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Optimization of Design of an AC-type Single-sided Silicon Strip Detector

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1. Introduction

Silicon detector has been widely used in a variety of fields due to high resolution of energy and position measurement and fast signal readout. Concept of silicon strip sensor, one of them, is obtained by splitting the large area sensor into small strips. It has been used for medical imaging, vertex detector, tracing particle trajectory, and so on.

We especially focus on AC-type single-sided silicon strip detector (SSSD) and study its patterning design. To optimize the sensors, width of p+ implant, presence of field shaper, and distance between guard-ring and edge are set to be as design parameters. SSSDs are designed with the various parameters and fabricated on n-type silicon wafer of 400 μm thickness.

We will present about the designed and developed SSSD, and the measurement results such as electrical characteristics and signal to noise ratio (SNR) of the fabricated sensors in this meeting.

2. Design and Fabrication

The SSSDs are fabricated on 6-inch, high resistivity (> 5 kΩ·cm), <100>, and n-type silicon wafers. The fabricated silicon sensors have basically PIN diode structure, which is n-type silicon substrate doped with p or n-ion on each side. Each SSSD has 32 strips on p-side and ohmic contact on n-side. The strip is composed of metal on the implant, p-ion doped area. A reverse bias voltage is applied to the sensor and then depleted region is formed. The electron-hole pairs that are created in this depletion region along the path of a charged particle are separated by applied reverse voltage. The position of passage of the charged particle is obtained by the location of the strips showing signals. The strip pitch is 730 μm for all designed sensor types and they are AC-type sensors that include coupling capacitor (CC) and biasing resistor. The capacitor is made by separating implantation strips and metallization strips by a thin oxide layer. The high ohmic biasing resistor can be made in polysilicon. The drawing of AC-type sensor design is shown in Fig. 1.

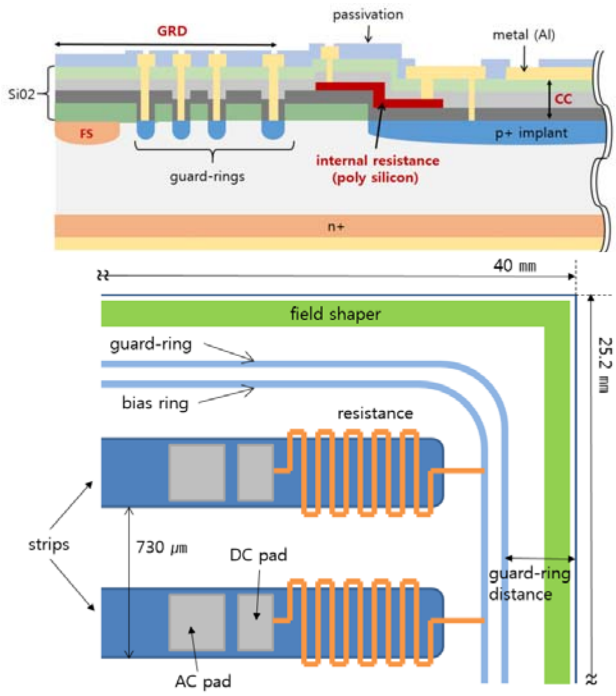

Fig. 1. Cross sectional view (top) and top view (bottom) of AC-type single-sided silicon strip detector.

Designed sensor types are split by three parameters as i) ratio of implant width to the strip pitch (I/P), ii) presence of field shaper (FS) and iii) guard-ring distance (GRD). At first, values of I/P are distinguished as 0.1, 0.2 and 0.4. These refer to *T. Osugi et al.* [1]. Because the strip pitches of all designed sensor types are same, the width of an implant would be considered as a design parameter instead of the I/P. It is set to be 80 μm, 150 μm and 300 μm. The FS parameter means that there is FS structure in the sensor or not. The FS is n-ion doped area on edge of the sensor to suppress leakage current from the edges. The other is GRD describing distance between the edge and the innermost guard-ring (Fig. 1). Except for A-3 sensor type that has smaller FS area and shorter GRD, the GRDs of the other type sensors are same. Therefore size of the sensors is 40.0 mm x 25.5 mm but that of A-3 is 38.0 mm x 23.5 mm. The detailed values of the design parameters are summarized in Table I.

Table I. Design parameters

Sensor #	Ratio of implant width to strip pitch	Width of implant [μm]	Guard-ring distance [μm]	Field shaper [μm]
A-1	0.4	300	1000	400
A-2	0.4	300	1000	none
A-3	0.4	300	500	50
B-1	0.1	80	1000	400
B-2	0.1	80	1000	400
C-1	0.2	150	1000	400
C-2	0.2	150	1000	400

3. Performance Tests and Results

3.1 Electrical Characteristics

Electrical characteristics such as leakage current and bulk capacitance determine quality of the fabricated silicon sensors. Leakage current is a kind of noise and smaller value is good. Usually, below 100 nA/cm^2 is good enough to get larger SNR and to detect minimum ionizing particle (MIP) signal. It is determined that the sensor is fully depleted from the bulk capacitance measurement.

The leakage current and bulk capacitance are measured with Keithley 6517A electrometer and HP 4277A LCZ meter as a function of reverse bias voltages, respectively, and the results such as current-voltage (IV) and capacitance-voltage (CV) would be reported. Capacitance fundamentally is given by Eq. (1). The relation of bias voltage and the depletion depth is known as Eq. (2) [2].

$$C = \varepsilon\varepsilon_0 \frac{A}{d} \quad (1)$$

$$d = \sqrt{2\varepsilon\varepsilon_0 \mu_e \rho (V_0 + V_{bias})} \quad (2)$$

- C : capacitance
- ε : relative permittivity of Si
- ε_0 : vacuum permittivity
- A : area of the sensor
- d : depletion depth at full depletion voltage
- μ_e : mobility of the electron
- ρ : resistivity of the silicon wafer
- V_0 : contact potential
- V_{bias} : applied reverse voltage

From Eq (1) and Eq (2), Eq. (3) in below is driven.

$$\frac{1}{C} \prec d \prec \sqrt{V_{bias}} \quad (3)$$

Fig. 2 shows IV and CV of 1 cm x 1 cm PIN diode. The inverse capacitance is squared to find the full depletion voltage, ~ 40 V, which is consistent with expectation as shown from Eq. (1) to Eq. (3). And operating voltage is determined to be 100 V. The leakage current at operating voltage is under 5 nA/cm^2. The measurements for all designed strip sensors are ongoing and the results will be reported in this meeting.

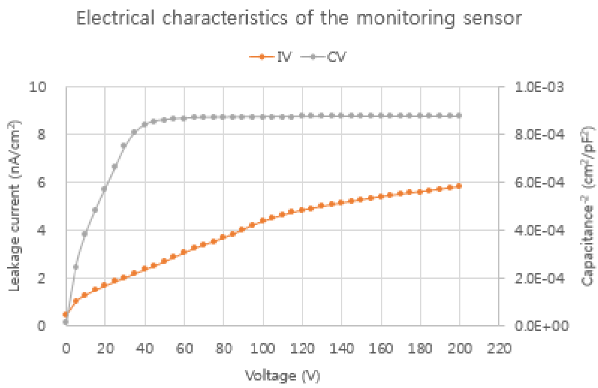

Fig. 2. Electrical characteristics, such as leakage current (orange) and inverse of the squared capacitance (gray) of the fabricated 1 cm × 1 cm PIN diode sensor.

3.2 Signal to Noise Ratio

There are many ways to show ability of detection. Among them, SNR is measured by using ^{90}Sr radioactive source and 1 cm x 1 cm PIN diode sensor, which is located on the fabricated wafer and used for investing the fabrication process.

Experimental setup for the SNR test is shown in Fig. 3. External trigger is used to clarify signals. A photo PIN diode sensor with 1 cm x 1 cm is used as a trigger sensor. This has the same size with the PIN diode signal sensor. The test is done with commercial electronics. The bias voltage (100 V) is directly supplied to the sensor by high voltage (HV) power supply. When the sensor is fully depleted, the beta rays from ^{90}Sr make signals of electron-hole pair in full depletion region. The signal of PIN diode and trigger sensor each passes through preamplifier, amplifier, and flash ADC (FADC) and ADC data of PIN diode is stored when the beta ray penetrates both PIN diode and trigger sensor.

Fig. 4 shows signal and pedestal distributions. The most probable value (MPV) of the signals is given to be 615.7 by fitting with landau function. The mean and sigma of the pedestal distribution are shown to be 120.5 and 5.083, respectively. From this results, SNR is calculated to be 97.42. It's enough to make distinction of signals because SNR is needed over 5 for MIP detecting.

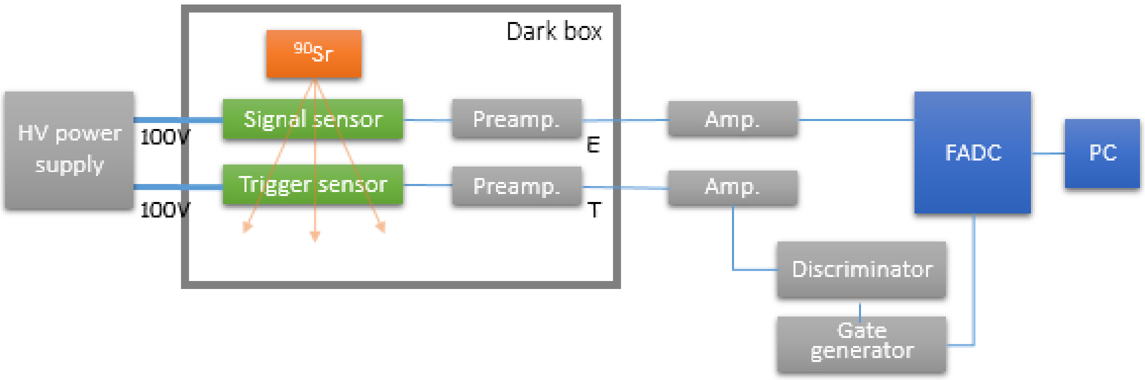

Fig. 3. Experimental setup for SNR measurement using ^{90}Sr radioactive source.

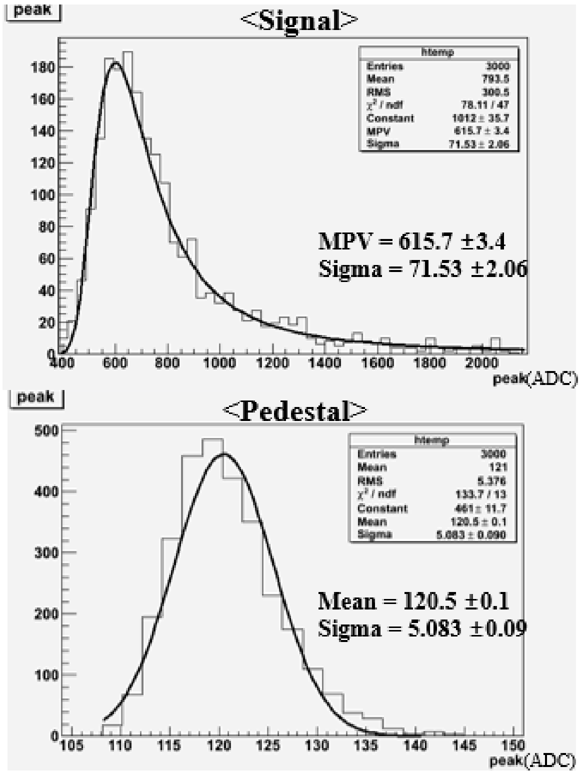

Fig. 4. Signal and pedestal distributions are obtained from the SNR measurement.

3. Conclusions

AC-type SSSDs are designed and fabricated with three design variables. Electrical characteristics measurement results of the PIN diode shows that the quality of the fabricated sensor is comparable to that of Hamamatsu and there is no critical defects during the fabrication process. The SNR of the PIN diode is measured to be 97.42 with commercial electronics. It is clear that the measured performance of the PIN diode is very excellent even if we use a home-made electronics. The performance tests of the designed and fabricated strip sensors are ongoing and the results will be presented in this meeting.

REFERENCES

[1] T. Ohsugi et al., “Design optimization of radiation-hard, double-sided, double-metal, AC-coupled silicon sensors”, Nuclear Instruments and Methods in Physics Research A, 436 (1999) 272-280

[2] W.R. Leo, Techniques for Nuclear and Particle Physics Experiments:a how to approach, (Springer-Verlag, Berlin, 1994), p.224.