High-Resolution Monolithic Pixel Detectors in SOI Technology

Toshinobu Miyoshi (KEK)

Co-authors
Y. ARAI
M. I. AHMED
P. KAPUSTA
Y. FUJITA
R. ICHIMIYA
Y. IKEMOTO
K. TAUCHI
A. TAKEDA

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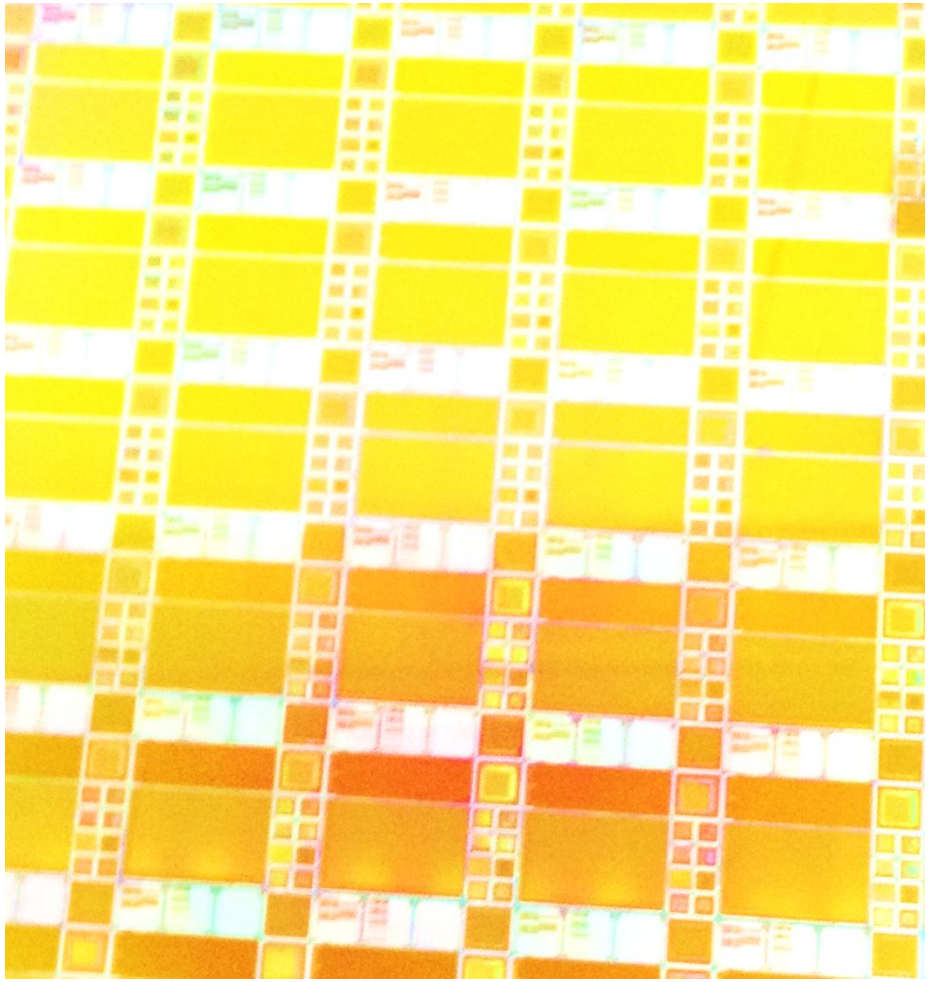
Outline

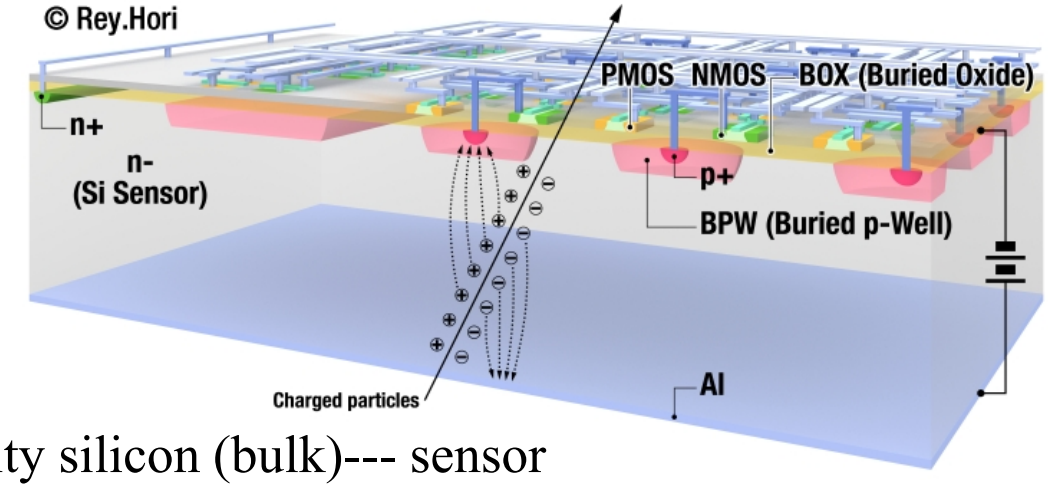
Introduction
(refer to Arai-san's slide)
-SOI image sensor
-Process & MPW

Integration-type pixel detectors
1. Analog & digital output study
- DIPIX
2. Spatial resolution study
- INTPIX5
- FPIX

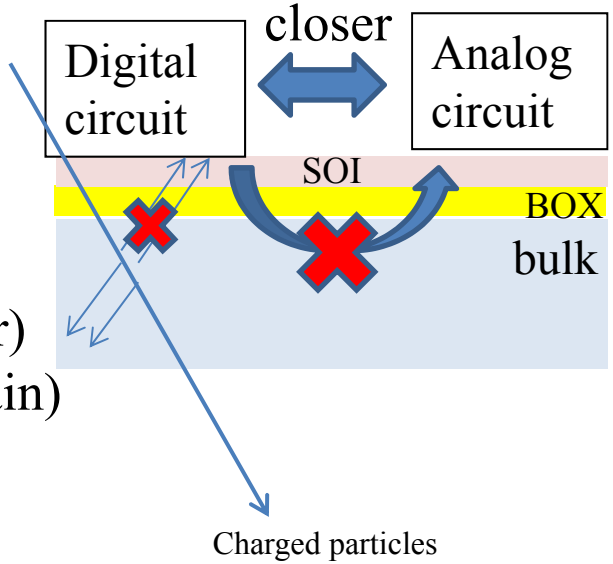
Summary



SOI monolithic pixel detector R&D



High resistivity silicon (bulk)--- sensor
Low resistivity silicon (SOI) --- circuit
SiO_2 --- insulator (BOX)



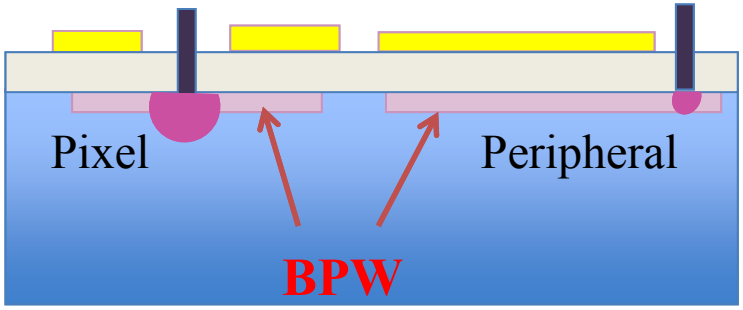
<u>The features of SOI monolithic pixel detector</u>

- No mechanical bump bonding (high yield, low cost)
- Smaller junction capacitance (high speed, low power)
- Small capacitance of the sense node (~10fF, high gain)
- No latch up, less SEE probability
- Operate in wide temperature (4-570K) range
- Based on industry standard technology→ lower cost

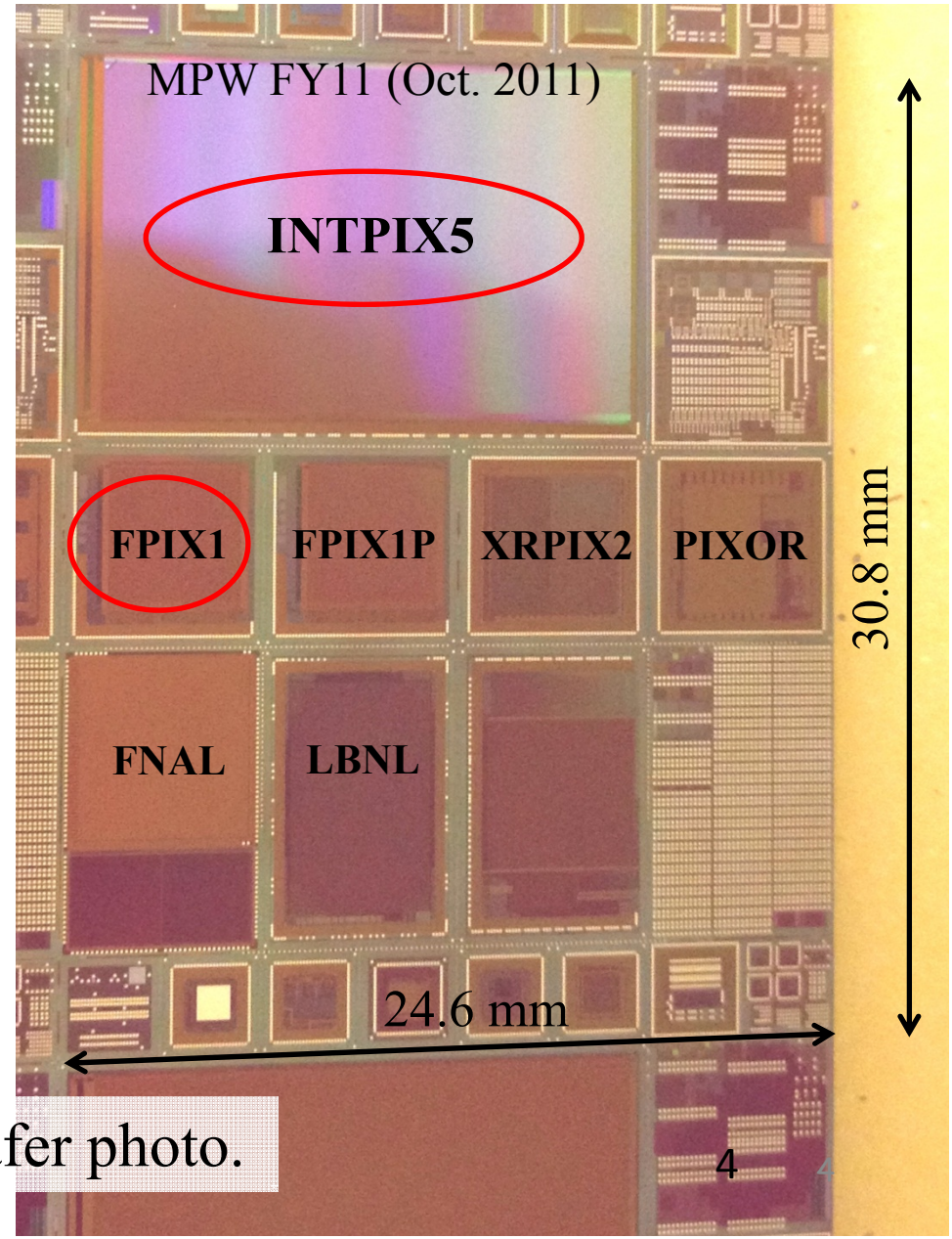
Process & MPW(FY11)

Wafer

(1) CZn 700 Ω cm ← Today's talk
INTPIX5
FPIX1
- Includes Buried P-Well process
Blocks the back-gate effect



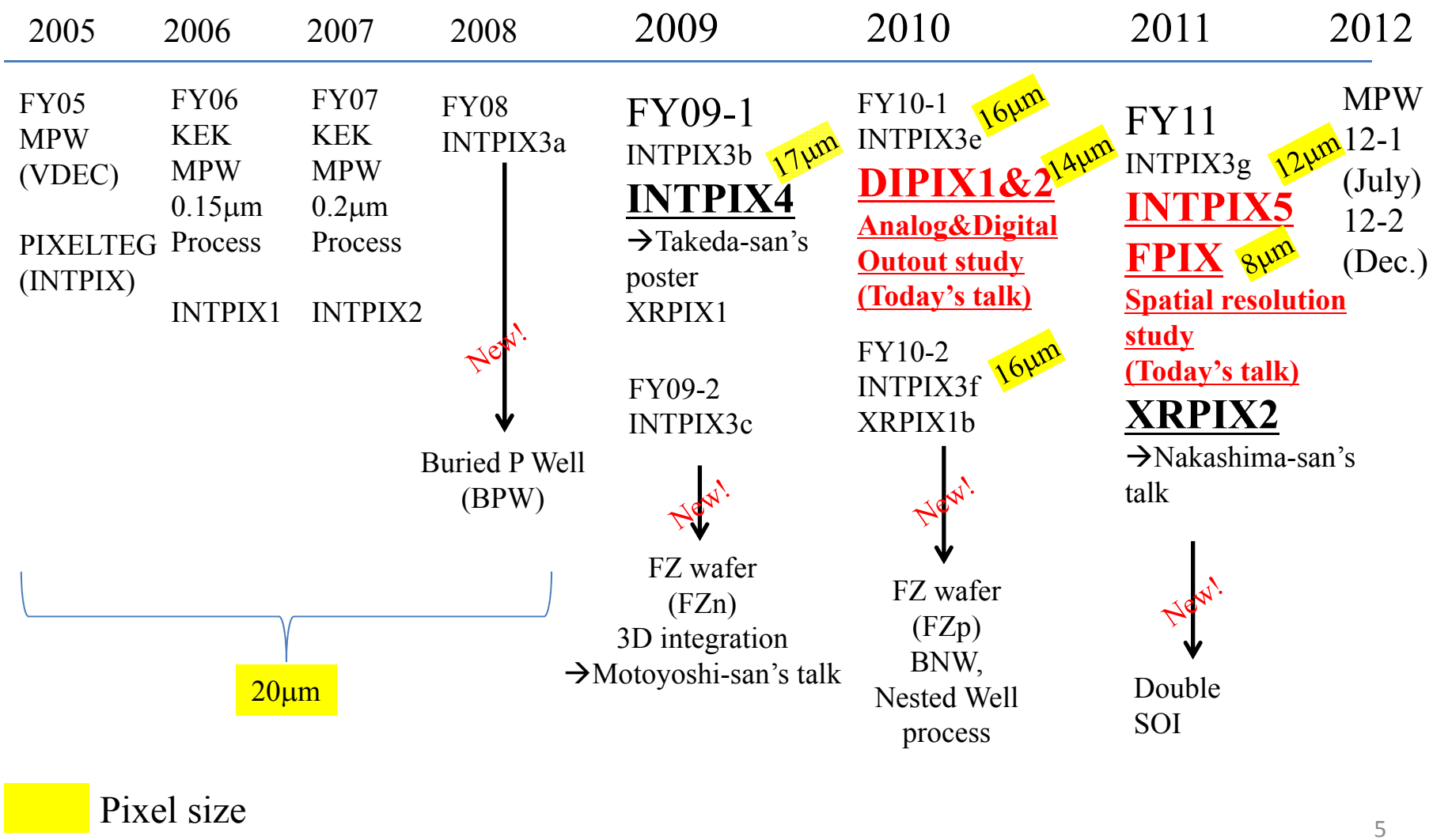
(2) FZp (BNW, p-stop)
(3) FZn (BPW)
(4) Double SOI (w. or w/o BPW)



Wafer photo.

SOI Integration type pixel detector

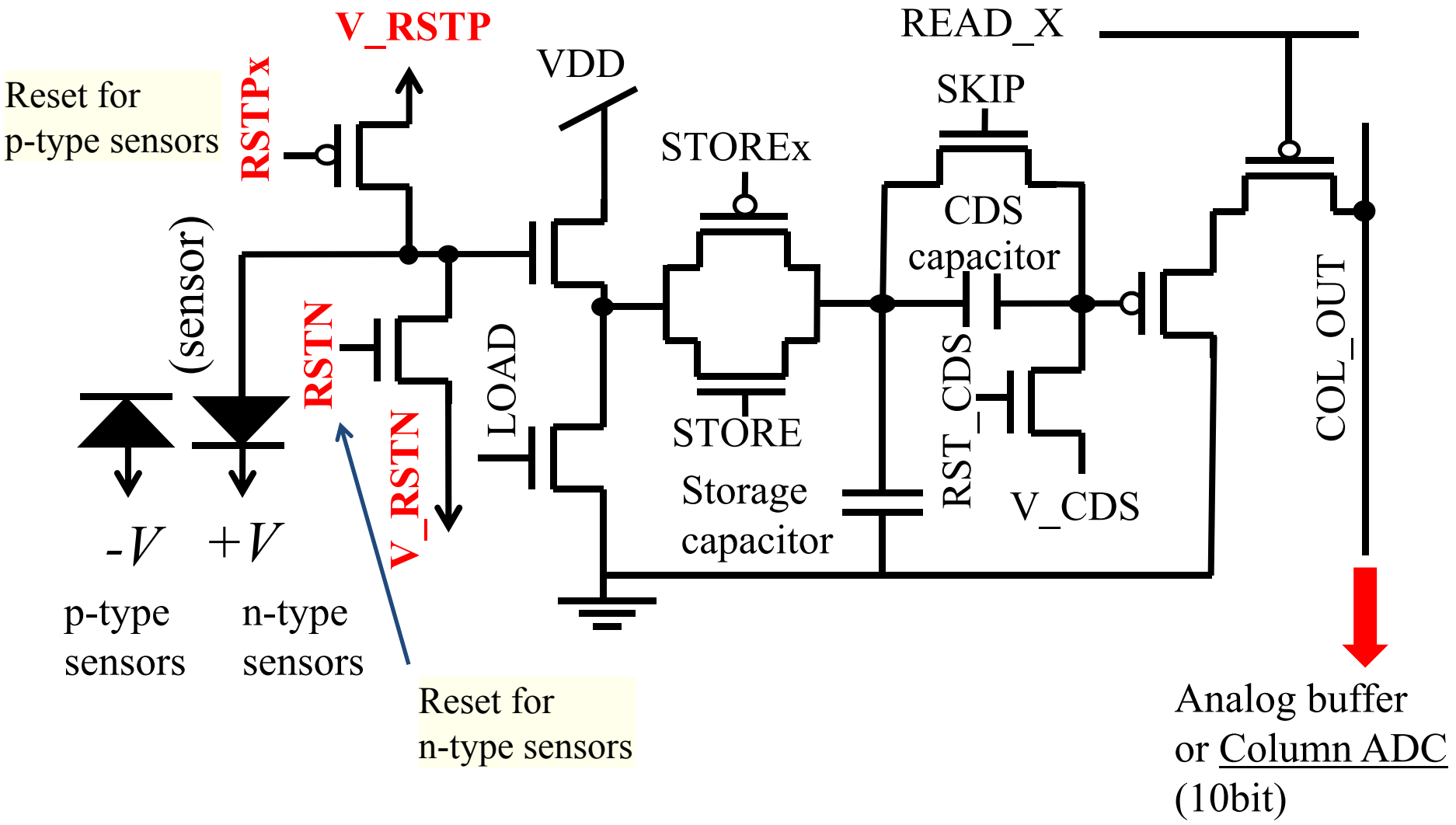
Features: small number of transistors → small pixel size



DIPIX1&2(dual-mode integration type pixel)

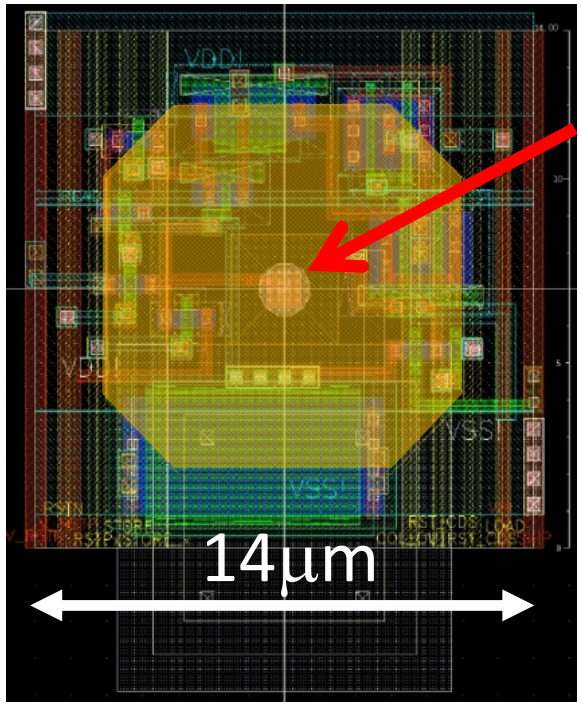
FY10-1

Pixel circuit

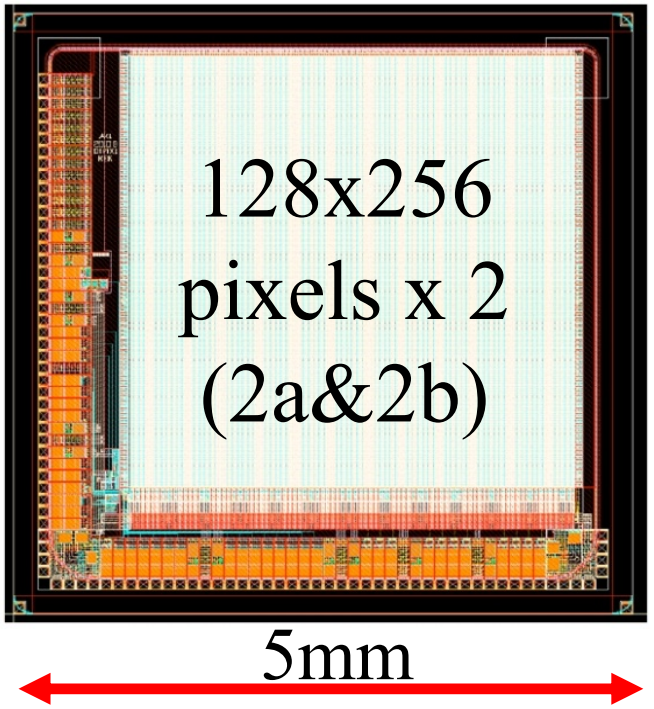


DIPIX pixel & top layout

Pixel layout



Chip layout



p-n implant are reversed each other

DIPIX1 n-type: BPW+BP2 (the same size) ←→p-type: BNW+BN2
DIPIX2 n-type: BPW only and BPW & BNW
(256x128x2) ←→p-type: BNW only and BNW & BPW

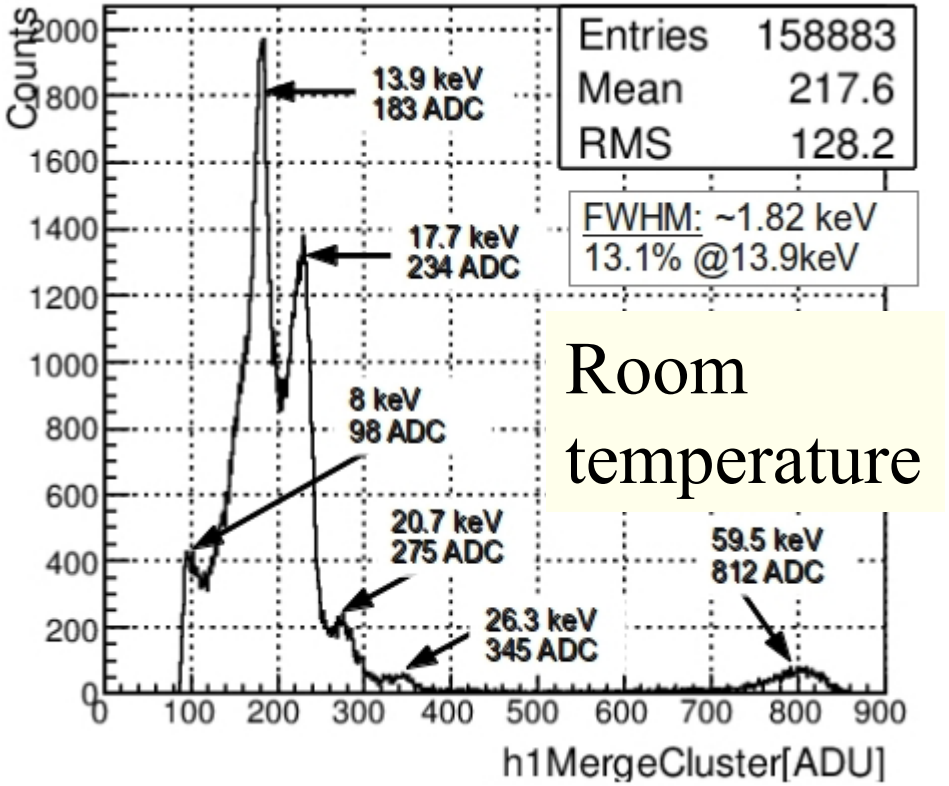
Analog output test

Am-241 source test @ Krakow

M. I. AHMED (Krakow)

Am-241 10 mCi (=370 MBq)
Radiation data

Type	Energy [keV]
Am-241 X-ray	59.5
Am-241 X-ray	26.3
Am-241 X-ray	13.9
Cu L X-ray	8.01
Np L X-ray	17.7
Np L X-ray	20.7



X-ray spectrum (Single pixel cluster only)

Condition
Integration time 100us
back-bias 80 V
Pedestal run 500 +5000 frames

Results
Noise ENC 85 e-
FWHM ~ 1.82keV : 13.1%@13.9keV
Gain 12 uV/e-

Digital output test

P. Kapusta (Krakow)

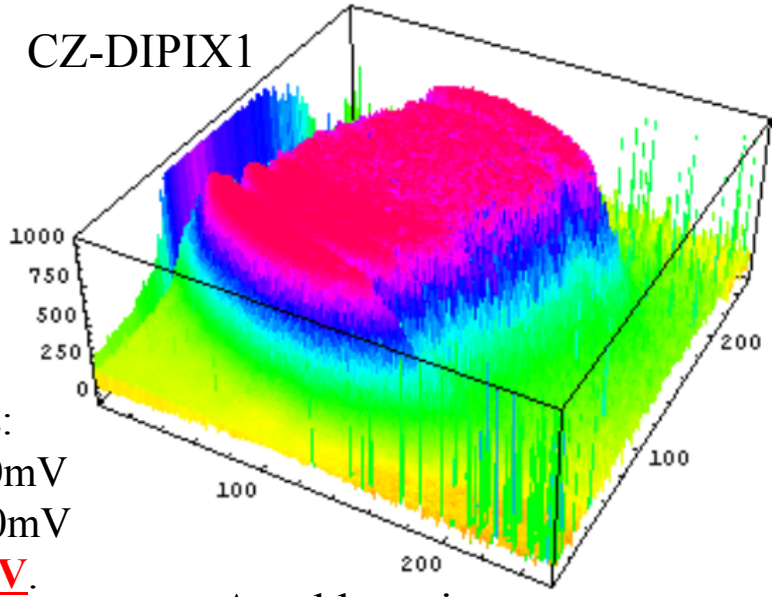
Column ADC

CZ-DIPIX1

Operational condition

I_{RG}=0.67uA, I_{RGSF}=5.2uA, ADC_CLK=50MHz

Conversion time 30 us for 50MHz clock
@1.8V limit (core supply),
Ramping capacitance 9.9 pF, and
Ramping current 0.67uA



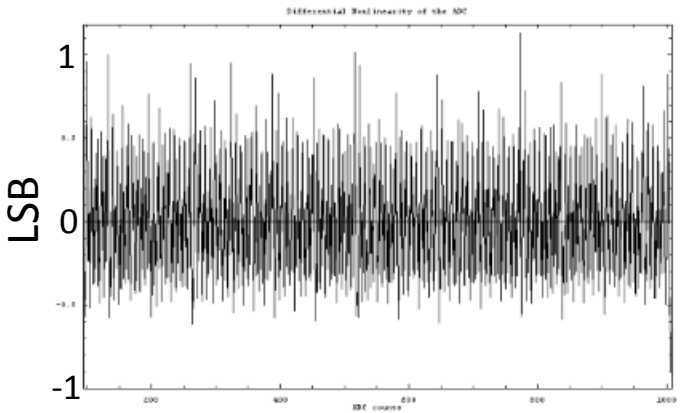
Parameters:
V_{RSTN}=750mV
V_{IPIX}=1800mV
VDET=50V.

A red laser image

Linearity

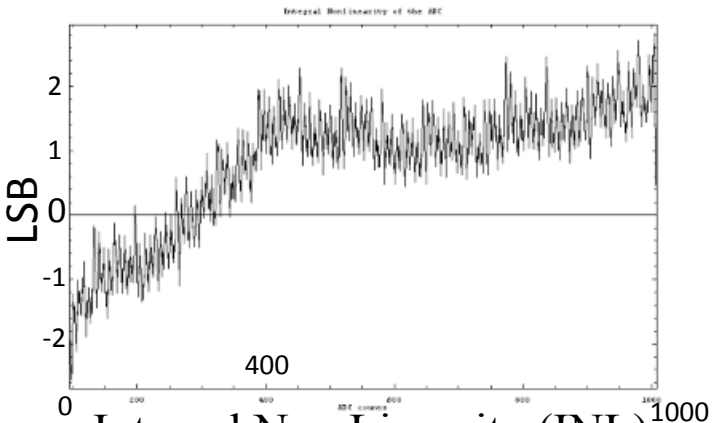
Input signal 720-1780mV(~1V) : ADC 94-1008(10bit).

DNL: -0.95 LSB to 1.13 LSB



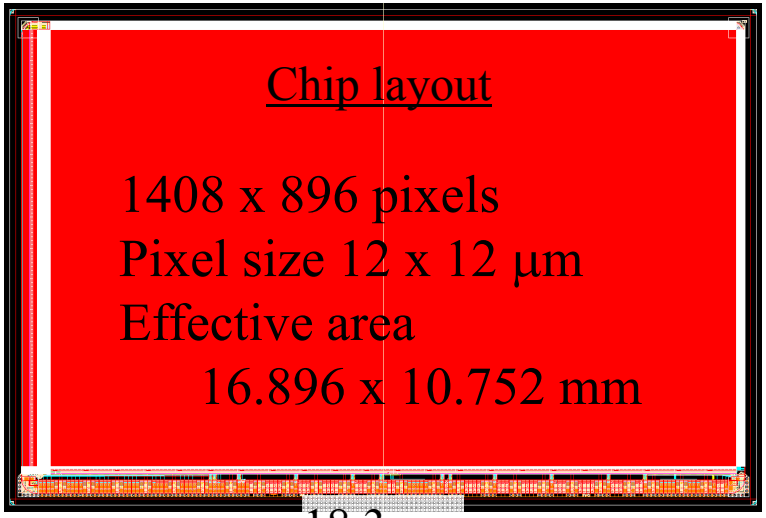
Differential Non Linearity (DNL)

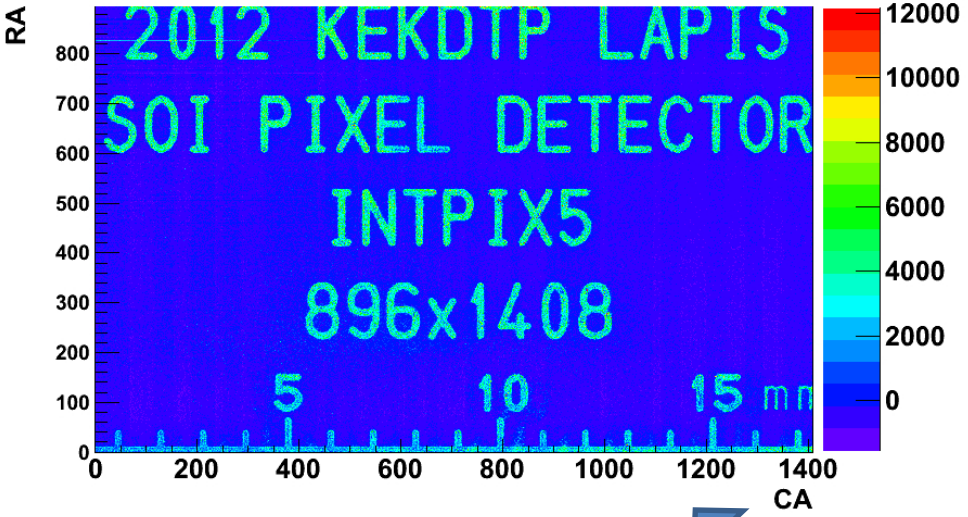
INL: -2.6 LSB to 2.8 LSB



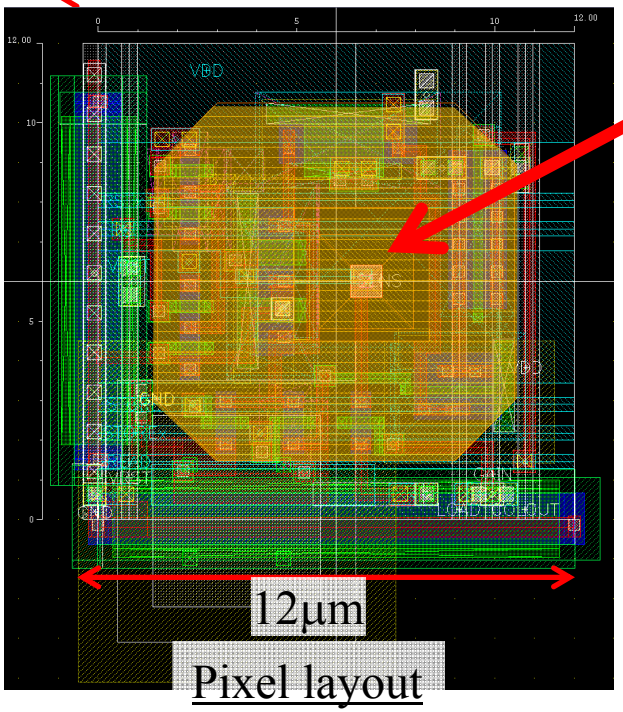
Integral Non Linearity (INL)

INTPIX5

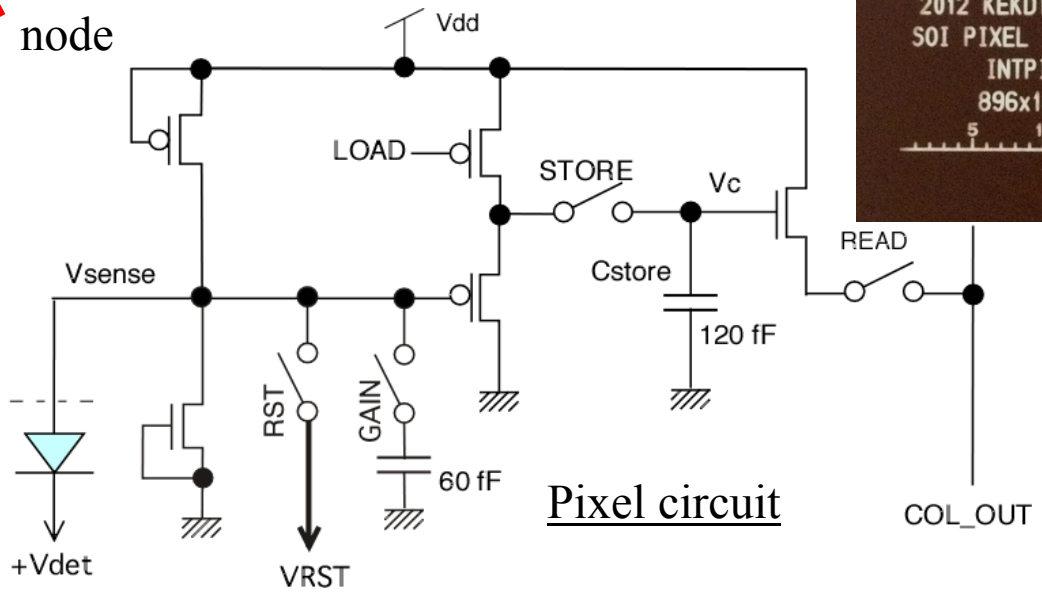




A plastic mask image
(red laser front illumination)



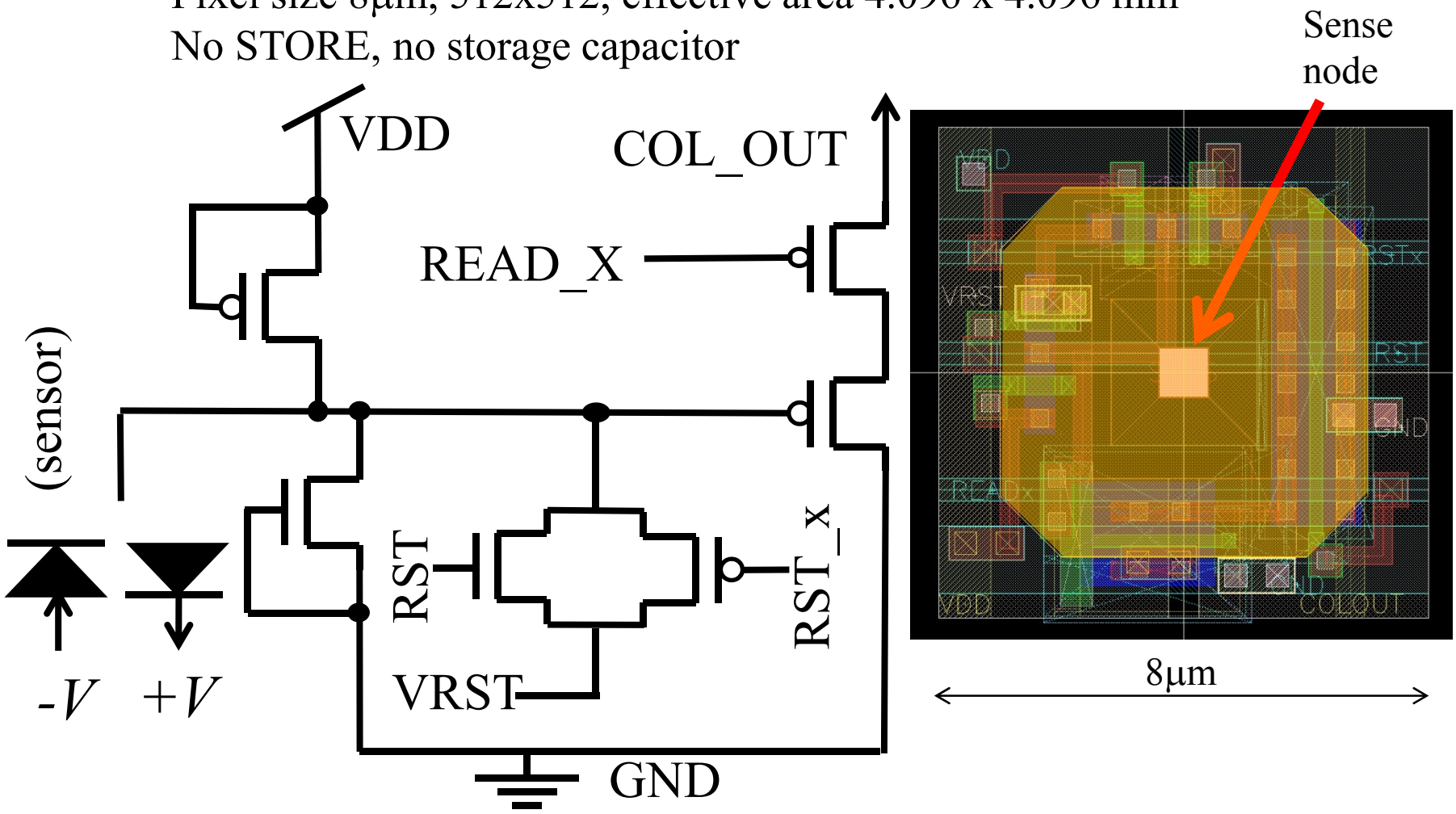
Sense node



Pixel circuit

FPIX1&1P

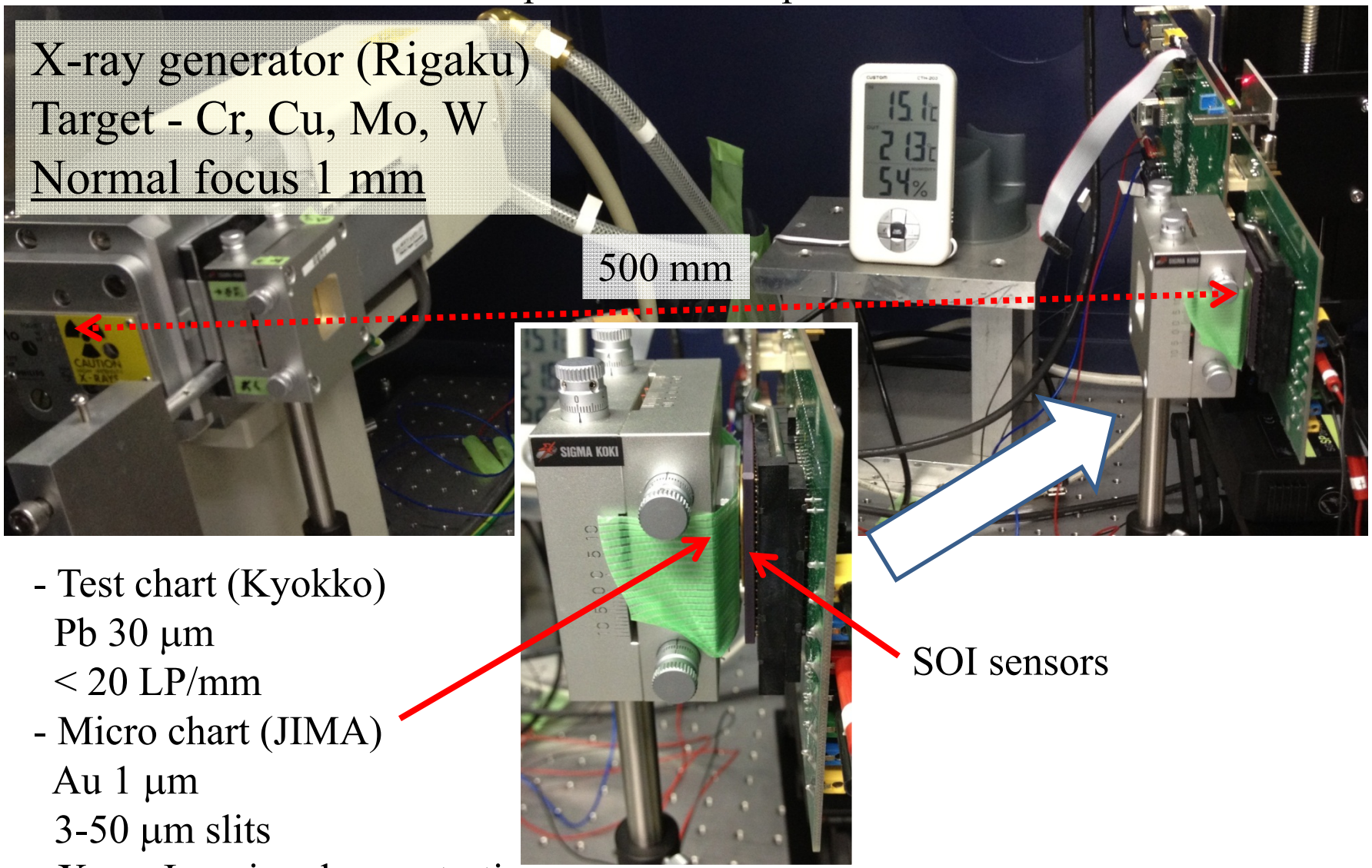
Pixel size 8µm, 512x512, effective area 4.096 x 4.096 mm
No STORE, no storage capacitor



We achieved 8 µm pixel circuit/layout

Spatial resolution study

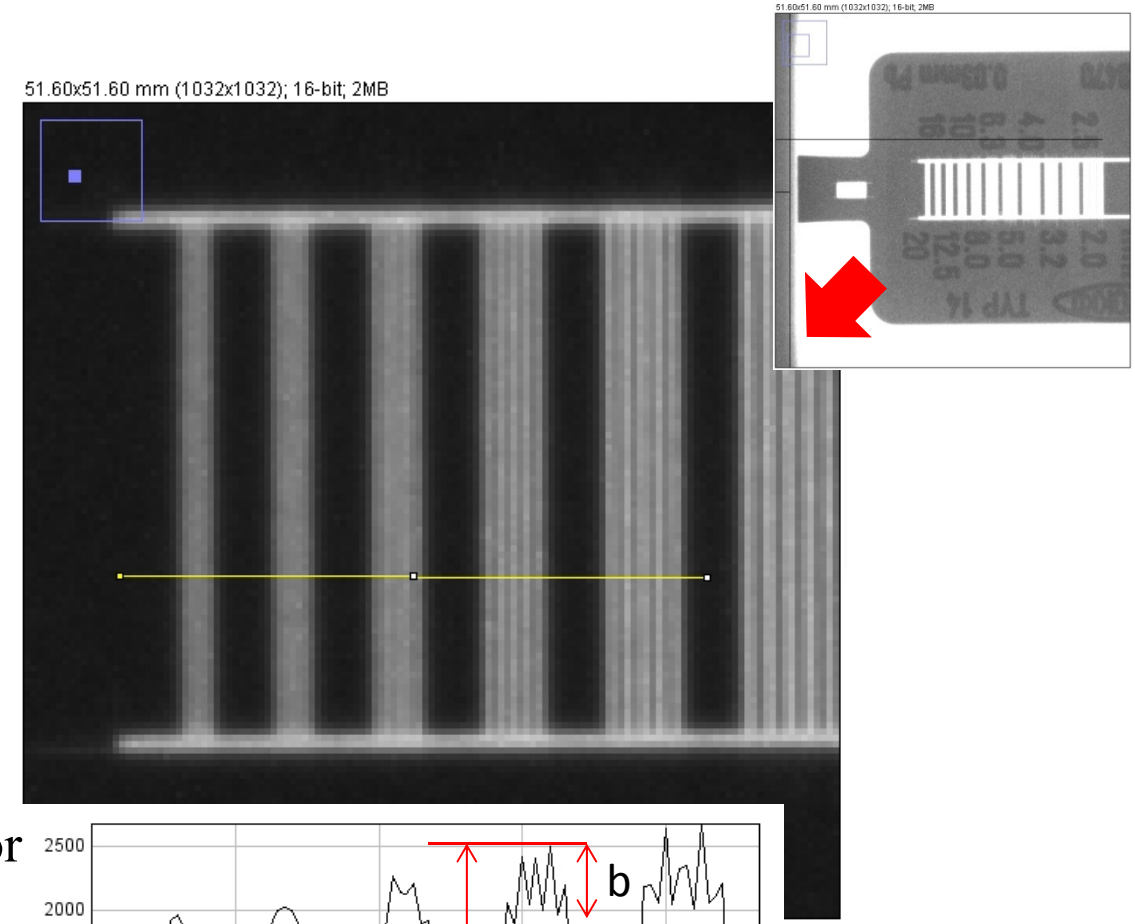
Experimental Setup

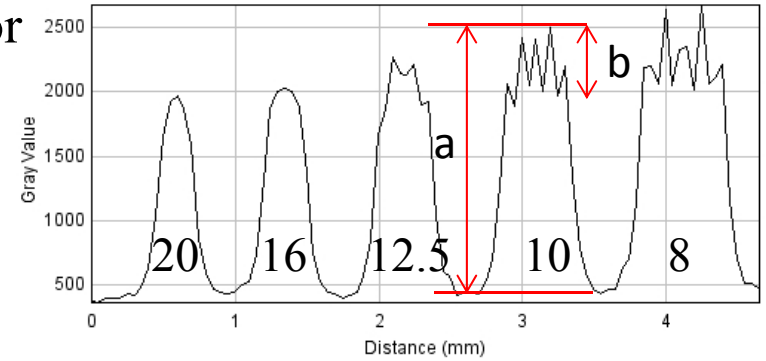


- Test chart (Kyokko)
  Pb 30 μm
  < 20 LP/mm
- Micro chart (JIMA)
  Au 1 μm
  3-50 μm slits
- X-ray Imaging demonstration

Definition of spatial resolution in commercial devices

Commercial flat panel sensor
Pixel size 50µm, 1032x1032 pixels
Converter CsI + CMOS sensors
14bits
"Spatial resolution" = 10 lp/mm
Measured value :
CTF~20% @ 10lp/mm
- Cu target X-ray tube 20kV-2mA
- exposure time 0.4s (min.)
- distance 500mm
- chart put just in front of the sensor

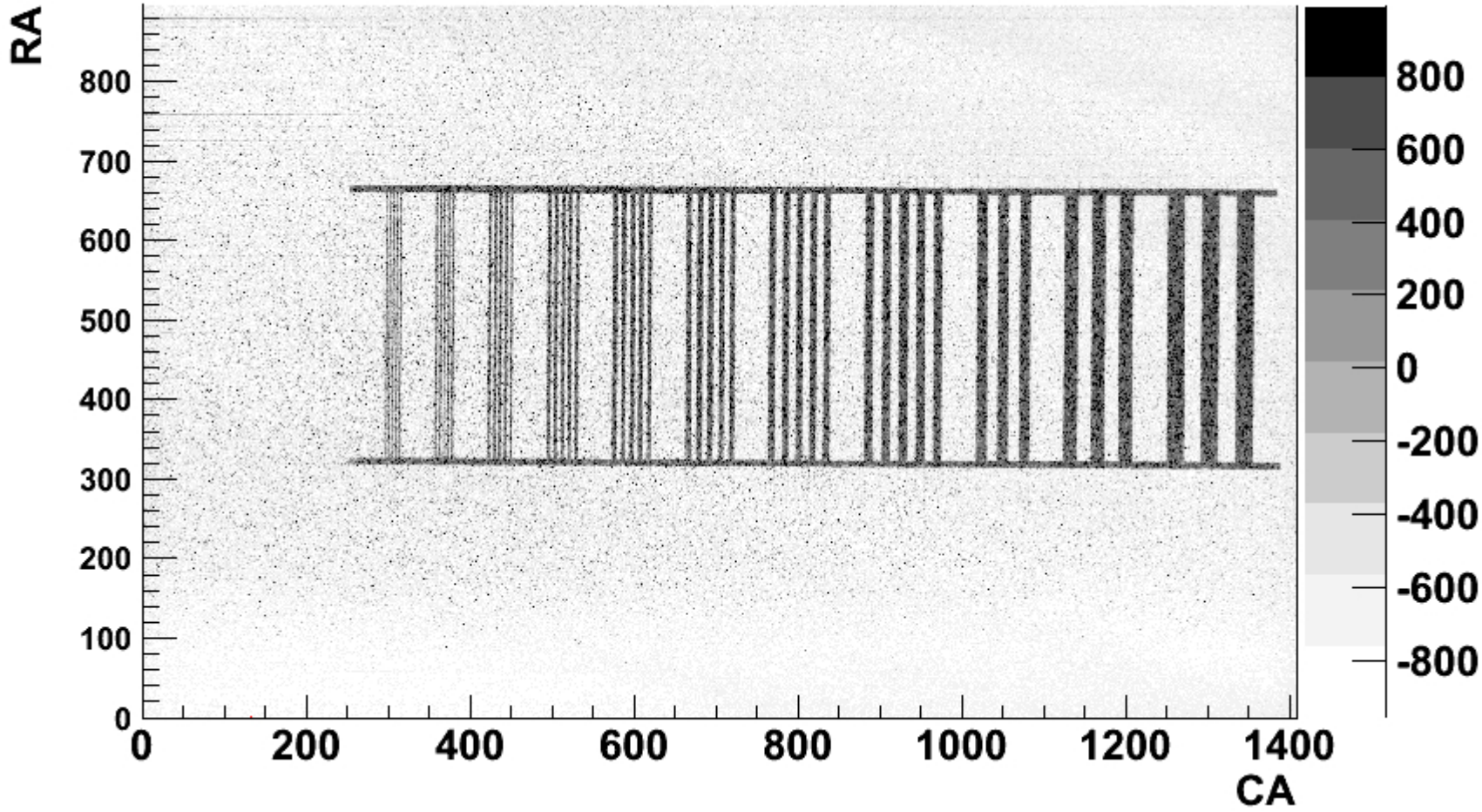




CTF[%]=*100* x *(b/a)*

Most of companies defines spatial resolution with even low CTF value

X-ray test chart X-ray image (INTPIX5)



Condition

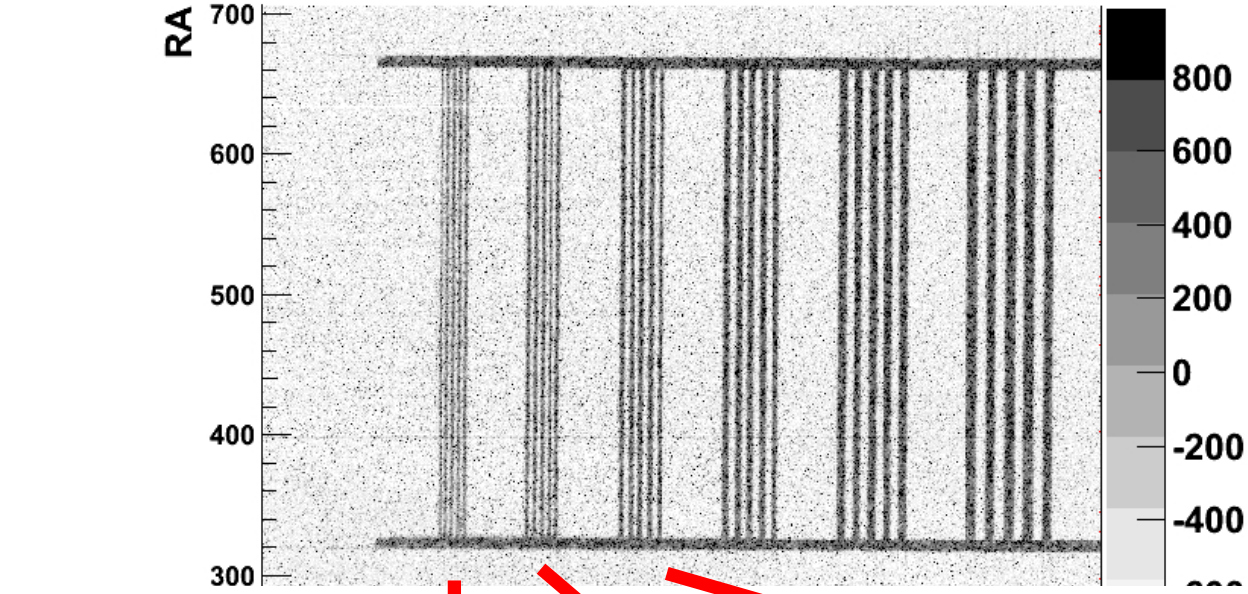
Normal focus (1mm) Cu target X-ray tube

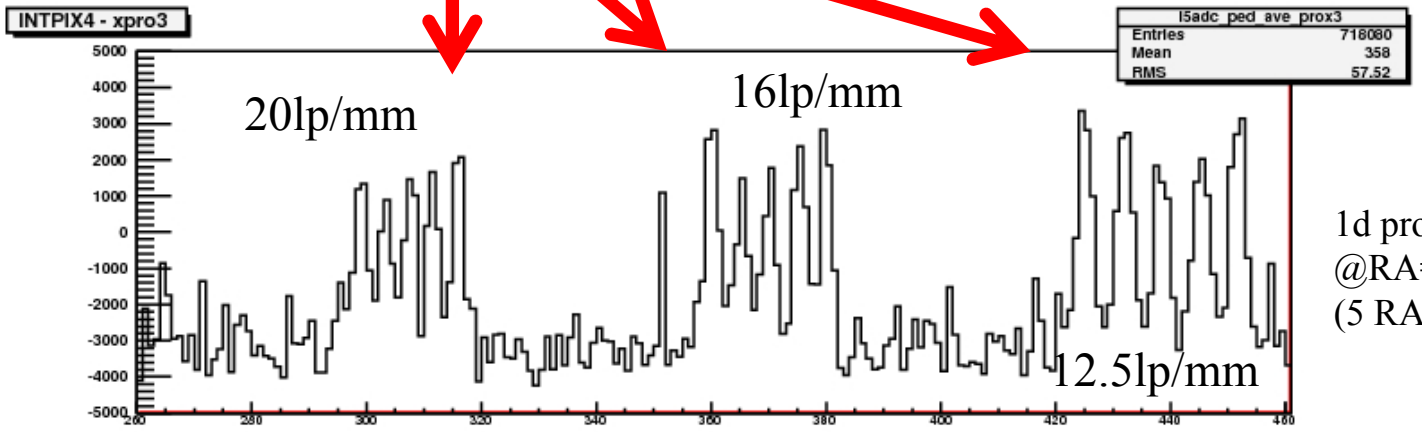
Distance between sensor and target 500 mm

Integration time 200us x 100 shots (net 20 ms exposure)

Sensor voltage (back bias) 150V (partial depletion)

X-ray test chart X-ray image (Zoom-in & profile)



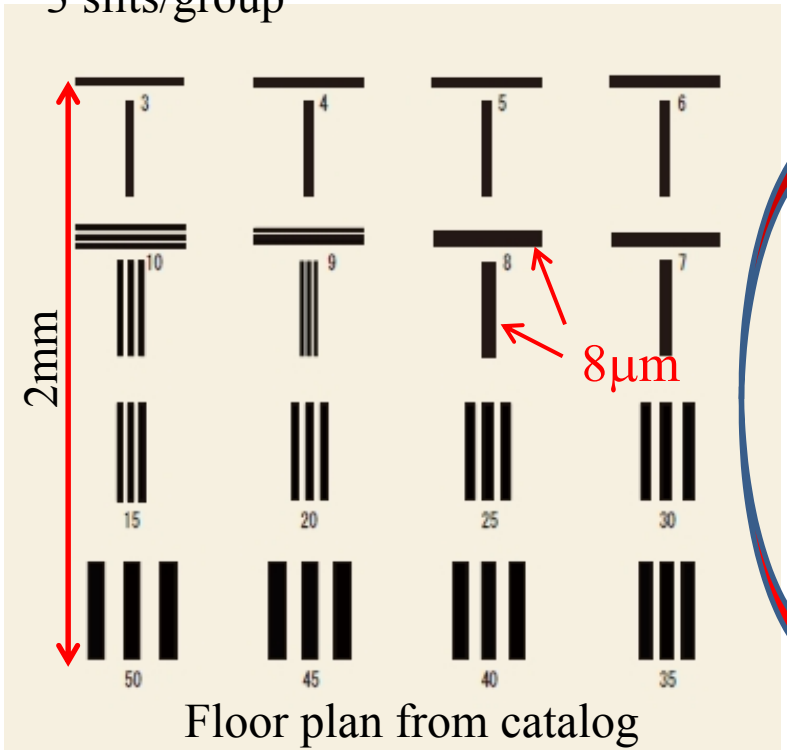


1d profile
@RA=500-504
(5 RA combined)

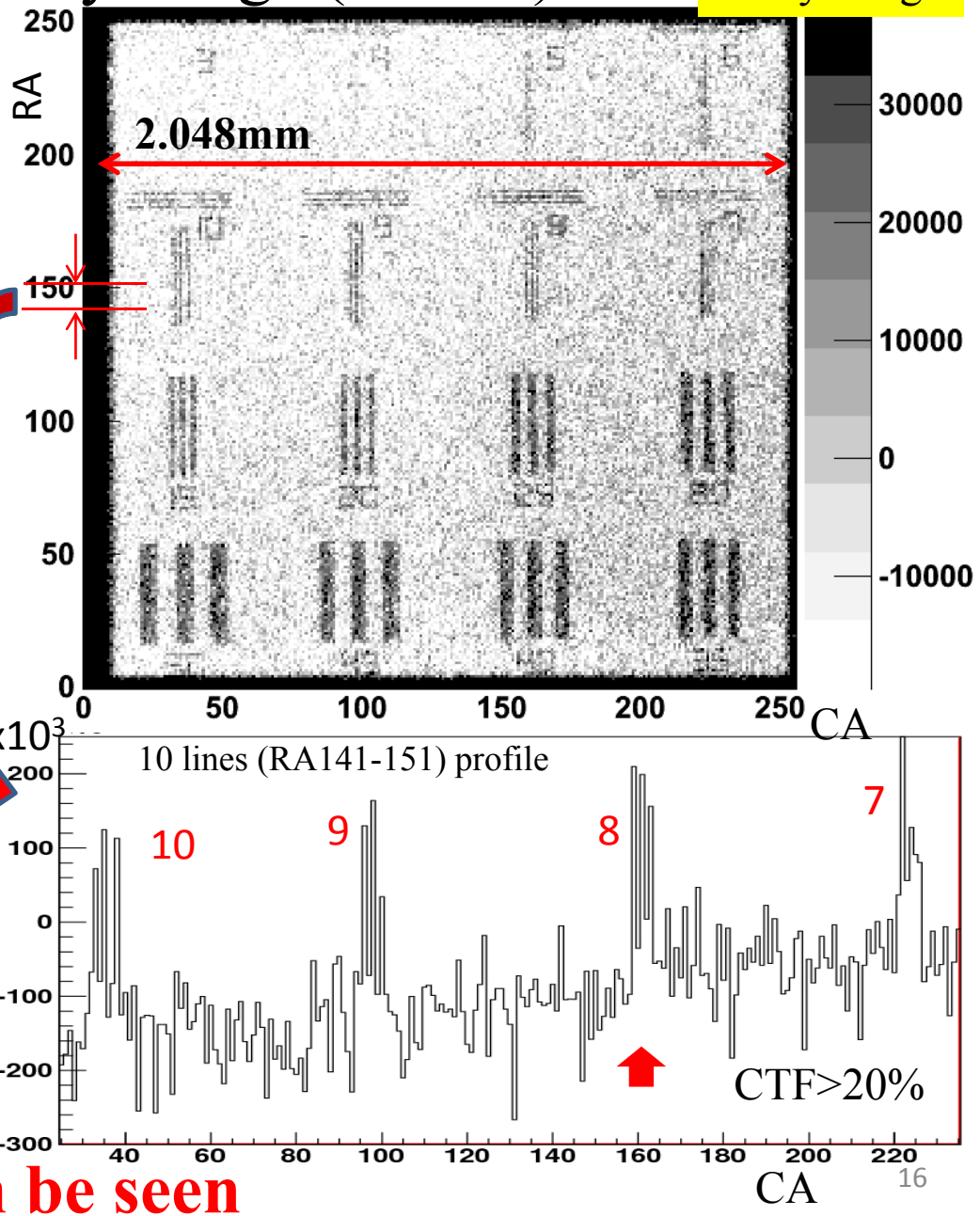
20lp/mm slits are clearly seen
CTF ~ 80%

Micro chart X-ray image (FPIX1)

JIMA RT RC-05 (1μm-Au absorber)
3 slits/group



Floor plan from catalog

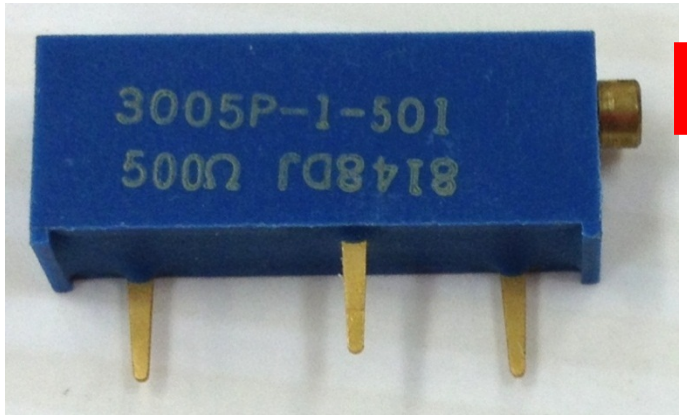


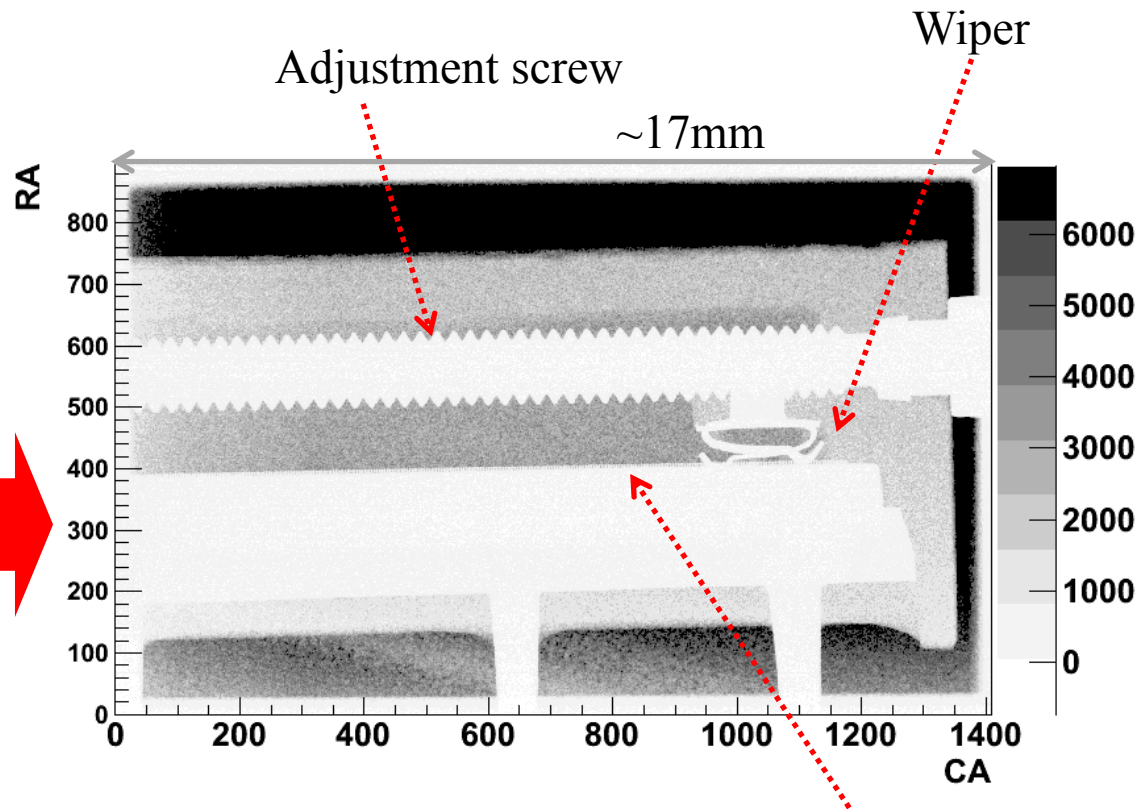
2000 event accumulation
Cr target 30kV-60mA(1.8kW MAX)
FPIX1 (CZn-260um)
Vdet=70V (partially depleted)
Temperature 15deg.

8μm lines can be seen

X-ray imaging demonstration

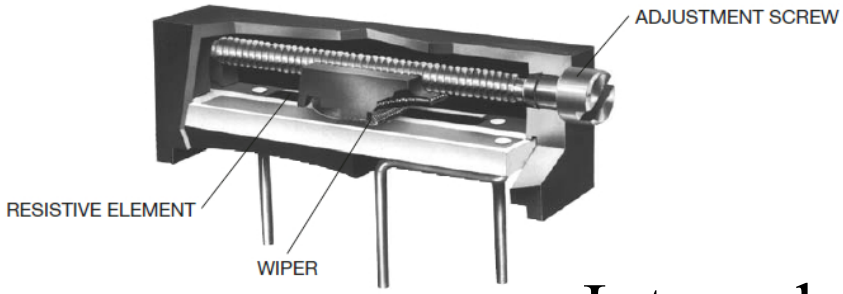
BOURNS 3005
Rectangular Trimpot
Trimming Potentiometer





INTPIX5 Back illumination
150V (partially depleted)
W: X-ray 60kV-10mA (L lines+continuous)
normal focus (1mm)
Distance 500mm
Integration time 200us x 100 shots

Resistive element



Schematic diagram
from catalog

Internal structure can be seen clearly

Summary

We have developed high-resolution integration-type pixel detectors
→ Pixel size 20 μm (2008) → 8 μm (2011)

We may go to smaller pixel size (a challenging work)
or larger pixel size (to add more function)

Am-241 X-ray spectrum was measured with DIPIX
Column ADC worked on DIPIX

INTPIX5 and FPIX1 showed expected spatial resolution
INTPIX5 CTF ~ 80% in 20 LP/mm
FPIX1 CTF > 20% in 8 μm slits
(Cf. 50 μm pixel flat-panel sensor → CTF ~ 20% in 10 LP/mm)

X-ray demonstration with W target X-ray tube was successfully done
We are looking for applications such as medical use,
X-ray imaging, screening inspection, and so on.