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A method to stabilize the temperature dependent performance of G-APD arrays

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ABSTRACT

This paper presents a compensation method to stabilize the temperature dependent performance of Geiger-mode Avalanche Photodiode (G-APD) arrays for Positron Emission Tomography (PET). The compensation method is used to identify the bias voltage range that provides stable performance even at different temperatures using the G-APD's characteristics, and to control the photo-peak variation as a function of temperature using the preamplifier gain within the identified bias voltage range. A pair of G-APD detectors and temperature sensors were located in the temperature chamber and the preamplifiers which can control the gain of the detectors using the digital potentiometer were positioned outside the chamber. The performance of the G-APD detector, especially energy resolution and coincidence timing resolution, was characterized as a function of bias voltage at different temperatures from 20 °C to 40 °C at 5 °C increments; the energy resolution, coincidence timing resolution, and photo-peak position of all channels of G-APD PET detectors before and after the preamplifier gain correction were then measured and compared. The results of this study demonstrated that the optimal bias voltage range providing the good energy and coincidence timing resolution, $12.1 \pm 1.2\%$ and 1.30 ± 0.09 ns, respectively, could be identified at the temperature range and the photo-peak variation and the performance at different temperatures could be stabilized by adjusting the preamplifier gain within the identified bias voltage range. We concluded the proposed method to be reliable and useful for the development of the PET system using G-APD arrays.

1. Introduction

Recently, the Geiger-mode Avalanche Photodiode (G-APD) has been increasingly studied for the development of positron emission tomography (PET) since it can provide a similar gain to that of photomultiplier tubes (PMTs) with low bias voltage, excellent timing resolution, and compactness [1–5]. The G-APD consists of a matrix of many hundreds or thousands of silicon photodiodes or microcells (typical size of 25–100 μm) per mm^2, joined together on a common substrate and operated at a few voltages above the breakdown voltage. The output signal of a G-APD is the sum of the electrical signals from micro-cells simultaneously triggered by the photons. Therefore, the amplitude A of a G-APD output signal is proportional to the microcell capacitance times the overvoltage (bias voltage–breakdown voltage), $A–C_{microcell}$ $(V_{bias}-V_{breakdown})$, where $C_{microcell}$ is the micro-cell capacitance, V_{bias} is the nominal bias voltage and $V_{breakdown}$ is the breakdown voltage of the G-APD.

Since the amplitude of the G-APD can drop with raising temperatures due to the increase of breakdown voltage and, consequently, the decrease of the overvoltage, the temperature variation represents a parameter that affects the significant electrical characteristics of the G-APD [6]. This temperature dependent characteristic can explain why the increase of the breakdown voltage leads to the decrease in the number of microcells contributing to the electrical signals and causes a smaller signal and poor performance. Thus, it is necessary to carefully control the amplitude of the G-APD as a function of temperature; several correction methods have therefore been studied to compensate for the photo-peak position as a function of temperature.

In general, the compensation method involves adjusting each bias voltage of the G-APD array to stabilize the overvoltage as a function of temperature [7–9]. However, this method need to finely control the bias voltage for adjusting the photo-peak position of each channel by using the temperature coefficient of the G-APD, which requires a complex bias voltage supplying scheme. Additionally, this method could not be applied to the G-APD with the common bias voltage per 4 channels (e.g. ArraySM-4, SensL, Irelands or S11828, Hamamatsu, Japan). Alternatively, another method has been studied to compensate for the photo-peak position as a function of temperature using the preamplifier

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gain adjustment [10]. However, this method must be applied carefully because the noise can be also amplified by the signal amplification. If the output signal is amplified by the preamplifier gain without the optimized bias voltage, poorer energy and coincidence timing resolution as well as smaller signal-to-noise ratio will result. As mentioned above, these compensation methods have some limitations and emphasize the gain correction as a function of temperature without explicit evaluation of the temperature dependent performance of a G-APD.

The purpose of this study was to characterize the G-APD performance, especially the energy resolution and coincidence timing resolution of all channels of the G-APD as a function of bias voltage at different temperatures (Fig. 1a), and then to propose and evaluate a method for stabilizing the temperature-dependent performance of the PET detector using G-APD (Fig. 1b–d). This method involves identification of a bias voltage range providing stable performance even at different temperatures (Fig. 1b) and then fine calibration of unstable photo-peak position as a function of temperature by adjusting the two-stage preamplifier gain within the identified bias voltage range (Fig. 1c). Finally energy resolution, coincidence timing resolution, and the photo-peak position of all channels of the G-APD PET detectors before and after the preamplifier gain correction were measured and evaluated (Fig. 1d).

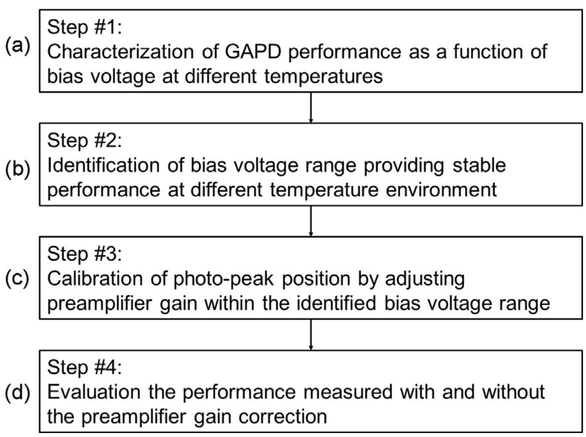

Fig. 1. Flow chart of the method proposed in this study to stabilize the performance of G-APD PET detector at different temperatures.

2. Materials and methods

2.1. PET detectors

The PET detector comprised a cerium-doped lutetium yttrium orthosilicate (LYSO, Fig. 2a, Sinocera, China) and Geiger-mode avalanche photodiode (G-APD, Fig. 2b, Hamamastu, Japan) arrays with 4×4 individual pixels arranged at a pitch of 3 mm. The LYSO array was polished on all sides and separated with white epoxy, except for on the entrance face. The specification of the G-APD array evaluated in this study is shown in Table 1.

2.2. Electronics and measurement equipment

The output signal of the G-APD sensor was amplified by a two-stage amplification circuit consisting of an amplifier chip (AD8039, Analog Devices, US) and a digital potentiometer (MAX5477, MAXIM integrated Products, US) (Fig. 3). The first stage had a fixed gain of about 10 to provide proper signal amplitude for subsequent signal processing. The second stage had variable gain between 2 and 12 with a feedback capacitor to control the photo-peak position of the detected signals and to filter the noise in the signals. The gain values of the amplification circuit were

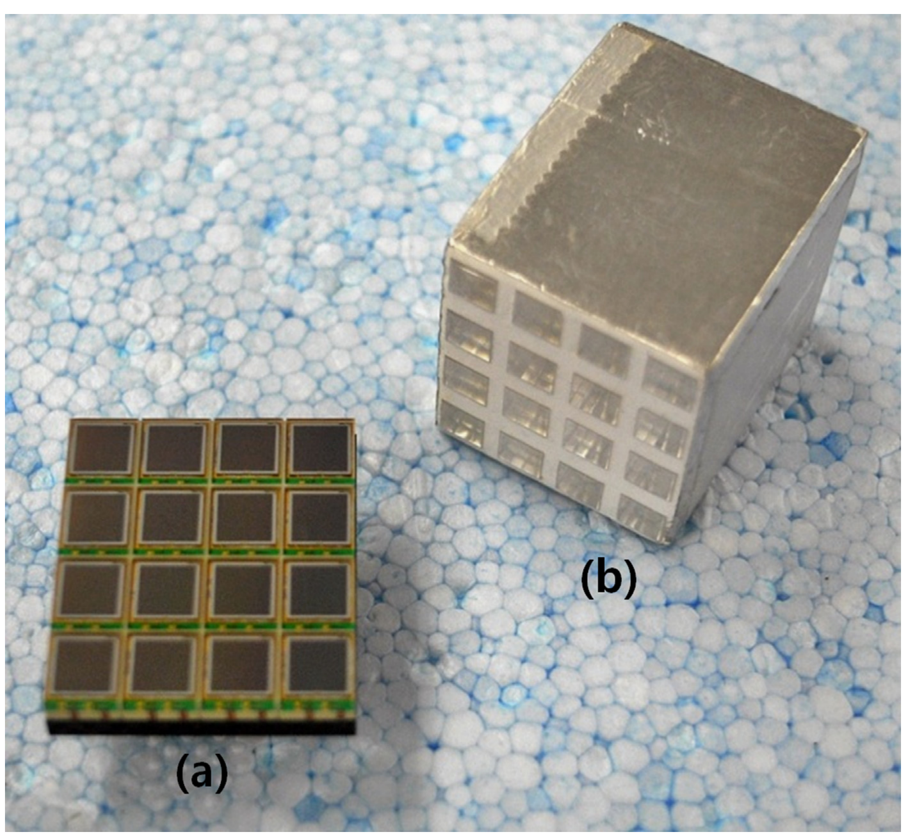

Fig. 2. 4×4 G-APD array (a) and LYSO array (b) consisting of PET detector module.