Mechanism of Nanostructure Formation on a Surface of CdZnTe Crystal by Laser Irradiation

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Abstract:

Self-organizing nanometer size structures are observed on the surface of CdZnTe crystal irradiated by strongly absorbed Nd:YAG laser irradiation (LR) at intensity range of 4-12 MW/cm^2. According to this model the Thermogradient effect has the main role in the interaction process of LR and semiconductors. The surface state of the CdZnTe under the influence of Nd:YAG laser irradiation has been studied. A state has been defined by atom force microscope. The influence of LR on the photoluminescence spectra has show that at a threshold intensity of LR I=4MW/cm^2 creation of nanometer size structure begins. A graded band gap structure with optical window was formed at the top of nano-hills.

Keywords: *self-organizing structure, Nd:YAG laser, CdZnTe crystal.*

1. Introduction

The semiconductor solid solutions of $Cd_{1-x}Zn_xTe$ are very promising materials for production of optoelectronic devices and detectors for registration of ionizing radiation [1]-[2]. This is caused by the big width of band-gap and high atomic number of zinc and also by possibility to produce this material with high specific resistance $\rho \approx 10^{10}\Omega$-cm. This material allows creating detectors with big active region capacity, low leak currents and absence of polarization effects. The quality of semiconductor detectors used for registration of ionizing radiation is characterized by the level of that unbalanced charge collection, which is formed under the impact of irradiation quanta. For quantitative charge collection process description the quantity that is equal to the production of mobility value (μ) on charge carrier life time value (τ), that is [3], is used. It defines the length of charge carrier free run that means the volume of active memory. In spite of progress, which is reached in the solution of charge collection problem, and therefore in efficiency of irradiation registration [4]-[7], the increase of charge carrier free run length is active region of the detector during registration of ionizing radiation is the topical task for $Cd_{1-x}Zn_xTe$ detectors.

As is generally known the impurities and defect composition and also the molar portions of CdTe in CdZnTe (0<x<1) can influence the values of μ and τ. Our previous research works of the influence of laser radiation on electro-physical characteristics of CdZnTe crystals has shown, that at high intensities of laser radiation can change the defect composition, irradiated surface morphology and distribution of Zn atoms in crystal takes place, influencing the change of μ and τ values. All these facts evoke the interest in research of such interaction of laser radiation with CdZnTe crystal, which results in the best efficiency of charge collection at γ and X-ray radiation registration.

1.1. Experimental details

High-purity raw materials CdZnTe were used. A single crystal of $Cd_{1-x}Zn_xTe$ (x = 0.1) has been grown by High-Pressure Vertical Zone Melting method. The grown crystals were cut into wafers with dimensions 10x10x1 mm^3. The experiments were carried out at the Research Laboratory of Semiconductor Physics in Riga Technical University, Latvia.

The changes of the structure and optical properties of the near-surface layer of undoped $Cd_{1-x}Zn_xTe$ (x=0,1) crystals caused by powerful laser pulses were studied. A Q-modulated Nd:YAG laser was used as the pulsed source of strongly absorbed radiation with wavelength λ = 0.532 μm and intensity from 4 to 12 MW/cm^2. Pulse duration was 10 ns.

Photoconductivity measurements were used to study the optical properties of the near-surface layer of $Cd_{1-x}Zn_xTe$ crystals before and after irradiation.

The surface structure of the ideally clean CdZnTe surface before and after laser processing was analyzed with atomic force microscopy (Veeco Digital Insruments CP-II).

To prevent the evaporation of Cd, the surface of $Cd_{1-x}Zn_xTe$ crystals was coated with a thin (0.3 m) film of SiO_2, which is transparent to the wavelength of laser radiation [8]. The laser radiation is absorbed by the $Cd_{1-x}Zn_xTe$ (x=0.1) crystal within a thin near-surface layer of the thickness $d \sim \alpha\text{-}1 \approx 10^{-4}\text{-}10^{-5}$ cm (absorption coefficient $a = 6 \cdot 10^4$ cm^{-1} [9]). Therefore, the main effects occur in a thin near-surface layer, the depth of which is determined by the length of thermal diffusion (0.1-0.7 μm [10]) and the absorption coefficient. Intensity of the laser radiation was below the threshold of thermal destruction of the SiO_2/ $Cd_{1-x}Zn_xTe$ structure. The irradiated surface was treated in aqueous solution of HF with aim to remove the SiO_2 film before the study of the surface morphology with the atomic force microscope.

1.2. Experimental results and discussion

Morphology of the semiconductor surface before and after irradiation was studied to find out the influence of high absorbed laser radiation on electro-physical properties of $Cd_{1-x}Zn_xTe$.

The morphological changes were found on the surface of the sample which was irradiated by laser beam with

laser intensity 12 MW/cm^2 (Fig. 1(a)). The changes observed were the cone-like ~10 nm high nanostructures, formed on the microstructure peaks (Fig. 1(b)).

Irradiation of $Cd_{1-x}Zn_xTe$ (x=0.1) crystals by Nd:YAG laser at intensities below the threshold intensity of 4 MW/cm^2 had not changed the surface morphology. The gene-ration of nanostructures began at intensities I ≥ 4 MW/ cm^2. The explanation of nanostructure formation is shown at Fig. 2.

The main role in the initiation of this process has thermogradient effect (TGE) [11]. In conformity with TGE atoms of Zn drift, in toward the minimum of the temperature, that is the bulk of in the sample, and atoms of Cd drift in opposite direction where the maximum of T to the irradiated surface.

The concentration of Zn atoms at the irradiated surface decreases as a result of this movement. The evaluation of our results using theoretical and experimental work [12] has shown that the average concentration of Zn atoms at the sample surface decreases [13].

During laser irradiation Zn atoms move in the bulk of the sample substituting Cd atoms, which move toward the irradiated surface of the sample.

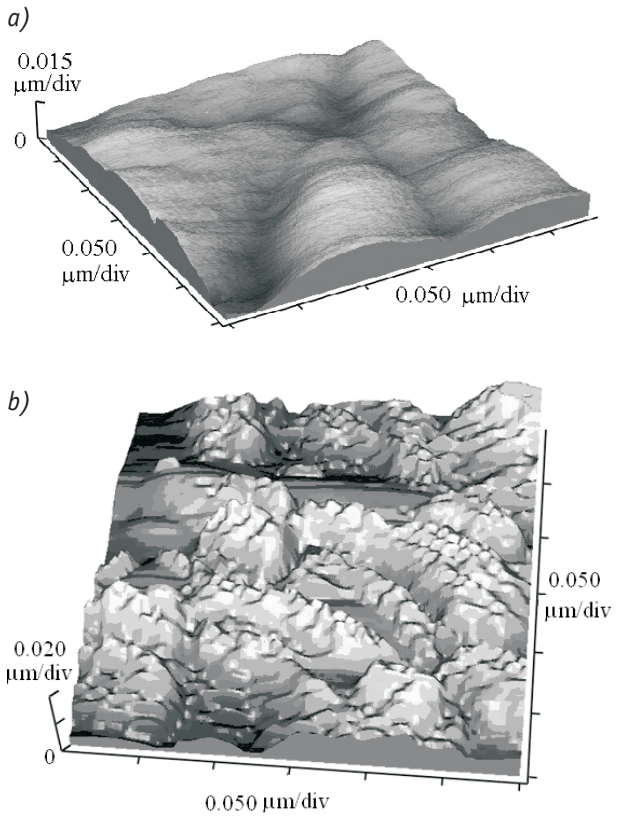

Fig. 1. Atomic force microscope images of the $Cd_{1-x}Zn_xTe$ (x=0.1) surface: a) before irradiation; b) after irradiation at the intensity of 12 MW/cm^2.

The two layers are formed near the semiconductor surface: the top layer consists of CdTe crystal and the lower layer - ZnTe crystal. A mismatch value of there crystal lattice for CdTe and ZnTe crystals is equal to 5.8% [14], that's why the mechanical stress between the layers of CdTe and ZnTe takes place.

The relaxation of this mechanical stress is reached by plastic deformation. This deformation leads to creation of nanostructures of the irradiated surface (Fig. 2) according to modified Stranskova-Krastanova model. The surface layer of the sample is characterized by high radiation stability, because the modified near surface layer contains more atoms of Cd, which have larger atom weight than atom of Zn.

A built-in electric field, generated by graded band gap, is directed in the bulk of the sample due to decrease of surface recombination speed.

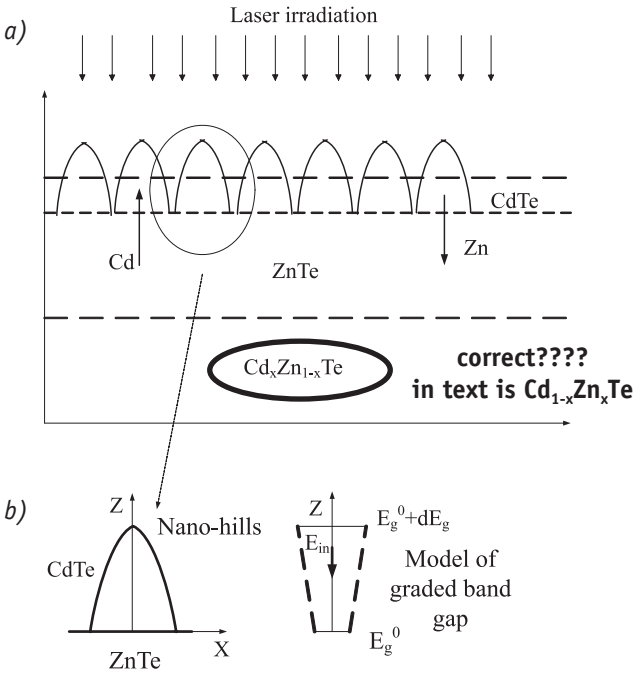

Fig. 2. A model of nanostructure formation a) profile of irradiated crystal b) change of graded band gap in nano-hills.

As a result the carrier collection in this structure (CdZnTe) increases, which is proved by photoconductivity parameter change. (Fig. 3)

The photoconductivity value of CdZnTe samples was recorded at temperature T=300K before and after irradiation by Nd:YAG laser. The photoconductivity curves show, that at laser intensity, that is less than 4MW/cm^2 the shift of "red border of spectral sensitivity" to the longer waves (smaller energies) and the decrease of surface recombination speed was observed. The irradiation by larger energy causes the shift of "red border of spectral sensitivity" to the shorter waves and the increase of the intensity of the photocurrent.

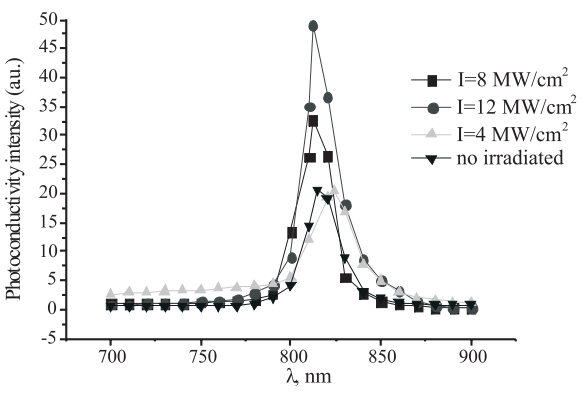

Fig. 3. Photoconductivity curve of CdZnTe detector sensitive element before and after irradiation by Nd:YAG laser.

The shifts of the photoconductivity curve could be explained by earlier meant results. Irradiation of the sample with intensity of 4MW/cm^2 the "red" curve shift is caused by the graded band gap formation with strict optical window, which was found in our previous work [15].

The sample irradiation with larger intensity causes the formation of nanostructure with open optical window. As a result the photocurrent value of the irradiated element increases in comparison with not irradiated sample, which indicates the $\mu\tau$ parameter value increase two times.

2. Conclusion

Studies of the effect of highly absorbed laser radiation on the optical properties of the $Cd_{1-x}Zn_xTe$ (x=0,1) compound have revealed the formation of nano-structures on the surface of the semiconductor under irradiation by the Nd:YAG laser within the intensity range of 4-12 MW/cm^2. A graded band gap structure with optical window is formed on top of the nano-hills. The spectral photo-sensitivity indicates that $\mu\tau$ parameter value increased two times.

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