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Monolithic arrays of silicon drift detectors for medical imaging applications and related CMOS readout electronics

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Abstract

Monolithic arrays of Silicon Drift Detectors (SDDs) have been recently proposed to be used with scintillators for high-position-resolution γ-ray imaging applications. Thanks to the low electronics noise due to the small value of the output capacitance, the SDD offers better performances with respect to conventional photodiodes of the same geometry. We show the results achieved with a small monolithic array of SDDs, each one with a front-end JFET integrated at its center, used as photodetector in a first prototype of Anger Camera. An intrinsic resolution better than 200 μm has been achieved with this prototype. Moreover, we describe a new monolithic array of SDDs composed of 77 single hexagonal units, each one with an active area of 8.7 mm^2, for a total active area of the device of 6.7 cm^2. Finally, the basic principles and the first results of the CMOS readout chip specifically designed for the readout of the signals from SDDs arrays are presented.

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Keywords: Silicon drift detectors; Gamma-ray imaging; Readout electronics

1. Introduction

In the field of medical imaging, the use of compact γ-ray imagers characterized by a high position resolution would allow to improve diagnostic capabilities with respect to conventional systems. Moreover, a sub-millimeter resolution capability is a mandatory requirement for detection systems to be used in the growing field of small-animal imaging [1]. A possible solution to improve both compactness and resolution compared to present gamma cameras based on scintillators read out with conventional photomultiplier tubes (PMTs) is the use of arrays of silicon photodiodes (PDs) [2]. With respect to PMTs, in fact, PDs offer a higher quantum efficiency, smaller dimensions and lower biasing voltages. However, conventional PDs could be limited in scintillation readout performances by their electronics noise, no more negligible with respect to PMTs because of the absence of gain. Avalanche photodiodes (APDs) combine the high quantum efficiency of PDs with the benefit of avalanche multiplication [3]. However, the statistical component to the resolution is affected by the statistics of the multiplication itself (noise factor) and the sensitivity of the gain to temperature and biasing variations represents a potential practical drawback in the use of APDs arrays for scintillation detection.

As an alternative to the mentioned photodetectors, silicon drift detectors (SDDs) have recently shown to achieve excellent performances in scintillation light detection. The SDD is a photodetector characterized by a very

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low value of output capacitance, in the order of 100 fF, independent from the active area of the device, which leads to a lower value of electronic noise when compared with a PD of equivalent area and thickness. SDDs used for scintillation readout have already shown to achieve state-of-the-art energy resolution in γ-ray spectroscopy [4] as well as sub-millimeter position resolution in γ-ray imaging [5].

In this work we show the recent results obtained with a first prototype of Anger Camera based on a CsI(Tl) scintillator coupled to a SDD array. Then, we describe a new large-area prototype of SDD array, designed for medical imaging applications. In the last section of the paper, we present the results of the development of a CMOS circuit aimed specifically at the readout of monolithic SDDs arrays.

2. Monolithic arrays of silicon drift detectors

We have recently developed a first prototype of Anger Camera based on a monolithic array of 19 hexagonal SDDs, arranged in a honeycomb configuration, as schematically shown in Fig. 1. Each SDD has an inner diameter of 2.4 mm and an area of 5 mm^2, for a total area of the array of 95 mm^2. Despite the small area, this first prototype was already significant to assess the performances achievable with this kind of γ-ray imager topology. Each SDD has a front-end JFET directly integrated on its center [6]. This solution reduces the stray capacitance of the connection between detector and electronics, minimizes the cross-talk and simplifies the front-end readout.

To reduce the contribution to the electronics noise depending on the leakage current, the detector was cooled down to −10 °C. To cope with the long time constant of the CsI(Tl) scintillator (about 1 μs) a RC-CR^2 shaping with 6 μs peaking time was adopted for the 19 electronics readout channels. The electronic noise of each individual unit of the SDD array has been determined by irradiating the array alone (without scintillator) with a ^{55}Fe source at a temperature of 0 °C. An average electronics noise of 19.1e− rms was measured among the units, with a maximum of 21.8e− and a minimum of 15.7e−. In the near future, faster scintillators like the recently proposed $LaBr_3$ [7], which has similar light output than the CsI(Tl) but much shorter decay time (∼25 ns), will also be tested. This scintillator will allow to match the best electronics noise of SDD (14e− rms) achieved when a peaking times as short as 1 μs is used.

A CsI(Tl) crystal, completely covering the active area of the SDD array, has been optically coupled to the SDD array. A crystal thickness of 3 mm was chosen, for a corresponding detection efficiency of 75% at 140 keV. The position of interaction of a γ-ray photon inside the scintillator was determined by using a maximum likelihood algorithm which provides better resolution and reduced non-linearities, especially at the borders of the sensitive area, with respect to a conventional Anger algorithm.

In Fig. 1, the result of the scan of a collimated ^{57}Co source (122 keV) in different points over the active area of the detector is shown. The collimator hole diameter was of 150 μm, with an estimated irradiation spot on the detector of 180 μm. The points of irradiation were obtained by moving the collimator by 500 μm on both X and Y direction, corresponding to 710 μm linear distance between

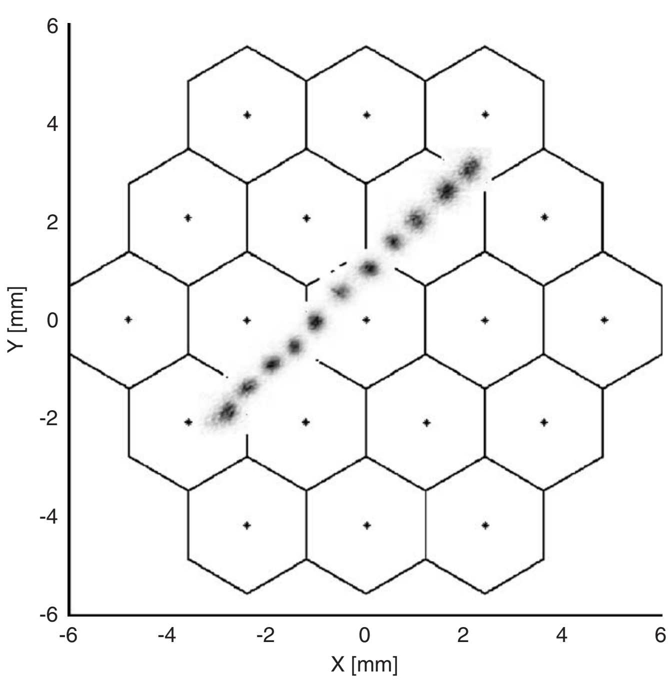

Fig. 1. Schematic layout of the 19 SDDs array superposed by the 2D position distribution of irradiation points separated by 0.7 mm and disposed along a line crossing the active area of the SDD-CSI(Tl) γ-ray detector.

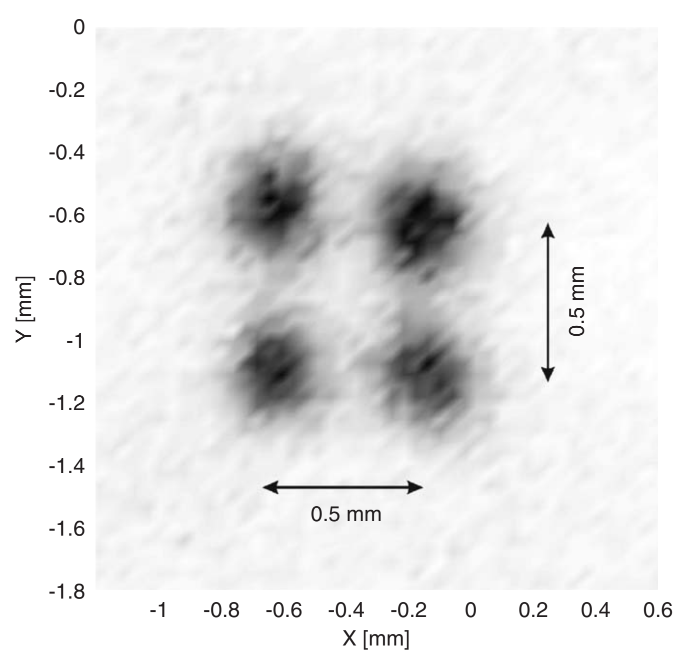

Fig. 2. 2D position distribution of four irradiation points in the central region of the SDD-CSI(Tl) γ-ray detector. The size of the irradiation spot is of 180 μm.