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Development of scintillation detectors based on avalanche microchannel photodiodes

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Abstract

Avalanche Microchannel PhotoDiodes (AMPDs) are solid state photodetectors with high internal gain and a density of independent channels up to $10^4/\text{mm}^2$. They are potential substitutes for photomultiplier tubes in a wide variety of applications in nuclear physics and nuclear medicine, especially when fine segmentation of the detectors and their operation in high magnetic fields is required.

In this work, we study the performance of a detector based on a LYSO ($2 \times 2 \times 10\,\text{mm}^3$) scintillation crystal and AMPD at detection of 511 keV γ-quanta. The detector shows linear energy response, an energy resolution of ~12%, and sub-nanosecond time resolution. These characteristics are encouraging for using AMPDs in detector systems of positron emission tomographs (PET) of the next generation.
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1. Introduction

An avalanche Microchannel PhotoDiode (AMPD) is a high gain solid state photodetector. It is realized as a matrix of independent micro-photosensors (channels) made on a common silicon substrate and connected in parallel. Each microchannel provides avalanche multiplication of charge carriers created in it by a photon and operates in gain saturated mode. The high density of the microchannels ensures linearity of the AMPD response over a wide dynamic range of input signals.

The AMPDs are produced in the Joint Institute for Nuclear Research (Dubna, Russia) in collaboration with the Mikron company (Zelenograd, Russia). For details on the AMPD types and their operation principle see Ref. [1].

The parameters of AMPDs, such as active area (up to $3 \times 3\,\text{mm}^2$), gain (10^4–10^6), and photon detection efficiency (PDE~20%), allow using them in applications previously opened only for vacuum photomultiplier tubes (PMTs). The most promising applications for AMPDs are when compact size of a detector and/or its operation in magnetic fields is essential. For example, by using AMPDs a scintillating fiber muon beam profile monitor [2,3] for operation in magnetic fields of a few Tesla and at count rates of several MHz has been built.

A vast field for application of novel photodetectors competitive to PMTs is in nuclear medicine. Development of the fifth generation of scanners for positron emission tomography (PET) requires detectors able to detect 511 keV γ-quanta with energy resolution better than 14%

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and time resolution $\leqslant 1$ ns [4]. Insensitivity of the detector to magnetic fields would allow to combine a PET and a magnetic resonance (MR) scanner in a single apparatus.

In this work we show that detectors meeting the above requirements could be built based on today's available AMPDs.

2. Measurements

The measurements were carried out with $1 \times 1\,\mathrm{mm}^2$ and $3 \times 3\,\mathrm{mm}^2$ active area AMPDs of type MW-3. The AMPDs of this type have a so-called micro-well structure [1]. They feature a high density of microchannels ($10^4/\mathrm{mm}^2$), gain up to 5×10^4, and high PDE in the blue and near ultraviolet regions of the spectrum. The operation voltage of the device is about 120–140 V.

An AMPD was mounted on the board of an amplifier (gain adjustable up to $\sim$100, bandwidth $\geqslant$500 MHz, details described in Refs. [2,3]). A LYSO ($Lu_{1.8}Y_{0.2}SiO_5$:Ce from Saint Gobain Crystals) scintillation crystal of size $2 \times 2 \times 10\,\mathrm{mm}^3$ was fixed with its smaller ($2 \times 2\,\mathrm{mm}^2$) face on an AMPD using a plexiglass holder. The crystal was wrapped in teflon tape, the optical contact to the AMPD was ensured using silicone optical grease BC-630. The measurement setup consisted of two identical γ-detectors facing each other and a ^{22}Na radioactive source positioned between them. Special care was taken in the alignment of the detectors and the source.

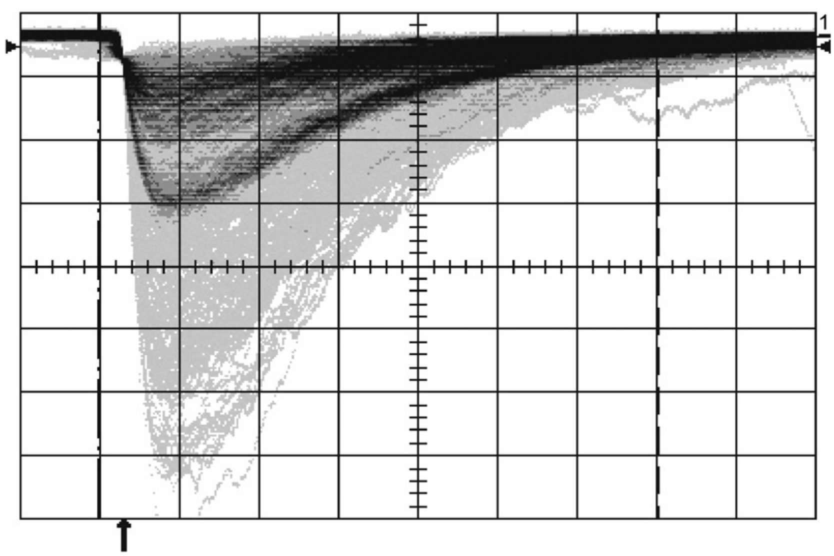

Fig. 1. Oscilloscope screenshot of the signals from a detector based on a $2 \times 2 \times 10\,\mathrm{mm}^3$ LYSO crystal and $3 \times 3\,\mathrm{mm}^2$ AMPD at registration of γ-quanta from a ^{22}Na radioactive source (horizontal and vertical scales are 20 ns/div and 20 mV/div, respectively).

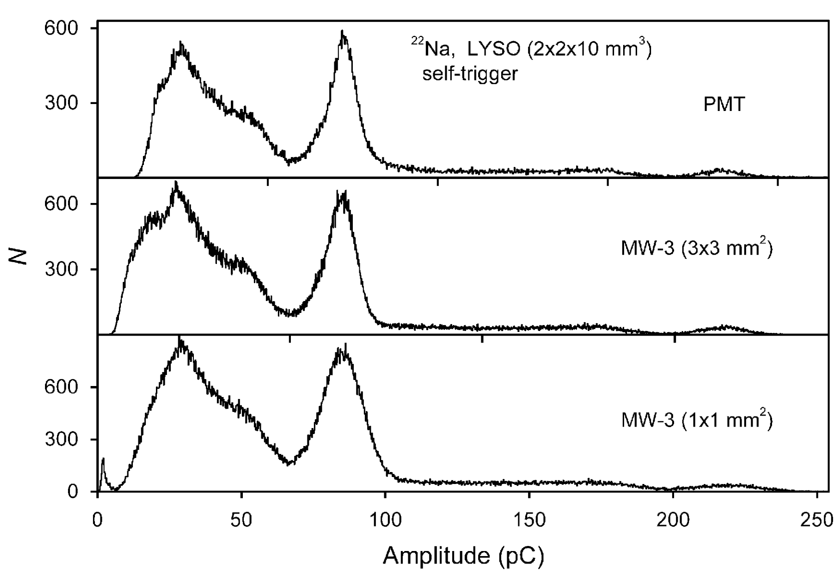

Fig. 2. Amplitude spectra obtained in self-triggering mode with PMT and AMPDs at detection of ^{22}Na γ-quanta with a LYSO scintillation crystal of size $2 \times 2 \times 10\,\mathrm{mm}^3$.

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