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CZT drift strip detectors for high energy astrophysics

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ABSTRACT

Requirements for X- and gamma ray detectors for future High Energy Astrophysics missions include high detection efficiency and good energy resolution as well as fine position sensitivity even in three dimensions.

We report on experimental investigations on the CZT drift detector developed DTU Space. It is operated in the planar transverse field (PTF) mode, with the purpose of demonstrating that the good energy resolution of the CZT drift detector can be combined with the high efficiency of the PTF configuration. Furthermore, we demonstrated and characterized the 3D sensing capabilities of this detector configuration.

The CZT drift strip detector ($10\,mm\times10\,mm\times2.5\,mm$) was characterized in both standard illumination geometry, Photon Parallel Field (PPF) configuration and in PTF configuration. The detection efficiency and energy resolution are compared for both configurations . The PTF configuration provided a higher efficiency in agreement with calculations. The detector energy resolution was found to be the same (3 keV FWHM at 122 keV) in both in PPF and PTF .

The depth sensing capabilities offered by drift strip detectors was investigated by illuminating the detector using a collimated photon beam of ^{57}Co radiation in PTF configuration. The width (300 μm FWHM at 122 keV) of the measured depth distributions was almost equal to the finite beam size. However, the data indicate that the best achievable depth resolution for the CZT drift detector is 90 μm FWHM at 122 keV and that it is determined by the electronic noise from the setup.

1. Introduction

The upcoming X-ray astrophysics missions in the keV to MeV band require instrumentation advanced in both spectral and imaging capabilities of the detectors and in the capabilities of X-ray imaging optics. The instrumentation for these types of telescopes requires detectors of high efficiency, with energy resolution on the order of a few keV and the capability of three dimensional (3D) position sensitivity.

Compound room temperature semiconductor detectors such as CdZnTe (CZT) and CdTe are good candidates for hard X-ray ($>10\,keV$) and $\gamma-$ray astronomy instrumentation. A major drawback for these type of detectors is the ineffective charge collection within the detector, especially for the holes which affect and degrade the detectors' spectral performance. At DTU Space, the development of CZT Drift Strip detectors [1] and [2], resulted in significant spectral performance improvements.

2. CZT drift strip detector

Fig. 1 shows the principle of CZT drift strip detectors. The detector structure is similar to the Silicon drift detector which was first time introduced by Emilio Gatti and Pavel Rehak in 1983 [3]. A CZT drift strip detector cell is shown between the dashed lines marked with A and B. The structure employs a number of drift strips (small black boxes) separating the anode readout strips (small white boxes labeled as Q_s) on one side and a planar electrode on the other. A voltage divider supplies each drift strip with a bias of $V_i=V_d\times(i/4)$, $(i=1,2,3,4)$, while the anode strips are held at ground potential. The detector is biased such that the electrons, produced by the photon interaction, are drifted to an anode readout strip with their transport properties (mobility-lifetime product, $\mu\tau_e$, up to $10^{-2}\,cm^2/V$ for CZT). The positive charges (holes) produced by the photon interaction have a poor mobility-lifetime product ($\mu\tau_h$, values up to $10^{-5}\,cm^2/V$) in CZT and will, with high probability, be trapped in the detector. However, the anode signal is unaffected by the holes since the anode strips are screened by the bias strips [1]. The anode signals are therefore proportional to the photon energy and high spectroscopic performance is ensured for CZT materials with

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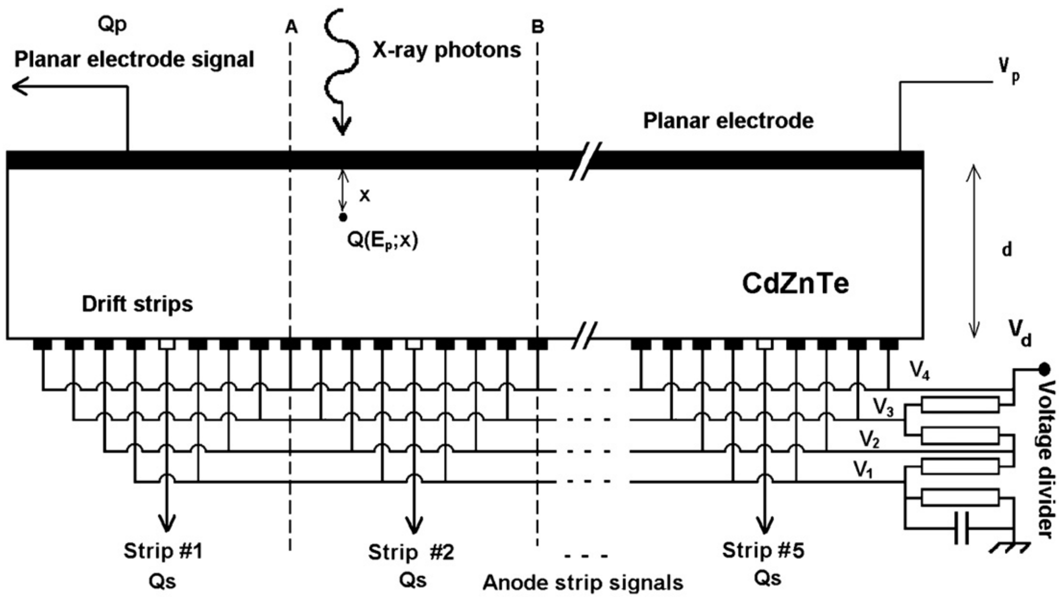

Fig. 1. Principle of the CZT drift strip detector. A drift strip detector cell is shown between dashed lines marked with "A" and "B". The drift strip electrodes and the planar electrode are biased in such a way that the electrons move to the anode strips (white boxes).

good electron drift properties. Although the spectroscopic properties of these detectors are almost independent of material hole transport properties, they are of course very dependent on the electron transport properties and especially, materials with fluctuating electron trapping lengths will result in degraded detector performance.

Not only does the drift strip readout technique provide an improved energy determination for CZT detectors, but it also yields information about the interaction depth of the detected photon. The depth information (depth sensing) can be derived from the ratio, $R \equiv Q_p/Q_s$, where Q_p is the planar electrode signal and Q_s the anode strip signal. The quantity R is almost linearly dependent on the photon interaction depth, x, with a value close to unity for interactions close to the planar electrode and a value close to zero for interactions near the strip electrodes. For further details see Ref. [1]. The depth of interaction (DOI) information can be used to correct residual electron trapping effects on the anode signal and improve further the detectors energy resolution.

Some of the best spectral performance figures for drift strip detectors have been reported for full illumination over a wide energy range in Refs. [4–6]. It is demonstrated in these reports that the CZT drift strip detectors can achieve energy resolutions which are within a factor of 2 to 3 of the CdZnTe Fano-limited resolution.

3. Applications

Instruments based on CZT drift strip detector systems have been proposed for for a number of space missions:

(1) The X-Ray Imager (XRI) on the Atmospheric X-ray Observatory (AXO) [7]. The AXO mission was proposed by the Danish Small Satellite program and was dedicated to the observation of X-rays generated in the Earth's atmosphere. The AXO XRI was an imaging instrument using a coded mask and a 2D $800\,cm^2$ CZT drift strip detector.

(2) AXO XRI was developed further and proposed as the Modular X-ray and Gamma-ray Sensor (MXGS) on board the Atmosphere Space Interactions Monitor (ASIM) [8]. ASIM is an accepted European Space Agency (ESA) mission for the International Space Station. It will study giant electrical discharges (lightning) in the high-altitude atmosphere above thunderstorms. The discharges are seen as optical, X-ray and Gamma-ray flashes in the stratosphere and the mesosphere.

(3) As focal plane detector for the Gamma-Ray Imager (GRI) [9] and [10]. The Gamma-Ray Imager was proposed for the ESA Cosmic Vision 2015-2025 plan. It was not accepted in the first round, but development work continues. GRI proposed for the first time the use of novel focusing optics to concentrate high energy photons on a small focal spot. The energy coverage of 10 keV–1.3 MeV will be achieved by combining a Laue crystal lens with a single-reflection multilayer-coated mirror. The GRI focal plan detector contains four stacked CZT layers operated in PTF configuration, surrounded by CZT side walls with about the same characteristics in terms of thickness and spatial resolution. The focal plane detector is based on 3D position-sensitive CZT drift strip detectors and was designed to optimize the response for the Point Spread Function characteristics foreseen for the GRI focusing optics.

4. Detector illumination geometry

Fig. 2 shows the possible illumination geometries used for CZT drift strip detectors. (a) Standard illumination geometry, Photon Parallel Field (PPF). The photons enter the detector perpendicular to the planar electrode. (b) Side illumination configuration, Photon Transverse Field (PTF). The photons enter the detector perpendicular to the side of the detector. This mode has the advantage that photons can be absorbed in the full length of the detector while the created charge at most will drift through the thickness of the detector. Therefore this detector illumination mode will provide high efficiency, preserving the excellent spectroscopic performance obtained for the CZT drift strip detectors. (c) PTF configuration as in (b) but with segmented planar electrodes orthogonal to the strips which achieves position sensitivity in the direction along the strips.

In this paper we report for the first time on results obtained for CZT drift strip detectors operated in PTF configuration as shown in (b).