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The VSiPMT project

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Summary. — Photon detection is a key factor to study many physical processes in several areas of fundamental physics research. Focusing the attention on photodetectors for particle astrophysics, the future experiments aimed at the study of very high-energy or extremely rare phenomena (*e.g.* dark matter, proton decay, neutrinos from astrophysical sources) will require additional improvements in linearity, gain, quantum efficiency and single photon counting capability. To meet the requirements of this class of experiments, we propose a new design for a modern hybrid photodetector: the VSiPMT (Vacuum Silicon PhotoMultiplier Tube). The idea is to replace the classical dynode chain of a PMT with a SiPM, which therefore acts as an electron detector and amplifier. The aim is to match the large sensitive area of a photocathode with the performances of the SiPM technology. We now present the preliminary study we are performing to realize a 3-inches VSiPMT prototype.

1. – Introduction

Photodetectors are widely used in many areas of fundamental physics research (*i.e.* astroparticle physics, nuclear and particle physics) as well as in medical equipment and check-ups (*i.e.* PET, Radioimmunoassay and Enzyme immunoassay as luminescent, fluorescent, Chemiluminescent Immunoassay) and even in everyday stuff (Fiberoptics communication, Remote sensing for security and safety, Environmental sensing for pollution detection, Defence).

Focusing on astroparticle physics experiments, up to the present the photon detection capability of photomultiplier tubes (PMTs) seems to be unrivalled. Anyway, they show many defects: fluctuations in the first dynode gain make single photon counting difficult; the linearity is strongly related to the gain; the transit time spreads over large fluctuations; the need of voltage dividers increases failure risks and the power consumption.

The future generation of experiments will require further improvement in linearity, gain, and sensitivity (quantum efficiency and single photon counting capability).

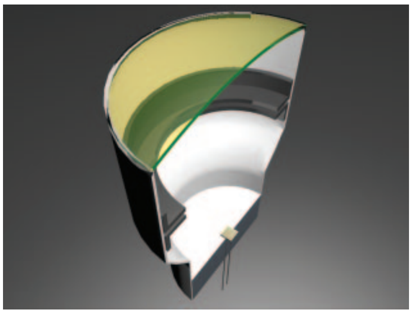

Fig. 1. – A cutaway of the VSiPMT showing the interior composition of the device.

So, even though PMTs represents a certified technology since 1936 [1], an alternative solution should be found.

The solid state photodetectors, APDs and SiPMs, represent a technological progress that goes beyond PMTs' limits. In particular, SiPM technology has achieved a very high level of performances, but the size limited by the thermal noise partially compromises their application in astroparticle physiscs experiments.

A big challenge is, therefore, to find a way to use SiPMs to detect photons from large surfaces and/or volumes, as typically needed in many astroparticle physics experiments.

2. – A new high gain photodetector: the VSiPMT

In this project we propose the development of a innovative photon detector, the VSiPMT (Vacuum Silicon PhotoMultiplier Tube), an new design for a modern hybrid photodetector based on the combination of a SiPM with a hemispherical PMT standard envelope.

The main idea was conceived in Naples in 2007 exactly with the goal to enlarge indirectly the SiPM sensitive surface, is to replace the classical dynode chain of a PMT with a SiPM, the latter acting as an electron multiplier at low voltage [2], see fig. 1.

For this purpose a special no-windowed SiPM is necessary to allow the electrons to enter into the silicon.

The VSiPMT project continued with the proof of feasibility of the device, provided in the INFN-Napoli laboratories, the results obtained encouraged Hamamatsu Photonics to realize two VSiPMT prototypes [3-5].

The prototypes underwent many tests in our laboratories [6], in order to achieve a full characterization of the devices.

The devices exhibit outstanding properties and performances beyond expectations, such as: excellent photon counting capability, fast response, low power consumption and great stability.

All these attractive features lead us to go ahead with a 2.0 phase aimed at the realization of a new optimized and usable version of the prototypes.

The starting point is working on the two main weak points of the current prototypes: the small photocathode surface and the poor linearity.

At the moment, we are working on the design of a 3-inch protoype with an optimized linearity, which involve all the constituents of the VSiPMT: photocathode, electrostatic focusing and SiPM.

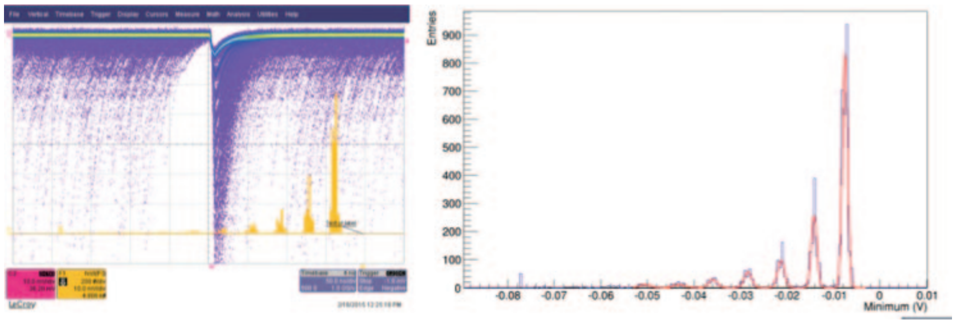

Fig. 2. – Left: Printscreen of the oscilloscope with the SiPM signals. Right: SiPM spectrum.

2˙1. *The focusing system.* – The electrostatic focusing is crucial for VSiPMT performances in terms of PDE and dynamic range. The photoelectron beam size is strongly dependent on the electrostatic focusing field. If the focusing is too weak, the photoelectron spot exceeds the size of the SiPM. Consequently, a fraction of the photoelectrons misses the target and is systematically lost, thus decreasing the overall PDE of the device. On the other side, a too strong focusing produces a too much squeezed photoelectron beam. In this case, the photoelectron spot intercepts only a fraction of the active surface of the SiPM, with a consequent reduction of the linearity.

The optimal solution therefore, is represented by an electrostatic focusing system that generates a photoelectron beam having the same size of the SiPM. This A new focusing solution going from a 3-inch photocathode to a 3 mm^2 SiPM is currently under study. Up to now, we are evaluating a multi-stage focusing system. Currently, the best configuration achieved is: photocathode at -4 kV, the focusing rings at -2 kV and the SiPM position out of focus (5 mm closer to the photocathode). In this way a spot size of 3.5 mm ϕ is obtained. The electrostatic system has been simulated by means of the COMSOL Multiphysics software.

2˙2. *The SiPM.* – The selected SiPM for the realization of the 3-inches VSiPMT prototype is an MPPC by Hamamatsu S10943-3360 (X) (special series without entrance window). The characteristics of the MPPC are listed in table I: The selected SiPM exhibits very good performances in counting capability, see fig. 2.

Table I. – *Table of the SiPM characteristics.*

SiPM	MPPC by Hamamatsu S10943-3360 (X) n.1
V_{bias}	67.15 V
Gain	$1.25 \cdot 10^6$
Dark Rate	1091 kcps
MPPC Area	$3 \times 3\,\mathrm{mm}^2$
Cell Size	50 μm
Total Number of Cells	3600

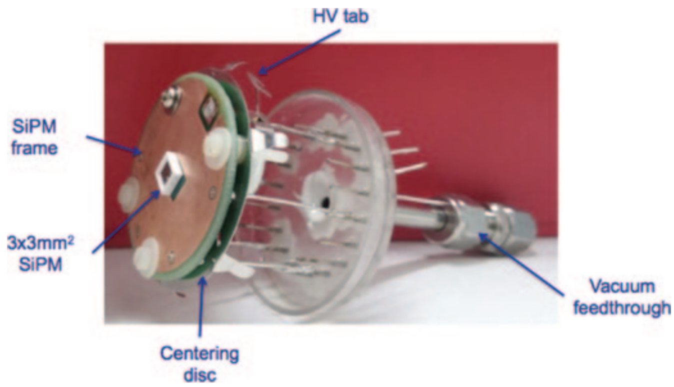

Fig. 3. – The amplification stage of the 3-inches VSiPMT prototype before being assembled into the glass tube.

2˙3. *The assembly of the new amplification stage.* – After the characterization, the SiPM is assembled on a base in order to be mounted into the glass tube.

The SiPM is mounted in the center of a PCB circular frame. The frame is copper-coated and, once grounded, acts also as guard-ring for the SiPM. The SiPM frame is connected to a metallic disc equipped with tabs that allow to center the frame and so the SiPM into the glass tube.

A borosilicate glass base supports the SiPM frame and the centering disc and close the VSiPMT. Six hardened steel feedthroughs allows to supply the right voltage to the SiPM, the photocathode and the copper-coating of the PCB. They hold up the whole structure operating both as spacers, to correctly position the SiPM along the tube axis, and as electric contacts.

One of the feedthroughs is equipped with a tab that supplies the high voltage to the photocathode leaning against the elctric contact deposited on the glass tube, see fig. 3.

2˙4. *The cut and the final assembly.* – As first attempt we want to realize a prototype aimed only at the test of the focusing system.

With this perspective, meanwhile the photocathode deposition system is set up, we choose to use a commercial ultrabialkali photocathode which performances are already known by taking it away from a PMT.

The cut of the PMT is made in two steps: carving the glass with a diamond grinding disk mounted on a bandsaw and then cutting with an Nichel hotwire. The first step is made in air, while the second is made in a glove box under inert atmosphere (the oxigen in the glove box is cleaned by pumping 5.0 argon gas with a bubbling system).

Once the PMT has been cut, still in argon atmosphere the dynode chain is removed and the new amplification stage is installed, see fig. 4. The lower part is sealed to the glass tube by using a vacuum ceramic sealant, Torr Seal.

A vacuum system is connected to the vacuum feedthrough of the base allowing to reach a very good vacuum condition ($\sim 10^{-11}$ mbar).

The prototype is currently under test.

Fig. 4. – A picture of the 3-inches prototype, taken during one of the mechanical tests on the device.

3. – Conclusions

The VSiPMT project was conceived at the University of Naples in 2007 to provide a valid alternative to PMTs. The simple substitution of the dynode chain with a SiPM allows to reach a very high gain totally provided by the pixels working in geiger mode. This has many advantages, such as: excellent photon counting, high gain with low voltage, negligible power consumption, high speed, compactness and simplicity. Up to now two small size industrial prototypes have been tested with excellent results except for the dynamic range.

We are now attempting to realize a larger prototype to study a configuration that can boost the dynamic range of the device, in order to obtain a usable device. Further improvements are currently under test to optimize the manufacturing process of the device.

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