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# X-ray response of CdZnTe detectors grown by the vertical Bridgman technique: Energy, temperature and high flux effects

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ABSTRACT

Nowadays, CdZnTe (CZT) is one of the key materials for the development of room temperature X-ray and gamma ray detectors and great efforts have been made on both the device and the crystal growth technologies. In this work, we present the results of spectroscopic investigations on new boron oxide encapsulated vertical Bridgman (B-VB) grown CZT detectors, recently developed at IMEM-CNR Parma, Italy. Several detectors, with the same electrode layout (gold electroless contacts) and different thicknesses (1 and 2.5 mm), were realized: the cathode is a planar electrode covering the detector surface ($4.1 \times 4.1$ mm$^2$), while the anode is a central electrode ($2 \times 2$ mm$^2$) surrounded by a guard-ring electrode. The detectors are characterized by electron mobility-lifetime product ($\mu_e \tau_e$) values ranging between 0.6 and $1 \cdot 10^{-3}$ cm$^2$/V and by low leakage currents at room temperature and at high bias voltages (38 nA/cm$^2$ at 10000 V/cm). The spectroscopic response of the detectors to monochromatic X-ray and gamma ray sources ($^{109}$Cd, $^{241}$Am and $^{57}$Co), at different temperatures and fluxes (up to 1 Mcps), was measured taking into account the mitigation of the effects of incomplete charge collection, pile-up and high flux radiation induced polarization phenomena. A custom-designed digital readout electronics, developed at DiFC of University of Palermo (Italy), able to perform a fine pulse shape and height analysis even at high fluxes, was used. At low rates (200 cps) and at room temperature (T=25 °C), the detectors exhibit an energy resolution FWHM around 4% at 59.5 keV, for comparison an energy resolution of 3% was measured with Al/CdTe/Pt detectors by using the same electronics (A250F/NF charge sensitive preamplifier, Amptek, USA; nominal ENC of 100 electrons RMS). At high rates (750 kcps), energy resolution values of 7% and 9% were measured, with throughputs of 2% and 60% respectively. No radiation polarization phenomena were observed at room temperature up to 1 Mcps ($^{241}$Am source, 60 keV), while a detector collapse characterizes the samples at $T < 10$ °C.

Comparison with two traveling heater method (THM) grown CZT detectors (REDLEN, Canada), fabricated with the same electrode layout, is also presented.

These activities are in the framework of an Italian research project on the development of energy-resolved photon counting (ERPC) systems for high flux energy-resolved X-ray imaging.
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## 1. Introduction

In the last two decades, cadmium telluride (CdTe) and cadmium zinc telluride (CdZnTe or CZT) detectors have been widely developed and used for room temperature X-ray and gamma ray spectroscopy [1–4]. CZT/CdTe detectors with thicknesses of 2–3 mm are able to efficiently absorb X rays in the 1–140 keV range and to provide good energy resolution even at room temperature. Recently, CdTe/CZT detectors, with pixelated electrode structures, were proposed for the development of energy-resolved photon counting (ERPC) systems for high flux energy-resolved X-ray imaging, very appealing in diagnostic medicine, industrial imaging and security screening [5–11].

Due to the high-flux conditions of these applications ($> 10^6$ photons mm$^{-2}$ s$^{-1}$), detectors with high bias voltage operation and good charge transport properties are required. Typically, CZT detectors with quasi-ohmic contacts (Au/CZT/Au, Pt/CZT/Pt) [6,12,13] compete with CdTe detectors with rectifying contacts (In/CdTe/Pt, Al/CdTe/Pt) [1,4,9,14], taking into account *bias induced polarization* [15–17] and *high flux radiation induced polarization*

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phenomena [18,19]. CdTe detectors with rectifying contacts, despite the excellent room temperature performance, suffer from the bias induced polarization [15–17]: a space charge builds up with time under the rectifying contact (anode electrode) producing a time dependent electric field profile [17] and then spectroscopic degradations. This limits the thickness of the CdTe detectors (typically $<2$ mm) and the successful operation at low temperatures. CZT detectors with quasi-ohmic contacts are immune to the bias induced polarization, allowing the fabrication of thicker devices ($>2$ mm) and room temperature operation. High flux radiation induced polarization is the major drawback of CZT detectors for ERPC systems. As well documented in the literature [7,18,19], high fluxes produce a charge buildup within the detector, which collapses the electric field and results in a catastrophic reduction of the charge collection efficiency. Due to the dependence of this effect on the charge transport properties of the crystal (mainly on the hole mobility-lifetime product), the bias voltage and the temperature, a careful choice of the detector material, the device properties (electrode contact, bias voltage, thickness) and the operating temperature is essential for the development of high-flux ERPC systems.

Recently, within an Italian research collaboration (DiFC of University of Palermo and IMEM-CNR Parma), we proposed to develop ERPC prototypes, based on CZT pixel detectors and digital pulse processing (DPP) electronics, for high flux energy resolved X-ray imaging applications (1–140 keV). In this framework, we developed, at first step, some CZT prototypes, with planar electrode structures, to investigate on both the crystal and the device properties. In this work, we will present the results of spectroscopic investigations (X-ray response at both low and high fluxes, charge transport properties, temperature dependence and spectral improvements through digital pulse shape analysis) on boron oxide encapsulated vertical Bridgman (B-VB) grown CZT detectors, recently developed at IMEM-CNR Parma, Italy [3,20–24]. An accurate characterization of the response of the detectors, at both low ($<300$ cps) and high (up to 1 Mcps) rates, to monochromatic X-ray and gamma ray sources ($^{109}$Cd, $^{241}$Am and $^{57}$Co) was performed by using a custom-designed digital readout electronics, developed at DiFC of University of Palermo (Italy). The readout electronics is able to continuously digitize and process the signals from the detectors (i.e. the preamplifier output signals) and performs a fine pulse shape and height analysis even at high fluxes.

A comparison with two traveling heater method (THM) grown CZT detectors (REDLEN, Canada) [12,13,25], fabricated with the same electrode layout is also presented.

## 2. Materials and methods

### 2.1. Detectors and front-end electronics

The detectors are based on CZT crystals ($4.1\times4.1\times1$, 2.5 mm$^3$), grown by the boron oxide encapsulated vertical Bridgman (B-VB) technique, which are currently produced at IMEM-CNR (Parma, Italy) [3,20–24]. Further CZT samples ($4.1\times4.1\times1$, 3 mm$^3$) were also fabricated by using CZT crystals grown by REDLEN Technologies (Canada) with the Traveling Heater Method (THM) technique [12,13,25]. Gold electroless contacts were realized by due2lab s.r.l and IMEM-CNR on both the anode (prepared by using water solutions) and the cathode (prepared by alcoholic solutions) of all CZT samples (B-VB and THM crystals). The anode surface is characterized, for all detectors, by a central electrode ($2\times2$ mm$^2$) surrounded by a guard-ring electrode (Fig. 1). The width of the guard-ring is 950 μm and the gap between the electrodes is 50 μm. The cathode is a planar electrode covering the detector surface. The main characteristics of the samples are summarized in Table 1.

To amplify the detector signals, we used a commercial AC-coupled charge sensitive preamplifier CSP (A250F/NF with external FET SK152, Amptek, USA) with a nominal equivalent noise charge (ENC) of about 100 electrons RMS. The CSP is characterized by a resistive-feedback circuit (feedback resistor $R_f=1$ GΩ; feedback capacitor $C_f=0.25$ pF) with a decay time of 250 μs.

The detectors and the CSP were mounted on a custom PCB board based on a Polytetrafluoroethylene (PTFE) substrate (the distance between the detector-anode and the CSP is less than 1 cm). The PCB board was enclosed in a shielded box placed on a Peltier thermal stage with temperature control within 0.1 °C, and filled with nitrogen gas to prevent condensation. The detectors were irradiated through a light-tight beryllium window.

### 2.2. Digital readout electronics

The response of the detectors at both low and high fluxes was measured by using a custom digital readout electronics, developed at DiFC of University of Palermo (Italy) [26–28]. In this section, we will present a brief description of the digital pulse processing (DPP) system. A detailed description of the system is reported in previous works [26–28].

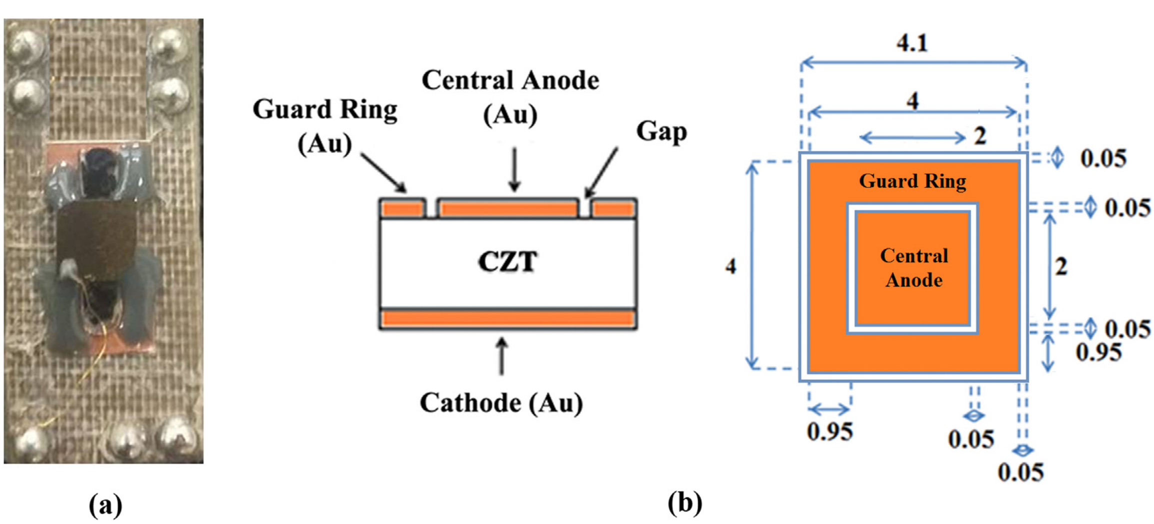


**Fig. 1.** (a) The 1 mm thick B-VB grown CZT detector (cathode side view). (b) Schematic cross section view of the detectors and the anode electrode layout (all dimensions are expressed in millimeters).

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