Radiation hardness of Multi-Pixel Photon-Counters (MPPC)

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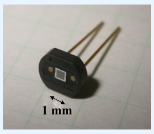
Introduction

Multi-Pixel Photon-Counter (MPPC) is a photon-counting semiconductor-device developed by Hamamatsu Photonics. Recently, the device has attracted much attention because of excellent features over Photo-Multiplier Tubes (PMTs), such as compactness, insensitive to magnetic fields, low power consumption, etc. For this reason, MPPC will be utilized for High Energy Physics experiment, space and medical-science applications.

Radiation hardness of MPPC is a important issue to be investigated for a practical use in high radiation environment. In general, radiation creates defects in Si devices due to ionizing and/or non-ionizing processes, resulting in characteristic change of the devices. Increase of leakage current is one of the signatures of radiation damage. In the case of MPPC, effects of the radiation damage might be significant because of its high gain (~10^6). In this report we present the effects of radiation damage with different radiation sources.



MPPC (400 pixel)
10363-11-050C

Collaborators

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Specifications of MPPC
(Hamamatsu Phonics, catalog)

No. of pixels	100, 400, 1600
Gain	7.5×10^5 (for 400-pixel type)
Sensitive area	1×1 mm^2
wavelength region	270 nm ~ 900 nm (peak: 400 nm)
P.D.E.	50 % (for 400-pixel type)
Timing resolution	220 ps (for 400-pixel type)

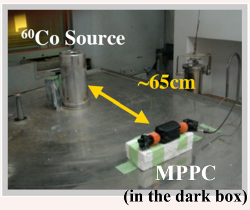
Required radiation hardness for typical applications

ATLAS	10^{14} 1MeV-N$_{eq}$/cm^2 / 10 years
KEK-B	10^{10}~10^{11} 1MeV-N$_{eq}$/cm^2
Space station	35 Gy / 5 years (electrons) 3.5 Gy / 5 years (protons)

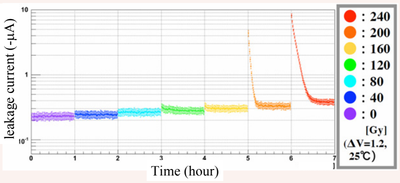
※1MeV-N$_{eq}$: 1MeV neutron equivalent fluence

γ-ray irradiation

Source: ^{60}Co 15 TBq @ Tokyo Tech
MPPC type: T2K-11-100C (100 pixels)
Dose rate: 10 Gy/h
Irrad. Time: 24 hours (total)
Total Dose: 240 Gy

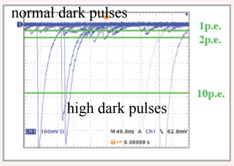


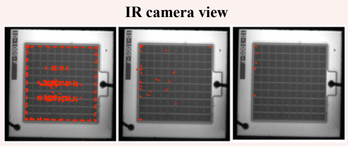
I_{leak} variation after each irradiation



- **Leakage current (I_{leak})**
  - slightly increased after each irradiation
  - drastically increased after 200 Gy irradiation, but recoverd within ~10 minutes.
    → caused by **high dark-pulses (>10 p.e.)**
- **Gain and Cross-talk rate**
  → No change up to 240 Gy after the recovery.

High dark pulses (observed after 200 Gy irrad.)



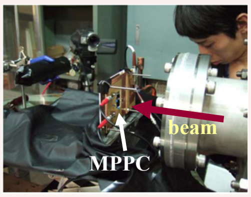


Just after after 5 min. after 10 min.

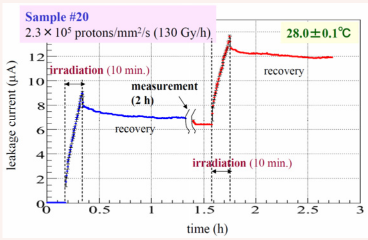
- **High dark pulses (> 10 p.e.)**
  - observed with normal dark pulses (1 p.e.) after the 200 Gy irradiation, where the drastic increase of I_{leak} is found.
  - **disappeared after ~10 minutes, but appeared again** when the bias voltage had been turned off and on.
- **IR camera view**
  - **localized spots were observed** in the peripheral region of the MPPC and bias lines. The spots were disappeared after ~10 minutes.
    → local drop of the break-down voltage due to charge trapping effects in the SiO_2 layer ??

Proton irradiation

Beam: proton 53.3 MeV @ RCNP
MPPC type: S10362-11-050C(400 pixels)
Flux: 2.3×10^5 p/mm^2/s (130 Gy/h)
3.0×10^4 p/mm^2/s (16 Gy/h)
Irrad. Time: 30 min. (total)
Total Fluence: 2.8×10^{10} p/cm^2 (=42 Gy)
(= 4.8×10^{10} 1MeV-N$_{eq}$/cm^2)

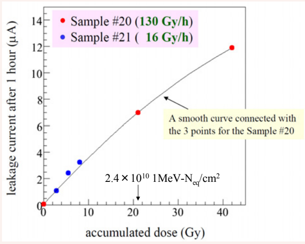


I_{leak} variation



- **Leakage current**
  - linearly increased during the irradiation
- **Annealing effects**
  - seen. but not completely recovered to the original condition within a few hour.
- **For lower-flux beam**
  - similar tendency was observed.

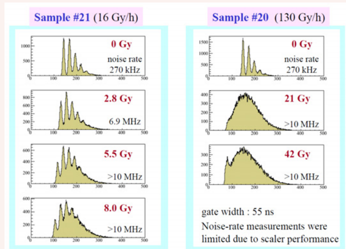
I_{leak} vs total dose



- **I_{leak} vs total dose**
  - Almost linear dependence
- **Rate dependence**
  - No dose-rate dependence
- **Comparison with SiPM**
  - almost the same damage level

(see, arXiv 0704,3514)

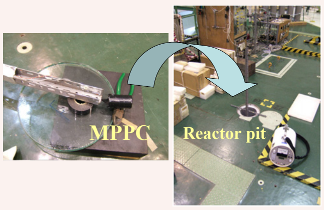
ADC spectra and noise rate



- **Dark rate**
  - Significantly increased after the irradiation
- **Photon counting capability**
  - **lost after 21 Gy irradiation due to noise pile-up and baseline fluctuation**
- **Gain**
  - No significant change up to 8 Gy (<5%)

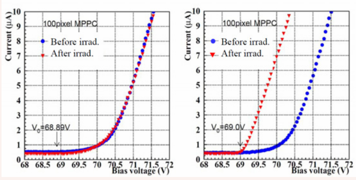
Neutron irradiation

Source: fast neutron reactor YAYOI
0.1 ~ 1 MeV (main component)
MPPC type: S10362-11-100CK(100 pixels)
S10362-11-050CK(400 pixels)
Total Fluence: ~ 1×10^7 n/cm^2
1×10^{10} n/cm^2
1×10^{11} n/cm^2
1×10^{12} n/cm^2



I-V curve

3.3×10^7 n/cm^2 1.0×10^{10} n/cm^2



- **Situation**

<3.3x10^7 n/cm^2	No significant change
>10^{10} n/cm^2	I-V curve drastically changed. Continuous pulse height (No photon counting capability)

- **Comparison with proton irradiation**
  - same level of damage with the proton irradiation

Summary

Three experiments have been performed with different sources (γ-ray, proton and neutron irradiation) to check effects of radiation damage on MPPC.

For the γ-ray irradiation, the leakage current slightly increased with dose (total dose effect) and drastically increased after 200 Gy irradiation due to high dark pulses. IR-camera images showed that the generation points of the high dark pulses were localized. This might be explained that the break-down voltage is locally dropped because of charge trapping effects in the SiO_2 layer. However, further investigation would be needed for the confirmation. Gain and cross-talk rate were not affected up to 240 Gy.

Variation of the leakage current for the proton irradiation was much larger than the γ-ray case on the same irradiated dose because of the damage in the Si bulk. This damage was not recovered within a few hour. After 21 Gy (2.4×10^{10} 1MeV-N$_{eq}$/cm^2) irradiation, photon counting capability was lost due to noise pile-up and baseline fluctuation.

For the neutron irradiation, we found drastic increase of the leakage current more then 10^{10} n/cm^2 although no significant change was observed less than ~10^7 n/cm^2. Variations of the leakage current before and after the irradiation are the same level between neutrons and protons, which suggests that the damage in the Si bulk is a main contribution in the case of the proton irradiation. Since some data points (10^8~10^9 n/cm^2) are lacking, we are planning to perform a neutron irradiation experiment again in this month.

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