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Wavelength shifter strips and G-APD arrays for the read-out of the *z*-coordinate in axial PET modules

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Abstract

The measurements presented in this paper are related to the development of a PET camera based on a 3-D axial geometry with excellent 3-D spatial, timing and energy resolution. The detector modules consist of matrices of long axially oriented scintillation crystal bars, which are individually coupled to photodetectors. The axial coordinate is derived from wavelength shifting (WLS) plastic strips orthogonally interleaved between the crystal bars and readout by G-APD arrays. We report on results from measurements with two LYSO crystal bars, read with PMTs, and two WLS strips readout with G-APD devices from Hamamatsu (called MPPC). The WLS strips are positioned orthogonally underneath the LYSO bars. Yields of about 80 photoelectrons from the WLS strips for an energy deposition in the LYSO crystals equivalent to the absorption of 511 keV photons are observed. The axial coordinate in the LYSO bars is reconstructed with a precision of about 1.9 mm (FWHM) using a digital reconstruction method. The resolution of an analog coordinate reconstruction method, which uses the pulse height measurement from the WLS strips is 2.8 mm (FWHM). This resolution is still compromised by the availability of only two WLS strips and will improve with a full stack of LYSO crystals interleaved with WLS strip arrays, which is presently under development for a PET demonstrator set-up.

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Keywords: PET; Axial geometry; Scintillator; LYSO; Wavelength shifter; G-APD

1. Introduction

The concept of a brain PET scanner module with axially arranged scintillation crystals has been described in detail in a previous publication [1]. This approach offers substantial advantages in performance compared with existing instruments. The main improvements in the new concept are true 3-D coordinate reconstruction of the 511 keV photon interaction and therefore no depth-of-interaction (DOI) uncertainty, improved spatial resolution and high detection efficiency, uniformity of spatial resolution over the complete field of view, and capability to identify photon interactions with Compton cascades.

In a recent article [2] we demonstrated the potential of wavelength shifting (WLS) strips to readout the axial z-coordinate of a γ interacting in long LYSO crystal bars ($3.2 \times 3.2 \times 100\,\mathrm{mm}^3$). However, in this work the strips were read out with conventional PMTs which would make it very difficult to realize large matrices of close crystal bars because of packaging constraints.

In the present article we describe and discuss measurements using instead G-APD arrays to read out the

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WLS-strips. Thanks to their immunity to magnetic fields, the use of G-APDs for the readout of both crystals and WLS strips opens up the possibility of simultaneous co-registration of the PET data with MRI.

The G-APDs have a quantum efficiency QE of ~30%, about twice the QE of PMTs at 490 nm wavelength, the emission peak of green WLS, which allows to obtain high detection efficiency, even for low energy recoil electrons from Compton interactions. Moreover, because of their size and geometric detection efficiency, G-APD arrays match the limited available space imposed by the design of matrices with closely stacked scintillating crystal bars [1].

We describe in detail the principle of the measurements based on a *pulsed low energy electron beam*, the test set-up and the optical properties and characteristics of its components. Unfortunately only two G-APDs were available for these measurements. The crystal bars were therefore read with a conventional PMT. From the test results, we deduce the achievable photon yields of the LYSO crystal bars and of the WLS-strips, parameters which determine the achievable energy resolution and the spatial reconstruction of the 3-D axial PET concept. We then present the performance obtained with a digital and an analog axial z-reconstruction method and compare it with MC simulations.

The low energy range is of particular interest for the 3-D axial camera concept in order to unambiguously discriminate and precisely reconstruct Compton interactions in LYSO crystal matrices. Therefore, the tests were performed in the energy interval of 50–300 keV. Above this interval, up to the photoelectric peak of the 511 keV γ ray, the photon yield of the LYSO bars and WLS-strips can be linearly extrapolated as previously demonstrated [2]. We also present measurements with a modified set-up where we read a LYSO crystal bar with a G-APD at energies up to 534 keV.

2. Experimental principle and set-up

In order to vary the energy deposition and its position along the LYSO crystal bars in an easily controllable way, we used a *pulsed and narrow low energy electron beam* (Fig. 1) which impinges at normal incidence the surface of the crystals. The electrons are generated by illuminating a semi-transparent CsI photocathode of 10 nm thickness, vacuum deposited on a gold mesh (optical transparency T~0.90) printed on a CaF_2 crystal disk, with short (~10 ns) UV light pulses. The light source, a self triggered H_2 flash lamp ($\lambda_{peak} = 160$ nm), is collimated in such a way that the light spot at the level of the photocathode has a Gaussian shape of 1.8 mm FWHM in both transversal coordinates (x, z).

A negative potential ($10\,kV \leqslant U_{acc} \leqslant 30\,kV$) is applied between the gold mesh underneath the CsI photocathode and a metallic transparent mesh ($T > 0.95$) at ground potential, mounted 0.5 mm above the LYSO bars. This configuration ensures a uniform parallel electric field which

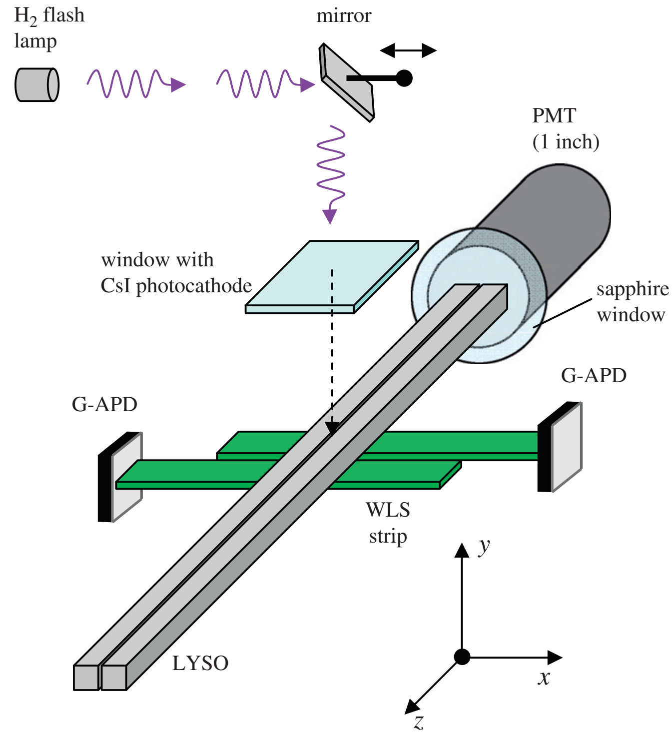

Fig. 1. Concept and schematic representation of the set-up.

defines the kinetic energy of the accelerated electrons when they hit the crystals. Apart from the transverse point spread (~0.3 mm) the electron beam spot size is preserved from the photocathode to impact plane.

The set-up allows (1) a precise adjustment of the energy deposited by controlling the number of photoelectrons N_{pe} emitted from the photocathode and the acceleration voltage U_{acc}, and (2) the scanning of the crystal surface by accurately displacing the light spot by means of a mirror indicated in Fig. 1.

The measurements were performed in vacuum at a pressure of a few 10^{-6} mbar.

2.1. Description of the set-up

The test set-up comprises two closed optically polished LYSO:Ce crystals[2] ($3.2 \times 3.2 \times 100\,mm^3$) mounted side by side with one of their end faces optically coupled through a vacuum tight thin (1 mm) sapphire window to a single PMT.[3] The opposite end faces of the bars are mirror coated with a vacuum evaporated Al film.

Two 60 mm long WLS strips[4] of $3 \times 1.1\,mm^2$ cross-section were mounted orthogonal and underneath the two LYSO crystals with a small gap. Each WLS strip was readout at opposite sides by a G-APD array from Hamamatsu[5] (MPPC[6] type S 10362-33-050 C) with

[2]Saint-Gobain Crystals, Nemours, France.
[3]XP3102, Photonis. Brive-La Gaillarde, France.
[4]EJ-280-10 ×, ELJEN Technology, Sweetwater, TX, USA.
[5]Hamamatsu Photonics K.K., Hamamatsu City, Japan.
[6]MPPC = Multi Pixel Photon Counter.