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Advanced monolithic pixel sensors using SOI technology

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http://rd.kek.jp/project/soi/

Outlines

SOI monolithic pixel sensors KEK DAQ system and performance Current issues and solutions Sensor performance (Integration-type pixel sensors) Future plan and summary



(FY13-1)

SPRiT (SOI Portable Radiation imaging Terminal)





MX1655

MX1711 (FY13-2)



FPIXb



SOI Monolithic pixel sensor

SOI=Silicon on insulator



<u>Targets</u> High-Energy Physics X-ray astronomy Material science Non-destructive inspection Medical application

2005-

The features of SOI monolithic pixel sensor

•No mechanical bump bonding. Fabricated with semiconductor process only

• Fully depleted (thick & thin) sensing region

with low sense node capacitance (~10 fF@17 μ m pixel) \rightarrow high sensor gain

- •SOI-CMOS; Analog and digital circuit can be closer \rightarrow smaller pixel size
- Wide temperature range (1-570K)
- Low single event cross section
- Technology based on industry standards; cost benefit

Process Summary

- KEK organizes MPW runs once/twice a year
- Mask is shared to reduce cost of a design
- Including pixel detector chip and SOI-CMOS circuit chip



Process	0.2µm Low-Leakage Fully-Depleted (FD) SOI CMOS
(Lapis Semiconductor Co. Ltd.)	1 Poly, 5 Metal layers (MIM Capacitor and DMOS option) Core (I/O) voltage : 1.8 (3.3) V
SOI wafer (200 mm ϕ = <u>8 inch</u>)	Top Si : Cz, ~18 Ω-cm, p-type, ~40 nm thick Buried Oxide: <u>200 nm thick</u> Handle wafer thickness: 725 µm → thinned up to 300 µm (Lapis) or ~50 µm (commercial process) Handle wafer type: NCZ, NFZ, PCZ, PFZ, double SOI
Backside process (2011~)	Mechanical Grind \rightarrow Chemical Etching \rightarrow Back side Implant \rightarrow Laser Annealing \rightarrow Al plating

Sensor test and DAQ system

Detector board

DAQ board



DAQ software & GUI

ROOT on linux Single thread scheme (2008-)



ROOT+QT+OpenCV(+picojson)+MSVC Multi-thread scheme (2014-)

Histogram Viewer		
	INTPIX DAQ Software	
Bundhase	SEABAS Connection SEABAS UP Address : UDP Part : SEABAS DP Address : UDP Part : SEABAS Convect SEABAS Convect Convection State : Convection Number : Calibration Number : Stated Event (MT) Stated Event (MT) State Event (MT)	Trinect
	DAQ Control DAQ STATE : PAUSE	
	Configure	
	Calibration	
	Run	
	Pause	
	Step	
	Exit	

NFZ-INTPIX4(FY2009) @ 150V 17µm pixel size x 832x512 Pixel scan time 400 ns/pixel

Monochromatic X-ray 33.3 keV



trimmer

65Hz, compressed



INTPIX4 still images with up-to-date system

INTPIX4+SEABAS2, 4ms x 2000fr, 150V, scan time 320ns/pixel 33.3keV monochromatic X-ray KEK Photon Factory BL-14C1



Current issues



Solutions

1. Additional pixel process

2. Improved SOI wafer

Various Implantation Options in Sensor part and Double SOI



p/n various doping density

Shield the back-gate effect / optimize charge collection efficiency Nested-well process (Increase crosstalk?)

Current issues and solutions



- 1. BPW process : effective to analog circuit in a pixel
- 2. Double SOI wafer : effective to digital circuit in a pixel
- 3. Additional process : improve charge collection efficiency

Breakdown voltage: double SOI sensor I-V measurement



Recover breakdown voltages: Similar to the single SOI case ¹¹

FET threshold shifts and compensation in DSOI

IV curves of an NMOS (2MGy irradiated) with Changing VDSOI2

Residual of Vth shifts of various FET types (FETs grouped into 3 in VSOI2 setting)



- S. Honda et al., "Total Ionization Damage Compensations in Double Silicon-on-Insulator Pixel Sensors", PoS (TIPP2014)039.
- K. Hara et al., "Initial Characteristics and Radiation Damage Compensation of Double Silicon-on-Insulator Pixel Device,", PoS(VERTEX2014)033.

N-type Double SOI pixel sensor

Charge (ADC count)

Response to infrared laser of 1064 nm wavelength and 10 ns pulse duration.



The average ADC count as function of the square root of the bias voltage for sensor.

Obtained similar linearity and sensitivity to pre-irradiation with VSOI2=-10 V

S. Honda et al., TIPP12014, 2-6 June 2014, Amsterdam PIXEL2014 presentation by M. Yamada



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Pre-irrad

SOI Pixel sensor with N-type, P-type (and double SOI wafers)

Spatial resolution study using NFZ-FPIXb P-type sensor study using PFZ-INTPIX7 compared with NFZ-INTPIX7

NFZ-FPIXb Front illumination NFZ/PFZ-INTPIX7 Front illumination







Pixel size 12 um x 1408 x 1408 pixels





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Spatial resolution X-ray test chart + X-ray tube



INTPIX4(17µm):0.57、FPIXb(8µm):0.83



Spatial resolution (2)

JIMA chart (RT RC-05) Au thickness 1um (very thin!)

X-ray tube: Target Cu

NFZ-FPIXb Cu 20kV 10ma Backbias 100V 1ms x 2000fr.

8um slit can be seen



before clustering



After clustering

Energy resolution



2011 JPS A. Takeda et al.

- X-ray spectra Am241 at room temperature
- Energy resolution (FWHM) @13.9keV

INTPIX4 CZN: 1.87 keV (13.4%), FPIXb FZN: 0.80 keV (5.8%)

P-type SOI sensor: PFZ-INTPIX7 vs. NFZ-INTPIX7

16 keV Monochromatic X-ray at KEK Photon Factory Beam spot size 0.4 mm x 0.4 mm Front illumination, Vbb 150V



PFZ SOI sensor has high leakage current and low breakdown voltage Modification of P-type wafer fabrication process is required.

Summary and future plan

SOI pixel sensor development since 2005 SOI pixel sensor system with Gbit Ethernet (SEABAS2) works fine

Current issues:

The back-gate effect will be suppressed by BPW process or double SOI Radiation hardness can be improved with double SOI

Initial test of double SOI, N-type, P-type sensors was successful All wafers need to be improved, especially p-type wafer

Future plan:

Crosstalk study must be done with counting-type pixel sensors Charge collection issue must be solved using novel idea of p/n implantation



Thank you for your attention!

Supplement

SOI Wafer for monolithic sensor

Smart cutTM by Soitec



High Resistivity Silicon:

N-type Czochralski, NCZ, 0.7 kOhm-cm, 300 µm-thick N-type Float Zone, NFZ, 2-7k Ohm-cm, 500 µm-thick P-type Czochralski, PCZ, 1k Ohm-cm, 300 µm-thick P-type Float Zone, PFZ, 2-40k Ohm-cm, 500 µm-thick

Double SOI (DSOI) pixel sensor



Middle SOI: Additional shield layer

Double SOI N-type sensor (2011-2013) MPW11(MX1501),12-1(MX1542),12-2(MX1594) Double SOI P-type sensor (2014-) MPW13-1(MX1655), MPW13-2(MX1711), MPW14(MX1786), MPW15-1(MX1850)