https://doi.org/10.15407/ujpe66.3.260

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INFLUENCE OF PULSED 266-nm LASER RADIATION ON THE OPTICAL PROPERTIES OF CdTe AND $Cd_{0.9}Zn_{0.1}Te$ IN THE REGION OF THE FUNDAMENTAL OPTICAL TRANSITION

Optical research of the transmittance and reflectance spectra of p-CdTe(111) single crystals and $Cd_{0.9}Zn_{0.1}Te$ solid solution specimens in a spectral interval of (0.8÷1.7× 10^{-6} m before and after their laser irradiation at the wavelength λ = 266 nm to energy doses of 17.2–47.01 mJ/cm^2 has been carried out. The structural gettering, i.e. the absorption due to the presence of regions in semiconductors with a defect structure that can actively absorb point defects and bind impurities, was found to be the main mechanism of influence of a pulsed laser radiation on the optical properties of thin near-surface layers in the studied crystals.

Keywords: CdTe, CdZnTe, transmission, reflection, absorption, laser irradiation.

1. Introduction

Detecting systems that can be used to effectively reveal and distinguish dangerous objects and radionuclides mainly include semiconductor sensors, which are sensitive to ionizing radiation of various types. In this aspect, special attention is paid to the CdTe and $Cd_{1-x}Zn_xTe$ semiconductor materials because of their attractive physical characteristics. The atoms of chemical elements in those compounds have relatively large atomic numbers and substantial cross-sections for the photoelectric absorption. The compounds themselves possess rather large forbidden gap widths and, accordingly, high resistivity values. Those advantages make the indicated semiconductors promising for the development of nuclear detectors that can operate at room temperature without cooling.

According to numerous studies over the world, a lot of attempts were made to design tools for detecting and measuring X-rays and gamma radiation that are based on metal-Cd(Zn)Te diodes [1–5]. One of the manufacturing stages of those sensor structures includes the laser treatment of the material surface [6, 7]. When studying the effect of laser radiation on a functional materials used in electronics, two parameters are very important: the energy of laser radiation, E, and the magnitude of the fundamental optical transition in a semiconductor, E_0.

The study of the mechanisms of laser radiation action on material is of importance for the further progress of the laser technology. There are thermal and non-thermal mechanisms. The latter include the impact, photochemical, and plasma mechanisms of laser treatment. In most cases, the thermal mechanism of laser treatment is the main among other mechanisms of laser radiation action. The mechanisms based on the non-thermal action of pulsed laser radiation on semiconductor materials include the ionization, non-radiative and radiative recombination, and shock wave (structural gettering). The laser gettering technique makes it possible to avoid the emergence of additional defects in the crystal and to create the required configuration of a deformation field (local areas) [8–10].

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2. Experimental Results and Their Discussion

In this work, in order to elucidate the mechanisms of pulsed laser radiation action on thin near-surface layers in semiconductors, the transmittance and reflectance spectra were measured within a spectral interval of $(0.8\div1.7)\times10^{-6}$ m for p-CdTe(111) single crystals with the specific resistance $\rho=(2\div5)\times\times10^{9}$ Ω cm and the $\mathrm{Cd_{0.9}Zn_{0.1}Te}$ solid solution specimens with the specific resistance $\rho=(0.5\div3)\times\times10^{10}$ Ω cm. The measurements were performed before and after the laser irradiation.

The surface of researched specimens was firstly subjected to a mechanical treatment (cutting, grinding, polishing) followed by a chemical treatment (washing, etching, washing) and the drying of specimens. At the next stage, the specimens $5\times5\times0.5$ mm^3 in dimensions were subjected to the laser irradiation. Namely, the crystal surface was uniformly irradiated at room temperature ($T=300$ K) with the help of single pulses generated by an Nd : YAG laser ($\lambda=266$ nm, the pulse duration $\tau=5\div6$ ns, and the irradiation energy dose interval is 17.2–47.01 mJ/cm^2).

The optical phenomenon of electromagnetic wave reflection is quantitatively characterized by the energy reflection coefficient (reflectance) R. The reflection coefficient R_{01} at the normal incidence of radiation onto a semiinfinite isotropic medium (semiconductor, solid) is determinedz by the formula

$$R_{01}=\frac{(n-n_0)^2+\chi^2}{(n+n_0)^2+\chi^2},\qquad(1)$$

where n_0 and n are the refractive indices of the environment and the semiconductor, respectively, and χ is the extinction coefficient of the semiconductor.

The optical penetration depth of electromagnetic waves into a semiconductor material, d_{opt}, is equal to $1/\alpha$, where α is the absorption coefficient of the semiconductor. For semiconductors, if the photon energy is higher than the absorption edge, the α-magnitude has an order of 10^4–10^6 cm^{-1}. Therefore, the reflected electromagnetic wave can probe only a very thin layer near the specimen surface (about 1 μm or thinner).

From classical physics, it is known that the transmittance T of functional electronic materials at the light wavelength λ can be given in terms of the reflection coefficient R_{01}, the absorption index α, and the specimen thickness d by the formula

$$T=\frac{(1-R_{01})^2e^{-\alpha d}}{1-R_{01}{}^2e^{-\alpha d}}.\qquad(2)$$

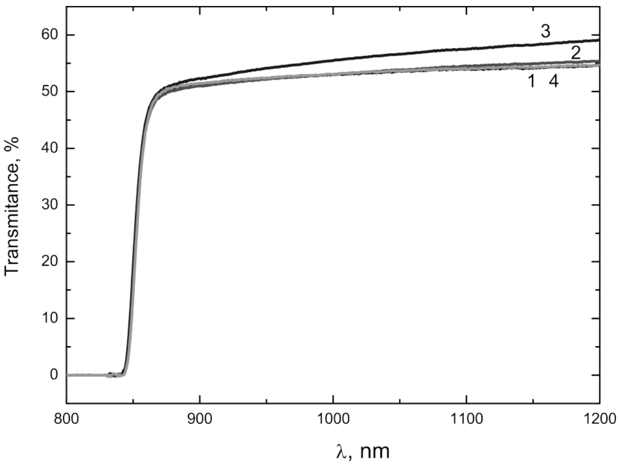

Fig. 1. Transmittance spectra of p-CdTe(111) single crystals: initial specimen (*1*) and specimens irradiated to energy doses of 17.2 (*2*), 30.84 (*3*), and 47.01 mJ/cm^2 (*4*). The laser radiation wavelength is 266 nm

In Fig. 1, the optical transmittance spectra $T(\lambda)$ of p-CdTe(111) single crystals with the resistivity $\rho=(2\div5)\times10^{9}$ Ω cm are shown for the initial specimen (curve *1*) and the specimens irradiated to energy doses of 17.2, 30.84, and 47.01 mJ/cm^2 (curves *2* to *4*, respectively). As we can see, the indicated laser treatment practically does not change the transmittance of p-CdTe(111) single crystals, i.e. the variations in the optical constants (the refractive index n, the extinction coefficient χ, and the absorption coefficient α) are not significant.

Figure 2 demonstrates the optical transmittance spectra $T(\lambda)$ of the solid solution $\mathrm{Cd_{0.9}Zn_{0.1}Te}$ with the resistivity $\rho=(0.5\div3)\times10^{9}$ Ω cm for the initial specimen (curve *1*) and the specimens irradiated to the same energy doses of 17.2, 30.84, and 47.01 mJ/cm^2 (curves *2* to *4*, respectively). Now, as one can see from the figure, if the solid solution $\mathrm{Cd_{0.9}Zn_{0.1}Te}$ is laser-irradiated to energy doses of 17.2 and 30.84 mJ/cm^2, the transmittance of this material is practically absent. But, at an energy dose of 47.01 mJ/cm^2, the transmittance becomes even higher in comparison with the transmittance of the initial specimen. Such a behavior of the trans-

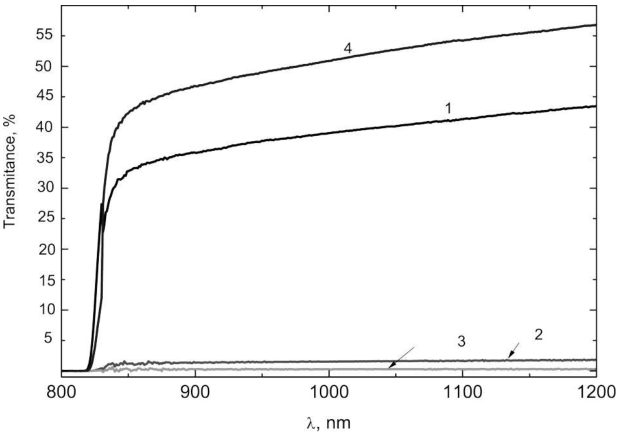

Fig. 2. The same as in Fig. 1, but for the $Cd_{0.9}Zn_{0.1}Te$ solid solution

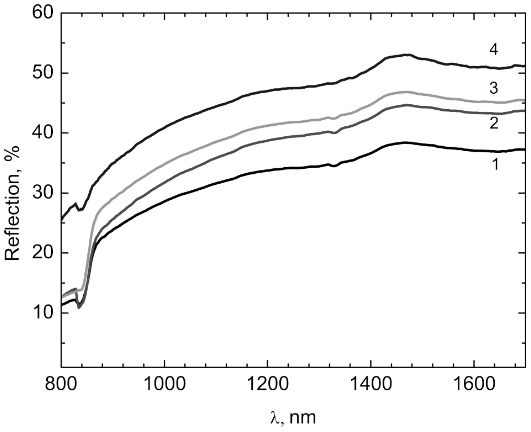

Fig. 3. Reflectance spectra of *p*-CdTe(111) single crystals: initial specimen (*1*) and specimens irradiated to energy doses of 17.2 (*2*), 30.84 (*3*), and 47.01 mJ/cm^2 (*4*). The laser radiation wavelength is 266 nm

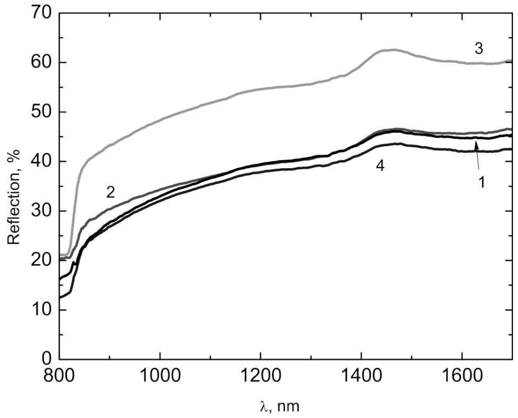

Fig. 4. The same as in Fig. 3, but for the $Cd_{0.9}Zn_{0.1}Te$ solid solution

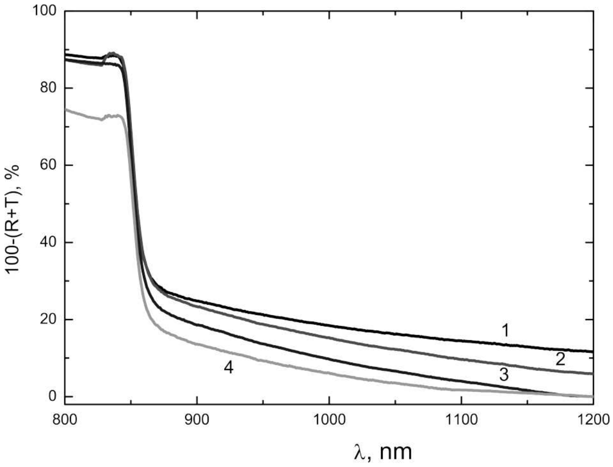

Fig. 5. Absorbance spectra of *p*-CdTe(111) single crystals: initial specimen (*1*) and specimens irradiated to energy doses of 17.2 (*2*), 30.84 (*3*), and 47.01 mJ/cm^2 (*4*). The laser radiation wavelength is 266 nm

mittance curves can be explained by laser-induced changes of the optical constants both in thin near-surface layers and in the bulk of the examined materials.

In Figs. 3 and 4, the optical reflectance spectra $R(\lambda)$ in the region of the fundamental optical transition E_0 are shown for the *p*-CdTe(111) single crystals and the $Cd_{0.9}Zn_{0.1}Te$ solid solution specimens, respectively, subjected to the same laser treatment (curves *1* correspond to the initial specimens, and curves *2* to *4* to the specimens irradiated to energy doses of 17.2, 30.84, and 47.01 mJ/cm^2, respectively). As one can see, the reflectance of the studied materials increases at higher energy doses of laser irradiation. This fact is explained by the integral effect, i.e. both a thin near-surface layer of a semiconductor material with the complex refractive index $\tilde{n}_s = n_s + i\chi_s$ and the material bulk with the complex refractive index $\tilde{n}_v = n_v + i\chi_v$, which is different from that of the near-surface layer, participate in the process of optical reflection. The obtained reflectance spectra of the specimens testify that the laser irradiation stimulates impurities and defects to interact with each other, which leads to the formation of neutral complexes and decreases the intensity of scattering processes by impurities. Hence, a thin surface layer in the studied material undergoes structural modifications. The behavior of the reflectance spectra indicates that the main mechanism of laser irradiation action has a non-thermal origin. Namely, it is structural gettering.

The reflection, R, transmission, T, and absorption, D, coefficients are coupled by the relation $R+T+D = 1$ (the scattering of electromagnetic waves in the researched specimens is not taken into account). Therefore, in this work, we also plotted the absorbance spectra $D(\lambda) = 1 - [R(\lambda) + T(\lambda)]$ calculated for the studied materials (Figs. 5 and 6). They completely correlate with the corresponding optical transmittance, $T(\lambda)$, and reflectance, $R(\lambda)$, spectra. These spectra show that the absorption in p-CdTe(111) single crystals laser-treated to energy doses of 17.2, 30.84, and 47.01 mJ/cm^2 diminished in comparison with the initial specimens in the low-energy spectral interval, i.e. at light (electromagnetic) wave energies E much lower than the energy of the fundamental optical transition E_0 (Fig. 5). In the case of the $Cd_{0.9}Zn_{0.1}Te$ solid solution, the absorption in the studied specimens considerably increased after their laser treatment to energy doses of 17.2 and 30.84 mJ/cm^2 (Fig. 6, curves *2* and *3*), but substantially decreased after the laser treatment to an energy dose of 47.01 mJ/cm^2 (Fig. 6, curve *4*). It should be noted that solid solutions, as a rule, contain inhomogeneities both on the surface and in the bulk of the specimens.

On the basis of the Heisenberg uncertainty principle $\Delta E\, \Delta t \geq \hbar$ for the energy E and the time t, the relaxation effects of the light absorption in crystals are described by the broadening parameter $\Delta E = \hbar/\tau$ (the broadening of the electronic transition E_0 is coupled with the lifetime of free charge carriers because of the interaction of the latter with lattice vibrations, impurities, and defects, including surface ones), where τ is the time of energy relaxation of photogenerated charge carriers [11]. According to experimental data obtained for the optical transmittance and reflectance spectra (Figs. 1–4) for p-CdTe(111) single crystals with the resistivity $\rho = (2\div5)\times10^9$ Ω cm and the $Cd_{0.9}Zn_{0.1}Te$ solid solution specimens with the resistivity $\rho = (0.5\div3)\times10^{10}$ Ω cm, the energy broadening in the optical spectra of those materials equals 0.05 and 0.071 eV, respectively. The energy relaxation time of photogenerated charge carriers was found to equal $\tau = 1.316\times10^{-14}$ s for p-CdTe(111) single crystals and $\tau = 0.927\times10^{-14}$ s for the $Cd_{0.9}Zn_{0.1}Te$ solid solution.

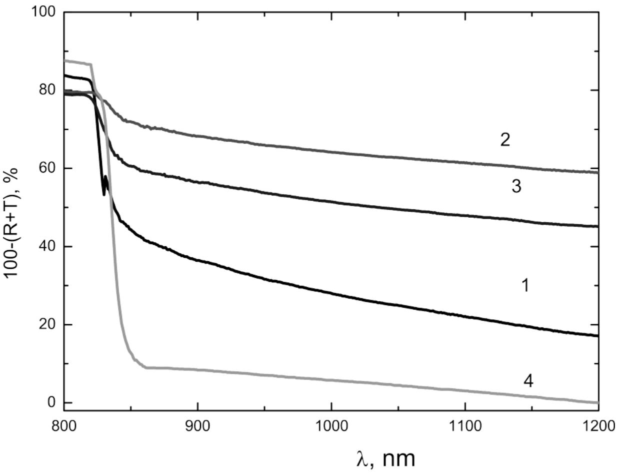

Fig. 6. The same as in Fig. 5, but for the $Cd_{0.9}Zn_{0.1}Te$ solid solution

According to the literature data [12–14], oxide coatings on the surfaces of the studied materials were amorphous films, the thickness of which varied from 0.5 to 7 nm. It should be noted that there exists an intermediate oxide layer at the semiconductor-oxide interface.

3. Conclusions

The transmittance and reflectance spectra of p-CdTe(111) single crystals and $Cd_{0.9}Zn_{0.1}Te$ solid solution specimens were measured in a spectral interval of $(0.8\div1.7)\times10^{-6}$ m before and after their laser irradiation at the wavelength $\lambda = 266$ nm to energy doses of 17.2–47.01 mJ/cm^2. The measurements allowed us to make the following conclusions.

a) The reflectance of researched materials increased after their laser treatment. It can be explained by the integral effect, i.e. both a thin near-surface layer of a semiconductor material with the complex refractive index $\tilde{n}_s = n_s + i\chi_s$ and the material bulk with the complex refractive index $\tilde{n}_v = n_v + i\chi_v$, which is different from that of the near-surface layer, are engaged into the process of optical reflection. The obtained reflectance spectra of the specimens testify that the laser irradiation stimulates impurities and defects to interact with each other, which leads to the formation of neutral complexes and diminishes the intensity of scattering processes by impurities.

b) The main mechanism of influence of a pulsed laser irradiation on the optical properties of thin near-surface layers in the studied crystals is the structural gettering, i.e. the absorption associated with the presence of semiconductor regions that have a defect structure and can actively absorb point defects and bind impurities. In *p*-CdTe(111) single crystals and $Cd_{0.9}Zn_{0.1}Te$ solid solution specimens, the cadmium, tellurium, and zinc oxides, as well as their complexes, play the role of getters.

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Received 16.02.20.
Translated from Ukrainian by O.I. Voitenko

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ВПЛИВ ІМПУЛЬСНОГО ЛАЗЕРНОГО ОПРОМІНЕННЯ (ДОВЖИНА ЕЛЕКТРОМАГНІТНОЇ ХВИЛІ 266 нм) НА ОПТИЧНІ ВЛАСТИВОСТІ CdTe ТА $Cd_{0,9}Zn_{0,1}Te$ В ОБЛАСТІ ФУНДАМЕНТАЛЬНОГО ОПТИЧНОГО ПЕРЕХОДУ E_0

В даній роботі проведено оптичні дослідження спектрів пропускання та відбивання монокристалів *p*-CdTe(111), а також твердого розчину $Cd_{0,9}Zn_{0,1}Te$ в діапазоні $(0{,}8–1{,}7) \cdot 10^{-6}$ м до та після лазерного опромінення на довжині електромагнітної хвилі $\lambda = 266$ нм в інтервалі енергій 17,2–47,01 мДж/см^2. Встановлено, що основним механізмом впливу імпульсного лазерного опромінення на оптичні властивості тонких приповерхневих шарів досліджених кристалів є структурне гетерування, тобто поглинання, зумовлене наявністю ділянок напівпровідників, що мають дефектну структуру і володіють здатністю активно поглинати точкові дефекти і зв'язувати домішки.

Ключові слова: CdTe, CdZnTe, пропускання, відбивання, поглинання, лазерне опромінення.