Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research A 588 (2008) 37–40
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

A broad energy range wide field monitor for next generation gamma-ray burst experiments

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Available online 17 January 2008

Abstract

A coded mask instrument based on Silicon Drift Detectors coupled to scintillators operated with a pulse shape discrimination technique is presented as a candidate wide field monitor for forthcoming gamma-ray burst (GRB) search missions. Such an instrument would allow an energy range extended from 1 keV to 1 MeV, in a single compact device, providing both a significant detection efficiency for the softest GRB (X-ray flashes), and the sensitivity to high energy necessary to constrain GRB spectral parameters.

PACS: 95.55.Ka; 29.40.Wk; 29.40.Mc

Keywords: Silicon drift detectors; Scintillation detectors; Gamma-ray bursts

1. Introduction

Despite the huge steps forward made in the last 10 years, the origin and physics of gamma-ray burst (GRB) are still far to be settled. Under this respect, the study of the prompt emission of GRB can provide unique information [1], such as: emission mechanisms (through temporal and spectral characterization), properties of the circum-burst environment (through spectral features below 10 keV), giving clues to the nature of the progenitors, and GRB standardization (through spectral peak energy luminosity correlations) for cosmological purposes. These studies require a broad energy band, from ~1 keV to ~1 MeV, and a good energy resolution. A wide field of view (FOV) (a few steradians) is also needed, in order to catch the high number of GRB (in Low Earth Orbit, Swift/BAT detects ~75 GRB/year/sr [2]). Moreover, the capability of localizing a GRB within a few arcmin in 10–20 s is of paramount importance, in order to allow fast and sensitive follow-up with X-ray and optical telescopes, to allow afterglow properties and redshift estimates. Finally, the possibility to combine a good energy resolution X-ray detector with a scintillation detector with good efficiency up to several hundreds keV in a single, compact device would be of great advantage for a space mission, where compactness and limited weight are crucial requirements.

In this paper the proposed detector will be described, together with the performance obtained in the laboratory. Then a coded mask instrument based on such a detector will be proposed, in the constraints frame of a medium size space mission, and its performance in terms of sensitivity to GRBs will be discussed.

2. Detector's description

2.1. Working principle

A gamma-ray detector based on a CsI(Tl) scintillating crystal coupled to a silicon photodetector is also a direct X-ray detector, for radiation interacting in silicon. Charge pulses either from X-ray interaction in silicon or scintillation light collection are quite different in shape due to the different timing properties and can be discriminated easily. In fact, while the electron–hole pair creation from X-ray interaction in silicon originates a fast signal (about 10 ns rise time), the scintillation light collection is dominated by the fluorescence states de-excitation time [0.68 μs (64%) and 3.34 μs (36%) for CsI(Tl) at room temperature] and a

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0168-9002/$ - see front matter © 2008 Published by Elsevier B.V.
doi:10.1016/j.nima.2008.01.053

few μs shaping time is needed in this case to avoid significant ballistic deficit. Moreover, interactions in silicon and in CsI yield different amount of charge per unit energy deposited, so discrimination of the place of interaction is necessary to obtain the correct photon energy. Pulse Shape Discrimination (PSD) techniques allow discrimination between signals with different timing properties [3].

Since the low energy threshold and the spectroscopic capabilities of such a detector are dominated by the electronic noise of the silicon photodetector, it was decided to use Silicon Drift Detectors (SDD) [4] because of their much lower intrinsic noise. Even if SDDs have been developed mainly as direct X-ray detectors [5], they have been also widely tested as photodetectors coupled to CsI(Tl) scintillators, see for example Ref. [6].

2.2. Experimental setup

A 10-mm^2 active area SDD with integrated JFET supplied by PNSensor GmbH was used. The fully depleted active thickness of the device is 300 μm. A CsI(Tl) cylindrical crystal, 10-mm high and 3.6 mm in diameter, was coupled to the detector's entrance window by means of a thin layer of previously cured siliconic resin. The crystal was wrapped with multi-layer polymeric film and PTFE tape.

To carry out PSD, the preamplified signal was sent to two different processing chains each of them comprising a spectroscopy amplifier with quasi-Gaussian shaping and a 4096 channels ADC. Shaping times were set to 0.5 μs in one processing chain (tailored to the detection of X-rays interaction in silicon, hereafter called the fast chain) and 3 μs in the other (tailored to the detection of scintillation light, hereafter called the slow chain). For each event with signals above threshold in both chains, the two ADC values were readout and saved on hard disk for subsequent analysis.

The detector was irradiated with gamma-ray sources from the electronic side, in such a way that photons pass through the silicon detector first and then, if not absorbed, through the scintillator. The hole in the ceramic housing allows gamma-rays to reach the silicon detector without attenuation. A detailed description of this detector and its characterization can be found in Refs. [7,8]. The spectra obtained can be visualized as bidimensional histograms as shown in Fig. 1, where the two axes are the fast and slow pulse height, for measurements recorded at −20 °C. As expected, events distribute along two straight lines depending on whether interaction takes place in silicon or in CsI.

2.3. Performance

Table 1 shows the detector's main characteristics, as obtained in laboratory tests.

For each event, the key parameter for PSD is the ratio r between the pulse height of the fast and slow processing chains, expressed in channels and corrected for ADC offset. For X-rays interacting in silicon at −20 °C $r_{Si} \simeq 0.96$ (it would be 1 if the gain of the two chains was exactly the same) and for gamma-rays interacting in CsI $r_{CsI} \simeq 0.51$. r_{Si} and r_{CsI} correspond roughly to the angular coefficients of the two straight lines shown in the bidimensional spectra of Fig. 1. The interaction type for each event (silicon or scintillator) is determined according to the r value. Since PSD capabilities depend on the electronic noise, PSD performance worsen approaching the detector's energy threshold, but are improved lowering the temperature.

In Fig. 2 the detection efficiency for on-axis photons is shown, together with the energy thresholds of the slow

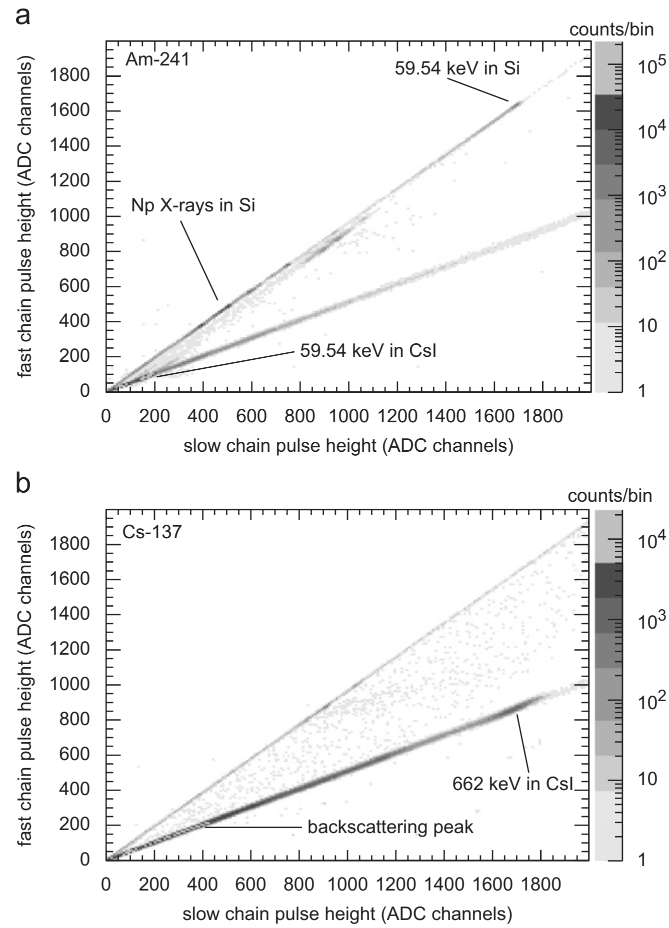

Fig. 1. Bidimensional spectra obtained with (a) ^{241}Am and (b) ^{137}Cs sources at −20 °C. Each image bin is 10 × 10 square channels. Channel values have been corrected for ADC offset. Events in silicon in the ^{137}Cs spectrum are due to the X-ray background and the Ba *K* X-rays.

Table 1
Detector's main characteristics

Detector property	Measured value
SDD electronic noise	40 e$^-$ rms for 0.5 μs shaping time at RT
Energy threshold in Si	1 keV at 10 °C
Energy threshold in CsI	9 keV at 10 °C
Energy resolution in Si	4.5% FWHM at 5.9 keV at RT
Energy resolution in CsI	6% FWHM at 662 keV at RT