Development of Silicon-On-Insulator Monolithic Pixel Detectors -FZ SOI sensor-

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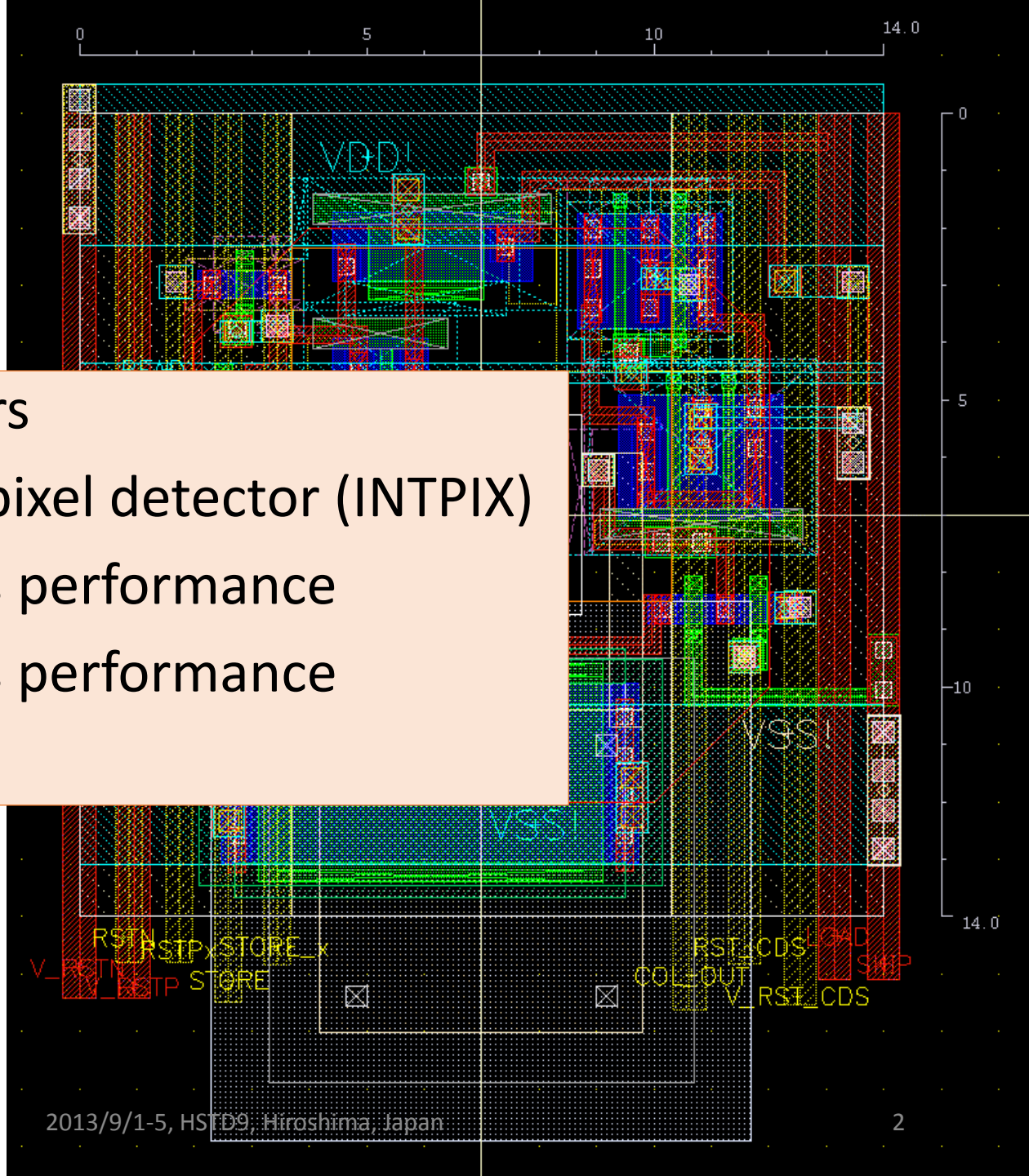
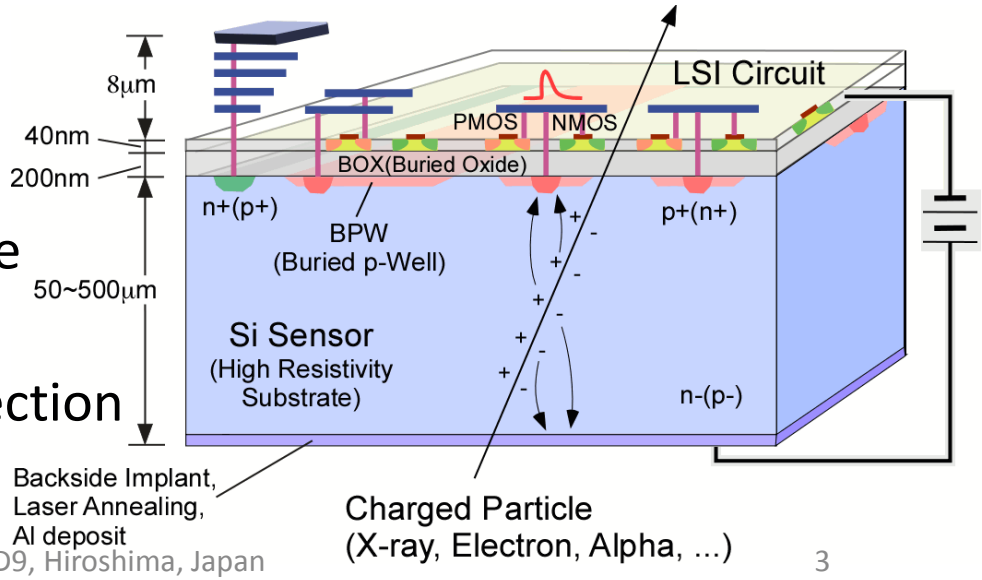
Outline

- SOI pixel detectors
- Integration type pixel detector (INTPIX)
- Cz INTPIX sensors performance
- FZ INTPIX sensors performance
- summary



Features of the SOI pixel detectors

- Bonded wafers : Thick High Resistivity Sensor + CMOS
- Monolithic Detector (-> High circuit density, Low material)
- Standard CMOS (-> Complex functions in a pixel)
- No mechanical bump bonding (-> High yield, Low cost)
- Full depleted sensor with small capacitance of the sense node
  (~10fF, High conversion gain, Low noise)
- Based on Industrial standard technology
  (-> Cost benefit and Scalability)
- No Latch Up, Low SEE σ
- Low Power
- Operate in wide temperature range
  (4 K-570 K (300 deg.C))
- BPW for the back-gate effect protection



Lapis Semiconductor* 0.2 µm FD-SOI Pixel Process

Process	0.2 µm Low-Leakage Fully-Depleted (FD) SOI CMOS 1 Poly, 5 Metal layers (MIM Capacitor and DMOS option) Core (I/O) voltage : 1.8 (3.3) V
SOI wafer (200 mm ϕ =8 inch)	Top Si : Cz, ~18 Ω-cm, p-type, ~40 nm thick Buried Oxide: 200 nm thick Handle wafer thickness: 725µm → thinned up to ~300µm (Lapis) or commercial process → ~50 µm (then, backside process…) Handle wafer: Cz (N) ~700 Ω-cm, FZ (N) > 3k Ω-cm
Backside process	Mechanical Grind →Chemical Etching →Back side Implant →Laser Annealing → Al plating

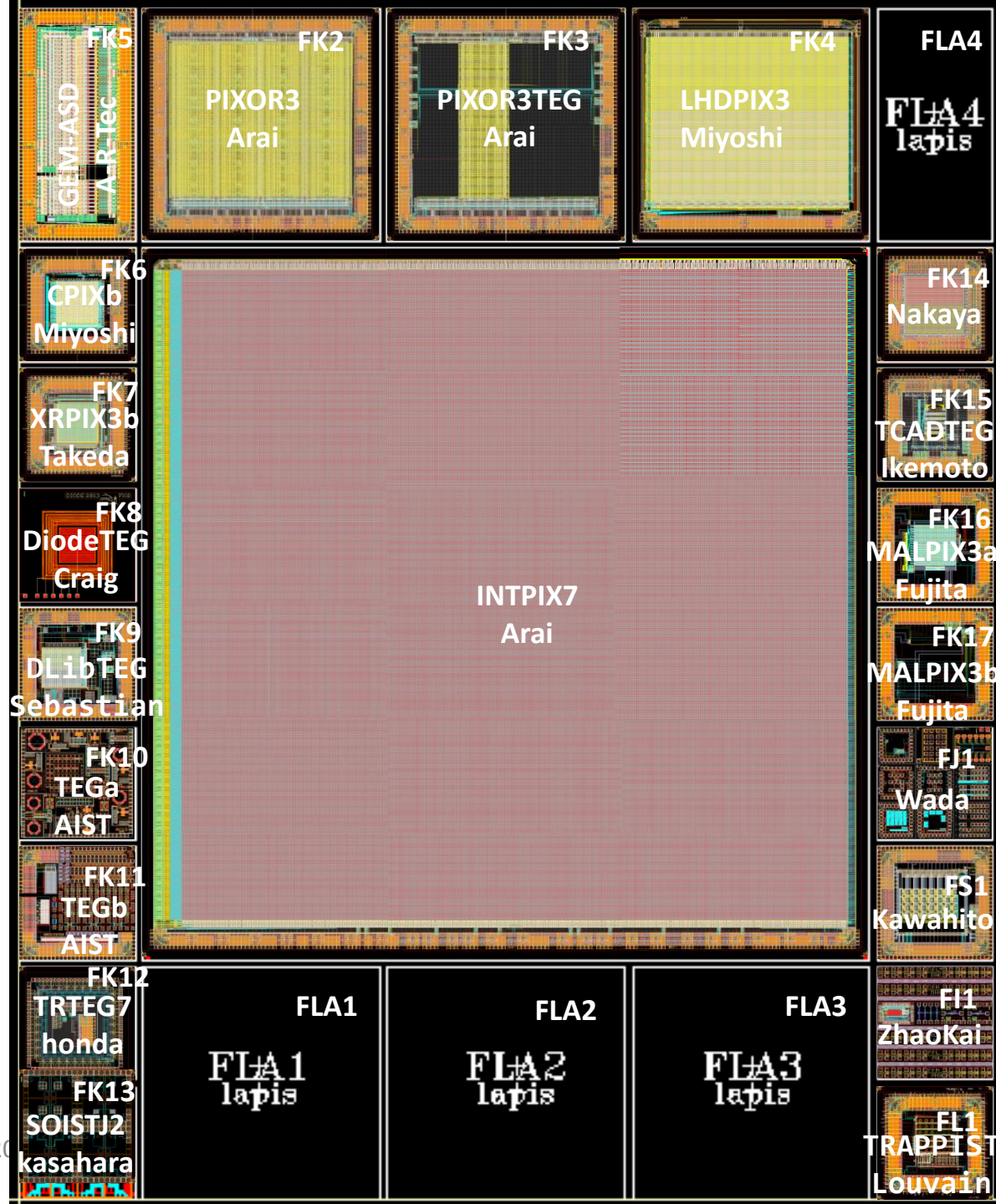
*former OKI semiconductor

MPW (Multi Project Wafer)

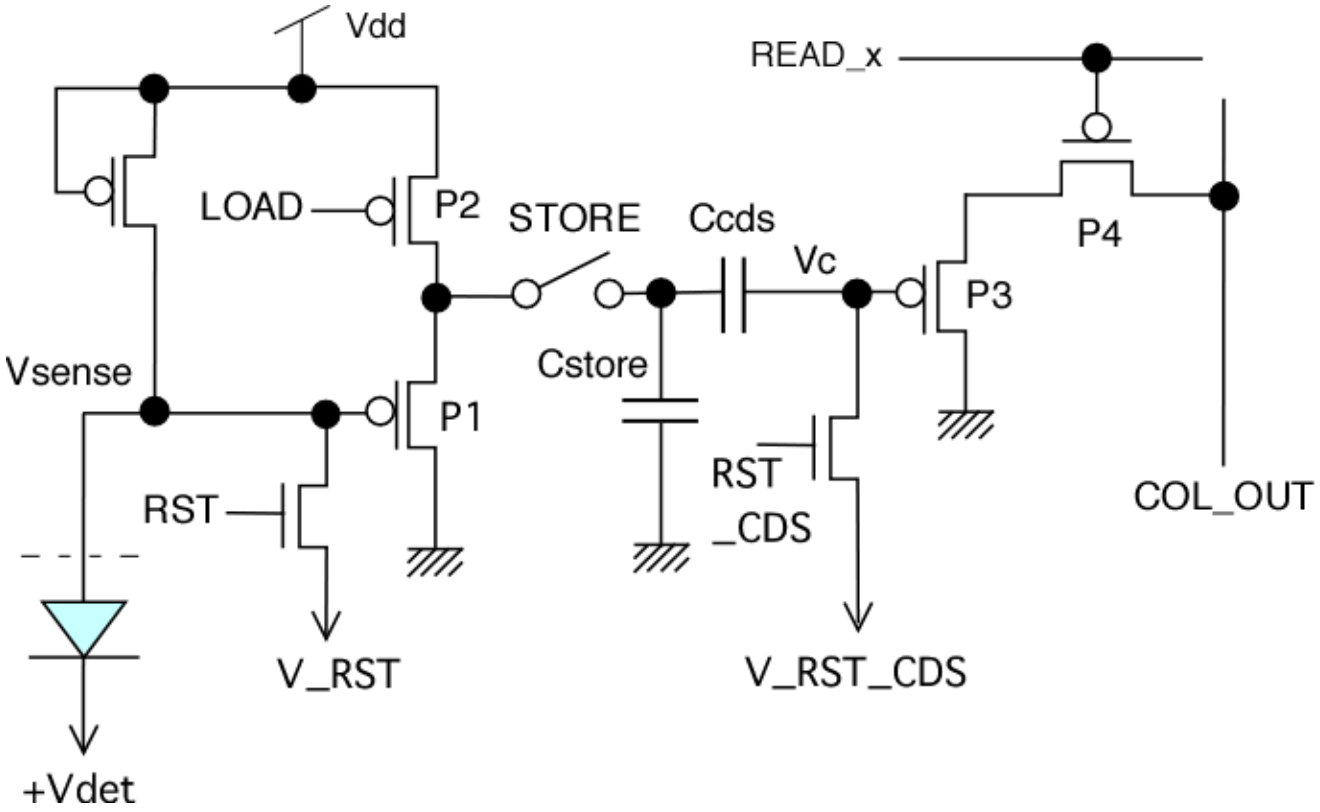
- mask size:

  24.6 x 30.8 mm^2

- KEK organizes MPW runs ~twice a year.
- Mask is shared to reduce cost of a production.



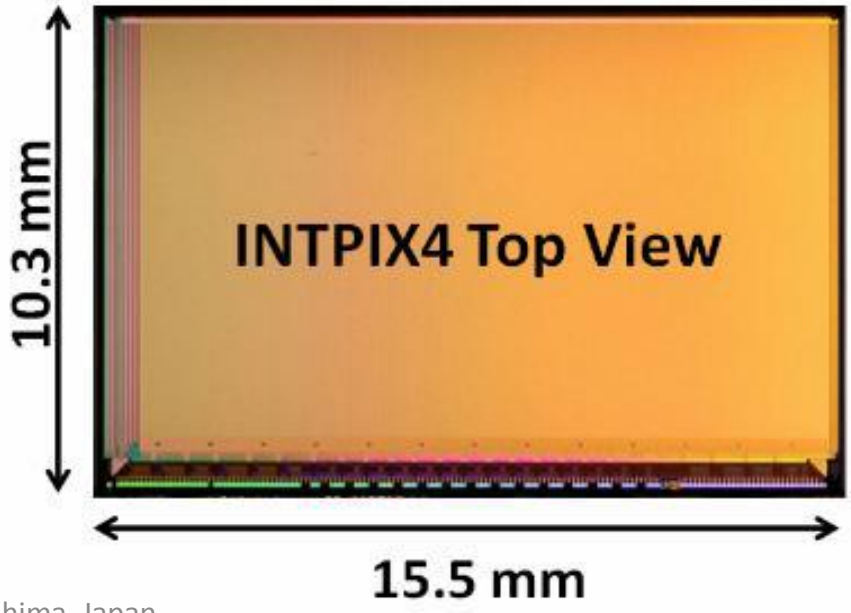
Integration Type Pixel (INTPIX)



The pixel circuit has CDS function.
2 Capacitors (Cstore and Ccds)

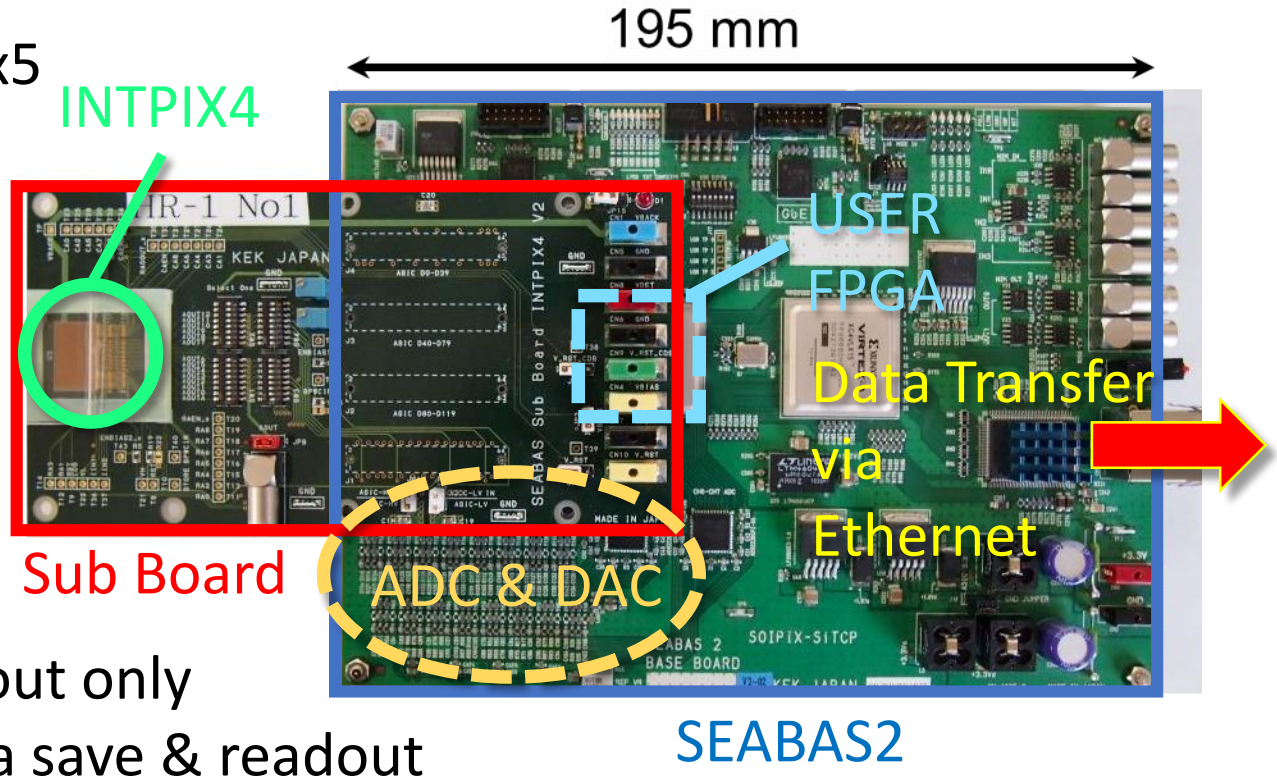
INTPIX4

- Integration type SOI pixel detector (mainly for X-ray imaging)
- Chip size : 10.3 x 15.5 mm^2 (Effective area : 8.7 x 14.1 mm^2)
- Number of pixels : 512 x 832 (~426k pixels)
- Pixel size : 17 μm^2
- Correlated Double Sampling (CDS) Circuit in each pixel
- 13 analog out
- Wafer (n type)
  - Cz: 700 Ω-cm (260 µm thick)
  - FZ: 7k Ω-cm (500 µm thick)
- Front / Back-side illumination



Evaluation board

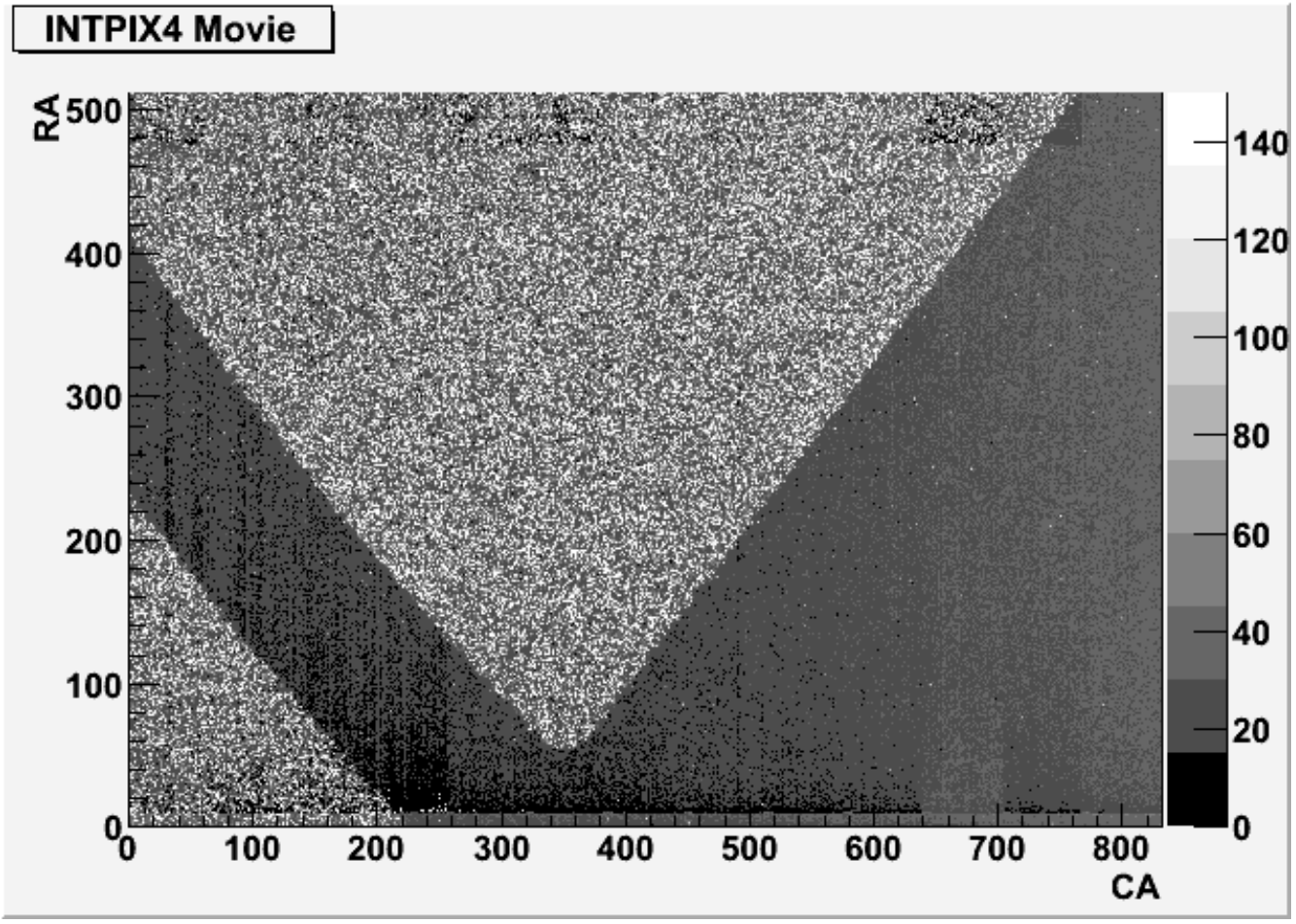
- Soi EvAluation BoArd with Sitcp 2 (SEABAS2)
- Gbit Ethernet
- User FPGA Virtex5
- Clock 50 MHz
- +/- 3.3 V
- ADC 16 ch
- DAC 4ch
- NIM I/O



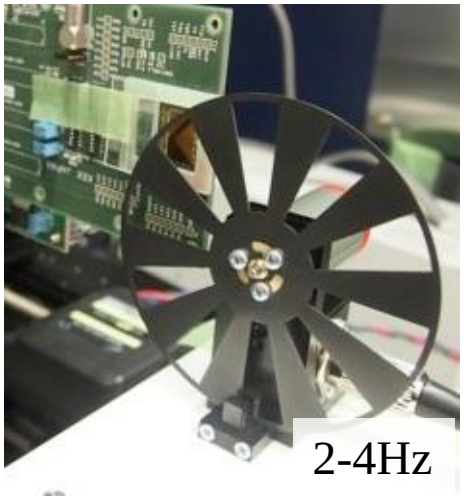
Readout rate

- ~60 fps for readout only
- ~20 fps with data save & readout

X-ray movie (Cz)



Optical chopper

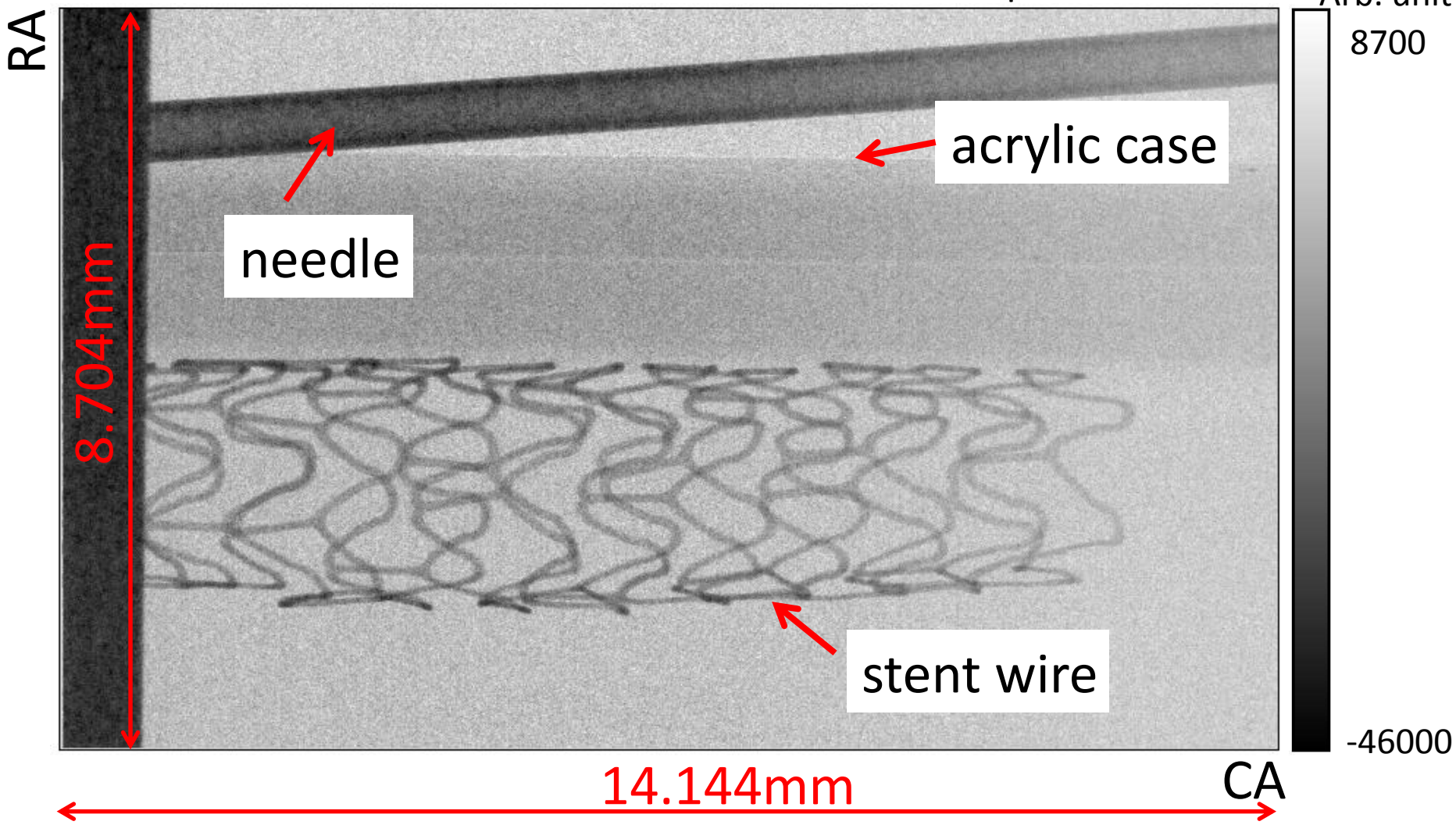


X-ray tube Mo target
30kV-40mA

Frame rate: ~20 fps
Int. time: 200 µs/frame
Back bias: 150 V

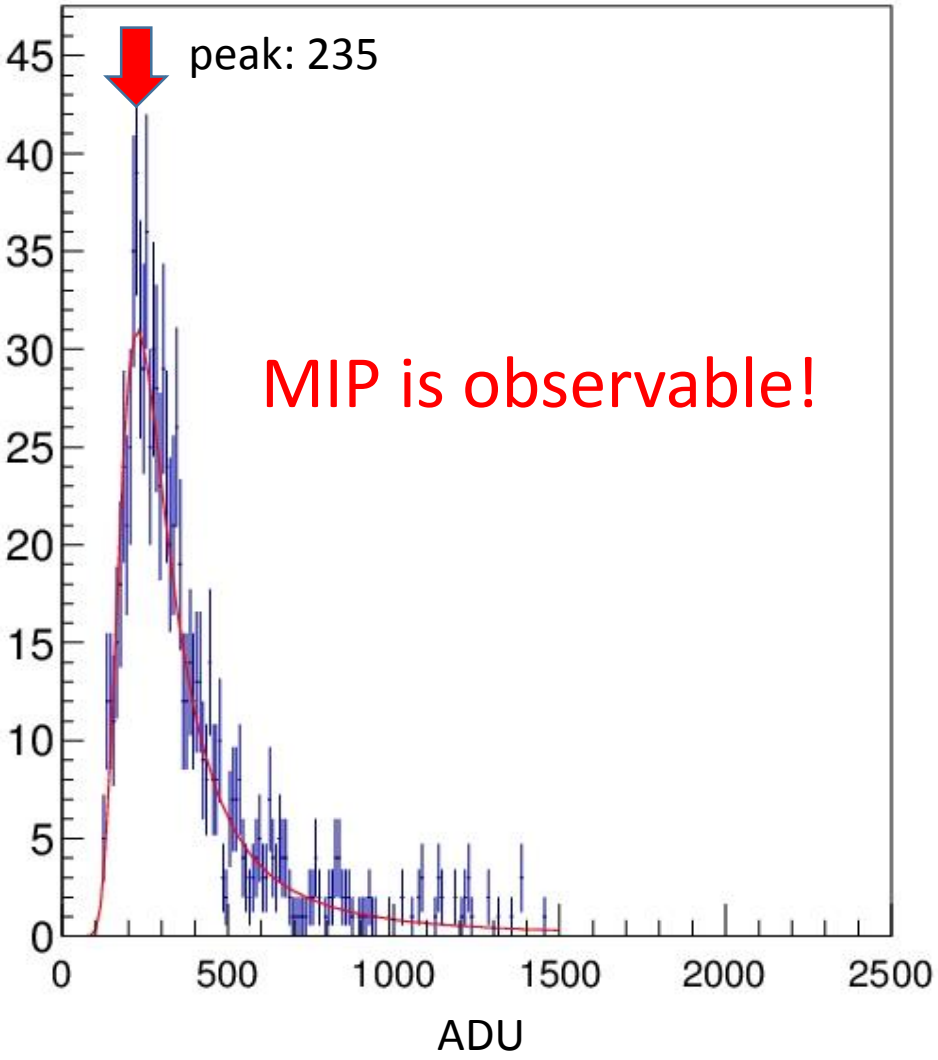
X-ray image (Cz)

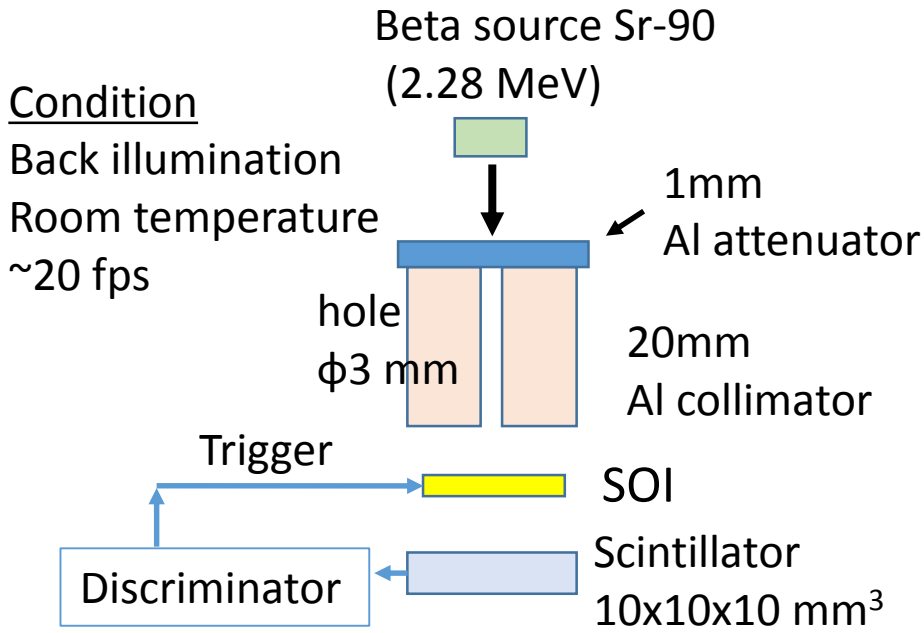
- PF-AR NE7A 33.3keV monochromatic X-ray
- int. time: 200 μs x 250 frames
- Total int. time: 50 ms
- NiTi stent wire: ϕ40 um



difference between [sample image] –[no sample image]

^{90}Sr beta source test (Cz)

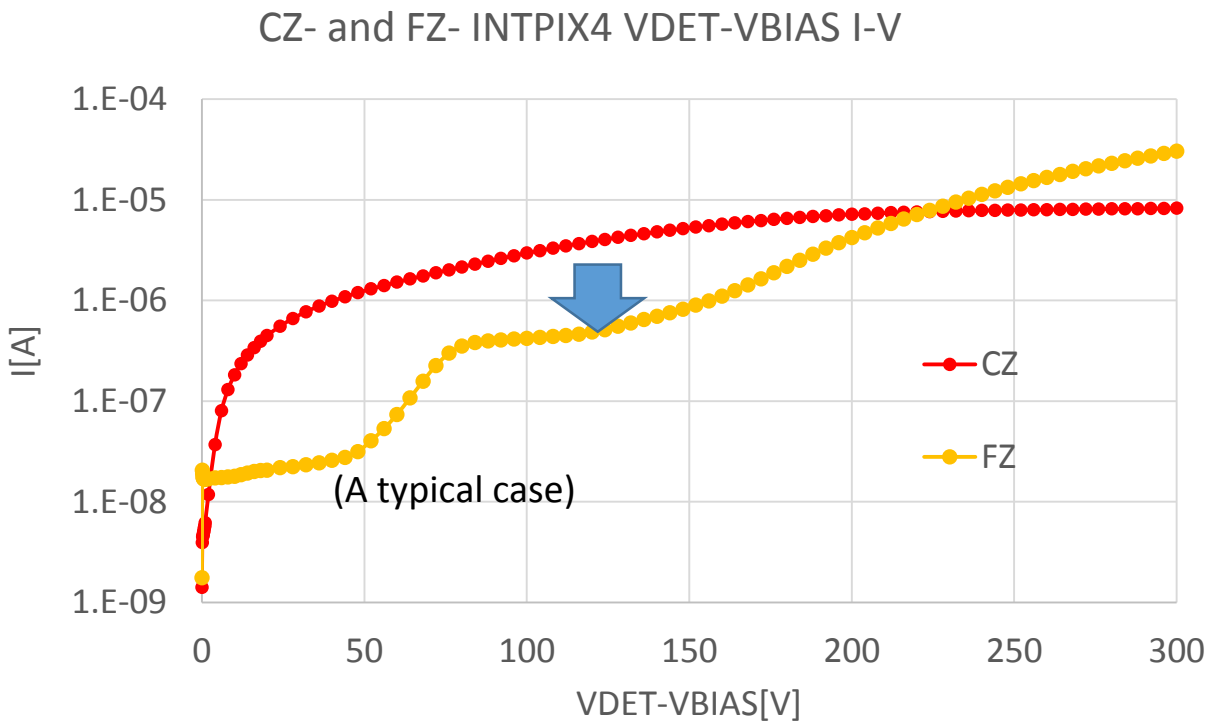




Sensor thickness: 260 µm
Bias voltage: 100 V
Depletion width: ~150 µm
Int. time: 400 µs

Pedestal sigma: ~**13**
S/N ~ 235/13 ~ 18

Wafer improvement (Cz->FZ)



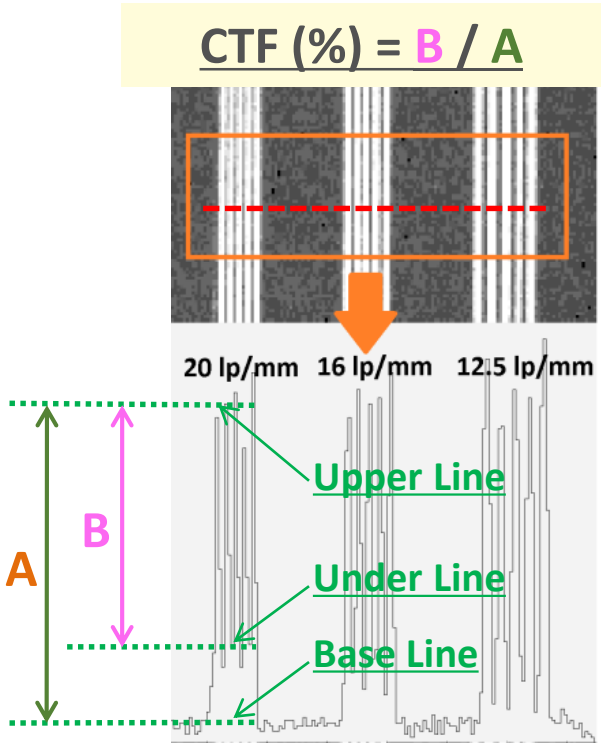
Leakage current is lower in FZ SOI sensors.

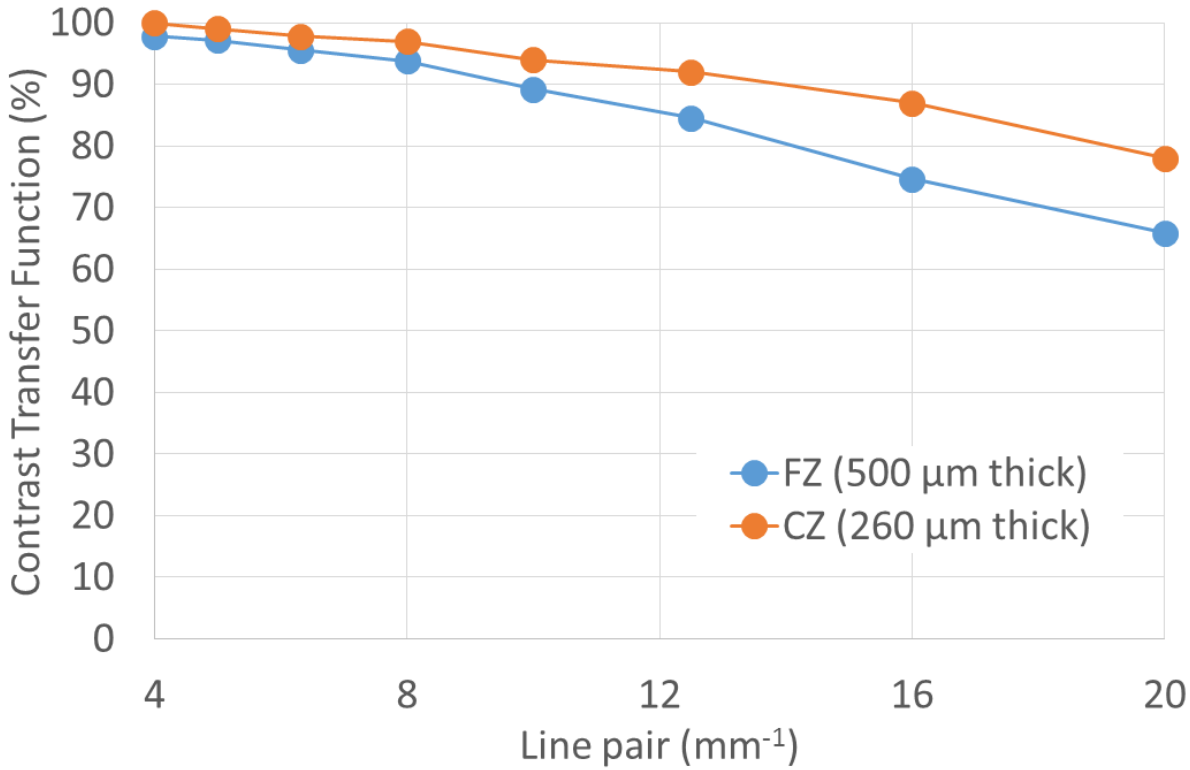
HSTD8 (2011) Cz-INTPIX4 performance study was shown.

HSTD9 (this conference) FZ-INTPIX4 performance study

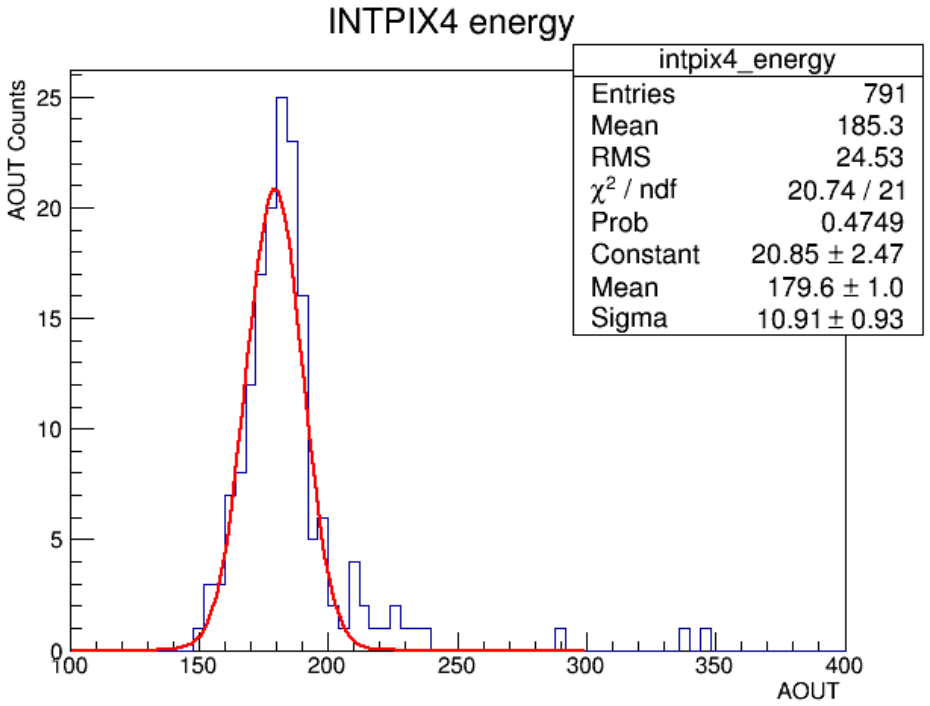
Spatial resolution (FZ)

- Evaluation of the spatial resolution by direct radiography in back-side illumination.
- CTF (Contrast Transfer Function) of the FZ N type (500um thick) sensor is a little bit worse than the Cz N type(260um thick) sensor due to it's thicker.
- Both FZ & Cz sensors are showing good CTF!





Energy spectrum (FZ)



^{109}Cd-Ka (22.2 keV) X-ray spectrum

- Bias voltage = 200 V
- Integration Time = 250 µs
- Back-side illumination
- temperature: 0 deg.C
- Single pixel hits are only selected

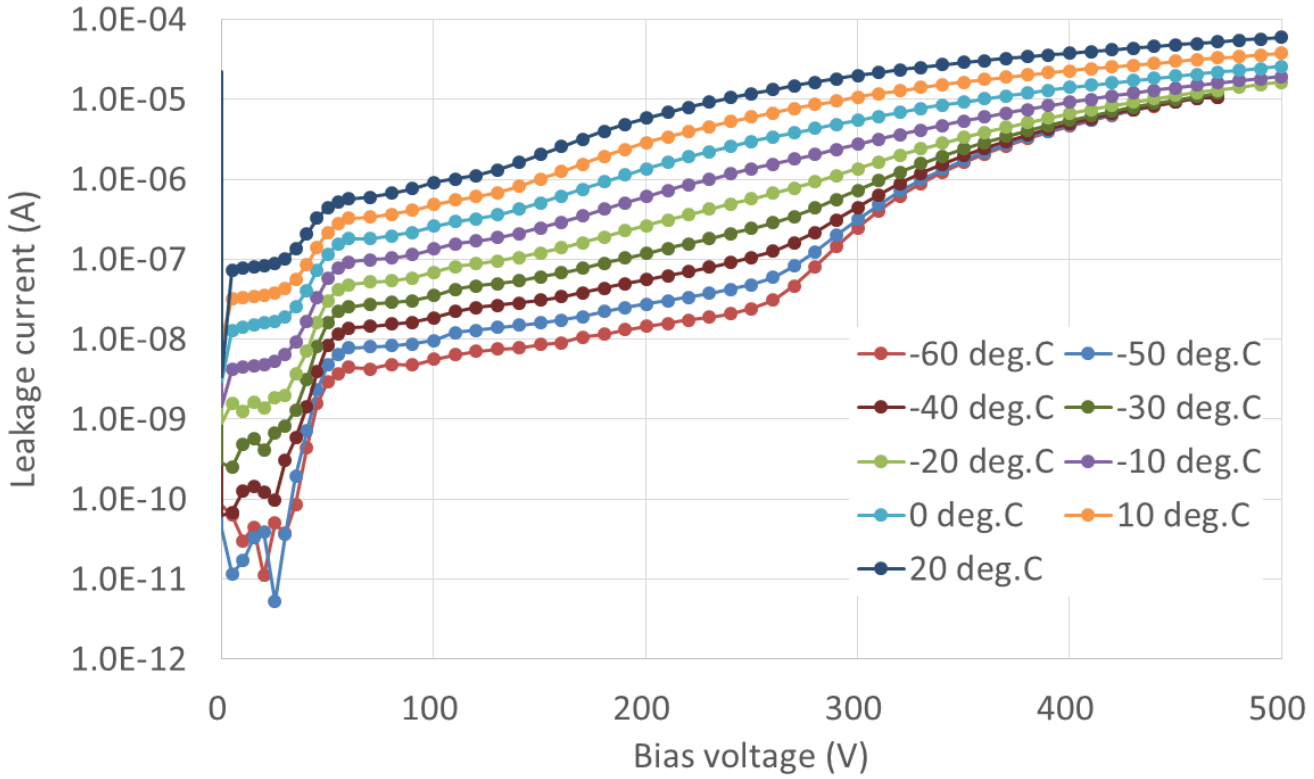
Gain = 17.08 µV/e-

(circuit gain = ~0.8)

FWHM: 14.3 % (882 e-) @22.2 keV

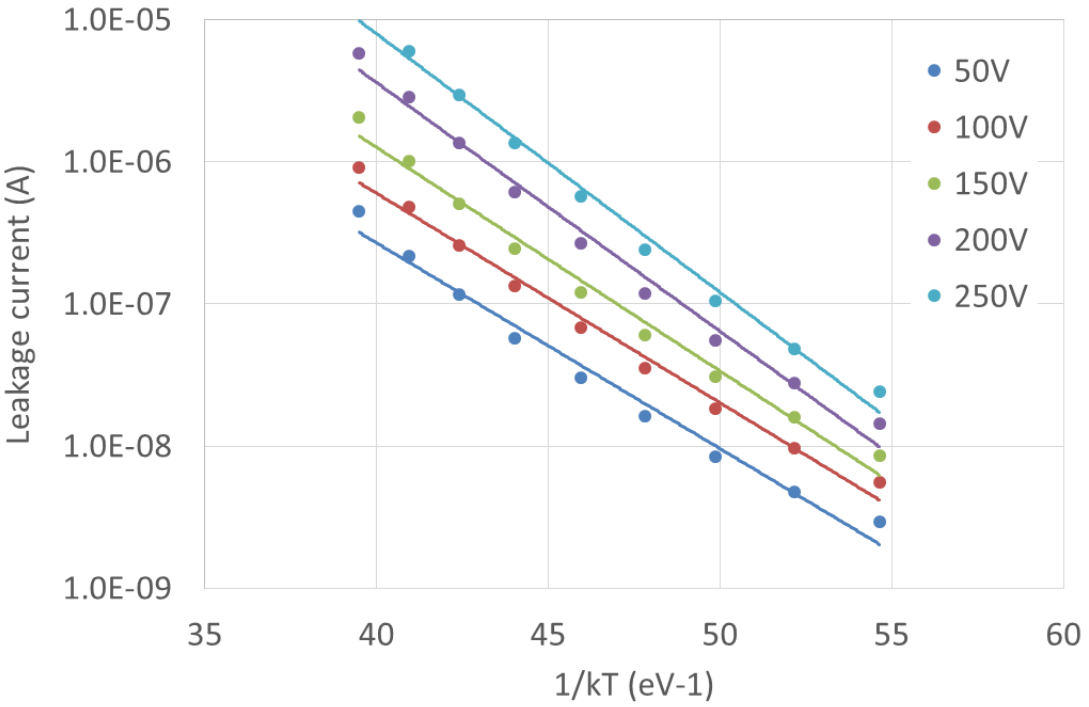
First X-ray spectrum taken with SOI-FZ sensor.

IV characteristics (FZ)



- Temperature: -60 deg.C ~ +20 deg.C (10 deg.C step)
- At each temperature, there is nosignificant breakdown.
- Current increase around 280V is probably caused by reaching the depletion region to side or back surface. The cause of the increase around 50V is under investigation.

Arrhenius plot (FZ)



$$I = Ae^{\frac{-Ea}{kT}}$$

I: Leakage current

A: Constant

E_a: Activation energy

k: Boltzmann constant

T: Absolute temperature

E_a = 0.41 eV @250 V

(Cz = 0.56 eV (=Eg/2))

Activation energy of the FZ sensor is less than that of the Cz sensor.
Thus other source but generation current is expected.

summary

We are developing monolithic pixel detectors using an SOI technology for X-ray and charged particle applications.

- INTPIX4 works successfully.
  - High resolution, high contrast, high rate X-ray images
- FZ sensors show good performance as well as Cz.
  - Spatial resolution: CTF 66 % @ 20 lp/mm
  - Energy resolution: FWHM 14.3 % @22.2 keV
  - ~10 times higher resistivity enables thicker sensing depth at moderate bias voltages.