Performance of a 3 mm×3 mm silicon photomultiplier for use on the X-ray calibration system of the SVOM gamma ray monitor*

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Abstract: The calibration detector of a gamma ray monitor (GRM) is designed to detect alpha particles from ^{241}Am and to send out the coincidence signal to the GRM X-ray detector. The silicon photomultiplier (SiPM), as a novel photon device, is a good candidate to convert alpha-exciting fluorescent photons into electric signals. Three types of SiPMs from SSPM and MPPC, each having an active area of 3 mm×3 mm, were compared in the matter of the spectra from low-intensity light, dark count, crosstalk probability and *I*-*V* curve. The temperature coefficient of SSPM-0710G9MM was also characterized. The application of a SiPM on the GRM has been proved to be feasible.

Key words: SiPM, crosstalk, temperature coefficient, calibration

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1 Introduction

The SVOM mission [1] includes a wide band observatory designed to observe gamma ray bursts (GRBs) from the visible band to the gamma ray band. The GRM [2] on board the SVOM satellite is able to provide the spectral observation of GRBs from 30 keV to 5000 keV. The GRM calibration detector (GCD) makes use of a plastic scintillator to detect alpha particles from ^{241}Am. The fluorescent photons are converted into electric signals by utilizing several photon detectors. The gamma photons from ^{241}Am are detected by the GRM's main detector and marked as calibration events if the GCD gives external trigger signals. The accumulated spectrum will be used to monitor the gain of the GRM detecting system.

The SiPM is a new type of avalanche photon-counting detector [3, 4] chosen in place of a photomultiplier tube (PMT) or an avalanche photodiode (APD). It is composed of multiple APD pixels operating in Geiger mode with resistive quenching [5]. For a given bias voltage, each APD pixel of the SiPM outputs a pulse signal regardless of the number of incident photons or particles. The signal output from the SiPM is the sum total of the outputs from all APD pixels. The SiPM offers a number of attractive appealing features including excellent photon-counting, room temperature operation, low bias operation, high gain (10^5–10^6), insensitivity to magnetic fields, excellent time resolution, etc. The alpha activity of ^{241}Am inside the GCD is limited to be less than 100 cps, which leads to the requirement of weak light detection. The GCD is located inside the FOV of the main detector, so that the dimension of the plastic scintillator which contains isotopes is confined to be several millimeters. The SiPM is thus a suitable device for

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Table 1. 3 mm×3 mm SiPM characteristics.

parameter	units	MPPC S10362-33-025C	MPPC S10362-33-100C	SSPM 0710G9MM
sensor geometry	mm	3.0×3.0	3.0×3.0	3.0×3.0
sensor area	mm^2	9.0	9.0	9.0
microcell dimensions	μm	25×25	100×100	33×33
number of micro-cells		14400	900	8100
fill or geometric factor	%	30.8	71.8	>60
operating temperature	℃	−20–40	−20–40	−40–40
storage temperature	℃	−20–60	−20–60	−40–60
temperature coefficient of gain	$℃^{-1}$	56 mV	56 mV	<1%
spectral response range	nm	320–900	320–900	400–800
peak sensitivity wavelength	nm	440	440	580
gain		2.7×10^5	2.4×10^6	1.8×10^5

receiving weak light and generating large signals.

Promising to meet the needs for future space particle physics experiments, this work presents the experimental results of three SiPMs from the Advatech Solid-State PhotoMulitiplier [4] (SSPM) series and the Hamamatsu MultiPixel Photon Counts [6] (MPPC) series, respectively. These three SiPMs have the same effective active area of 3 mm×3 mm but different pixel numbers: SSPM-0710G9MM, MPPC S10362-33-025C, MPPC S10362-33-100C. The main characteristics are shown in Table 1.

2 Signal readout and data acquisition

The front-end electronics is the interface between the detector and the data to be acquired. We have developed a preamplifier circuit based on discrete electric components. Two space-qualified transistors are applied to revert and amplify the signals. A diagram of the readout circuit is given in Fig. 1. The signal from the front-end electronics is fed into a CAEN N6751 waveform digitizer which is a 1-unit wide NIM module housing 2/4 Channel 10 bit 2/1 GS/s Digitizer on a single ended MCX coax.

3 Experimental results

The data were taken at a room temperature of 26 ℃. The SiPM was housed in a dark box. For MPPC S10362-33-025C with the alpha spectrum by BC408, the typical signal waveform was recorded in Fig. 2(a). Analyzing the waveform, the pulse height and width can be derived. The pulse height spectrum is plotted in Fig. 2(b), where the peak corresponds to 58 pixels fired with V_{op}=71.9 V. In Fig. 2(c), the

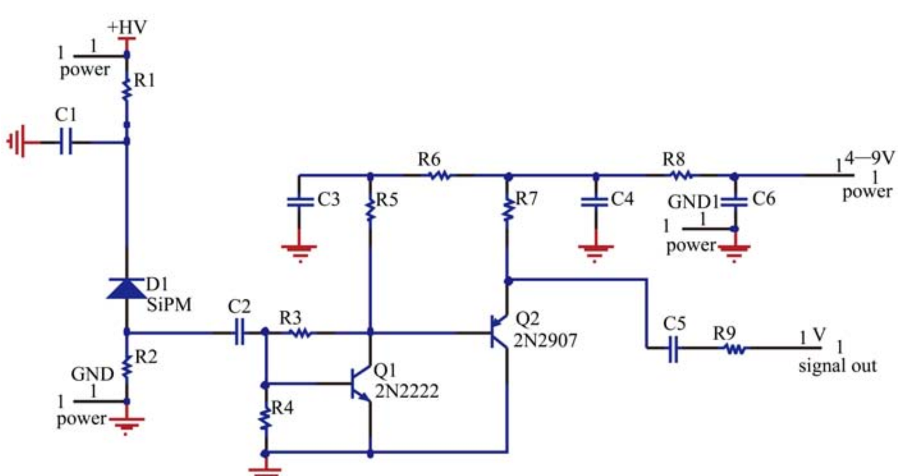

Fig. 1. The readout circuit connected to the SiPM.

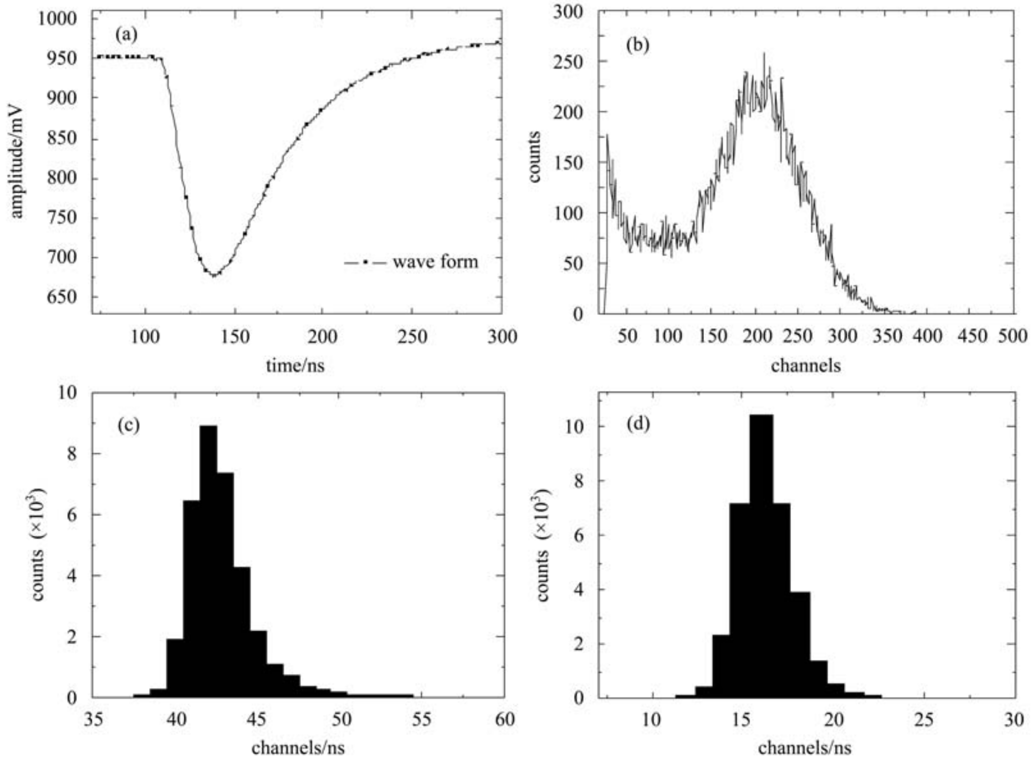

Fig. 2. (a) Typical signal waveform, (b) SiPM pulse height spectrum from the alpha spectrum by BC408, (c) the width of signal and (d) the width of the rise edge.

width of signal is defined as the time difference at the two points of half pulse height. The width of the signals is around 42 ns and that value will be used in space physics experiments. To detect the trigger signal, the width of signals should be large enough to match the end electronics. The width of the rise edge (Fig. 2(d)) is around 16 ns which is the time difference between the point of peak and half pulse height.

To study the intrinsic characterizations of the device, MPPC S10362-33-025C is biased with $V_{\rm op}$ = 71.9 V and over-voltage. ΔV=2 V was placed in a light tight box. The dark count spectrum is recorded in Fig. 3. The thermal single electron peaks are resolved with 1pe, 2pe, 3pe. The ratio of dark count rates corresponding to 1.5pe and 0.5pe threshold gives an estimate of the crosstalk probability. Seeing the upper panel in Fig. 4, the crosstalk probability of SSPM-0710G9MM is lower than Hamamatsu MPPC. The crosstalk probability of MPPC S10362-33-025C is a little bigger than the MPPC S10362-33-100C, since 025C has 14400 pixels while 100C has only 900 pixels. For 050C with 3600 pixels, a typical crosstalk value between 15% and 20% was found at 23 ℃ and Gain = 4.0×10^5 [7]. For the 3 SiPMs of SSPM-0710G9MM, MPPC S10362-33-025C and MPPC S10362-33-100C, the I-V curves were

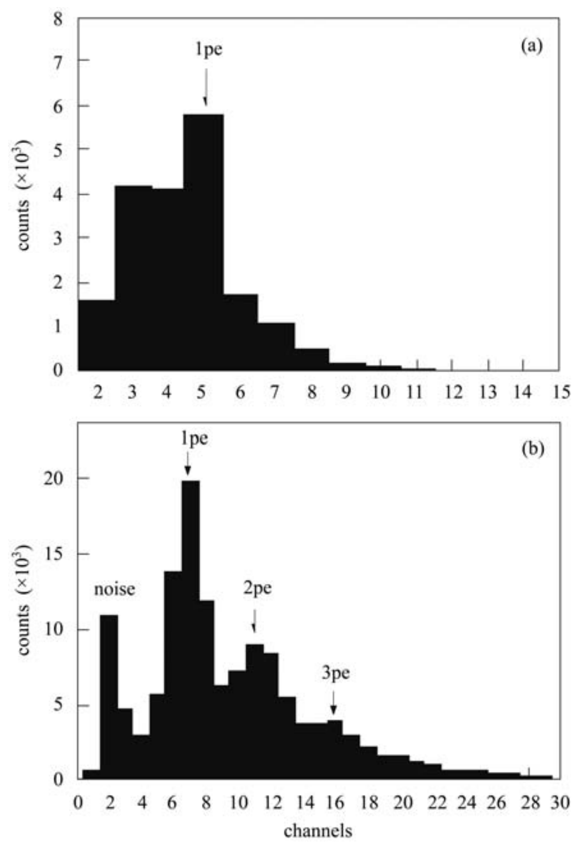

Fig. 3. MPPC S10362-33-025C dark count spectrum of $V_{\rm op}$=71.9 V (Fig.(a)) and ΔV= 2 V(Fig.(b)).

measured around room temperature 26 ℃ in Fig. 4 lower panel. The current of MPPC S10362-33-025C is much lower, while the currents of MPPC S10362-33-100C and SSPM-0710G9MM are larger. In Table 1, we can see that the gain for S10362-33-025C, S10362-33-100C and SSPM-0710G9MM is $2.7.\times10^5$, $2.4.\times10^6$, 1.8×10^5, respectively. The gain of Hamamatsu MPPC S10362-33-025C and SSPM-0710G9MM is almost the same, but the current of SSPM-0710G9MM is much bigger.

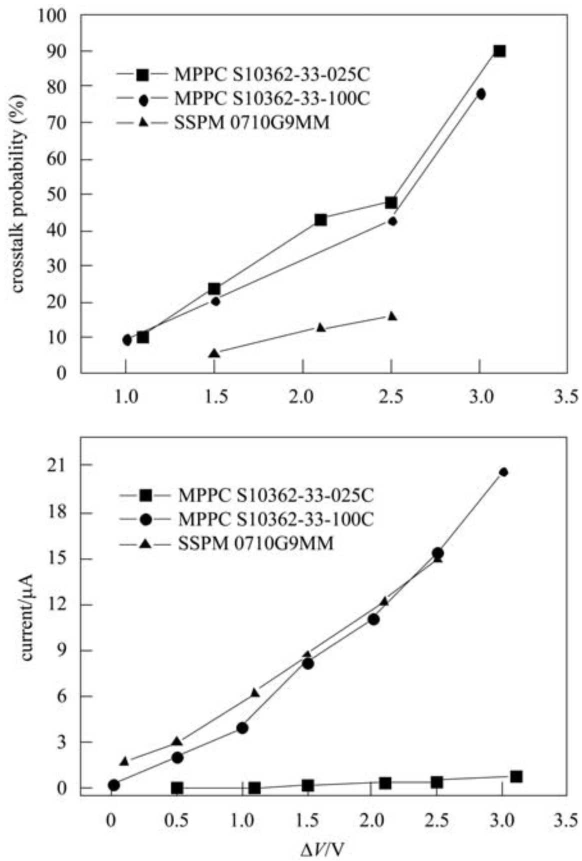

Fig. 4. The crosstalk probability and I-V curve as a function of over-voltage (ΔV) at 26 ℃.

The temperature dependence of the gain is very important for space physics experiments due to the wide temperature range of the environment. For SSPM-0710G9MM coupled with a plastic scintillator, the gains have been measured from 41 ℃ to −1.3 ℃. Fig. 5 gives the alpha spectra tested at room temperature by BC408. Comparing the dark count spectrum in Fig. 3 and the alpha spectrum in Figs. 2 and 5, a proper threshold at the ∼50 channel for MPPC S10362-33-025C can clearly distinguish the source events from dark events. The threshold for different combinations of scintillators and SiPM devices will be slightly different according to the test results. The counting rate by using a plastic scintillator is about 100cps. And the rate of dark counting is less than 0.05cps if the trigger threshhold is set at 60th channel. Since the plastic scintillator emits blue light and the SSPM does not match in wavelength, the alpha signals and the noise are not well

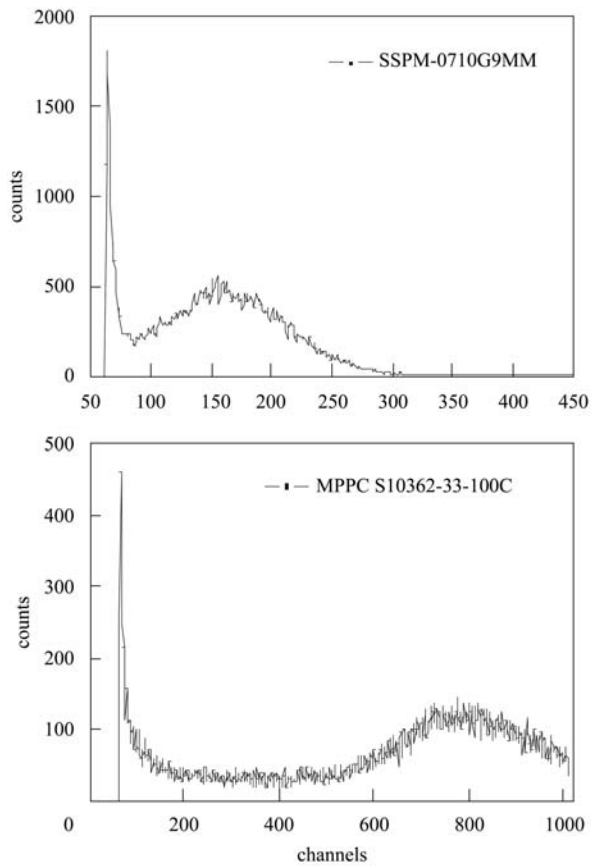

Fig. 5. The alpha spectrum tested at room temperature by BC408.

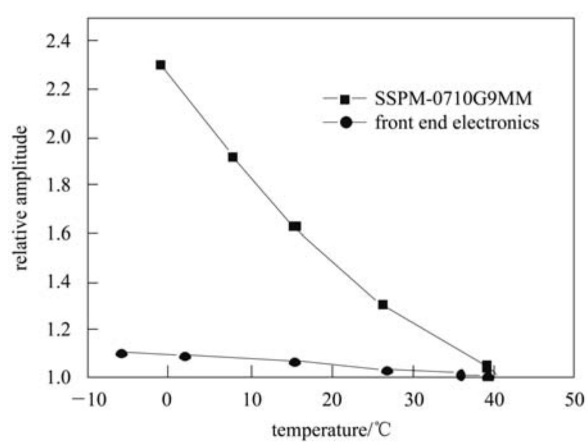

Fig. 6. The measured relative output amplitude as a function of temperature of SSPM-0710G9MM.

separated. About 3 times larger signals may be achieved by using green plastic scintillators (e.g. BC430). At 41 ℃, normalizing the signal output amplitude to 1, the relative amplitude can be derived. As shown in Fig. 6, the relative output amplitude of the SiPM varies by 2.3 times than at −1.3 ℃. So the temperature coefficient of SSPM-0710G9MM and the front-end electronics can be achieved as −2% and −0.1%, respectively. For stable operation, the gain should be kept constant and this can be done either by stabilizing the temperature or by feedback control on the reverse bias voltage [7]. If no control methods are introduced, the threshold shall be finely set to distinguish between the noise and source signals during the whole operating temperature range.

4 Conclusion

The SiPM is a good choice for use in the calibration detector of the GRM as it should have low crosstalk, dark current and temperature coefficient, and the gain should be as high as possible. The anti-radiation performance should also be good considering space application. The test results performed in our lab show that the SiPM is hopefully a perfect device to meet our requirement, though the SSPM series and MPPC series both have advantages and disadvantages. Based on the test data, optimization in the plastic scintillator and the front-end electronics will be carried out in the near future.

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