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Change in the Bulk Resistivity of CdZnTe with Selected Near IR Light

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Abstract:

The change in bulk resistivity of CdZnTe (CZT) crystals was measured during infrared (IR) light between 950 and 1000 nm. The crystals are grown using one of the state-of-the-art methods either the traveling heating method or the modified Bridgman method. The change resistivity was evaluated using the steady-state current with and without light. Additionally, the change in current with both IR sources were correlated to the influence of secondary phases (SP) in each crystal using IR transmission microscopy to determine whether the number and size of the impurities has a drastic effect based on the current-voltage (IV) characteristics. SP at various depths within CZT are connected to the existence of variable depth, IR-excitable traps that lie within the bandgap. The release of these traps will significantly affect the overall current in the system. However, the current increase may not match the overall energy of the light utilized are more dependent on the size and quantity for each energy range.

Key words: CdZnTe, bulk resistivity, IR, defect distribution, Light, secondary phases, current-voltage (IV), trap states

Introduction:

High quality characteristics of $Cd_{1-x}Zn_xTe$ (CZT) include high density, high resistivity, wide band gap, and favorable charge transport properties. These make CZT a promising candidate for use as room temperature (RT) x-ray and gamma-ray detectors.[1, 2] Changes in crystal growth methods and post-growth processing over the years have significantly reduced defect levels throughout the crystal bulk though CZT is still on the edge of becoming an attractive alternative for industrial use over traditional detector materials, including silicon and germanium.[3, 4] Some post-growth detector fabrication methods including surface chemical etching and Schottky contact deposition has led to reduced charge transport through the bulk crystal due to carrier trapping at the detector surface. Additionally, charge traps such as impurities and defects, including secondary phases (SP), may further limit charge transport through the bulk.[5] Numerous studies have been shown to investigate charge compensation and carrier transport both in the bulk and over surfaces of CZT detectors.

Previous work has shown selected infrared (IR) light increases charge transport throughout the bulk of CZT with negligible effect on the surface noise. Light directly increases carrier concentration by de-trapping shallow carriers, thereby directly increasing the amount of carriers collected at the electrodes.[6, 7] The IR light effect of CZT charge transport through the bulk may be inferred through evaluation of the bulk resistivity. The influence of IR light is known to lead to an effective reduction of the bulk resistivity of CZT; though the idea hasn't been thoroughly examined in literature.[8] The influence of selected IR light on charge transport through the bulk would be apparent in current-voltage (IV) resistivity curves under very low applied bias (e.g. under 10 V). At higher applied bias, the current across the device is determined by a combination between the barrier height of the surface contact and current transmission through the contact interface.[9]

Experimental:

The CZT crystals that were used for this study include: R64039B, grown by Redlen Technologies (Victoria, B.C., Canada) and YT 3-7-5 and YT 3-7-8, grown by Yinnel Tech (YT, South Bend, IN). All three CZT crystals were grown with ~10% Zn content. R64039B was grown using the traveling heater method and has been post growth annealed while both YT-3-7-5 and YT 3-7-8 were grown using a modified Bridgman method described by Funaki *et* al and utilized without any post growth treatments.[10] Estimated band gap for CZT with 10% Zn is ~1.6 eV. Greater detail on these three crystals may be found elsewhere including focused ion beam/scanning electron microscopy measurements and x-ray topography mapping.[5,11] All crystals were polished with 0.05 μm alumina grit before sputter-depositing gold (Au) contacts onto the top and bottom surfaces in a semi-hemispherical geometry. While the top and bottom contacts were sputter-deposited, side contacts were drop plated using electroless Au. In this geometry, similar to Frisch grid, the bottom surface and all side surfaces are completely coated with Au. The top contact is a centrally located 1.5 mm diameter pixel. Room temperature (24.0 ± 0.5 °C) bulk current was measured for all crystals by applying a low, bulk-dominate voltage. To determine the effect of sub-bandgap light on the crystal resistivity, a single 950 nm light emitting diode (LED) was positioned at a fixed distance above the crystal surface and light produced was varied at multiple optical powers. Adsorption measurements suggest an estimated 36% to 49% of the total incoming LED light was transmitted through the top contact. Adsorption was determined experimentally by sputtering gold onto an optically clear glass slide and measuring the difference in transmitted optical power. Bias was applied via the Cd rich surface, opposite that of the LED light. Crystal bulk resistivity was calculated using the bulk component of each IV curve (low bias: 0-10 V).[12] The crystal was further stressed to +/- 800 V to establish whether the initial resistivity/conductivity changed at higher voltage (i.e. the lines crossed).

SP throughout each crystal were measured by transmission IR microscopy using a Nikon Eclipse LV100 POL microscope and a Nikon DS Fi2 camera. Images were processed using Nikon NIS Elements. Three dimensional images were obtained for samples using a motorized stage moving along the z axis. This stage allowed the crystal to move while keeping the camera at a steady focus plane. A minimum intensity projection was created by the computer to do quantitative determination of SP density. The SP appear as dark spots in the CZT crystal; the CZT itself is transparent to IR light.

Optical absorption of CZT across IR spectra (above 800 nm) is dependent on absorption of specific defect states within the bulk. To locate these defect states around approximate positions within the bandgap, absorption measurements were completed for each CZT crystal using a Varian Cary 400 UV/VIS spectrophotometer. Measurements were taken from 750 nm up to 1100+ nm.

Results and discussion:

The bulk resistivity values are provided with corresponding IV curves shown in Figure 1. Bias was applied to each crystal over three separate periods: without light (A), with crystal light using a 950 nm filter (B), and with crystal light using a 1000 nm filter (C). In each case, bias voltage was applied across ± 800 V. Without light, bulk resistivity values of each crystal are at thresholds above 10^{10} Ω cm^2 which is expected of high quality, low defect material.[9] Selected light using a 1000 nm filter reduces the calculated bulk resistivity (ρ) in each crystal by approximately 1.5 orders of magnitude. Additionally, using a 950 nm filter, ρ is enhanced slightly further for crystals YT 3-7-5 and R64039B, although this improvement is not shown in crystal YT 3-7-8. However, the change in bulk resistivity from light is indicative of photon interaction with charge carriers and charge traps in the mid-gap energy region of each crystal. The significant difference between ρ with and without light describes significant quantity of charge carriers trapped in shallow and mid-gap states. The use of selected IR light de-traps electrons and holes throughout the bulk and reduces recombination sites, leading to greater increase in current with time as compared to measurement without light.

The relative position of IR-affected traps within the CZT bandgap can be described using absorption profiles, shown in Figure 2. Absorption saturation occurs for profiles of all three crystals for all wavelengths below ~815 nm. (+/- 5 nm) Although the absorption falls off exponentially above this wavelength, the presence of various defects and defect concentrations is evident through the different rates of decline in the absorption in the near IR region.[13] Defects in the crystal affecting the relative free carrier concentration and carrier relaxation time lead to imperfections in the exponential decay described in the absorption curvature of a perfect bulk crystal. There are some imperfections evident in the absorption decay for all crystals shown in Figure 2. However, these materials represent still high crystal quality based on their consideration as detector grade material with relatively few shallow and mid-level defects present in the bulk and no gross impurities. Relative concentration of SP comparatively against each crystal is confirmed in the absorption profiles found in Figure 2. The steep profile of crystal R64039B from 820 nm to 850 nm is indicative of a lower number of larger defects. After the initial drop off at 850 nm, the Redlen crystal R64039B levels off at a higher absorption than either of the YT crystals shown in figure 2B. This is indicative of higher defect density in the shallow region for this material where the change in bulk resistivity is also higher when illuminated in this energy range.

The contribution of defects to variance in bulk resistivity between crystals was further investigated using using IR transmission microscopy for each crystal. This technique is well known for effective detection of SP and varying other structural defects in (otherwise) low impurity CZT.[14] Although CZT is transparent to IR, SP scatter at these wavelengths, allowing contrast images to provide a 3D representation of defects/vacancies throughout the bulk. (Figure 3) On typical images, the SP larger than 10 μm occur as larger dot elongated by the 3D stretch, while smaller SP register as dots.

Although numerous possible mid-level and shallow-level defect states have been documented,[15] the dominant midgap trap for as-grown CZT is one associated with Te_{Cd} anti-site defects or to V_{Cd} related to impurities including excess Te.[16] IR transmission 3D micrographs of each crystal, captured in Figure 3, show SP clearly present throughout all three CZT crystals. Concentration of SP has been calculated and compared based on diameter, charted in Figure 4. YT 3-7-5 and R64039 have similar levels of smaller defects (below 10 μm diameter). YT 3-7-5 has the greatest number of total SP, followed by R64039B then YT 3-7-8, although there is only small difference between total number of <10 μm SP for R64039B and YT 3-7-8. However, YT 3-7-8 contains many, much larger SP than the R64039B material. Additionally, YT 3-7-5 contains a similar concentration of “mid-sized” SP. As shown in Figure 3 (C), R64039B does not appear to have any large or mid-sized SP. This is mostly attributed to the post growth annealing process Redlen crystals experience that YT materials lack. In both YT crystals, SP larger than 10 μm diameter account for approximately 10% of the total concentration. Crystals YT 3-7-5 and YT 3-7-8, which contain larger SP, exhibit more rolling, less steep absorption profiles over this wavelength range.

This result is supported by Xu *et al.* who found that a higher concentration of SP leads to a higher bulk leakage current.[14] The increase in leakage current was attributed to the narrow bad gap of Te (~0.3eV), producing a noticeable gain in electrical conductivity with increasing SP. Interestingly, while the use of IR light lowers bulk resistivity of CZT crystals by two orders of magnitude regardless of SP concentration, crystals with greater concentrations of SP exhibit greater change between bulk resistivity with and without IR light than crystals with fewer SP. In other words, the effect of SP to lower bulk resistivity of CZT crystals is enhanced when using IR light.

Conclusions:

The high concentration of SP present in all three crystals may help explain characteristics of the bulk resistivity both with IR light at various energies and without light at all. A higher number of total defects couples with a lower bulk resistivity value. The bulk resistivity of CdZnTe is directly affected by the presence of IR light. We have shown the IR light leads to an increase in bulk current by two orders of magnitude for all CZT crystals tested. Crystals were grown under two different conditions, both methods incorporating ~10% Zn. All three exhibit initial resistivity values (without light) typical of state-of-the-art material. It is suggested the significant increase in bulk current under IR light is tied to de-trapping of charge carriers associated with mid level traps belonging to SP throughout the bulk crystal. Moderate density of such SP with random, uniform distribution throughout all three bulk CZT crystals has been confirmed using IR transmission 3D microscopy. However, additional work is still necessary to determine the influence of SP on bulk current through high-quality CZT material.

Figure Captions:

Figure 1. Current-voltage (IV) curves shown with all three crystals including YT 3-7-5, YT 3-7-8, and R64039B and varying light conditons. (A) no LED light; (B) LED filtered at 950 nm; (C) LED filtered at 1000 nm.

Figure 2. Absorption profile for the three CZT crystals: (A) Below 900 nm and (B) Above 900 nm. (Complete absorption occurs below 800 nm.) The absorption plots have been normalized for three crystals at the band edge.

Figure 3. IR transmission microscopy minimum intensity projection is shown in 3D of total bulk crystal volumes for: (A) YT 3-7-5; (B) YT 3-7-8; and (C) R64039B. SP larger than 10 µm appear as circles elongated through 3D projection.

Figure 4. SP size distribution for CZT crystals obtained from IR transmission images YT 3-7-5 – forward slash pattern, black (color); YT 3-7-8 – solid pattern, red (color); R64039 – backward slash pattern, blue (color).

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