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Effect of surface preparation technique on the radiation detector performance of CdZnTe

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Abstract

Synthetic CdZnTe (CZT) semiconducting crystals are highly suitable for the room temperature-based detection of gamma radiation. The surface preparation of Au contacts on surfaces of CZT detectors is typically conducted after (1) polishing to remove artifacts from crystal sectioning and (2) chemical etching, which removes residual mechanical surface damage however etching results in a Te rich surface layer that is prone to oxidize. Our studies show that CZT surfaces that are only polished (as opposed to polished and etched) can be contacted with Au and will yield lower surface currents. Due to their decreased dark currents, these as-polished surfaces can be used in the fabrication of gamma detectors exhibiting a higher performance than polished and etched surfaces with relatively less peak tailing and greater energy resolution.
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Keywords: Radiation detectors; X-ray topography (crystal defects); Resistivity; X-ray topographic imaging

1. Introduction

CdZnTe or ''CZT'' crystals are attractive to use in homeland security applications because they detect radiation at room temperature and do not require low temperature cooling as with silicon- and germanium-based detectors. Relative to germanium and silicon detectors, CZT is composed of higher Z elements and has a higher density, which gives it greater ''stopping power'' for gamma rays making a more efficient detector. Single crystal CZT materials with high bulk resistivity ($\rho > 10^{10}\ \Omega$ cm) and good mobility-lifetime products are also required for gamma-ray spectrometric applications. However, several factors affect the detector performance of CZT are inherent to the as grown crystal material such as the presence of secondary phases, point defects and the presence of impurities (as described in a literature review by James and co-workers) [1]. These and other factors can limit radiation detector performance such as low resisitivity, which causes a large electronic noise and the presence of traps and other heterogeneities that result in peak tailing and poor energy resolution [1].

Improvements in detector design have occurred that also improve the radiation detection capabilities of CZT crystals. Although these detector designs like the Frisch-grid [2] show great promise for maximizing the capabilities of CZT as a gamma radiation spectrometer (as shown recently by Chen et al.) [3–5] one of the simplest, inexpensive and more common methods of quickly evaluating good and poor radiation detector material is with the use of a planar detector geometry. The penetration depth of low energy gammas (60 keV) and alpha particles is quite low, <200 μm in CZT. The testing of a planar detector with such sources has thus two advantages: (1) the nuclear response is easy to interpret since it should be generated by the bulk collection of electrons, and (2) the overall performance is sensitive to surface preparation via possible mechanisms of surface recombination [6], electronic noise induced by injecting contacts, and surface current leakage [7].

The influence of surface treatment for the purpose of passivating the non-cathode and non-anode surfaces of CZT in

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detectors to reduce their leakage currents has been well studied [1,8–11]. The typical surface treatment on the anode and cathode sides of CZT detectors prior to contact application is usually done by polishing with abrasive grit followed by chemical etching as mentioned by Schlesinger et al. [1].

2. Experimental details

In this study, we examined the effect of surface treatment on the electronic and X-ray topographic properties of two CZT crystals. They were grown by the modified vertical bridgman (MVB) method to have 10% Zn content as described in Li and co-workers [5] and procured from Yinnel Tech (South Bend, IN). A 12 mm × 12 mm × 7 mm portion of the crystal designated CZT3-7-8 and a 12 mm × 12 mm × 4.7 mm portion of the crystal designated YT-5 were polished by standard methods with 0.3 μm alumina followed by 0.05 μm alumina. Half of each crystal was then etched with a 1% Br:MeOH solution (99.98% pure). These crystals were then characterized by IR imaging using a CCD camera for image recording, and prepared with gold (Au) contacts deposited by the sputtering technique. The Au contacts allowed for detector performance testing, surface and bulk current–voltage measurements.

X-ray topography (XRT) studies were performed at the Advanced Photon Source at Argonne National Laboratory (Argonne, IL) using beam line 33-BM. An incident X-ray energy of 9 keV was selected from the white radiation source using a double crystal monochromator with Si (1 1 1) crystals. A rotating foam disc located between the sample and monochromator functioned as a random phase object to remove structure in the incident beam due to phase contrast resulting from imperfections in the beam line Be windows. The faces of the crystals were oriented parallel to (1 1 1) and symmetric (3 3 3) images were recorded from this face. The film was positioned parallel to the sample surface so that the recorded images would not have any foreshortening. Images were recorded on a high contrast lithographic film and in all images the diffraction vector points out of the image.

3. Results and discussion

The surfaces of these treated samples were characterized by transmission IR imaging using a CCD camera for image recording and by XRT prior to applying the gold contacts. A representative IR image of YT-5 is shown in Fig. 1a (IR data for CZT3-7-8 not shown). There are several triangular-shaped objects in addition to objects that appear circular or more polygonal in shape. These secondary phases, which were also identified in sample CZT3-7-8 (data not shown) are sometimes referred to as inclusions or precipitates [12]. The synchrotron-based XRT studies were performed using a

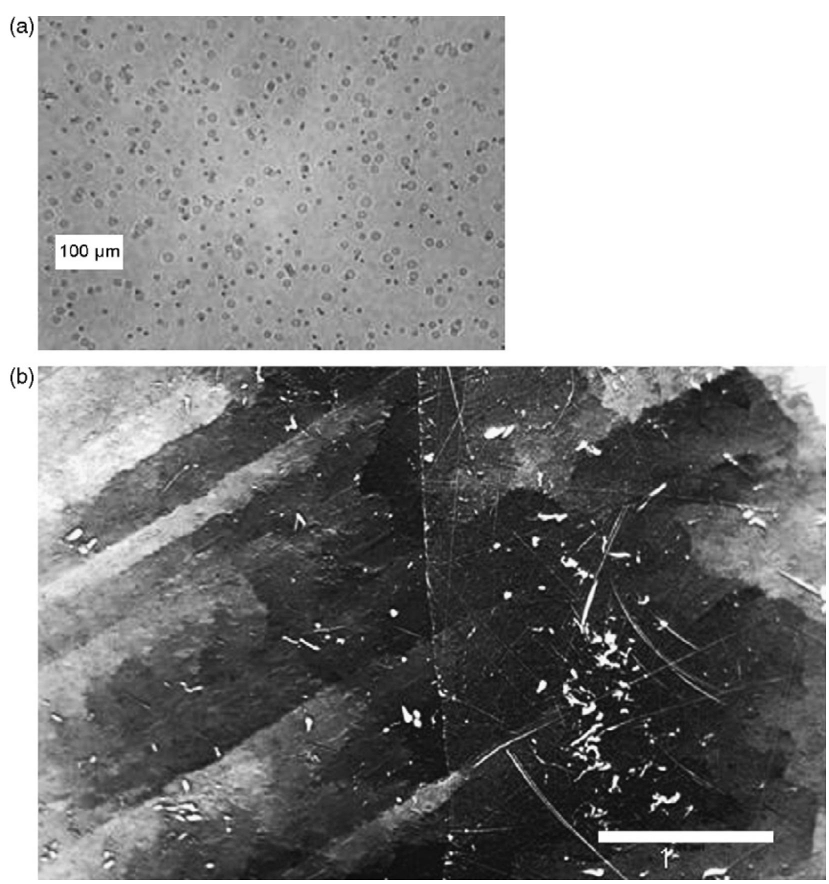

Fig. 1. Characterization of YT-5 using (a) transmission IR imaging (area: 1.5 mm × 2.0 mm; depth of field is 0.25 mm) and (b) X-ray topography by the (3 3 3) symmetric reflection after polishing followed by etching with 1% bromine methanol (left side) and polishing with no etch (right side).

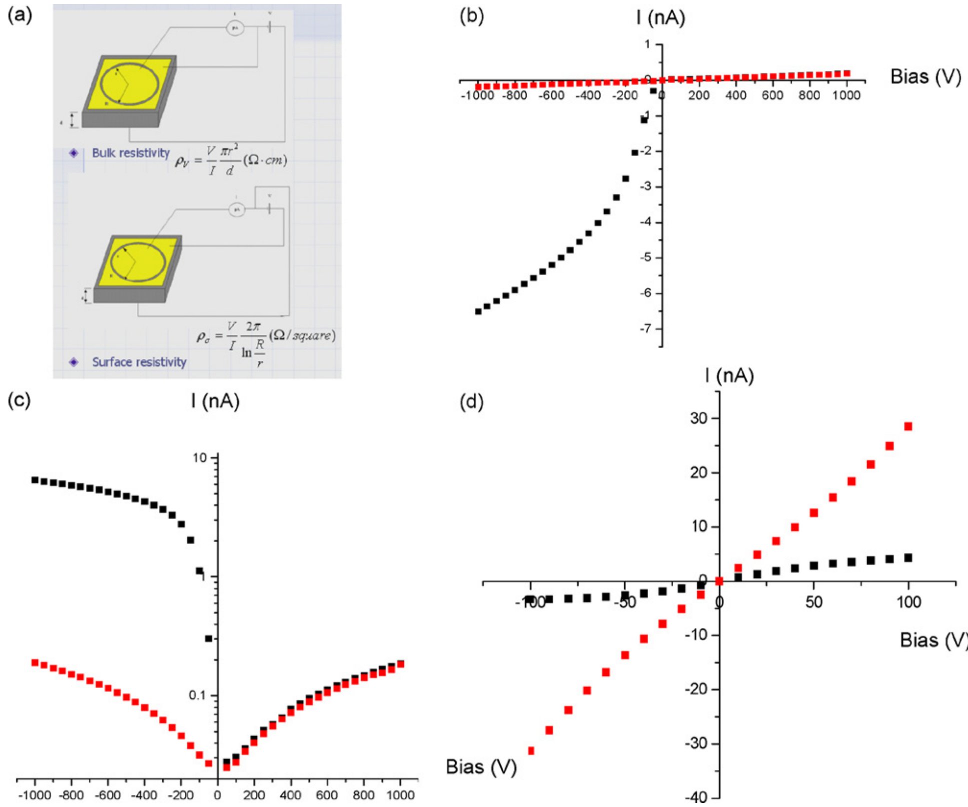

Fig. 2. (a) The theoretical difference between the measurements of bulk versus surface resistivity and the measurement of bulk and surface current–voltage for polished and polished and etched surfaces of CZT, (b) bulk current–voltage measurements for YT-5 in normal scale ($\rho v = 7 \times 10^{10}$ Ω cm), (c) bulk current–voltage measurements for YT-5 in log scale and (d) surface current–voltage measurements for YT-5 ($\rho_\sigma = 6.1 \times 10^{11}$ Ω/Sq. for polished surfaces, $\rho_\sigma = 1.1 \times 10^{11}$ Ω/Sq. for polished and etched surfaces). Black symbols represent polished surfaces. Red symbols represent polished and etched surfaces.

(3 3 3) symmetric reflection from the surface. XRT data for sample YT-5, after treatment with (on the right half) polishing and (on the left half) polishing plus etching are shown in Fig. 1b. Both sides of the crystal show considerable inadvertent surface damage from shipping and handling, which could have a deleterious affect on detector performance particularly for low energy (5–20 keV) X-rays where the penetration depth corresponds to the thickness of the damaged layer. For high energy (100–1000 keV) gamma rays, the signal is developed primarily by the motion of the charge in the undamaged bulk region of the crystal. Additionally, the etched side of YT-5 shows more micro structural details than the other side due to the removal of the damaged surface layer. Similar XRT images were observed for CZT3-7-8 (data not shown).

The surface and bulk current–voltage curves of these two CZT materials were measured using a planar detector design with sputtered Au contacts. The theoretical representation of these two types of current–voltage measurements is presented in Fig. 2a. High bulk resistivity materials and a high metal/semiconductor barrier permit the use of high bias during radiation detector performance studies. A low surface resistivity produces lower electronic noise. Fig. 2b–d shows bulk and surface current–voltage measurements for the two crystals and the two types of surface treatments. These results show that the as-polished (un-etched) surface treatment process resulted in lower surface current measurements relative to the polished and etched treatments.

Subsequent radiation detector performance studies were then performed with these two crystals using alpha and gamma sources. The results are shown in Fig. 3a–d (alpha particle detector data for CZT3-7-8 not shown). The as-polished crystals had higher performance for both alpha particle and gamma-ray detection than the crystals that were etched after polishing and it is believed that this was caused by the improved blocking character of the Au/CZT contact. There was considerably less peak tailing in the as-polished samples as well as greater signal-to-noise and energy resolution.

4. Conclusions

This study examined the effect of surface treatment on the surface quality, bulk and surface current–voltage behavior, and radiation detection performance of CZT. Unanticipated findings, which were reproducible with two CZT crystals from different boules include the following: (1) Au contacts that are sputter deposited on polished and un-etched surfaces produce better performing radiation detectors than those that are etched after polishing and (2) the presence of a surface with considerable physical damage that can be observed using X-ray topographic

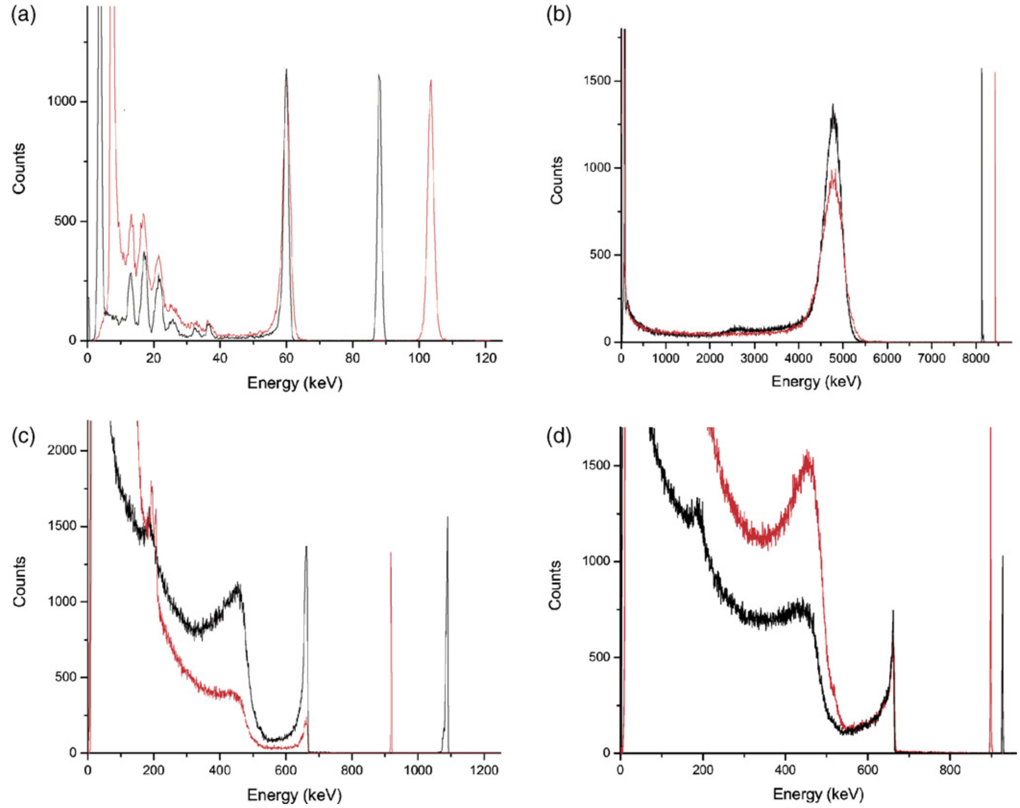

Fig. 3. Radiation detection using a single element planar detector on polished and polished and etched surfaces with (a) ^{241}Am gamma (bias of 500 V, shaping time 1 μs, FWHM: 2.9% for as-polished and 4.1% for polished and etched), (b) alpha source with the YT-5 crystal (bias of 1000 V, shaping time 3 μs, FWHM: 9.8% for polished and 11.9% for polished and etched surfaces), (c) ^{137}Cs gamma detection using the CZT3-7-8 crystal (bias of 1000 V, shaping time 0.3 μs, FWHM: 1.7% for polished and 2.0% for polished and etched surfaces) and (d) ^{137}Cs gamma detection (bias of 1000 V, shaping time 3 μs, FWHM: 1.6% for polished and 2.2% for polished and etched) using the YT-5 crystal. Black symbols represent polished surfaces. Red symbols represent polished and etched surfaces.

imaging does not always correlate with lowered radiation detector performance. One possible explanation for these two findings is the fact that the etching process, which removes the surface damage, leaves a residual chemical contamination on the surface of the CZT crystal. This contamination could result from interactions between the etchant and impurities in the CZT. While this contamination is not imaged by topography it may interfere with the ability of the Au to make a good contact to the surface and hence limit detector performance.

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