Vacuum Silicon PhotoMultipliers: recent developments

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Abstract

VSiPMT (Vacuum Silicon PhotoMultiplier Tube) is an innovative design for a modern hybrid, high gain, silicon based photodetector based on the combination of a SiPM with a hemispherical vacuum glass PMT standard envelope. In such a device photoelectrons emitted by the photocathode are accelerated and focused by an electric field towards a small focal area covered by the SiPM which therefore acts as an amplifier, thus substituting the classical dynode chain of a PMT.

With a view to the realization of a first prototype of VSiPMT our group is carrying out a preliminary work aimed at the study of SiPM performances as an electron detector, including an accurate Geant4-based simulation of the interaction between SiPM and electron beams. In order to perform a full characterization of the SiPM we developed an experimental setup for the extraction and the acceleration of a beam of backward secondary electrons emitted after the bombardment of a carbon foil by a proton beam extracted in a TTT-3 accelerator.

Key words: SiPM, VSiPMT, MPPC, hybrid photodetector

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1. Introduction

Silicon PhotoMultipliers (SiPMs) are arrays of inverse polarized diodes operating in Geiger mode with a gain of $10^5$-$10^6$, comparable with that of PMTs, thus showing single-photon sensitivity and excellent photon-counting capability. SiPMs show many advantages over PMTs, such as higher quantum efficiency, lower operation voltages and insensitivity to magnetic fields. However their main drawback is represented by their small sensitive surface.

In order to overcome this limit our group has suggested a solution consisting in an innovative design for a modern hybrid, high gain, silicon based Vacuum Silicon PhotoMultiplier Tube (VSiPMT) based on the combination of a SiPM with a hemispherical vacuum glass PMT standard envelope \cite{1}. In such a device photoelectrons emitted by the photocathode are accelerated and focused by an electric field towards a small focal area covered by the SiPM which therefore acts as an amplifier, thus substituting the classical dynode chain of a PMT.

With a view to the realization of a first prototype of VSiPMT our group is carrying out a preliminary work aimed at the study of the performances of a SiPM as an electron detector, consisting in the full characterization of the SiPM with a laser source \cite{2} and with an electron source. Before the realization of the second step we performed a Geant4-based simulation of the interaction between a SiPM and an electron beam with different angles of incidence and different initial energies, simulating all the typical low-energy electromagnetic processes they could be involved in and calculating backscattering coefficient, range in Silicon, total released energy, backscattered energy fraction and average energy loss in Silicon. The electron source for the characterization will be a beam of backward secondary electrons emitted after the bombardment of a carbon foil by a proton beam extracted in a TTT-3 accelerator. In this work we describe our experimental setup and our preliminary results.

2. SiPM as an electron detector

SiPMs are arrays of Geiger-mode diodes set on a common anode with individual quenching resistors. Each diode, when activated, gives the same current response, so the output signal is proportional to the number of diodes hit. In a VSiPMT the SiPM acts as an electron detector. In this case electron-hole pairs are created by ionization, therefore for this process to happen there is an energy threshold for photoelectrons impinging on the surface of the SiPM. However since electrons, unlike photons, produce electron-hole pairs along all the ionization track, they produce a higher signal amplification. According to our simulations, in order to penetrate inside the depletion region ($\sim 1 - 1.2 \mu m$) of our SiPM (a S10943-8702 MPPC by HAMAMATSU, special non-windowed series) a normally incident electron beam needs to be accelerated up to an energy of $\sim 10keV$ (see Figure 1). At this energy the backscattering coefficient $\eta$ is $\sim 12.6\%$ and the backscattering energy fraction is equal to 0.22, while the total released energy is $\sim 7.5keV$.  

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3. The experimental setup

To extract and accelerate the electron beam necessary for the characterization of the SiPM we require an experimental setup composed by (see Figure 2):

• a 2 MeV proton beam;
• a 30\,\mu g/cm^2 carbon foil;
• an electrostatic mirror for acceleration and deflection of the electron beam;
• a two-steps Micro Channel Plate for beam detection.

The 2 MeV proton beam is extracted in a TTT-3 linear accelerator and is used to bombard the carbon foil. In the proton-carbon scattering process forward and backward secondary electrons (SE) are emitted. The production of SE can be described by a three-step model: first, the creation of excited electrons via collisions of protons with target atoms in the solid, then the transport of liberated electrons through the bulk to the surface and finally the transmission through the surface potential barrier [3]. In order to get a 10\,keV electron beam the carbon foil is kept at −10\,kV. The first electrostatic grid collects and accelerates backward electrons towards an electrostatic mirror composed of two plane and parallel grids, exploiting the same potential difference between the carbon target and the first acceleration grid. The first mirror grid has the same potential of the first acceleration grid while the second one has the same potential of the carbon foil in order to provide a deflection of the electron beam where the angle of emission is equal to the angle of incidence. A 90 degrees deflection is necessary to avoid the SiPM to intercept, during the characterization phase, the incident proton beam and backscattered protons.

In order to hold grids at the required potentials, the system is kept under high vacuum conditions (10^{-9}\,bar).

The SiPM will be earthed, while in this preliminary phase of beam detection and monitoring the three electrostatic lenses of MCPs are kept at −2\,kV, −1.1\,kV and −100\,V respectively (Figure 2).

4. Conclusion and perspectives

In a VSiPMT photoelectrons emitted by a photocathode are accelerated and focused by an electric field towards a small focal area covered by a SiPM. With a view to the realization of a first prototype our group has developed an experimental setup for the full characterization of a S10943-8702 non-windowed MPPC by HAMAMATSU with an electron source. Actually a 10\,keV focused electron beam has been extracted, deflected and measured by MCPs. The next step will consist in replacing MCPs with our SiPM for the characterization phase.

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References