Nuclear Instruments and Methods in Physics Research A 610 (2009) 390–392

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Spatial distribution of photo-sensitivity in new micro-pixel avalanche photodiodes: Assembly of 64-element arrays

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ARTICLE INFO

Available online 27 May 2009

Keywords:
Micro-pixel Avalanche Photodiode, MAPD
Photodetector
Detector array
SiPM
APD

ABSTRACT

A 64-element array was assembled out of 3×3-mm^2 Micro-pixel Avalanche Photodiodes (MAPD) for use in the next-generation PET scanners. Spatial distribution of photo-response across the surface of a single element as well as bias voltage variation between elements of the array was studied.

1. Introduction

Many practical applications such as high-energy physics and medical tomography require compact position-sensitive detectors with good energy resolution and high uniformity of parameters. In the past few years there has been a significant interest in silicon Micro-pixel Avalanche Photodiodes (MAPD) with the capability to register very weak light pulses down to single photons. An assembly of MAPD arrays with scintillating crystals potentially is a good position-sensitive detector with reasonable coordinate and energy resolution.

Currently there are three types of the MAPD based on different operation principles [1,2]. The present work shows results of investigations into spatial uniformity of the third MAPD type with very high pixel densities, up to 40 000 pixels/mm^2. These provide the best up-to-date photo-response linearity. Uniformity of the photo-response (gain) was investigated across the surface of a single element as well as between different elements.

This work was aimed to aid the development of MAPD arrays for use in the new generation of Positron Emission Tomography (PET) scanners as well as in Cherenkov detectors for the PANDA project (GSI, Germany). Design and operation principles of the tested MAPD samples are described in [3].

2. MAPD design and parameters

The tested MAPD-3A samples were developed and manufactured by Zecotek Photonics Singapore Pte. Ltd. The presented MAPD-3A samples have sensitive area of 3×3 mm^2 and pixel density 15 000 mm^{-2}. Gain dependence on voltage of a typical MAPD-3A sample at room temperature is shown in Fig. 1. The gain was calculated as a ratio of the photosignal charge at the given bias voltage to the value at bias voltage of 10 V when gain is equal to one.

In order to determine photo-response uniformity, the MAPD surface scanning was performed with a laser emitting at 630 nm. The spot of the laser beam was 20 μm in diameter and the duration of the light pulse was 100 ns. The measurements were made at two values of bias voltage: 10 and 64.5 V, which corresponded to gain values 1 and 100, respectively. Fig. 2 shows the dependence of the photocurrent amplitude on a laser spot position across the MAPD-3A surface. It was established that the non-uniformity of photosensitivity within almost entire sensitive area of MAPD does not exceed 15%.

An array of 64 MAPD-3A photodiodes was assembled on custom-designed printed circuit board (PCB). There was no special selection or binning of elements for the array. The bottom aluminum contacts of the MAPD were glued to the PCB contact pads connected to pins. All MAPD elements were biased and tested independently. Fig. 3 shows photos of the 8×8-element array samples assembled from MAPD-3A devices.

Bias voltage values at which the gain of all 64 elements reached the same value of 20 000 were measured. A light-emitting diode (LED) with wavelength 450 nm and pulse width 100 ns was used as a light source for these measurements. Experimental results on bias voltage spread between 64 MAPD elements in the array at constant gain are shown in Fig. 4. As one can see from the plot, the maximum deviation of the bias voltages

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doi:10.1016/j.nima.2009.05.122

from the mean value does not exceed 0.26 V, which is less than 1% of the mean bias voltage.

High uniformity and reproduction of the parameters of the developed devices allows to assemble from them arrays of arbitrary dimensions. MAPD-3A arrays assembled for the purposes of this study have the following parameters: Table 1.

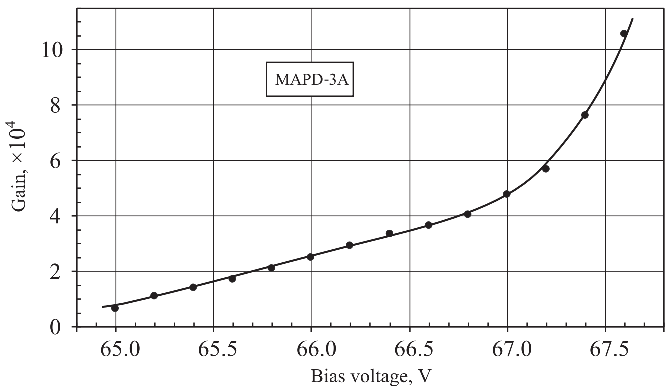

Fig. 1. Dependence of MAPD-3A gain on bias voltage (measurements were taken at $T = 20\,^{\circ}$C).

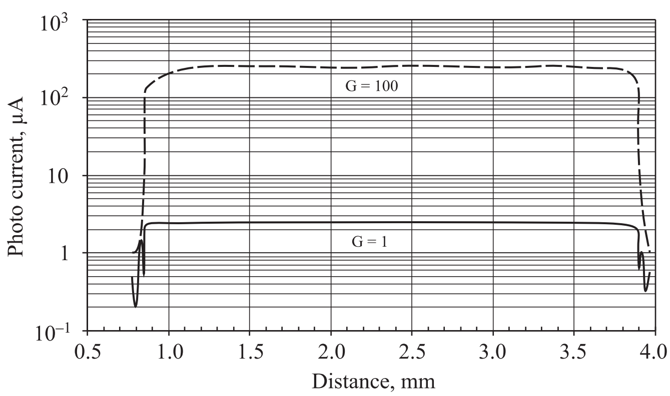

Fig. 2. Dependence of the photo-current amplitude on a 20 μm laser spot position across the MAPD-3A surface. Solid line corresponds to unit gain and dashed line, to gain equal to 100.

3. Conclusion

The inherent advantages of MAPD architecture over traditional PMT detectors (compactness, insensitivity to magnetic fields, low operating voltages) as well as over earlier designs of

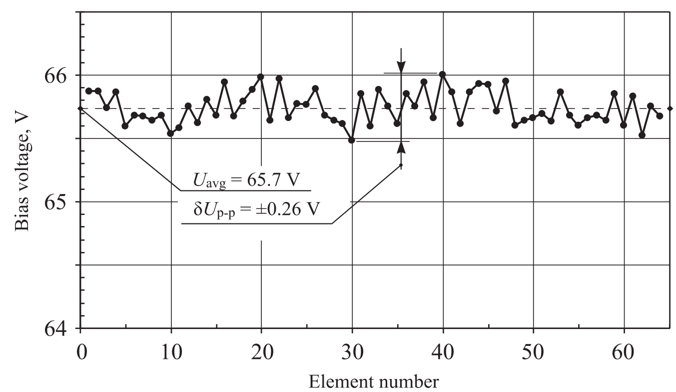

Fig. 4. Distribution of bias voltage of 64 MAPD elements at which gain is equal to 20 000.

Table 1

Parameter	Value
Number of elements	64
Element-sensitive area, mm^2	3×3
Micro-pixel density, mm^{-2}	15 000
Spacing between sensitive areas, mm	0.6
Operating voltage, V	65–67
Gain	$>10\,000$

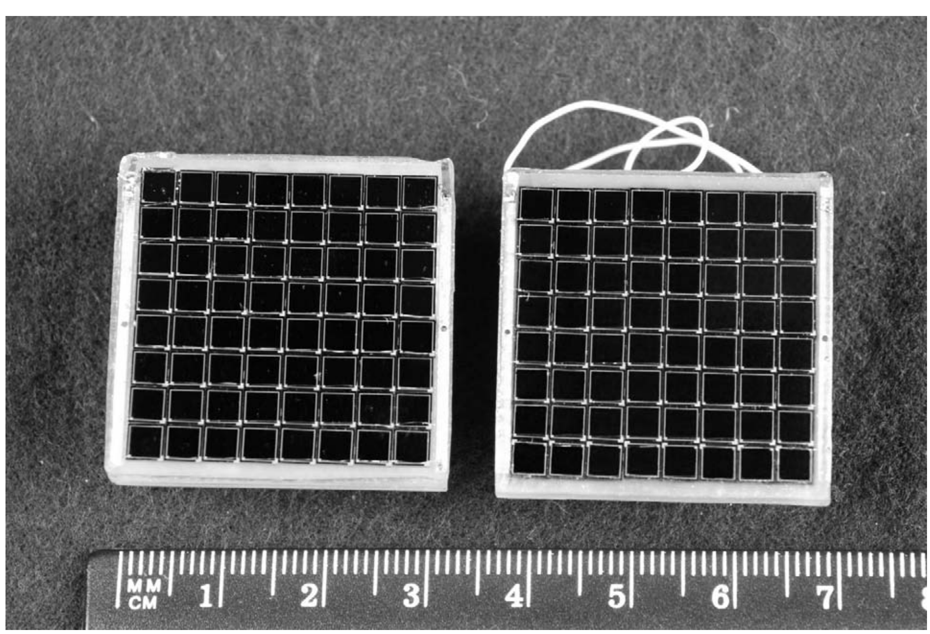

Fig. 3. Photo of the 64-element array assembled from 3×3-mm^2 MAPD-3A photodiodes.

micro-pixelated avalanche detectors, such as SiPM (very large dynamic range and high-energy resolution) are essential for modern low-light detection techniques. The present study has also confirmed that MAPD design and production methods allow straightforward integration of individual elements into large two-dimensional arrays. These 64-channel MAPD arrays together with appropriate scintillating crystals may be successfully used in the new generation of Positron Emission Tomography scanners, Cherenkov detectors of PANDA experiment (GSI, Germany), in devices for control and protection of objects, and other fields that need compact position-sensitive sensors with high detection efficiency.

Acknowledgement

The research and development work was supported by Zecotek Photonics, Inc. with a grant contribution from INTAS, No. 05-1000008-8114.

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