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A new detector concept for silicon photomultipliers

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A novel design and principle of performance of silicon photo-multipliers are presented. The new design comprises a semiconductor substrate and an array of independent micro-photo-transistors formed on the semiconductor substrate. Each micro-photo-transistor contains a photosensitive base operating in Geiger mode and an individual micro-emitter covering a small part of the base layer, thereby creating together with the latter one a micro-transistor. The micro-transistor operates as a binary switch with on and off states due to a high value of over voltage applied to the base electrode. Both micro-emitters and photosensitive base layers are connected with two independent metal grids via their individual micro-resistors. The total value of signal gain in the proposed silicon photo-multiplier is a result of both the avalanche gain in the base layer and the corresponding gain in the micro-transistor. The main goals of the new design are: to decrease significantly both optical cross-talk at high signal amplification and the device capacitance; to improve speed of forming of single photo-electron pulses received from the micro-transistor circuit.

Collaboration

MAPD-collaboration
on joint scientific, technological and innovative activity on development and application of micro-pixel avalanche photo diodes (MAPD), also named as silicon photomultipliers (SiPMs).

`List of members:`

- Joint Institute for Nuclear Research, Dubna, Russia.
- Institute for Nuclear Research, of the Russian Academy of Sciences, Moscow, Russia.
- National Nuclear Research Center, Baku Azerbaijan.
- National Academy of Aviation, Baku, Azerbaijan.
- Institute of Physics of the National Academy of Sciences, Baku, Azerbaijan.
- Zecotek Photonics Inc., Canada.
- Zecotek Imaging Systems Pte. Ltd., Singapore.
- Dubna-Detectors Ltd., Russia.

Summary

The present contribution suggests decreasing significantly the both optical crosstalk at high avalanche amplification and special capacity of silicon photomultipliers, as well as to improve the speed of photo response. The new device comprises a silicon substrate and an array of independent micro-phototransistors formed on the silicon substrate. Each micro-phototransistor contains a photosensitive base (pixel) operating in Geiger mode and an individual micro-emitter covering a small part of the base layer, thereby creating together with the latter one a micro-transistor. The micro-transistor operates as a binary switch with on and off states due to a high value of overvoltage applied to the base electrode. Both micro-emitters and photosensitive base layers are connected with two independent metal grids via their individual micro-resistors (Z.Sadygov and

A.Sadigov. Semiconductor avalanche detector. –Russian patent #2528107, dated 10.09.2014).
In operating mode, positive bias is applied to the silicon substrate relative to the both the common metal grid and the additional metal grid. In a kind of the small sizes the pixels can work in Geiger mode at which the bias may exceed the characteristic breakdown voltage by ΔU=2V. Geiger mode avalanche process starts in case of occurrence an single photoelectron in a pixel, and this results in increasing potential drop on the individual micro-resistor 3 up to ΔU=2V In the same time potential of the pixel is decreased by the same value. The potential drop ΔV~2B completely opens a potential barrier between the base (pixel) and the individual emitter, because of its high current flows through the individual emitter. This pulsed current is limited by the additional individual micro-resistor. Pulsed current is switched off when potential of the pixel reaches previous value by means of charging via the individual micro-resistor. Thus, photo signal in the device is amplified again in micro-transistor. The amplified signal is detected on external load resistance connected to an electric circuit of the additional metal grid. Full value of amplification factor of the signal is defined as M0~Mav*Mtr, where Mav –amplification factor of avalanche process, Mtr –amplification factor of the micro-transistor. Besides rise time of the photo signal is improved due to low capacitance micro-transistors. For example, at typical sizes of pixels of 50μm×50μm, the sizes of micro-transistors do not exceed 5μm×5μm.
Main advantages of the new device.
•Low crass talk because of lowering avalanche gain.
•Last photo response due to individual micro-transistors working in digital mode.
•Very low (about 50 times less) capacitance of devices.
•Capable for use in TOF detectors due to fast photo response.
•Capable for use in astrophysics detectors due to low capacitance.

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