Development of Double-sided Silicon microstrip Detector

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Motivation

Design Philosophy

Intermediate/Front Tracker (LD)

Large/Huge View
- maximize $BL^2$
  - relatively moderate magnetic field
  - large inner length of ECAL
  - plays as intermediate trackers
  - provide $dE/dx$ measurement

Main/Front Tracker (SD)

SiD View
- compensate for a smaller measurement length with
  - improved spatial resolution and
  - higher magnetic field
Motivation

Numbers of Silicon Sensor

Based on this concept, a total of silicon area is about 56m². This means we need about 6000 wafers for the silicon sensor based on 4 inch wafer.

Wafer size: 10 x 10 cm² (4 inch)
Number of Wafers: 6000 (incl. spares)
Motivation

Applications of Silicon Sensor

Medical Imaging

Diffraction Sensor for Bio-Structure

Specialized Sensor

Non-destructive Sensor

Space science Technology Sensor
Introduction

Working Principle

(Carrier Generation & Transport)

[ Carrier (e/h pair) Generation in Semiconductors ]

1. Thermal
2. EM-Radiation (Photon)
3. Charged Particles

[ Carrier Transport ]
Carrier (e/h pair) split by E-field
: Drift Current
**Introduction**

**Working Principle (Why do apply Reverse bias?)**

- **Zero Bias**: Thermal equilibrium
- **Reverse Bias**: depletion region is induce potential barrier larger than zero bias, no current
- **Forward Bias**: depletion region is reduce flow current

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**[Space charge region for Bias ]**

- **Zero Bias**: Thermal equilibrium
- **Reverse Bias**: depletion region is induce potential barrier larger than zero bias, no current
- **Forward Bias**: depletion region is reduce flow current

**[Glossary]**

- **Space charge region**: net charge density due to ionized donors in n-region and ionized acceptors in the p-region
- **Depletion region**: another term for space charge region

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To increase the width of the depletion layer to make silicon bulk as sensitive detector volume,
Introduction

Working Principle of DSSD

Advantage of Double-sided microstrip Detector

- Two Dimensional position information
- Good sensitivity and High speed of response
- High resolution: Larger signal current than ionization chamber
The sensor has the double metal structure for readout signal to reduce the multiple coulomb scattering due to material budget.
**Introduction**

**DSSD Parameters**

<table>
<thead>
<tr>
<th>LIST</th>
<th>DC – TYPE</th>
<th>unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p+ side</td>
<td>n+ side</td>
</tr>
<tr>
<td>Sensor size</td>
<td>55610 X 29460 (include sawing line)</td>
<td>μm</td>
</tr>
<tr>
<td>Wafer thickness</td>
<td>380</td>
<td>μm</td>
</tr>
<tr>
<td>pitch</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>readout trace pitch</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>implant strip #</td>
<td>511</td>
<td>511</td>
</tr>
<tr>
<td>number of readout</td>
<td>511</td>
<td>511</td>
</tr>
<tr>
<td>strip length</td>
<td>25600</td>
<td>51072</td>
</tr>
<tr>
<td>strip width</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

The pitches of the sensors are 50 μm and 100μm for n-side and p-side. But the readout pitches are the same for the n-side and p-side. Sensors have 511 readout channels on each side.
Fabrication of DSSD

Introduction

F# \rightarrow n+ side
B# \rightarrow p+ side
n-side : 5 Mask
p-side : 6 Mask
Introduction

DSSD Prototype

n+ implanted
p-stop in atoll

readout pad in staggering

p+ implanted
readout strip
via in hourglass

guard ring

N side

P side
Introduction

P-Stop Structure

Problem: electrical shortening
SiO₂ has Positive Charge, so makes electron accumulation layer

Solution: P-Stop structure

P-Stop

N-Strip
Electrical Test of DSSD
Method for Sensor Measurement

This measurement will provide us information of the bulk characteristics of the sensor. These drawings and photos show the way how we measure electrical properties of our fabricated sensor.
Electrical Test of DSSD

Sensor Measurement Devices

The Auto Test System controls the measurement device and stores all results in a computer.
Electrical Test of DSSD

Cleaning room

Wedge bonder is used for the connection between sensor and hybrid board.

All of measurement are done in a cleaning room and fabricated silicon sensor are stored in the desiccator.
Electrical Test of DSSD

1. 1st Run Fab Out Sensor Result

- Several failed strips
- P-strip Leakage  
  ~ 1nA/strip @100V
- P-strip Guard Ring  
  ~1mA/sensor @100V

The leakage currents of many silicon strip are about 1nA up to 100 V but leakage current level of silicon bulk (sensor) is about 1mA due to several failed strips which draw high leakage current. This tells us how hard to make all of strips have small leakage current of about 1nA.
Electrical Test of DSSD

2. Test Run for Optimization of Fabrication

(a) Oxide Only I-V Test
- Oxide Only
  - Several failed strips
  - P-strip Leakage: 3 ~ 10nA/strip @100V

(b) Oxide + Nitride I-V Test
- Oxide + Nitride
  - P-strip Fail: Nothing
  - P-strip Leakage Variation

To protect sensor, we added nitride in the fabrication process.
Electrical Test of DSSD

3. 3rd Run Fab-Out Sensor Result

(a). I-V Test

(b). C-V Test

Optimize Fabrication for DSSD
Oxidation / Nitride

IV test Result
• P-strip Fail : NOTHING
• P-strip Leakage : 8 ~ 50nA/strip @100V
• P-Guard-ring Current ~ 1uA @ 100V

CV test Result
• Fully Depletion Voltage : ~100V
• Operating Voltage : 120V
We used Sr-90 beta source for our source test. At this time we did not use any electric hybrid board for this test since we are still developing hybrid board. After we applied bias voltage to sensor, we tried to see sensor response to beta source on the oscilloscope.
Source Test of DSSD

Our result shows that peak itself is better than Hamamatsu's photo diode but noise level is worse than Hamamatsu's. We are planning to do signal-to-noise (S/N) test in this month.
Radiation Damage Test - introduction

35MeV Proton Beam
Test for Radiation Hardness of DSSD
$10^{12}, 10^{13}, 10^{14}, 10^{15}$ [number of proton/cm$^2$]
Radiation Damage Test - introduction

Displacement damage function

For Silicon

100 MeVmb = 2.14 keV cm²/g

The dE values of the proton is the almost same as that of the neutron for this beam energy range.
Radiation Damage Test - introduction

1. Log table

<table>
<thead>
<tr>
<th>Target (number of proton/cm²)</th>
<th>Sensor</th>
<th>Average Current</th>
<th>Number of Proton</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{12}$</td>
<td>C3T3</td>
<td>2.78 nA, 63sec</td>
<td>$1.08 \times 10^{12}$</td>
</tr>
<tr>
<td>$10^{13}$</td>
<td>G5T2</td>
<td>10.24 nA, 125sec</td>
<td>$8 \times 10^{12}$</td>
</tr>
<tr>
<td>$10^{14}$</td>
<td>C3T2</td>
<td>56.83 nA, 250sec</td>
<td>$8.88 \times 10^{13}$</td>
</tr>
<tr>
<td>$10^{14}$</td>
<td>E3T2</td>
<td>57.75 nA, 250sec</td>
<td>$9.02 \times 10^{13}$</td>
</tr>
<tr>
<td>$10^{15}$</td>
<td>E3T3</td>
<td>56.60 nA, 42min</td>
<td>$8.91 \times 10^{14}$</td>
</tr>
</tbody>
</table>

2. Test Schematic
Radiation Damage Test : Result of electrical test
I-V Test of irradiation DSSD

Our results show that leakage currents do not have radiation effect up to $10^{12}$ proton/cm$^2$.
But radiation damages are clearly shown above $10^{13}$ proton/cm$^2$. 
Our sensor is DC-type and RC chip has to be located in the hybrid board. Sensor will be bonded to RC chips by wire bonding. VA chip will receive an analog signal and this will move to ADC for signal readout.
Hybrid Board Layout

- P-side biasing line
- N-side biasing

<table>
<thead>
<tr>
<th>SYM</th>
<th>DIAM (mm)</th>
<th>TOL</th>
<th>QTY</th>
<th>NOTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>0.450</td>
<td></td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>x</td>
<td>0.700</td>
<td></td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>+</td>
<td>2.794</td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td>78</td>
<td></td>
</tr>
</tbody>
</table>

biasing line
Hybrid Board Design

As both side of the sensor Biasing

mechanical design for sensor with hybrid board
SUMMARY and Plan

• 1st Design Sensor - 1st, 2nd, 3rd Run done
  – we optimize the double-sided silicon sensor and fabricated sensors

• New Fabrication (2nd Design) of sensor with feedback from 1st fabricated sensor test measurements just started.
  – one lot takes 3 months

• Source Test
  – We clearly saw signal peak with the beta source and we will do signal-to-noise test soon.

• Radiation Damage Test
  – Radiation damage test again with different temperatures and conditions.
  – Extract damage parameters from these measurements

• Making Hybrid Board Prototype
  – DSSD (DC-type) + RC chip + VA Chip

END – Thanks (ARIGATO)
Full depletion voltage (N-type R=5KΩ)

⇒ full depletion layer thickness = 380 μm

1. Doping concentration

\[ N_D = \frac{1}{q\mu_n} = \frac{1}{1.6 \times 10^{-19} \cdot 1500 \cdot 1600} = 8.3 \times 10^{11} \text{cm}^{-3} \]

\[ \mu_n = 1500 \text{(Drift mobility \left[ cm^2/V \cdot s \right]: electron} \quad (\text{※} \mu_p = 450: \text{Hole}) \]

2. Depletion layer

\[ d = \sqrt{\frac{2\varepsilon \varepsilon_0}{qN_p} (V_{bi} - V)} \quad V = \frac{qN_D}{2\varepsilon \varepsilon_0} d^2 \]

\[ = \sqrt{\frac{2 \cdot 11.8 \cdot 8.854 \times 10^{-14}}{1.6 \times 10^{-19} \cdot 8.3 \times 10^{11}} (V)} \]

\[ = 3.96 \times 10^{-3} \sqrt{V} \text{ cm} \text{ or } 3.96 \times 10^{-6} \sqrt{0.572 \times V} \]

380 × 10^{-6} m = 3.96 × 10^{-3} \sqrt{V} \]

\[ V = 92 [V] \rightarrow \text{full depletion} \]

3. Capacitance

\[ C = \frac{\varepsilon \varepsilon_0}{d} = \sqrt{\frac{\varepsilon \varepsilon_0 qN_D}{2V}} = \sqrt{\frac{(11.8)(8.854 \times 10^{-14})(1.6 \times 10^{-19})(8.3 \times 10^{11})}{2.92}} \]

\[ = \frac{2.64 \times 10^{-10}}{\sqrt{184}} = 0.1 \times 947 \times 10^{-10} = 10 \mu F \]

put) Full depletion later = 380 μm ⇒ Voltage and Capacitance
Electrical Test of DSSD

Sensor Measurement Method:
N side Test (Surface Character)

- P Stop pad
- GND
- N side pad
- HV
- PIN
- HV
Wire bonding

Wedge Bonder

Wedge (tip)

Bias-ring

VA chip

Adaptor

Sensor