Performance Test Results of a Single-sided Silicon Strip Detector with a Radioactive Source and a Proton Beam

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1. Introduction

Due to high intrinsic precision and high speed properties of a silicon material, the silicon detector has been used in various applications such as medical imaging detector, radiation detector, positioning detectors in space science and experimental particle physics. High technology, modern equipments, and deep expertise are required to design and fabricate good quality of silicon sensors. Only few facilities in the world can develop silicon sensors which meet requirements of sensor performances. That is one of main reasons that the silicon sensor is so expensive and it takes time to purchase the silicon sensor once it is ordered.

We designed and fabricated AC-coupled single-sided silicon strip sensors and developed front-end electronics and DAQ system to read out sensor signals. The silicon strip sensors were fabricated on a 5-in. n-type silicon wafer which has an <100> orientation, high resistivity (>5 kΩ·cm) and a thickness of 380 μm.

We measured the signal-to-noise ratio (SNR) of each channel by using a radioactive source and a 45 MeV proton beam from the MC-50 cyclotron at the Korea Institute of Radiological and Medical Science (KIRAMS) in Seoul. We present the measurement results of the SNRs of the silicon strip sensor with a proton beam and radioactive sources.

2. Concepts of a Single-sided Silicon Strip Detector

The silicon sensor is fully depleted by applying a reverse bias voltage.[1)] One of advantages for the full depletion is that silicon bulk can be used as the active sensor volume. When charged particles pass through silicon bulk, electron-hole pairs are produced and electrons are collected in electrodes by the electric field. The high resolution of the silicon strip detector is achieved by dividing large area diode into many small strips and reading charge signals out separately. The position of the charged particle is then determined by the location of the strip showing signal.

A specification of the fabricated silicon strip sensors is shown in **Table 1**. The sensor is single-sided and has 64 channels with a 500 μm pitch, and the active area is 3.2 x 3.2 cm^2 with a thickness of 380 μm.

high resistivity (> 5 kΩ·cm), <100>-oriented, and n-type silicon wafers	
sensor area (μm^2)	35,000 × 35,000
sensor thickness (μm)	380
strip pitch (μm)	500
number of implanted strips	64
implanted strip width (μm)	400
readout strip width (μm)	420

Table 1 A specification of the fabricated AC-coupled single-sided silicon strip sensor.

The designed and fabricated silicon strip sensor has capacitively coupled readout structure which provides the advantage of shielding the electronics from sensor leakage current. In AC-coupled sensor design, capacitances of a sensor were made by separating implantation and metallization of the strips. Meanwhile, biasing resistors of a sensor were made in polysilicon. A thickness of the SiO_2 layer, width and thickness of the polysilicon were optimized to provide required capacitance and biasing resistance, respectively. The DC pads were also built for leakage current measurement.

Design, fabrication process and electrical characteristics measurements of the fabricated AC-coupled silicon strip sensors are described in detail by Kah et al.[2)]

To be considered as a good sensor, we required the leakage current of the sensor should be less than 10 nA/strip at the full depletion voltage. The leakage current of a single strip was measured[6)] to be about 1.4 nA at 60 volts and the capacitance value showed flatness from above 40 volts.

Two low noise analog ASICs, VA1 chips, were used for analog signal readout. We depleted VA Hybrid board, VA Interface board, and VA Control board[3)] to read sensor signal out. The serially clocked signals of 64 channels were read out for each event with a 12-bit 64 MHz Flash analog-to-digital converter (FADC).[4)] The FADC was located in a VME crate and was read out by the Linux-operating PC through the VME-USB2 interface. The DAQ system and analysis program were written in the framework of ROOT[5)] package.

3. Radioactive Source and Proton Beam Test of Silicon Strip Detector

We used the AC-coupled silicon strip detector to measure the SNRs of the 64 readout channels with a radioactive source and a proton beam. **Figure 1** shows the photograph of inside of the Al light-tight box. Experiment was performed at room temperature and sensor was biased at 46 volts to fully deplete the sensor.

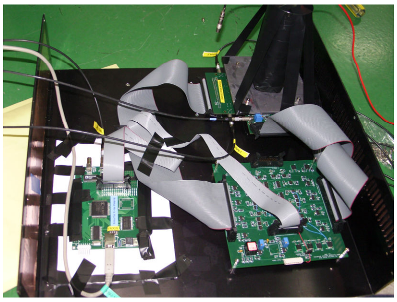

Fig. 1 Inside of the Al light-tight box which has single-sided silicon strip sensor and readout electronics assembly.

A CsI(Tl) scintillation crystal and a 2-in. photomultiplier tube were used to trigger signal events. The silicon strip sensors, readout electronics and a CsI(Tl) crystal are all assembled in an aluminum light-tight box to shield light and reduce electromagnetic interference.

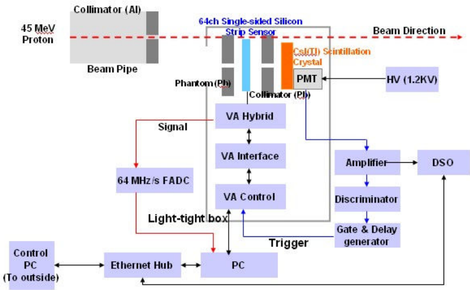

Fig. 2 Experimental setup for performance tests of the manufactured silicon strip detector with a proton beam at the KIRAMS. Sensor assembly is placed off the beam axis to protect the sensor from radiation damage.

Two VA1 chips were used to read signals, each of them controlled 32 channels. Sensor signals from the FADC were recorded in the PC and were analyzed. The experimental set up is shown in **Fig. 2**.

Figure 3 shows the pulse height spectrum with a proton beam, which has a pedestal and a signal peak. A bread distribution in the lower side of the pedestal is due to cross talk comes from closely spaced signal traces on PCB and it is estimated 3~5%. The signal-to-noise was measured to be 29.1 ± 2.2 for a MIP.

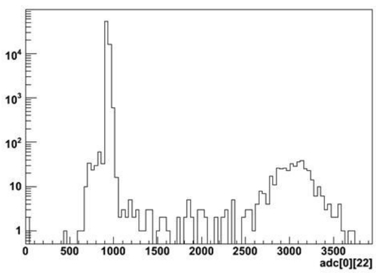

Fig. 3 Pulse height spectrum of a single strip channel measured with a proton beam.

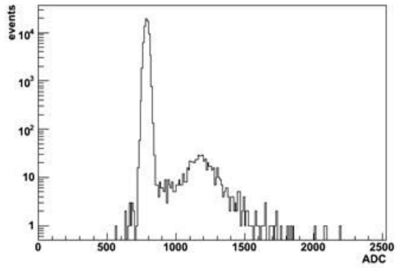

Fig. 4 Pulse height spectrum of a single strip channel measured with a ^{90}Sr radioactive source.

We also performed the SNR measurement by using a ^{90}Sr radioactive source with the same experimental setup as the proton beam test. **Figure 4** shows the pulse height spectrum measurement of a single strip channel and a signal-to-noise is measured. The signal-to-noise was measured to be 26.4 ± 0.327 for a MIP and this result is consistent with the proton beam test result.

4. Conclusion

The AC-coupled single-sided silicon strip sensors were designed and fabricated on the 5-in. silicon wafers. The front-end electronics was built for sensor signal readout and assembled with the fabricated silicon strip sensors in the Al light-tight box.

The signal-to-noise ratio of the silicon strip sensors with readout electronics was measured with a proton beam and a radioactive source. The SNR with a 45 MeV proton beam at the KIRAMS was measured to be better than 25 for a MIP and the detail analysis with a ^{90}Sr radioactive source is in progress. Our experiment showed that the measurement results of the SNR of the silicon detector and electronics assembly can provide the feasibility of using it as a X-ray imaging sensor.

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