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Recent Trends in the Development of CdTe and CdZnTe Semiconductor Detectors for Astrophysical Applications

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Cadmium telluride (CdTe) and cadmium zinc telluride (CdZnTe) offer great promise as x-ray and gamma ray detectors. Due to the high detection efficiency, the good room temperature performance and the recent improvements on crystal growth technology, CdTe and CdZnTe detectors have obtained an increasing interest in the field of hard x-ray and gamma ray astronomy. In this paper, we report on the R&D activities on CdTe and CdZnTe detectors for high energy space instrumentation. Our group has been involved in the design of new multilayer hard x and soft gamma ray Laue lens telescopes and, in particular on the development of focal plane detectors based on CdTe and CdZnTe. Here we present the activities carried out on these detectors for the evaluation of imaging, spectroscopy and polarimetry performances in the hard X and soft gamma ray energy range.

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Introduction

The development of new concentrating multilayer telescopes for hard x- rays (1 – 100 keV) and focusing instruments based on Laue lens operating from 60 keV up the MeV, requires focal plane detectors with high efficiency, fine spectroscopy (a few % FWHM at 60 keV) and with a moderate spatial resolution (between 0.5 and 2 mm). For these applications, cadmium telluride (CdTe) and cadmium zinc telluride (CdZnTe) are considered high performance and reliable materials. Due to the high detection efficiency and the good room temperature performance, these detectors have obtained a great attention from the scientific community involved in the X- and gamma-ray band applications [1,2]. Arrangement of contacts in pixels or strips on these detectors allow the precise reconstruction of the positions of incident x-rays. Moreover, the recent improvements on crystal growth technology with adequate homogeneity and purity is a favourable condition that contributed to confirm CdTe/CdZnTe as effective semiconductor for high performance spectrometers. Currently CdTe and CdZnTe detectors are successfully used in space missions. The International Gamma-Ray Astrophysics Laboratory (INTEGRAL), launched in 2002, carries the Imager on Board the Integral Satellite (IBIS) based on CdTe detectors and the SWIFT satellite, launched in 2004, carries the Burst Alert Telescope (BAT) based on CZT detectors. Next space missions such as EXIST (Energetic X-ray Imaging Survey Telescope) and the NuSTAR (Nuclear Spectroscopic Telescope Array) small explorer satellite will utilize focal plane detectors based on CdZnTe. In this scenario, our groups have been involved, since several years, in the development of new hard x and soft gamma ray telescopes and focal plane detectors based on CdTe/CdZnTe. Here we present the activities carried out on CdTe/CdZnTe detectors as focal plane detectors for imaging, spectroscopy and polarimetry in the hard X and soft gamma ray energy range.

CdZnTe and CdTe pixel detector prototypes for imaging, spectroscopy and polarimetry

Pixellated CdTe/CdZnTe detectors, designed for their imaging capabilities, show good energy resolution due to their single charge carrier sensing properties [1]. The pixel array structure of the anode enhances the electron contribution to the detector signal thus reducing the spectral distortions (hole tailing) due to hole trapping. In the framework of hard x-ray focusing telescopes (10-100 keV) design, our group has been involved in the development of two CdZnTe pixel detectors as focal plane detector prototypes [3]. The detectors ($10\times10\times1$ and $10\times10\times2$ mm^3 single crystals) were designed by our collaboration and fabricated by eV Products, USA. The anode layout is based on an array of 256 pixels with a geometric pitch of 0.5 mm in order to ensure an angular resolution of 30 arcsec (HPD). Spectroscopic investigations showed good energy resolution at room temperature (5.8 % FWHM at 59.5 keV for the 1 mm thick detector; 5.5 % FWHM at 59.5 keV for the 2 mm thick detector) and low tailing in the measured spectra, confirming the single charge carrier sensing properties of the CdZnTe pixel detectors.

Polarimetry has been recognized as a very important observational parameter for high energy astrophysics, as confirmed also by very recent and important results obtained from SPI/INTEGRAL data on the polarization of the Crab pulsar. Polarimetric observations can provide important information about geometries, magnetic fields, composition, and emission mechanisms in a wide variety of gamma-ray sources such as pulsars, solar flares, active galactic nuclei, galactic black holes, or gamma-ray bursts. In the framework of the POLCA II experiment (Polarimetry with CdZnTe Array), a 5 mm thick CdZnTe pixel detector was developed [4]. The detector, fabricated by Imarad, is characterized by an array with 16×16 pixels and a pixel area of 2.5×2.5 mm^2. The detector, operated at room temperature, shows an energy resolution of 5% (FWHM) at 122 keV. Fig. 1 shows the polarimetric Q factor values vs. energy obtained with a monochromatic linearly polarized beam over the energy range between 150 and 700 keV and compared with Monte Carlo simulation results.

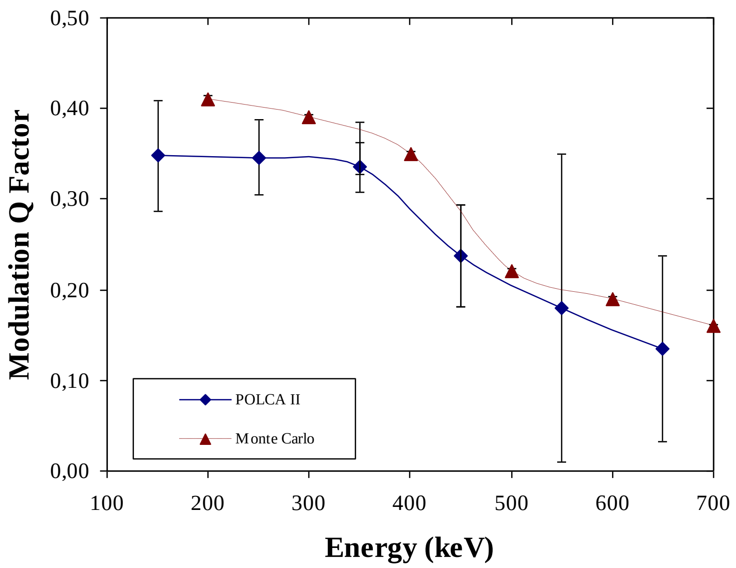
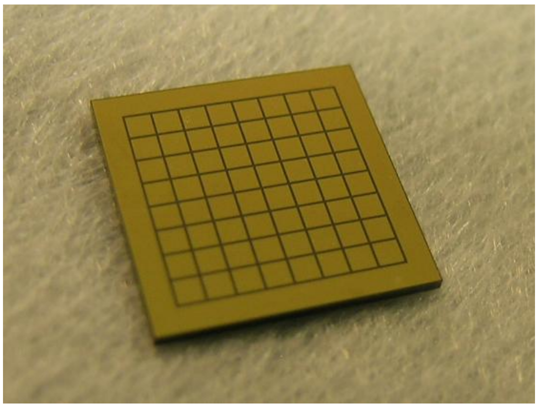


Figure 1: The *Q* factor as function of the energy for a 5 mm CdZnTe prototype when irradiated by a monochromatic 99% polarized photon beam. Monte Carlo simulation results obtained in similar conditions are shown for comparison.

In the POLCaliste experiment, recently started in the framework of a collaboration between INAF and CEA Saclay, polarimetric measurements will be performed with an innovative hard x-ray micro-camera (Caliste 64 [5]) based on a 2 mm thick CdTe (from Acrorad Co.) detector with pixellated Al Schottky anodes (Fig. 2a). The detector anode is an 8 x 8 array of 900 μm pixels. The pixels are separated by a 100 μm gap, and are surrounded by a 900 μm guard ring. The planar cathode is platinum and the anode electrodes are aluminum-titanium-gold.



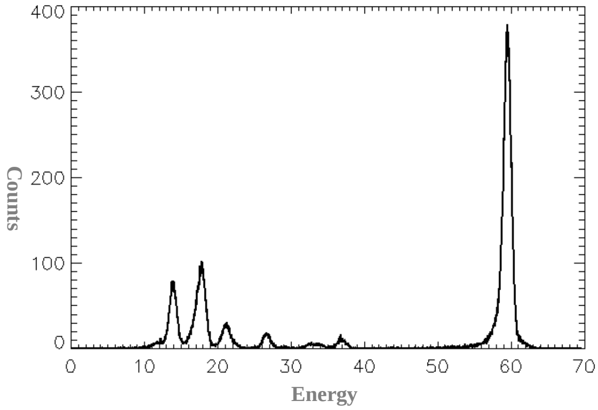


Figure 2: (a) The CdTe detector. **(b)** The ^{241}Am measured spectrum (double events spectrum) with the CdTe detector; the detector shows an energy resolution of 1350 eV (FWHM) at 59.5 keV.

Spectroscopic tests result in a mean energy resolution of ~1.35 keV FWHM at 59.5 keV.

A 3D CdZnTe position sensitive spectrometer

It has been demonstrated that the presence of drift strips on the anode surface improve the performance of CZT detectors [6]. Fig. 3 shows the layout of a three-dimensional (3D) CdZnTe drift strip detector.

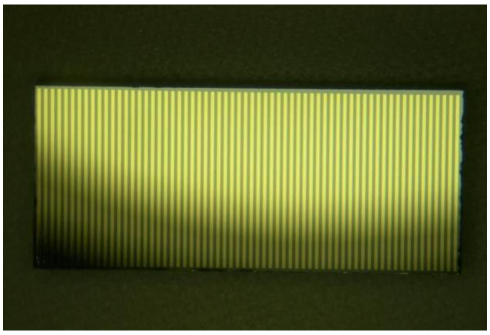


Figure 3: The 3D CdZnTe position sensitive spectrometer (anode side).

The detector, currently on development by our group within the INAF PRIN 2007 project [1], is a 3D depth-sensing position sensitive prototype designed as a pathfinder for a Laue lens telescope focal plane such as the Gamma Ray Imager (GRI), a hard X and soft gamma ray mission recently submitted to ESA in the framework of the Cosmic Vision program. Within this mission proposal, our collaboration has proposed a focal plane based on a stack of thick (up to 20 mm) CdZnTe layers that will allow operation between few keV up to 1 MeV and to perform high sensitivity measurements contemporarily in imaging, spectroscopy and polarimetry. The sensitive unit is a drift strip detector based on a CZT crystal, (10×20 mm^2 area, 2.5 mm thick), irradiated transversally to the electric field lines direction (PTF configuration). The anode is segmented into 8 detection cells, each comprising one collecting strip and 8 drift strips. The drift strips are biased by a voltage divider, whereas the anode strips are held at virtual ground. The cathode is divided in 4 horizontal strips, orthogonal to the anode strips, for the reconstruction of the Z interaction position. These orthogonal strip configuration, designed for the 3-D position sensing, ensures fewer readout channels than a pixellated structure, thus reducing the electronic complexity and the power consumption of the focal plane detector. Currently the read-out electronics (RENA3 chips) and the electronic boards with the CZT crystals and the service electronics are under test and characterization.

Conclusions

In this paper a brief review on the development of CdTe and CdZnTe detectors is given with a particular emphasis on activities carried out in Italy. Among the various topics in this continuously growing field, we point out prototyping activities for astrophysical applications. The detectors development, currently in progress, involve a quite large research group geographically well distributed and representing different research institutions and skills, and aim mainly to achieve a complete and effective detector prototype for focal plane applications, also within the framework of international projects. Also, we consider very important the growth of spectrometer-grade CdTe and CdZnTe crystals in Italian laboratories. In particular, this research line, that recently gives quite good results, will allow to the Italian scientific community a better autonomy in the critical issue of the procurements of good quality CZT crystals.

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