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Modification of the surface state and doping of CdTe and CdZnTe crystals by pulsed laser irradiation

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ABSTRACT

The photoelectric and electrical properties of high-resistivity *p*-like CdTe and $Cd_{0.96}Zn_{0.04}Te$ single crystals and barrier structures on their base before and after laser irradiation in different conditions are studied. Irradiation of samples with nanosecond ruby laser pulses was carried out in two different ways. In the first case, the Cd(Zn)Te crystals were subjected to laser action directly from the surface and irradiation within a certain range of intensities resulted in a decrease in the surface recombination rate and increase in the photoconductivity signal. The surface region with a wider bandgap in CdZnTe crystals was formed. In the second case, the samples were irradiated from the side pre-coated with a relatively thick In dopant film and it caused rectification in the I–V characteristics as a result of laser-induced doping of the thin Cd(Zn)Te surface region and formation of a built-in *p-n* junction. The application of the fabricated M-*p-n* structured In/Cd(Zn)Te/Au diodes for X-ray and γ-ray detectors is discussed.

1. Introduction

Recently, significant progress in growth technology of high-resistivity CdTe and CdZnTe semiconductors has already made possible to decrease a number of accidental impurities, native point and extended defects and obtain high-quality single crystal wafers suitable for fabrication of high-energy radiation detectors [1–3]. Nowadays, the bottleneck in technology of producing Cd(Zn)Te-based detectors is the treatment of the crystal surface and formation of electrical contacts. The ability to create metal-semiconductor contacts with desired properties (ohmic or blocking contact, electrical junction, etc.) and which are mechanically sound and electrically stable is a key requirement in fabrication of Cd(Zn)Te-based detectors [1–5]. The contact performance depends strongly both on the electrode metal and semiconductor surface preparation before metallization [1–10]. Furthermore, the parameters of metal-semiconductor interfaces can be modified by various treatments of the Cd(Zn)Te crystals during and after electrode deposition.

Surface processing plays one of the major roles in manufacturing Cd(Zn)Te-based radiation detectors because surface properties control many aspects of device performance and operation, for example, the maximum applied bias is often limited by the surface conductivity. In order to achieve a low leakage current, room temperature detectors have usually been developed as diode structures with Schottky contacts or electrical junctions [1–10]. Diodes based on a built-in *p-n* junction are preferred over Schottky diodes, however in this case, there is a problem of heavy doping of high-resistivity *p*-like Cd(Zn)Te crystals because of self-compensation by dopant-native vacancy pairs [11]. In order to suppress the dopant self-compensation mechanism, introduce and activate In atoms with a high concentration in a thin surface layer and thus to form a shallow and sharp *p-n* junction, we have applied laser-induced doping [8–10]. Irradiation of Cd(Zn)Te crystals with nanosecond laser pulses can change the morphology and structure of the surface region [12–15]. In order to monitor the surface state, the photoconductivity spectra of Cd(Zn)Te crystals before and after laser irradiation were measured. Photoresponse spectroscopy is one of the effective methods which is highly sensitive to changes in the surface state, defect system and energy band structure of semiconductors. In this study, the effect of nanosecond laser pulses on the surface state and photoelectric properties of Cd(Zn)Te crystals is discussed. The use of the laser procedure for doping of the surface layer of Cd(Zn)Te semiconductors is analyzed and

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electrical and photoelectric characteristics of the fabricated In/CdTe/Au barrier structures are investigated.

2. Experiment

Experimental investigations were made using commercial (111) oriented Cl-compensated semi-insulating CdTe and high-resistivity $Cd_{0.96}Zn_{0.04}Te$ single crystals of *p*-type conductivity. The linear dimensions of the samples were 5 mm × 5 mm × 0.5 mm and resistivity was $\sim 10^9\ \Omega$ cm and $\sim 10^7\ \Omega$ cm, respectively. Before electrode depositions, the surface of Cd(Zn)Te crystals was chemically cleaned or/and subjected to laser etching [13].

For measurement of the photoconductivity spectra, reasonable ohmic indium contacts were alloyed on the one surface of the samples. The whole area between contacts was entirely and uniformly irradiated at $T = 300$ K. The pulsed radiation source was a ruby ($\lambda = 694$ nm) laser emitting single pulses of $\tau = 20$ ns duration (FHWHM). The incident laser pulse intensity W was varied in a wide range below and above the melting thresholds of the semiconductors.

The experimental setup and procedures of laser-induced doping and formation of In/Cd(Zn)Te/Au barrier structures are schematically shown in Fig. 1. The samples were irradiated with

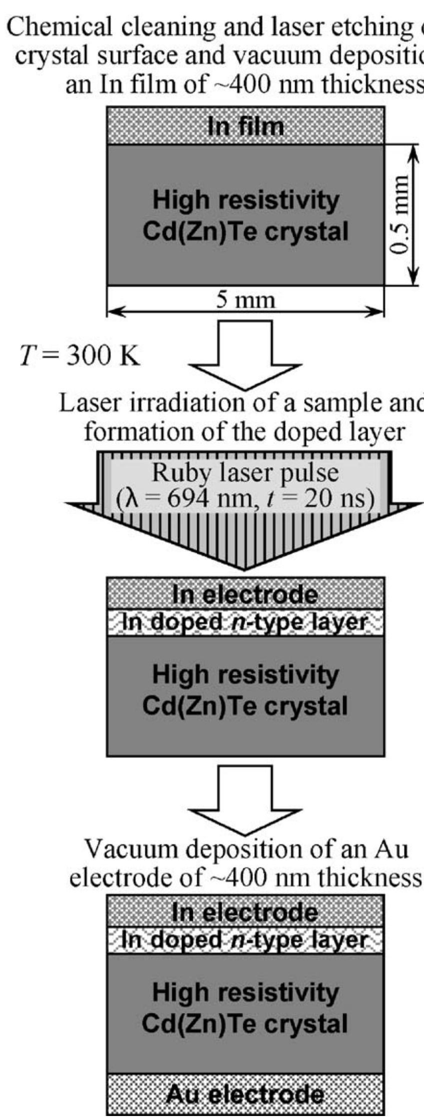

Fig. 1. Experimental setup of the laser-induced doping procedure and fabrication of In/Cd(Zn)Te/Au barrier structures.

ruby laser pulses from the side pre-coated with a relatively thick In dopant film. The thickness of the deposited In film was such that it was not completely evaporated during laser irradiation and the film served further as an electrode. However, some number of In atoms penetrated into the surface region of the crystals, as a result of the action of stress and shock waves [10]. For CdTe crystals, the laser radiation parameters were chosen to obtain the surface layer with a high concentration of In atoms which substituting Cd atoms act as donors and thus to form a sharp *p*-*n* junction [11]. In the case of the CdZnTe semiconductor, the samples were irradiated from the In-coated side with ruby laser pulses of increasing intensity.

The photoconductivity spectra of Cd(Zn)Te crystals and photoresponse spectra of In/Cd(Zn)Te/Au barrier structures were measured by the standard procedure at a fixed modulation frequency of 400 Hz using a MDR diffraction spectrometer. The fabricated In/Cd(Zn)Te/Au diodes was examined by measurement of I–V characteristics which were taken in the dark and under illumination with an incandescent lamp. All measurements were performed at $T = 300$ K.

3. Results and discussion

The photoconductivity spectrum of the Cd(Zn)Te crystals before laser irradiation had a typical Δ-shape, indicating enhanced surface recombination in the strong absorption region (Fig. 2a, b, curves 1). Irradiation of the crystals with ruby laser pulses within a certain range of intensities resulted in increasing the photoconductivity signal and raising the short-wavelength wing of the spectra (Fig. 2a, curves 2 and 3 and Fig. 2b, curves 2–5). These changes were evidence of a decrease in the surface recombination rate because of laser-induced cleaning of the crystal surface, desorption of contaminations and oxides, and annealing of structural imperfections.

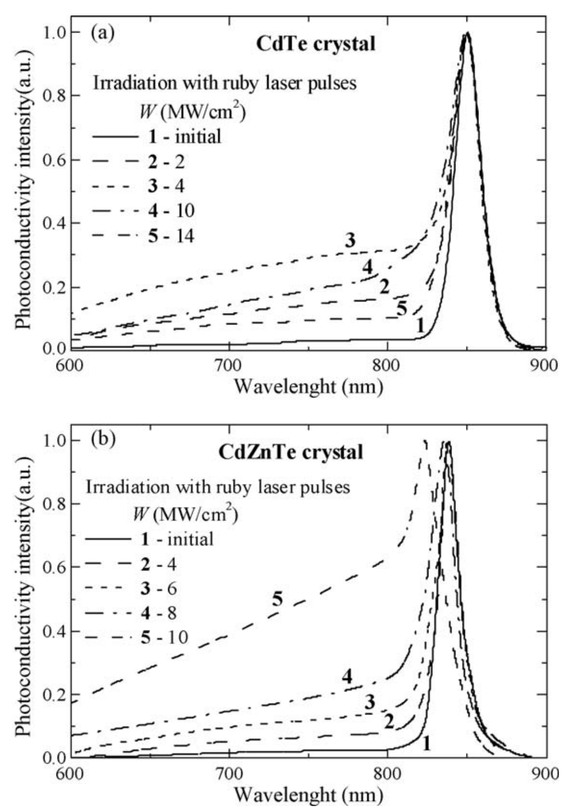

Fig. 2. Photoconductivity spectra of the CdTe (a) and CdZnTe (b) crystals before (curves 1) and after (curves 2–5) irradiation with different laser pulse intensity.