BNL-90488-2009-CP

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*Presented at the 2009 SPIE Optics & Photonics Conference*
San Diego, CA
August 2-6, 2009

October 2009

**Nonproliferation and National Security Department**
**Detector Development and Testing Division**

**Brookhaven National Laboratory**
P.O. Box 5000
Upton, NY 11973-5000
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# Electric Field Distribution of Cadmium Zinc Telluride (CZT) Detectors


G. Yang*, A. E. Bolotnikov, G. S. Camarda, Y. Cui, A. Hossain, K.Kim, and R. B. James

Brookhaven National Laboratory, Upton, NY, USA 11973;

*gyang@bnl.gov; phone 1 631 344-4341; fax 1 631 344-3374; Brookhaven National Laboratory



## ABSTRACT

Cadmium Zinc Telluride (CZT) is attracting increasing interest with its promise as a room-temperature nuclear-radiation-detector material. The distribution of the electric field in CZT detectors substantially affects their detection performance. At Brookhaven National Laboratory (BNL), we employed a synchrotron X-Ray mapping technique and a Pockels-effect measurement system to investigate this distribution in different detectors. Here, we report our latest experimental results with three detectors of different width/height ratios. A decrease in this ratio aggravates the non-uniform distribution of electric field, and focuses it on the central volume. Raising the bias voltage effectively can minimize such non-uniformity of the electric field distribution. The position of the maximum electric field is independent of the bias voltage; the difference between its maximum- and minimum-intensity of electric field increases with the applied bias voltage.



**Keywords:** Radiation detection, CdZnTe, Electric field, X-ray mapping, Pockels effect.


## 1. INTRODUCTION

The compound semiconductor Cadmium Zinc Telluride (CZT) is garnering considerable attention due to its excellent potential for application in nuclear-radiation detection. CZT's unique merits, viz., its high average atomic number, sufficiently large bandgap, good electron-transport properties, along with the availability of materials with acceptable cross-sectional areas and thickness, support its high detection efficiency and good energy resolution at room temperature [1-4]. An important parameter substantially affecting the transport behavior of charges and, therefore, the performance of CZT detectors, is the distribution of the internal electrical field; a uniform distribution always is desirable. However, different applications sometimes require cutting the CZT crystals into various dimensions, e.g., width/height ratios that may well change the distribution of the electric field. To improve the performance of CZT detectors, it is essential to clarify the effects of the sample's dimensions on this distribution.

We prepared three CZT detectors of different width/height ratios and undertook micron-scale X-ray mapping on them using highly collimated synchrotron X-ray radiation at Brookhaven's National Synchrotron Light Source (NSLS). Such measurements reflect directly the electric field's two-dimensional distribution [2]. Further, because CZT belongs to a group of crystals exhibiting a linear electro-optic effect, we measured the Pockels effect (PE) to reveal the field's corresponding lateral distribution [3,4]. Here we report our findings, and discuss the factors affecting the electric field distribution.

## 2. EXPERIMENTAL PROCEDURES

We separately cut each of our three CZT crystals into different dimensions, i.e., 15 x15 x 10 $mm^3$, 10 x10 x 10 $mm^3$, and 5 x 5 x 10 $mm^3$ (Fig. 1).The corresponding width/height ratios are 3:2, 1:1, and 1:2. We polished the crystals with a 0.05-µm particle-size alumina suspension, and rinsed them in methanol. After removing the mechanically damaged layers from the crystals' surfaces with a 2% bromine-methanol solution, we placed planar Au-CZT electrodes on the top and bottom surfaces of the crystal.

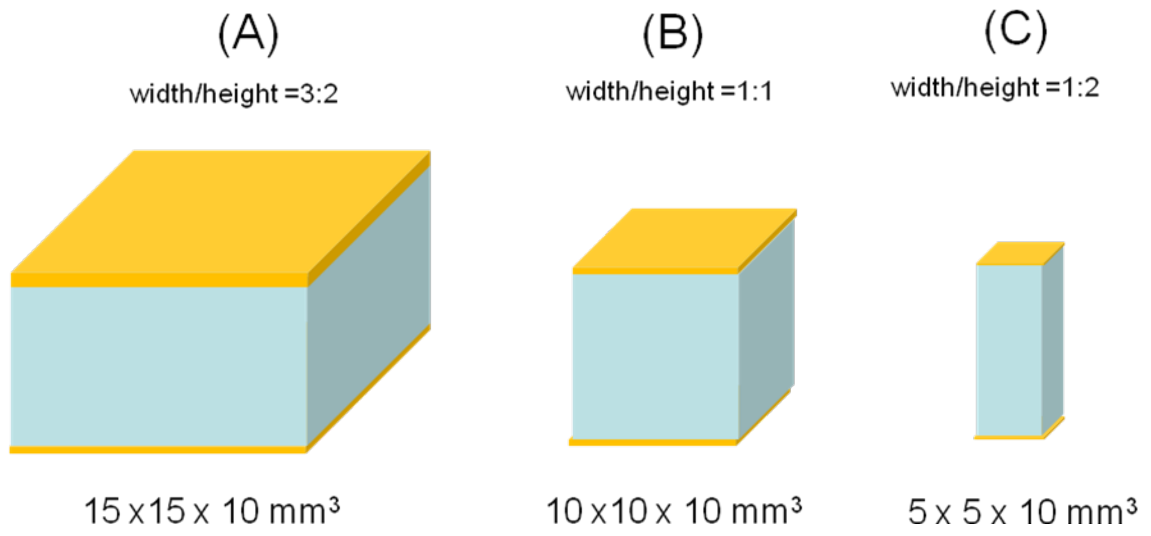


Fig.1 Schematic Diagram of CZT crystals with different width/height ratios

Fig. 2 is a schematic diagram of the micron-scale X-ray mapping system we developed at NSLS. The CZT detectors were irradiated with an X-ray beam, 25x25 $um^2$, from synchrotron radiation. We collected the corresponding energy spectra and their associated information (i.e., pulse height, photopeak position, and FWHM) for each position of the beam. Then, by raster-scanning the CZT detector in the x- and y-directions and plotting the detector's response over its entire area, we acquired X-ray response maps. Because a detector's response is related to charge collection, and is strongly affected by the internal electric field, such measurements yield information on the field's two-dimensional distribution. In the ideal case of a uniform electric-field distribution inside a CZT detector, the resulting X-ray response map would display a pattern identical to that of the electrode used to read the signals. A distorted pattern measured from a real CZT device would signify a deviation from uniformity of the actual electric field distribution.

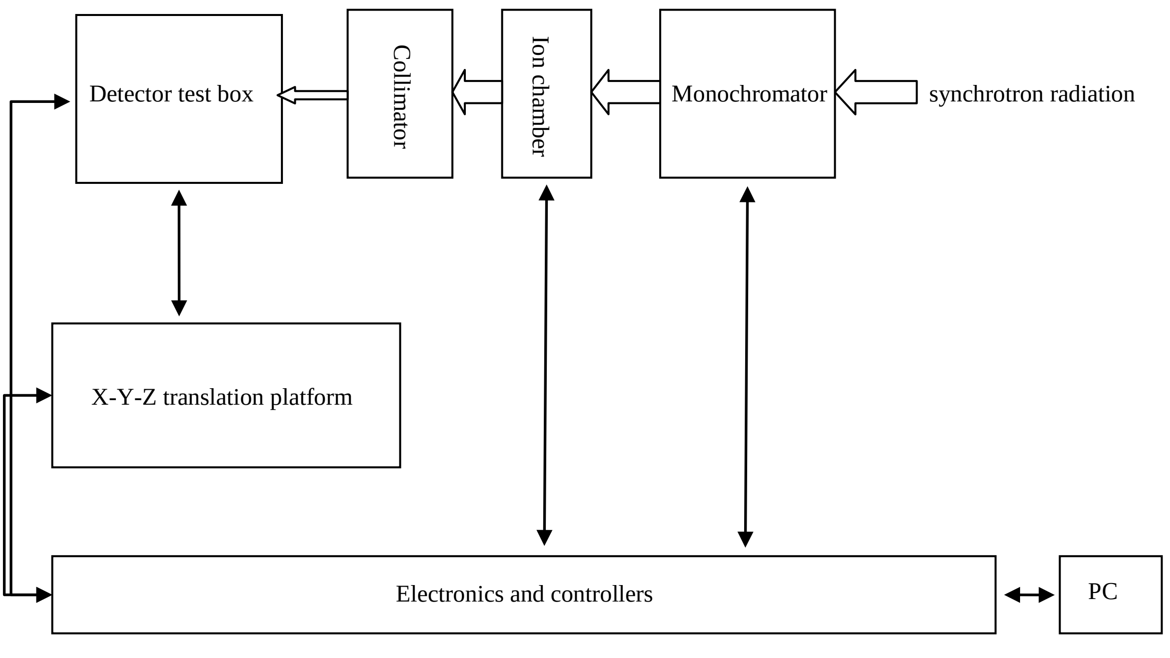


Fig. 2. Schematic diagram of X-ray mapping at NSLS

Further, we employed a PE measurement system, illustrated in Fig. 3, to reflect the corresponding lateral distribution of the internal electric field. In this system, a collimated Xenon lamp with a 950-nm IR filter illuminated the entire detector. Two linear polarizers separately acted as the polarizer and the analyzer. The transmitted light, focused on a CCD camera controlled by SynerJY software, generated satisfactory PE images.

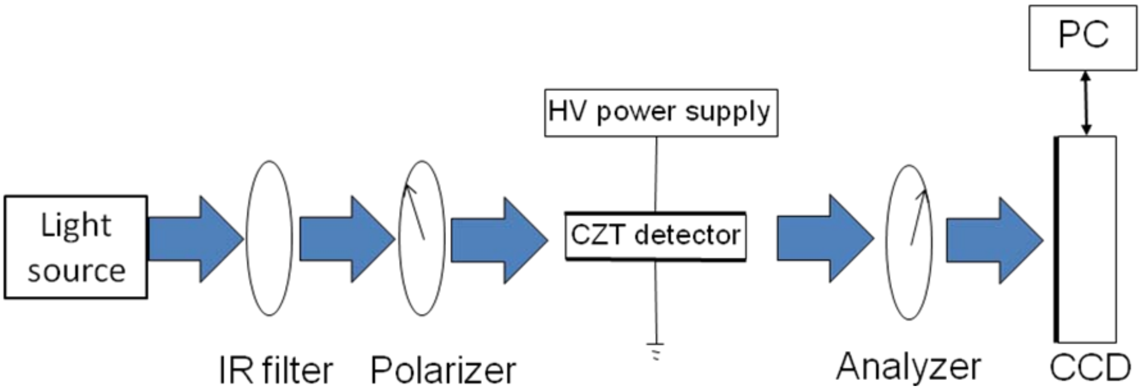


Fig. 3 Schematic diagram of the Pockels effect measurement system

## 3. RESULTS AND DISCUSSIONS

Fig. 4 shows the X-ray mapping results from the three CZT detectors of different width/height ratios. For detector A (width/height ratio, 3:2), the X-ray map reveals a relative uniform color distribution over the whole area, signifying that the carrier-collection capability is similar throughout the volume, and that the detector's electric field is uniform. The X-ray map from detector B, with a lesser width/height ratio of 1:1, clearly shows that intensity at the center is much stronger than that at the edges. The corresponding energy spectra demonstrate that its carrier-collection capability deteriorates when the X-ray beam moves from the crystal's center to its edges; this means the electric field in the center is stronger than that at the edges. For detector C with the lowest width/height ratio of 1:2, the insufficiency of carrier collection at the edges becomes much more pronounced. Undoubtedly, the efficiency of carrier collection worsens near the detector's edges with the decrease in width/height ratio. Likely, the detectors' dimensions dictate these changes in the electric field, and therefore, affect the carrier-collection behaviors.

To confirm this point, we acquired PE measurements from the three detectors. According to Guenther[6], the intensity of transmitted light passing through the crossed polarizer and analyzer is described by

$$I = I_0 \sin^2 \left(\frac{\pi\, n_0^3 r d}{\lambda} E\right), \tag{1}$$

where $I_0$ is the maximum light intensity passing through uncrossed polarizers, $n_0$ is the field-free refractive index, r is the linear electro-optic coefficient for CZT, $d$ is the light path length through CZT crystal, $\lambda$ is the free space wavelength of the illuminated IR light, and $E$ is the mean electric-field along the optical path.

Since $\frac{\pi\, n_0^3 r d}{\lambda} E << 1$ [3], we have

$$I \approx I_0 \left(\frac{\pi\, n_0^3 r d}{\lambda} E\right)^2 \propto E^2 \tag{2}$$

and

$$E \propto \sqrt{I} \tag{3}$$

Therefore, we can deduce the distribution of the electric field (side view) from the intensity distribution of the PE image. Fig. 5 shows the corresponding electric field distribution. Detector A exhibits a uniform electric field throughout its entire volume, while detectors B and C have inactive volumes of electrical field in the corners. The inactive volume of the electrical field is the largest when the detector's width/height ratio is reduced to 1:2. These results strongly support our X-ray mapping analysis, viz., decreasing the detector's width/height ratio aggravates the non-uniform distribution of electric field, and focuses it on the central volume.

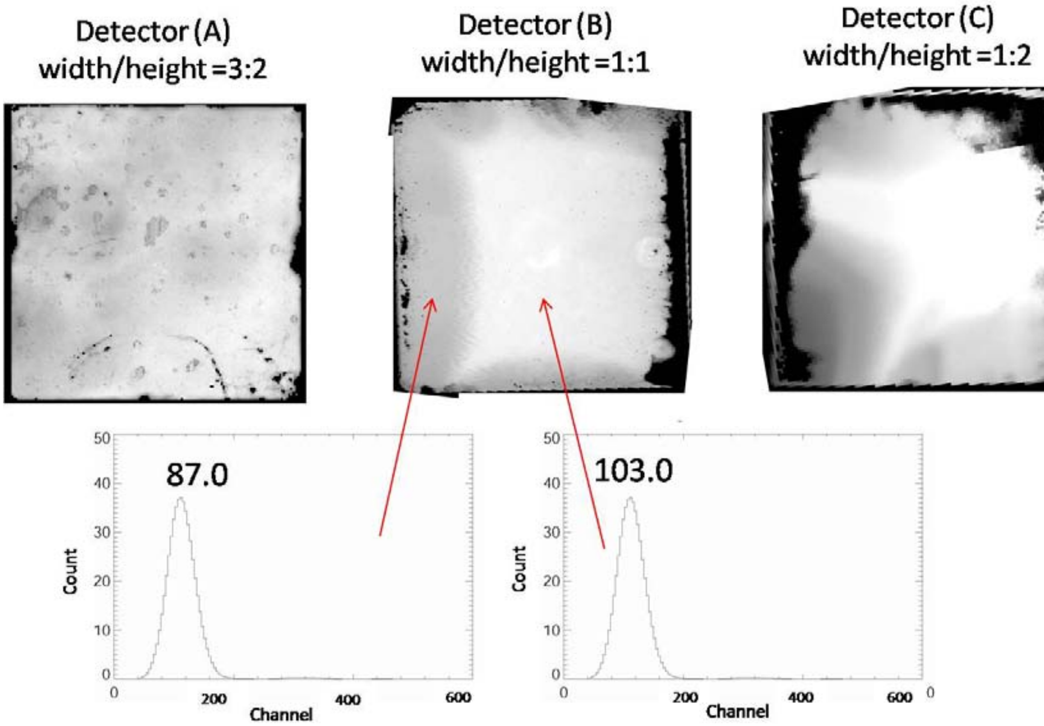


Fig. 4 X-ray mapping results from the three CZT detectors of different width/height ratios. The corresponding energy spectra show that the carrier-collection capability deteriorates when the X-ray beam moves from the crystal's center to its edges.

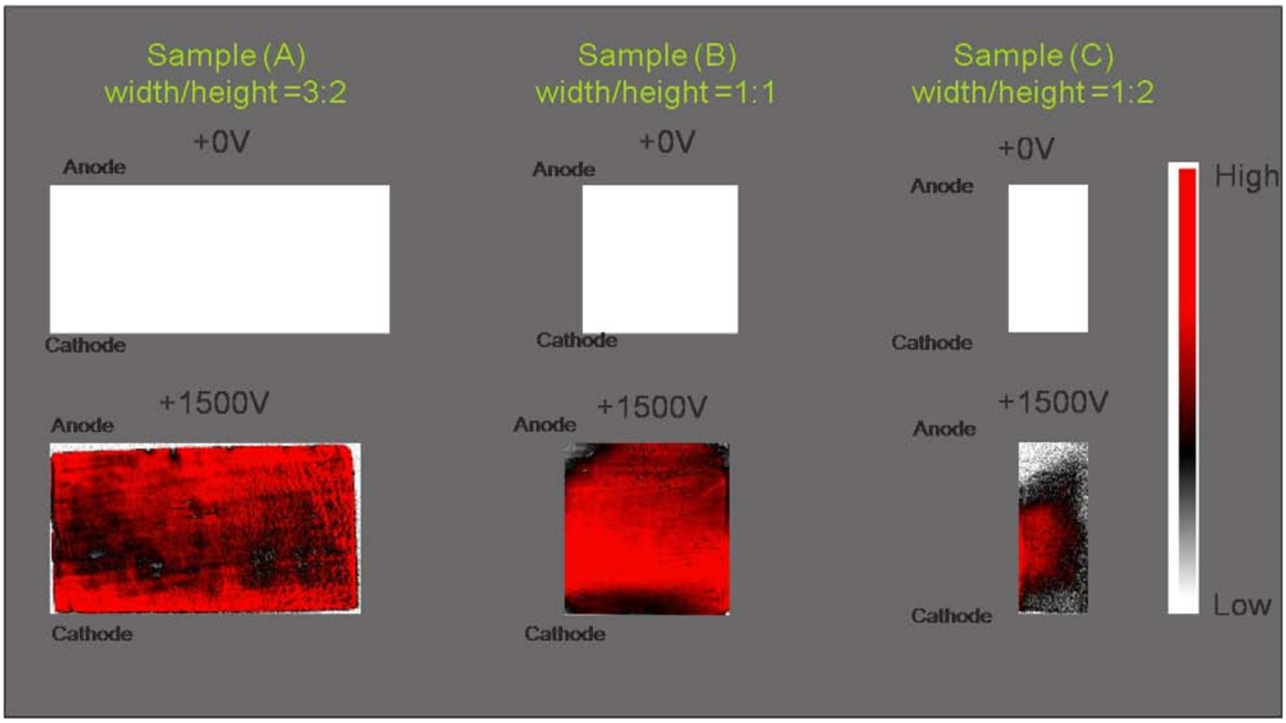

Fig.5 Electric field distribution of CZT detectors with different width/height ratios, revealed by PE measurements. Detector A exhibits a uniform electric field throughout its entire volume, while detectors B and C have inactive volumes of electrical field in the corners.

To further understand this phenomenon and find an effective method to ameliorate this degradation of the electric field, we increased the bias voltage and measured the corresponding change of electric field, as shown in Fig. 6. As the bias voltage rose from +500V to +2000V, the inactive volume of electric field continuously declined, suggesting that heightening the bias voltage can effectively minimize the non-uniform distribution of the electric field.

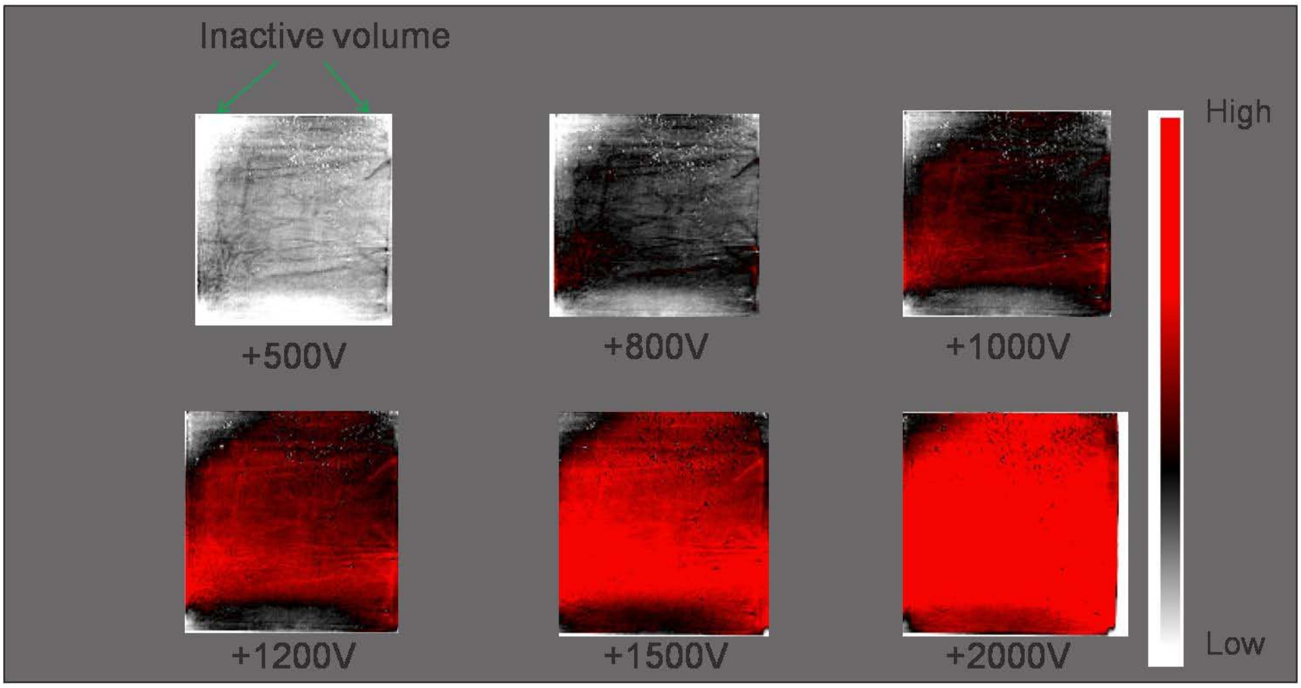


Fig. 6 Electric field distribution of CZT detector (B) under different bias voltages. When the bias voltage rose from +500V to +2000V, the inactive volume of the electric field continuously declined.

Further supporting our conclusion, Fig. 7 shows the internal electric field's profile in the center volume of detector B. From the anode to the cathode, this field firstly increases laterally from the anode towards the cathode until it reaches its maximum value; thereafter, it decreases towards the cathode. Fig. 8 depicts the position of the maximum electric field under different bias voltages. It demonstrates that the position of the maximum electric field tends to remain the same, even when the bias voltage is increased from +500V to +2000V; this finding suggests that the position of the maximum electric field is independent of the bias voltage. However, we note that the difference between the maximum- and minimum-intensity of the electric field within the detectors behaves completely differently, obviously increasing with the applied bias voltage (Fig. 9).

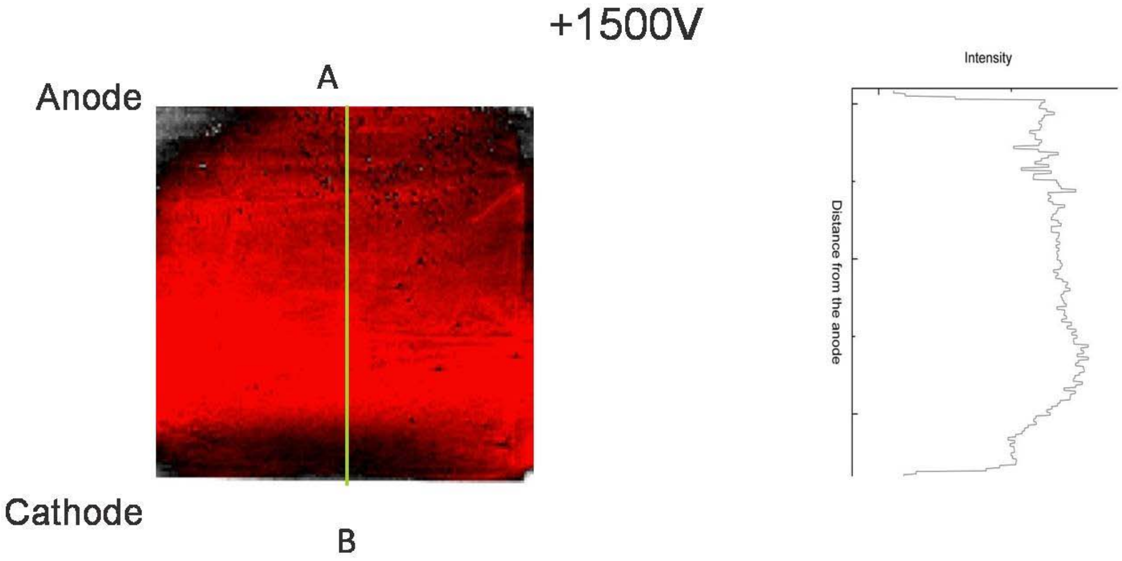


Fig.7 Electric field profile in the center volume of detector (B), revealed by PE measurements. The field firstly increases laterally from the anode towards the cathode until it reaches its maximum value; thereafter, it decreases towards the cathode.

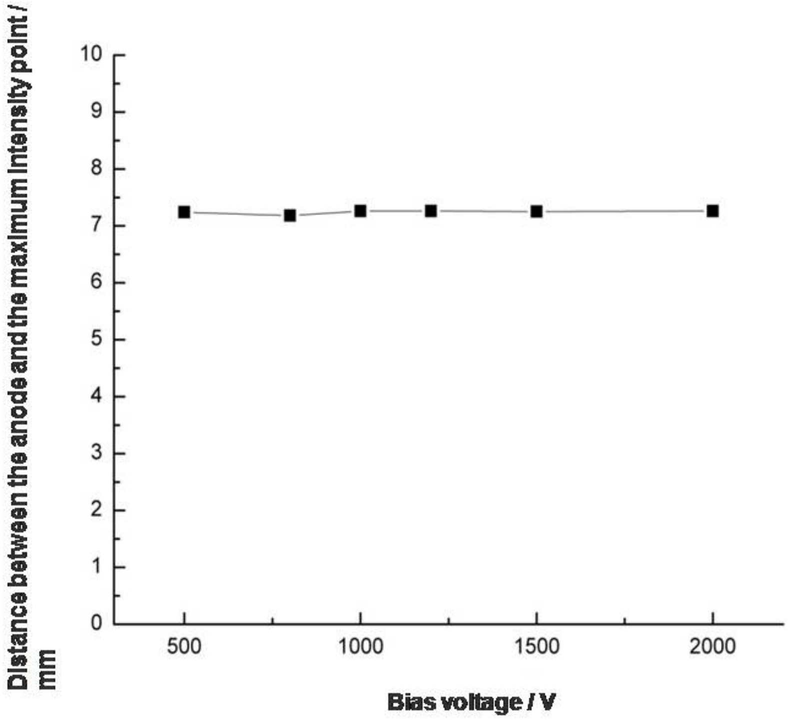


Fig.8 Position of the maximum electric field under different bias voltages for detector (B).

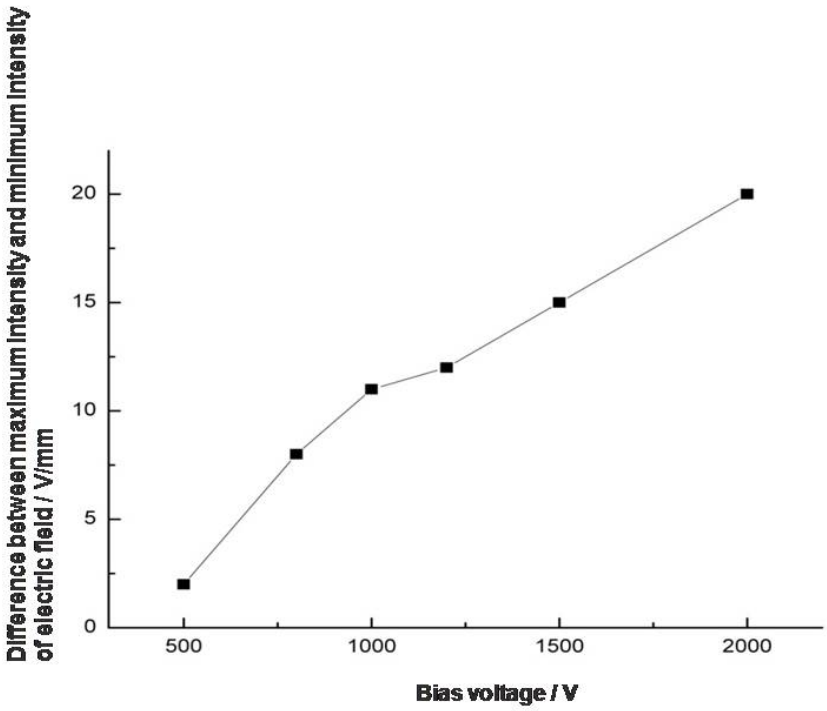


Fig.9 Difference between maximum intensity and minimum intensity of the electric field under different applied bias voltages

## 4. SUMMARY

We investigated the effect of a CZT detector's width/height ratio on the distribution of its internal electric field using a synchrotron X-Ray mapping technique, and a Pockels-effect measurement system. Our experimental results show that decreasing the detector's width/height ratio aggravates the non-uniform distribution of electric field, and focuses it on the central volume. Increasing the bias voltage effectively minimizes such non-uniformity in the electric field's distribution. The position of the maximum electric field is independent on the bias voltage; the difference between the maximum- and minimum-intensity of the electric field increases with the applied bias voltage.

## ACKNOWLEDGMENT

This work was supported by US Department of Energy, Office of Nonproliferation Research and Development, NA-22, and the Defense Threat Reduction Agency. The manuscript has been authored by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy. The United States Government retains, and the publisher, by accepting the article for publication, acknowledges, a worldwide license to publish or reproduce the published form of this manuscript, or allow others to do so, for the United States Government purposes.

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