunctional electronic devices.

Keywords: *switching, X-ray analysis, thin films, S-shaped characteristic, threshold voltage, chain structure, fluorescence spectrum, $InGaSe_2$ compounds.*

1. INTRODUCTION

In [1] the ternary compounds $A^{III}B^{III}C_2{}^{VI}$ were intensively studied. These compounds have not lost their urgency up today owing to their unique physical properties and practical application. The above-mentioned compounds and their triple analogues $A^{III}B^{III}C_2{}^{VI}$ belong to the group of chain-layered crystals [1-3]. These compounds occupy a special place among high anisotropy crystal structure compounds. In references, there exist many papers devoted to structural, physical-chemical , electro-physical, photoelectrical and other properties of triple compounds as $A^{III}B^{III}C_2{}^{VI}$ [4-6]. In particular, along with investigations of physical properties, the energy-band structures, optic functions were calculated effective mass of electrons and holes were determined and by the researchers of current-voltage characteristics of compounds as $A^{III}B^{III}C_2{}^{VI}$ it was revealed that these compounds possess switching properties with memory[7]. In references there are numerous works development to current-voltage characteristics (current-voltage characteristic) of semiconductor compounds and solid solutions of above mentioned type, and also to search of new materials with more qualitative phyisical parameters [8,9]. There are also some informations on investigation of triple compound $InGaSe_2$, in particular, electro-physical, thermo-physical properties were investigated, the energy-band structure and optic functions were calculated. But the properties including current-voltage characteristic of the compound $InGaSe_2$ were not studied enough.

Furthermore, for studying the properties of these samples, influencing on measurable parameters, the highly sensitive fluorescence method is used. The luminescence spectra of semi-conductors give valuable information of energy-band structure and electron properties. They are widely used in investigation of optic properties of semi-conducting nanoparticles. The goal of the paper is to study the current-voltagecharacteristics and spectra of fluorescence of the compound $InGaSe_2$.

2. METHODS OF CALCULATION

For the synthesis of $InGaSe_2$ the elements with the following purity were used: In – especially pure, Ga – 99,996 and Se – SP(ultrapure). The ampoules were cleaned by mixture HF with distilled water. After chemical cleaning the ampoules evacuated to 0,0133 Pa were located into a furnace at 1000℃ for 24 hours then cooled to room temperature and were filled with highly cleaned elements. For synthesis of $InGaSe_2$ in order to decrease the explosion risky, the amploues the mixture was slowly (with velocity 0,5 deg/min) heated from room temperature to 200℃. Then temperature was increase d te 950℃ and for homogenization of the alloy it was hold at this temperature during 48 hours. Then the crucible was slowly with velocity 0,6 mm/hour cooled by moving from warm zone to cold one at 350℃, was hold during 8 hours and cooled to room temperature at temperature 970℃ .

The current-voltage characteristics of $InGaSe_2$ was studied on rectangular form samples of size $7x1x1mm^3$. In and Cu served as contacts. The contacts were verified by four-point method, by sequential measurement of resistance in samples. The current supplying the ends of rectangular samples is directed so that the current through the sample flows along the axis $\vec{c}$ of the monocrystal current- voltage characteristic were investigated in direct current according to standard technique described in [11].

Investigations of luminescent properties of the compound $InGaSe_2$ were carried out by means of spectrofluorimeter Cary Eclipse the production of the firm Varian. Principal device and working elements of the device are given in the scheme (fig.1)

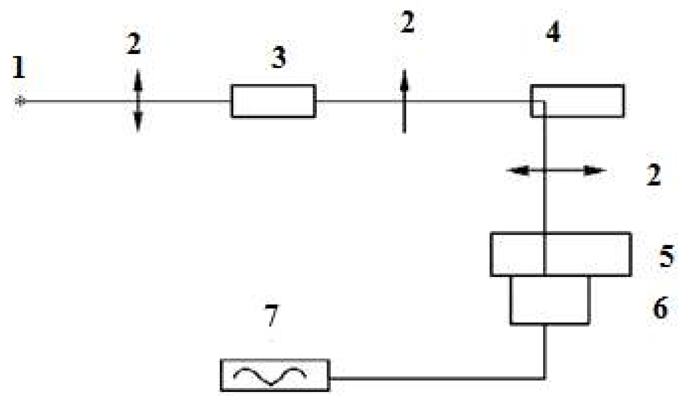

Fig. 1. Scheme the device spectrofluorimeter: 1 - source; 2 - lenses; 3 - excitation monochromator; 4 - ditch to place the sample; 5 - monochromator for emitting light; 6 - photomultiplier; 7 - recording device

As a radiation source used a xenon lamp working in impulse condition with width of impulse 2 mcs and power 75 kWatt. Both monochromotors possess high velocity scanning abilities. It means that 3 sec. suffices for defnition of total spectrum. By means of spectrofluorimeter Cary Eclipse af the range of wavelength 200-900 nm one can observe the fluorescence and phosphorescence phenomena. Changing the width of transmission slot from 1,5 to 20 nm one can manage the intensity of the signal going in optic system. The measurements are conducted in automated condition. Auxiliary proqrams admit to choose various measurement conditions
and to control working elements.

3. RESULTS AND DISCUSSION

With increasing the voltage I(U) the characteristic damped and was strictly nonlinear and of S-shaped form it was revealed that in ohmic area, temperature remains constant, and in the area of negative differential drag increases to temperature T, usually greater than ambient temperature.

The current-voltage characteristic of $InGaSe_2$ was studied af different temperatures at the temperature range 80-300 K (fig.2). As it follows, at lower voltages I(U) dependen is linear and the contact is ohmic.

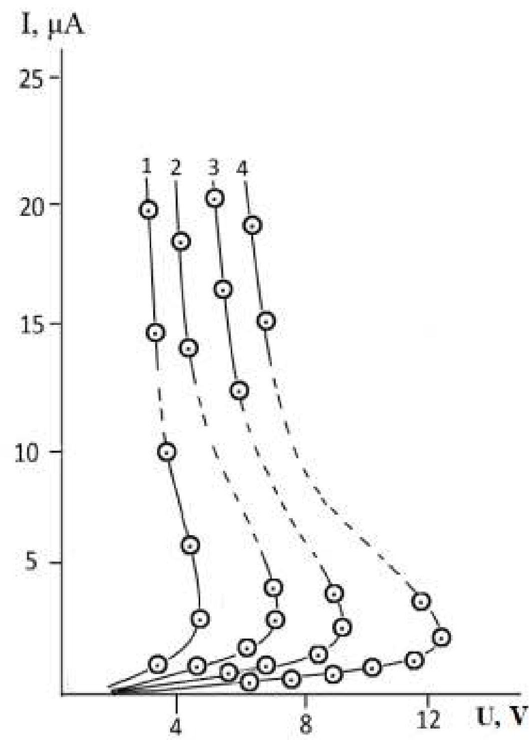

Fig. 2. The current-voltage characteristics of $InGaSe_2$ at different temperatures 1-300 K; 2-250 K; 3-150 K; 4-80 K.

The results of investigations of current-voltage characteristic of the compound $InGaSe_2$ at statical condition at different temperatures are given in fig.2.

S-shaped characteristic in the area of high currents with the best expressed area of neqative drag later on becomes critical current (threshold current). A part of negative differential drag on the curve of the device is strongly expressed at lower ambient temperatures. As is seen from the curve, the passage from lower to higher electroconductions af lower temperatures is stepwise. In the area of neqative differential drag I(U) of the curve twe measured the samples temperature at each point by means of thermoelement attached to the sample. To this end thermally insulated and antielectric paste was used. The results are shown in fig.3.

The experiment showed that the samples temperature is higher than ambient temperature. Dependece of threshold voltage on sample's temperature was shown in fig.4.

Analysis of the obtained results shows that the area controlled by current is corrected with increasing the sample's temperature. According to the obtained data(fig.2), there happens migration of threshold voltage to higher values with decreasing ambient temperature and weak appearance of the area of negative differential drag on current-voltage characteristic because of ambient temperature increase.

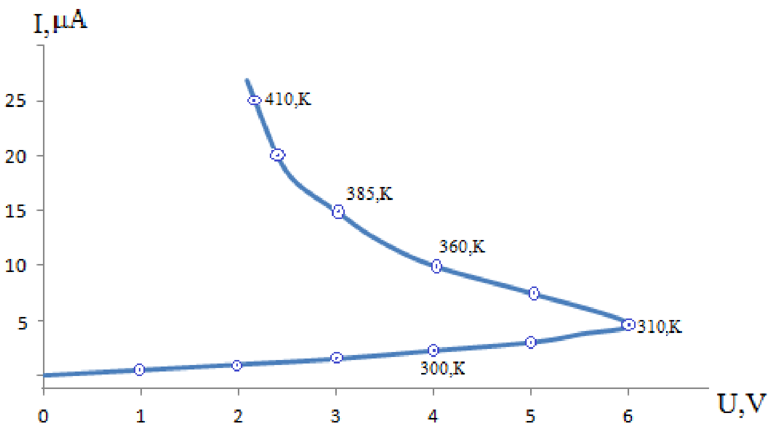

Fig. 3. The current-voltage characteristic of $InGaSe_2$ (chart showing temperature changes in the negative area)

Note that the OC on current- voltage characteristic diode on the basis of $InGaSe_2$ may by formed only in availability of internal positive feedback. For a diode with S-shaped current-voltagecharacteristic, positive feedback in current is formed.

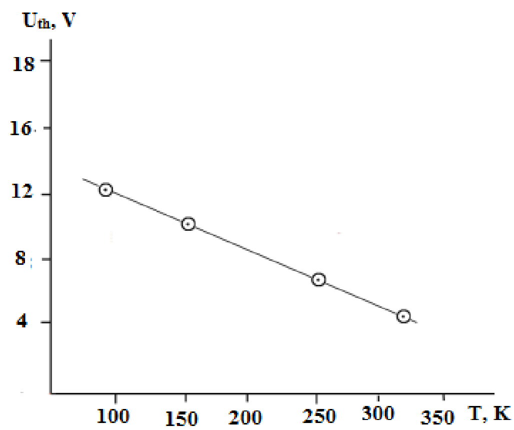

Fig. 4. The dependence of the threshold voltage of the temperature for $InGaSe_2$

This means that any change of current should cause its further change in the same direction. Analyze the conditions of appearance of negative differential drag in $InGaSe_2$ with p-n passage junction. Such a diode way by represented in the form of sequentially switched electrone-hole junction and drag of highohmic basic area of the samples. In this case, the voltage U applied to the diode on the basis of the compound $InGaSe_2$ consists of voltage drop on p-n junction U_0 and on the thickness of the base U_T :

$$U=U_0+U_T \qquad (1)$$

Moreover

$$U_T = IR_T = \frac{I}{\sigma_T}; U_0 = \left(\frac{\beta kT}{q}\right) \ln\left(\frac{I}{I_0}+1\right);$$

where I_0 is a pre-exponential factor; β is a coefficient accepting the values between 1 and 2 depending on parameters of p-n junction and flowing current, R_T and σ_T is drag and conductance of the thickness of the base of the diode: $\sigma_T=\sigma_0+\sigma^*$ (σ_0 is the conductance of the base in the absence of injection, σ^* is additional conductance stipulated by injection and growing by increasing the current through the sample).

In the case when the material is homogeneous and doesn't contain the trapping cite, concentration of injected carriers of current linearly increase with increasing the current through the p-n junction. In availability of traps or in homogeneities the conductance in basic area, with change of the flowing current will change not by linear but by more complicated law that may be expressed in the form

$$\sigma_T = \sigma_0 \left[1 + \left(\frac{I}{I_1} \right)^{\gamma} \right],$$

Where I_1 is a constant value expressed by electro physical parameters of the base material. In this case, expression (1) takes the form

$$U = \frac{Id}{\sigma_0 \left[1 + \left(\frac{I}{I_1} \right)^{\gamma} \right]} + \frac{\beta kT}{q} \ln\left(\frac{I}{I_0} + 1 \right). \qquad (2)$$

By differentiating equation (2), we find differential drag of the direct branch of the considered diode:

$$\frac{dU}{dI} = \frac{1 + \left(\frac{I}{I_1} \right)^{\gamma} (1-\gamma)}{\sigma_0 \left[1 + \left(\frac{I}{I_1} \right)^{\gamma} \right]^2} d + \frac{\beta kT}{q(I+I_0)}.$$

When passing from the positive differential drag to negative one, $\frac{dU}{dI} = 0$. Therefore, the condition of existence of the negative drag may be written in the form

$$1 + \left(\frac{I}{I_1} \right)^{\gamma} (1-\gamma) + \frac{\beta kT}{qd} \frac{\sigma_0 \left[(1 + I/I_0)^{\gamma} \right]}{I + I_0} = 0.$$

This condition may be fulfilled only for $\gamma>1$. At linear or weaker dependence of the conductance of the base through p-n junction, i.e. for $\gamma \le 1$, the area OC on current- voltage characteristic is absent. Thus, it is seen from the cited example that change of conductance of the base only at the expense of injection doesn't reduce appearance of OC area on current- voltage characteristic of the diode. There should exist one more reason of change of conductance.

At small voltages, the drag of the base is great and almost all applied voltage drop on a diode. With increasing voltage, the injected carrier's concentration in the base increases and its drag drops. However, for $\gamma \le 1$, R_T decreases no faster than drag of p-n junction. Therefore, with increasing current the voltage field increases. The current is a monotone function of the applied voltage. If $\gamma>1$, the conductance of the thickness increases faster than conductance of p-n junction. This reduces to decrease in the proportion of the voltage drop on the base and this reduces to strengthening and new redistribution of voltage between the base and p-n junction. This is a positive feedback necessary for appearance of negative drag. Thus existence of additional base area accompanying the injection of mechanism of increasing of conductance is the necessary condition for emergence of negative drag in $InGaSe_2$. For understanding the nature of negative drag, it is necessary to consider namely these physical phenomena additional to injection.

Current-voltage characteristic with long base (d>>L) and at the coefficient of injection of p-n junction equal to a unit may be approximately represented by the expression [10]:

$$I = \frac{kTch(d/L)}{2q\rho_0 L(b+1)} (e^{qU/ckT} - 1),$$

where, *L* is the length of diffusive shift at higher levels of injection; ρ_0 is the resistivity; *b* is the ratio mobility of electrods and holes; *d* is the thickness of the base area:

$$C = 2(b + ch\,d/L)/(b+1).$$

The constant *c* exponentially increases with increasing the ratio d/L. Therefore, total current very strongly depends on this ratio. If with increasing the level, the lifetime increases, this reduces to sharp increase in current. The carrier density on the base increases avalanche.

Injection of not the main carriers by p-n junction increases their lifetime in volume. For this reason the further reduction of the base drag that reduces to redistribution of voltage between the base and p-n junction happens. The share of voltage in p-n junction increases. As a result, there happens additional injection of carriers of current, further increase of lifetime etc. Such a process reduces to emergence of OC on current- voltage characteristic of the compound $InGaSe_2$.

In conclusion, it should be noted that the three-fold compound $InGaSe_2$ possessing switching properties with memory and its S-shaped current- voltage characteristic may be successfully used in creation of sensitive switches.

The results obtained by us is good consistent with the publisteed literature data[9,13].
The typical feature of the spectrum of fluorescence (CF) is high resolving ability accompanied by the processes connected with chemical structure of the sample, of the elements of the structure and other dynamic changes SF possesses rather short time range as after 10^{-8}sec. After light absorption, fluorescence begins. During this period of time all the processes on molecular level, nonradioactive energy transfers and exchange of charges and energies between the components find their reflection in spectra of fluorescence. Therefore SF are very convenient when observing the results of short dynamic processes, by studying statically composition and properties of the structure and also the processes that are revealed by means of light signal. The narrow stripes of luminescence found in the visible area depend on the sizes of semiconductor nanoparticles, and analyzing this dependence one can determine the influence (or effect) of the sizes of nanoparticles on optic and electric properties of nanocomposites.

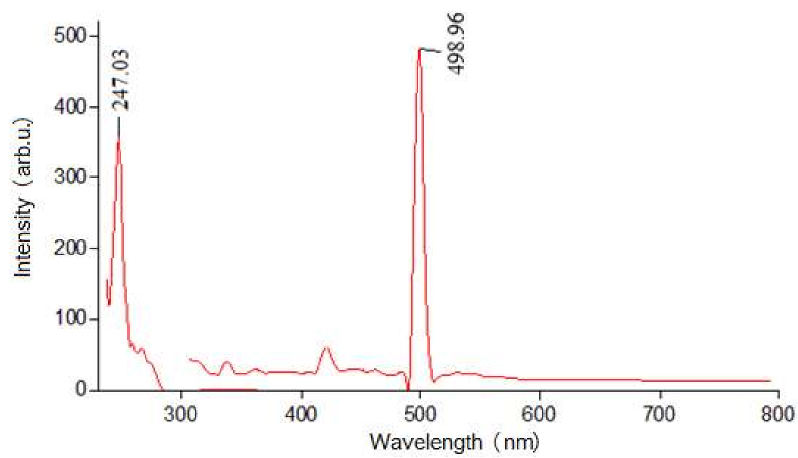

Fig. 5. The fluorescence spectrum of $InGaSe_2$

The results of investigations of the spectrum of fluorescence is represented in fig.5. The excitation spectrum of $InGaSe_2$ at wavelength 247.03 nm was shown. The spectra were recorded at the width of the slot 2.5 nm. As is seen, at wavelength 322.00; 415.97; 498.95 nm we observe the peaks of excitation spectra for $InGaSe_2$. The greatest peak holds at the excitation signal with wavelength 498.95 nm. Intensity of the peak inherent to the wavelength 498.95 nm is much more than intensity of peaks af 322 and 415.87 nm.

Thus, twe studied the spectra of fluerescence of the compound $InGaSe_2$ at the range of wavelength 300-600 nm, revealed that the given material may be widely used in multifunctional electronic devices[12].

4. Conclusion

Investigations of current-voltage characteristics of the three-fold compound $InGaSe_2$ in static mode showed that this compound possesses switching properties with memory. Experimental current-voltagecharacteristics of the compound $InGaSe_2$ are linear at lower, and nonlinear at higher current densities. The nonlinear mode (ODC – areas) has S-shaped form. Stable state of current- voltage characteristic and peculiarities of their ODC area way be interpreted by electronic – thermal mechanism. It was revealed that increase of heating of the inner part of the sample reduces to increase in high concentration of free carriers in this area because of semi-conductor character of $InGaSe_2$ and reduction of the value of the threshold voltage. With changing ambient temperature,the sizes of ohmic contact and from $InGaSe_2$ one can obtain switches with required physical parameters. The spectrum of fluorescence of the compound $InGaSe_2$ was studied, and it was revealed that the present phase possesses luminescence properties at wavelength 498.95 nm and may be widely used in multifunctional electronic devices. The results obtained by us is good consistent with the publisteed literature data[14].

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