X-ray imaging camera using INTPIX4NA SOIPIX detector with SiTCP-XG 10GbE based high-speed readout system

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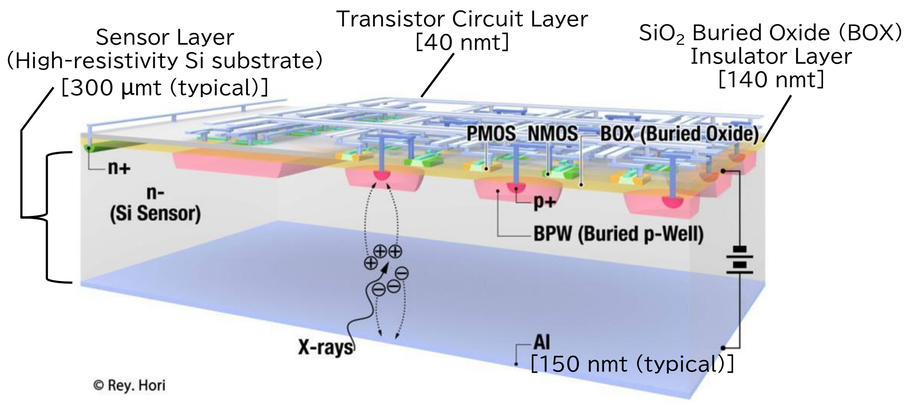
INTPIX4NA SOIPIX Detector

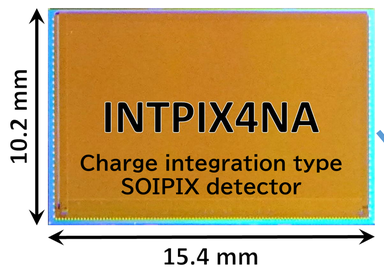
■ Structure of SOIPIX



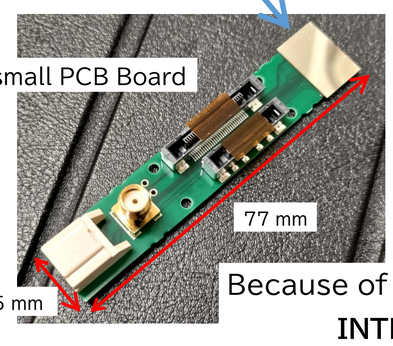
The SOIPIX (Silicon-On-Insulator PIXel) detector is a unique monolithic structure imaging device which is under development by the SOIPIX group led by KEK.

This detector structure is based on a 0.2 µm complementary metal-oxide-semiconductor (CMOS) fully depleted silicon on insulator (FD-SOI) pixel process developed by Lapis Semiconductor Co., Ltd.

■ INTPIX4NA



Implemented to small PCB Board



Because of its sensitivity and spatial resolution performance,

INTPIX4NA is suitable for imaging with 5-20 keV low-intensity X-ray.

Specification

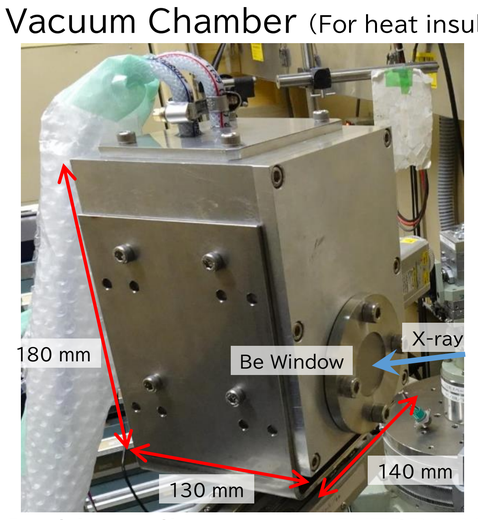
Nishimura, R. et al., J. Inst. 16_P08054 (2021)

Chip size	15.4 × 10.2 mm²
Sensitive area	14.1 × 8.7 mm²
Pixel matrix	832 columns × 512 rows (425,984 pixels)
Pixel size	17 × 17 µm²
Pixel gain	9.3—10.6 µV/*e* (Actual measurement value)
Spatial Resolution	$MTF_{\text{Nyquist Frequency (29.4 cycle/mm)}} > 56$ %, $MTF_{50\%} > 33$ cycle/mm, $MTF_{10\%} > 60$ cycle/mm (Actual measurement value)
Shutter	Global Shutter
Sensor layer	300 µmt (Typical), N type Floating Zone Si wafer
Power Consumption	280 mW (Reset state)
Other features	In-Pixel Correlated Double Sampling (CDS)

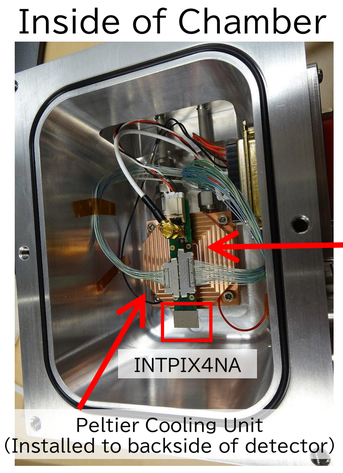
X-ray Camera package

■ Peltier Cooling system

Vacuum Chamber (For heat insulation and avoid condensation)



Inside of Chamber



INTPIX4NA on PCB board

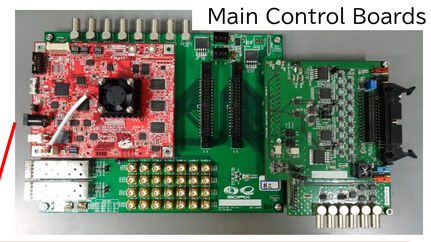
In this cooling system, INTPIX4NA is installed to vacuum chamber, for heat insulation and avoid condensation while cooled down.
While in operation, the detector is cooled to -15℃～-20℃ (typical) by Peltier cooling unit.
Waste heat transported by the Peltier unit from the detector is removed from the chamber by the water-cooling system.

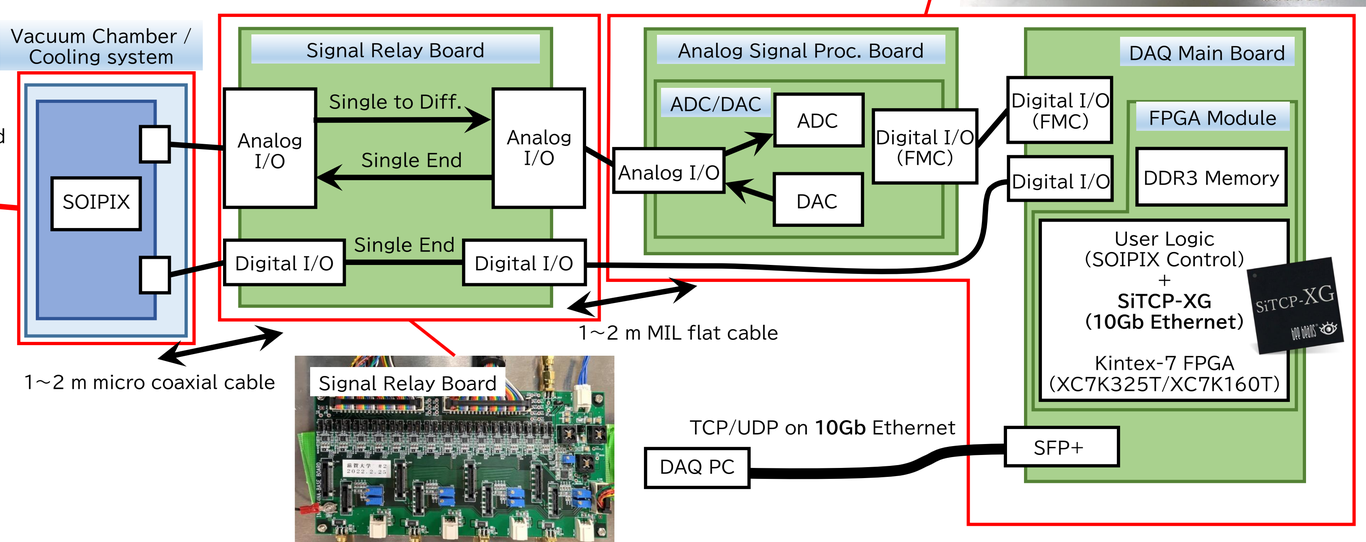
With this cooling system, INTPIX4NA can be operate with longer exposure time (0.5 s / frame).

■ PF-DAQSIX

Photon Factory Data AcQuisition system for SOIPIX Imaging with XG-Ethernet

This readout system is developed for INTPIX4NA SOIPIX detector at KEK Photon Factory (PF).
This system consists of the KX-Card7, AMD Xilinx Kintex-7 FPGA module by Prime Systems, Inc., and several interface boards developed by KEK-PF and collaborators.
SiTCP-XG (Bee Beans Technologies Co., Ltd.) is used as FPGA based 10GbE network controller for high-speed data transfer.

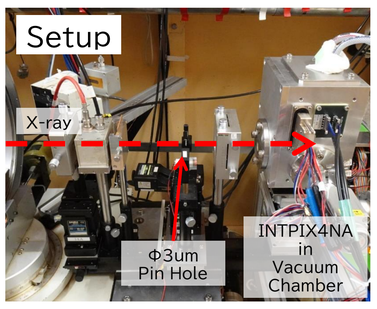




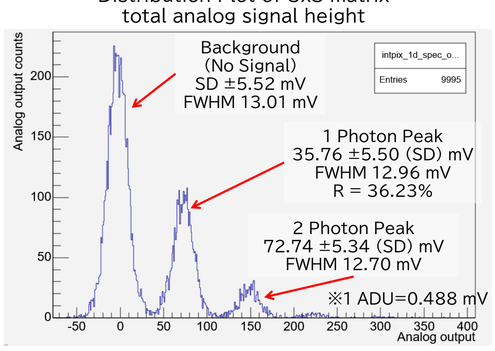
Performance test results

■ Energy Resolution and ENC

Tested at PF BL-14A



Distribution Plot of 3x3 matrix total analog signal height



Experimental conditions

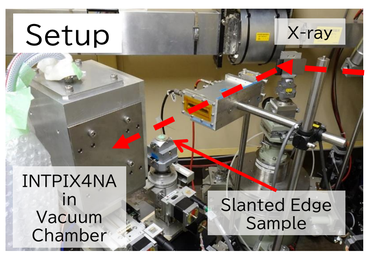
- X-ray : 12 keV monochromatic
- X-ray beam collimated by ϕ3um pinhole was injected to pixel (Col 415, Row 279).
- Energy Resolution ($R(\%) = FWHM_{peak}/Mean_{peak} * 100$) was calculated from total analog signal height of 3x3 matrix (pixel (415, 279) and adjacent 8 pixels).
- Detector temperature : -20℃
- Exposure Time : 1 ms × 9995 frame

Energy Resolution : 36.23 %@12 keV

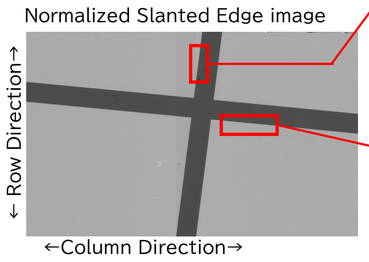
Equivalent Noise Charge (ENC) from Background peak :
FWHM : 13.01 mV, Standard Deviation : 5.52 mV
→SD per pixel : 0.61 mV = ENC (SD) per pixel 61.36e
(Significantly smaller than charge amount by 5keV photon (~1400e / photon).)

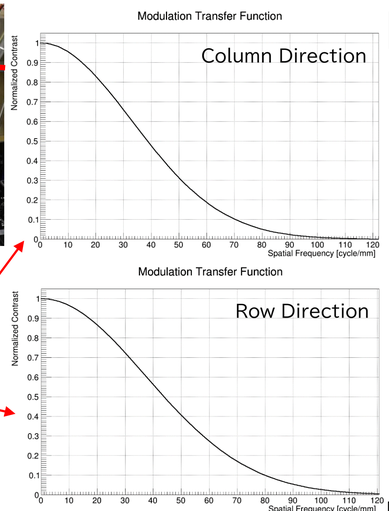
■ Spatial Resolution

Tested at PF BL-14B



Normalized Slanted Edge image





Experimental conditions

- X-ray : 9.6 keV monochromatic
- Calculate Modulation Transfer Function (MTF) from slanted edge contrast.
- Detector temperature : -20℃
- Exposure Time : 1sec (1 ms × 1000 frame)

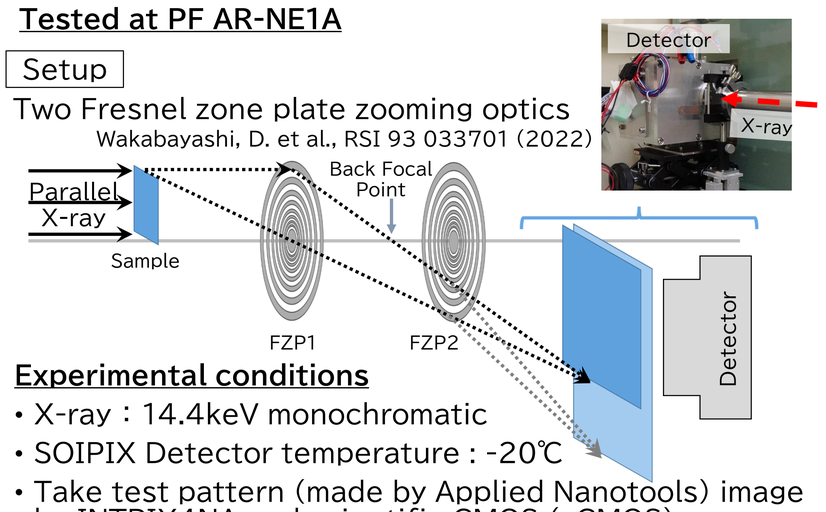
MTF@ Nyquist Frequency (29.4 cycle/mm) > 65%

■ Imaging with low intensity X-ray

Tested at PF AR-NE1A

Setup

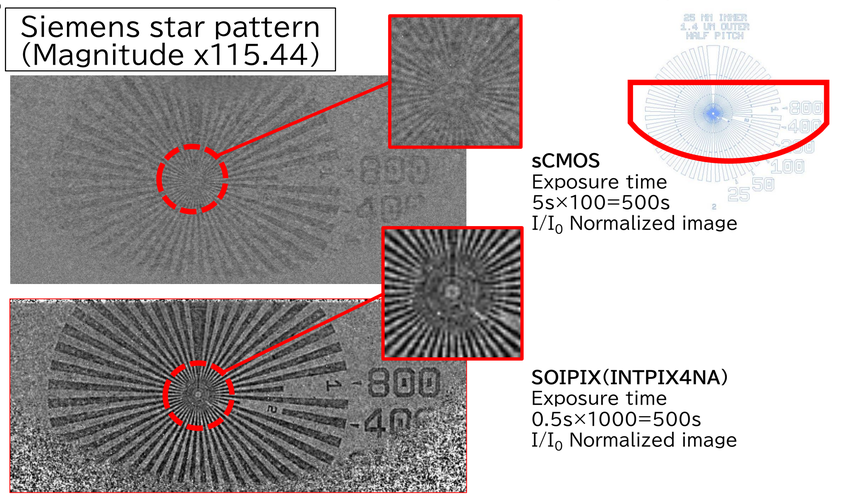
Two Fresnel zone plate zooming optics
Wakabayashi, D. et al., RSI 93 033701 (2022)



Experimental conditions

- X-ray : 14.4keV monochromatic
- SOIPIX Detector temperature : -20℃
- Take test pattern (made by Applied Nanotools) image by INTPIX4NA and scientific CMOS (sCMOS) camera.

Siemens star pattern
(Magnitude x115.44)



Got higher contrast than scientific CMOS (sCMOS).
Central pattern, that cannot be resolved by sCMOS, was resolved !

Conclusions

- Sufficient detection performance confirmed at PF BL-14A/BL-14B.
- Confirmed higher resolution performance than scientific CMOS (sCMOS) for low X-ray intensity condition at two Fresnel zone plate zooming optics in PF AR-NE1A.

This X-ray camera is suitable for imaging under low-intensity, low-contrast conditions, such as soft tissues that do not contrast well, objects with fine structures, and specimens that are vulnerable to radiation damage.