PROCEEDINGS OF SCIENCE

Radiation damage of MPPC by γ-ray irradiation with ^{60}Co

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We studied radiation damage of MPPC using ^{60}Co γ-rays, up to total accumulated dose of 240 Gy. Leakage current and dark noise rate increase as a function of radiation dose. On the other hand, no significant change was observed for gain and crosstalk. After 240 Gy irradiation, we observed large dark-noise pulses as well as localized spots with leakage current along the outer edge and bias line of the device. This study will provide important information for practical application and for identification of issues for future developments.

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1. Introduction

The MPPC (Multi-Pixel Photon Counter) was developed by Hamamatsu Photonics K.K. [1], which is made up of multiple APD (avalanche photodiode) pixels operated in Geiger-mode. The device has some good features, such as low-voltage operation, high gain, insensitivity to magnetic field, or compact size. Because of these characteristics, the device is planned to be used in many high energy physics experiments, such as ILC or T2K. The device is supposed to be operated under a high radiation environment in many cases . Therefore, its radiation damage is a critical issue for practical applications. The radiation damage has been unknown since MPPC is a very recently developed device. We studied the radiation damage of MPPC using a ^{60}Co γ-ray source.

2. Test Method

We used a 100-pixels MPPC, which is a prototype (Type No : T2K-11-100C), for irradiation. Basic characteristics of the MPPC sample at the operation voltage (V_{op} = 70.7 V) are shown in Table. 1. V_{op} =70.7 V is equivalent to ΔV = 1.2 V, where ΔV (over-voltage) is the difference between the applied and the breakdown voltage. The MPPC was irradiated using a 15 TBq ^{60}Co source at the ^{60}Co γ-ray irradiation facility in Tokyo Institute of Technology. The dose rate can be adjusted by changing the distance between the sample and the γ-ray source (e.g. when placing the MPPC at 65 cm from the source, the dose rate is 10 Gy/h).

Basic characteristics	
gain	2.4×10^6
1 p.e. noise rate	334 kHz
2 p.e. noise rate	38 kHz

Table 1: Basic characteristics specification of the MPPC for irradiation at V_{op} and 25 ℃. The 1 (2) p.e. noise rate is obtained a using 0.5 (1.5) p.e. threshold with a pulse counter.

The procedure of this measurement is described as follows. Reference data, which is leakage current, gain, noise rate and crosstalk, were obtained at a laboratory beforehand. Then we irradiated 40 Gy (10Gy/h × 4 hours) in the ^{60}Co room. During this irradiation, leakage current was measured at the same ΔV under the room temperature (a thermostatic chamber couldn‘t be used in the ^{60}Co room). After irradiation, the MPPC was brought back to the laboratory, and we measured leakage current and basic performances to see the damage effect. Thermostatic chamber could be used here, so we kept always 25 ℃ during measurements in the laboratory. Leakage current was measured for one hour to see the annealing effect, where annealing means recovery from the radiation damage during applying the bias voltage. Then basic performances such as gain, noise rate, and crosstalk were measured. This procedure was repeated 6 times, up to a total accumulated dose of 240 Gy.

3. Leakage current measurement

In general, under a reverse bias voltage, the leakage current passing through a semiconductor device is due to creation of electron-hole pair by mainly thermal excitation, and the irradiation

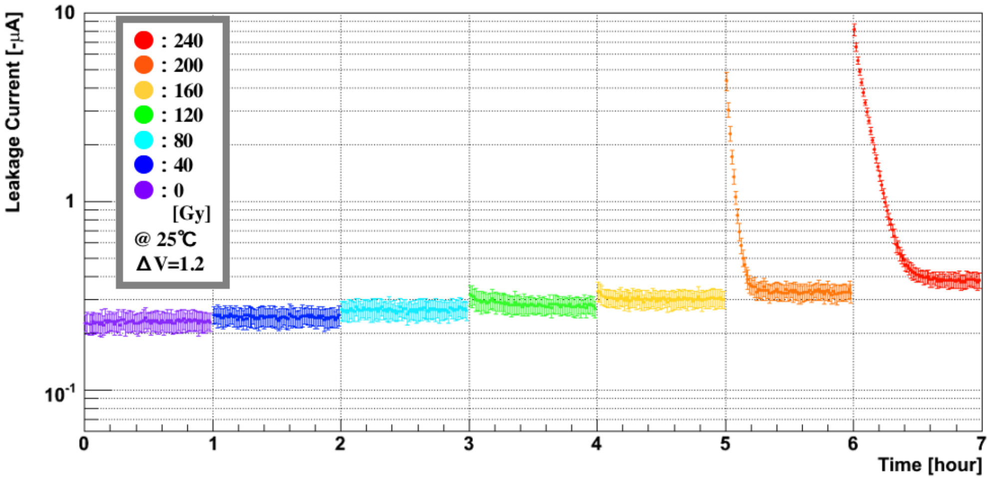

Figure 1: Comparison of leakage current during one hour measurement after each 40-Gy irradiation at the same condition of $V_{\rm op}$ and 25 ℃. Time, horizontal axis, is used only as a guide.

increases leakage current. It is known that the silicon bulk and surface (junction between the oxide and semiconductor) in the device are damaged by irradiation, and these damages result in increase of leakage current [2]. Hence, the leakage current is a fundamental quantity to see the radiation damage of a semiconductor device. With a Keithley SourceMeter model 2400, leakage current was measured as a function of the applied voltage, or time.

In order to see the change in leakage current, we compared measurements of leakage current performed during one hour just after each 40-Gy irradiation in the same condition of $V_{\rm op}$ and 25 ℃. As shown in Figure. 1, annealing effects were observed after 120 Gy or more. The value of leakage current decreased after applying the bias voltage and got settled in 30 minutes at most. By comparing the leakage current observed during the second half (30 minutes) of each one hour measurement, we conclude that the leakage current becomes 1.7 times as high as the original value. The reason using the second half of each measurement is to see the effect after annealing. Very high leakage currents just after irradiations of 200 Gy and 240 Gy are apparent.

We looked at the waveform of MPPC output by an oscilloscope to get more information. Figure. 2 shows the waveform after 240-Gy irradiation, and large dark pulses appeared during the time when high leakage current was observed. Those large dark pulses disappeared as leak current got settled. This phenomenon took place again when we turned on the bias voltage some time after the voltage while since voltage had been turned off, but the effect was annealed to some extent.

In order to investigate where the large dark pulses are generated, we took a picture of MPPC samples by an infrared camera applying the bias voltage at $V_{\rm op}$. In Figure. 3, at the red points on the irradiated sample, infrared light is emitted due to the Joule heat caused by the passage of leakage current. On the non-irradiation sample, there were no such "hot-spots". Investigating at the picture of the irradiated sample in detail, the hot-spots are found to be located on the edge of the pixels, outermost edge of the device and along the bias line. Note that the bias line are alternately placed to connect all the pixels.

This result indicates that there is a relation between the large dark pulse and the device struc-

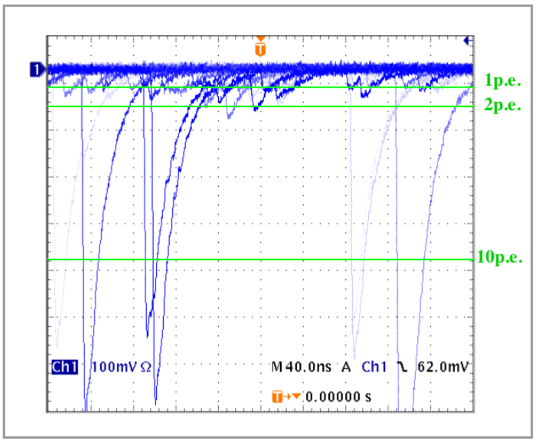

Figure 2: The waveform of MPPC after 240-Gy irradiation. Large dark pulses appeared while high leakage current was observed.

ture. Similar phenomena were reported in radiation damage studies of a silicon micro strip sensor, which has the same MOS (Metal-Oxide Semiconductor) structure [3]. They found micro-discharge around the pixel edge, and it generated random pulse noises.

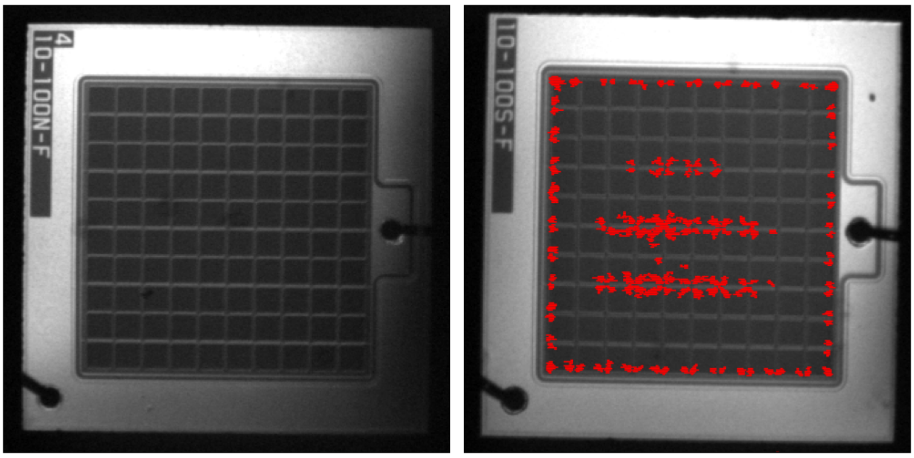

Figure 3: Infrared pictures of a non-irradiation sample (left) and the irradiated sample (right). At the red points on the irradiated sample, infrared light is emitted due to the Joule heat cause by passage of leakage current.

4. Measurements of other quantities

We measured gain, noise rate, and crosstalk as the quantities to evaluate the radiation damage. These basic performances were measured after enough annealing took place in order to separate from instantaneous effects such as the large dark pulses.

The gain, G, was measured by flashing a LED and recording the MPPC output pulses with a charge sensitive ADC. It can be given as follows:

$$G = \frac{Q_{pixel}}{e} = \frac{(1\ photo\ electron\ peak - pedestal\ peak)\ \times\ ADC\ resolution}{Amplifier\ gain\ \times\ e}$$

where Q_{pixel} is the output charge caused by a Geiger discharge of one pixel, ADC resolution is 0.25 pC/bin, Amplifier gain is 50, and e is the elementary charge. The resulting gain as a function of the bias voltage is plotted in Figure. 4. No significant change was observed until 240-Gy irradiation. Small variations of the gain are within the systematic effect by the temperature control.

For noise-rate and crosstalk measurement, first we determined 0.5 p.e. and 1.5 p.e. threshold by observing dark pulses with an oscilloscope. One (two) p.e. noise rate is obtained by using a 0.5 (1.5) p.e. threshold for the scalar. In avalanche multiplication process, photons can be generated (which is different from initial photon). If the photons are detected by other pixels, the MPPC outputs higher pulse height than the one corresponding to the number of incident photons. This phenomenon is called the crosstalk, and it is defined as follows:

$$Crosstalk = \frac{2\ p.e.\ noise\ rate}{1\ p.e.\ noise\ rate}$$

The result of noise rate as a function of the bias voltage is shown in Figure. 5. Noise rate increased along with the total dose. Particularly, 1 p.e. noise rate at V_{op} increased about 1.5 times higher after 240-Gy irradiation. The measured crosstalk as a function of the bias voltage is shown in Figure. 6. No significant change was observed for the crosstalk up to 240-Gy irradiation.

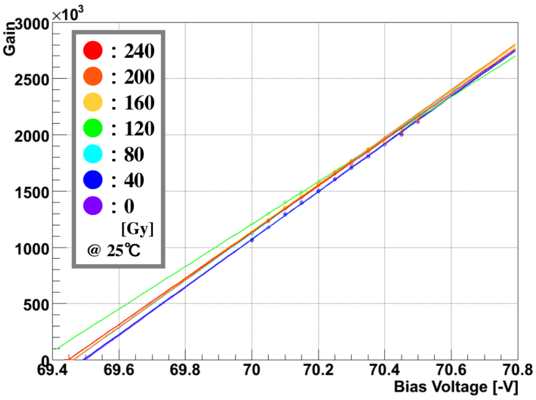

Figure 4: The gain as a function of the bias voltage.

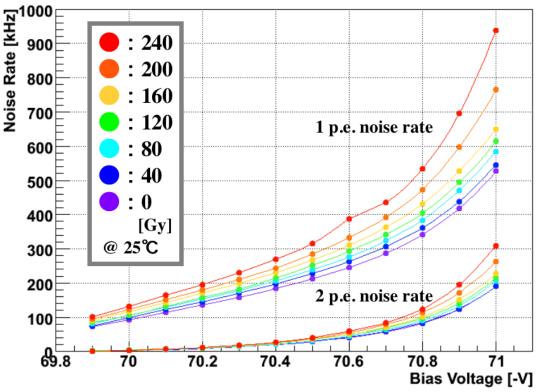

Figure 5: Noise rates as a function of the bias voltage.

All these measured quantities are summarized in Figure. 7 as the ratio to the original value under the condition of V_{op} and 25 ℃. Leakage current and Noise rate increased as total dose increased. After 240-Gy irradiation, leakage current increased by about 1.7 times and noise rate increased by about 1.5 times. For gain and crosstalk, no significant change were observed.

5. Conclusions

We studied radiation damage of the MPPC using ^{60}Co gamma-rays. Total accumulated radiation dose was 240 Gy. Leakage current and noise rate increased as a function of total dose. After

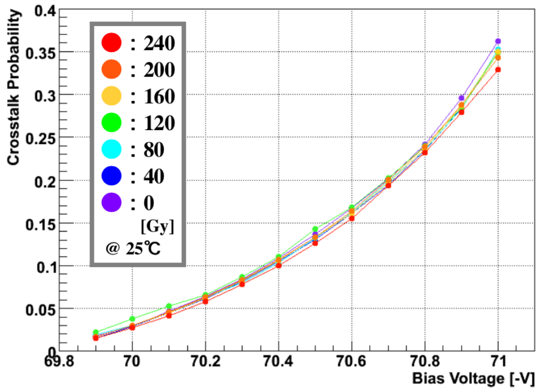

Figure 6: Crosstalk as a function of bias voltage.

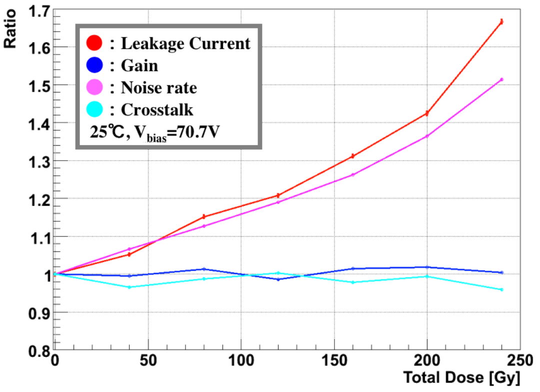

Figure 7: All the measured quantities are shown by the ratio to the original values as a function of the total radiation dose. The measurement are carried on under 25 degree celsius with applying voltage at $V_{\rm op}$.

recovery 240 Gy, the former and the latter increased about by 1.7 times and 1.5 times with the respect to the original values, respectively, under the condition of 25 degree celsius and $V_{\rm op}$. For gain and crosstalk, no significant changes were observed.

Furthermore, we observed large dark pulses after 240 Gy while high leakage current was observed. Using infrared camera, we found that the infrared radiations take place in the edge of the pixels, on outermost edge of the device and along the bias line. These infrared emission spots are due to the Joule heat of the localized leakage current. This phenomenon is supposed to be related to the large dark pulses.

In summary, the knowledge obtained by this study will provide important information for practical applications as well as further developments of the MPPC.

6. Acknowledgment

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