Signal-to-Noise Measurement and Radiation Damage Study of a Silicon PIN diode with a Proton Beam

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1. Introduction

Silicon material has great potential to radiation detectors and is applicable to the multi-detectors and large area detectors. It can be combined with CMOS circuits monolithically [1]. There are various types of silicon radiation detectors such as discrete, one or two dimensional detector for particle counter and imager, linear or cylindrical silicon drift detectors (SDDs) for position sensing and X-ray or optical photon detectors, and silicon photo-multiplier (SiPM), [2] etc. These detectors are mostly based on the PN or PIN junction diode and thus device structures are simple.

We designed and fabricated silicon PIN diodes on 5-in. high resistivity, <100> n-type wafer with 380 μm-thick. The active area of the diode is 1 cm x 1cm.

The silicon diode was exposed to a 45 MeV proton beam from the MC-50 cyclotron at the Korea Institute of Radiological and Medical Science (KIRAMS) [3] in Seoul. The signal-to-noise ratio (SNR) of the PIN diode was measured and the leakage currents as a function of the reverse bias voltages were also measured before and after the proton beam irradiation. We present SNR measurement of the silicon diode and the understanding of radiation-included detector deterioration.

2. Fabrication of the Silicon PIN Diode

We fabricated a silicon PIN diode having p+ active area of 1cm x 1cm on high-resistivity n-type FZ (float zone) silicon wafer. The process sequences to fabricate the diode are shown in Fig. 1.

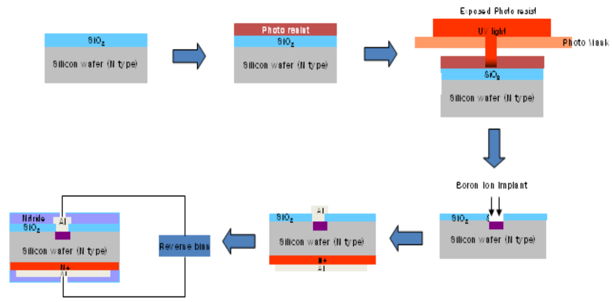

Fig. 1 Fabrication process flow chart of the silicon PIN diode.

The capacitances and leakage currents of the fabricated diode were measured with HP 4277A LCZ meter and Keithley 6517 picoameter as a function of reverse bias voltages, respectively. The measurement results are shown in Fig. 2. The capacitance levels showed flatness above 30 volts as expected theoretically from the resistivity of the wafer [4]. To be used for the SNR measurement by using a proton beam, we required that the leakage current of the sensor should be less than $10nA/cm^2$ at the operation voltage.

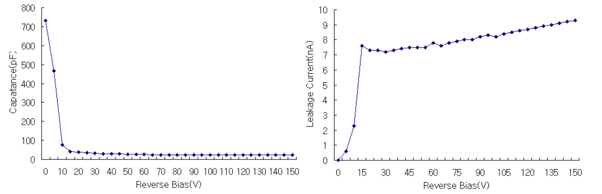

Fig. 2 Capacitance and leakage current measurement results of the silicon PIN diode as a function of reverse bias voltages.

3. Proton Beam Test

3.1 Signal-to-Noise Ratio Measurement

The SNRs of the diode were measured by using a proton beam. Figure 3 shows the experimental set up for the SNR measurement with a proton beam. Experiment was performed at room temperature and 46 volts was biased to fully deplete the sensor. For the trigger purpose, we used the other silicon PIN diode (which is called as "trigger sensor").

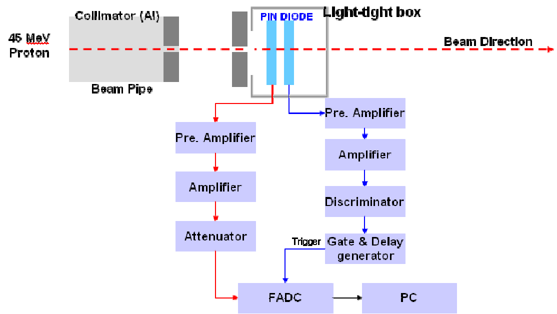

Fig. 3 Experimental setup for SNR measurement of the silicon PIN diode with a proton beam at the KIRAMS.

A 25MHz USB2 based home-made Flash Analog to Digital Converter (FADC) board has one analog input, one trigger input and one output. An analog signal from the silicon PIN diode was connected into the analog input of the FADC board via a preamplifier, an amplifier and an attenuator. A signal from the trigger sensor was connected into the trigger input of the FADC board via a preamplifier, an amplifier, a discriminator and a gate and delay generator. The FADC outputs were recorded into a personal computer and data was analyzed with C++ based data analysis program [5].

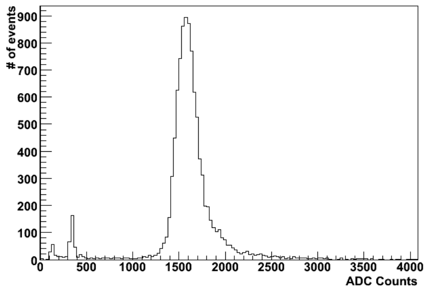

Fig. 4 The pulse height spectrum of the silicon PIN diode with the proton beam.

Figure 4 shows the measurement result and the SNR of the PIN diode was measured to be 20.8 after corrected for the minimum ionizing particle.

3.2 Radiation Damage Study

The different PIN diode sensor which has relatively high leakage current values was used with the same proton beam for radiation damage test. Figure 5 left plot shows the leakage currents as a function reverse bias voltages before irradiation (circle point), 10 min. later (square point) and six days later (triangle point) after irradiation, respectively

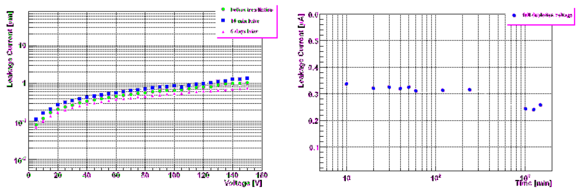

Fig. 5 The leakage current of the PIN diode before and after irradiation with a 45 MeV proton beam (left) and the leakage current distribution at full depletion voltage after annealing at 80 degree for 10 min. (rignt).

The prototype was irradiated with proton beam flux of 2 × 10^{12} and measurement showed the negligible effect in the leakage current. We expect the silicon sensor will be damaged at radiation hard environment [6] and the rate of damage decreases depending on the temperature at which the silicon is kept during the waiting period [7]. We annealed the PIN diode after irradiated the proton beam and measured the leakage current dependency on the times at full depletion voltage. Figure 5 right plot shows the leakage current values at full depletion voltage after annealing at 80 degree for 10 min.

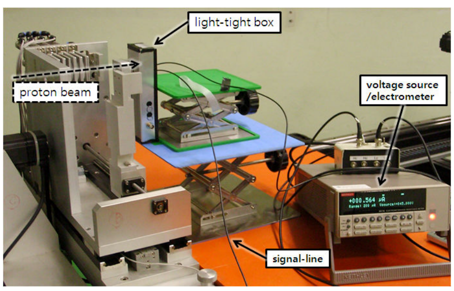

Fig. 7 Experimental set up for current monitoring of silicon PIN diode.

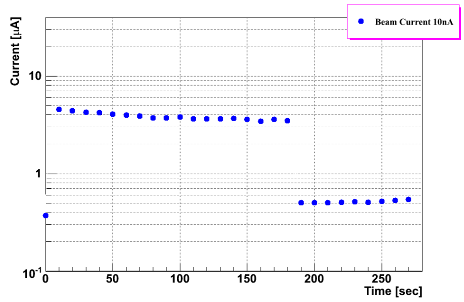

Fig. 8 The current was measured as the silicon diode was exposed to the proton beam. The region of high current indicates the beam was on.

To see changes in the current when the sensor was exposed to the proton beam, we monitored the currents of the sensor in real time. Figure 7 shows the proton beam monitoring system and Fig. 8 shows the result of the proton beam monitoring. About factor of 10 increase in the current was observed when the diode was exposed to the proton beam.

4. Conclusions

We designed and fabricated silicon PIN diodes on 5-in. high resistivity, <100> n-type, and 380 μm-thick silicon wafer and the active area of the diode is 1 cm x 1 cm. For the sensor performance test, we required that the fabricated sensor should be fully depleted at the operation voltage and the leakage current of the sensor should be less than 10 nA at the operation voltage. The silicon diode was exposed to a 45 MeV proton beam from the MC-50 cyclotron at the Korea Institute of Radiological and Medical Science (KIRAMS) in Seoul. The signal-to-noise ratio (SNR) of the PIN diode was also measured with the proton beam to be 20.8 after corrected for the minimum ionizing particle. The prototype was irradiated with 2 x 10^{12} proton fluence but we did not observe a significant increase in the total leakage current for the sensor. By introducing the proton beam to the silicon sensor, we observed increase of about a factor 10 in the leakage current. The silicon sensor can be used in the proton beam monitoring system at moderate radiation environment.

REFERENCES

[1] P. Rehak, "Silicon Radiation Detectors" *IEEE* Trans. Nucl. Sci. **51**, 5, 2492 (2004).
[2] Jong-Moon Park et al., *JKPS*, Vol. **51**, 10 (2007).
[3] www.kirams.co.kr
[4] G. Lutz, Semiconductor Radiation Detector, Springer, New York, pp 101-102, 1999.
[5] H.J. Hyun et al., "Performance Study of the Silicon Strip Detector" *Conf. Rec. 2006 IEEE Nuclear Science Symp.*, (2006)
[6] H.J. Hyun et al., KJPS, Vol. **50**, 1548 (2007).
[7] G. Lutz, Semiconductor Radiation Detector, Springer, New York, pp 296-297, 1999.