# Development of Silicon Photomultiplier in India using CMOS Technology

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## Introduction

A silicon photomuliplier (SiPM) is a multi-pixel photodiode in which a number of pixels fabricated on a common substrate and each operating in the Geiger mode are connected in parallel. SiPMs have excellent characteristics such as higher quantum efficiency, lower operation voltages, compact size, fast timing response (~100 ps), high gain (~$10^6$) and insensitivity to the magnetic fields. These devices find interesting applications in the fields of nuclear and high energy physics, astrophysics, radiation monitoring and medicine. Considering wide range of applications of SiPMs, the development of SiPMs in India using 6" CMOS foundry of SITAR, Bangalore has been initiated. Considerable effort has been devoted to the device design and development of fabrication technology to realize the first prototypes of SiPM. In this paper, the current status of this development is described.

## Device Design and Fabrication Technology

The SiPMs have been designed to have pixels sizes of 15 μm x 15 μm to 50 μm x 50 μm. The number of pixels in these prototypes has been varied from a few hundred to a few thousand. The devices cover an area of 1mm$^2$ to 6 mm$^2$. The SiPMs have been fabricated on a p-type epitaxial layer. Each pixel is composed of a $n^+$–p junction in series with a polysilicon quenching resistance ($R_q$). All pixels are connected in parallel through the aluminum layer on the photo-sensitive side and the substrate on the other side. The active area of pixels is covered by an anti-reflection coating. The fabrication of the SiPMs has been carried out using a complex process sequence involving several oxidation cycles, implantation and drive-in cycles, poly deposition and implant process, etc. The process parameters have been chosen to obtain SiPMs with specific characteristics in terms of dark current, breakdown voltage and optical response. Subsequent to wafer fabrication, the prototype SiPMs have been packaged using a TO or PCB package. Fig.1 shows fabricated wafer incorporating prototype SiPMs and test structures.

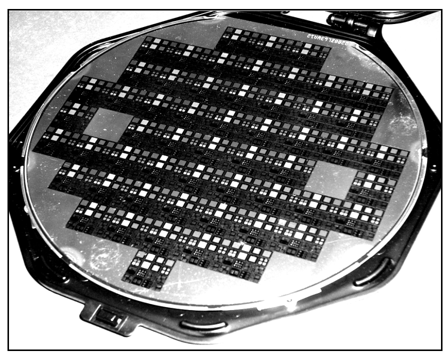

**Fig. 1** Fabricated wafer showing SiPMs

## Characteristics of SiPMs

Prototype SiPMs were tested for dark currents, dark counts and light response at BARC. Forward and reverse characteristics of the SiPMs and single pixels were obtained using current–voltage (I-V) measurements. An automated setup comprising a picoammeter with programmable voltage source was used for these measurements. The SiPM was housed in a dark box. Typical dark characteristics for the SiPM are as shown in Fig.2 The breakdown voltage ($V_{bd}$) and the $R_q$ values have been determined from the reverse and forward characteristics, respectively. The breakdown voltages between 60 V -75 V were observed for different types of SiPMs. Different SiPMs and single pixels of the same type distributed over the wafer showed good uniformity in these parameters. The value of $R_q$ was observed to be between 300kΩ–500kΩ, depending on the length of the poly resistor. This was in agreement with the values obtained by measurements carried out on poly resistor test structures. The poly resistors also showed good uniformity of the resistor values over the wafer.

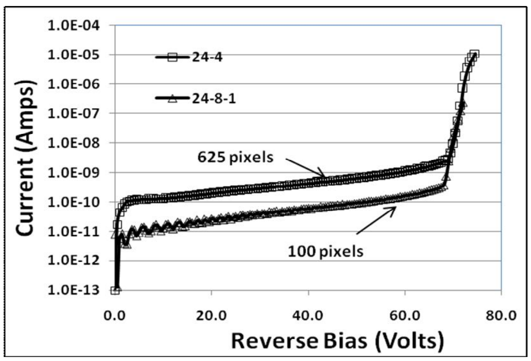


**Fig.2** Dark characteristics of SiPM with pixel geometry of 50 μm x 50 μm

The pulses in the absence of external photon i.e. dark counts have been observed using a fast amplifier of rise time 1ns and gain 200. A digital oscilloscope of band width 1GHz has been used for these measurements. Depending on the geometry of pixels, pixel numbers and over voltage, the SiPMs showed a dark count rate of a few hundred kHz to a few MHz. Fig. 3. shows the dark pulse from the SiPM. The functionality of the SiPM prototype devices has been tested using an external pulsed LED light source. The front surface of the SiPM was illuminated using an optical fiber and the pulses were observed on the digital storage scope. The SiPM was enclosed in a dark box so that no external light is incident on the surface. The pulse amplitude was observed to increase as the light intensity was increased. Fig. 4 shows the output pulses observed due to external pulsed light. A dedicated experimental setup for noise reduction and calibration of SiPM output signal is being developed.

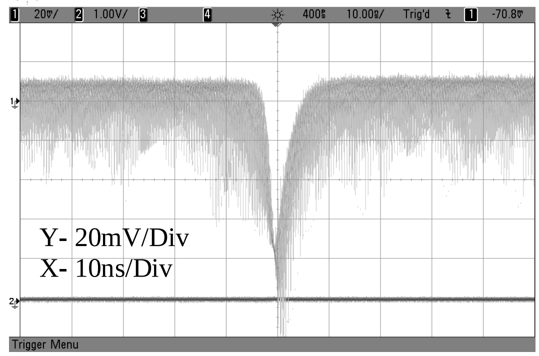


**Fig.3** Dark counts observed for a SiPM with pixel area of 490 $\mu m^2$, 225 pixels,

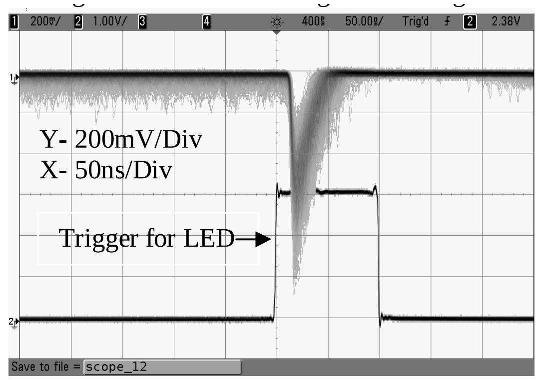


**Fig.4** Response observed for LED light for a SiPM with pixel area of 490 $\mu m^2$, 225 pixels,

## Summary

Indigenous technology development for SiPM fabrication in India has been initiated. The first prototype devices have been fabricated and the functionality of SiPM has been verified. The SiPMs are also being characterized at CERN. Keeping in mind that this is first prototypes produced without optimized technology, the performance observed is encouraging. Significant improvement in the performance is expected in the next batch after optimizing critical process parameters.

## Acknowledgements

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