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Optical Sensors of $Cd_{1-x}Zn_xTe$ Bulk Semiconductors Grown by Vertical Bridgman-Stockbarger method

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Abstract

The focus of this paper is to study the optical and electrical characteristics of cadmium telluride (CdTe), zinc telluride (ZnTe) and their ternary compounds. Cadmium zinc telluride (CZT) is a tunable band gap II–VI compound semiconductor. In this work, we grew the CZT crystals from the melt using the vertical Bridgman–Stockbarger method, and the $Cd_{1-x}Zn_xTe$ alloys crystals range of Zn composition(x) 0 to 1 that the CdTe of one binary crystal to the ZnTe crystal. The band-gap energies modulated from 1.41 eV(CdTe) to 2.09 eV(ZnTe) with the increasing content of Zn, which were varied by absorption spectra. According to the extended Vegard's Law has been predicted by absorption spectra. The empirical relation between band-gap energies and composition ratio accorded with a bowing parameter b (b = 0.53 eV). We used the CZT crystals which had a high transmittance in the infrared(IR) range to measure. We measured the band gap energy and responsivity for each of our samples by transmission spectroscopy and photoconductivity(PC) spectrum, respectively. By using a 405 nm wavelength laser as an exciting light source to do photoluminescence(PL) spectra and the Frequency response of PC.

1. Introduction

CZT is a tunable band gap II–VI compound semiconductor, which has driven considerable attention. It has a wide range of band gap energies between 1.41 and 2.09 eV and has a potential for optical applications. CZT alloys are one candidate of semiconductor materials for room-temperature optoelectronic devices. CZT semiconductor has applications in x-ray and gamma-ray detectors due to its high average atomic number [1].

A high quality CZT semiconductor is also a candidate for the top cell of solar cells due to its high transmittance in the infrared(IR) range. With such characteristics, it can also be applied to the ultraviolet(UV) detectors. The study of this work is to investigate the potential of CZT crystals for photodetector(PD) applications. The $Cd_{1-x}Zn_xTe$ crystals were grown in a high temperature and high pressure vertical environment with different Cd and Zn content. The growth method is Bridgman–Stockbarger techniques. The crystal grown had a crystal rod of 1 cm in diameter and the slices thickness about 1 to 1.5 mm in this way. The $Cd_{1-x}Zn_xTe$ crystals with six different Se compositions (x = 0, 0.1, 0.49, 0.89, 0.94 and 1, respectively) have been grown by Bridgman–Stockbarger method. We measured the band gap energy for each of our samples by transmission spectroscopy and PL spectra, respectively. As a UV-PD application, we explore the applicability by PC responsivity measurements and optical experiments. We also performed temperature-dependent transmission measurements to study their temperature-dependence of energy band gap energy.

Based on the above analysis, the relationship between the energy gap offset and the doping ratio are verified and discussed.

2. Results and discussions

Figure 1(a) shows the absorption spectra of $Cd_{1-x}Zn_xTe$ with different Zn contents. Obvious blue shift behavior of the absorption edge is observed upon increasing the Zn composition. The direct band-gap semiconductor can be calculated from eq. (1).

$$(\alpha h\nu)^2 = A\left(h\nu - E_g\right) \qquad (1)$$

The calculated band-gaps of $Cd_{1-x}Zn_xTe$ alloys are tuned with variation of Zn composition. Their band-gaps would change from 1.41 to 2.09 eV, which is in line with the extended Vegard's Law. Figure 1(b) presents the composition-dependent band-gaps of $Cd_{1-x}Zn_xTe$ alloys. The result is accorded with the conventional bowing, as described in eq. (2):

$$E_g(x) = xE_g(ZnTe) + (1-x)E_g(CdTe) - bx(1-x) \qquad (2)$$

where the band-gap bowing parameter b was calculated by absorption spectra, the values of b was 0.53 eV.

We measured the band gap energy and responsivity for each of our samples by transmission spectroscopy and PC, respectively. In this study, we mainly discussed four samples of $Cd_{1-x}Zn_xTe$ crystals which had a high transmittance in the

IR range (x = 0.49, 0.89, 0.94, 1). The PC measurements have been performed by using a 130 W of halogen lamp equipped with a 0.25 m spectrometer. We can find for low zinc composition (x < 0.49) the absorption edges basically close to the onset of PC spectra, but for high zinc samples the PC spectra become very wide in the Figure 3. In the PL spectrum, we observe the free exciton and bound exciton, which comes from the defect in the Figure 2(a)(b). Among them, it can be observed that the PL spectrum of $Cd_{0.51}Zn_{0.49}Te$ crystal has relatively symmetrical luminescence, which is a better crystal with lower defects.

We use the Varshni semiempirical relationship to fit the evolution of the energetic position versus the temperature in Figure 4(a). Varshni's equations contain three fitting parameters for the variation of the band gap energy with temperature (see eq. (3)).[2]

$$E_i(T) = E_i(0) - \alpha_i T^2/(\beta_i + T) \tag{3}$$

Using a white LED was be a light source which had a composite wavelength to measure current–voltage characteristic(I-V) curves of $Cd_{1-x}Zn_xTe$ crystals in Figure 4(b). The results show that $Cd_{1-x}Zn_xTe$ crystals (x = 0.89 and 0.94) have a better response current.

For a further discussion, we used a 405 nm wavelength laser to excite its photo-responsivity at a difference in frequency and bias voltages. Photo-responsivity of the $Cd_{1-x}Zn_xTe$ crystals is a significant parameter to conclude the sensitivity of photodetector. Figure 5(a) indicates the frequency dependence of responsivity, which is excited by a 405 nm wavelength laser operating at various frequencies between 1 Hz to 10 kHz. The $Cd_{1-x}Zn_xTe$ crystals (x = 0.89 and 0.94) linear frequency response between 1Hz and 10 kHz. The photo-responsivity of $Cd_{1-x}Zn_xTe$ crystals have been taken at different bias voltages as shown in Figure 5(b). At high bias voltage, the responsivities of $Cd_{1-x}Zn_xTe$ crystals (x = 0.89 and 0.94) had a better linear trend.

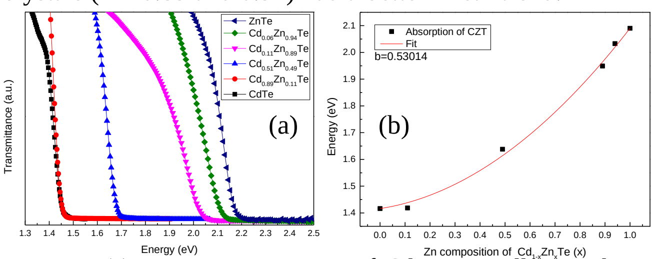

Figure 1. (a)Transmittance spectra of $Cd_{1-x}Zn_xTe$ alloys with six different Se compositions (x = 0, 0.1, 0.49, 0.89, 0.94 and 1, respectively), and (b)composition-dependent band-gaps and the corresponding fitting curve of CZT alloys.

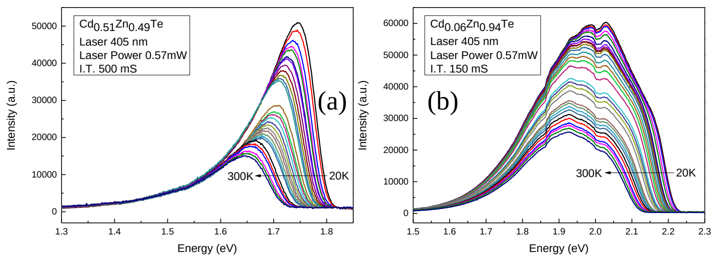

Figure 2. (a)(b)PL spectrum of $Cd_{1-x}Zn_xTe$ crystals for Temperature-dependent (x = 0.49 and 0.94).

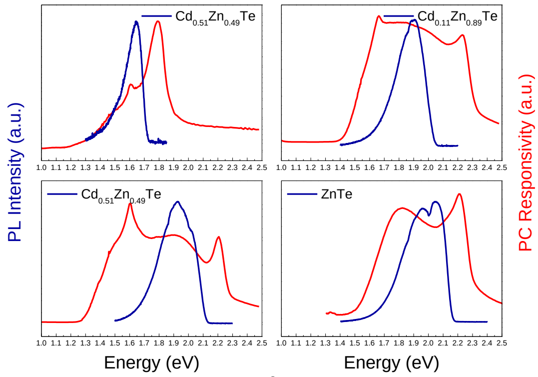

Figure 3. PC and PL spectrum of $Cd_{1-x}Zn_xTe$ crystals. (The optical power of the lamp spectrum approximate to 0 mW at 2.5 eV.)

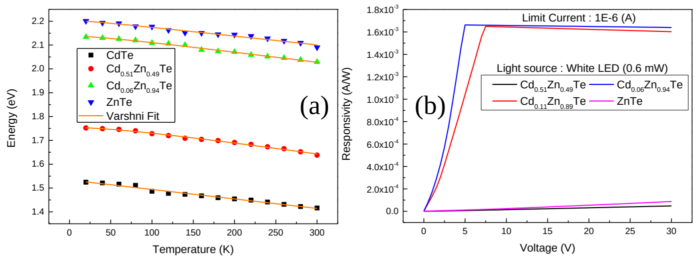

Figure 4. (a)Temperature -dependent band-gaps and the corresponding fitting curve of $Cd_{1-x}Zn_xTe$ alloys. (b) I-V curves of $Cd_{1-x}Zn_xTe$ crystals.

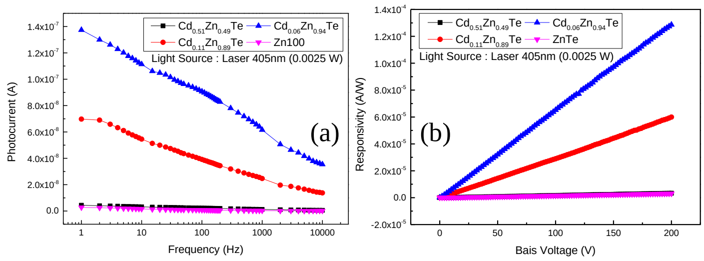

Figure 5. (a)Frequency response of PC curves and (b) photo-responsivity curves at different bias voltages of $Cd_{1-x}Zn_xTe$ crystals.

3. Conclusions

By the Bridgman-Stockbarger method grown, the absorption spectra provide a good relationship between the band gap energy and Zn composition. Defects activated PL due to interplay between bound, charged, and free excitons. In the absorption spectrum of the CZT samples still have the main absorption edges even though the PC spectra become very wide. This method provides effective band-gap engineering by controlling doping ratio to promote their physical and chemical properties, such as zinc concentration, growth technique, pulling rate, applied thermal gradient profile and rotation speed. In the PC with different bias voltage, the CZT crystals can withstand extremely high voltages and have a stable linear frequency responsivity between 1 Hz to 1 kHz. Among these $Cd_{1-x}Zn_xTe$ crystals (x=0.89 and 0.94) have more potential as PD under the same bias voltage.

References

[1] K. Strzalkowski, J. Phys. D: Appl. Phys. 49 (2016) 435106.

[2] P. Geng et al , J. Phys. D: Appl. Phys. 50 (2017) 40LT02