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Study of photo-sensor candidates for the MEMSTEL project

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Abstract: The MEMSTEL (Micro Electro Mechanical Systems Space Telescope) is a space-based experiment being designed to investigate the origin of extreme energy cosmic-ray (EECR) particles above 5×10^{19} eV. The fluorescent light generated in extensive air showers (EAS) when EECRs hit the atmosphere can be detected from low Earth orbit. MEMSTEL will implement a novel idea of a tracking mirror based on semiconductor MEMS technology. The light signal will be focused on a relatively small area of readout photo-sensors using a tracking mirror. One candidate for MEMSTEL photo-sensors is the conventional multi-anode photo multiplier tube (PMT). Recently, a new type of photo-sensor was developed for particle detector readouts - the silicon photo multiplier (Si-PM). This compact photo-sensor is comprised of a large array of micro-cells operating in a limited Geiger mode, and provides high gain (~ 10^6) with low operating voltage (~ 50 V). The compact design, light weight and low power consumption make this device an excellent photon-detector candidate for space-based experiments. In this paper, we report on the comparative performance of a 1×1mm^2 Si-PM, a conventional PMT, and a Hybrid Photo Diode (HPD) in lab tests, reading out light generated by Light Emitting Diode (LED) as well as by scintillating fibers excited with a radioactive source.

Introduction

The Micro Electro Mechanical Systems Space Telescope (MEMSTEL) [1,2] project is intended to study extreme energy cosmic-rays (EECRs) beyond the GZK cutoff [3,4] with a MEMS (Micro Electro Mechanical Systems)-based mirror to focus light from EECR showers in the atmosphere to an array of photo-sensors on a satellite. This will increase the detection efficiency of EECRs within the weight and power budget available in the current payload. To accomplish this task, a photo-sensor with optimal weight and sensitivity must be selected. This paper will present tests of silicon photo multiplier (Si-PM) characteristics in comparison to conventional photo multiplier tube (PMT) and Hybrid Photo Diode (HPD) with a Light Emitting Diode (LED) light source and scintillation light from fibers excited by a radio-active source.

Test of a Si-PM

The Si-PM [5] is a very attractive photo-sensor for space-based experiments due to its compact form factor, low power and low operating bias voltage. We have tested a Si-PM [6] with an active area of 1×1 mm^2 (Fig. 1). Figure 2 shows the test setup used to read out the Si-PM exposed to light from a blue LED, including a pulse generator to power and trigger the LED, a power supply for bias, and a 4 G-Sample/s, 500 MHz bandwidth digital oscilloscope (LeCroy LT374).

Figure 1: A 1 × 1 mm^2 active area Si-PM (a US one cent coin is shown for scale).

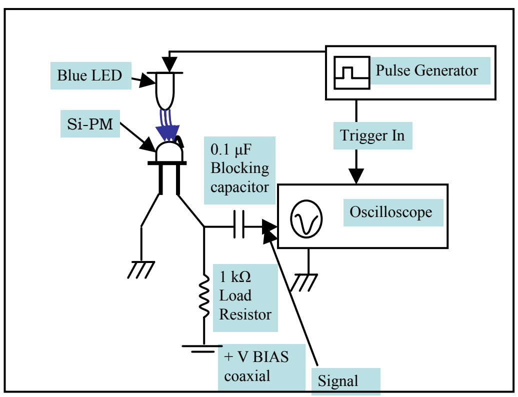

Figure 2: Diagram of a test setup to read out Si-PM signal with a blue LED light source using an oscilloscope.

Using the test setup in Fig. 2 with a bias voltage of + 54 V, we were able to see a single cell break down (= single photo electron) signal (Fig. 3). The signal is self-triggered with a threshold value less than a 1/3 of a single photo-electron (p.e.) to avoid trigger bias. When the signal is read out with a 50 Ω termination, using an oscilloscope, the single p.e. signal is ~ 3 mV in amplitude and ~ 5 ns full width in this readout circuit. The rise time is ~ 1 ns, confirming the fast response of the Si-PM. A second signal can be seen ~ 100 ns after the first, indicating ~ 10 MHz dark current signal rate, assuming the interval is typical. In the lower part of Fig. 3, a distribution of integrated signals for ~ 37,100 triggered events is shown in linear scale. The single, double and triple p.e. signals are clearly separated, with an estimated signal to noise ratio (S/N) of ~ 4.6.

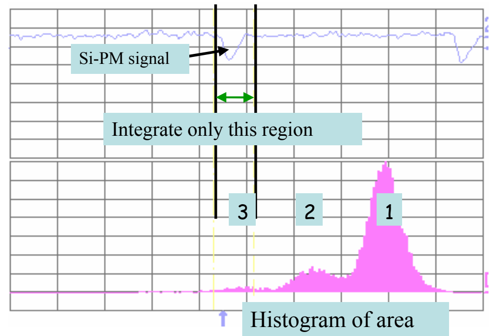

Figure 3: A single photo-electron (p.e.) signal from the Si-PM biased at + 54 V in self-trigger mode (trace at top). The horizontal time bin size is 10 ns and the vertical signal bin size is 2 mV. A distribution of ~37,100 integrated signals in the gated region is shown (bottom, linear scale) in units of [mV × ns]. The signals from 1 and 2 p.e. are clearly separated. The signal to noise ratio is estimated at ~ 4.6.

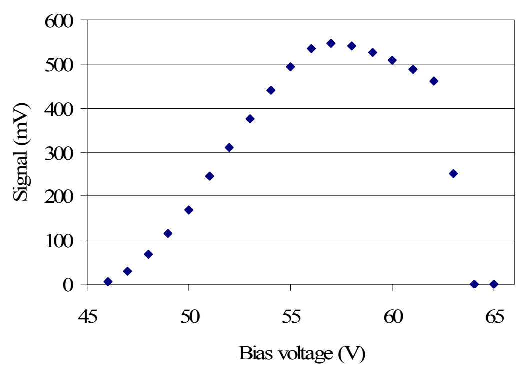

Figure 4: Si-PM response to LED light as a function of bias voltage. The LED light was set to saturate the Si-PM with about an 80 ns width.

We investigated the characteristics of a Si-PM with an LED light source at different bias voltages. The amplitudes of Si-PM signals were measured from an LED input with a width of ~ 80 ns and an intensity that saturated the Si-PM (Fig. 4). The amplitude value is an average of more than 500 triggered signals. We can see that the Si-PM goes into avalanche mode starting 46 V and the signal keeps increasing up to 57 V. The Si-PM behaves like a short circuit starting at ~ 63 V. Figure 5 shows the pedestal mean and RMS noise level with respect to bias voltage without LED signal, using a random trigger from the pulse generator. Up to 45 V, where the Si-PM starts to show signal, the ~ 0.3 mV noise RMS is mainly from the readout electronics since the gain of the Si-PM is very low until it reaches the single cell breakdown with a gain of ~10^6. However, once the Si-PM enters avalanche mode at V = 46 V, the single p.e. noise (= breakdown dark noise) starts contributing to the noise as observed from the signal on the oscilloscope. The amplitudes and rates of the dark noise signal increase in amplitude and frequency as the bias voltage is increased, until the Si-PM becomes a short circuit.

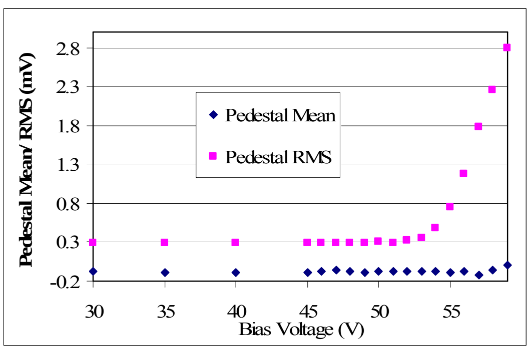

Figure 5: Pedestal mean and RMS values of Si-PM as a function of bias voltage with random trigger from the pulse generator.

Conclusions

A 1 × 1 mm^2 active area Si-PM was investigated as a photo-sensor candidate for the MEMSTEL project. Using a lab readout circuit, we confirmed the single p.e. signal from the single-cell breakdown is well separated from the double and triple p.e. signals. The signal to noise ratio was ~ 4.6. The bias voltage dependence test showed the pedestal mean value is constant up to the region where the dark signal rate and amplitude increase. Due to the dark signals, the pedestal RMS starts increasing from ~ 52 V. Further studies will be presented including test results of the Si-PM with scintillation light signal from fibers irradiated with a radioactive source, allowing comparison with other photo-sensors, such as PMTs and HPDs.

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