INCREASE OF CdZnTe:In CRYSTAL QUALITY BY Nd:YAG LASER RADAITION

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Abstract

The improvement of CdZnTe:In crystal quality using 1064 nm Nd:YAG laser radiation has been shown. The increase of optical transmission in the 8-20 μm range and decrease of photoluminescence spectra A^0X band intensity and respectively the increase of D^0X and FE band were observed. The evidence of CdZnTe:In quality and resistivity increase after laser irradiation is demonstrated. This effect is explained by compensation of Cd vacancies by In interstitial atoms due to temperature gradient around Te inclusion.

Key words: *CdZnTe, Te inclusion, Nd:YAG laser*

Cadmium zinc telluride (CdZnTe) is a very useful material for x- and γ-ray radiation detectors due to high stopping power, suitable wide bad-gap, good electron transport properties, flexibility in configuring contacts [1-3]. These properties assure high energy resolution and efficient radiation detection at room temperature. However, the structural defects, such as, grain boundaries, Te inclusion and uncompensated point defects play a key role in determination of CdZnTe detector performance. CdZnTe with high concentration of V_{Cd} exhibit mainly p-type conductivity and low resistivity, even 10^6 Ω·cm in their as-grow state. This material is not acceptable for x- and γ- ray detections.

Usually, high resistivity is achieved through electrical compensation of acceptors (V_{Cd}). Better results can be achieved by CdTe doping with zinc and indium. The resistivity of doped CdTe increase till 10^{10} Ω·cm [4, 5]. As noted in [6] a part of In atoms after doping remains in the electrically inactive interstitial state. As a result, there is no full compensation of Cd vacancies.

Recently, the possibility to change the composition of the surface layer of CdZnTe using Nd:YAG laser (λ=532 nm) was shown. After laser irradiation the intensity of D^0X line in PL spectrum caused by the interstitial Cd atoms was increased, but on the other hand the decrease of A^0X line produced by V_{Cd} was observed. The described changes were observed at the surface layer of the semiconductor. Therefore, it is possible to interact with Te inclusions located in the bulk of the semiconductor using the 1064 nm laser with photon energy less than the semiconductor band-gap.

In-doped CdZnTe single crystals grown by the vertical gradient freeze methods were used in our experiment. Crystals were grown using high-purity

Cd, Zn and Te 7N materials and were doped with 3ppm by In atoms. The crystals grown by the described method are characterized by high concentration of Te inclusions and shallow unidentified impurities. Experiments were carried out at room temperature, atmospheric pressure and humidity 60%. 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 (I-V) characteristics measurements, and photoluminescence (PL) measurements. The samples were irradiated by Nd:YAG with following parameters: wavelength λ=1064 μm, pulse duration λ=5 ns, power P=1.0 MW, spot diameter d=6 mm. The sizes of the samples were 5.0x5.0x4.0 cm^3. The bulk of CdZnTe crystal between electric contacts was irradiated by intensity I=5.0 MW/cm^2 and maximum number of laser pulses 3.6×10^4.

I-V characteristics measurements were carried out by Keithley 6487 Picoammeter. FTIR spectra measurements were carried out by Bruker Vertex 70 spectrometer in the wavelength range of 1 μm to 18 μm for evolution of free carrier absorption. The PL spectra measurements were carried out at the tested surface before irradiation and after irradiation by laser. Photoluminescence spectra were measured at 5K using λ=632.8 nm line of Ag+ laser with excitation power less than 200 mW.

I-V characteristics after irradiation with 3.6×10^4 laser pulses showed the increase of sample resistivity up to 4 times. The increase of resistivity can occur due to various reasons, for example, decrease of charge carrier mobility, but the most common reason is decrease of free charge carrier concentration. Qualitatively, this process can be estimated by change in the optical transmission spectra of the crystal. According to the paper [7] the free-carrier absorption effects mainly dominate in the IR spectra of the 8-20 μm range. The absorption of light by free charge carriers is mainly caused by the presence of the uncompensated electrically active residual impurities and V_{Cd}. The transmission of the CdZnTe:In crystal increased after irradiation by the laser. This effect is explained by decrease of V_{Cd} concentration in the irradiated sample due to recombination with In interstitial (In_i) atoms.

The PL studies of CdZnTe have been carried out with the aim to confirm the suggested hypothesis.

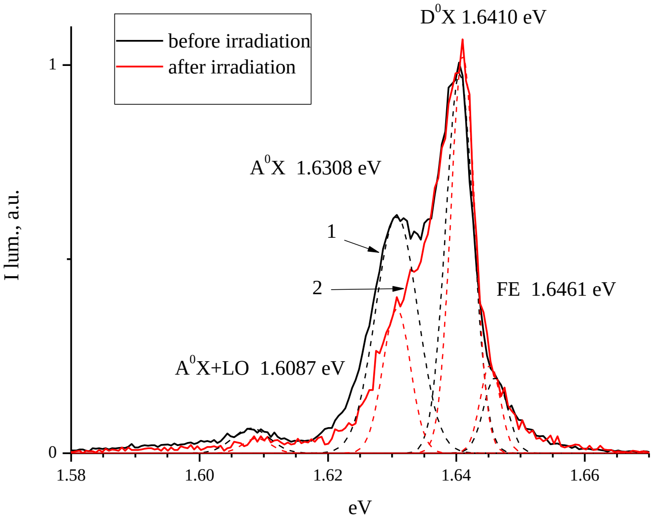

Fig. 1. PL spectra of CdZnTe samples before (curve 1) and after irradiation by the Nd:YAG laser (curve 2) with pulse number 3.6×10^4.

The typical PL spectrum of $Cd_{1-x}Zn_xTe$:In obtained from non-irradiated sample at 5 °K (fig. 1) contains an intense A^0X band at 1.6308 eV ascribed to excitons bound on shallow acceptors (V_{Cd}) and its longitudinal optical phonon replicas (A^0X-LO) at 1.6087 eV, and D^0X band at 1.6410 eV ascribed to exciton bound on shallow donor Cd_i and In atoms substituting Cd in crystal lattice (In_{Cd}).The dominant line of the CdZnTe:In spectra is D^0X, in contrast to CdZnTe, where A^0X peak is typically dominant peak [8]. The presence of free exciton (FE) peak at 1.6461 eV and absence of donor-acceptor pair (DAP) in PL spectra of CdZnTe:In crystal is seen as the evidence of high crystal quality of the semiconductor [8]. After irradiation of the sample by the laser the intensity of D^0X band increase, but intensity of the A^0X peak decreases, as shown in fig.1 curve 1 and 2, correspondingly. We explain changes in PL spectrum of CdZnTe:In sample in the following way. It is known [6] that a part of In atoms exist in the interstitial state and does not compensate V_{Cd}. Under action of the laser In atoms from interstitial state move to the lattice site where they substitute V_{Cd}. The increase of the CdZnTe: In crystal resistivity is explained by the increase of the compensation degree of V_{Cd} by In atoms. It is possible to explain the effect by the temperature gradient effect (TGE) [9] in the following way.

Photon energy of the laser radiation is lower than the band-gap of the CdZnTe:In crystal therefore the absorption is weak. At the same time, the Te inclusions, which are chaotically distributed in the bulk of the semiconductor, cause the crystal to strongly absorb the laser radiation. There is a strong temperature gradient around Te inclusions.

According to the TGE In_i atoms drift toward Te inclusions and V_{Cd} - to the opposite direction. As a result, recombination of V_{Cd} with In_i takes place. The evidence of our suggestion is displayed in PL spectra where the intensity of A^0X peak decreases as compared to the non-irradiated state, but D^0X increases.

The evidence of the heating process around Te inclusions is the thermo-focusing into crystal. As the result of the heating process, the laser ablation of crystal the surface opposite the irradiated surface was observed during the experiment.

The possibility to increase CdZnTe:In crystal resistivity by fundamental frequency of Nd:YAG laser radiation at intensity higher than 5.0 MW/cm^2 was shown. This effect is explained by the presence of temperature gradient around Te inclusions caused by their property to absorb laser radiation. As a result, the recombination of In_i atoms and V_{Cd} takes place.

References

1. James R.B., Schlesinger T.E. at all. Semiconductors for room temperature nuclear detector applications. Academic Press, New York, vol.43, 1995. 334 p.
2. Schlesinger T.E., Toney J.E. at all. Cadmium zinc telluride and its use as a nuclear radiation detector material. Materials Science and engineering report, 32, 2001, 103-189 p.
3. Yang G., Bolotnikov A.E. at all. Impurity gettering effect of Te inclusions in CdZnTe single crystals. J Crys.Grows, 311, 2008, 99-102 p.
4. Fiederle M., Babentsov V. at all. Growth of high resistivity CdTe and (Cd,Zn)Te crystals. Crys. Research &Technology 38, 2003, 588-597 p.
5. Fiederle M., Ebling D., Eiche C., Hofmann D. M. at all. Comparison of CdTe, CdZnTe and CdTeSe crystals: application for γ- and X-ray detectors. J. Cryst. Growth 138, 1994, 529-533 p.
6. Yang G., Wanqi Jie at all. Effect of In doping on the properties of CdZnTe single crystals. Journal of Crystal growth 283, 2005, 431-437 p.
7. Sen S., Rhiger D. at all. Infrared absorption behavior in CdZnTe substrates. Journal of electronic material, V.30, nr.6, 2001, 611-618 p.
8. Qiang Li, Wanqi Jie at all. Photoluminescence analysis on the indium doped CdZnTe crystal. J Appl. Phys. 100, 2006, 013518
9. Medvid' A. Redistribution of the Point Defects in Crystalline Lattice of Semiconductor in Nonhomogeneous Temperature Field. - In: Defect and Diffusion Forum, Vol., 210-212, 2002 (Defects and Diffusion in Semiconductors - an Annual Retrospective), 89-101 p.

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