IL NUOVO CIMENTO Vol. 30 C, N. 5 Settembre-Ottobre 2007
DOI 10.1393/ncc/i2008-10267-7

First results of comparative studies of silicon photomultipliers(*)

C. Bosio([1]), S. Gentile([2]), E. Kuznetsova([1]) and F. Meddi([2])

([1]) *INFN, Sezione di Roma 1 - Rome, Italy*
([2]) *Università di Roma "La Sapienza" - Rome, Italy*

(ricevuto il 3 Marzo 2008; pubblicato online il 29 Aprile 2008)

Summary. — The presented results are obtained during the first steps taken in order to develop a set-up and measurement procedures which allow to compare properties of diverse samples of silicon photomultipliers. The response to low-intensity light was studied for silicon photomultipliers produced by CPTA (Russia), Hamamatsu (Japan), ITC-irst (Italy) and SensL (Ireland).

PACS `85.60.Gz` – Photodetectors (including infrared and CCD detectors).
PACS `85.60.Ha` – Photomultipliers; phototubes and photocathodes.

1. – Introduction

Fast development of the silicon photomultiplier technology results in a number of different SiPM types available on market and produced by different manufacturers. Systematic studies done with various types of SiPM would provide start information for an optimal choice of the device appropriate for a given application. The results presented here are obtained during the first steps taken in order to develop a set-up and measurement procedures which allow to compare properties of diverse SiPM samples.

The measurements discussed here include current-voltage characteristics and studies of the SiPM response to low-intensity light. While results of the former measurements are mostly used to check the sample operability and to define the range of bias voltages for the latter studies, the measurements of the SiPM response to the light provide a number of parameters suitable for the comparison of different samples.

2. – Measurement set-up

A principal scheme of the measurement set-up is shown in fig. 1. The bias voltage and current through a SiPM sample are monitored in the voltage circuit. The SiPM is

(*) Paper presented at the 1st Workshop on Photon Detection for High Energy Medical and Space Applications; Perugia, June 13-14, 2007.

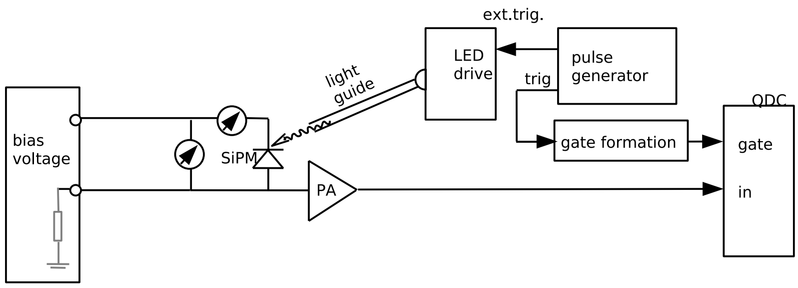


Fig. 1. – A principal scheme of the measurement set-up. The bias voltage and current through a SiPM sample are monitored in the voltage circuit. The SiPM is illuminated with light from a Light-Emitting Diode (LED) operated in a pulse mode. The signal from SiPM is read out with a charge-sensitive preamplifier (PA) and digitised with an integrating ADC. The LED pulse and ADC gate are synchronised by means of a common trigger.

illuminated with light from a light-emitting diode operated in a pulse mode. The LED drive developed by Institute of Physics ASCR (Prague) provides current pulses with tunable amplitude and duration and a sharp rise time down to 2 ns [1]. The signal from SiPM is read out with a charge-sensitive preamplifier and digitised with an integrating ADC. The LED pulse and ADC gate are synchronised by means of a common trigger.

No temperature control is implemented yet; the measurements are done at room temperature. Temperature variation during the measurements done for one sample did not exceed 2 °C, for all measurements discussed here the total variation was less than 4 °C.

3. – Measurement results

Five samples of silicon photomultipliers have been studied. CPTA([1]) produced samples distributed by Obninsk University and Forimtech([2]), HAMAMATSU produced Multi-Pixel Photon Counter S10362-11-025C [2], ITC-irst([3]) and SensL([4]) produced samples were compared on the base of the measurement results.

Figure 2 shows the current-voltage characteristics measured for the listed samples.

Figure 3 shows an example of the SiPM response to low-intensity light measured with the described set-up. The peaked structure indicates the number of cells fired during one light pulse, starting with the pedestal for no cells fired. The distance between peaks corresponds to the SiPM gain.

The spectrum is fitted as a sum of Gaussian distributions:

$$\sum_i G(N_i, \mu_i, \sigma_i) = \sum_i G(N_i, \mu_0 + i \cdot g, \sigma_i), \tag{1}$$

where μ_0 corresponds to the pedestal position and g is gain in units of ADC counts.

([1]) CPTA, Russia, `http://www.zao-cpta.ru`
([2]) Forimtech SA, `http://www.forimtech.ch`
([3]) ITC-irst, Italy, `http://www.itc.it/irst`
([4]) SensL, Ireland, `http://www.sensl.com`

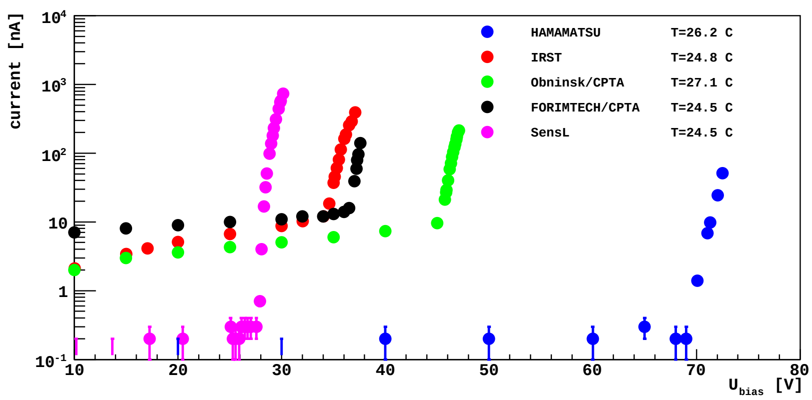


Fig. 2. – The current-voltage characteristics measured for the studied samples.

From statistical considerations the width of the i-th peak σ_i can be expressed as

$$\sigma_i = \sqrt{\sigma_0^2 + i \cdot \langle \sigma_{px} \rangle^2}, \tag{2}$$

where σ_0 is the pedestal width and $\langle \sigma_{px} \rangle$ represents fluctuations of the one-cell response averaged over the active area of the sample.

In order to check reproducibility of the measurements and fitting procedures, a series of spectra was taken for the same bias voltage but under different light intensities. Figure 4 shows the fitted width of the i-th peak as a function of the peak number obtained from different measurements (left) and the corresponding averaged values (right). The right plot is fitted according to eq. (2).

The gain as a function of the overvoltage $U_{\text{bias}} - U_{\text{brd}}$ was studied for several values of the bias voltage. The breakdown voltage U_{brd} is defined here as the bias voltage corresponding to the gain equal to one. Figure 5 shows the results obtained for the measured samples.

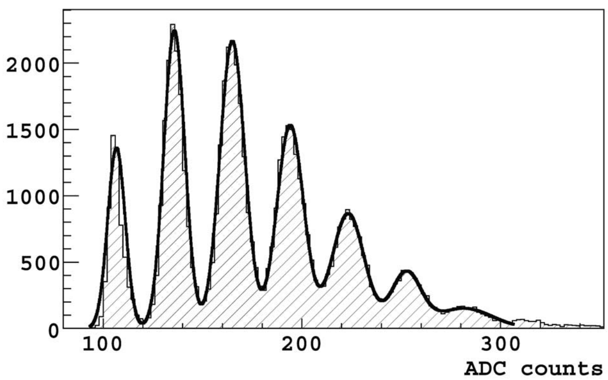


Fig. 3. – ADC spectrum of the SiPM response to the low-intensity pulsed light (dashed histogram) fitted to a superposition of seven Gaussian peaks (gray line).

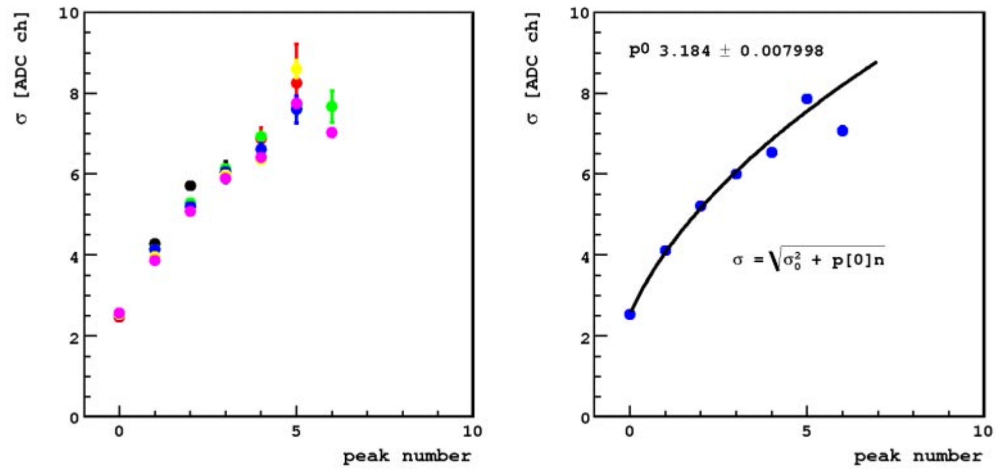


Fig. 4. – Fit values for the width of the i-th peak as a function of the peak number (left). The results obtained from different measurements are shown with different markers. The corresponding averaged values as a function of the peak number (right) are fitted according to eq. (2).

Figure 6 shows gain normalised to the corresponding values of pedestal width (left) and $\langle\sigma_{px}\rangle$ (right) as functions of the overvoltage. Being averaged over the active area of SiPM, $\langle\sigma_{px}\rangle$ contains statistical and systematic parts:

$$\langle\sigma_{px}\rangle \sim \sqrt{N + \sigma_{\mathrm{nu}}^2}\,, \tag{3}$$

where N is the average number of charge carriers in the avalanche and σ_{nu} represents

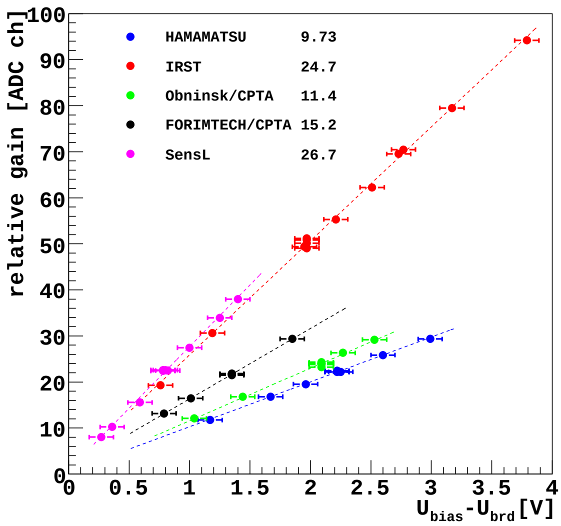
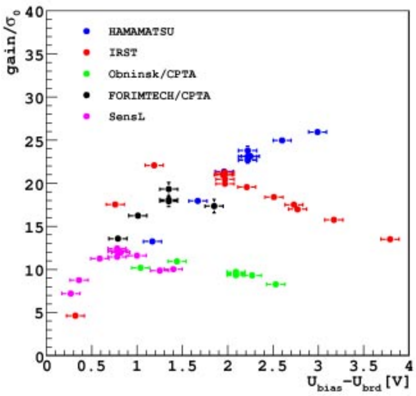


Fig. 5. – Gain as a function of the overvoltage. Slope values obtained from the linear fit are shown on the top.



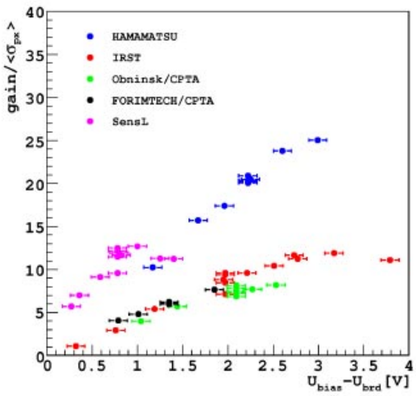


Fig. 6. – The gain normalised to the corresponding values of pedestal width (left) and $\langle\sigma_{px}\rangle$ (right) as functions of the overvoltage.

non-uniformity of the amplification over the SiPM active area. Since gain $g \sim N$, the ratio $g/\langle\sigma_{px}\rangle$ shown in fig. 6 (right) tends to a linear behaviour for the small gain values $N \ll \sigma^2_{\rm nu}$. For the large gain values $N \gg \sigma^2_{\rm nu}$ the dependence would correspond to square root law $g/\langle\sigma_{px}\rangle \sim \sqrt{N}$ in the case of a constant $\sigma_{\rm nu}$. As seen from fig. 6 (right) ratio $g/\langle\sigma_{px}\rangle \sim \sqrt{N}$ obtained for some of the samples indicate growth of the non-uniformity factor $\sigma_{\rm nu}$ with the bias voltage.

4. – Conclusion

The obtained results demonstrated operability and potential of the developed set-up. Further development and tune of the set-up, measurement procedure and data treatment will allow to obtain comparative characteristics of diverse types of silicon photomultipliers.

* * *

We would like to thank Prof. R. Battiston (University and INFN of Perugia), Prof. V. Saveliev (Obninsk State University and DESY), Dr. I. Polak (Institute of Physics of the ASCR, Prague) and Mr. N. D'Ascenzo for support and fruitful discussions.

REFERENCES

[1] CALICE Collaboration, *Memorandum to DESY-PRC*.
[2] HAMAMATSU, *Product catalogue* (`http://jp.hamamatsu.com/products/sensor-ssd/4010/index_en.html`).