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Experimental results from Al/p-CdTe/Pt X-ray detectors

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ABSTRACT

Recently, Al/CdTe/Pt detectors have been proposed for the development of high resolution X-ray spectrometers. Due to the low leakage currents, these detectors allow high electric fields and the pixellization of anodes with the possibility to realize single charge carrier sensing detectors. In this work, we report on the results of electrical and spectroscopic investigations on CdTe diode detectors with Al/CdTe/Pt electrode configuration ($4.1 \times 4.1 \times 0.75$ and $4.1 \times 4.1 \times 2$ mm^3). The detectors are characterized by very low leakage currents in the reverse bias operation: 0.3 nA at 25 °C and 2.4 pA at −25 °C under a bias voltage of −1000 V. The spectroscopic performance of the detectors at both low and high photon counting rates were also investigated with a focus on the minimization of time instability, generally termed as polarization, looking for the optimum bias voltage and temperature. Good time stability, during a long-term operation of 10 h, was observed for both detectors at −25 °C and by using an electric field of 5000 V/cm. The 2 mm thick detector exhibited good energy resolution of 6.1%, 2.5% and 2.0% (FWHM) at 22.1 keV, 59.5 and 122.1 keV, respectively. Performance enhancements were obtained by using digital pulse processing techniques, especially at high photon counting rates (300 kcps). The 2 mm thick detector, after a digital pulse shape correction (PSC), is characterized by similar performance to the thin detector ones, opening up to the use of thick CdTe detectors without excessive performance degradations. This work was carried out in the framework of the development of portable X-ray spectrometers for both laboratory research and medical applications.

1. Introduction

In the last two decades, room temperature cadmium telluride (CdTe) and cadmium zinc telluride (CdZnTe) detectors have been proposed and used for high resolution X-ray and gamma ray spectroscopy [1–10]. Thanks to their high atomic number, high density and wide band gap, CdTe detectors ensure high detection efficiency and excellent spectroscopic performance even at room temperature. CdTe detectors are already successfully used for X-ray and gamma ray astronomy, such us balloon (CACT μS [11]), satellite (INTEGRAL [12]) experiments and recently chosen for future missions (SVOM [13], Astro-H [14]). Detection systems, based on CdTe detectors, are also developed for medical applications: nuclear cameras [15], positron emission tomography [16] and mammographic X-ray spectroscopy [17–21]. Typically, high-resolution CdTe detectors are fabricated with rectifying contacts, working as diodes with indium (In) as the anode electrode on a p-type CdTe wafer and platinum (Pt) as the cathode [2,6,17–21]. Rectifying contacts ensure low leakage currents, if compared with an ohmic electrode configuration (Pt/CdTe/Pt), allowing high bias voltage operation and optimum charge collection. Due to the difficulties of dividing an In electrode into pixels, aluminum (Al) has been recently found to be a good alternative electrode material for diode detectors [22]. In addition to low leakage currents comparable to those of standard In/CdTe/Pt detectors, Al/CdTe/Pt detectors allow pixellization of anodes and then the possibility to realize electron-collecting-type diode detectors. Time instability under bias voltage (generally termed as polarization) is the major drawback of CdTe diode detectors, as well documented in the literature [22–31]. Polarization phenomena, due to hole trapping and detrapping from deep acceptor levels (typically related to cadmium vacancies), cause a progressive degradation of the spectroscopic performance with time: losses in detection efficiency, energy resolution and a progressive shift of the photopeaks towards lower energies. These degradations occur more rapidly at high temperatures, at low bias voltages and for thick detectors, as widely shown in several works [22–31]. Several solutions have been proposed to suppress polarization: high bias voltage operation, low temperature, low detector thickness and switching off the bias voltage at regular time intervals. In this work we present experimental investigations on CdTe diode detectors with Au/Ti/Al/CdTe/Pt electrode configuration. We studied the electrical and the spectroscopic properties of the detectors, looking for the

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optimum performance and taking into account polarization effects. Moreover we point out the improvements in the detector response, especially at high photon counting rates, by using digital pulse processing techniques. This work was carried out in the framework of the development of portable X-ray spectrometers for both laboratory research and medical applications.

2. Materials and methods

2.1. Detectors and electronics

The detectors are based on CdTe crystals ($4.1 \times 4.1 \times 0.75$ and $4.1 \times 4.1 \times 2\ mm^3$), manufactured by Acrorad (Japan). The anode surface (Au/Ti/Al) is characterized, for both detectors, by a central electrode ($2 \times 2\ mm^2$) surrounded by a guard-ring electrode. The width of the guard-ring is 950 μm and the gap between the electrodes is 50 μm. This anode configuration ensures low leakage currents than a continuous electrode. The cathode is a planar electrode (Pt) covering the entire detector surface.

To amplify and filter the detector signals, we used a commercial ac-coupled charge sensitive preamplifier CSP (A250, Amptek, USA) and a standard spectroscopy amplifier (672, ORTEC, USA), equipped with different shaping time constant values of 0.5, 1, 2, 3, 6 and 10 μs. A commercial multichannel analyzer (MCA-8000A, Amptek, USA) was used to sample and to record the shaped signals.

To improve the spectroscopic performance of the detectors, we also acquired the preamplifier output pulses by using a custom digital pulse height analyzer, developed by our group [32–34]. The digital system performs a height and shape analysis of the detector pulses (preamplifier output pulses), digitized by a 14-bit, 100 MHz ADC (NI5122, National Instruments). Fast and slow shaping, automatic pole-zero adjustment, baseline restoration and pile-up rejection allow a precise measurement of the height (i.e. the energy) and the peaking time of the pulses. The system also performs a pulse shape analysis (pulse shape discrimination and linear correction), based on the correlation between the peaking time and the height of the pulses [34]. Pulse shape discrimination (PSD) and linear pulse shape correction (PSC) techniques [34] to compensate incomplete charge collection and pile-up distortions were used.

2.2. Electrical and spectroscopic measurements

The leakage current measurements were performed in a custom shielded box, temperature controlled (Peltier cells), by using two source-measure units (Keithley 2410 and 236). To investigate on the spectroscopic performance of the system, we used X-ray and gamma ray calibration sources (^{109}Cd: 22.1, 24.9 and 88.1 keV; ^{241}Am: 59.5, 26.3 keV and the Np L X-ray lines between 13 and 21 keV; ^{57}Co: 122.1, 136.5 keV and the W fluorescent lines, $K_{\alpha1}=59.3$ keV, $K_{\alpha2}=58.0$ keV, $K_{\beta1}=67.1$ keV and $K_{\beta3}=66.9$ keV, produced in the source backing). The 14 keV gamma line (^{57}Co) is shielded by the source holder itself. For high rate measurements, we also used another ^{241}Am source with higher activity and with the Np L X-ray lines shielded by the source holder.

To characterize the spectroscopic performance, we evaluated the typical characteristics of the peaks in the measured spectra: centroid, energy resolution (FWHM) and the area. The photopeak area was calculated as twice the high side area (HSA), i.e. the area between the peak centroid line and the peak's high-energy toe. Each energy peak was analyzed by using a custom function model, which takes into account both the symmetric and the asymmetric peak distortion effects [3]. Measurements at different temperatures were performed by using a temperature chamber (described in an our previous work [8]) with active cooling and heating. Both the detectors and the CSP were placed inside the chamber.

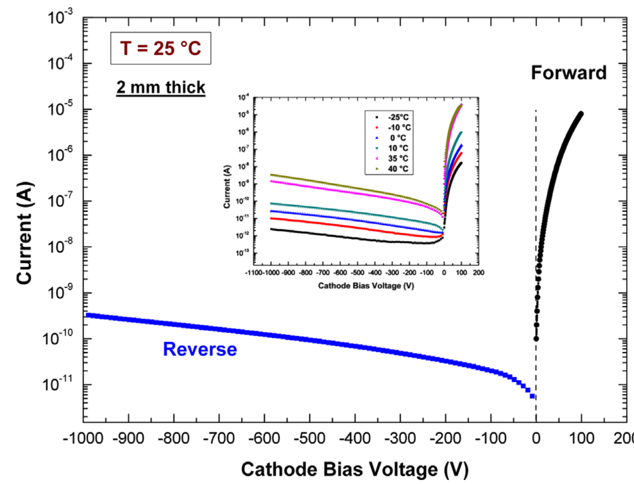

Fig. 1. Current–voltage characteristics of the 2 mm thick CdTe detector at room temperature ($T=25$ °C). The inset shows the current–voltage curves at different temperatures, from −25 °C to 40 °C.

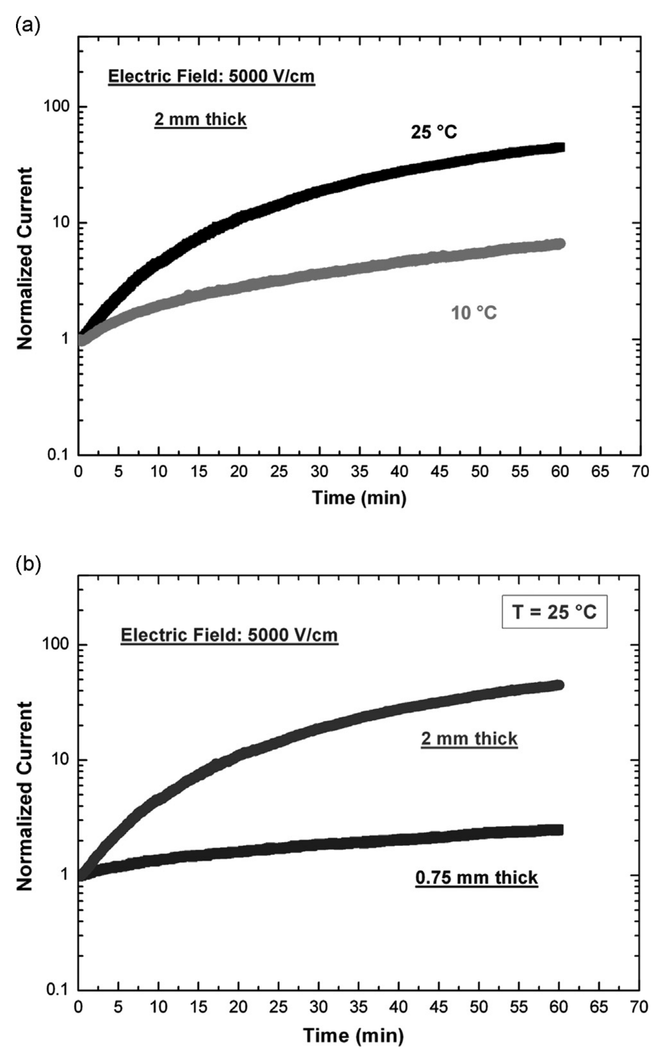

Fig. 2. Time evolution of the leakage current of the CdTe detectors. The leakage current increasing with time occurs more rapidly at high temperature (a) and for thicker detectors (b). Data are normalized to the first measurement.