Electrical and photoelectric properties of crystal $InGaTe_2$

ABSTRACT

The electroconductivity, photoconductivity and relaxation curves of the nonequilibrium photoconductivity in $InGaTe_2$ crystals under incandescent lamp light sources and laser light have been experimentally investigated. It is shown that the optical absorption in the $InGaTe_2$ due to indirect and direct optical transitions, the band gap of 1.02 eV and 1.42 eV, respectively. Acceptor centers are found, at a depth of 0.203 eV and 0.801 eV. At high levels optical excitation in $InGaTe_2$ observed two-photon absorption. It was found that the nonequilibrium photoconductivity observed in $InGaTe_2$ crystals under the action of 1st and 2nd harmonic of neodymium laser radiation, due to the impurity, bipolar and the two-photon photoconductivity

Keywords: compound İnGaTe$_2$, indirect and direct optical transitions, non-linear optic properties, photoelectric properties

1. INTRODUCTION

Tellurides complex semiconductor compounds of the class $A^{III}B^{III}C_2^{VI}$ are of interest as materials for radiation detectors. Radiation resistance and effect of radiation on electrical conductivity is intensively studied in compounds as $TlGa\,(In)Te_2\,(Se,S)$ [1-6]. $InGaTe_2$ crystals in comparison with other compounds $A^{III}B^{III}C_2^{VI}$ little studied. The power zonal chart was calculated theoretically by the pseudopotential method [7] and dispersion curves of high freguency dielectric permittivity and temperature dependences of differential termo-emf [8,9] were studied. The obtained date are not sufficient for making general idea on physical properties of $InGaTe_2$ monocrystals and as well as for specifying values of the fundamental parameters.

In this paper we report the results of the investigation of an experimental study of electroconductivity, photoconductivity in $InGaTe_2$ crystals wide range of temperatures and at different levels of optical excitation.

As is known, at higher degrees of optic excitation a sufficiently high concentration nonequilibrium carrier of current is achieved and this involves emergency of certain qualitatively new features of semiconductors as non-linear optic and photoelectric properties, saturation effects at absorption of light, etc. The use of laser radiation with tunable wavelength and with different excitation intensities can simultaneously detect impurity, its own as well as nonlinear photoconductivity, if any, are in the investigated crystals.

Experimental study of the generation-recombination processes in $InGaTe_2$ crystals by laser radiation is of particular interest due of the possibility of their application in optoelectronics.

2. METHODS OF CALCULATION

The single crystals $InGaTe_2$ were grown by the Bridgeman method have tetragonal crystal structure with spatial symmetry $D_{4h}^{18}(I4/mcm)$, with lattice parameters $a = 8{,}463\,\overset{0}{A}$ and $c = 6{,}981\,\overset{0}{A}$. The Bridgman method is a popular way of producing semiconductor crystals. The samples for measurements were cut out from an ingot in the form of a rectangle with the sizes of 6×3×1 mm^3 and with such an orientation that the lighting happens in the direction parallel to the crystallography axes "c". $InGaTe_2$ monocrystals had p-type conductivity and depending on the growing conditions had a resistivity in the range $(1\cdot10^3 \div 1\cdot10^6)$

Om·sm. A silver paste is used as ohmic contact. Photoconductivity of the $InGaTe_2$ crystals was investigated by collinear source of light at stationary mode, by the method of modulation of light intensity at freguency at 47kHz. Photoconductivity $InGaTe_2$ crystals investigated incandescent lamp light sources in a stationary regime, the method of modulating the intensity of light at a frequency of 47 kHz. 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, 355 nm with reconstructed wavelength at the range from 410-710 nm was used as radiation source the impulse duration $\Delta t = 1 \cdot 10^{-8}$ 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 Fig.1. 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 $E_1 = 0{,}203$ eV and $E_2 = 0{,}801$ eV. Given that samples have p-type conductivity, it should be noted that the temperature dependence of σ in the temperature range of 100-500 K, due to thermal ionization of acceptor centers and activation of filled electron acceptor. It should be noted that the temperature dependence of the electrical conductivity in different samples are identical.

Photoconductivity of $InGaTe_2$ crystals were investigated in the temperature range 132–373 K (Fig. 2). Photocurrent range cover a very wide range of energy from 1,2 eV to 2,6 eV. 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 $I_f(h\nu)$. In the range $I_f^{1/2} \sim h\nu$ experimental points in the area of long-wave edge lie on the same line that indicates the availability of indirect transition with energy 1,02 eV (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 equals

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

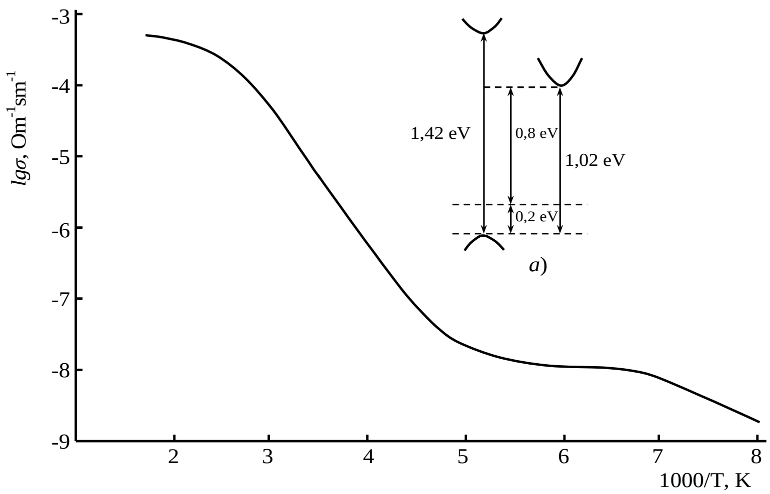

Fig. 1. The dependence of the electrical conductivity of crystal $InGaTe_2$ on the temperature. a) - the energy diagram $InGaTe_2$

where $h\nu$ - is the energy of quantum, E_g^{in} - is the width of the band structure, E_p -is the energy of the phonon that 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 $InGaTe_2$ crystals is achieved at 1,42 eV. 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 1,42 eV stipulated generation of nonequilibrium charge carriers.

Temperature dependence of photocurrent in $InGaTe_2$ is represented in Fig.3. As is seen from the Fig. 3,

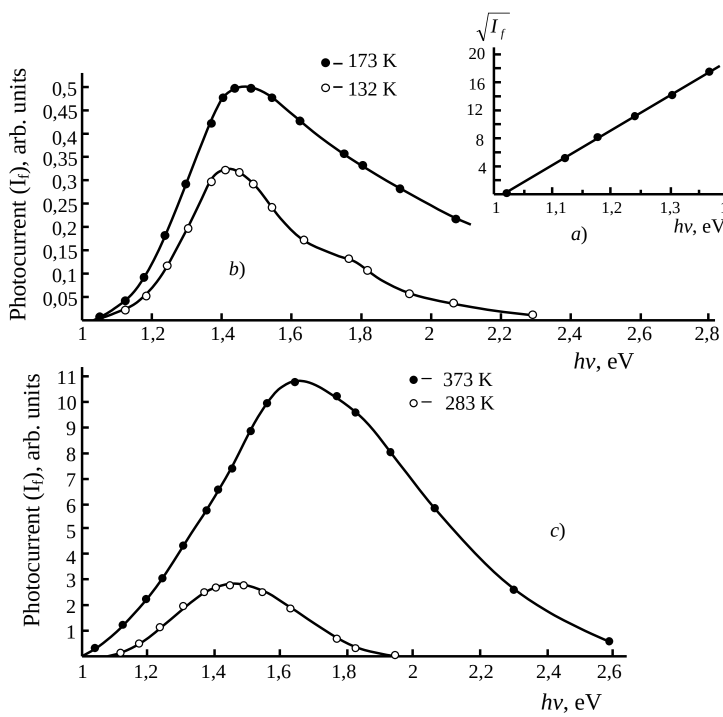

Fig. 2. Photocurrent spectra of $InGaTe_2$ crystals with different temperatures.

temperature clearing of photocurrent happens at higher than 373 K. The range of photocurrent remined in the temperature clearing area has a sharp edge in the area of long-wave absorption and maximum of the range is at 1,42 eV . It is clear that in the area of temperature quenching of photocurrent main contribution to the photoconductivity make nonequilibrium charge carriers generated as a result of direct optical transitions with an energy of 1.42 eV. Figure 1,a shows the energy band diagram $InGaTe_2$ crystals, built on the basis of experimental studies of the temperature dependence of the electroconductivity and photocurrent spectra.

In Fig.4 dependences of amplitude values of nonequilibrium photoconductivity of $InGaTe_2$ crystals on intensity of laser radiation are represented.

As is seen from the figure 4, 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 $\lambda = 1{,}06$ μm $(\hbar\omega = 1{,}17\text{eV})$, LAC at first has linear dependence, and at higher intensities the saturation has been observed (curve1). In high nuclear (pure) crystals, we observe square dependent (curve 2). The experiments carried out in high- nuclear samples of second harmonic Nd:YAG laser , ($\lambda = 0{,}53$μm, $\hbar\omega = 2{,}34\text{eV}$) has the dependence I_f **~$I^{0,5}$** (curve3).

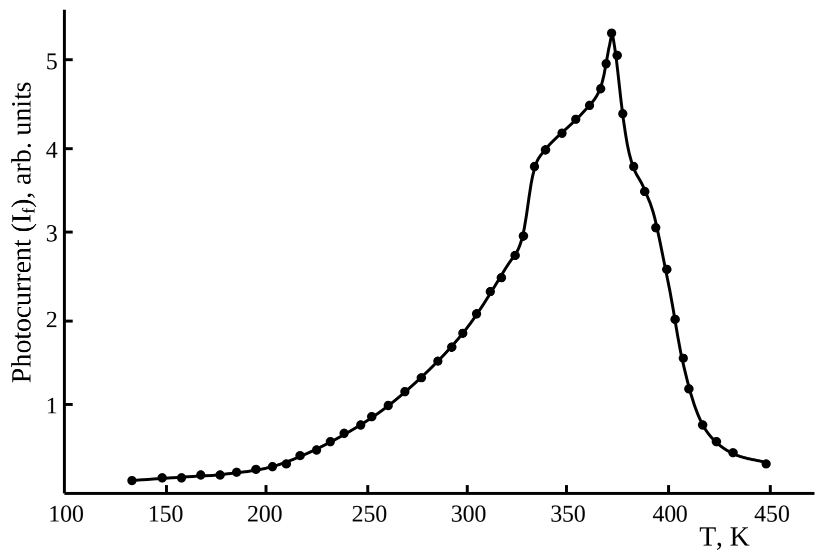

Fig. 3. Dependence of the photocurrent on the temperature in $InGaTe_2$

The curves of relaxation of nonequilibrium 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 Fig. 5 . As is seen from the figure for low-nuclear samples, relaxation time is independent of light intensity, while for high-nuclear samples we observe its reduction with increase in power of a rating.

Before, we discuss the experimental results, it should be noted that the excitation of semiconductors incandescent lamp light sources, with a photon energy less than the band gap $(\hbar\omega < E_g)$ observed photoconductivity due to impurity levels. In the case of impurity photoconductivity the Lux-Amper characteristic (LAC) photoconductivity is of linear character and is saturated 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. Our experimental results indicate that the low-resistivity $InGaTe_2$ crystals (Eg = 1,42eV) when excited by laser radiation with a photon energy of $\hbar\omega = 1{,}17\text{eV}$ impurity photoconductivity appears (Figure 4, curve 1).

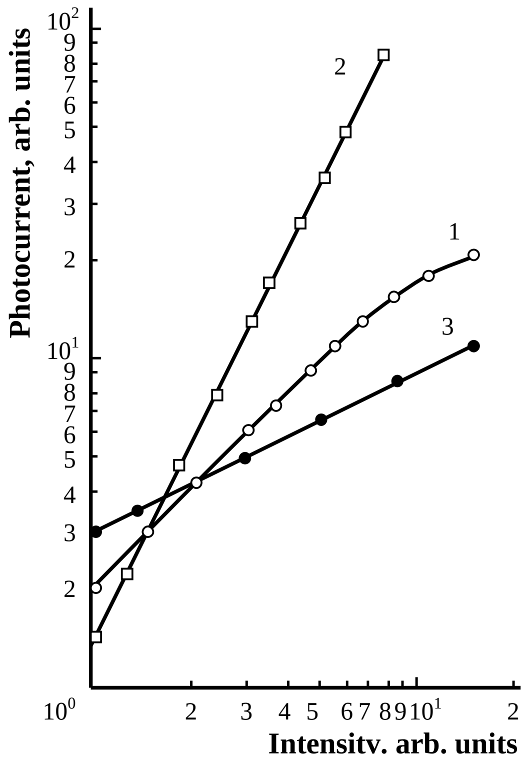

Fig.4. The dependence of the photocurrent on the laser intensity in $InGaTe_2$: 1, 2-low-resistance and high-resistance samples excited by the first harmonic of the laser, 3- high-resistance samples excited by the second harmonic of the laser.

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 multiquantum transitions: optical absorption, investigation of absorption of IR-light or extreme high-frequency radiation by nonequilibrium current carriers excited by light source of high intensity, recombination 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 – photons 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 $\alpha^2 \sim I_0$.

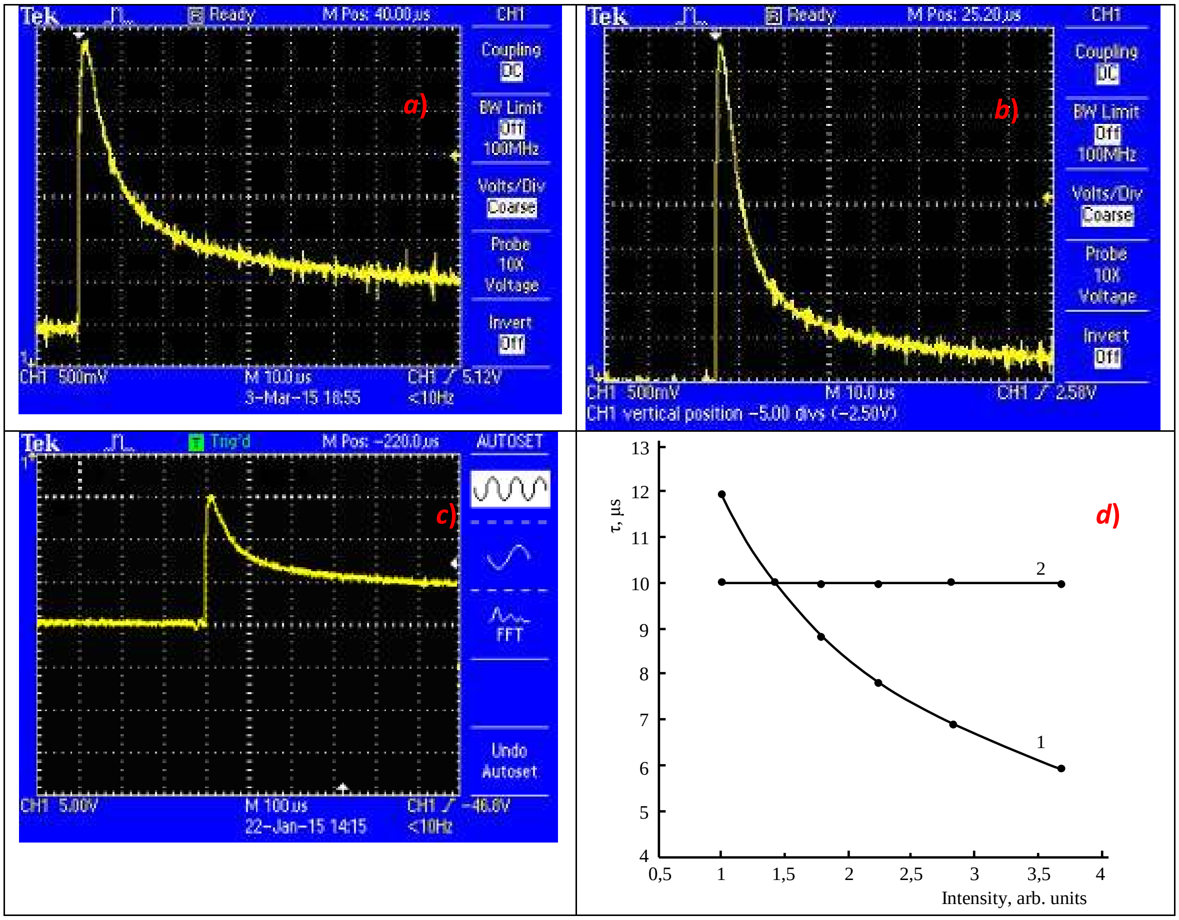

Fig.5. The curve of relaxation of nonequilibrium photoconduction in $InGaTe_2$ at laser excitation: low- nuclear (a) and high – nuclear (b) sample at excitement light with power of quantum – $\hbar\omega = 1{,}17$ eV, c) high – nuclear sample at excitement light with power of γ quantum $\hbar\omega =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

The most direct way of registering multiphoton absorption process is the study of nonequilibrium photoconductivity in semiconductors [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 Lux-Ampere characteristic of photoconduction testifies on two-photon photoconduction in $InGaTe_2$ crystals 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 (~ in 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 $InGaTe_2$ crystals by the second harmonic of neodymium laser, the power of the guantum ($\hbar\omega = 2{,}34$ eV) considerably exceeds the width of the band structure of the crystal (E_g=1,42 eV). 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 monocrystal *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 $InGaTe_2$ monocrystals 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 nonequilibrium current carriers by laser radiation, the mechanism of one-photon and two-photon absorption of quantum is detected.

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