Development of a 200-nm-resolution X-ray imaging detector with a field of view of 2 mm square

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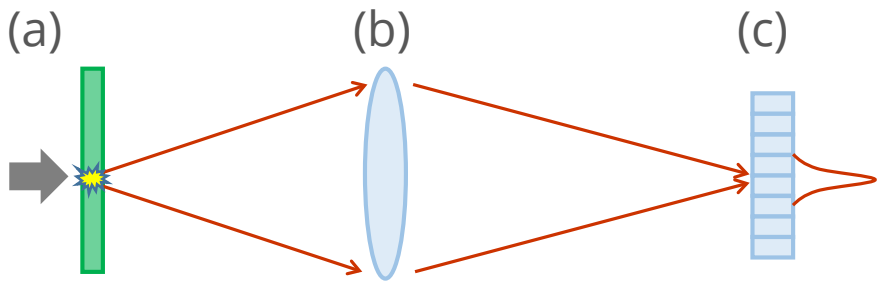
SACLA

Introduction

Lens-coupled imaging detector

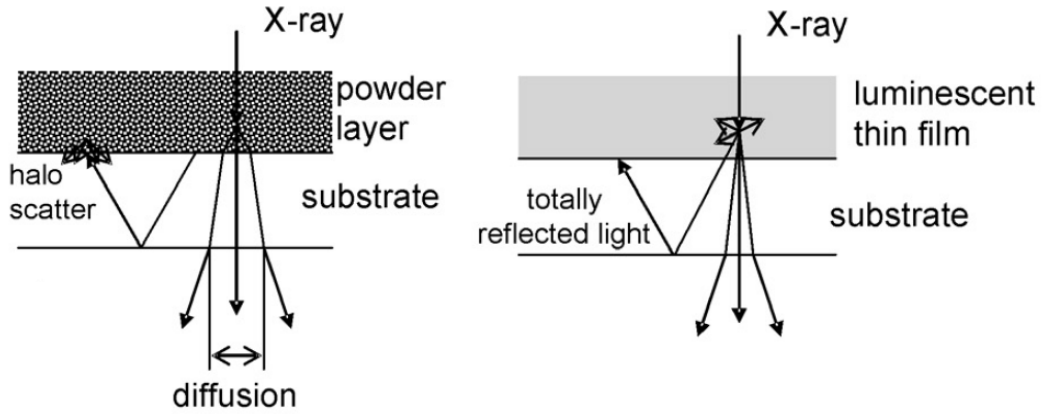


(a) Scintillator
- Thickness matched to depth of field

(b) Optics
- High NA for resolution enhancement

(c) Image sensor
- Optimum sampling of airy disk

Resolution deterioration



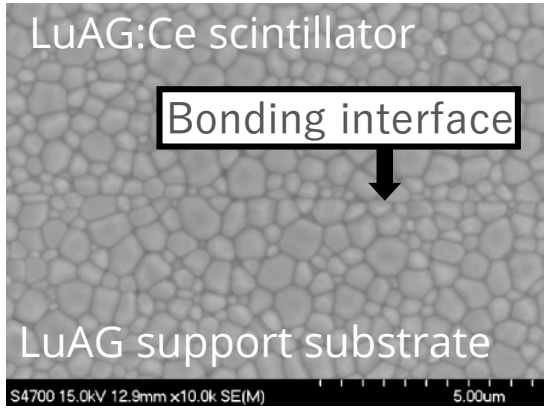
H. Graafsma and T. Martin, in Advanced tomographic methods in materials research and engineering 277 (2008)

- Residual pores and voids
- Unmatched interface
- Distortion
- Rough surfaces
- X-ray damage of an adhesive layer
- X-ray damage of imaging optics

Development of indirect detector at SACLA

Transparent ceramic film scintillator

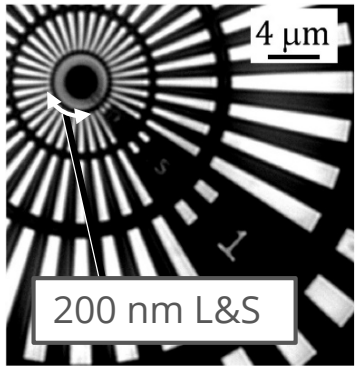
5-μm-thick LuAG:Ce



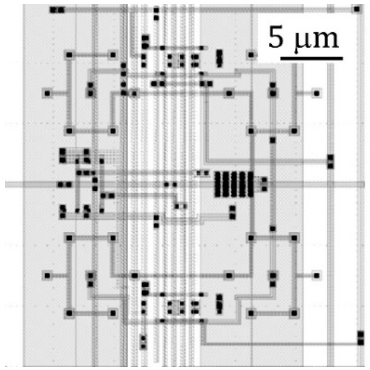
SEM image of bonding area

- No pores and voids
- Quasi-homogeneous refractive index
- Low distortion
- High radiation hardness
- Strong radiation shielding
  (10^{-40} at 10 keV, 10^{-11} at 20 keV, 10^{-4} at 30 keV)

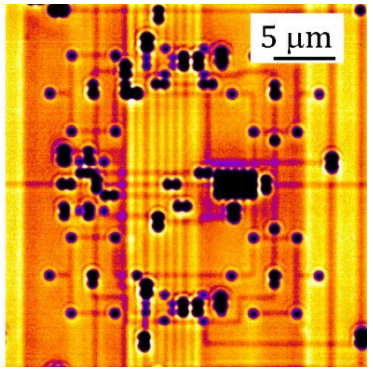
Demonstration of resolving power



X-ray transmission image of test chart

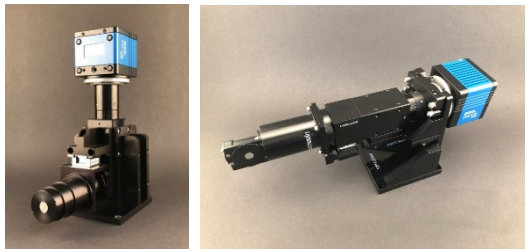


200 nm process VLSI circuit drawing



X-ray transmission image of VLSI

- Near diffraction-limited performance
- So far about 10 detector systems are deployed at SPring-8/SACLA mainly for the beam monitors

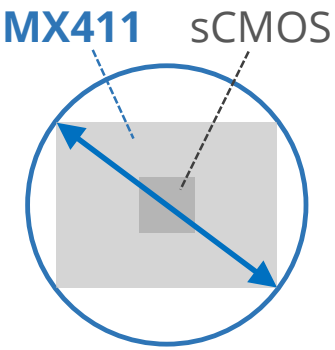


Deployed imaging units

See the detail in the appendix slide (page 6)

Enhancement of field of view

Large format image sensor

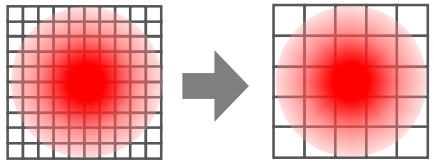


diagonal 67 mm

SONY IMX411 sensor

14,192 x 10,640, 3.76 μm pixels
53.3 x 40 mm^2 chip
Back illumination
16 bit depth

Sampling optimization



Airy disk radius = 2~3 effective pixels
(spatial resolution)

NA optimization

$$\mathrm{D.Q.E} = \underbrace{\eta_{xqe}}_{\text{X-ray shot noise}} \underbrace{\left(1 + \frac{1}{\eta_{ly} \cdot \eta_{ce} \cdot \eta_{vqe}}\right)^{-1}}_{\text{Photon shot noise}}$$

η_{xqe} : X-ray Q.E.
η_{ly} : Light yield
η_{ce} : Light throughput
η_{vqe} : Visible photon Q.E.

Upgraded detectors

		Developed lens	Commercial off-the-shelf lenses			
		Lens A1	**Lens A2**	**Lens A3**	**Lens A4**	**Lens A5**
Resolution (L&S)	**[μm]**	~0.2	0.45	0.6	1.0	1.9
Field of view	**[mm²]**	2.6 x 1.9	7.6 x 5.7	10.3 x 7.7	15.2 x 11.4	53.3x 40.0
Conversion	**[e-/X-ray]**	10.6 @ 10 keV	1.98 @ 10 keV	1.21 @ 10 keV	0.78 @ 20 keV	0.33 @ 30 keV
DQE	**[%]**	15 @ 10 keV	42 @ 10 keV	44 @ 10 keV	31 @ 20 keV	21 @ 30 keV

Summary

- Transparent-thin-film scintillator was successfully produced.
- Near-diffraction-limited resolution is achieved.
- Imaging systems are deployed to SACLA & SPring-8.
- An indirect detector resolving 200 nm line & space with a FOV of 2 mm square is planned to be developed for high resolution X-ray CT.

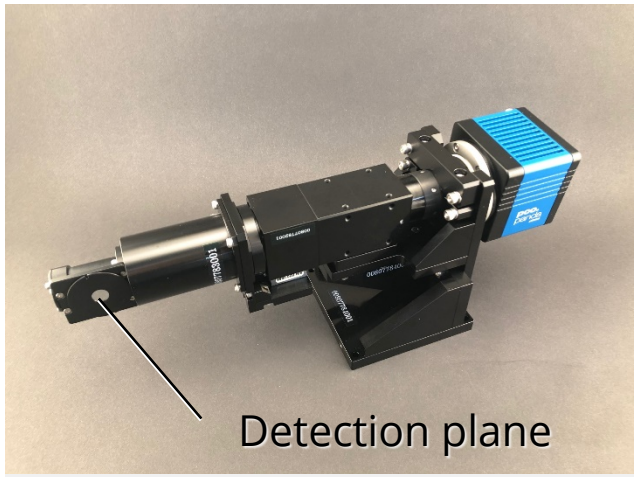
Thank you for your attention

Deployed imaging units at SACLA & SPring-8

Standard unit

High resolution

Off-axis unit



High energy, narrow space

- 5 μm-thick LuAG:Ce scintillator layer (min.)
- ϕ 21.4 image circle
- Radiation shielding for objective lens protection
  (attenuation of 10^{-40} at 10 keV, 10^{-11} at 20 keV, 10^{-4} at 30 keV)
- Scintillator replaceable
- Objective lens replaceable
- Camera optionality (c-mount)
- Sample-scintillator proximity design (min. 0.3 mm w.d.)

Optical configuration		100x	50x	20xHR	20x	10x	5x	2x	1x
Resolution(L&S)	[μm]	~ 0.2	~ 0.25	~ 0.25	~ 0.35	~ 0.65	~ 1.1	~ 2.6	~ 4.0
Field of view	[mm^2]	0.13 x 0.13	0.27 x 0.27	0.67 x 0.67	0.67 x 0.67	1.3 x 1.3	2.7 x 2.7	6.7 x 6.7	13 x 13
Conversion	[e-/10 keV]	~ 12	~ 8	~ 8	~ 3.2	~1.4	~ 0.35	~ 0.06	~ 0.02

Configuration to resolve 200 nm L&S patterns

Objective line-up for Standard unit

Objective line-up for Off-axis unit

These imaging units and scintillators are commercially available from SIGMAKOKI CO.,LTD.