



# Prospects for a 1 keV - 1 MeV monolithic gamma-ray detector and possible application in X/gamma-ray astronomy

M. Marisaldi and C. Labanti

IASF - CNR/INAF, Istituto di Astrofisica Spaziale e Fisica Cosmica, sezione di Bologna,  
Via Gobetti 101, 40129 Bologna, Italy

**Abstract.** A X and gamma-ray detector based on a Silicon Drift Detector (SDD) coupled to a CsI(Tl) scintillating crystal is presented. The device is operated both as a direct X-ray detector for photons interacting in silicon, and as an indirect detector for photons interacting in the scintillator. Pulse shape discrimination (PSD) technique is used to discriminate the interaction type. The use of SDDs allows a low energy threshold (1 keV) and a good energy resolution both at X-ray energies (5.8% at 5.9 keV) and for gamma-rays interacting in the scintillator (6.9% at 662 keV), at room temperature. Pulse shape discrimination is possible throughout the detector's energy range. The detector's performances are described and discussed, and a concept study for a wide field gamma-ray transient monitor employing such detectors is presented.

**Key words.** Silicon drift detectors – Gamma-ray detectors – Pulse shape discrimination –

## 1. Introduction

A monolithic X/gamma-ray detector with good spectroscopic capabilities and significant efficiency throughout three orders of magnitude between 1 keV and about 1 MeV would be of great advantage for a space mission, where compactness and limited weight are crucial requirements. We have explored the possibility of building such a detector based on a CsI(Tl) scintillating crystal coupled to a Silicon Drift Detector (SDD) (Gatti & Rehak 1984). SDDs peculiar characteristic is their very low output capacitance so that an electronic noise from 5

to 10 times lower than that of a PIN photodiode (PD) of equivalent active area can be obtained. Even if the SDDs used for the realization of this device have been developed mainly as high resolution, room temperature direct X-ray detectors (Lechner et al. 1996), they have been also widely tested as photodetectors coupled to CsI(Tl) scintillators (Fiorini et al. 1997).

When coupled to a scintillating crystal, a silicon photodetector is still a direct detector for X-rays interacting in the silicon bulk. While the electron-hole pair creation from X-ray interaction in silicon creates a fast signal (of the order of 100 ns rise time, dominated by the charge drift time), the scintillation light collection is a slow process dominated by the fluorescence states de-excitation time (0.68  $\mu$ s (64%) and 3.34  $\mu$ s (36%) for CsI(Tl) at room tem-

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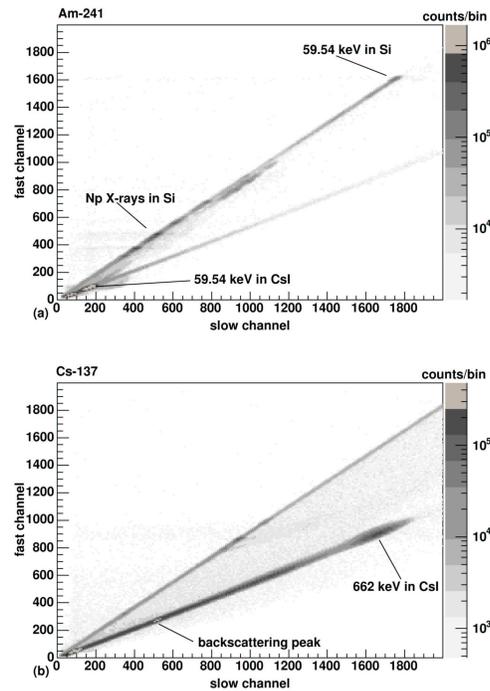
*Send offprint requests to:* M. Marisaldi  
*Correspondence to:* marisaldi@bo.iasf.cnr.it (M. Marisaldi), IASF - CNR/INAF sezione di Bologna, Via Gobetti 101, 40129 Bologna, Italy

perature). So, charge pulses following an interaction either in the scintillator or in the photodetector have different timing properties and can be discriminated by means of Pulse Shape Discrimination (PSD) techniques.

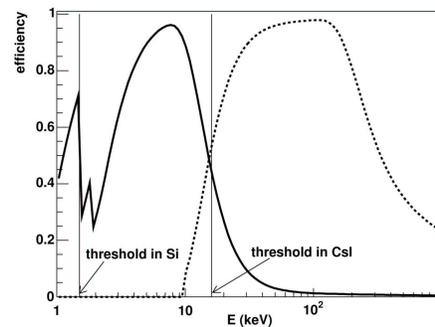
## 2. Detector's description

The detector has been realized with a 10 mm<sup>2</sup> active area SDD coupled to a cylindrical CsI(Tl) crystal 3.6 mm in diameter and 10 mm thick. The pre-amplified signal was sent to two parallel processing chains with different shaping times (fast chain: 0.5  $\mu$ s; slow chain: 3  $\mu$ s). The shaped signals were A/D converted and stored on disk for subsequent analysis. The detector was irradiated with gamma-ray sources from the SDD side, in such a way that photons pass through the silicon detector first and then, if not absorbed yet, through the scintillator. All measurements were performed at room temperature. The spectra obtained with <sup>241</sup>Am and <sup>137</sup>Cs sources can be visualized as bidimensional histograms as shown in figure 1, where the two axes represent the fast and slow chains pulse height. As expected, events distribute along two straight lines depending whether interaction takes place in silicon or in CsI. The key parameter to allow discrimination is the ratio  $r$  between the pulse height of the fast and slow processing chains, expressed in channels and corrected for ADC offset. For gamma-rays interacting in the scintillator  $r \approx 0.54$  while for photons interacting in silicon  $r \approx 0.92$  (these values depend on the electronics settings). A good energy resolution at X-ray energies (5.8% at 5.9 keV, 1.2% at 60 keV) and a low energy threshold of about 1 keV are allowed by the excellent SDD's low noise properties (41  $e^-$  rms in this case with the fast chain). Regarding the slow chain, a light yield of 23.4  $e^-$ /keV was obtained; an electronic noise of 82  $e^-$  rms allows an energy threshold of 1.5 keV for interaction in silicon and 16 keV for interaction in CsI. The detector is not optimized yet: light yield improvements have already been obtained with better crystal wrapping and optical coupling.

A more complete description of the detector's working principle and performance is reported in Marisaldi et al. (2004). Nearly



**Fig. 1.** Bidimensional spectra obtained with <sup>241</sup>Am (a) and <sup>137</sup>Cs (b) sources. Each image bin is 10x10 square channels. Channel values have been corrected for ADC offset. Events in silicon in the <sup>137</sup>Cs spectrum are due to the X-ray background and the Ba K X-rays.



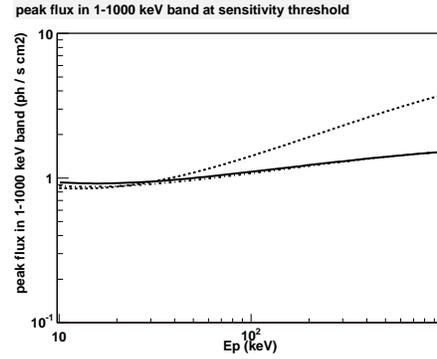
**Fig. 2.** Expected detector efficiency for on-axis photons. Solid line: efficiency for interactions in silicon. Dashed line: efficiency for interactions in CsI. The energy thresholds of the slow chain for both types of interactions are shown.

100% interaction type discrimination by means of PSD is possible for energies greater than 3.6 keV in silicon or 35 keV in the scintillator. For lower energies,  $r$  distributions start overlapping and 100% disentanglement is no longer possible. Nevertheless, discrimination of the interaction type with a good degree of accuracy is possible throughout the detector energy range.

In figure 2 the expected efficiency of the detector for on-axis photons is shown. For energies between about 10 keV and 16 keV (the threshold in CsI) there is an efficiency gap due to the decrease of efficiency in silicon. This gap could be further reduced lowering the SDD electronic noise, for example by moderate cooling of the device. The use of a low noise photodetector such as SDD is clearly essential for this application. In fact a higher electronic noise would shift the energy thresholds consequently at higher energies, thus widening the efficiency gap for energies below the threshold in CsI. Moreover, the  $r$  distributions would have higher FWHM, so the PSD capabilities of the detector would be degraded and the energy threshold for 100% events disentanglement would be shifted at higher values.

### 3. Possible application: a wide field X/gamma-ray transient monitor

The detector described could be especially suitable for a wide field X/gamma-ray transient monitor. Its extended range properties would allow simultaneous detection efficiency at hard X/gamma-ray energies and good spectroscopic capabilities between 2 and 15 keV. To accomplish the wide field of view requirements, a coded mask instrument could be employed. As a rough example with currently available detectors, let us consider a coded mask instrument with pixel dimension 3.6 mm, a square detection plane 40 cm in side, a coded mask 80 cm in side placed 1 m far from the detector. With such an instrument, a fully coded field of view of  $43.6^\circ$  would be obtained. A total number of about 12000 detectors would be employed, but that is not a major concern as more than 4 thousands scintillation detec-

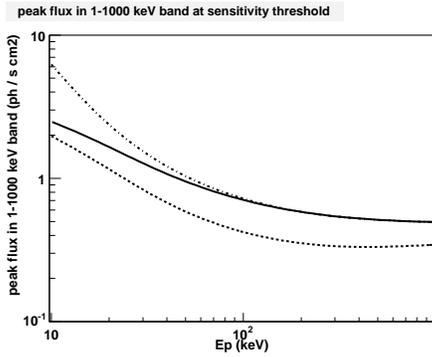


**Fig. 3.** Peak flux (1-1000 keV) threshold of SDD/CsI detector. Low energy trigger band 1.5-40 keV. Solid line:  $\alpha=-1$ ,  $\beta=-2$ . Dashed line:  $\alpha=-0.5$ ,  $\beta=-2$ . Dot-dashed line:  $\alpha=-1$ ,  $\beta=-3$ . (GRB Band function parameters)

tors are currently flying and successfully operated, i.e. the IBIS/PICsIT instrument onboard the INTEGRAL satellite (Labanti et al. 2003).

The sensitivity to Gamma-Ray Bursts (GRB) of the proposed instrument has been evaluated following the approach outlined in Band (2003). Given the detector's efficiency as a function of energy, as reported in figure 2, the instrument's geometrical parameters, the background and the significance level, the broadband photon flux  $F_T$  at the detector's threshold can be derived as a function of the bursts spectral parameters.  $F_T$  is the integral photon flux in the 1-1000 keV energy band of the weakest burst that can be detected by the instrument. Lower  $F_T$  values mean a higher detector's sensitivity. In figures 3 and 4 the broadband photon flux  $F_T$  at the detector's threshold is reported as a function of the bursts peak energy  $E_p$  and for 3 different sets of the Band GRB function spectral parameters  $\alpha$  and  $\beta$  (Band et al. 1993).

Figure 3 refers to a low energy trigger band (1.5 - 40 keV), while figure 4 refers to a high energy trigger band (20 - 1000 keV). These calculations have been carried out considering the diffuse high energy background given in Gruber (1992), a 0.5 open mask fraction, an accumulation time  $\Delta t = 1$  s i.e. the time resolution with which the flux is measured, and a



**Fig. 4.** Peak flux (1-1000 keV) threshold of SDD/CsI detector. High energy trigger band 20-1000 keV. Solid line:  $\alpha=-1, \beta=-2$ . Dashed line:  $\alpha=-0.5, \beta=-2$ . Dot-dashed line:  $\alpha=-1, \beta=-3$ . (GRB Band function parameters)

significance level  $\sigma_0 = 4$ . A significant sensitivity to GRB can be obtained. As this is a rough example, better results can be obtained with a fine tuning of the detector's parameters and geometry of the instrument.

#### 4. Conclusions

The possibility to combine a good energy resolution X-ray detector with a scintillation detector having good efficiency up to about 1 MeV in a single, compact device is presented. Such a detector could be of great advantage for a space mission where compactness and limited weight are crucial requirements. The detector has been

realized using a SDD coupled to a scintillating crystal, applying PSD techniques to discriminate X-rays interacting in silicon and higher energy photons interacting in the scintillator. This detector could be employed, for example, in a wide field X/gamma-ray transient monitor with sensitivity extended in a wide energy band and good spectroscopic capabilities in the few-keV energy range.

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