Electrical and photoelectric properties of crystal $InGaTe_2$

ABSTRACT

Electrconduction, photoconduction and the curves of relaxation of noteguilibrium photoconduction in the crystals $InGaTe_2$ under collinear and laser light were carried out experimentally. It is shown that the optical absorption in $InGaTe_2$ is carried out by indirect and direct optical transitions, the band gap is accordingly 1,02eV and 1,42eV. Found that acceptor centers are with the depth of 0.203 eV and 0801 eV. At high levels optical excitation in $InGaTe_2$ observed two-photon absorption. It was found that heat non-eguilibrium photoconduction detected in the crystals $InGaTe_2$ under the first and second harmonic of radiation of Neodymium laser caused impurity, bipolar and two-photon photoconduction.

Keywords: compound İnGaTe2, indirect and direct optical transitions, non-linear optic properties, photoelectric properties

1. INTRODUCTION

Tellurides of complex semiconductor compounds of the class $A^{III}B^{III}C_2^{VI}$ are interest as a material for recieves of radiation. Radiation resistance and effect of radiation on electrical conductivity is intensively studied in compounds as $TlGa(In)Te_2(Se,S)$ [1-6]. The crystal $InGaTe_2$ being the representatives of the mentioned class of compounds, have not been studied enough compared with other compounds. The power zonal chart was calculated theoretically by the pseudopotential method [7] and disperion curves of high freguency dielectric permittivity and temperature dependences of differetial termo-emf [8,9] were studied. The obtained date are not sufficient for making general idea on physical properties of monocrystal $InGaTe_2$ and as well as for specifying values of the fundamental parameters.

In this paper we cite experimental results of the investigation of electroconductivity and photoconductivity of $InGaTe_2$ width range of temperature of different values of optic excitation.
As is known, at higher degrees of optic excitation a sufficiently high consentration noneguilibrium carrier of current is achieved and this involves emergency of certain qualitatively new features of semoconductors as non-linear optic and photoelectric properties, saturation effects at absobtion of light, degeneration of carriers, etc. Application of laser radiation with the reconstructed wavelenght and with different excitation intensities allow simultaneously detect impurity, characteristic ann also nonlinear photoconductivity if they hold in the crystals under consideration. Experimental investigation of generation recombination processes in $InGaTe_2$ laser radiation is of great interest because of their application in optoelectronics.

2. METHODS OF CALCULATION

The monocrystal $InGaTe_2$ grown up by the Bridgeman method process tetragonal syngony of crystal structure with optical symmetry $D_{4h}^{18}(14\,mcm)$ with lattice parameter $a = 8{,}463\overset{0}{A}$ and $c = 6{,}981\overset{0}{A}$ the samples for measurements were cut out from an ingot in the form of a rectangle with the sizes 6×3×1 mm^3 and with such an orientation that the lighting happens in the direction parallel to the crystallography axes "c". The monocrytal $InGaTe_2$ possesed p-type conductivity and depending on the mode of a method of cultivation of a crystal, specific resistand varied at the range ($1·10^3 ÷ 1·10^6$) Ом·см. A silver paste is used as ohmic contact . Photoconductivity of the crystal $InGaTe_2$ was investigated by collinear source of light at stationary mode, by the method of modultion of light intensity at freguency at 47kHz. At higher level of optic excitation, the pulse laser Nd: YAG with built in generators of the second and third harmonic intended for generation of radiation with wavelength 1064, 532, 355nm with reconstructed wavelength at the range from 410-710nm was used as radiation source the impulse duration $\Delta t = 1·10^{-8}$sec: maximum power ~12 MVt/sm^2. Intensity of laser radiation was measured (changed) by means of calibrated neutral filters. In the work nonstationary digital system including memorable oscillograph and computer system was used. The experimental technigue is similar to one described in the paper [10].

3. RESULTS AND DISCUSSION

Dependence of electrical conductivity σ on temperature T is represented in figure1. As is seen from the figure, in the dependence $\lg\sigma \sim 10^3/T$ one can isolate two rectilinear areas belonging to generation of charge carrier with electronic transitions $E_1 = 0{,}203$ эВ and $E_2 = 0{,}801$ eV. At wide interval of temperature 100-500 K the samples have p-type conductivity, we can note that temperature dependence of σ is stimulated by thermal ionization of acceptor centers and activation of electrones from the filled acceptor level. It should be noted that the character of temperature dependence of electrical conductivity in different samples was identical ranges.

Photoconductivity of the crystal $InGaTe_2$ were investigated at interval of temperature 132–373K (fig 2). Photocurrent range cover a very wide range of energy from 1,2eV to 2,6eV. Photosensitivity of the crystals steadily increases according to temperature increase. As is seen from the figure the long-wave edge of ranges of photocurrent don`t subject to Moss criterion. The character optic transition in $InGaTe_2$ is seen from dependence $I_{\phi}(h\nu)$. In the range $I_{\phi}^{1/2} \sim h\nu$ experimental points in the area of long-wave edge lie on the same line that indicates the availability of indirect transition with energy 1,02eV (fig.2a). Determination of the width of the band structure is of semiconductors by this method is quite justified . As absorption coefficient for indirect transitions is much less than for direct transitions, its definition from the absorption range is not really a simple task. Many authors use for that a more sensitive method as the photoconductivity method.

It is known that the absorption coefficient for indirect transition for eguals

$$\alpha \sim (h\nu - E_g^{\text{in}} \pm E_p)^2 \quad (1),$$

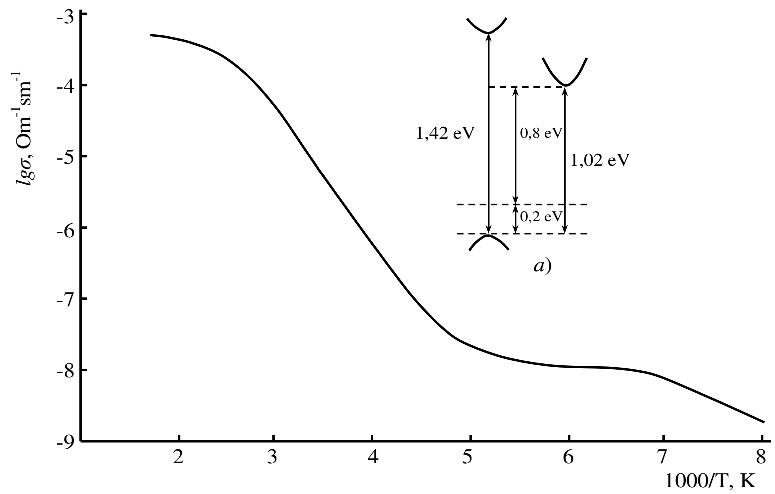

Fig. 1. The dependence of the electrical conductivity of crystal $InGaTe_2$ **on the temperature. a) - the energy diagram** $InGaTe_2$

where hv- is the energy of guantum, E_g^{in} - is the width of the band structure, E_p is the energy of phonon participating in indirect optic transitions. As the photoconductivity size $I_F^{1/2} \sim \alpha^{1/2}$, then removing the dependence of I_F on energy $h\nu$ in the weak abroption zone (at energies less than the direct zone) one can determine the width of the band structure of indirect transitions.

Maximum photosensitivity of the crystal $InGaTe_2$ is achieved at 1,42eV. High photoconductivity in the fundamental absorption area testified on availability of direct optical transitions in the crystal. Therefore, we can suppose that, in addiction to indirect transition in the monocrystal $InGaTe_2$, the direct optical transition with the energy 1,42eV stipulated generation of noneguilibrium charge carriers.

Temerature dependence of photocurrent in $InGaTe_2$ is represented in fig.3. As is seen from the figure, temperature clearing of photocurrent happens at higher than 373K. The range of photocurrent

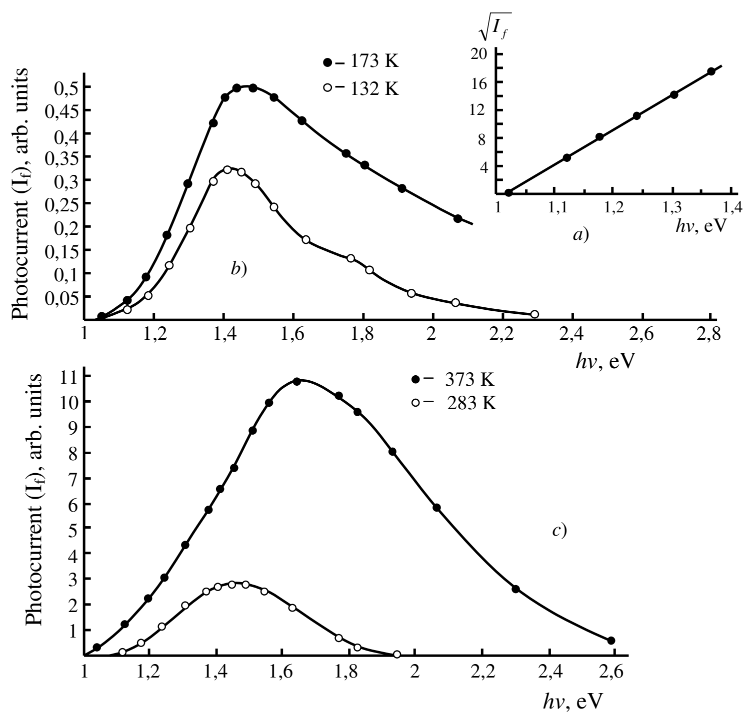

Fig. 2. Photoconductivity spectra of crystal $InGaTe_2$ **with different temperatures.**

remined in the temperature clearing area has a sharp edge in the area of long-wave absorption and maximum of the range is at 1,42eV . It is clear that in temperature clearing area of photocurrent, the noneguilibrium charge carriers generated by indirect transitions with energy 1,02eV direct ones with energy 1,42eV make basic contribution in in photoconductivity. Based on experimental results of investigation of temperature dependence of electrical conductivity and ranges of photocurrent of crystal $InGaTe_2$ their power zonal chart represented in fig.1a is constructed.

In fig.4 dependences of amplitude values of oneguilibrium photoconductivity of crystal $InGaTe_2$ on intensity of laser radiation are represented.

As is seen from the figure, we observe considerable variety in the form of lux-Ampere charasteristics (LAC). In the case of excitement of low nuclear samples by the impulses of laser light with the wavelength of $\lambda = 1{,}06$ mkm ($\hbar\omega = 1{,}17\text{eV}$), LAC at first has linear dependence, and at higher intensities the saturation is observed (curve1). In high nuclear (pure) crystals, we observe sguare dependent (curve 2). The experiments carried out in high- nuclear samples of second harmonic Nd:YAG laser , ($\lambda = 0{,}53$ mkm, $\hbar\omega = 2{,}34\text{eV}$) has the dependence $\Delta\sigma \sim \mathbf{I}^{0,5}$ (curve3).

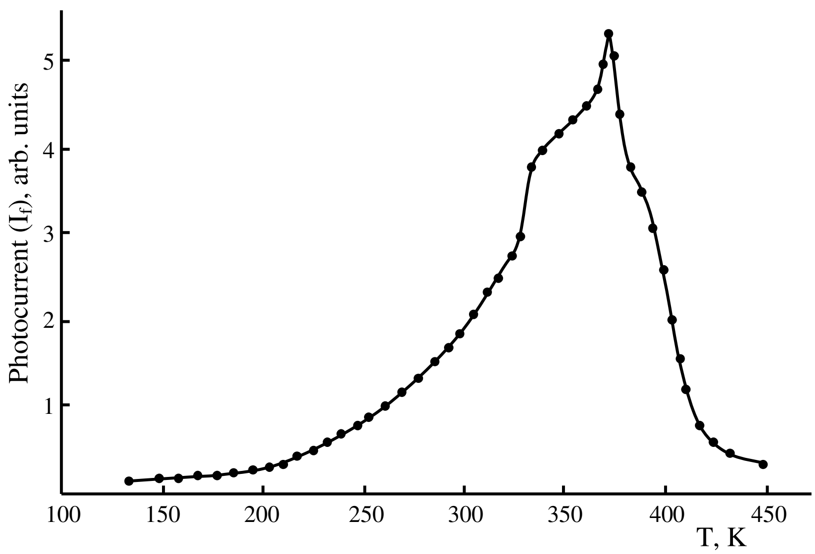

Fig. 3. Dependence of the photocurrent on the temperature in $InGaTe_2$

The curves of relaxation of noneguilibrium photoconductivity for two groups of samples of excitation of the first (curve a,b) and second harmonic (curve c) Nd:YAG of the laser are given in figure5 . As is seen from the figure for low-nuclear samples, relaxation time is independent of light i tensity, while for high-nuclear samples we observe its reduction with increase in power of a rating.

Before we pass to discussion of experimental results, it should be noted that by exciting semiconductors by ordinary light sources with the energy of guantum less than the width of the band structure $(\hbar\omega < E_g)$ we observe impurity photoconduction. In the case of impurity photoconductivity the Lux-amper characteristic (LAC) ofphotoconductivity is of linear character and is sated with growth of intensity of exciting light [11]. The last circumstance is stipulated by the fact that at rather great light intensities practically all carriers from impurity centers may be transfered by the light to the zone. Such a saturation of LAC is very seldom is observed at ordinarily used light intensities.

The obtained experimental results justity that in low-nuclear crystal $InGaTe_2$ (E_g =1,42eV) excitement by laser radiation with energy of quantum $\hbar\omega = 1{,}17\text{eV}$ the impurity photoconduction holds (fig.4, curve 1).

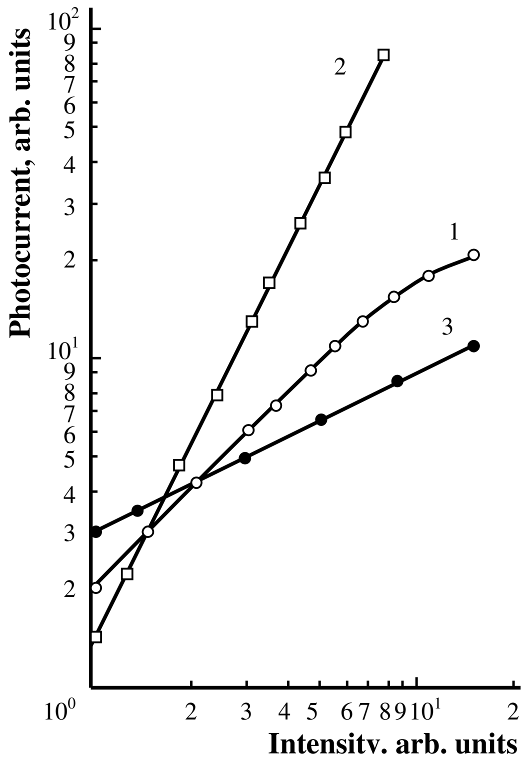

Fig.4. The dependence of the photocurrent on the laser intensity in $InGaTe_2$: 1, 2-low-resistance and high-resistance samples excited by the first harmonic of the laser, 3- high-resistance samples excited by the second harmonic of the laser.

On the other hand, at excitement of the semiconductor by laser light with power of photon less than the width of the band structure, the multiphoton light absorption in semiconductors corresponding to birth or the couple electron-hole at simultaneous absorption of several photon [12,13] is also essential. There exist zone methods for investigating multiguantum transitions: optical absorption, investigation of absorption of IK-light or extreme high-frequency radiation by noneguilibrium current carriers excited by light source of high intensity, re combinational radiation photoconduction. All mentioned methods are based directly or indirectly on the known relations between concentrations of nonequilibrium current carriers Δn generated at absorption of n – photos in elementary act, by the light absorption coefficient α, probability of multiquantum transition of $W^{(n}$ and intensity of exciting light I:

$$\alpha^n \sim I_0^{n-1}, \quad W^{(n)} \sim \Delta n \sim I^{(n)} \qquad (2)$$

In particular, at two-photon absorption $\alpha^2 \sim I_0$.

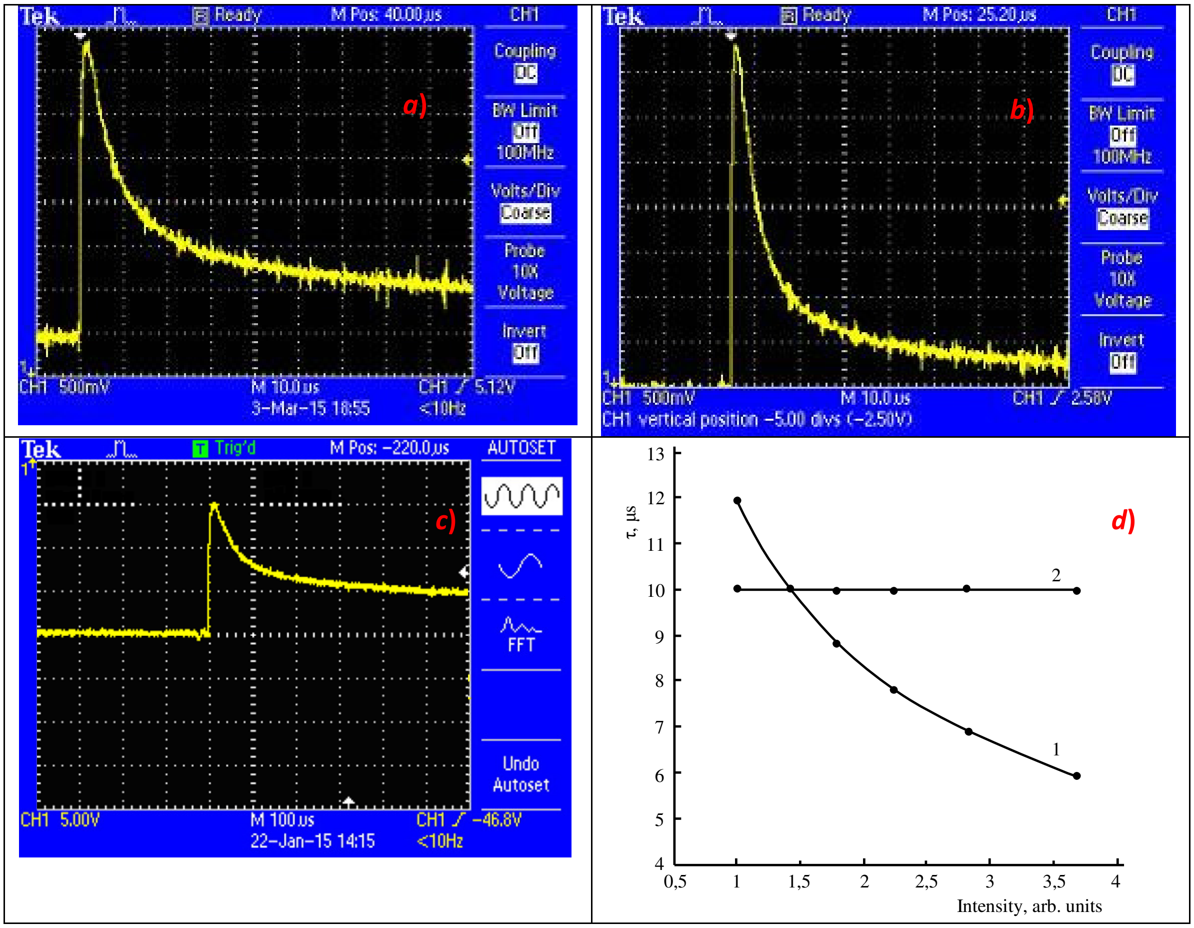

Fig.5. The curve of relaxation of nonequilibrium photoconduction in $InGaTe_2$ at laser excitation: low- nuclear (a) and high – nuclear (b) sample at excitement light with power of quantum – $\hbar\omega = 1{,}17$ eV, c) high – nuclear sample at excitement light with power of γ quantum $\hbar\omega = 2{,}34$ eV, d) dependence of relaxation time on intensity of excitement for high – nuclear (curve 1) and low – nuclear (curve 2) samples at excitement by laser radiation, with power of quantum $\hbar\omega = 1{,}17$ eV.

Investigation of nonequilibrium photoconduction in semiconductor in the most direct method for registrating the multiphoton absorption process [14-16]. The considerable advantage of the method is that, here the crystal width has no principal roll and therefore the most perfect crystals of small sizes may be used the two – photon photoconduction may be detected, and consequently, the two – photon absorption coefficient may be measured at intensity considerably less than the ones at which the two – point absorption begins two occur in experiments on transmission therefore, the two – photon photoconduction, may be a very useful method for detection of two – photon transition and a convenient way for measuring the two- photon absorption coefficient supplementing the method of different measurement on transmission.

As is known, photoconduction in semiconductors is determined by the formula

$$\Delta\sigma = e\mu\alpha\beta I_0\tau \qquad (3)$$

Where, e- is the elementary charge, μ -is the mobility of carriers, a is the absorption coefficient, β- is the quantum fiend, I_0-is light intensity, τ- is the lifetime of nonequilibrium carriers.

At one – photon absorption the absorption coefficient is independent of light intensity, so $\Delta\sigma \sim I_0$. At two – photon absorption is $\alpha^2 \sim I_0$, therefore $\Delta\sigma \sim \alpha^2 \cdot I_0 \sim I_0^2$. Existed of square depended in Lav- Ampere characteristic of photoconduction testifies on two-photon photoconduction in crystal $InGaTe_2$ under laser radiation. Comparison of the curves of relaxation of impurity and two – photon photoconduction (Fig.5 curves a, b) also shows this . At two- photon excitation, the relaxation time is much less (~2 times) in comparison with impurity photoconduction, and it depends on excitation level. By increasing the excitation intensity, the relaxation time decreases (fig. 5 d. curve 1) and here with the slow component of relaxation curve undergoes considerable charge. In the case of impurity photoconduction, the relaxation time is independent on excitation intensity (fig. 5 d. curve 2)

It should be noted that at excitation of crystal $InGaTe_2$ by the second harmonic of neodymium laser, the power of the guantum ($\hbar\omega = 2{,}34$ эВ) considerably exceeds the width of the band structure of the crystal (E_g=1,42эВ). Therefore, photoconduction is of bipolar character. In this case, we observe square recombination that leads to the dependence $\Delta\sigma(\Delta n) \sim \sqrt{I_0}$. Experimental results confirm such dependence $\Delta\sigma$ to I_0 (fig.4, curve 3).

4. CONCLUSION

In monocrstal p-$InGaTe_2$ grown up by Bridgeman method at wide temperature range (200–500K), electroconduction is stipulated by ionization deionization of acceptor centers forming energy level with depth of occurance 0,2eV and 0,8eV in the band structure of crystal. The interzonal optical transitions in monocrystals $InGaTe_2$ is realized by indirect ($E_g^{нп}$=1,02эВ) and direct ($E_g^{п}$=1,42эВ) transitions. In the range temperature 130-373K, with growth of temperature , the photosensitivity steadily increases. In photogeneration of noneguilibrium current carriers by laser radiation, the mechanism of one-photon and two-photon absorption of guantum is detected.

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