FIRST RESULTS OF SILICON PHOTOMULTIPLIER STUDY PERFORMED AT THE UNIVERSITY "LA SAPIENZA" OF ROME

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Our first results on Silicon Photo-Multiplier (SiPM) properties study are presented. The reported measurements allowed us to develop and tune both the setup and the measurement analysis procedures. The current-voltage (I-V) characterization and the response to low-intensity light were studied on samples produced by CPTA (Russia), Hamamatsu (Japan), ITC-irst (Italy) and SensL (Ireland). Limitations of our present set-up and the underway improvements in our laboratory are discussed in order to add also the Photon Detection Efficiency (PDE) in the qualification parameters of diverse samples of SiPM available on market.

1. Introduction

The Silicon Photo-Multiplier (in short SiPM) with single photon counting capability born from an original suggestion proposed by Golovin and Sadygov in the 90's [1, 2]. It consists of a solid state matrix segmented in cells all connected in parallel in reverse bias mode just above the breakdown value. The basic block is a junction working in limited Geiger mode thanks to a passive quenching resistor ($R_{quenching}$) implanted on the surface together with the aluminum layer in series with the applied bias in order to reduce the real bias to the SiPM below the breakdown value, when the avalanche is in place. In this way is allowed the detection on the same cell of another photon after a recovery time driven by the single pixel capacitance in reverse bias mode and the quenching resistance. Typically, for $R_{quenching}$ = 300kΩ and pixel junction area of 25μmx25μm with thickness of ~1μm for the spatial extension of the breakdown electrical field, a value of ~30ns is obtainable as recovery time. It's evident that

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in spite of the binary response of each cell (typically ~10^5-10^6 electrons for each photoelectron triggering the avalanche) in reason of the breakdown mechanism, the matrix works like an analogue device providing an output signal proportional to the number of the photo-electrons generated by the photon conversion. The SiPM has the capability to detect extremely low photon fluxes giving proportional information. The dynamic range provided by SiPM is linked to the number of cells. The main points that can summarize the features are:

- Low bias voltage operation (typically less than 100V). This implies low power dissipation, then ease to operate, reliability and cheaper price.
- High gain. Consequence is high signal and also high signal over noise in optimal bias voltage region and temperature controlled.
- Insensitivity to magnetic field. Proved for value of some Tesla, compared to one order of magnitude less in case of usual vacuum photo multiplier.
- Mechanical robustness. Thanks to the compact dimensions, follows not only to be more reliable also for this reason, but it is very attractive in all the space applications where weight is a pay load.
- Fabrication technology is compatible with standard process of micro-electronics industry. Mass production will then profit of cheaper price.

All this considerations made the Silicon Photo-Multiplier very attractive for a lot of research fields: high energy physics, astrophysics, medical applications and robotics.

2. Measurement setup

The schematic of our measurement setup is reported in Fig.1. Firstly has to be noted that in this phase of measurement the setup do not yet make possible to control the temperature: was possible only to measure it. On the other side, all reported measurements are done at room temperature (~24^{o}C). The temperature variation was within ~2^{o}C during each measure session on one SiPM sample, and for all the measurements reported was not more than ~4^{o}C. The first purpose of our setup is to allow the measure of current-voltage characteristics on each SiPM under test in dark condition (i.e. without any external light signal injected). Assuming a maximum value for the current in breakdown condition of ~1μA and ~100kΩ for the limitation resistor in series in the polarization voltage circuit (i.e. external to the SiPM, as shown in the Fig.1), then the monitored voltage bias could be affected by less than ~0.1V. The second purpose of the setup is to acquire via a charge ADC the output of the SiPM seen through a fast pre-amplifier (pA) when an external pulsed low intensity light signal is injected. The pulsed light is coupled with an optical fiber on the SiPM, and is emitted from a LED (Light Emitting Diode) stimulated by a fast pulse adjustable both in duration and in amplitude. Typical pulse duration used to drive the LED was ~6ns. A trigger synchronizes the LED pulse and the gate for the ADC. Finally, a dark rate study in breakdown regime is feasible with a simple modification of the chain, inserting a discriminator and a counter scale at pA output level.

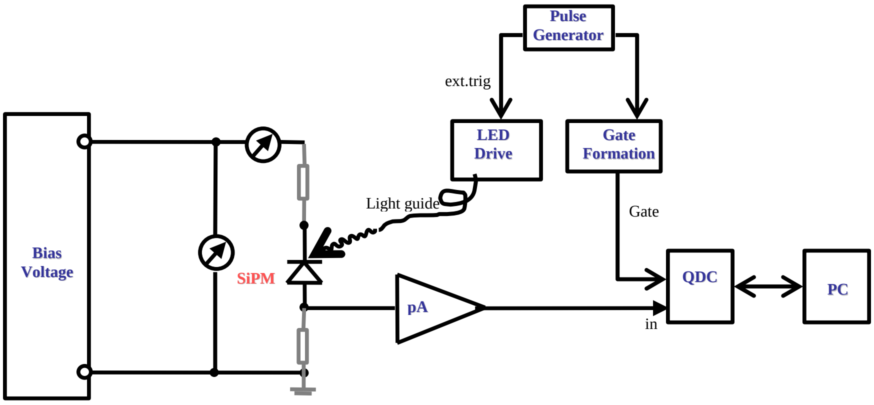

Figure 1. The static polarization circuit (on the left part), the pulsed light injection circuit (on the middle) and the readout via an integrating ADC circuit (on the right) are shown.

3. Measurement Results

We tested one type of Silicon Photo-Multiplier from five different producers. The total area of the matrix of each tested SiPM was 1mm^2 segmented in a number of cells ranging from 500 up to 1600. The linear dimension of each cell was from 25µm up to 50µm. Two of the five samples have been produced by CPTA (Russia) and distributed one by Obninsk University and the other by Forimtech. One sample was from Hamamatsu (Japan) (S10362-11-025C). One sample was from ITC-irst (Italy) (SIT6V1PD1). Finally, one sample was from SensL (Ireland) (SPMScint1000). In Fig.2 a mosaic of microphotographs each one done on an optical microscope is reported.
The current-voltage measurements show a similar behavior on the five SiPM giving breakdown voltage value ranging from 28V up to 70V. Such information is useful as starting guess for the following phase: measure the SiPM response to low-intensity pulsed light. In Fig.3 a typical spectrum of one of the tested sample is reported. The various peaks indicate the various numbers of fired cells

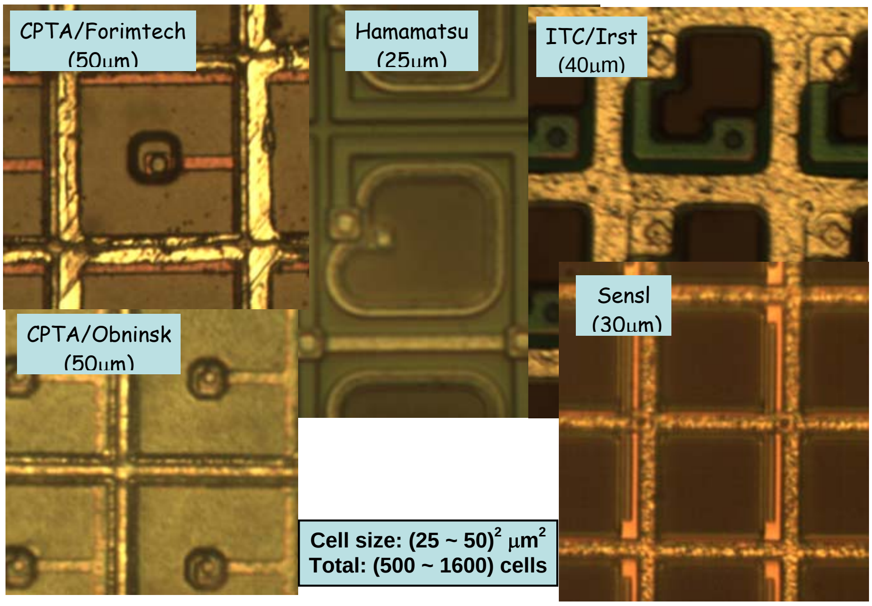

Figure 2. A mosaic of five photos taken by a microscope of the five tested SiPM is shown. To be noted that the shown photos are not in scale. The matrix structure is evident. The packages are TO5 for SenL and TO8 for the others.

at each light pulse. The first one on the left refers to the pedestal (i.e. is the case of no fired cell). The second peak refers to the case of one photoelectron generated in one cell of the matrix. The distance between peaks corresponds to the SiPM gain. The spectrum is fitted as a sum of Gaussian distribution. Apart the normalization factors and the standard deviations σ_i that are individual for each Gaussian, the pedestal position (μ_0) and the gain (g) are global parameter for all the fitted spectrum. Then the position (μ_i) of a specific peak i^{th} is given by the relation $\mu_i = \mu_0 + i \cdot g$. The obtained (from the fit) standard deviation (σ_i) of the i^{th} peak can be parameterized in terms of a quadratic combination of the pedestal standard deviation σ_0 with $<\sigma_{pix}>$. The last term stands for the standard deviation of one-cell averaging over the active area of the matrix.

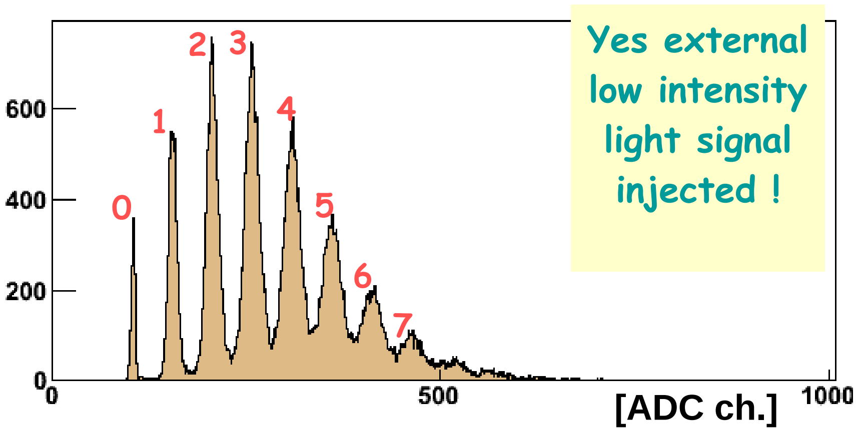

Figure 3. Typical raw pulse height spectrum (in terms of ADC counts) obtained from one SiPM pulsed by a low intensity LED light. On the reported spectrum the multi peak structure refers to the various numbers of fired cells in a particular triggered light pulse impinging the matrix.

In Fig.4 are reported for all the tested SiPM the gain versus the over voltage (i.e. at the applied bias voltage is subtracted the breakdown voltage).

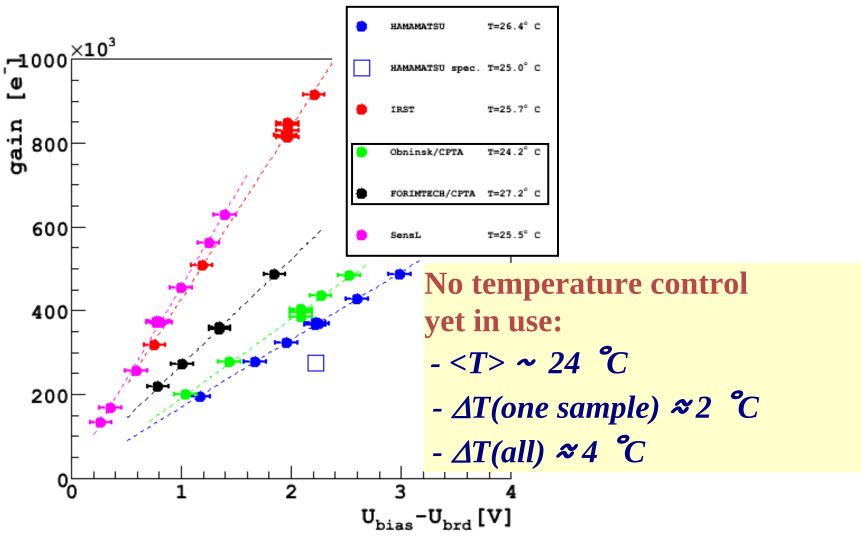

Figure 4. Gain as a function of the over voltage (V_{bias} - $V_{breakdown}$) for the tested SiPM is reported.

4. Conclusion

The first explorative phase just performed, point out the need to improve the setup implementing a temperature control at the level of 0.1^{o}C with long time scale stability. Became possible a measurement program extension of the characteristic parameters for a SiPM as a function of the temperature. The data analysis of the spectra could be further developed including both efficiency and cross-talk estimations. At this point the validity of the results requires an extension to more statistics. Finally modifying the optical part of the excitation measure the Photo Detection Efficiency (PDE) as a function of light wave length.

Acknowledgments

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References

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