Radiation Damage of Pixelated Photon Detector by Neutron Irradiation

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Abstract

In this presentation, the effect of neutron radiation to the basic property of Pixeleted Photon Detector(PPD) will be presented, following the study shown at NDIP09. In the study Hamamatsu MPPCs are exposed to neutrons using reactor YAYOI up to 10^{12} /cm^2. After the irradiation it is known that the noise rate increases rapidly. But the effect of irradiation to the optical crosstalk and afterpule is not well studies. These properties are stueies using waveform analysis of the dark noise. Waveform from the MPPC noise recorded using Oscilloscope are processed with decomposition filter using FFT.

Introduction

Hamamatsu MPPC

The MPPC one of PPD developed by Hamamatsu Photonics is now widely used in high energy physics experiments. The KEKDTP group has performed a series of radiation test for the MPPC with γ rays, protons, neutrons and heavy irons.

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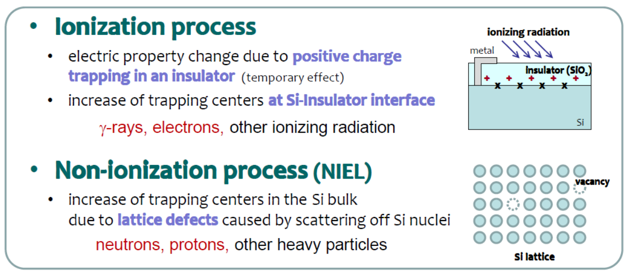


- **Ionization process**
  - electric property change due to **positive charge trapping in an insulator** (temporary effect)
  - increase of trapping centers **at Si-Insulator interface**

  γ-rays, electrons, other ionizing radiation
- **Non-ionization process (NIEL)**
  - increase of trapping centers in the Si bulk due to **lattice defects** caused by scattering off Si nuclei

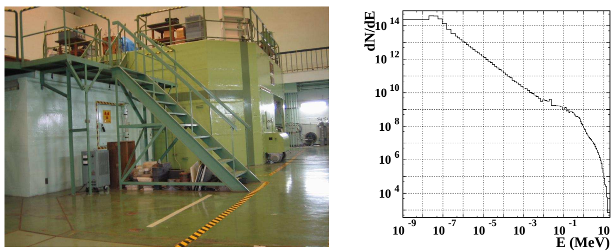
  neutrons, protons, other heavy particles

Formation of new centers in the Si band gap raises thermal carrier generation

Radiation damage of semiconductor device is roughly categorized into two processes, namely Ionization and Non-ionization processes(NIEL). And these two processes give different effect to the device. It is considered that gamma-rays contribute to Ionization process while the neutron is due for the Non-ionization process.

Neutron Irradiation Test

Neutron irradiation test is performed at the reactor 弥生 (YAYOI) of University of Tokyo at Tokai. The reactor has maximum 2kW output thermal power and the average energy of neutron is about 370 keV. Fluence can be adjusted either changing reactor power or duration of the irradiation as the number of neutrons can be described as $\sim 4 \times 10^5$ neutron/cm^{2}Ws. Properties of each MPPC sample are measured before and after irradiation using the same settings to compare the difference while keeping systematic effect small. In order to reduce the effect of temperature variation to the MPPC measurements are performed at 20 °C by using thermostatic chamber.

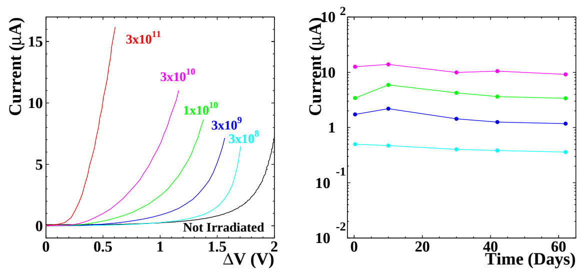


Reactor 弥生 (YAYOI) and Neutron Energy Spectrum

Results

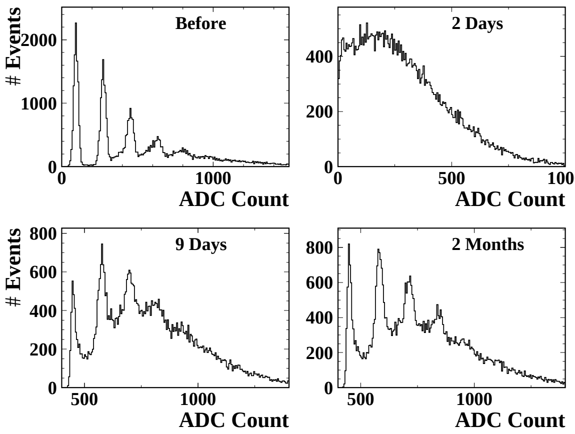
Leak current and dark noise rate increase rapidly as the neutron fluence, while the effect to breakdown voltage and gain are small. Crosstalk probability is not affected upto 10^{10} neutrons/cm^2. Photon detection efficiency is not affected by the neutron radiation. Single photon countability is lost above 10^{11} neutrons/cm^2 while the response curves preserves. Recovery from the damage is very slow.

Leak Current



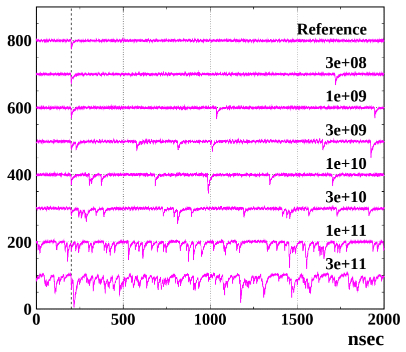
Leak Current after irradiation

ADC Distribution



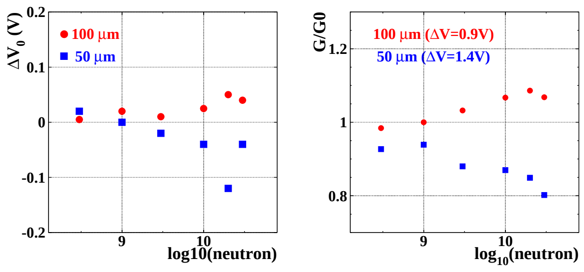
ADC distribution before and after 2×10^{10}/cm^2 irradiation

Waveform



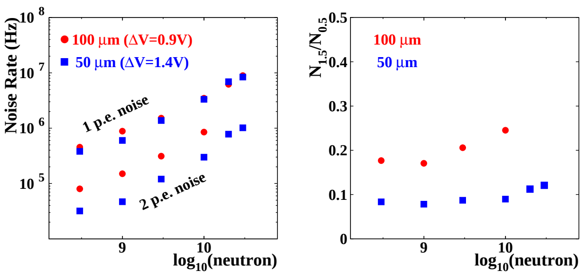
Typical Waveform after different level of irradiating

Gain and Breakdown Voltage



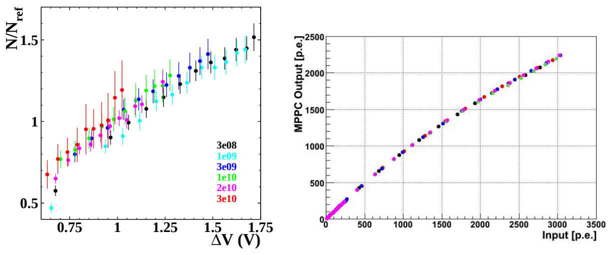
(Left) Gain (Right) breakdown voltage v Fluence

Noise Rate and Crosstalk



Noise Rage (left) Cross-talk probability v Fluence

PDE and Response Curve

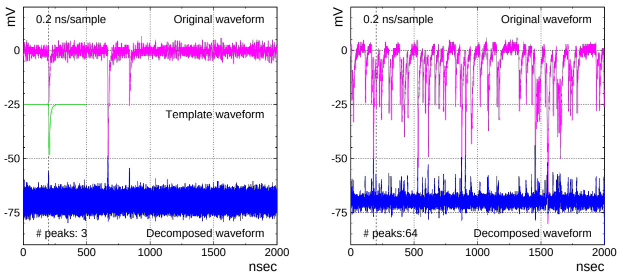


(Left) PDE relative to Reference MPPC (Right) Response curve for different irradiation

Measurement of Afterpule

Waveform of MPPC noise signal is recorded using digital oscilloscope. Waveform is digitized with 5GS/s for 10000 sampling points corresponding to 2μs duration. The recorded waveforms are offline processed with decomposition filter using Fast Fourier Transformation to get timing and pulse height information. Template waveform used in the decomposition is obtained by fitting averaged waveform with a function,

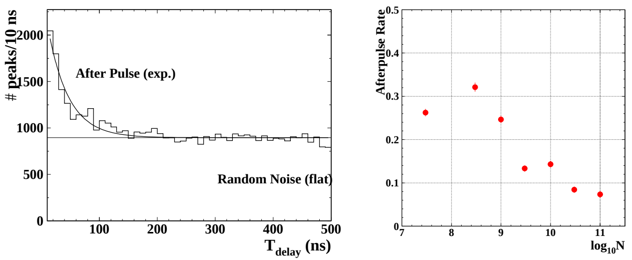
$$f(t) = -\frac{t^{\alpha_1}}{\tau_1} \cdot \exp\left(-\frac{t^{\alpha_2}}{\tau_2}\right).$$



Waveform before and after decomposition for (Left) reference sample and (Right) irradiated sample.

From the timing and pulse height information, noise rate and crosstalk rate can also be calculated and were consistent with the measurement with other method using scaler, plotted above. The timing distribution is then fitted with an exponential function corresponding to the contribution from afterpulse and a flat component by random noise. From the fitting, the number of afterpulse was obtained. Finally the afterpulse rete is calculated by the definition,

$$\text{Afterpulse rate} \equiv \frac{\text{\# After Pulse}}{\text{\# Trigger Pulse}}.$$



(Left) Timing distribution of random noise and afterpulse. (Right) Afterpulse rate as a function of neutron fluence.