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Time Of Flight Detectors: From phototubes to SiPM

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Abstract

A sample of Silicon Photomultipliers was tested because they looked promising for future space missions: low consumption, low weight, resistance to radiation damage and insensitivity to magnetic fields. They have been studied in laboratory by means of the same characterization methods adopted to calibrate the fine mesh photomultipliers used by the Time Of Flight of the AMS-02 experiment. A detailed simulation was made to reproduce the SiPM response to the various experimental conditions. A possible counter design has been studied with front end electronics card equipped with SiPMs and Peltier cell for thermoregulation. A proper simulation based on COMSOL Multiphysics package reproduces quite well the Peltier cell nominal cooling capability.

Keywords: Silicon photomultipliers; Thermoregulation; Simulation; Space experiments

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1. Introduction

The Italian National Institute of Nuclear Physics (INFN) has made an effort in the Development and Applications of Silicon Photomultipliers (SiPM) for medical physics and astrophysics (DASiPM experiment). The SiPM is a matrix of Avalanche Photodiodes (APD). The pixels have a low bias voltage supply of about 50 V and their gain is of the order of 10^5–10^6.

With respect to earlier photodetectors based on semiconductors, the SiPM has a new capability: the measurement of the light intensity which is proportional to the number of pixels triggered by photons. Actually the SiPM is semidigital and semianalogue at the same time: each pixel operates as a binary device, but the SiPM on the whole is an analog detector, which can measure the light intensity within its dynamical range [1]. The SiPM dynamic range is determined by the finite number of pixels ($\sim 10^3/\mathrm{mm}^2$). Moreover, as the SiPM depletion region is small (~μm) and the operating electric field is very high (2–3×10^5 V/cm) with high carrier velocity (10^7 cm/s), the Geiger discharge is extremely short and the SiPM signal is intrinsically very fast. Such interesting features suggest that this photodetector can be a possible substitute for the usual photomultiplier [2] in experiments, where low consumption, low weight and fast timing are required. For all these reasons a sample of SiPMs has been tested by using the same techniques used for the photomultipliers of the Time Of Flight (TOF) of the AMS experiment [3]. The experimental results were successfully compared with a proper simulation of the detector response. Another simulation has been performed in order to understand a Peltier cell capability to thermoregulate the SiPM in space. The design of a possible counter shows how the SiPM can be used in conjunction with optical fibers and Peltier cells for TOF techniques of space experiments.

2. The SiPM calibration

The single photoelectron (sphe) response for a fine mesh photomultiplier was compared with the sphe response of an SiPM and it was found that the peaks corresponding to the various photoelectrons are not so easily seen with the fine mesh as for the SiPM [3]. The SiPM response to many photons has also been compared to the PMT one: in both detectors the response to various light intensities, at the same voltage supply, is an indication of the gain. For usual

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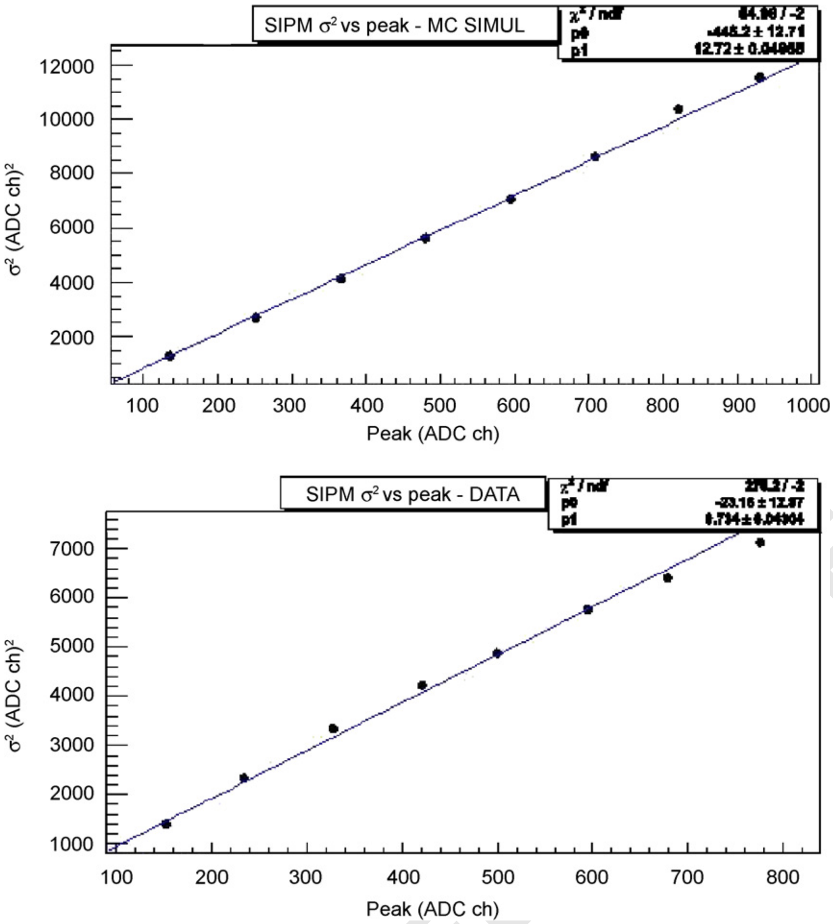

Fig. 1. SiPM response line to different light intensities at fixed voltage supply; the slope is proportional to the gain from the data (below) as from the simulation (above) [3].

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PMT, in fact, the *response line*,[1] has the slope which is proportional to the gain [4].

We found that also for the SiPM the slope of the response line is proportional to the gain obtained from the sphe peak and the simulation reproduced the data quite well, as you can see from Fig. 1.

The gain measured from the sphe peak is correlated to the gain measured from the *response line*, as you can see from Fig. 2, where the data of a Silicon photomultiplier from Photonique company are reported [3]. This property can be used in space to calibrate SiPM coupled to scintillators as different light intensities can be obtained by selecting different portions of the barrel to produce scintillation photons revealed by the silicon photomultipliers [6].

3. Possible space counter design and electronics

In order to use SiPMs for TOF applications, we designed a specific counter (shown in Fig. 3) where the photodetectors are coupled to a scintillator through light guides. The readout electronics and the thermoregulating Peltier cells are disposed on a printed board to fit the thickness of the counter side ($10 \times 120\,\mathrm{mm}^2$).

In our first design we have chosen voltage amplifiers (good time resolution) with large band and low noise transistors (MGF 4953A HEMT, NE 3210 S01).

We are preparing the electronics printed board, whose mechanical scheme is shown in Fig. 4, so that one channel by side will be connected to eight silicon photomultipliers to measure the signals from the light guides mounted along the thickness of the counter long side.

The card will also be provided with connectors and chips, in the center, to control the Peltier cell at the counter side, for the thermoregulation of the SiPMs and of the electronics, as in Fig. 4.

4. Study of a Peltier cell thermoregulation

The thermoelectric modules, better known as *Peltier cells* from their discoverer, act as a “heat pump”: heat moves from one side to the other of a junction between different conductors as direct current flows inside. The Peltier cell consists of a matrix of doped semiconductor elements

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[1] σ^2 vs peak of charge response to different light intensities [4].

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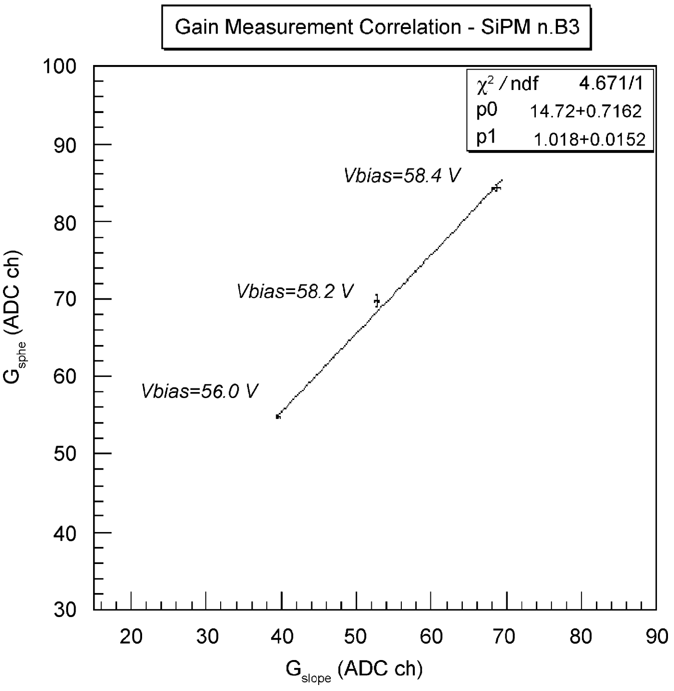

Fig. 2. SiPM gain as measured from the slope of the response line and from the sphe peak (in ADC units); there is a correlation between the two methods [3].

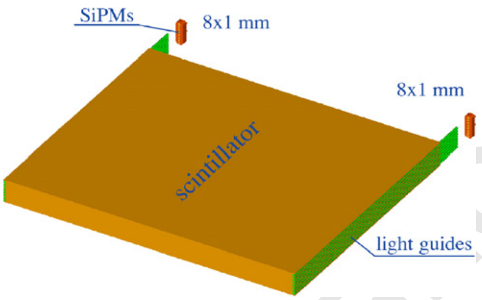

Fig. 3. Counter design with eight light guides to be read by SiPMs.

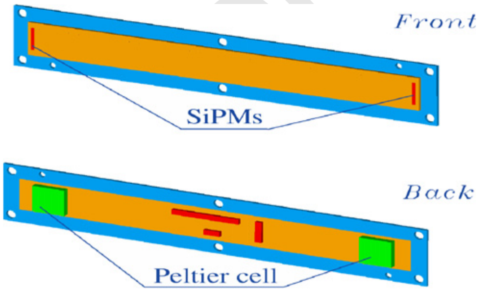

Fig. 4. Scheme of the counter front end printed board with the Peltier cells to thermoregulate the SiPMs at the counter sides.

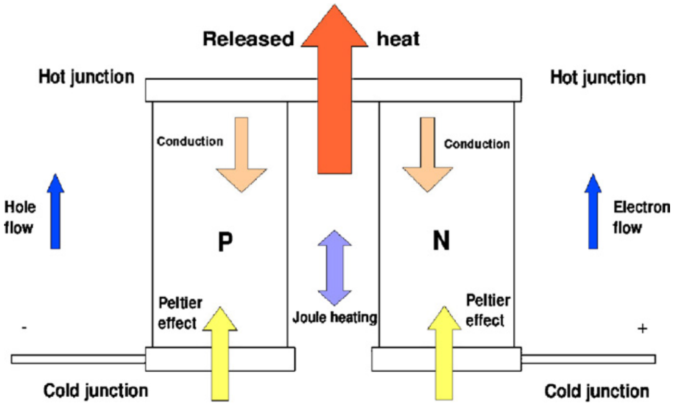

Fig. 5. Heat flows in the same versus through two adjacent pellets differently doped, as current passes from one to another.

(“pellets”), joint in pairs, soldered to copper strips so that the pairs are electrically in series but thermically in parallel. As the heat is moved by the majority carriers, the adjacent pellets are differently doped to permit the right heat flow with the current (Fig. 5).

We have studied a Peltier cell PE-031-07-10 of the Supercool Company [7], composed of 31 pellets, each of dimensions 0.45 mm^2 × 1.0 mm. The cell was given certain characteristics from the producer: with 1.56 A of current it could “pump” 1.5 W so to maintain a temperature gradient of 45° [8]. The simulation of the cell, to verify these nominal characteristics, has been performed through the COMSOL Multiphysics package [9] by selecting two main modules: namely the “Heat transfer by conduction” for the thermal behavior and the “Conductive media DC” for the electrics settings. The two modules equations that are used by the COMSOL solver represent, respectively, the conservation of energy and of current in the cell, and they are coupled through a variable generated by the electrics module and representing the Joule heat dissipated by the cell. Some modifications were necessary to implement the Peltier effect, nominally in the “weak form” of the pellet heat equation [8]. The simulation permits to combine the heats conducted in and out into one “net heat conducted out” therm, thus quantifying the cooling property of the Peltier cell. The pellet simulation was given in input the alimentation current (1.56 A) and the emission power of the SiPM printed board device (1.5 W). The final cooling power, from the simulation, corresponds to the nominal one, as you can see from Fig. 6 (for a couple of pellets) and from Fig. 7 (for a matrix), the devices are brought continuously to 253 °K pumping heat to the hot side of the cell (at about 300 °K).

5. Conclusion

The SiPMs can be used in space experiments for their characteristics and they can be also monitored in flight as we found a correlation between the SiPM response to many photons and the gain measured with the single photoelectron. A space counter has been designed with light guides to collect signals to SiPMs and a Peltier cell for

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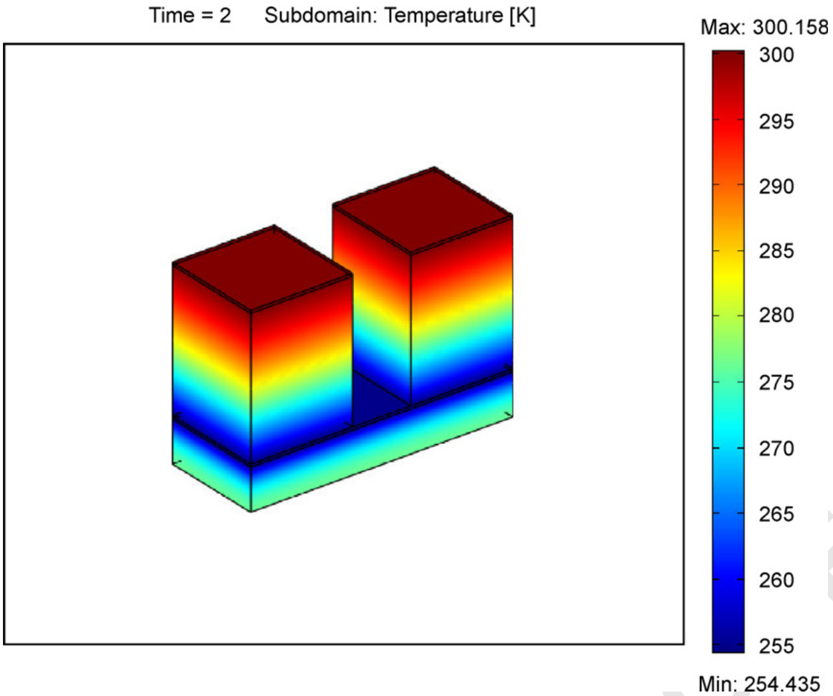

Fig. 6. Simulation of heat flow through two coupled Peltier cells differently doped attached to a device that emits like a SiPM with the printed board. The cold side is brought continuously to 253 °K.

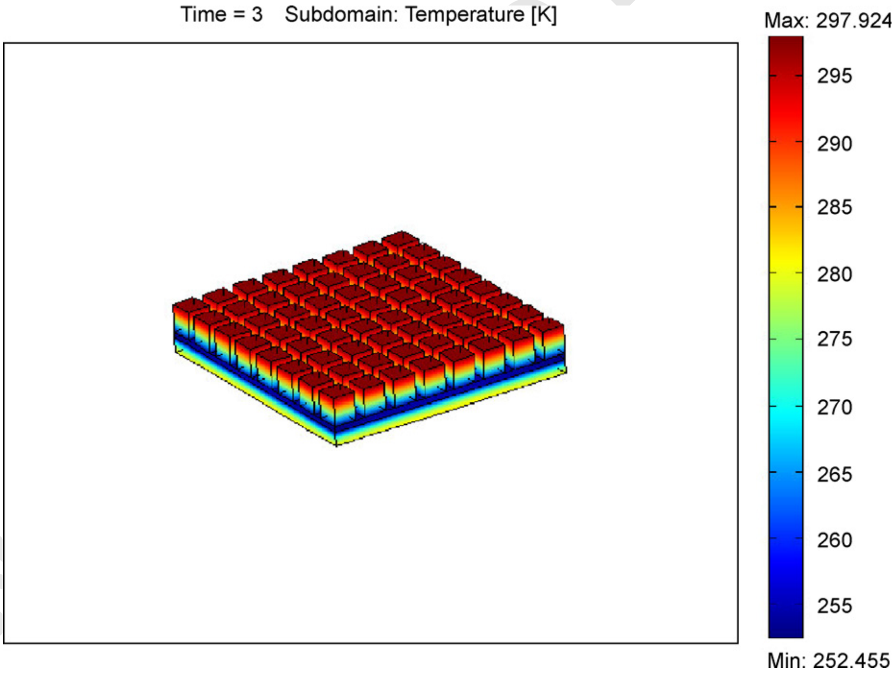

Fig. 7. Simulation of heat flow through a matrix ($10\,mm^2 \times 2.5\,mm$) of pellets on a printed board. The cold side is brought continuously to 253 °K.

thermoregulation has been studied with a proper simulation confirming the cell nominal characteristics.

Q4 6. Uncited reference

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