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Optical test setup for Silicon Photomultipliers

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ABSTRACT

Silicon Photomultipliers (SiPMs) are semiconductor-based photon detectors. Their most important properties, gain and photon detection efficiency, are dependent on or influenced by voltage and temperature and need to be characterised for optimal usage of the SiPMs. The test setup has been built for optical and electrical characterisation of SiPMs. The setup provides a temperature-stabilised SiPM mount, an LED-based multi-purpose light source offers continuous and pulsed operation mode for wavelengths from 300 nm to 650 nm. The result is a complete characterisation of the SiPM within a desired range of operation voltage and ambient temperature.

1. Introduction

To understand the behaviour of an SiPM, one needs knowledge about its properties as a function of overvoltage and temperature [1–5]. The major control parameter of SiPMs is the operating voltage. The overvoltage (V_{ov}) is the operating voltage minus the temperature dependent breakdown voltage (V_{br}). At this voltage the internal charge amplification starts to work. The overvoltage determines the gain in every avalanche.

The noise (dark counts) are avalanches triggered by thermally generated charges. The correlated noise of the SiPM is the consequence of two major effects: The first one is optical crosstalk which is induced in neighbouring pixels mostly by UV-photons generated during the avalanche. This generates output pulses which are faking multi-photon signals. The second effect is afterpulsing which is induced by trapped charges in the amplification zone. Depending on the position of the trapped carrier the additional delayed signal can vary in height. Being trapped at the beginning of the amplification zone, the signal can reach nearly one photo equivalent (p.e.) while a charge trapped at the end will produce no significant signal.

The most important optical property of an SiPM is described by its photon detection efficiency (PDE). It can be measured as a relative PDE (in relation to a reference detector with known quantum efficiency), showing the form of the PDE without an absolute defined scale. If the number of incident photons per pulse is low and well known the absolute PDE can be calculated with the Poisson method, which requires a pedestal with zero fired pixels.

2. Concept

The test setup is based on four functional groups: temperature stabilisation, multi-purpose light source, data acquisition and a control and analysis computer (Fig. 1). A calibrated PIN diode from Hamamatsu is used as a reference detector for the light flux. A spectrometer is used for wavelength measurements. The aim of the test setup is a fully automatic characterisation of the SiPMs regarding these parameters and effects. Similar approaches were presented in [6,7].

3. Multi purpose light source

The multi-purpose light source is an LED-based light source with adjustable light flux and selectable pulsed or continuous operating mode. The custom-made pulser is capable of pulses up to 120 V with a manually adjustable electrical pulse width (3–80 ns) and a repetition rate up to 50 kHz. The light flux reaches from single incident photons to multiple thousands per mm^2 and pulse.

A moveable pickup with two fibres allows us to select one out of the 17 installed LEDs and the required light path. The two options for the light path are to send the light either directly into the beam splitters or into a monochromator and then further into the beam splitters. The monochromator allows us to select a narrow spectral range ($\Delta\lambda \leq 10$ nm) from the incoming light. If higher light fluxes are required the direct input to the beam splitters is used, but with a broader spectral range depending on the selected LED. The spectral range covered by this light source reaches from 300 nm to 650 nm.

4. Temperature stabilisation

The Peltier-based temperature stabilisation unit allows us to operate SiPMs at constant temperatures from below $-35\,^{\circ}$C to more

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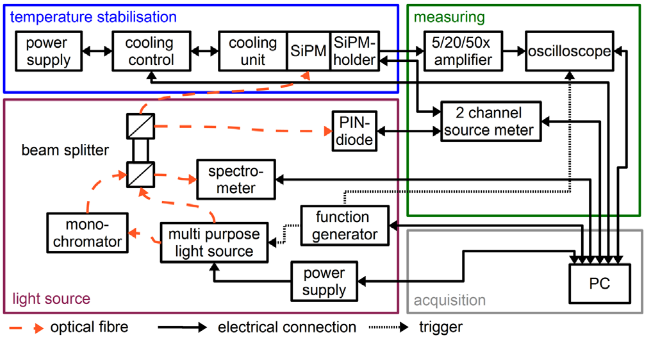

Fig. 1. Schematic view of the test setup with four functional groups.

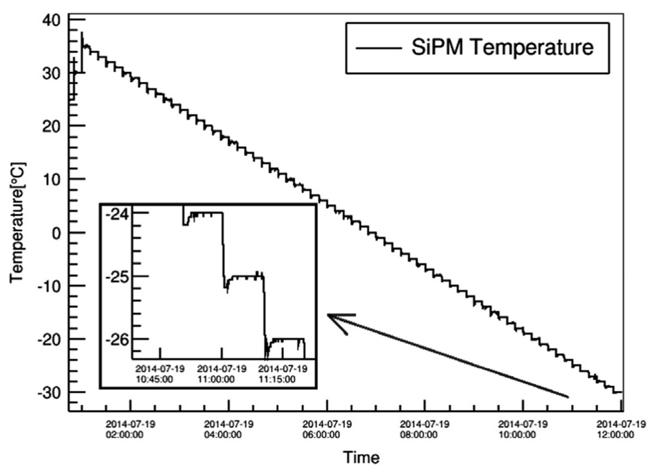

Fig. 2. Performance of the temperature stabilisation. The target temperature setting was decreased by 1 °C for every 10 min. The overshoot (visible in the zoomed part) after changing the target temperature is tolerated for faster stabilisation.

than +60 °C. The temperature variation is less than 0.1 °C which is determined by the smallest ΔT measured by the used digital temperature sensors placed in the cold mass surrounding the SiPM. Stabilisation of the SiPM temperature after changing the target temperature takes about 60 s for a small change of $\Delta T = O(1\,°C)$ and about 180 s for larger temperature changes ($\Delta T > 10\,°C$). Fig. 2 shows the performance of the temperature stabilisation over a range from +40 °C to −30 °C. The zoomed window shows the time required to achieve a stable temperature.

5. Data acquisition

A dual-channel sourcemeter (Keithley 2614B) and an oscilloscope (Agilent DSO 9204H) are used for data acquisition. The sourcemeter allows for simultaneous measurements of SiPM current and reference detector current which are used to calculate the relative photon detection efficiency (PDE). In addition an *I–V* curve is recorded for the SiPM. The oscilloscope is used in two different modes. The first mode is the long trace mode which records traces with 4.1 ms length at a time resolution of 100 ps per data point. These traces are then analysed in detail by first applying a trigger threshold scan. This delivers the trigger level which is used subsequently by the edge finder. The output of the edge finder can then be used to generate time distributions, pulse height spectra, traced-based software charge-to-digital converter (QDC) spectra and much more. The second mode uses the segmented memory mode of the oscilloscope to quickly record triggered pulses from the SiPM signal which is used as a software-based QDC. This results in much better statistics compared to the trace-based QDC at the same time.

6. Measurements

The *I–V* characteristics are recorded with the dual channel sourcemeter up to a limit of 1 mA with a continuous light flux. From the derivation of these characteristics with respect to the voltage, V_{br} is determined as the position of the maximum [8]. Alternatively the QDC spectra of various operating voltages are used to extrapolate to zero gain.

The optical crosstalk is determined from a dark QDC spectrum. For this the total number of entries above the pedestal is divided by the number of entries in the one p.e. peak.

For the afterpulsing effects a distribution of the time between two identified pulses is created and a sum of two exponential function is fitted to the data. A short and a long time constant are obtained from the fit.

A simultaneous measurement of the SiPM current and the reference detector current at different wavelengths of the incident light delivers the data needed to calculate the relative PDE of the SiPM in combination with the calibration data for the reference detector.

From the QDC spectra recorded with few photon pulses of known intensity and wavelength the absolute PDE can be calculated.

7. First results

All results shown were measured using a Hamamatsu MPPC S10362-33-100C with $3 \times 3\,mm^2$ active area and 100 μm cell pitch or a Hamamatsu MPPC S10362-11-100C with $1 \times 1\,mm^2$ active area and 100 μm cell pitch.

7.1. Determination of breakdown voltage

Fig. 3 shows the derivation generated from the *I–V* data. From this curve the V_{br} can be identified as the position of the maximum, i.e. the highest relative increase of the current under reverse bias. The accuracy of this measurement depends on the voltage difference between the measurement points, the temperature stability (0.1 °C variation corresponds to about 6 mV shift in V_{br}) and the absolute accuracy of the sourcemeter (0.015% of reading plus 50 mV).

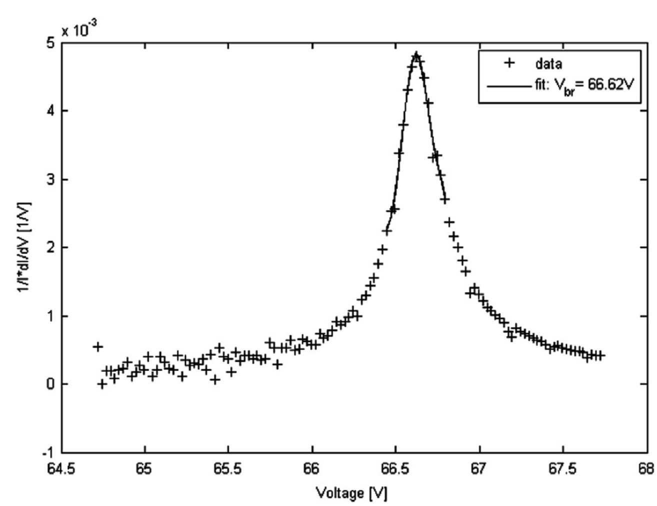

Fig. 3. Derivation generated from measured *I–V* data at −25 °C for the $3 \times 3\,mm^2$ SiPM.