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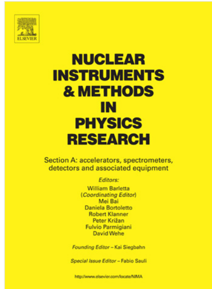

Study on SiPM breakdown voltage, dark current and gain from room down to liquid nitrogen temperature

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Study on SiPM breakdown voltage, dark current and gain from room down to liquid nitrogen temperature

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Abstract

Silicon Photo-Multipliers (SiPMs) at cryogenic temperatures are very promising for the realization of scintillation light detectors to be adopted in particle physics experiments dedicated to neutrino and Dark Matter searches. For these reasons, we tested several devices from different manufacturers with particular emphasis to breakdown voltage, dark current and gain changes at different temperatures. The system, based on a cryo-pump with a cold head, permits to scan the temperature from 300 K down to 50 K. A second system, based on a climatic chamber, was also used. We found that all devices can be operated at cryogenic temperatures. Furthermore, the thermal component of the noise decreases at low temperature, thus allowing the use of the device at higher overvoltage.

Keywords: photo-detectors, SiPM, cryogenic apparatus
PACS: 14.60.Pq, 29.40.Wk

1. Introduction

A number of neutrino and Dark Matter experiments [1] [2] plan to use Silicon Photo-Multipliers (SiPMs) at cryogenic temperatures as scintillation light detectors. Despite the smaller window surface with respect to traditional large area Photo-Multiplier Tubes (PMTs), SiPMs operating at cryogenic temperature have the advantage of a thermal component of the noise decreasing with the reduction of the temperature, thus allowing the use of these devices at higher overvoltage [3] [4]. Moreover, SiPMs can also be efficiently integrated into tiles that cover large areas and feature better radio purity than PMTs. For these reasons, it is fundamental to test devices from different manufacturers with particular emphasis to breakdown voltage, dark current and gain changes at cryogenic temperatures. To this purpose, we built two systems: the first based on a cryo-pump with a cold head, allowing to scan the temperature from 300 K down to 50 K; the second based on a climatic chamber with a temperature range from -60° C to +60° C. Then, we verified the performance of a number of new SiPMs models.

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2. Experimental apparatus

Two different experimental setups have been used: the first one, shown in Fig. 1, is composed by a cryo-pump (Helix Cryo-Torr 8F) with a cold head and a vacuum chamber. The cold head is connected to a copper cylinder which allows to achieve a temperature down to 50 K at the level of SiPMs placement. The chamber contain also the SiPMs signal trans-impedance amplifier (model AdvanSiD ASD-EP-EB-N) far from the cold cylinder, an optical fiber and several temperature sensors (Pt1000). A pumping system (a primary scroll and a turbo-molecular) allows to reach a vacuum condition with a pressure $p = 10^{-6}$ mbar inside the chamber, to isolate the cold head.

The second setup, depicted in Fig. 2, consists of a climatic chamber (F.lli Galli model Genviro-030LC) with a temperature range from -60° C to +60° C, housing the SiPM under test. The inner part of the chamber can be connected to the exterior by means of electrical and optical (optical fiber) feed-through. A picoAmmeter is used to apply the voltage to the SiPM and to measure the current. Signals are acquired by means of a LeCroy digital oscilloscope for further analysis.

In both setups an Hamamatsu PLP10-040 laser diode, with an emission wavelength at 405 nm, pulse width of 60 ps (FWHM)

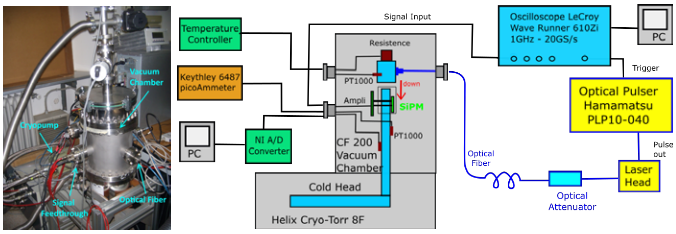

Figure 1: Picture (left) and sketch (right) of the first experimental apparatus based on a cryo-pump with a cold head.

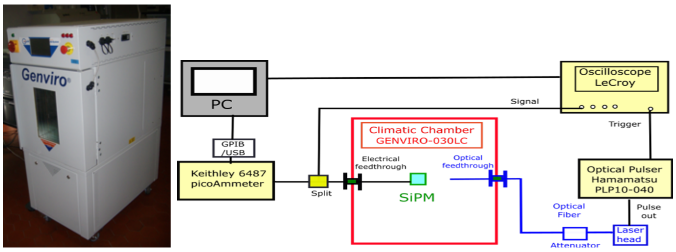

Figure 2: Picture of the climatic chamber (left) and sketch of the second experimental apparatus (right).

and peak power of 200 mW, was used to illuminate the device under test.

3. Results

We decided to perform a number of tests on some 3×3 mm^2 SiPMs produced by Hamamatsu (model S12512 and S13360), and AdvanSiD (model ASD-NUV3S-P and ASD-RGB3S-P) and the new VUV4 2×2 array, 6×6 mm^2 each from Hamamatsu. Here the preliminary results are shown in terms of I-V curves (see Fig. 3), breakdown voltage (see Fig. 4), dark current for VUV4 (see Fig. 5 left) and gain for the other four models (see Fig. 5 right).

The new Hamamatsu VUV4 exhibits a very good linearity of the breakdown voltage as a function of the temperature, down to 77 K (liquid nitrogen) Moreover, the dark current decreases by two order of magnitudes from room to cryogenic temperature, making possible to operate at larger overvoltages, thus at higher gains. This new model of SiPM is therefore very promising for cryogenic applications and it surely deserves further studies also dedicated to its timing properties. For what concerns the other models, their breakdown voltage shows a change in

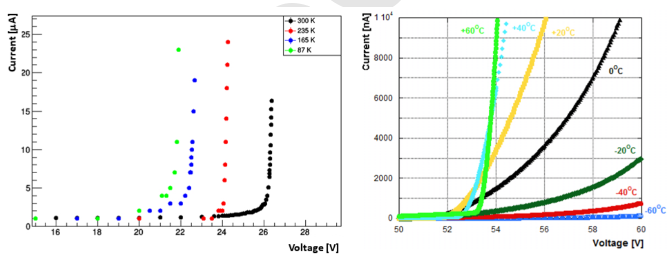

Figure 3: I-V curves at different temperatures. Left: AdvanSiD NUV. Right: Hamamatsu VUV4.

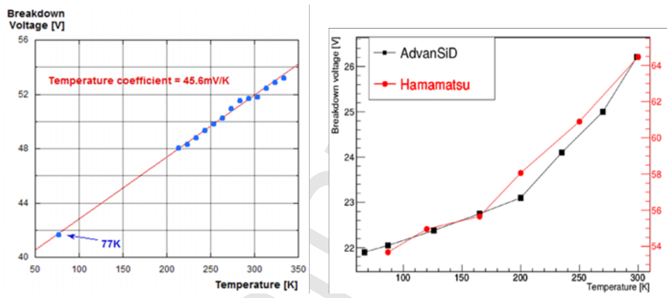

Figure 4: Breakdown voltage vs. temperature. Left: Hamamatsu VUV4. Right: AdvanSiD and Hamamatsu 3×3 mm^2.

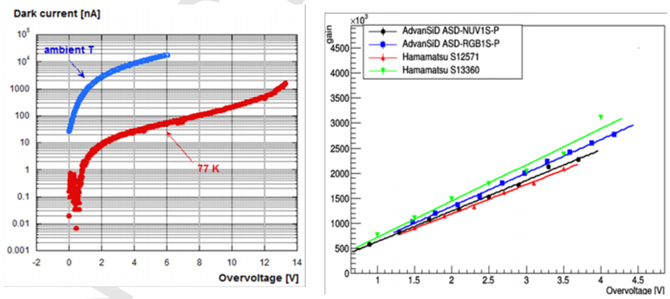

Figure 5: Left: dark current of Hamamatsu VUV4 at room temperature and at 77 K as noise measurement. Right: gain at 87 K for AdvanSiD and Hamamatsu 3×3 mm^2.

slope below ∼ 200 K. Anyway, all these four models from AdvanSiD and Hamamatsu exhibit also a gain linearly increasing with the overvoltage at the liquid argon temperature (87 K), as expected: we can then say that all the tested models can work at this cryogenic temperature of interest with high gain and low noise. More investigation will be performed also on their time response and Quantum Efficiency in cryogenic conditions.

4. Conclusions

These SiPM arrays have good performances in terms of breakdown voltage, dark current and gain when tested in cryogenic conditions. Therefore, they are suitable to be used for novel design scintillation light detectors dedicated to future neutrino and Dark Matter experiments.

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