Recent application studies of INTPIX4NA SOIPIX detector based X-ray camera using SiTCP-XG 10GbE based high-speed readout system at KEK facilities

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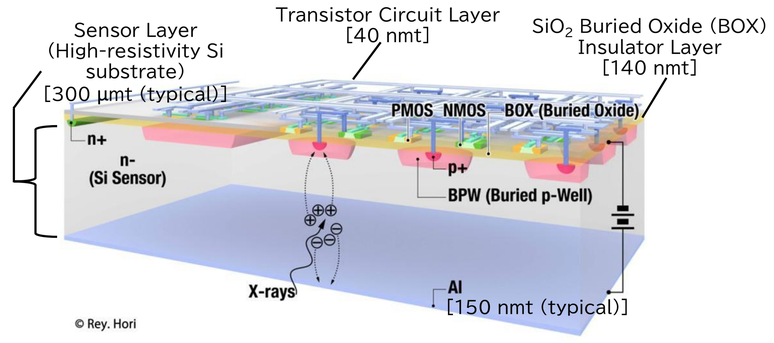
INTPIX4NA SOIPIX Detector

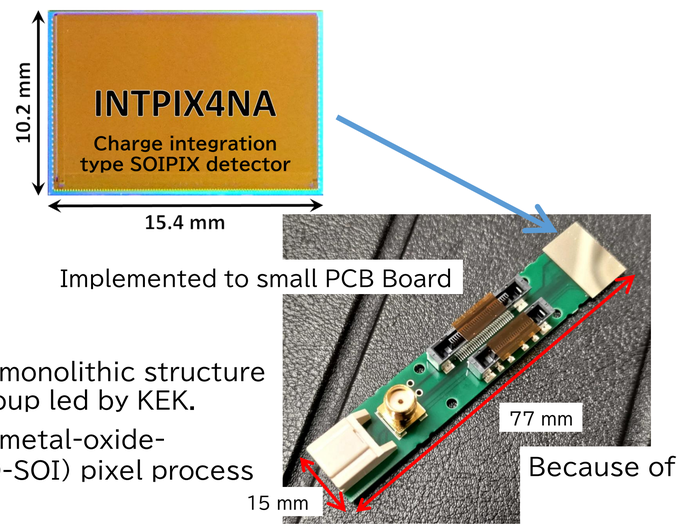
■ Structure of SOIPIX



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



Specification

Nishimura, R. et al., J. Inst. 16 P08054 (2021)

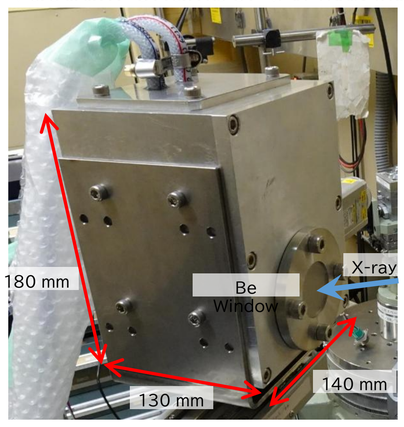
Chip size	15.4 × 10.2 mm²
Sensitive area	14.1 × 8.7 mm²
Pixel matrix	832 columns × 512 rows (425,984 pixels)
Pixel size	17 × 17 μm²
Pixel gain	9.3—10.6 μV/*e* (Actual measurement value)
Spatial Resolution	MTF $_{\text{Nyquist Frequency (29.4 cycle/mm)}}$ > 56 %, MTF $_{50\%}$ > 33 cycle/mm, MTF $_{10\%}$ > 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)

Because of its sensitivity and spatial resolution performance,
INTPIX4NA is suitable for imaging with 5-20 keV low-intensity X-ray.

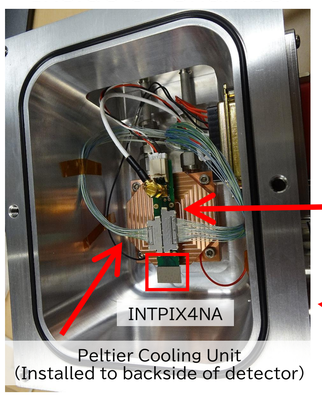
X-ray Camera package

■ Peltier Cooling system

Vacuum Chamber (For heat insulation and avoid condensation)



Inside of Chamber



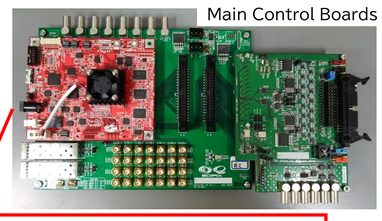
INTPIX4NA on PCB board

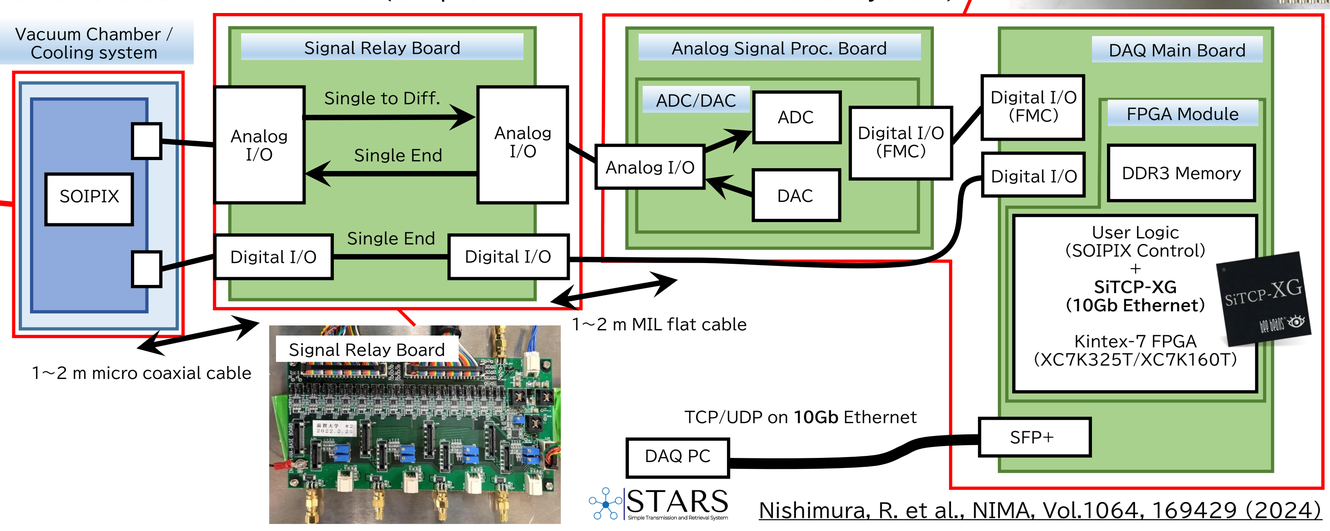
In this cooling system, INTPIX4NA is installed to vacuum chamber, for heat insulation and avoid condensation while cooled down.
While in operation, the detector is cooled to -15℃~-30℃ (typical) by Peltier cooling unit.
Waste heat transported by the Peltier unit from the detector is removed from the chamber 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.
The control DAQ Software is written by C++, can be worked on both Windows and Linux.
This Software supports remote control via STARS (Simple Transmission and Retrieval System).


Main Control Boards



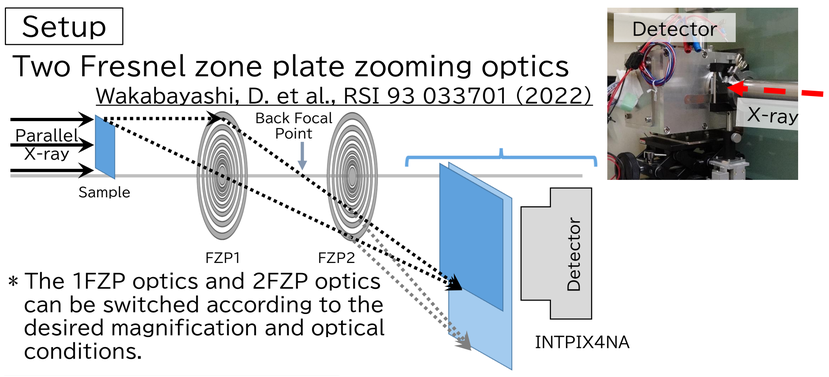
Nishimura, R. et al., NIMA, Vol.1064, 169429 (2024)

Recent application studies in KEK

■ X-ray zooming microscope using two Fresnel zone plates (FZPs) at PF AR-NE1A

Setup

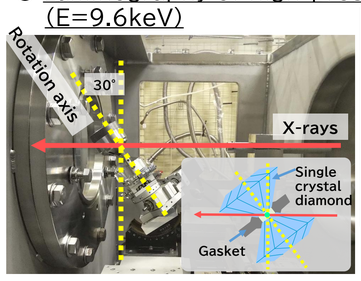
Two Fresnel zone plate zooming optics
Wakabayashi, D. et al., RSI 93 033701 (2022)

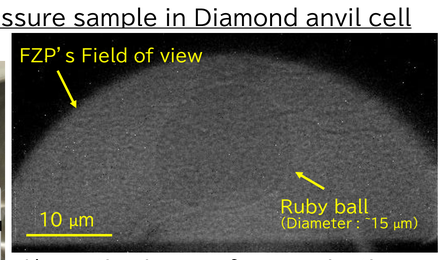


* The 1FZP optics and 2FZP optics can be switched according to the desired magnification and optical conditions.

Measurement Results

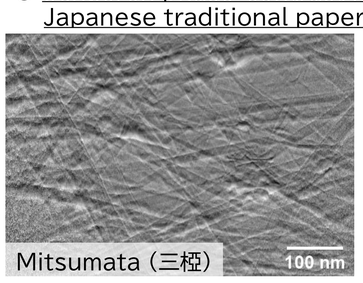
○ Laminography of high-pressure sample in Diamond anvil cell (E=9.6keV)





Absorption image of one projection
Magnitude : x178 (2FZP optics)

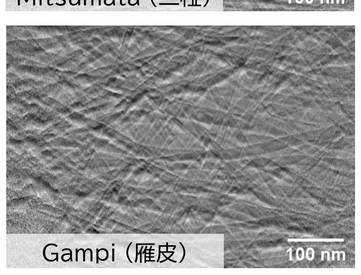
○ Schlieren phase-contrast microscopy of fiber texture in Japanese traditional paper “Washi (和紙)”(E=9.6keV)

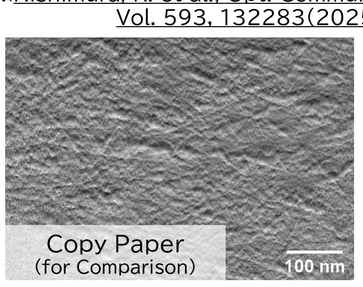


Phase-retrieval image from single-shot schlieren image※
(Two type of Washi and Copy paper for comparison)

Magnitude : x61 (1FZP optics)

※Nishimura, R. et al., Opt. Commun., Vol. 593, 132283(2025)



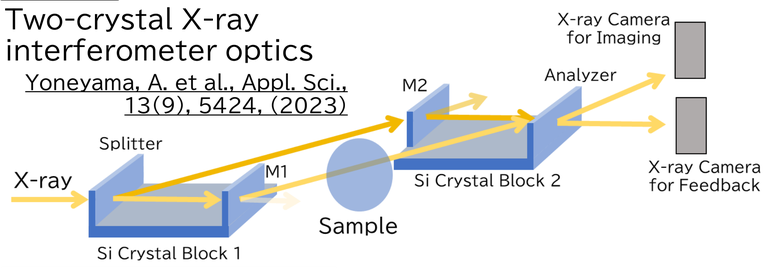


INTPIX4NA images demonstrate excellent contrast even under low-intensity X-ray conditions.

■ Phase-contrast X-ray imaging using a two-crystal X-ray interferometer at PF BL-14C

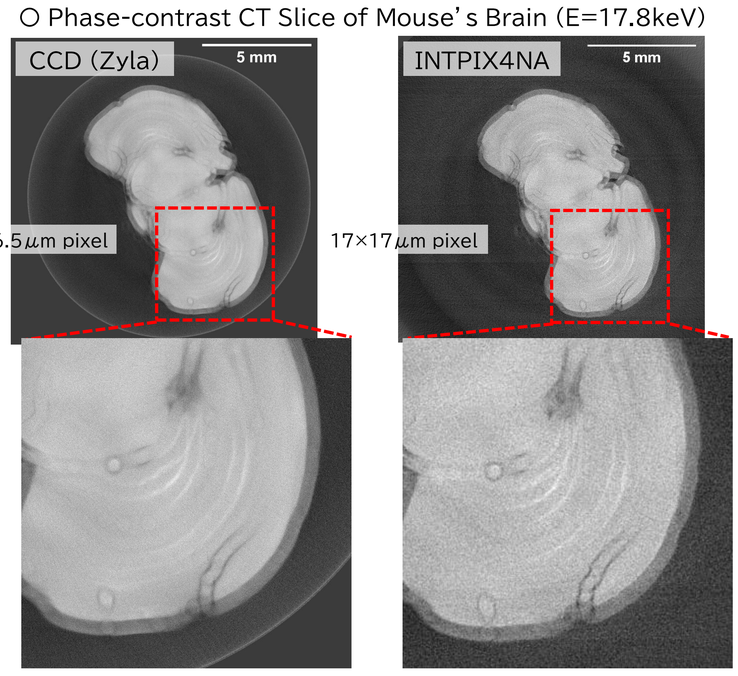
Setup

Two-crystal X-ray interferometer optics
Yoneyama, A. et al., Appl. Sci., 13(9), 5424, (2023)



Measurement Results

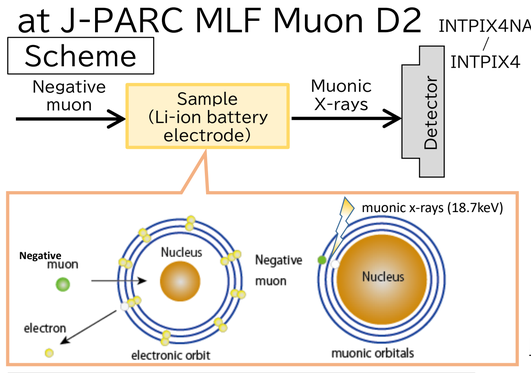
○ Phase-contrast CT Slice of Mouse's Brain (E=17.8keV)



INTPIX4NA images structural boundaries more clearly.

■ Non-destructive detection of lithium in Li-ion battery electrode materials using muonic X-rays at J-PARC MLF Muon D2

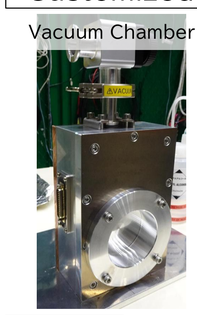
Scheme

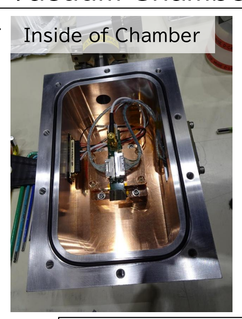


Using muon characteristic X-rays generated when negative muons are captured by lithium nucleus, the distribution of lithium metal within the sample is measured non-destructively.

Umegaki, I. et al., Anal. Chem., 92, 12, 8194−8200, (2020)

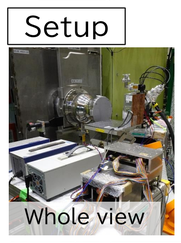
Customized Vacuum Chamber

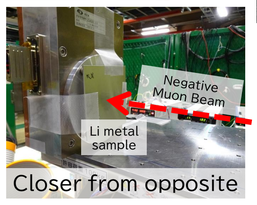

Vacuum Chamber


Inside of Chamber

The cooling system from Peltier unit to outside of chamber was changed from water cooling to air cooling in accordance with the change in cooling temperature.
This system can cool the detector to -5℃ (typical).

Setup

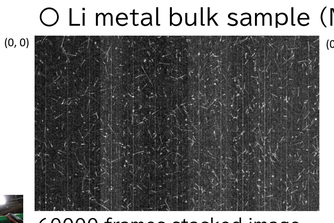

Whole view



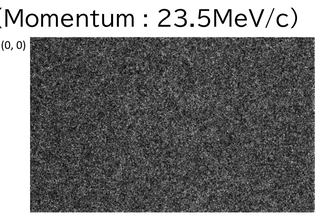
Closer from opposite

Measurement Results

○ Li metal bulk sample (Momentum : 23.5MeV/c)



60000 frames stacked image
(Including all detected particle)



60000 frames stacked image
(Signals not believed to be X-rays are excluded)

It is expected that X-rays signals can be sufficiently separated from the signals of various particles.

Conclusions

- We developed an X-ray camera using INTPIX4NA and SiTCP-XG 10GbE based readout system.
- INPIX4NA X-ray camera is being used for several experiments conducted at KEK facilities.
- Some experimental results have demonstrated superior performance compared to conventional equipment currently in use at KEK facilities.