SiPM Performance Characterization and Radiation Hardness Tests for sPHENIX

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1. Introduction

The electromagnetic (EMCal) and hadronic (HCal) calorimeters for the sPHENIX experiment will use ~ 100,000 Silicon Photo-Multipliers (SiPMs) as optical sensors (Hamamatsu S12572-33-015P). The effects of radiation damage in SiPMs from gamma rays has been measured and compared with the damage produced by neutrons. We designed and constructed an SiPM testing device that measures the breakdown voltage and gain curve with the SPS (single photon spectrum) method. It was used to characterize the SiPMs for the sPHENIX calorimeter preproduction prototype.

2. Irradiation facilities

Solid State Gamma-Ray Irradiation Facility (SSGRIF) at Brookhaven National Laboratory

- Gamma (Co-60) radiation at 10 krad/h with a total dose of 1 Mrad [a]
- D-T generator to produce ~ 14 MeV neutrons with a flux 10^5 n/cm^2/s, fluence 10^9 n/cm^2

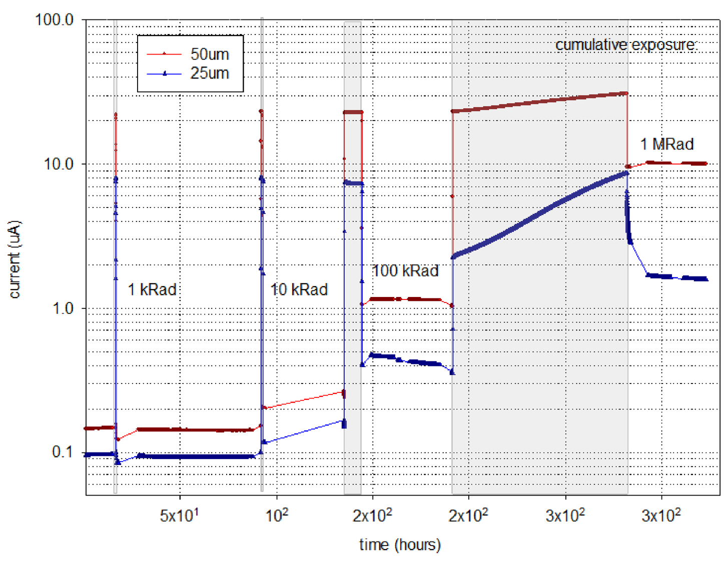
Institute for Nuclear Physics Research (Atomki)

- Gamma (Co-60) dose rates 4 krad/h and 18.6 krad/h up to the total dose 270 krad
- Cyclotron produces a beam of protons that impinged on a beryllium target and produced neutrons with an energy spectrum up to ≥ 17 MeV, flux 8.0 $\times 10^7$ n/cm^2/s, fluence 10^{12} n/cm^2

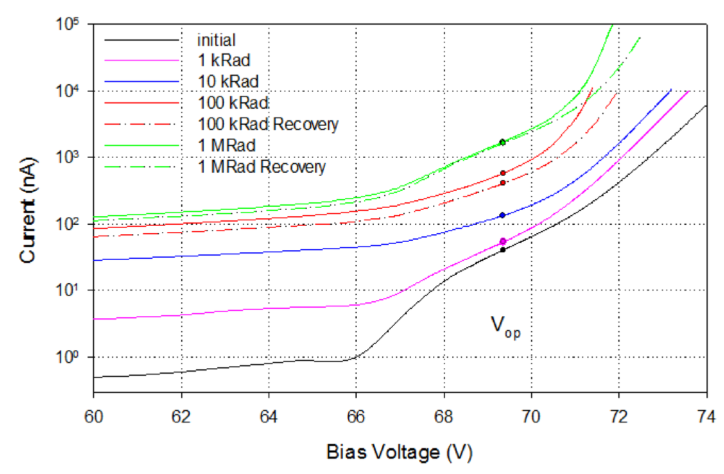
[a] 1 rad = 0.01 Gy

3. Gamma ray irradiations

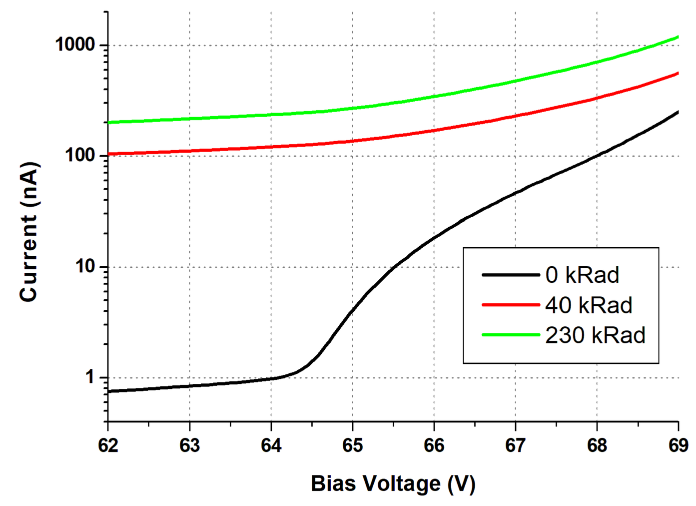
Gamma ray irradiations at the SSGRIF were carried out up to an integrated dose of 1 Mrad.



Time was taken between the exposures to measure the samples and to observe any change in current over time due to annealing.



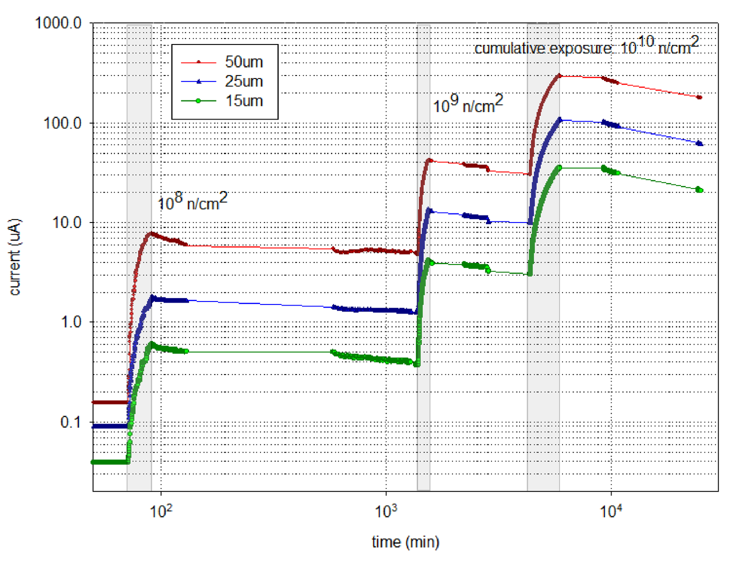
The current increases dramatically during irradiation due to the large current induced by gamma rays from the source, but this induced current drops dramatically when the source is removed. The results show a large increase in dark current both at the operating voltage and below the breakdown voltage. There is virtually no recovery for doses up to 10 krad, and only a small recovery for doses of 100 krad and 1Mrad.



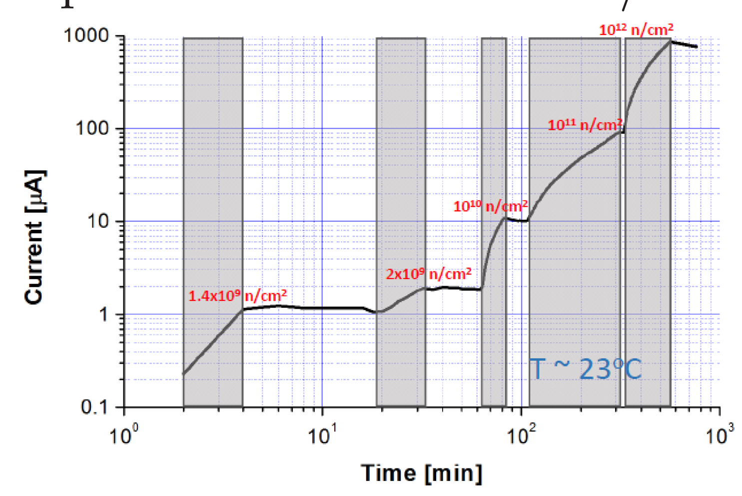
At the Atomki the cumulative doses achieved were 40 krad and 230 krad at a dose rate of 4 krad/h and 18.6 krad/h. The same effect of an increase in dark current both above and below the breakdown voltage is again seen for this device.

4. Neutron irradiations

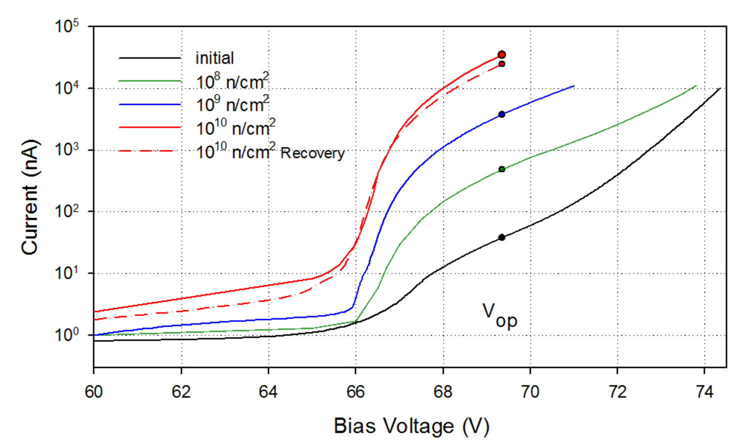
The expected neutron fluence per RHIC run is 10^{10} n/cm^2. Neutron irradiations at the SSGRIF were carried out in a series of steps, and reached a neutron fluence of 10^{10} n/cm^2



With the Atomki cyclotron it was possible to reach a total cumulative exposure of 10^{12} n/cm^2.



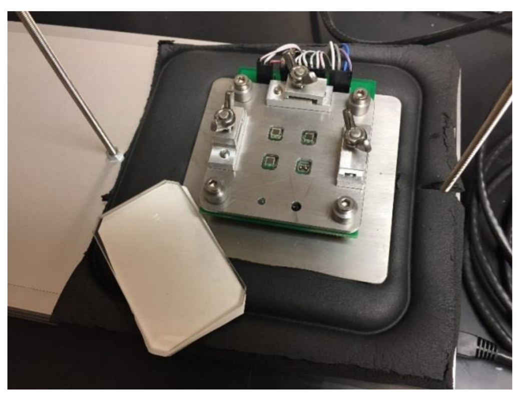
The dark current increases steadily during the irradiation and then decreases slowly after the source is removed, in contrast to the behavior seen with the gamma ray exposures. The slow decrease after exposure to neutrons is evidence for room temperature annealing, although the amount of recovery is rather small.

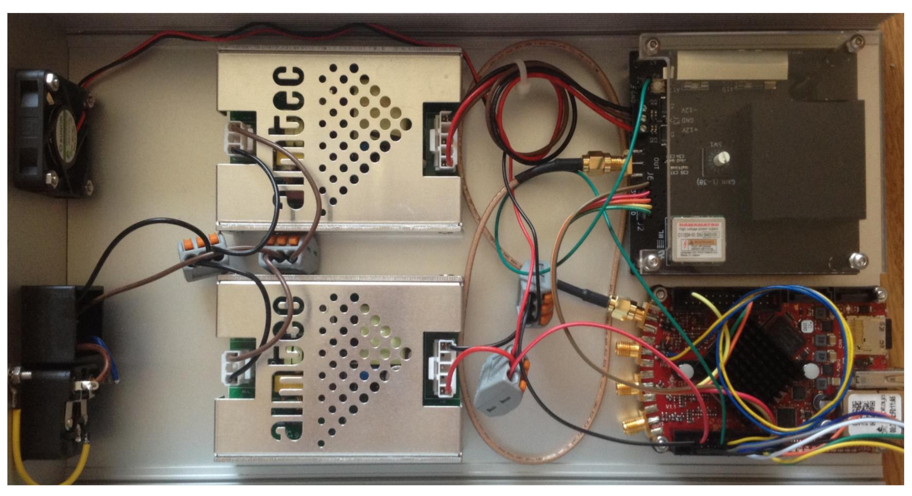


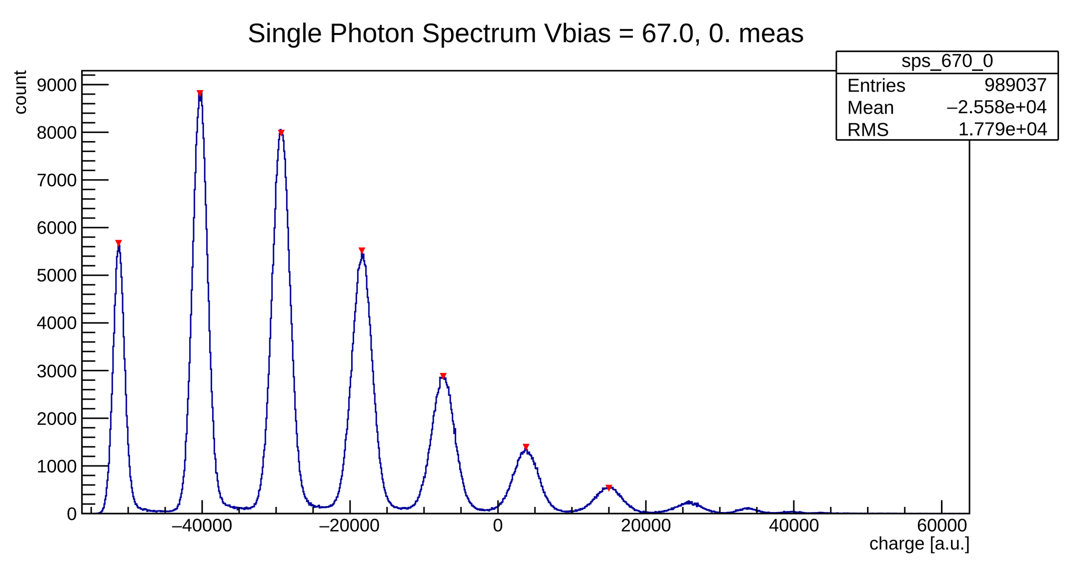
The large increase in current occurred only above the breakdown voltage, in contrast to the gamma ray irradiations, indicating that the damage occurred more in the bulk material as opposed to at the surface.

5. SiPM testing device

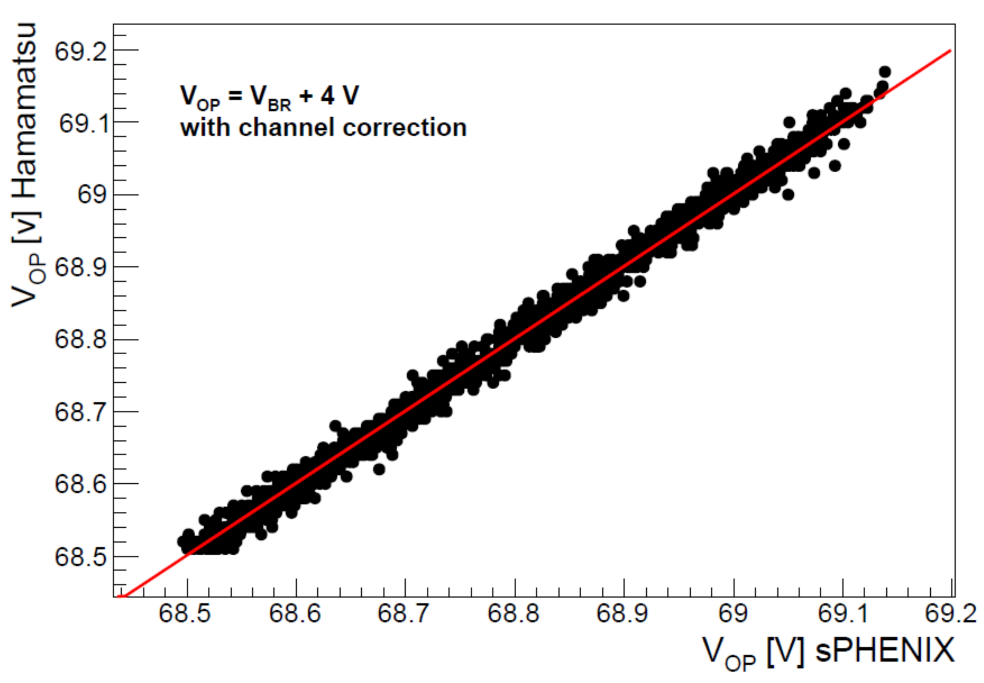
Designed at constructed at Univerity of Debrecen, the device can perform Single Photon Spectrum (SPS), 4 SiPMs per turnover, in 10 minutes







1428 SiPMs were tested, the results agreed with Hamamatsu operating voltage.



6. Conclusions

We have carried out a systematic study of radiation damage in SiPMs produced by gamma rays and neutrons. The effects of damage caused by different types of particles manifest themselves differently in the devices due to the differences in their damage mechanism.

- Damage produced by gamma rays is consistent with damage produced by ionization.
- Damage produced by neutrons is consistent with damage produced in the bulk material caused by displacements in the silicon lattice due to interactions with high energy neutrons.
- The main effect of the damage is a large increase in the dark current which persists long after the radiation source is removed with only slight recovery at room temperature.
- The radiation induced dark current caused by gammas has a significant contribution below the breakdown voltage, while neutron induced damage produces a larger increase in dark current above the breakdown voltage.

Large scale testing of sPHENIX SiPMs is feasible, the breakdown voltage (V_{br}) and the gain can be measured with the SPS method, and can be compared with the V_{br} from the IV measurement.
Device can be upgraded to test at least 64 SiPMs each in a period of 4 hours or less. With 3 devices + 1 spare distributed at 3 sites ~ 500 SiPMs can be tested a day.
We are working on a set of devices with an automatic inserter, quality control and sorter.