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Scintillation crystal readout by multi-APD for event localization

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Abstract

This work is aimed to assess the feasibility of a gamma-ray scintillation detector for radionuclide imaging characterized by good energy resolution and point-of-interaction measurement at room temperature. To obtain such performances the single-event scintillation light must be read from more than one crystal face. We have preliminarily analyzed the energy response using CsI:Tl crystals and Si-APD. Results concerning energy response are presented in terms of linearity and resolution. The single-APD configuration, chosen as a reference, has shown very good energy linearity in the range 80–662 keV and a 7.6% FWHM energy resolution at 662 keV. Similar linearity results have been obtained for the 5-APD case, while energy resolution worsens down to 13.2% FWHM. These results could be further improved using APD with reduced peripheral dead zones.

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Keywords: Scintillation detector; Silicon avalanche photodiode; Radionuclide imaging

1. Introduction

The recent availability of Si-APD [1,2] having Large Area (LAAPD) of detection [3,4] gives a chance to study the feasibility of a compact gamma-ray scintillation detectors characterized by point-of-interaction identification and good energy response for radionuclide imaging. These APD, available in flat ceramic package [5,6], are suitable for low-light-level measurement in the visible range. They are mainly characterized by high quantum efficiency, good internal charge multiplication and wide spectral response in the visible. In addition, they can be used in presence of even intense magnetic fields. The use of multi-APD would enable the measurement of Point Of Interaction (POI) coordinates that could be used for spatial resolution improvement of PET scanners [7–9]. This work presents preliminarily results obtained with different detector assemblies composed of a CsI:Tl crystal readout by different numbers of APD. In particular, the pulse-height linearity and energy resolution, in the range useful for nuclear medicine imaging, have been analyzed at room temperature.

2. Theoretical background

A scintillation event produces a light spot made of a number of visible photons. Under the hypothesis of isotropic emission, the spot may be represented as a spherical wave centered at the POI. The wave intercepts crystal's walls producing luminance values depending on POI coordinates and on crystal geometry.

A parallelepiped crystal having each face polished and fully coupled to the active area of a single APD, represents the ideal case in which each visible photon emitted at POI has the highest probability to be detected by the APD located along its direction. This ideal detector shows the following properties: (a) a minimized number of interactions of visible photons within the crystal bulk, (b) a minimized number of visible photons interactions with the crystal walls and (c) APD responses to single-event that are related to the luminance at the corresponding crystal face.

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3. Equipment and methods

All tested assemblies utilized $9.0 \times 9.0 \times 10.6\,mm^3$ CsI:Tl crystals, made by Hilger Crystals [10]. The scintillation material has been mainly preferred due to the optimal spectral matching between its emission spectrum and the APD quantum efficiency and because of its easy handling.

Nowadays the scintillation readout can be performed by single LAAPDs or by arrays of small APDs. Nevertheless, the second option shows two major disadvantages due to the large number of pixels to be handled and to the reduced light level impinging on each array element. In our study we chose the Hamamatsu S8664-55 model [6], a Si-LAAPD with $5 \times 5\,mm^2$ active area in a $10.6 \times 9.0\,mm^2$ ceramic package with a 0.45 mm thick Epoxy window. Unfortunately this APD shows a 74% peripheral dead zone. To evaluate the effect of dead zones on total light collection, a thin white reflective–diffusive frame has been positioned, over the optical window, around the APD active area. In this way we have tried to simulate the ideal configuration with 100% active area: the white coating should enhance the light collection and consequently increase the pulse-height value. On the contrary, this remedy makes impossible the POI reconstruction as it introduces reflections on crystal faces which cause a loss in spatial information. The confidence that in the next future progresses will be made in the reduction of APD dead zones has encouraged this study [11].

Note that crystal sides have been chosen to fit the overall APD dimensions. In this way we have realized the highest light collection avoiding light-guides together with the possibility of performing multi-APD readout.

Fig. 1 explains the specifications of crystals machining reported in Table 1, where Roman numbers identify the crystal's faces and the letters specify the surface manufacturing (f = fine machined, p = polished). To improve the light collection f faces have been whitened while p faces have been coupled to APD windows using optical grease. The whitening material, used for crystal and for APD dead zones, consists of a 30 μm thick carbon plastic polymeric film. Fig. 2a reproduces APDs with and without white frame and a crystal, wrapped in the same polymeric film. Fig. 2b shows an initial step of the 5-APDs assembling: faces II and VI of a crystal have been coupled to APDs using whitening frames.

Each APD has been connected to a low-noise conventional electronic chain. Tennelec TC171 and ORTEC 142A preamplifiers models have been used. Tennelec TC244 and ORTEC 570 have been used as amplifier-shapers with 6 and 2 μs shaping time, respectively. A Cremat electronics, made by CR-110 preamplifier, CR-150-AC-NC board, CR-200 amplifier, and CR-160–4 μs board has also been successfully tested [12].

To equalize channel's gains a ORTEC 448 pulse generator has been used to supply the same charge signal to each preamplifier's test input. Main amplifier's gains have been correspondingly modified to obtain the same pulse height.

To realize the correct APDs gain balancing, two ways could be used in principle: (a) to look for factory-selected APDs having the same gain value at the same or almost similar high voltage bias, or (b) use an independent high voltage module to supply the appropriate bias voltage to each APD in order to obtain the same gain value for all channels. Due to the wide range of HV factory bias voltages characterizing the APDs in our availability (from −356.2 to −413.2 V), our choice was forced to the second option, using five ORTEC 428 detector bias supply modules. The trigger signal has been produced, in each detector assembly, summing the signals obtained from all APDs. A fast rise-time signal, adequate to correctly synchronize the digitization system, has been obtained utilizing an ORTEC 454 amplifier with 100 and 10 ns differentiation and integration constants, respectively.

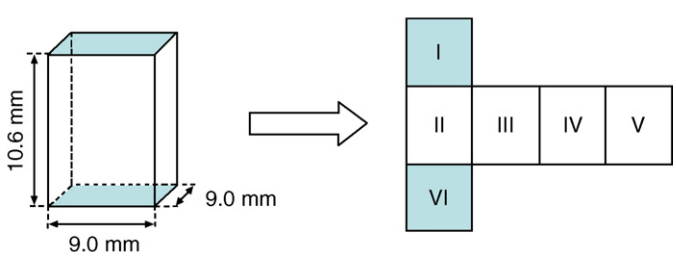

Fig. 1. Crystal sketch. Face's Roman numbers refer to Table 1.

Table 1
Crystal's specifications: type corresponds to the number of APDs used for scintillation readout; surface's manufacturing is specified face by face (f = fine machined, p = polished)

Type	Surface's manufacturing					
	I	II	III	IV	V	VI
1	*p*	*f*	*f*	*f*	*f*	*f*
4	*f*	*p*	*p*	*p*	*p*	*f*
5	*p*	*p*	*p*	*p*	*p*	*f*

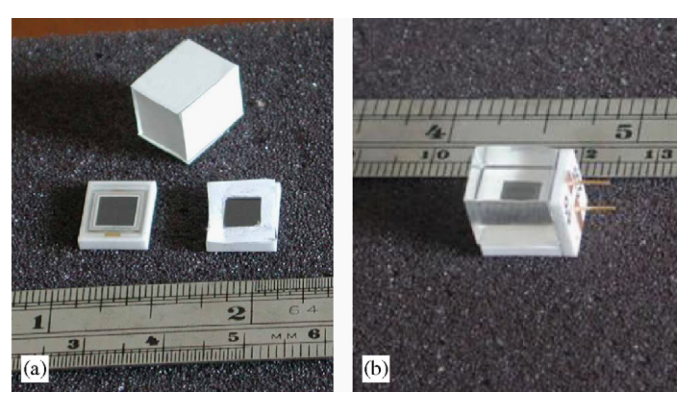

Fig. 2. Detector elements: (a) whitened crystal and two APDs without and with frame; (b) assembling the 5-APDs configurations: two faces have been coupled to APDs.