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Illumination response of CdZnTe

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ABSTRACT

CdZnTe (CZT) semiconducting crystals are of interest for use as room temperature X- and γ-ray spectrometers. Several studies have focused on understanding the various electronic properties of these materials, such as the surface and bulk resistivities and the distribution of the electric field within the crystal. Specifically of interest is how these properties are influenced by a variety of factors including structural heterogeneities, such as secondary phases (SPs) and line defects as well as environmental effects. Herein, we report the bulk current, surface current, electric field distribution and performance of a spectrometer-grade CZT crystal exposed to above band-gap energy illumination.

Keywords: CdZnTe, CZT, detector, semiconductor, X-ray, γ-ray

1. INTRODUCTION

CdZnTe (CZT) semiconducting crystals (grown with 10% Zn) are of interest for use as room temperature X- and γ-ray spectrometers because of their high stopping power and high bulk resistivity.[1] Other potential applications of CZT semiconductors include medical and space imaging, solar cells, and as substrates for the growth of other materials that are used for infrared detector applications.[1-4] Several factors can affect the charge transport and collection properties of these materials including the presence of defects and heterogeneities such as secondary phases (SPs)[5], surface properties [6], and electric field distribution[7, 8]. Recently, the optical properties of CZT have also been of interest for the development of new optoelectronic applications.[9-12] Our study will report the effects of above-band-gap illumination on the electronic properties of a single CZT crystal.

We have used a variety of techniques, including surface and bulk current measurements and electric field imaging (via the Pockels effect) to probe the electrical properties of a CZT crystal with and without illumination with 630 nm light. We correlate these results to changes in the spectrometer performance during illumination with 630 nm light of increasing intensity. The specific responses of the crystal and the observed changes in the electrical properties provide further insight into the optoelectronic properties of CZT.

2. EXPERIMENTAL

2.1 Crystal Details and Preparation

The studies discussed herein were performed using a CdZnTe crystal designated R64039B (9.93 x 10 x 4.5 mm^3) with ~10% Zn content (boule), acquired from Redlen Technologies (Victoria, B.C., Canada). This crystal was grown using the traveling heater method. The estimated band gap for CZT with this Zn content is ~1.6 eV.[8] This crystal was previously determined to have a $\mu\tau_e$ of 0.0068(± 5%) $cm^2\ V^{-1}$ and a bulk resistivity of 7.3 x 10^{10} Ω cm.[13]

The top and bottom surfaces of the crystal were mechanically polished using standard techniques, with a final 0.05 μm alumina polish. First, gold contacts were sputtered onto the surfaces of the as-polished crystal in a in a planar detector design for performance, bulk current and Pockels measurements. In this configuration we estimate a light transmission through the gold contacts of 36 to 49%. After these measurements, the crystal was repolished and refabricated in a

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single-pixel detector design (with the pixel on the Te-rich surface) in order to measure the photoinduced surface currents. The pixel diameter was 5 mm with a 250 µm gap between the pixel and the guard.

2.2 Pockels Measurements

The Pockels setup used to capture the space charge field data has been described elsewhere and is illustrated in Figure 1.[7] A 1115 nm lamp was set perpendicular to the applied bias on the crystal and the 640 nm LED was placed at a fixed distance above the anode (Te-rich face), parallel to the applied electric field. Pockels images were taken with and without illumination with a -350 V bias applied to the bottom (Cd-rich face) of the crystal, opposite the LED illumination. The space charge field data was analyzed using the Scanning Probe Image Processor (SPIP™) software by Image Metrology to generate line profiles of the distribution of the electric field intensity.

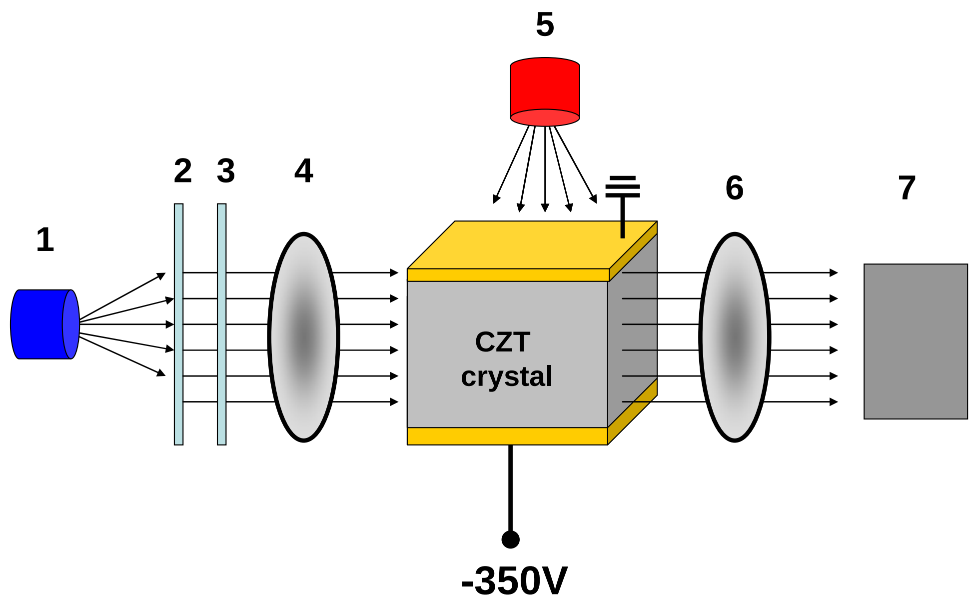

Figure 1. Schematic of Pockels measurement setup. An electric field is applied across the crystal (shown in middle) during the measurement. Numbers indicate different components as follows: (1) 75 W high stability xenon arc lamp, (2) condenser, (3) IR narrow band filter with a bandpass of 1115 ± 5 nm, (4) polarizer 1, (5) 630 nm LED light source, (6) polarizer 2, (7) InGaAs IR camera connected to a computer. Polarizers 1 and 2 cover a range of 1000 to 2000 nm with an extinction factor greater than 1000:1.

2.3 I-V Measurements

Bulk current measurements were made with the crystal in planar design in the Pockels setup as shown in Figure 1. For these measurements, the steady-state bulk current of R64039B was measured with a bias of -350 V applied (electric field of 780 V cm^{-1}) to the bottom contact of the crystal (Cd face). At ~150s, the crystal was exposed to illumination with a 630 nm LED placed at a fixed distance of ~38 mm over the top contact of the crystal (anode, Te-face). The illumination power was 90 µW with an estimated 36 to 49% light transmission through the contact. The bulk current was monitored before, during and after illumination.

The surface current-voltage measurements were made with and without illumination as shown in Figure 2 with the crystal in a single pixel design as described above. In this case, the 630 nm LED, 6.37 µW was positioned at a fixed distance of ~36 mm over this pixel surface during the measurements. The exposed surface area for the crystal was 2.01 x 10^{-2} cm^2, with an estimated 8 to 11% light transmission through the Au contacts.

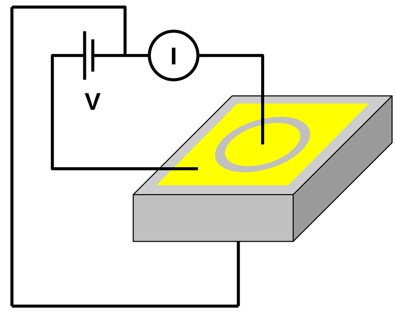

Figure 2. Experimental set-up for measuring surface currents of crystal in single pixel configuration. The bias is applied between center pixel and guard.

2.4. Performance Measurements

The spectrometer performance of the crystal was measured in the planar detector configuration using a ^{241}Am (59.5 keV) gamma source. The performance was measured first without illumination and then with illumination at 630 nm with 3 different powers; ~0.43 µW, ~24 µW, and ~106 µW. In this case, the LED was held at a fixed distance of ~36 mm over the anode (Te-rich face) of the crystal with an estimated 36 to 49% light transmission through the contact. For each measurement, a bias of -350 V was applied to the bottom, Cd-rich face of the crystal. The collection time for each measurement was 2 minutes, with a 1 µs shaping time.

3. RESULTS AND DISCUSSION

The steady-state bulk current measurements and surface current measurements with and without illumination are shown in Figures 3 and 4, respectively. Illumination at 630 nm increases both the bulk and surface currents in this crystal. From the steady-state bulk current measurements, we also see that the illumination at 1115 nm used for creating images of the electric field distribution in CZT via the Pockels effect, increases the bulk current only slightly. We note that the surface current increases by almost two orders of magnitude during illumination, despite the fact that the power of illumination during the surface measurements is <10% of that used for the bulk current measurements. In both cases, the illumination slightly above the band gap creates electron-hole pairs near the surface which contribute to the increase in current.

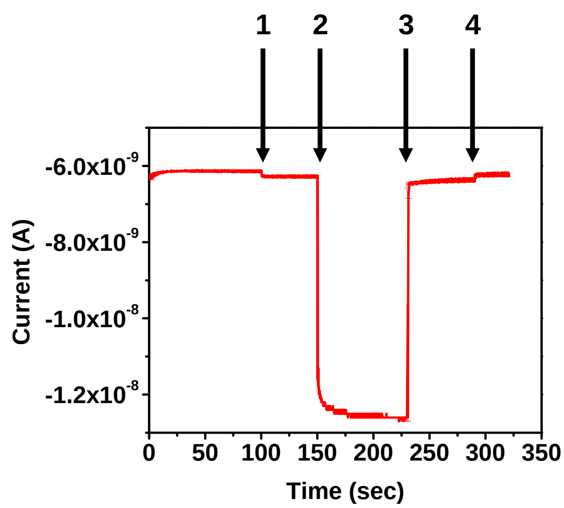

Figure 3. Steady state bulk current measured in Pockels set up, with crystal contacts in planar configuration. The curve is an average of three IV measurements. A -350 V bias is applied to the bottom (Cd-rich) face of the crystal, opposite the LED illumination. The bulk current (resistivity) increases (decreases) during illumination at 630 nm. Arrows indicate: (1) turn on

of 1115 nm illumination, perpendicular to the applied electric field; (2) turn on of 630 nm, illumination at 90 µW power; (3) turn off of 630 nm illumination; and (4) turn off of 1115 nm illumination.

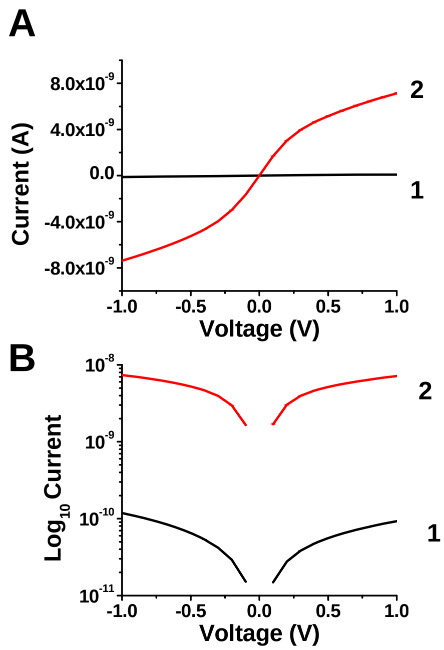

Figure 4. Surface current measured between pixel and guard contacts on the Te rich surface of R64039B. Each curve is an average of three IV measurements. The surface current (surface resistivity) increases (decreases) during at 630 nm. Curves 1 and 2 are with no LED (dark) and red LED (630 nm), respectively.

Pockels images and the corresponding line profiles of the electric field distribution taken with and without illumination at 630 nm (106 µW) are shown in Figure 5. The images reveal some non-uniformity in the electric field distribution, which is attributed to internal stress in the crystal. However, the images also reveal that illumination at 630 nm (under the conditions reported here) does not have an effect on the distribution or intensity of the internal electric field. In contrast to the results presented herein, previous studies have suggested that illumination of CZT with above band-gap light can alter the internal electric field, due to the release of trapped electrons from defect states which drift toward the anode.[14, 15]

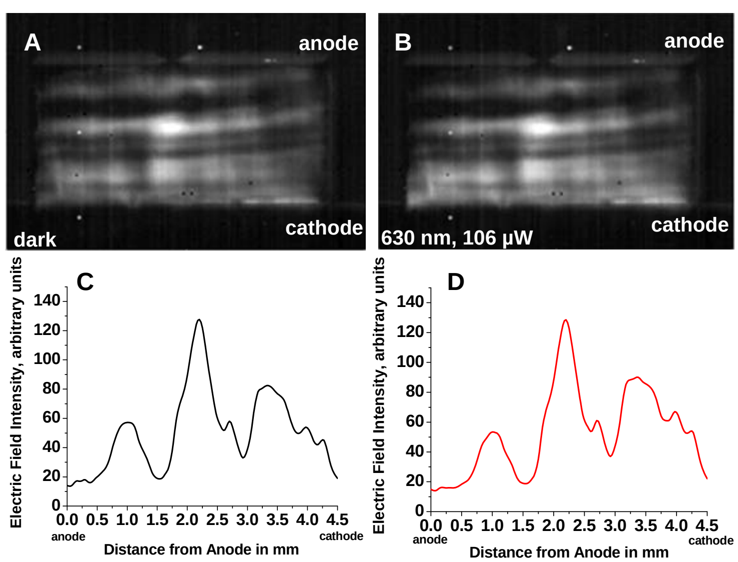

Figure 5. Pockels images and corresponding line profiles of electric field intensity measured (a) without and (b) with LED illumination at 630 nm.

The spectra are shown in Figure 6 and reveal a steady decrease in performance as a function of illumination intensity at 630 nm. The average FWHM values were determined from three consecutive performance measurements without illumination and at each illumination power and are as follows: 3.669 ± 0.03 keV, no illumination; 3.823 ± 0.03 keV, 0.43 µW illumination; 4.108 ± 0.09 keV, 24 µW illumination; and 5.442 ± 0.06 keV, 106 µW illumination. The spectra reveal that the average FWHM and the intensity of lower energy noise increases as the illumination power increases, while the intensity of the peaks decreases as the illumination intensity increases.

We note that photo-induced current spectroscopy studies on CdTe and CZT have utilized above-band-gap illumination to create electron-hole pairs in the top portion of the crystal.[16-20] In the configuration used for the performance measurements discussed above, the excess photo-holes are injected into the bulk of the crystal and trapped, and the current transient after the illumination is turned off is due to de-trapped holes. We do not observe transient current in our bulk current measurement, which suggests that the increased bulk current is due to photoinduced electrons near the cathode. The results shown here are consistent with the observations from current-voltage and Pockels analysis in that there is no observed change in the electric field intensity in the crystal during illumination. Therefore we attribute the decrease in performance to the increase in the bulk and surface current on illumination, causing a decrease in the signal to noise ratio and inefficient charge collection at the contacts. Similar observations with regard to spectrometer performance have been reported for surface etching of CZT with a 1% Br:MeOH solution.[6] In this case, the surface current increased as a result of etching and subsequently, the spectrometer performance decreased.

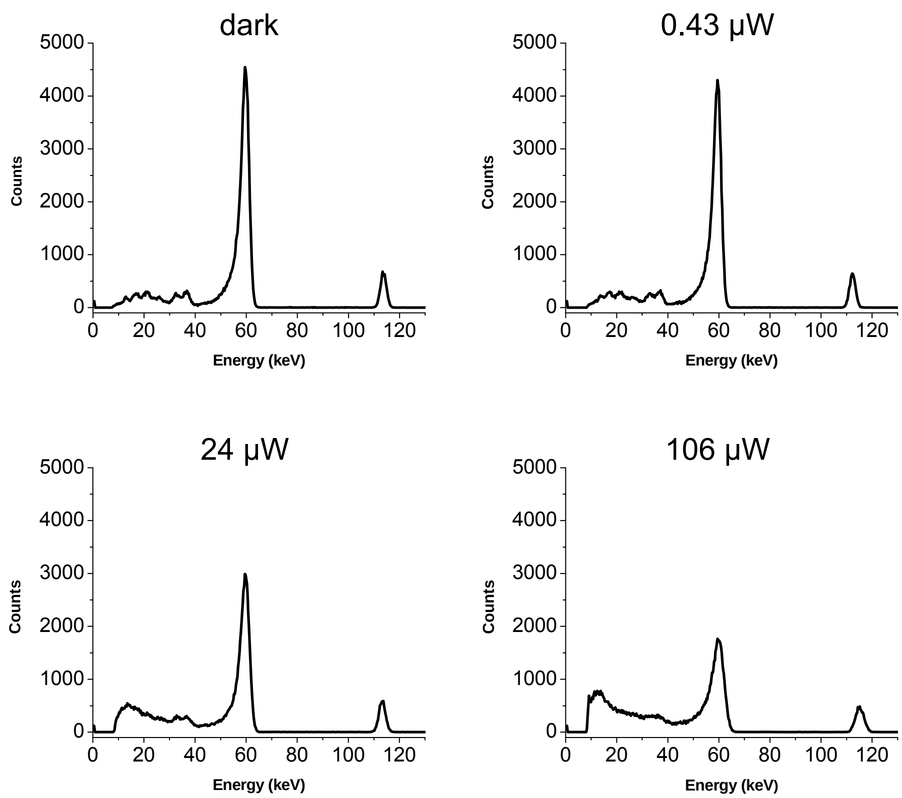

Figure 6. Radiation spectrometer data for R64039B using a ^{241}Am source (-350 V bias on bottom of crystal, Cd-rich face). Light exposure conditions for each are indicated and each spectra shown is the best (lowest FWHM) of three measurements taken for each exposure condition. Each spectrum represents a 2 minute collection time with a 1 µs shaping time. The average FWHM and the intensity of lower energy noise increases as the illumination power increases, while the intensity of the peaks decreases as the illumination intensity increases. Average FWHM values are as follows: 3.669 ± 0.03 keV, no illumination;

3.823 ± 0.03 keV, 0.43 μW illumination; 4.108 ± 0.09 keV, 24 μW illumination; and 5.442 ± 0.06 keV, 106 μW illumination The peaks observed at ~115 keV are the Pulser peaks to measure the electronic noise.

4. CONCLUSIONS

We have used a variety of techniques, including surface and bulk current measurements, spectrometer performance, and electric field imaging (via the Pockels effect) to probe the electrical properties of a CZT crystal with and without illumination with 630 nm light. Our results show that when the crystal is illuminated with this above-band-gap light, the surface and bulk currents increase, the detector performance decreases, and the electric field distribution does not change. The combination of these results suggests that the decrease in detector performance during illumination is due to the increase in surface currents due to a larger number of photocarriers in the crystal.

5. ACKNOWLEDGEMENTS

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