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Institute of Technical Physics

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OPTIMIZATION OF CADMIUM ZINC TELLURIDE CRYSTAL PHYSICAL PARAMETERS BY NANOSECOND LASER.

Doctoral thesis

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APPROVAL

I confirm that I developed the doctoral thesis that is submitted for consideration at Riga Technical University for the doctoral degree. This thesis has not been submitted to any other university.

Edvīns Daukšta …….

Date: ……

The doctoral thesis is written in English, contains an introduction, 8 chapters, conclusions, list of references, 53 figures and illustrations, 99 pages in total. The list of references contains 114 titles.

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ANNOTATION

A comprehensive study of pulsed laser influence on CdZnTe crystal physical properties is presented in this doctoral thesis. The main focus of this doctoral thesis is to investigate dependence of laser parameters on the physical properties of the CdZnTe crystal: different wavelength, pulse duration, intensity and dose. The practical significance of this doctoral thesis is to develop laser technology for CdZnTe crystal preparation for radiation detector applications.

It was proven that CdZnTe crystal sustain γ-radiation better after preirradiation with highly absorbing laser. This is due to the generation end redistribution of intrinsic point defects in temperature gradient field. The mechanism of CdZnTe γ-radiation hardness enhancement is proposed. Moreover, it was proven that high intensities of highly absorbing laser radiation leads to the formation of CdTe/CdZnTe heterostructure and the effects are based on the drift of zinc atoms in to the volume of the crystal and cadmium atoms to the surface due to the temperature gradient field. Furthermore, it is possible to reduce residual impurities and dissolve indium secondary phases by weakly absorbing laser radiation due to the generation of temperature gradient field around tellurium inclusions.

Experimental results are discussed and explained in context of scientific literature.

The thesis is written in English, its volume is 99 pages. The doctoral thesis includes 53 figures, 6 tables, 51 equations and 114 references.

ANOTĀCIJA

Šis promocijas darbs ir veltīts nanosekunžu lāzera starojuma iedarbības izpētei uz CdZnTe kristālu fizikālajām īpašībām. Promocijas darba mērķis ir izpētīt CdZnTe fizikālās īpašībās pēc apstarošanas ar lāzeru pie dažādiem parametriem: viļņa garums, impulsa garums, intensitāte un doza. Praktiskais promocijas darba pielietojums sevī ietver lāzer tehnoloģijas izstrādi pielietojumam radiācijas detektoru ražošanā.

Darbā pierādīts, ka CdZnTe kristāls ir izturīgāks pret γ-starojumu pēc apstarošanas ar stipri absorbējamu lāzera starojumu. Tas notiek pašdefektu ģenerācijas un to telpiskās pārdalīšanās dēļ. Darbā tiek skaidrots CdZnTe kristāla γ-starojumu izturības mehānisms. Kā arī tika pierādīts, ka augstas intensitātes stipri absorbējams lāzera starojums izraisa CdTe/CdZnTe heterostruktūras veidošanos, šis efekts tiek pamatots ar cinka atomu dreifu kristāla tilpumā un kadmija atomu pārvietošanos virsmas virzienā temperatūras gradientā. Turklāt, lai samazinātu nevēlamo piemaisījumu koncentrāciju un izšķīdinātu indija sekundārās fāzes, var izmantot vāji absorbējamu lāzera starojumu, kas apkārt telūra ieslēgumiem izveido temperatūras gradientu.

Eksperimentālie rezultāti un to izvērtējums tiek pamatoti ar zinātniskās literatūras datiem.

Promocijas darbs ir uzrakstīts angļu valodā un satur 99 lapaspuses. Promocijas darbā ir iekļauti 53 attēli, 6 tabulas, 51 formula un 114 atsauces uz literatūru.

1. INTRODUCTION

CdZnTe has been used as room temperature x-ray, γ-ray radiation detectors, infrared detectors and solar cells for decades [1]–[3]. CdZnTe possess favorable physical properties required for production of ionizing and non-ionizing radiation detectors: high stopping power due to high atomic number (Z) of the components, relatively wide band gap that ensures high resistivity of the crystal and therefore low noise due to the leakage current. Furthermore, CdZnTe has higher radiation hardness than CdTe [4].

It is important to have a large volume crystal with low defect concentration, high purity and homogeneity to manufacture a radiation detector with high charge collection efficiency and consistent response to the excitation. Unfortunately, it is difficult to grow large volume CdZnTe crystal without any undesirable defects due to its fundamental properties. Defects are easily formed during the growth process and are hard to get rid of by post processing methods. CdTe and related compound technologies are evolving relatively slow even through a relatively low melting point and vapor pressure. Despite all the possible applications, one of the problems is still a lack of knowledge about materials structural properties and difficulties to prepare homogeneous compounds and alloys.

Modern CdZnTe crystal growth technology involves Bridgman and modified high-pressure Bridgman methods, which allows obtaining CdZnTe crystals with reasonable quality. Still, the quality of available CdZnTe crystals is not comparable to silicon or gallium arsenide crystal quality and it is far from ideal. The high quality of detectors is achieved by electrical compensation of acceptors (V_{Cd}) and thermal annealing. Laser annealing of CdTe and CdZnTe crystals has been known for some time [6]. However, the CO_2 laser used in these experiments usually leads to the damage of the treated crystal surface.

Nowadays, CdZnTe radiation detectors are widely used in many fields such as, x-ray and γ-ray spectroscopy [37–39], medicine [40,41], homeland security [42], x-ray and γ-ray imaging [40,43,44] and astronomy [41,45].

The aim

The aim of this thesis is to investigate pulsed nanosecond laser radiation influence on physical properties of CdZnTe.

Novelty

1. A laser method to increase the ionizing radiation hardness of CdZnTe crystal by formation of radiation hard near surface layer by pulsed nanosecond Nd:YAG laser, was developed.
2. A laser method to form CdTe/CdZnTe heterostructure in CdZnTe crystal by pulsed nanosecond Nd:YAG laser, was developed.
3. A laser method to improve CdZnTe γ-ray detector by pulsed nanosecond Nd:YAG laser, was developed.

Practical significance

Practical significance of the conducted research is determined by the limitations and flaws of the commercially available CdZnTe. It was concluded that the pulsed Nd:YAG nanosecond laser can be used to increase radiation hardness and spectral sensitivity of the detector. As well as, form CdTe/CdZnTe heterojunction which is one of the approaches to reduce leakage current and electronic noise of the detector. Described CdZnTe laser modification methods can be applied to plain CdZnTe crystals, as well as, to fabricated detectors due to high locality of laser influence.

2. LITERATURE REVIEW

CdTe and CdZnTe are II-IV group semiconductor with band gap from 1.4 till 2.2 eV. The width of the band gap depends on Zn concentration. CdTe and CdZnTe has a cubic zinc blende crystalline lattice with F43m space group symmetry. Each sub-lattice is occupied by the Cd, Zn or Te atoms, which are arranged in a tetrahedrons. Each atom shares its four valence electrons with neighboring atoms.

The alloy $Cd_{1-x}Zn_xTe$ consists of CdTe crystal with randomly substituted Cd atoms by Zn atoms and is expressed as a fraction of *x*. In fact, the lattice constants for CdTe and ZnTe are about 6.482 Å and 6.104 Å, respectively [7]. The difference in the lattice constants of CdTe and ZnTe lead to changes in average unit cell dimensions.

Moreover, the substitution of Cd by Zn not only decrease the lattice constant of CdTe, but also increase the band gap of the resulting CdZnTe [10]. As it was mentioned before, higher bandgap can provide higher resistivity of the detector material. Also, ZnTe binding energy is higher in comparison to CdTe, therefore lattice is strengthened and leads to better mechanical properties. Moreover, addition of Zn increases the maximum solid solubility of Te [11].

The fundamental feature of CdTe and CdZnTe is the bonding between adjacent atoms, which is covalent bond with slight ionic properties. This is typical for II-VI compound, but not for the group IV semiconductors which have purely covalent bonding. This divergence form purely covalent bonding leads to the formation of wide range of native defects and their complexes. However, the main problem in studying these defects is lack of direct investigation methods.

Nowadays, detector grade CdTe crystals are grown by traveling heater mode (THM) [12]–[15], High Pressure Bridgman (HPB) [13] and Classical Bridgman (CB) [13] methods.

The optical properties of the material are dependent on its band gap. CdTe and CdZnTe are direct band gap semiconductors. The absorption band edge for CdTe is ~850 nm and for CdZnTe ~800 nm (depends on Zn concentration). The transmission range of CdTe is determined by the short wavelength limit of the band gap (800 nm) and the long wave limit is determined by the lattice vibration ~30000 nm [17]. Within this range the CdTe is almost transparent with transmission of about 63%.

The five factors that are responsible for optical loss in infrared region are [17]:

1. interband electronic transitions;
2. fundamental and harmonic crystalline lattice vibrations, including multiphonon processes;
3. absorption by impurities, either by electrons bound to defects, localized optical impurity modes, or inner shell electronic transitions;
4. free carrier absorption;
5. optical scattering loses due to the precipitate, inclusions voids or strains;

The fifth factor often has the dominant role for the total optical transmission. However, it can be neglected for samples annealed in Cd and Te atmosphere, because of Te inclusion and precipitate dissolution.

Free carrier absorption arises due to the interaction of photons with the free electrons and holes. Optical absorption in the infrared region could be used to characterize the concentration of the free charge carriers.

Another important parameter for laser processing technologies is optical penetration depth, δ, which is calculated as an inverse from the optical absorption coefficient, α.

There are several types of defects: vacancies, interstitials and extrinsic impurities.

Point defects can be grouped in to two main categories:

1. Intrinsic point defects (vacancies, interstitials and antisites),
2. Extrinsic point defects (dopants and impurities).

Te precipitates and inclusions have an adverse effect on the performance of CdZnTe devices. The average size of Te precipitates is considered to be in the range of 10 nm and 30 nm, whereas the typical diameter of Te inclusions is in the range of 10 ~ 100 μm [19], [20], see Figure 2.1.

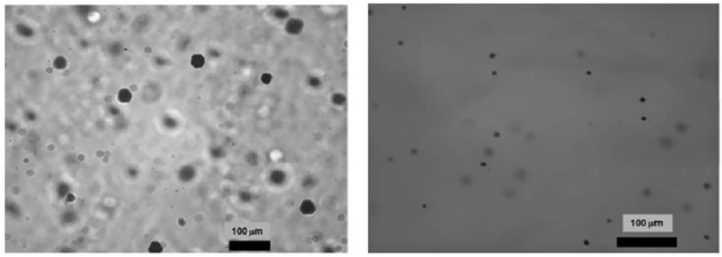

Figure 2.1 IR microscopy images of Te inclusions inside the CdZnTe crystal [20].

It is important to note that the impurities usually trapped at Te inclusions are segregated at the first-to-freeze and last-to-freeze section of the ingots [2]. It has been accepted that the nonuniform distribution of Te inclusions can significantly affect the charge transport properties and deteriorate the spectroscopic performance of CdTe/CdZnTe nuclear radiation detectors [2].

X-ray and γ-ray radiation detectors must have high resistivity and low concentration of charge carrier traps that lead to incomplete charge collection and broadening of the signal [8]. Mostly, high resistivity of materials is achieved by purification or addition of electrically active dopants. Therefore, compensation of existing impurities by introduction of dopants is an important challenge in the field of semiconductor material fabrication.

When a γ-photon travels through the detector, electron-hole pairs are created. The electrical field forces the electron cloud to move towards the positive electrode, while the holes drift in the opposite direction. As these carriers move, a charge is accumulated at the electrodes, which can be detected by a charge-sensitive amplifier.

3. EXPERIMENTAL METHODS

The samples were provided by prof. Ernesto Dieguez from "Crystal growth laboratory", Universidad Autónoma de Madrid. Another source of the samples was Ritec Ltd., Latvia. Crystals grown by this method has high Te inclusion concentration and shallow impurities.

After the polishing, sample was chemically etched to remove the damaged surface [22]–[30].

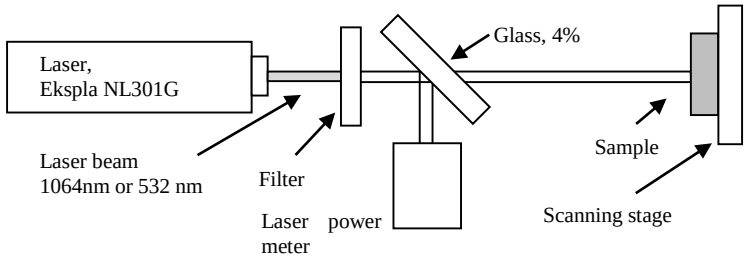

Figure 3.1. The schematic of the laser irradiation setup.

We employed three experimental techniques to identify the changes of the crystal properties after irradiation by the laser: Fourier transform infrared spectroscopy (FTIR), current voltage characteristics (I-V) measurement and photoluminescence (PL) spectra measurements. Prior to irradiation and measurements the samples were mechanically lapped, polished and chemically etched in brome – methanol solution.

I-V characteristics measurements were carried out with a Keithley 6487 Picoammeter. I-V characteristics were taken at a steady-state current condition.

FTIR spectra measurements were carried out by a Bruker Vertex 70 spectrometer in the wavelength range of 1 μm to 18 μm for evolution of the free charge carrier absorption, which indicates the presence of electrically active point defects.

The PL spectra measurements were carried out at the tested surface before and after irradiation by laser. The photoluminescence spectra were measured at 5 K using λ=632.8 nm line of HeNe laser with excitation power lower than 200 mW.

Samples were γ-irradiated by a ^{60}Co source (E_γ photons = 1.2 MeV) at room temperature with a dose rate of $5 \cdot 10^5$ Rad = 5.0 kGy, before and after irradiation by pulsed Nd:YAG laser.

γ-Radiation sensitivity measurements were performed before and after preirradiation by laser. The ^{241}Am was used as a source of γ-radiation.

4. RESULTS AND DISCUSSIONS

4.1. Radiation hardness

CdZnTe exposure to the ^{60}Co γ-rays leads to the formation of intrinsic point defects [31]. However, laser preirradiation of the CdZnTe leads to the increase of radiation hardness. This effect will be discussed in this chapter and mechanism of laser influence on radiation hardness of CdZnTe is proposed. The temperature of near surface layer does not exceed the melting temperature of 1277.15 K, see Figure 4.1.

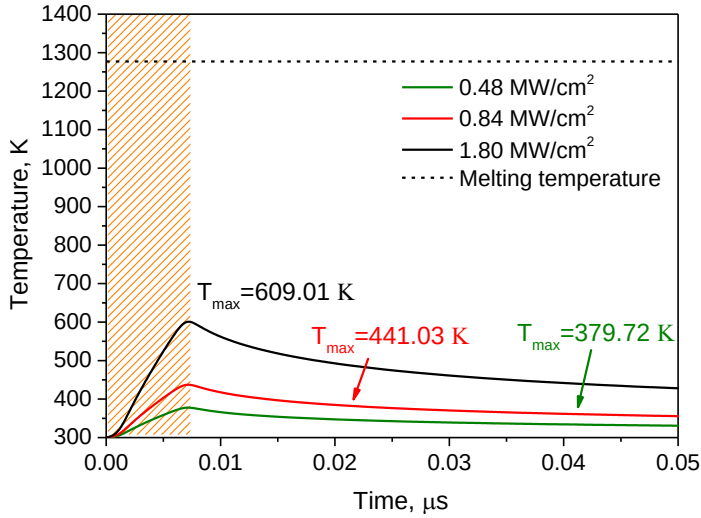

Figure 4.1 The calculated time dependence of the temperature of the laser irradiated CdZnTe sample by different laser intensities. Striped area represents the laser pulse duration.

Irradiation of $Cd_{0.9}Zn_{0.1}Te$ crystal by the laser leads to the appearance of D^0X band and increase of A^0X band. The appearenec of D^0X band is due to the generation of cadmium intersitital atoms and the increase of A^0X band is due to the cadmium vacancies.

Irradiation of $Cd_{0.9}Zn_{0.1}Te$ crystal by γ-rays with a dose rate of 5×10^5 Rad = 5.0 kGy leads to the increase of A^0X band intensity in PL spectra of $Cd_{0.9}Zn_{0.1}Te$ crystal, as shown in Figure 4.2. Intensity of A^0X band increased ~9 times in comparison to intensity before γ-irradiation. In the same time D^0X band in PL spectrum of $Cd_{0.9}Zn_{0.1}Te$ crystal disappears completely.

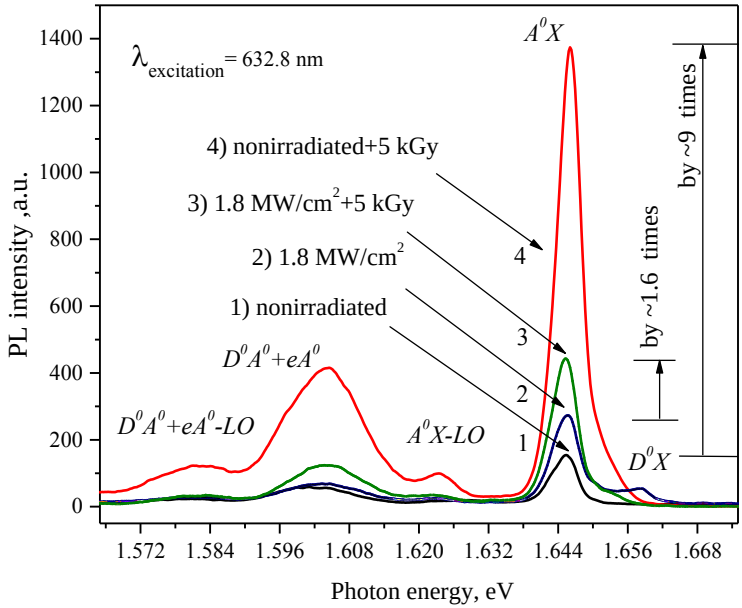

Figure 4.2 The PL spectra of $Cd_{0.9}Zn_{0.1}Te$ crystal before 1 and after irradiation by Nd:YAG laser: 2 - irradiated by Nd:YAG laser with intensity 1.8 MW/cm^2; 3 – previously irradiated by Nd:YAG laser with intensity 1.8 MW/cm^2 and subsequently by γ- ray with a dose rate of 5.0 kGy; 4 – irradiated by γ- ray with a dose rate of 5.0 kGy.

We explain this effect by Cd vacancies generation and localization in the excited luminescence thin layer after γ-irradiation of $Cd_{1-x}Zn_xTe$ crystal.

Gamma radiation causes the generation of additional Cd vacancies and interstitial Cd atoms, which causes the growth of the intensity of the A^0X line in the PL spectrum. Generation and recombination process takes place simultaneously, when the existing interstitial atoms or atoms generated under the influence of gamma radiation moves and fills the existing vacancies or newly generated vacancies.

Figure 4.3 and Figure 4.4 shows intensities of A^0X and D^0X depending on laser irradiation intensity. Changes in PL spectra start at laser intensity 0.84 MW/cm^2. But the effect of radiation hardness increase is more pronounced with laser intensity 1.8 MW/cm^2.

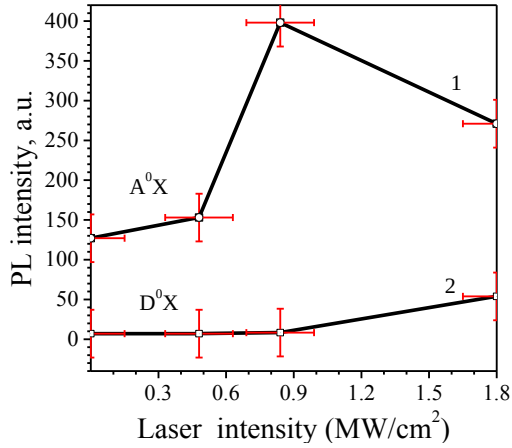

Figure 4.3 The PL intensity of A^0X (1) and D^0X (2) bands of CdZnTe crystal as a function of Nd:YAG laser intensity: irradiated by the laser.

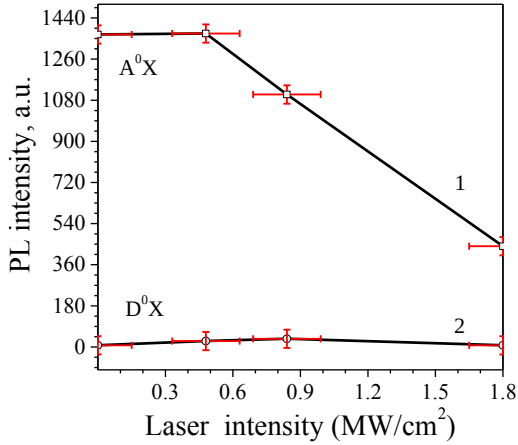

Figure 4.4 The PL intensity of A^0X (1) and D^0X (2) bands of CdZnTe crystal as a function of Nd:YAG laser intensity: irradiated by the laser and after subsequently irradiation by γ-ray with a dose rate of 5.0 kGy.

As a result, the rate of increase in the concentration of vacancies and interstitial atoms is slowed down because of their partial recombination. These processes can be explained by a decrease of A^0X line intensity growth, which also means an increase in radiation resistance of semiconductor.

It should be noted that such mechanism of "defect healing" is valid only up to certain values of radiation doses at which the number of donors formed by laser irradiation may still restrain the formation of the vacancies.

4.2. CdTe/CdZnTe heterostructure formation

CdTe and CdZnTe are promising materials for x-ray and γ-ray detectors. However, due to the low mobility-lifetime product $\mu_h\tau_h \sim 10^{-5} – 10^{-4}$ $cm^2 \cdot V^{-1}$ for holes and $\mu_e\tau_e \sim 10^{-4} – 10^{-3}$ $cm^2 \cdot V^{-1}$ for electrons, considerable amount of charge carriers are lost. Moreover, hole trapping results in a broad low energy shoulder in radiation spectra. To solve this problem, high bias voltages may be applied, however, this will increase leakage current and electronic noise. Therefore, several research groups have proposed the use of Schottky diode structure [32] or heterostructure [33]–[35] to allow using higher bias voltages with significantly lower (by the orders of magnitude) leakage current end electronic noise.

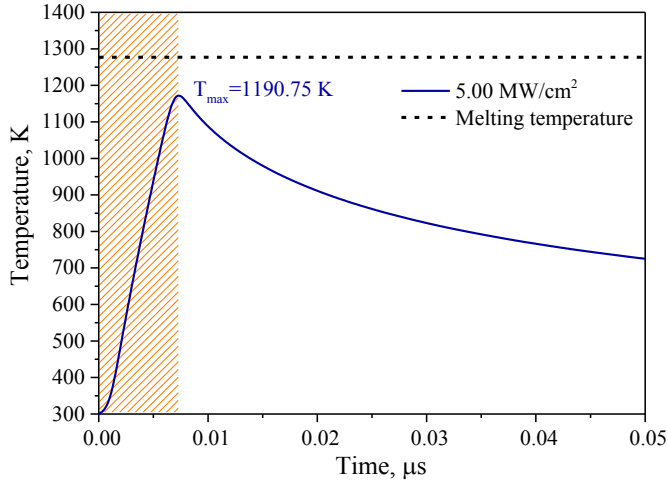

Figure 4.5 The calculated time dependence of the temperature of the laser irradiated CdZnTe sample by different laser intensities. Striped area represents the laser pulse duration.

The laser-induced surface modification is investigated in p-$Cd_{0.9}Zn_{0.1}Te$ under irradiation by nanosecond pulses of Nd:YAG laser with an intensity 5 MW/cm^2. The conductivity type inversion of the near-surface region with thickness of several micrometers is observed. The electrical contacts are prepared by electroless deposition of Au on the irradiated surface. The spectral dependence of the photovoltaic response is explained by formation of the graded band gap in the laser irradiated region.

Temperature gradient effect is suitable to explain the barrier structure formation on the surface of CdZnTe. See Figure 4.5 for transient temperature at the surface of the sample.

Thus, pulsed laser irradiation of p-$Cd_{0.9}Zn_{0.1}Te$ results in formation of the surface layer with n-type conductivity. The inversion of the conductivity type occurs on the micrometer depth. The photovoltaic measurements in the surface-barrier structures prepared the laser-irradiated surface is explained by appearance of the graded-gap region. The barrier structure possesses diode like properties, as can be seen in

Figure 4.6.

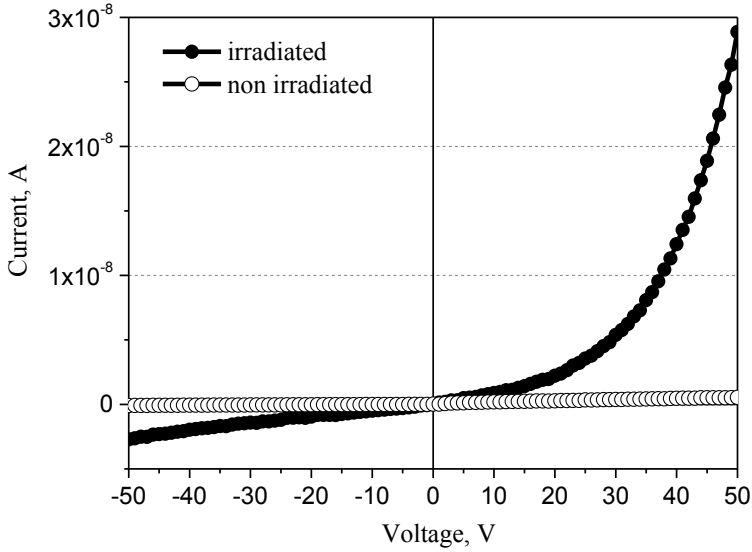

Figure 4.6. I-V characteristics of CdTe/CdZnTe heterojunction

The photoresponse generated by these barriers should have an opposite sign. The lack of the sign inversion in

Figure 4.7 may indicate that the depth of the heterojunction is sufficiently larger than the diffusion length of nonequilibrium holes), whereby it does not affect the measured photoresponse. Note also that the long-wavelength edge of the photoresponse $\lambda_c \cong 810$ nm corresponds to the absorption depth of the order of 1 μm, as the absorption coefficient at this wavelength is ~10^3 cm^{-1}.

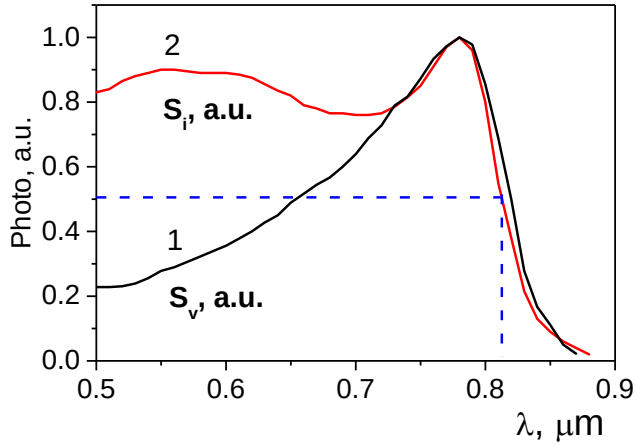

Figure 4.7 Photosensitivity spectra in contacts on the non-irradiated (1) and irradiated (2) surfaces measured in the short-circuit current mode at T = 295 K.

4.3. Improvement of CdZnTe radiation detector parameters

It has been observed that λ=1064 nm laser irradiation with intensity 5.0 MW/cm^2 leads to decrease of the leakage current. After irradiation by 10^5 laser pulses the reduction of the leakage current is no longer observed. From the analysis of I-V characteristics before and after irradiation by laser the resistivity of the sample doubled. The increase of the resistivity can be explained by at least two mechanisms. The first one is the decrease of the charge carrier mobility and the second one is the decrease of the free charge carrier concentration. Qualitatively, this effect can be estimated by a change in the optical transmission spectra of the crystal [36]. The increase of resistivity was correlated with IR spectra before and after laser irradiation.

FTIR spectra of the non-irradiated and laser irradiated samples are shown in Figure 4.8. It is known from literature that the absorption in the 8-20 μm range of the IR spectra is primarily determined by the free charge carrier absorption. The absorption of light by the free charge carriers is mainly caused by the presence of the uncompensated electrically active residual impurities and V_{Cd} [36]–[39].

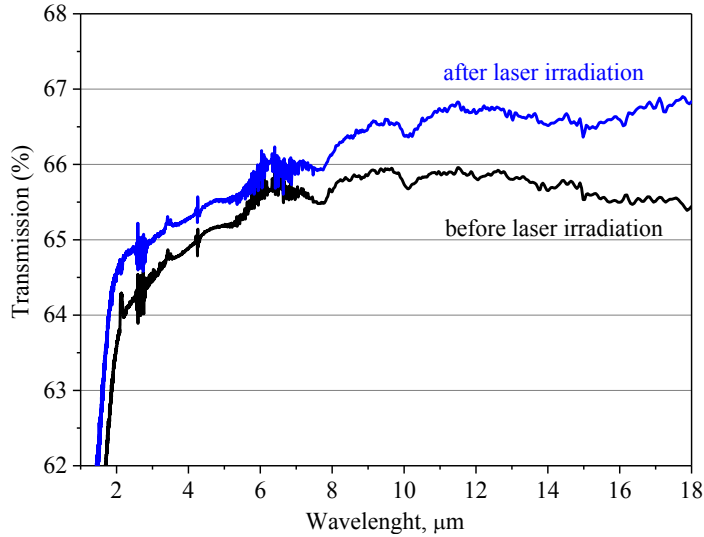

Figure 4.8. FTIR spectra of CdZnTe samples before (curve 2) and after irradiation (curve 1) by the Nd:YAG laser.

The typical PL spectrum contains an intense A^0X band at 1.6308 eV ascribed to excitons bound on shallow acceptors (V_{Cd}) or residual impurities (Cu, Fe, etc.) and its longitudinal optical phonon replicas (A^0X-LO) at 1.6087 eV, and D^0X band at 1.6410 eV ascribed to excitons bound to shallow donor Cd_i and In atoms substituting Cd in crystal lattice (In_{Cd}) [5]. The dominant line in PL spectra of In-doped CdZnTe crystal is D^0X, in contrast to the undoped CdZnTe, where usually A^0X is the typical dominant peak [5], [40].

The presence of free exciton (FE) peak at 1.6461 eV and the absence of donor-acceptor pair (DAP) in PL spectra of CdZnTe crystal is an evidence of high crystal quality of the semiconductor [5]. The intensity of

D^0X band increased after irradiation, but the intensity of the A^0X peak decreased, as shown in Figure 4.9.

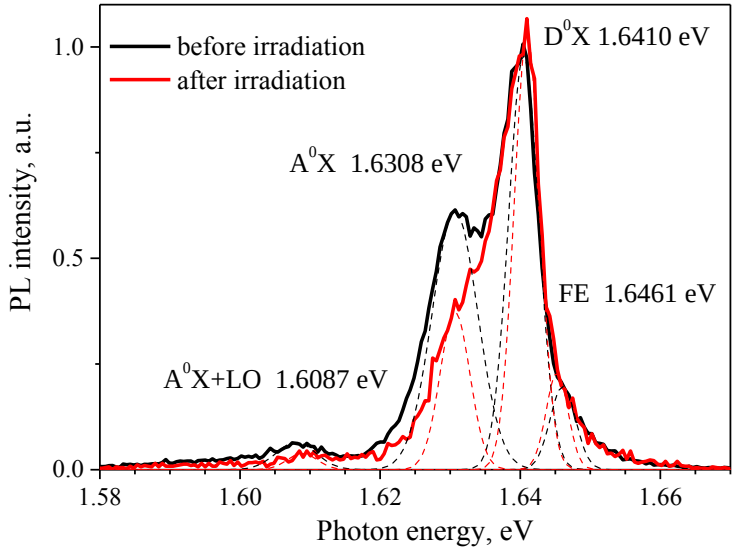

Figure 4.9 PL spectra of CdZnTe samples before (curve 1) and after irradiation (curve 2 -with pulse number 3.6×10^4 pulses) by the Nd:YAG laser.

The changes in the PL spectrum of CdZnTe are explained in the following way. It is known that a part of the In and Cd atoms exist in the interstitial state [5], [41]. After laser irradiation of the sample V_{Cd} are substituted by In and Cd from interstitial state, according to (1) and (2),

$$In + V_{Cd}^{2-} \leftrightarrow In_{Cd}^{+} + 3e^{-} \quad (4.1)$$

$$Cd_i^{2+} + V_{Cd}^{2-} \leftrightarrow Cd_{Cd}^{0} \quad (4.2)$$

According to the formulas above, these defects recombine, forming neutrally charged Cd_{Cd}^0. Therefore, the concentration of donors increase, but concentration of acceptors - V_{Cd} decrease. As a result, the intensity of A^0X band in PL spectrum decreases, Figure 4.9. It is known that In can occupy V_{Cd} to form a shallow donor state In_{Cd}, a single ionized acceptor $[In_{Cd}^{+}V_{Cd}^{2-}]^{-}$ and a neutral entity $[2In_{Cd}^{+}V_{Cd}^{2-}]^{0}$ according to the equations [42], [43]

$$In_{Cd}^{+} + V_{Cd}^{2-} \leftrightarrow [In_{Cd}^{+}V_{Cd}^{2-}]^{-} \quad (4.3)$$

$$In_{Cd}^{+} + [In_{Cd}^{+}V_{Cd}^{2-}]^{-} \leftrightarrow [2In_{Cd}^{+}V_{Cd}^{2-}]^{0} \quad (4.4)$$

$$Cd_{i}^{2+} + [In_{Cd}^{+}V_{Cd}^{2-}]^{-} \leftrightarrow In_{Cd}^{+} + Cd_{Cd}^{0} \quad (4.5)$$

The self-compensation process reduces the concentration of donor attributed to In_{Cd}^{+} and acceptor attributed to $[In_{Cd}^{+}V_{Cd}^{2-}]^{-}$, which is in agreement with experiments, the change of intensity of D^0X line is insignificant.

Spectral resolution can be characterized by the FWHM of the peaks in the γ-ray spectra. Therefore, fitting of Gaussian peaks was performed and FWHM data was extracted, see Figure 4.10 and Figure 4.11. One can see in that the FWHM of the characteristic peaks decrease up to 30%.

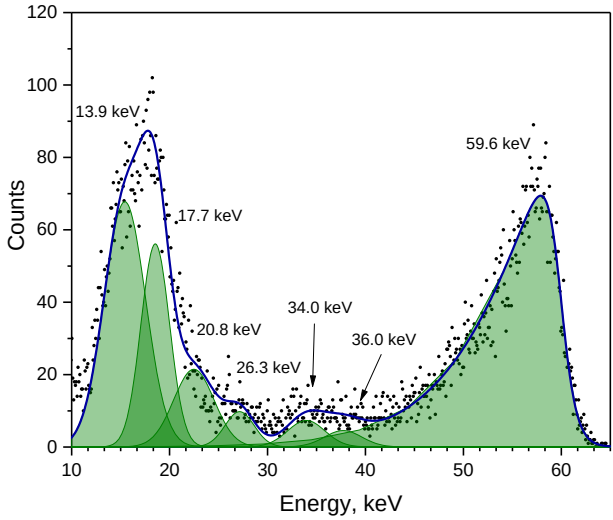

Figure 4.10 Best fit results for ^{241}Am γ-ray spectrum CdZnTe detector crystal before laser irradiation.

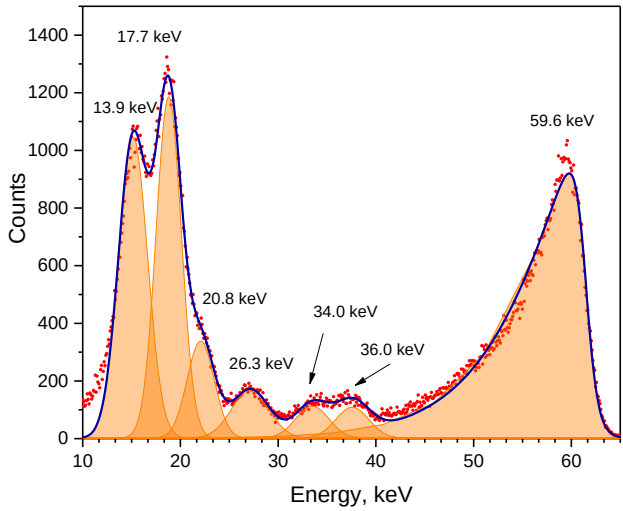

Figure 4.11 Best fit results for ^{241}Am γ-ray spectrum of laser irradiated CdZnTe detector crysta

Table 4.1 Peak position and FWHM values of fitted peaks before and after laser irradiation.

Peak position, keV	FWHM before laser irradiation, keV	FWHM after laser irradiation, keV	Change of FWHM after laser irradiation, %
13.9	5.0 ± 0.13	3.5 ± 0.08	-30.0
17.7	3.4 ± 0.14	3.0 ± 0.14	-11.7
20.8	4.7 ± 0.64	3.2 ± 0.51	-31.9
26.3	3.9 ± 0.79	4.1 ± 0.70	5.1
34.0	4.5 ± 1.39	4.0 ± 1.10	-11.1
36.0	4.5 ± 1.96	4.0 ± 1.00	-11.1
59.6	8.6 ± 0.13	7.7 ± 0.06	-30.0

FINAL CONCLUSIONS

1. Radiation hardness of CdZnTe.

It was demonstrated that radiation hardness of $Cd_{0.9}Zn_{0.1}Te$ crystal increased after irradiation by pulsed nanosecond laser with λ=532 nm at intensities range from 0.84 till 1.8 MW/cm^2. The increase of radiation hardness is explained by the formation of Cd_i enriched layer near the surface of the $Cd_{0.9}Zn_{0.1}Te$ crystal. The Cd_i enriched layer forms due to laser-induced temperature gradient at the depth of ~123 nm.

2. Formation of CdTe/CdZnTe by the laser.

CdTe/CdZnTe heterojunction was formed after irradiation by pulsed λ=532 nm laser above the intensity 5 MW/cm^2. Due to the temperature gradient 10^8-10^9 K/m, Zn atoms drift away from highest temperature to the lowest, but Cd_i drift in opposite direction toward the irradiated surface of the crystal.

3. Improvement of CdZnTe radiation detector parameters

Pulsed nanosecond Nd:YAG λ=1064 nm laser at intensity 5 MW/cm^2 has an effect of improvement of CdZnTe radiation detector parameters (signal to noise ratio, FWHM, spectral resolution). Te inclusions strongly absorb the λ=1064 nm laser radiation and heat up within nanosecond timescale forming huge temperature gradient ~10^8 K/m. The temperature gradient is forcing the impurities to gather around Te inclusions and In atoms to react with cadmium vacancies, purifying the crystal.

THESES TO BE DEFENDED

1. Ionizing radiation hardness of CdZnTe crystal increase by 7.4 times after irradiation by 532 nm Nd:YAG laser at intensity from 0.84 till 1.8 MW/cm^2. The radiation hardness increase due to the drift of cadmium interstitials to the surface and cadmium vacancies to the volume of the crystal.

2. CdTe/CdZnTe heterostructure is formed by the pulsed nanosecond 532 nm Nd:YAG laser at intensity 5 MW/cm^2. The Cd_i drift to the surface and Zn in to the volume of CdZnTe crystal.

3. Selective laser annealing of the CdZnTe crystal with Te inclusions by the pulsed nanosecond 1064 nm Nd:YAG laser at intensity 5 MW/cm^2 leads to the improvement of CdZnTe ionizing radiation detector parameters, charge collection efficiency by 5% and spectral resolution by 30%.

PUBLICATIONS

Monograph

1. "Nd:YAG Laser", book edited by Dan C. Dumitras, chapter "Application of Nd:YAG Laser in Semiconductors' Nanotechnology", Artur Medvid', Aleksandr Mycko, Pavels Onufrijevs and Edvins Dauksta, Publisher: InTech

Patent

2. LV 14439 B Pusvadītāju radiācijas izturības uzlabošanas paņēmiens, Aleksandrs Mičko, Artūrs Medvids, Edvīns Daukšta

Publications

3. Mychko A., Medvid A., Dauksta E., Laser-induced increase of resistivity and improvement of optical properties of CdZnTe crystal, Journal of Crystal Growth, Volume 415, 2015, Pages 47-50 **(Scopus) (Web of Science)**

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