Silicon-Photomultiplier Inspection and Test Plan

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Abstract

Silicon-Photomultiplier (SiPM) sensors will be used by several detector subsystems in the ePIC experiment at the Electron-Ion Collider (EIC). The requirements and specifications for the SiPM sensors detailed in the respective Specifications documents for the detector subsystems. The vendor will deliver the SiPM sensors in trays and sensors will be pre-sorted by the vendor, such that the variation of breakdown voltages (VBR) in each tray is 0.1 V or less. Acceptance tests will be performed on a subset of each delivery installment for conformance with the specifications.

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1. PRODUCT PROPERTIES

The following properties are important for the successful operation of SiPM sensors in particle detectors.

- **Sensor size and front surface condition:** The sensor size (including pixel pitch) is chosen for the specific requirements of the detector system. The size is integral for the construction of the signal readout chain and how the components fit into the available space. The condition of the front surface is essential for high efficiency and optimal detection of photons.
- **Breakdown voltage**: The breakdown voltage is the minimum reverse bias voltage required for the device to operate in Geiger or avalanche mode. It is temperature dependent
- **Operating voltage**: SiPM sensors are operated a few volts above the breakdown voltage in order to achieve a desired gain factor (on the order of a few 10^5). In addition to the temperature dependence, the gain factor can be affected by small difference of the Si-wafer properties during production. As such, the offset from the breakdown voltage may be slightly different for different production batches of sensors.

Other important properties include the dark count rate (noise level), the peak sensitivity and photon detection efficiency, and the protective layer material in front of the active sensor. These properties are detailed in the respective Specifications document and they are certified by the vendor after production.

2. PROCESSES AND PROCEDURES

This section will describe the processes and procedures that are required to evaluate each of the properties described in the preceding section.

2.1. Sensor size and front surface condition

2.1.1. In-Process Testing

In-Process testing is done by the vendor. The sensor production often includes proprietary information and trade secrets. In these cases, the vendor will provide a Certificate of Conformance that refers to all applicable specifications.

2.1.2. Incoming Inspections or Acceptance Testing

A visual inspection of the front surface of the SiPM sensors is required for acceptance testing for a subsample of each delivery batch. The inspection includes the shipping conditions of all packages and potential damage during handling and shipping.

Trays are selected randomly from each delivery batch for further testing. Once the dimensions of the trays are confirmed with caliper measurements, the visual inspection of the opened trays is sufficient.

2.1.3. Verification Testing

Verification testing is not necessary before the SiPM sensors are mounted on the PCP or flex boards. Visual inspection of the sensors on the assembled boards should be part of the acceptance testing for the boards.

2.1.4. Failures and Non-Conformances

Damaged packages may not affect the contents (trays and sensors in trays). If the trays are in good condition, the SiPMs can be baked out to mitigate potential damage from humidity before sensor testing or mounting.

Damaged trays will likely have resulted in scattered sensors in the package. These packages will be returned to the vendor.

Damaged sensors (scratched front surface or broken edges of the protective layer) will result in the tray being rejected. If several trays are combined in one vacuum-sealed pouch, the whole pouch will be rejected.

If sensors have the wrong size, the package will be returned to the vendor.

2.2. Breakdown Voltage

2.2.1. In-Process Testing

The breakdown voltage is certified by the vendor per tray. This includes a maximum variation of breakdown voltages among all SiPM sensors within one tray (or several trays if combined in one vacuum-sealed pouch).

2.2.2. Incoming Inspections or Acceptance Testing

The breakdown voltage is measured for a subsample (few percent) of each delivery batch. Trays are selected randomly for testing. Acceptance testing is based on the variation of breakdown voltages in each tray. Measured voltage should be confirmed at the same temperature are certified or they should be corrected to it.

2.2.3. Verification Testing

Verification testing of the breakdown voltage is not planned for all detector subsystems (see Operating Voltage for more details).

2.2.4. Failures and Non-Conformances

Trays which fail the acceptance criteria for the breakdown voltage will be rejected and returned to the vendor.

2.3. Operating Voltage

2.3.1. In-Process Testing

Similar to the breakdown voltage, the operating voltage is certified by the vendor. It is typically 3-4 V above the breakdown voltage.

2.3.2. Incoming Inspections or Acceptance Testing

The operating voltage can be used instead of the breakdown voltage for acceptance testing. Both have a linear relationship as certified by the vendor.

2.3.3. Verification Testing

Verification testing of the operating voltage is of higher importance to some detector subsystems because the gains should be matched between readout channels. In many cases, the gain matching via individual voltage adjustment is not possible after installation of the sensors. Verification testing may include a measurement of the temperature dependence.

2.3.4. Failures or Non-Conformances

Same as for the breakdown voltage, trays which fail the acceptance testing will be returned to the vendor.

3. EXPERIMENTAL/TEST SETUPS

A permanent setup for the measurement of the breakdown and/or operating voltage will be available for all detector subsystems which require acceptance and verification testing of SiPM sensors. Minor modifications to trays and test sequences will be required depending on the sensor size and desired operating voltage. Some detectors may require temperature control for cooling.

3.1. Measurement of the breakdown / operating voltage

The breakdown voltage is the minimum reverse bias voltage required for the device to operate in Geiger or avalanche mode. The resulting sudden increase in dark current is used in the test procedure.

The test setup can operate a few dozen or more SiPM sensors in parallel (through a multiplexer board). The SiPMs are placed into a cassette with the specific dimensions of the sensors. Gold plated springs on a PCB board are used to create electrical contacts when pressed against the SiPMs without the need for bonding or soldering. The holder also contains thermal sensors, which are placed close to the SiPMs to ensure the required temperature tracking for the measurement of the breakdown voltage. After loading of the SiPMs, the layered cassette plates are screwed together with wing nuts, the closed cassette is placed inside a light-tight dark box, and the control/readout multiplexer board is connected. The control unit is operated through a computer, where automated scripts can be used to run different measurement sequences. For the determination of the breakdown voltage, a series of voltage settings is scanned to find the increase in the dark current (so-called I-V curve).

An additional mechanism on the opposite side allows for the distribution of light from an LED to shine onto the SiPMs. The pulsed LED is used for the determination of the operating voltage in single-photon mode.

3.1.1. Resource Requirements

Indoor laboratory space with space for test cassette loading, dark box, and computer / control unit

3.1.2. Test Conditions

Room temperature or controlled temperature (depending on detector requirements)

No dew condensation (low humidity if controlled temperature below 20 °C)

3.1.3. Equipment

- Multiplexer board (developed by University of Debrecen) with test cassette for SiPM sensors
- Light tight box for test apparatus
- NI PXIe-1082 control unit (alternatively Keithley 60xx source measure unit)
- Windows computer for data acquisition system
- Optional (for Verification measurements): robotic setup for cassette loading
- Optional: temperature control elements in the dark box

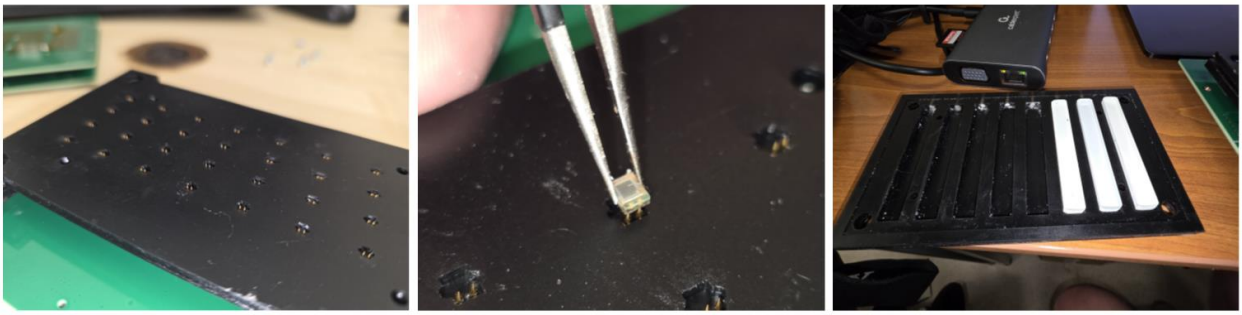

Figure 1: Loading of SiPM sensors into the test cassette. **(left)** Layer for SiPM sensors **(middle)** placing a SiPM into the cassette **(right)** light distribution system on top of the SiPM layer

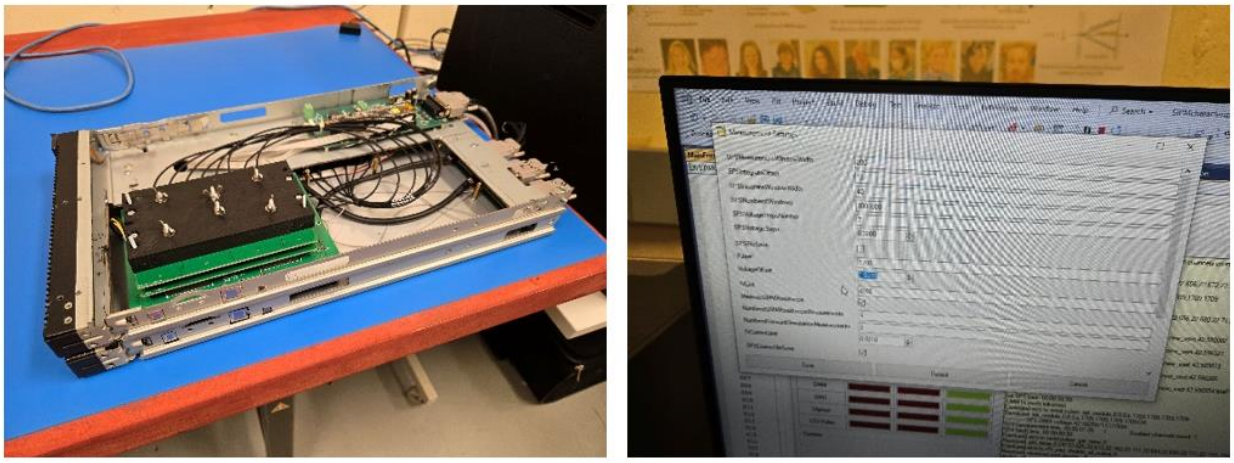

Figure 2: **(left)** Closed test cassette connected to multiplexer control board. Fibers in the back are the light distribution system from an external LED. **(right)** Parameter settings in the control program

4. ENVIRONMENT, SAFETY & HEALTH CONSIDERATIONS

The procedures will be implemented in a way consistent with the environment, safety, and health policies of the relevant work areas. Within Jefferson Lab the process is described in the ES&H manual Chapter 3200, Work Planning and Control Program and at BNL within the SBMS: "Work Planning & Control for Experiments and Operations".

5. RECORDS AND DOCUMENTATION

5.1. Manufacturer/Producer Records

The vendor will provide a Certificate of Compliance for each delivery batch. The certificate will cover all articles, materials, and products as specified in the Statemen of Work and Specifications documents.

5.2. Deliverable Documentation and Records

Inspection and acceptance testing will be tracked with Travelers for all delivery batches. The travelers will be appended by measured breakdown/operating voltages for all tested SiPM sensors (spreadsheets with summary plots). All testing and inspection data that is collected as part of the validation, verification and

testing plan will be provided to the project as part of the final report. Verification testing will be used for initial calibrations in the experimental database.

6. REFERENCES

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