Studies of SiPM and Scintillation Plates with Waveshifter Fiber and SiPM Readout

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Abstract– **We have been studying the performance of SiPM devices and Scintillation Plates read out with SiPM. Applications are for the detection of ionizing radiation, for example in particle and nuclear physics experiments. Results are presented on performance of the SiPM using pulsed LEDs and scintillating tiles excited by radioactive sources, and for SiPM devices that have been used to transduce waveshifted scintillation signals from scintillation tiles with embedded waveshifter fiber.**

I. Introduction

We are presently engaged in two studies: the first is to investigate the performance characteristics of several Solid State Photo Multipliers (SiPMs), and the second is to use these SiPM as phototransducers to qualify new waveshifter materials as possible replacements for the standard Y11 in future particle physics experiments. The SiPM have high photodetection efficiency for longer wavelength visible light and this is a good match for the emission wavelengths of the waveshifters (λ ~ 500 nm).

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II. Characterization Studies of the SiPM

For the investigations reported here, devices were studied in 1mm x 1mm and 3mm x 3mm formats. The detected photo response and noise rate characteristics were evaluated as a function of bias voltage and device temperature.

For best performance, the manufacturers recommend that such devices be operated at -20^{o}C. This is straightforward for applications that require the use of relatively few discrete SiPM and where space is available for on-board Peltier cooling. But this approach is challenging for larger scale integrated systems requiring many channels of SiPM – for example in tracking or calorimetry applications where large numbers of channels (in the thousands) could be needed. In such situations it is more practical to operate the devices cooled to a temperature just above the dew point. This helps to mitigate potentially high noise rate while eliminating moisture build up on the devices. Device noise rate is also a function of temperature, so some cooling (actually temperature control) is desirable and necessary to maintain stable device operation over time. The SiPM noise rate is also a function of device active area, with 3mm x 3mm structures showing a noise rate approximately 9 times that of the 1mm x 1mm devices.

The thermal control for the SensL devices is provided by a Peltier thermo-electric device. The entire structure (see Fig.1) is encapsulated which avoids any moisture or frost build up on optically sensitive surfaces.

A typical spectrum of detected photo response from a 3 mm x 3 mm SiPM is shown in Fig. 2 in which device illumination is provided by a pulsed LED with a peak wavelength of λ ~ 625 nm. Distinct photopeaks can be clearly seen. The leftmost is the pedestal, corresponding to no detected SiPM signal in response to an applied LED pulse. Then successively to the right is the single photoelectron peak, then two photoelectrons, and so on. The data are well described by a Poisson distribution.

The SiPM gain is defined as the separation between the photopeaks, which we define operationally to be the separation between the first photopeak and the pedestal. Fig. 3 displays the SiPM gain as a function of temperature for a 1mm x 1mm device and indicates modest decrease in gain with increasing temperature.

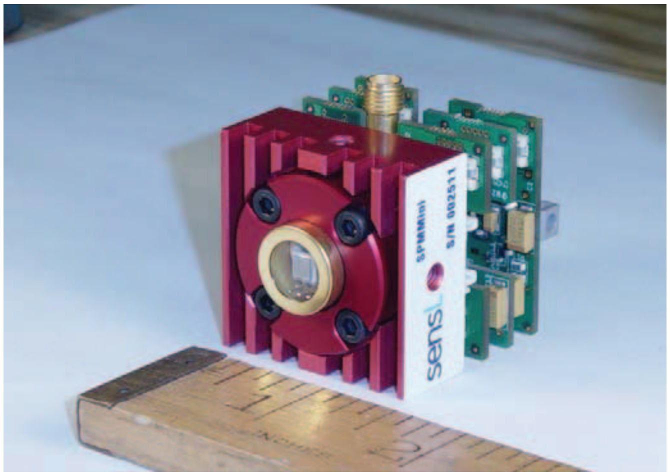

Figure 1. A photograph of a SensL 3mm x 3mm SiPM package with thermal cooling.

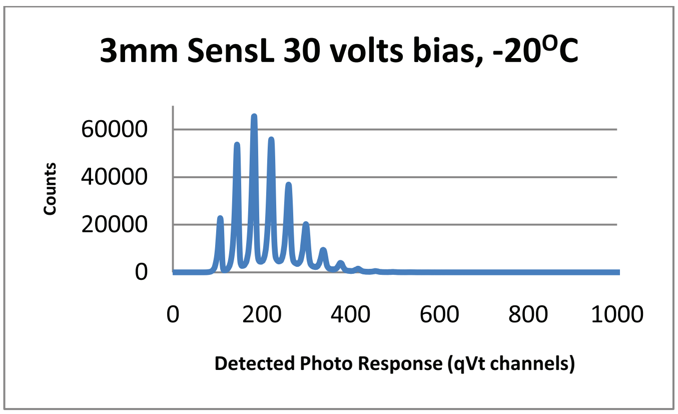

Figure 2. Spectrum of detected photo response from a SensL 3mm x 3mm SiPM as recorded in a LRS 3001 qVt. Device was illuminated with a pulsed LED. Horizontal axis is in qVt channels (0.25pC/ch). Vertical axis is yield in counts. Left-most peak is the pedestal corresponding to no SiPM response. Spectrum follows a Poisson distribution.

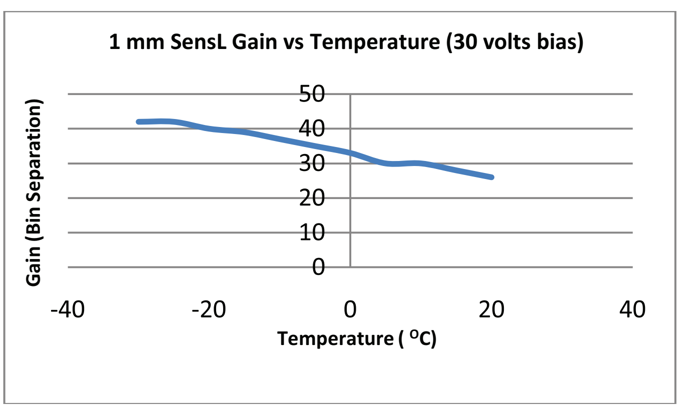

Figure 3. Temperature dependence of the gain of a 1mm x 1mm SensL SiPM. Gain is measured as peak separation in bins between the first photopeak and the pedestal in the Detected Photo Response distribution.

The SiPM detected photoelectron response is determined from the mean value of the photo response spectrum, interpreted as a Poisson distribution. This distribution is relatively independent of temperature over the range -20°C ≤ T ≤ 20°C.

The most dramatic dependence upon temperature was observed for device noise rate, shown in Fig. 5 for a 1mm x 1mm SiPM. For characterization of noise rate as a function of temperature in these studies, noise rate was defined conservatively as the number of detected SiPM signals per unit time greater than cut at the 0.5 photo response level or half-way between the pedestal and the first photopeak.

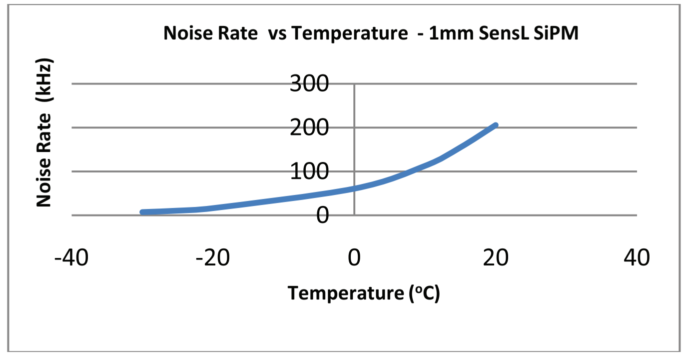

Figure 5. Noise rate in kHz vs Temperature for a 1mm x 1mm SensL SiPM operated at a $V_{bias} = 30V$.

The noise rate for a 3mm x 3mm device is shown in Fig. 6. As can been seen, the noise rate is approximately an order of magnitude higher, corresponding to the larger area of the structure. The slight rise below -20°C is not fully understood, but is thought to be due to the properties of the onboard thermionic cooler.

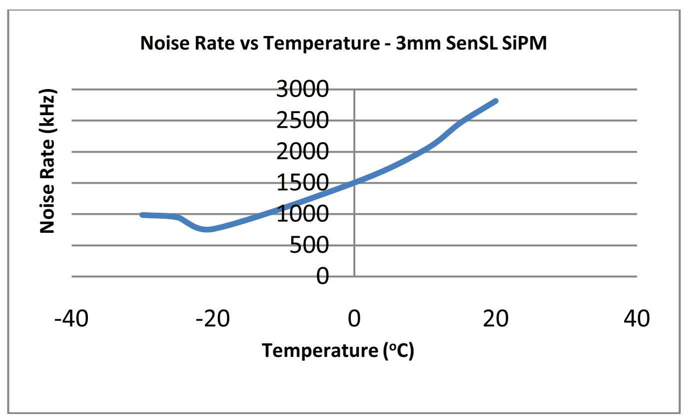

Figure 6. Noise rate in kHz vs Temperature for a 3mm x 3mm SensL SiPM operated at a $V_{bias} = 30V$.

This temperature setting of -20°C was then used for scintillating tile/waveshifter fiber studies described below, in which discrete devices of 3mm x 3mm area were used as phototransducers. It should also be noted that at an operating temperature just above dew point, 15°C, device operation is usefully improved over that at room temperature. Such a temperature setting would be a useful choice for applications requiring the large scale integration of SiPM.

III. SCINTILLATING FIBER/WAVESHIFTER FIBER STUDIES

We have made extensive studies of scintillators and waveshifters using conventional photodetection techniques such as photomultiplier tubes. [1] Because of their compact size and excellent photosensitivity at long visible wavelengths, SiPM are good choices to detect light emitted from scintillating fibers and from scintillating tiles with wavelength shifting fiber read out. We have studied the response of scintillating tiles of 10 cm x 10 cm cross sectional area and 0.63 cm thickness, read out with Kuraray double clad waveshifter fiber of 940 micron diameter and 1 m length, inserted into a ball groove in the tile. Both ends of the fiber are optically finished by diamond flycutter and the end embedded within the tile is aluminized. The emergent end is mounted into a custom fitting which holds the fiber directly in front of a 3mm x 3mm SiPM. The test arrangement is shown in Fig. 7. Given the characterization studies described above, the SiPM was operated at a bias voltage of V_{bias} = 30 Volts and temperature of -20^{o}C. The scintillation tile is excited by ionizing radiation, either from radioactive sources (^{106}Ru or ^{90}Sr) and/or cosmic rays. An external trigger is formed by a small 1cm x 1cm x 0.16 cm scintillation counter that sits physically above the tile, and a RCA 8575 photomultiplier that looks directly into one edge of the tile.

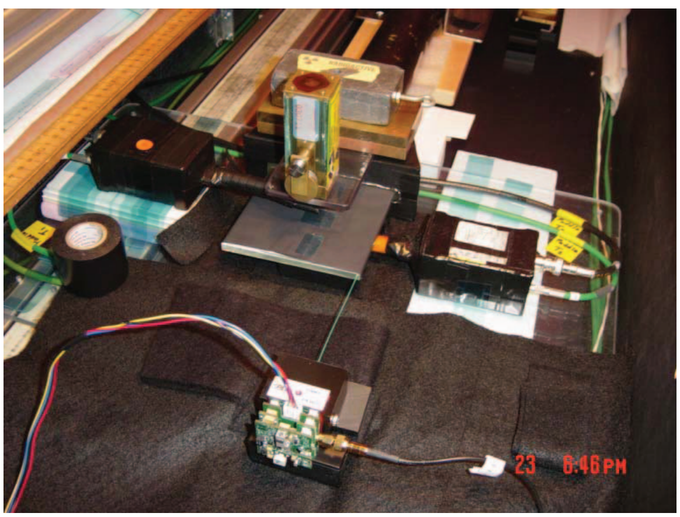

Figure 7. Setup for source testing of tile/fiber/SiPM readout. The tile under test is just beneath the source holder in the center of the field of view. The waveshifter fiber emerges from the tile and delivers light to the SiPM (bottom foreground). Separate scintillation counters (left, and right and rear) are used to provide a trigger.

When the trigger is received, the SiPM signal as well as the signal from the RCA 8575 are displayed on a digital storage scope, Tektronix DPO-4104, or recorded into a LeCroy LRS3001 qVt for further analysis.

Several waveshifter materials have been under test in our laboratory for potential replacement of the standard waveshifting dye Y11. While very efficient, the decay time of Y11 is relatively slow (τ ~ 8ns under laser excitation and τ ~ 25ns as a waveshifter for fast scintillators). The new materials, developed in collaboration with Ludlum Measurements, Inc (identified as DSB1, DSB2, DSF1, DSF2) have much faster fluorescence decay (τ ~ 3 ns under laser excitation and τ ~ 12 ns waveshifters for fast scintillators). These dye materials have been incorporated into Kuraray Double-clad fiber of identical diameter (940μm) and length (1m) to those of commercially available Y11 material used in the CMS experiment.

A typical photo response spectrum of a 3mm x 3mm SiPM recorded during source (or cosmic ray) excitation of a tile/fiber structure is shown in Fig. 8. Again, distinct photopeaks are clearly observed, but in this case the distribution is not Poisson, but rather Landau in character with a longer tail to larger values of detected photo response. Accordingly, we have fit these source-generated distributions with a Moyal function [2] of the form:

$$y = A \exp\left\{-\frac{1}{2}\left[\left(\frac{x-xm}{\sigma}\right) + \exp\left(-\left(\frac{x-xm}{\sigma}\right)\right)\right]\right\} + B$$

where y is the yield in counts, xm is a characteristic mean value of the photo response and σ is a measure of the width of the distribution. The data are presented in Table 1. In addition to the Moyal parameters, the average value of the photo yield from the histogram xav was determined directly and this quantity is also included in the table for the various waveshifter samples (WLS). The data are presented for SiPM operation at room temperature and at -20^{o}C. To provide a relative measure of waveshifter response to the standard Y11, ratios are taken for a given shifter with respect to Y11 for both xav and xm and these are labeled Rav and Rm respectively.

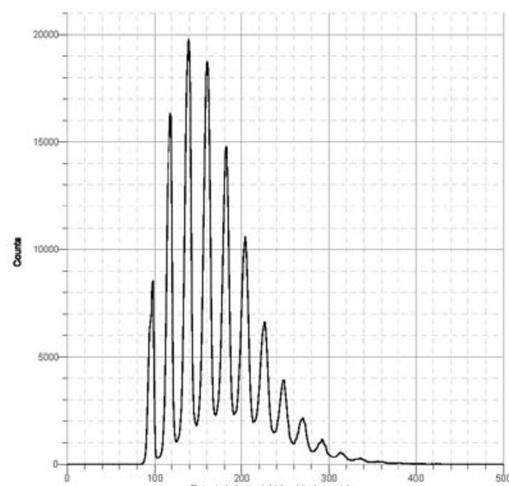

Figure 8. Detected photo response from a scintillating tile excited by a ^{90}Sr source and read out with a DSB2 waveshifter fiber and SensL 3mm x 3mm SiPM operated at -20^{o}C. Vertical scale is number of counts. Horizontal scale is in qVt channels, (0.25pC/channel). Left-most peak is the pedestal (corresponding to no detected light in the SiPM).

As indicated in the table, the new dyes have approximately 80%-85% of the total fluorescence efficiency of Y11. This was noted in earlier studies with PMTs and is reconfirmed here with the SiPM.

IV. Future Tests

The group is now developing the instrumentation necessary for testing small solid and liquid (including water-based) samples using SiPM, GaAs PMTs, standard PMTS or some combination of these. These will be useful in studying photoyields from scintillation materials that have emission in the longer wavelength visible region for future experiments.

Table 1. Detected Photo Response.

Average (xav) and Moyal mean (xm) detected photo responses for a scintillating tile read out with various wavelength shifting fibers (WLS) and 3mm x 3mm SensL SiPM.

WLS	Temp	xm	Rm	xav	Rav
Y11	room T	3.33	1.00	4.71	1.00
DSB1	room T	2.84	0.85	3.79	0.80
DSB2	room T	2.85	0.86	4.05	0.86
DSF1	room T	2.58	0.77	4.02	0.85
DSF2	room T	2.67	0.80	3.95	0.84
Y11	-20 C	3.25	1.00	4.76	1.00
DSB1	-20 C	2.68	0.82	3.94	0.83
DSB2	-20 C	2.64	0.81	3.85	0.81
DSF1	-20 C	2.68	0.82	4.03	0.85
DSF2	-20 C	2.36	0.73	3.62	0.76

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