Fabrication and performance test of the silicon photo-strip detector coupled with a crystal scintillator

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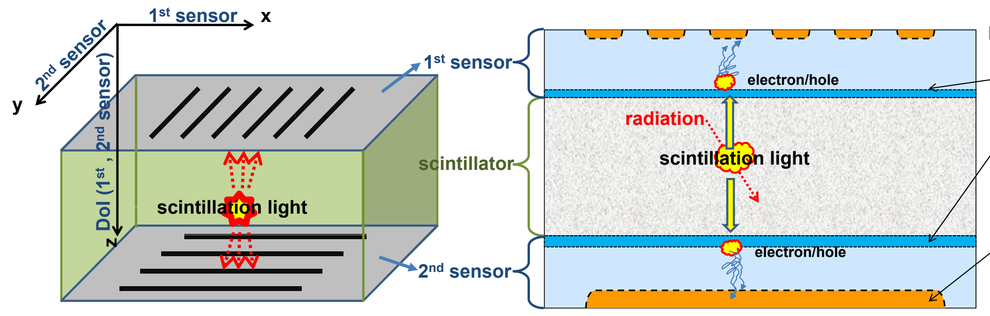
We develop a silicon photodetector coupled with a crystal scintillator. The silicon photo-strip detector consists of a single crystal and two silicon photo-strip sensors. The photo-strip sensor is designed and fabricated based on concept of a AC-coupled single-sided silicon strip sensor but the incident layer of the strip sensor is modified to detect scintillation light. The two photo-strip sensors sandwiching opposite face of one crystal scintillator are oriented orthogonal to each other. When a particle enters a crystal, the scintillation light is emitted and converted into electron-hole pairs in the silicon photo-strip sensors. This detector configuration provides the two-dimensional position information and a depth of interaction by measuring signal ratios between the first and second photo-strip sensors. This detector concept can be applied in radiation, medical applications and nuclear medical cameras.

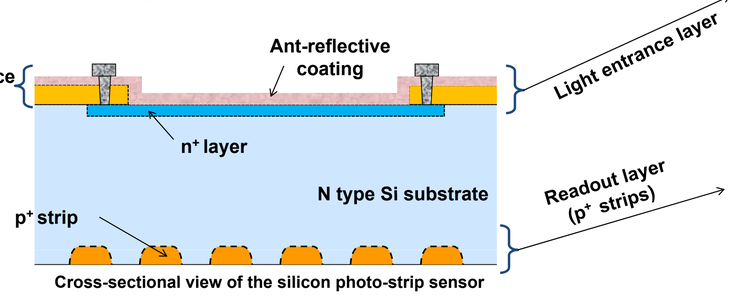
Concept of the detector

- **One crystal scintillator + two photo-strip sensors**
  - Two sensors sandwiching opposite faces of a scintillator are oriented orthogonal to each other
  - The detector provides position information in an x, y, z coordinate
  - A depth of interaction by measuring signal ratios between the first and second photo strip sensors
  - The device may be applied in radiation application, medical application, and nuclear medical cameras

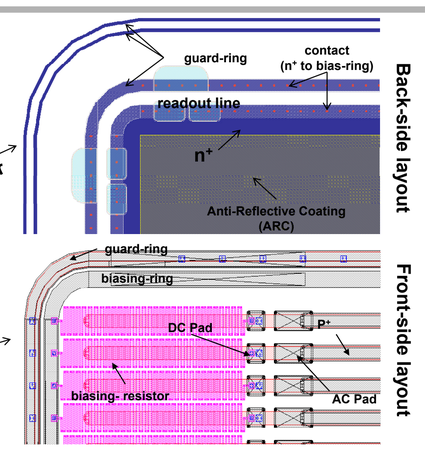


Conceptual drawing of the detector

- **Light entrance window**
  - This is one of key features for the detection of light in the strip sensor
  - The thickness of n^+ doping layer has to be as thin as possible for minimum dead layer
  - Anti-reflective coating is formed by stacked dielectric layer with appropriate thickness



Cross-sectional view of the silicon photo-strip sensor



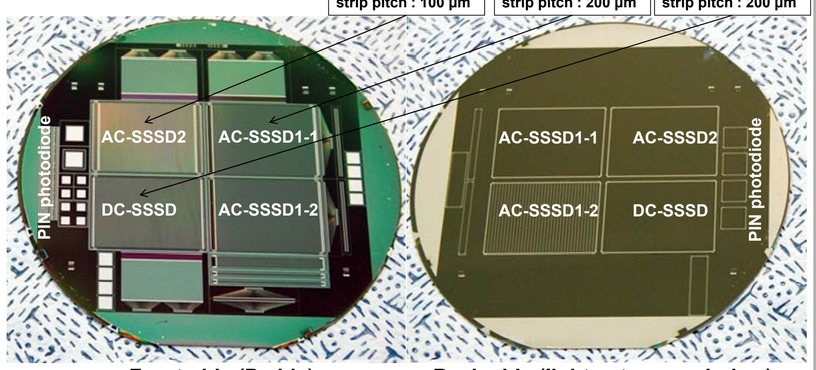
- **AC-coupled readout strip channels**
  - Providing position information of the scintillation light
  - Shielding the electronics from leakage current
  - Coupling capacitors are made by separating implantation and metallization
  - Biasing resistors are made of poly-silicon

- **Photo-masks design**
  - A total of 6(front-side)+4(rear-side) mask are necessary to fabricate the sensor
  - DC pad is need to measurement for electrical characteristics such as leakage current, coupling capacitance and biasing resistance
  - AC pad is needed for signal readout

Fabrication of the photo-strip sensor

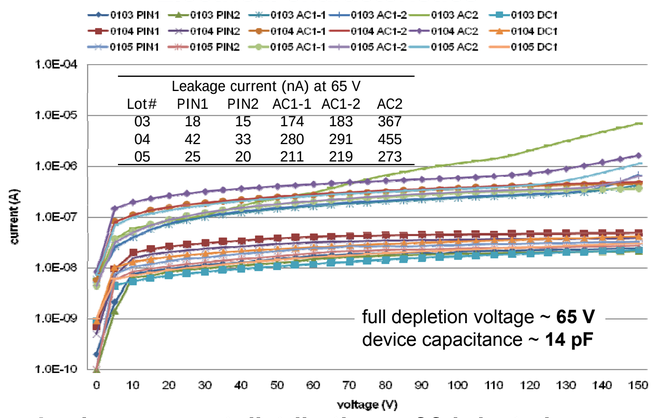
n-type ,<100>-oriented, high resistivity, 380 μm thick, 5-inch Si wafer

AC-SSSD2	AC-SSSD1	DC-SSSD
area : 38 x 28 mm²	area : 38 x 28 mm²	area : 38 x 28 mm²
readout strips : 256	readout strips : 128	readout strips : 128
strip pitch : 100 μm	strip pitch : 200 μm	strip pitch : 200 μm



Front-side (P-side) Back-side (light entrance window)

Electrical characteristics

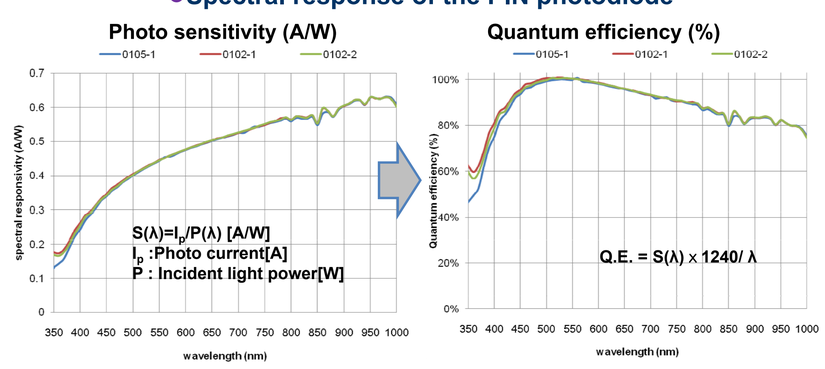


Leakage current (nA) at 65 V

Lot#	PIN1	PIN2	AC1-1	AC1-2	AC2
03	18	15	174	183	367
04	42	33	280	291	455
05	25	20	211	219	273

Leakage current distributions of fabricated sensors

Spectral response of the PIN photodiode

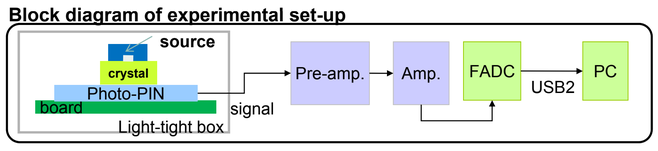


Spectra-photometry test at Korea Research Institute of Standards and Science

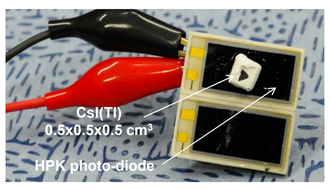
Developed sensors show good photo sensitivity
- 460 ~ 660 nm > 95 % Q.E.
- 490 ~ 580 nm > 99 % Q.E.

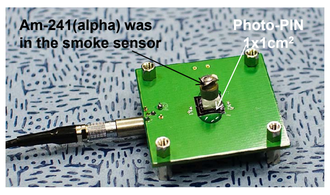
PIN photodiode coupled with the CsI(Tl) crystal

Block diagram of experimental set-up



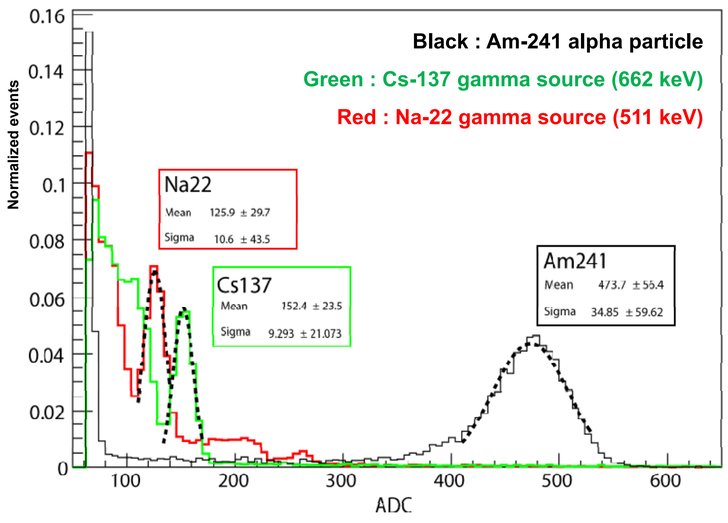
Comparison with commercial(HPK) photodiode



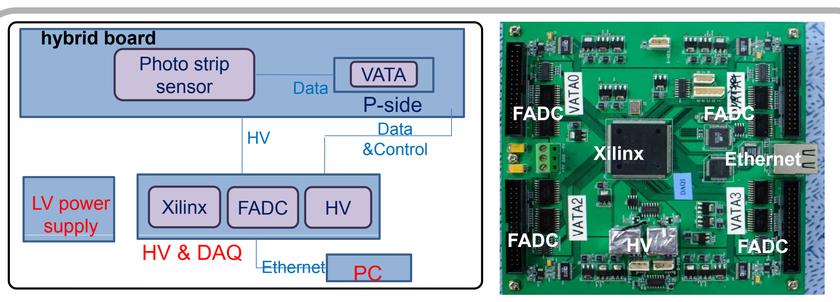


item		KNU	HPK
Current (nA) @ 100V		19.2	5.4
Capacitance (pF) @ 100V		104	105
pedestal	Mean (ADC)	43	48
	Sigma (ADC)	5	8
Am-241 (alpha)	Mean (ADC)	474	479
	Sigma (ADC)	34	41
Na-22 511keV	Mean (ADC)	126	134
	Sigma (ADC)	11	13
	Energy resolution at FWHM	**20.5%**	**22.8%**
Cs-137 662keV	Mean (ADC)	153	162
	Sigma (ADC)	9	11
	Energy resolution at FWHM	**13.8%**	**16.0%**

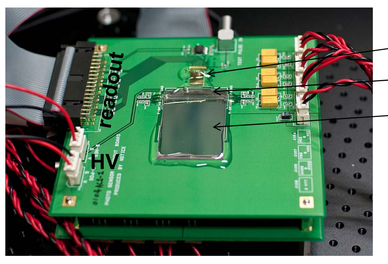
Pulse height distributions with various radioactive source



Front-end electronics and DAQ system



Schematics of the electronics and Picture of the home-made DAQ board

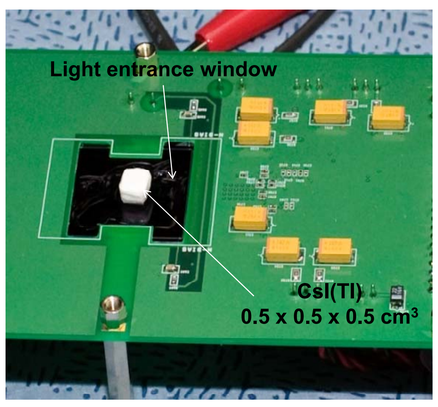


- *VATA analog chip
- pitch adaptor
- Photo-strip sensor

*VATA : 128 channels a low noise charge sensitive preamplifier, a shaper, and a sample and hold for each channels, multiplexed analogue readout and common wire-or'ed trigger output

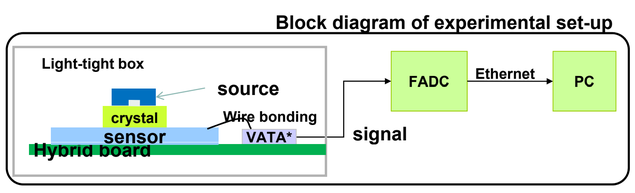
Performance test results of the photo-strip sensor with readout electronics

The photo-strip sensor coupled with the CsI(Tl)

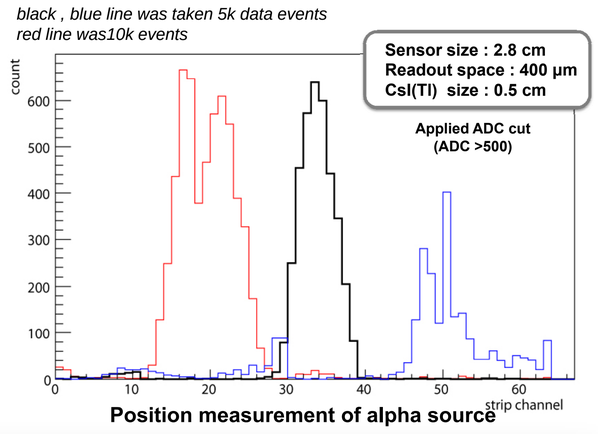


Pictures of the CsI(Tl) coupled fabricated sensor on the hybrid board

Block diagram of experimental set-up

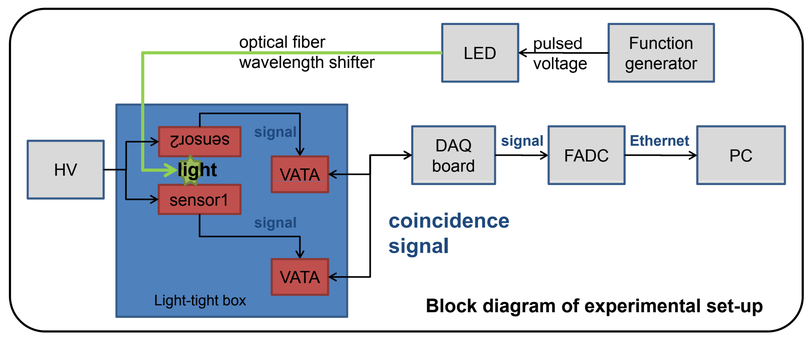


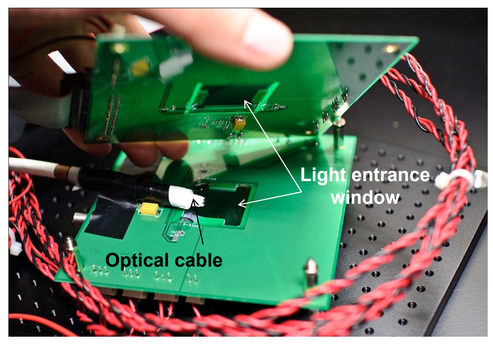
black , blue line was taken 5k data events
red line was10k events



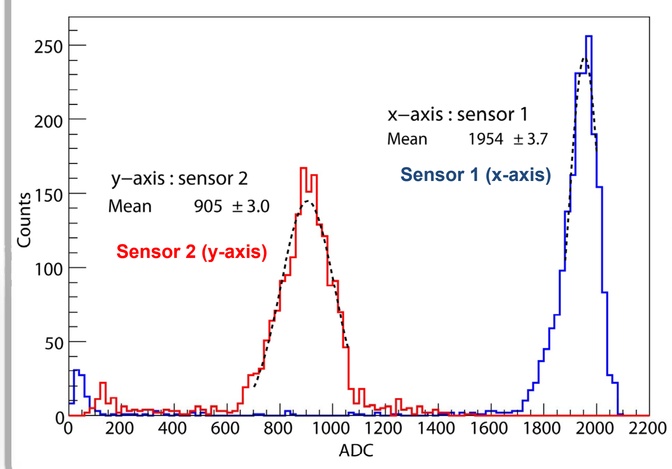
Position measurement of alpha source

Reconstruction of 2D position information by using the LED source

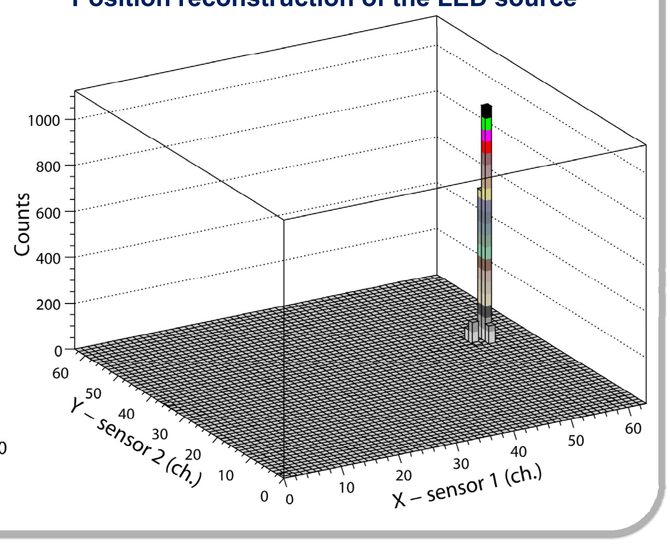




Pulse height distribution of two photo sensors



Position reconstruction of the LED source



Summary

- **Silicon photo-strip sensors are developed**
  - –Strip pitch 100/200 μm / Channel : 256/128
  - –PIN photodiode
- **Fabricated sensors show good electrical characteristics**
  - –Depletion voltage = 65V
  - –Leakage current < 2nA/strip
- **Sensors show good photo sensitivity**
- We measured the signal of the fabricated photo sensor coupled with CsI(Tl) crystal using several radioactive sources
  - – **Energy resolution : 13.8% (611 keV, gamma-ray)**
- The readout electronics is tested with the photo-strip sensor
- **The photo-strip detector provides 2 dimensional position information**

PLAN
- From 2D position results, we can also obtain the interaction point of LED by pulse height distribution of two photo sensors
- Plan for imaging test with a CsI(Tl) crystal

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