Performance Test of Silicon PIN diode with Radioactive Sources

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1. Introduction

The silicon sensor has been developed and used in various areas due to its intrinsic high position resolution and fast speed of response for medical imaging sensors, radiation detectors, positioning detectors in space science and experimental particle physics. High technology, modern equipments and deep expertise are needed to design, develop and manufacture silicon sensor be top in quality.

Silicon PIN diodes with an active area of 1 cm × 1 cm were fabricated on a high resistivity, <100>-oriented, n-type, 380-um thick and 5-in. silicon wafer. These diodes were manufactured on purpose to monitor strip sensor fabrication processes. We measured the radiation detection responses of the silicon PIN diodes and observed photopeaks from radioactive sources, Am-241, Sr-90, and Cs-137. The spectrums of simulations were compared with those of the source tests to understand the measurement results. We present the energy resolution and the signal-to-noise ratio(SNR) [1] of the diode measured by using the radioactive sources.

2. Characteristic of silicon PIN diode

The silicon sensor can be fully depleted by applied reverse bias voltage [2]. One of advantages of full depletion is that silicon bulk can be used as an active sensor volume. When charged particles pass through the silicon bulk, electron-hole pairs are produced and electrons are collected in n-side and holes are collected in p-side by the electric field.

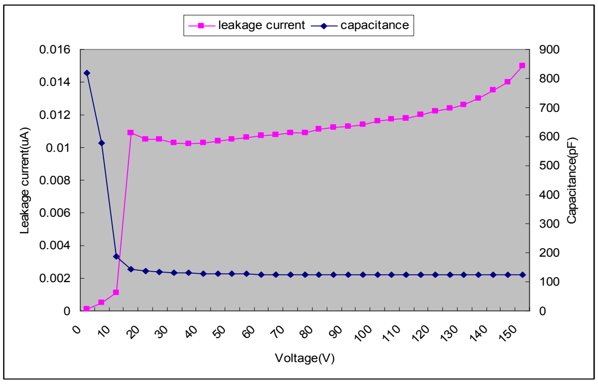

Figure 1. Electrical Characteristics of a silicon PIN diode with bias voltage variance. (Red line means leakage current in order of mA and blue line means capacitance in order of pF.

As we measured the characteristic of the silicon PIN diodes (N-type doped with boron), the reverse bias voltage for full depletion was determined to be over 20 volts in Figure 1. Therefore, we applied the reverse bias voltage of -40 volts to read 'hole' signal in fully depleted silicon PIN diode. [3, 4]

3. Readout system of silicon PIN diode test with radioactive sources

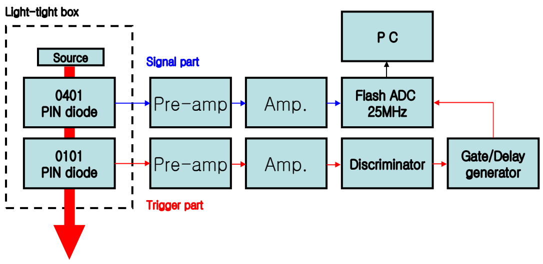

Figure 2. The readout schematic of silicon PIN diode test for radiation detection.

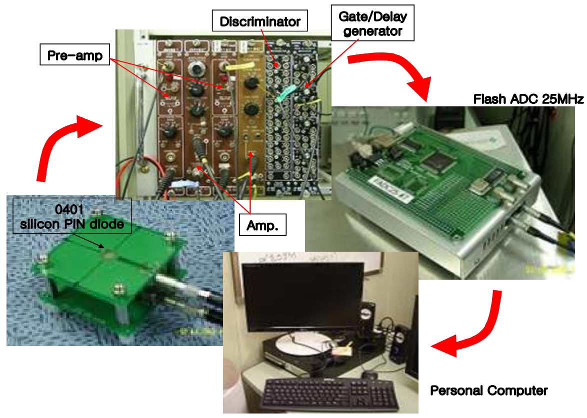

Figure 3. Experimental setup of silicon PIN diode test

The readout system consists of a pair of silicon PIN diodes, pre-amps and amplifiers, a gate/delay generator, a Flash ADC(Analog-to-Digital Converter) 25-MHz board, and a personal computer as in Figure 2.

Analog (current) signals from the silicon PIN diodes convert into voltage in each pre-amp, and the signals are increased by amplifiers with a gain of 20 and 3-μs shaping time. The discriminator and the gate/delay generator make the signal from the second PIN diode (0101) into a trigger signal. The amplified analog signal (0401) and the trigger signal are fed to 12-bit Flash ADC 25-MHz board. The digitized signal from Flash ADC board is taken and analyzed in a personal computer using ROOT, C++ based program [5]. Figure 3 shows a picture of the connection between equipments in the experiment.

4. Measurement and simulation results

Table I: Isotope table of Am-241, Sr-90, and Cs-137

Radioactive source	Radiation type & energy level		Decay probability (%)
	β, γ	keV	
Am-241	γ	11.9	0.86
	γ	13.9	13.3
	γ	17.8	19.4
	γ	20.8	4.9
	γ	26.3	2.4
	γ	59.5	35.9
Sr-90	β	546	100.0
Cs-137	γ	32	5.8
	γ	661	85.1
	β	514	94.4
	β	1,175	5.6

To characterize the performance of the silicon PIN diode, we measure the signal-to-noise ratio (SNR) and resolution using radioactive sources such as Am-241, Sr-90, and Cs-137. Table I shows the isotope table of Am-241, Cs-137, and Sr-90 sources.

The tests with Am-241 and Cs-137 sources actually use random trigger because γ fully deposits its energy in a silicon PIN diode. However, we use a trigger by the second PIN diode for Sr-90 as β source pass through a PIN diode.

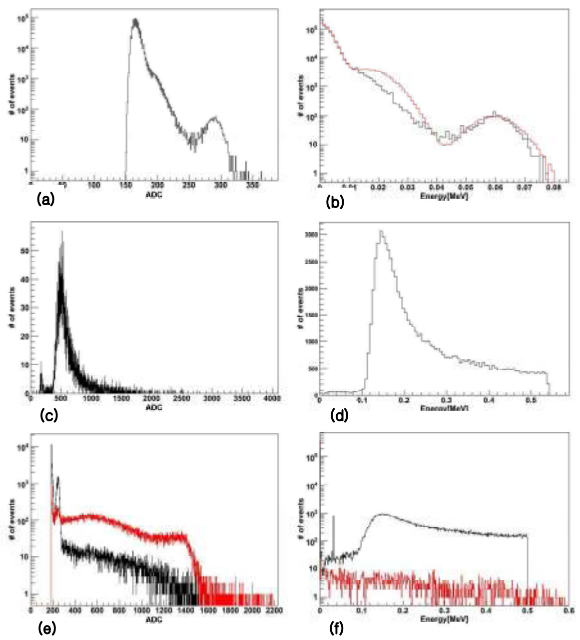

Figure 3. Results of the test and the simulation with radioactive sources. (a) Am-241 test with random trigger (b) Comparison of the real data (black line) and normalized simulation data (red line) of Am-241 (c) Sr-90 test with trigger from the second PIN diode (d) Simulation result of Sr-90 (e) Cs-137 test without collimator (red line) and with 3mm lead collimator (black line) (f) Simulation results of Cs-137, not included resolution smearing, without collimator (black line) and with 3mm lead collimator (red line)

For understanding the result, it is compared with Geant4 simulation [6]. The comparison is shown in Figure 4.

Am-241 test shows a sharp peak of 59.5 keV γ as we expected. The peak is used for calibration that converts ADC value into energy. The discrepancy around 10~20 keV energy level of Am-241 plot assumed to be due to the wider resolution in the low energy region (In the simulation, we used the resolution of the PIN diode at 59.5keV to smear whole energy region).

In the test of Sr-90, the SNR of the silicon PIN diode is measured to be 36.0. The distributions show similar shape.

We use Cs-137 source to compare a resolution at the lower energy level (32keV γ) with 59.5 keV γ. Two different conditions were set – without collimator and with 3mm lead collimator – to reduce β background. The test without collimator shows 32keV gamma peak and beta distribution exactly, but the test with 3mm lead collimator is observed that the beta distribution is clearly decreased. In the simulation of Cs137 with 3mm lead collimator, we cannot observe the peak of 32keV gamma, but an unknown peak around 30keV showed up in the real data. The unknown peak is expected to be an X-ray from lead (Pb), therefore more detail process is in progress.

5. Summary

A silicon PIN diode was designed, fabricated, and tested. The test with the radioactive sources and simulation is in progress to understand a fabrication performance of the PIN diode.

The signal-to-noise ratio of the silicon PIN diode was measured to be 36.0 with Sr-90, a β radioactive source. The test and the simulation with Am-241 and Cs-137 show the resolution of the silicon PIN diode in radiation detection. The result of Am-241 has different distribution at 10~20 keV energy level and the plots of Cs-137 show different results between the real data and the simulation. For understanding the results, another process such as using Si(Li) detector with radioactive source is also planned due to it’s good resolution.

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