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Spectroscopic response of a CdZnTe multiple electrode detector

L. Abbene[a,b,*], S. Del Sordo[c], F. Fauci[a,b], G. Gerardi[a,b], A. La Manna[a,b], G. Raso[a,b], A. Cola[d], E. Perillo[e], A. Raulo[e], V. Gostilo[f], S. Stumbo[g,h]

[a] *Dipartimento di Fisica e Tecnologie Relative, Università di Palermo, Viale delle Scienze, Edificio 18, Palermo 90128, Italy*
[b] *INFN, Sezione di Catania, 95125 Catania, Italy*
[c] *IASF/INAF, Sezione di Palermo, 90146 Palermo, Italy*
[d] *IMM/CNR, Sezione di Lecce, 73100 Lecce, Italy*
[e] *Dipartimento di Scienze Fisiche, Università Federico II and INFN, Sezione di Napoli, 80126 Napoli, Italy*
[f] *Baltic Scientific Instruments, Ganibu Dambis 26, LV-1005 Riga, Latvia*
[g] *Struttura Dipartimentale di Matematica e Fisica, dell'Università di Sassari, 07100 Sassari, Italy*
[h] *INFN, Sezione di Cagliari, 09042 Cagliari, Italy*

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Abstract

The spectroscopic performances of a CdZnTe detector (crystal size: $5 \times 5 \times 0.9\,\mathrm{mm}^3$) with five electrodes (cathode, anode and three steering electrodes) were studied. The anode layout, which consists of a circular electrode ($\phi = 80\,\mu\mathrm{m}$) surrounded by two ring electrodes (gap $= 100\,\mu\mathrm{m}$; radial width $\Delta r = 100\,\mu\mathrm{m}$) and by one electrode that extends to the edge of the crystal, is mostly sensitive to the electron carriers, overcoming the well known effect of the hole trapping in the measured spectra. We report on the spectroscopic response of the detector at different bias voltages of the electrodes and at various photon energies (^{109}Cd, ^{241}Am and ^{57}Co sources). The CdZnTe detector exhibits excellent energy resolution (0.87 keV FWHM at 22.1 keV, 1.15 keV FWHM at 59.5 keV and 1.91 keV FWHM at 122.1 keV; working temperature $-10\,^{\circ}$C) and low tailing (FW.1M to FWHM ratio of 1.87 at 22.1 keV, 1.93 at 59.5 keV and 2.01 at 122.1 keV). This study stresses on the excellent spectroscopic properties and the stability of the CdZnTe detectors equipped with a custom anode layout. Furthermore, the obtained results make such detectors very attractive candidates as X-ray spectrometers mainly for medical applications.

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Keywords: CdZnTe detectors; Multiple electrode detectors; Steering electrodes; X-ray and gamma ray spectroscopy; Small pixel effect

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1. Introduction

Interest in the use of cadmium zinc telluride (CZT) as X-ray and gamma ray detector has grown rapidly in recent years [1–3]. Due to the high quantum efficiency and good room temperature performances, CZT spectrometers are very attractive in many disciplines, such as medicine [4,5] and astrophysics [6,7]). Poor hole charge transport properties are the major drawbacks of CZT detectors. Hole trapping causes poor charge collection that gives rise to large tailing on the low energy side of the peaks in measured spectra (hole tailing effect). Several methods have been proposed to overcome the hole tailing. Among these methods, single polarity charge sensing techniques, based on the collection of one type of charge carriers (electrons), have been widely used for CZT detectors. Single polarity charge sensing is generally obtained by using electronic methods (pulse rise time discrimination [8]) and by developing careful anode electrode design (pixels [9], coplanar grids [10], strips [11,12], steering grids [13–15]). In the detectors with a pixel anode layout the

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[*] Corresponding author. Dipartimento di Fisica e Tecnologie Relative, Università di Palermo, Viale delle Scienze, Edificio 18, Palermo 90128, Italy. Tel.: +39 091 6615053; fax: +39 091 6615063.
E-mail address: abbene@difter.unipa.it (L. Abbene).

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weighting potential is low near the cathode and rapidly rises close to the anode. The charge induced on the collecting anode (pixel), proportional to the weighting potential as stated by the Shockley–Ramo Theorem [16,17], is thus contributed mostly from the drift of charges (electrons) in the immediate vicinity of the pixel (small pixel effect [9]). In this paper, a study of the spectroscopic response of a CZT detector, equipped with five electrodes, is reported. The small anode electrode and the additional electrodes on the anode surface, properly biased, optimize the charge collection, minimizing the effect of the hole trapping [9,13] and the effect of the charge carrier diffusion on the detector response. Here, we investigated on the spectroscopic performances of the detector by varying the bias voltage applied on the electrodes, in order to find the best compromise among several competitive effects: the broadening of the electron cloud due to diffusion and mutual electrostatic repulsion [18,19], the charge trapping and the noise associated with the leakage currents (either surface and bulk ones). The response of the detector to various X-ray and gamma ray energies (22.1, 59.5 and 122.1 keV) is presented and discussed. This work is preliminary to further studies concerning the development of portable systems, based on CZT detectors, for medical applications.

2. Materials and methods

2.1. Detector and read-out electronics

The CZT detector was designed by our collaboration and fabricated by the Baltic Scientific Instruments, Riga (Latvia). The detector is based on a CZT crystal ($5\times5\times0.9\,\mathrm{mm}^3$) produced by eV Products (USA). Electrical resistivity of about $10^{10}\,\Omega\,\mathrm{cm}$ and electron mobility-lifetime product $\mu\tau_e$ of about $1.1\times10^{-3}\,\mathrm{cm}^2/\mathrm{V}$ characterize the CZT crystal (supplied by the manufacturer). The cathode (HV) is a planar platinum electrode covering the whole detector surface. The anode surface consists of a circular platinum electrode (the signal electrode; $\phi = 80\,\mu\mathrm{m}$) surrounded by two ring electrodes (HV1 and HV2; gap = $100\,\mu\mathrm{m}$; radial width $\Delta r = 100\,\mu\mathrm{m}$) and by one electrode (HV3) that extends to the edge of the crystal (Fig. 1). The cathode (HV) and the three steering electrodes (HV1, HV2, and HV3) are negatively biased, while the central pixel is at virtual ground. A Peltier cell cools both the CZT crystal and the input FET (2N4416 n-channel FET; DC-coupled to the detector) of the charge sensitive preamplifier; the temperature was measured and monitored by a standard PT100 sensor. Cooling the detector minimizes the charge carrier diffusion and reduces the leakage current, allowed us to apply higher bias voltages to the electrodes of the detector; moreover, cooling the FET increases its transconductance, which reduces the electronic noise. The detector, the FET and the Peltier cooler are mounted in a hermetic TO-8 package, equipped with a light-vacuum tight Beryllium window. The FET output signals were acquired by a standard nuclear spectroscopy signal chain (charge sensitive preamplifier, linear amplifier and shaper, and multichannel analyzer). A test charge sensitive preamplifier, based on a low noise operation amplifier (AD797), optimized for low count rate X-ray spectroscopy [20], was used. The preamplifier output signals were shaped by a standard shaping amplifier (570, ORTEC) with an optimized shaping time of $2\,\mu\mathrm{s}$. A standard multichannel analyzer (MCA-8000A, Amptek, USA) was used to sample and to record the shaped signals.

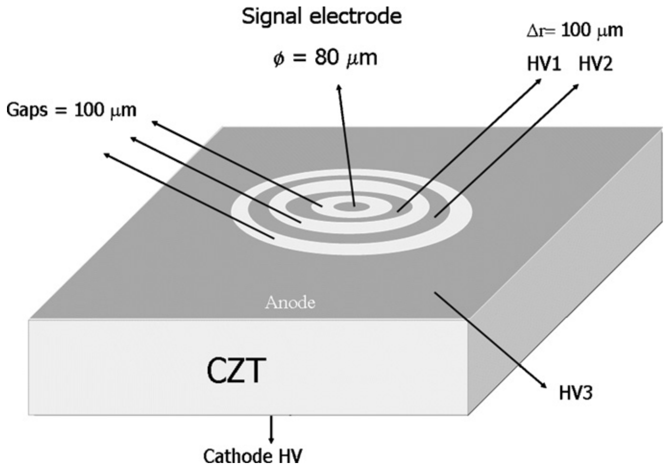

Fig. 1. The layout of the CZT multiple-electrode detector. The small anode electrode is surrounded by three steering electrodes (HV1, HV2 and HV3).

2.2. Detector response and spectra analysis

We measured the CZT detector response by using X-ray and gamma ray calibration sources (^{109}Cd: 22.1, 24.9 and 88.1 keV; ^{241}Am: 59.5 keV; ^{57}Co: 122.1, 136.5 keV and the W fluorescent lines, $K_{\alpha1} = 59.3\,\mathrm{keV}$, $K_{\alpha2} = 58.0\,\mathrm{keV}$, $K_{\beta1} = 67.1\,\mathrm{keV}$, $K_{\beta3} = 66.9\,\mathrm{keV}$, produced in the source backing). The 14 keV gamma line (^{57}Co) and the Np-L X-rays (^{241}Am) are shielded by the source holder itself. An XY micro-translator system allows us to irradiate the cathode surface of the detector with collimated sources (W collimator $\phi = 50\,\mu\mathrm{m}$; positioned at the detector center). The measurements were performed at low temperatures (−5; −10 °C). The spectroscopic performances of the detector were analyzed by evaluating the following parameters in measured spectra: *energy resolution*, *photofraction* and *peak-to-valley ratio*. The full-width at half-maximum (FWHM) of the full-energy peaks was assumed as a measure of the *energy resolution* of the detector. The *photofraction* is defined as the ratio of the Gaussian area of the full-energy peak to the total counts of the entire response function above 7 keV (in the case of the 59.5 keV photons); we used the threshold energy of 7 keV in order to avoid the fluctuations of the number of counts due to electronic noise. In order to quantify the low energy tail of the full-energy peaks, we measured the peak-to-valley ratio and the full width at $\frac{1}{10}$th of the maximum (FW.1M).