Introduction of MPCCD detector systems at SACLA

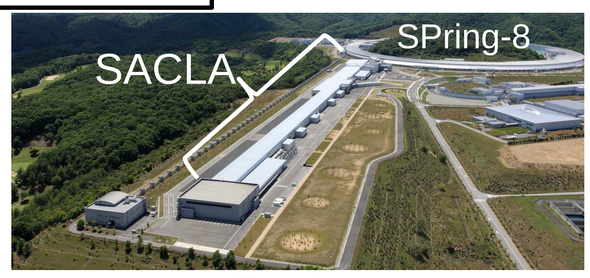
SACLA Users' Meeting 2019 poster No. 9

K. Ozaki[1], S. Ono[1], O. Sugata[1], Y. Matsuda[1*], T. Kameshima[1,2], Y. Inagaki[1], T. Tosue[1], K. Kobayashi[1,2], Chih-Hsun Lin[3], Ming-lee Chu[3], N. Tanaka[4], K. Kubo[4], H. Murao[4], D. Kosaka[5], T. Imamura[5], A. Iwata[5], T. Hatsui[1]
(RIKEN[1], JASRI[2], Academia sinica[3], MEISEI ELECTRIC CO., LTD.[4], A-R-Tec Corp.[5])
*Y. M is now with MIST Co., Ltd

Outline

We have developed an Multi-port CCD (MPCCD) detector family as X-ray two dimensional detector for the SACLA facility [1]. The MPCCD detector has been operated from the start of commissioning in May 2011 more than seven years. In order to fully exploit the potential of SACLA, we have developed variants of sensors, camera systems, and camera heads. As of now, we have successfully developed three types of sensor device, two generations of camera system, and 16 variants of camera head. In this presentation, we report current status of the MPCCD detector family.

Introduction



SACLA features
Intensity : 10^{11} phs./pulse
Pulse width : < 10 fs
Repetition rate : 60 Hz
Energy range : 4.0-20.0 keV

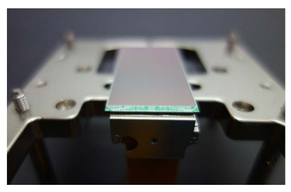
Requirements for detector
- > 1000 phs./pulse/pixel
- Single photon detection
- Charge integration type
- Radiation hardness over 1 annual dose (～60 Mrad.)
- ≦50 μm pixel size
- Large area

Facility decision
The facility develops MPCCD detector as a special detector.
(Because of the requirements can not be achieved by COTS detectors.)

Sensor variants

Phase I : Standard device
- Epitaxial silicon
- Front illumination

Phase III : Thicker device
- Bulk silicon
- Back illumination
- Low noise type (Phase III-L) was also developed.



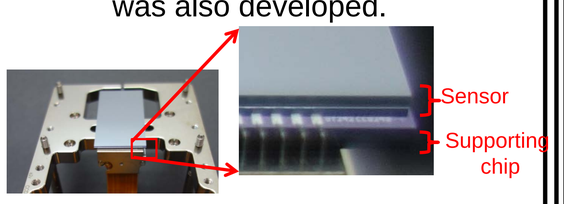
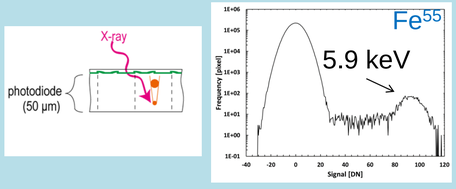


Table. 1 Performance of sensors under service

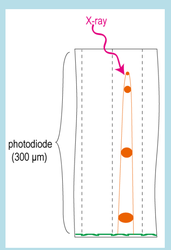
	Phase I family	Phase III family	
	Phase Ib	Phase IIIb	Phase III-L
Feature	Workhorse at SACLA for most of the experiments.	Higher Q.E. by compromising on PSF.	Higher Q.E. by compromising on PSF. Lower noise by compromising on Peak signal.
Image format	1024 x 512 pixels, 50 μm pixel Front illumination	1024 x 512 pixels, 50 μm pixel Back illumination	
Sensitive layer thickness [μm]	50	300	
ENC [e^- r.m.s.]	110～180	130～230	32～47
PSF [μm r.m.s.]	3.3@12keV, 830 phs.	9.4@12 keV,49 phs. 13.9@12 keV, 1030 phs.	
Q.E. [%@12 keV]	19	73	
Full-well capacity	3.5～4.3 Me^- 2130～2620 phs.@6 keV	3.2 Me^- 1950 phs.@6 keV	1.7 Me^- 1030 phs.@6 keV

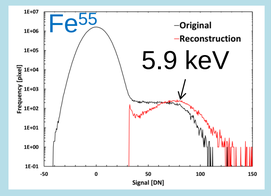
Single photon detection

Phase I family — Phase Ib

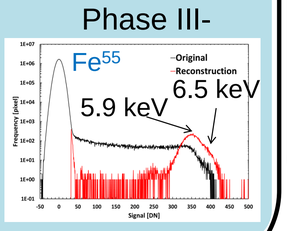


Phase III family — Phase IIIb

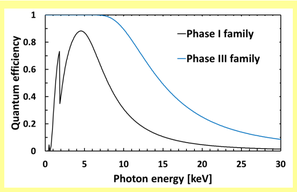




Phase III-



Comparison of Q.E.



Camera system

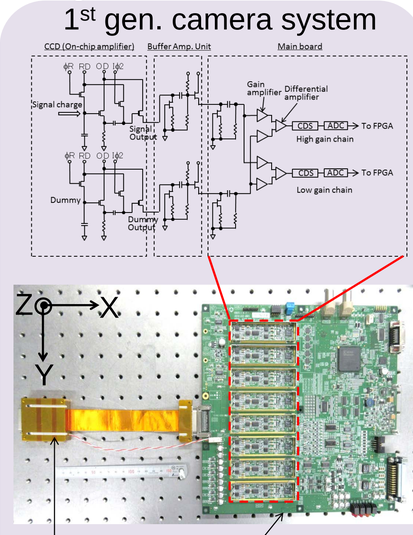
1st gen. camera system worked well at first.[1]
But・・・

- **Issues in the accuracy**
  - ✓ Port-wise cross-talk
  - ✓ Undershoot (serial & parallel)
- **Only 30 fps operation**
  - ✓ Significant accuracy degradation at 60 fps operation.
- **New needs from users**
  - ✓ In-vacuum operation
  - ✓ > 4 M pixel detector with 4-side butted sensor array

Compact camera system was developed to solve all issues and to achieve all needs

Signal readout circuit schematics and circuit photos

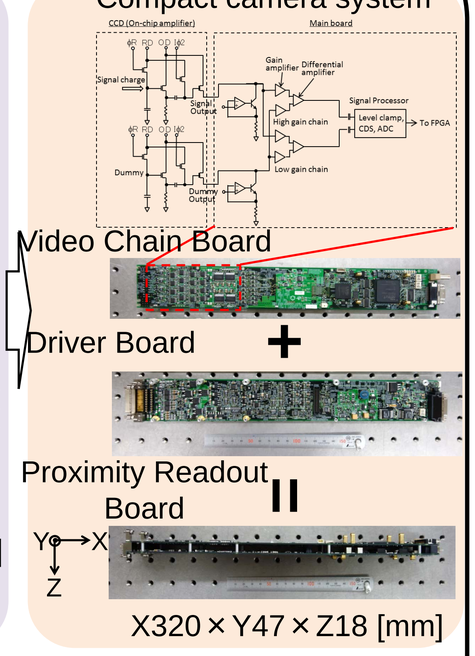
1st gen. camera system



X260 × Y250 × Z51 [mm]

X217 × Y50 × Z15 [mm]

Compact camera system



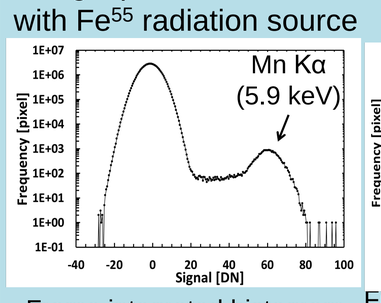
X320 × Y47 × Z18 [mm]

Table. 2 Detector performance for phase Ib sensor

	1st Gen.	Compact	Units	Note
Parallel transfer time	6.4	3.2	μs	
Pixel readout rate	3.33	5.56	MHz	
Frame rate	30	60	Hz	Max.
System noise	100～250 0.06～0.15	110～180 0.07～0.11	e^- r.m.s. phs.@6keV	
Background distribution	Gaussian	Gaussian	N/A	
Peak signal	> 3.8	> 3.8	Me^-	
Full-well	Measurement impossible	> 3.5	Me^-	Parallel CTE > 99.999 %
Non-linearity	1	1	%	Max.
Port-wise cross-talk	2000 (calibrate < 50)	2000 (calibrate < 50)	ppm	Max. Linear
Background time-stability	< 45 < 0.03	< 90 < 0.05	e^- p-p phs.@6keV	At 12 h
Undershoot (parallel)	> 0.4	Undetectable (< 0.01)	%	
Undershoot (serial)	0.3	0.2	%	Max.

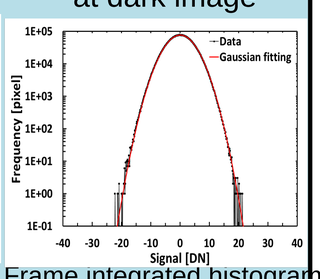
Estimation for noise performance

Single photon detection with Fe^{55} radiation source



Frame integrated histogram (Integrated frames are 1000.)

Signal distribution at dark image

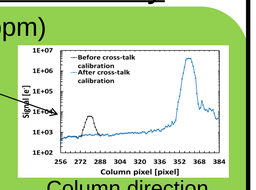


Frame integrated histogram (Integrated frames are 100, System gain = 26.2 e^-/DN)

Estimation for signal accuracy

Crosstalk signal (1300 ppm)

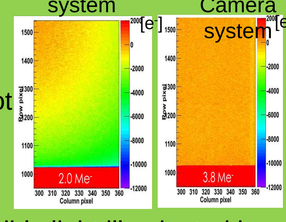
Port-wise crosstalk



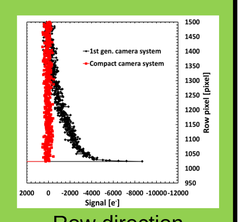
He-Ne laser illuminated image

Column direction line profile at row number = 587

Undershoot (Parallel)

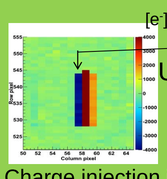


Visible light illuminated image



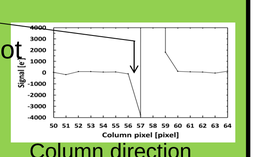
Row direction Line profile at column number = 296

Undershoot (Serial)



Charge injection image (4 Me^- injected in red part)

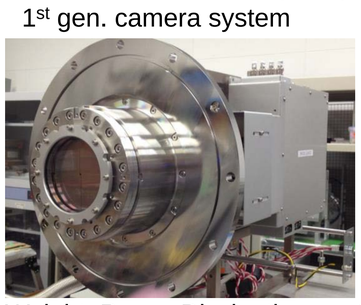
0.08 % Undershoot

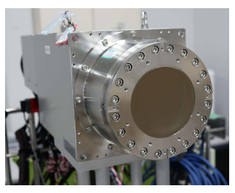


Column direction Line profile at row number = 528~544 (Row direction averaged)

Detector example (Octal sensor detector)

1st gen. camera system — Compact camera system





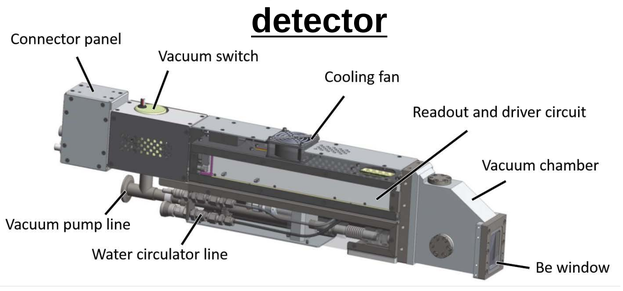
Weight, Power Dissipation, and Footprint reduced significantly.
Power Dissipation is 29 W for a CCD, which contribute to the X-ray optics stability

Table. 3 Additional function for detector

	1st Gen.	Compact	Note
Analog binning	Possible	Possible	1(V)x2(H) or 2(V)x2(H)
In-vacuum operation	Impossible	Possible	Water cooling
Electro magnetic pulse protection	None	Possible	10 Hz operation only. Additional board necessary.
Self-diagnosis	None	Possible	

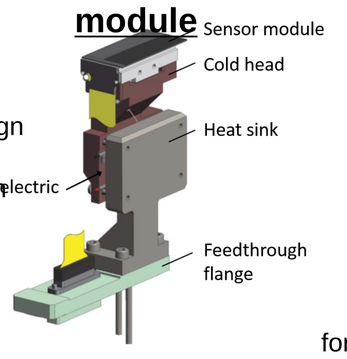
Camera-head variants

Single sensor detector

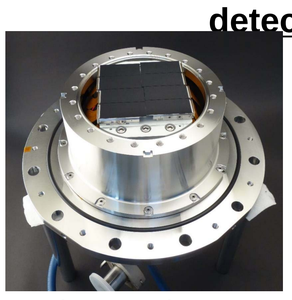


Camera-head module

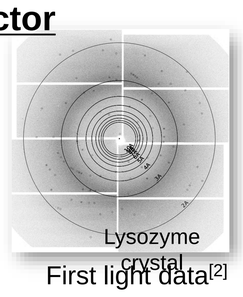
- Fast and flexible array design
- Fast construction



Octal sensor detector

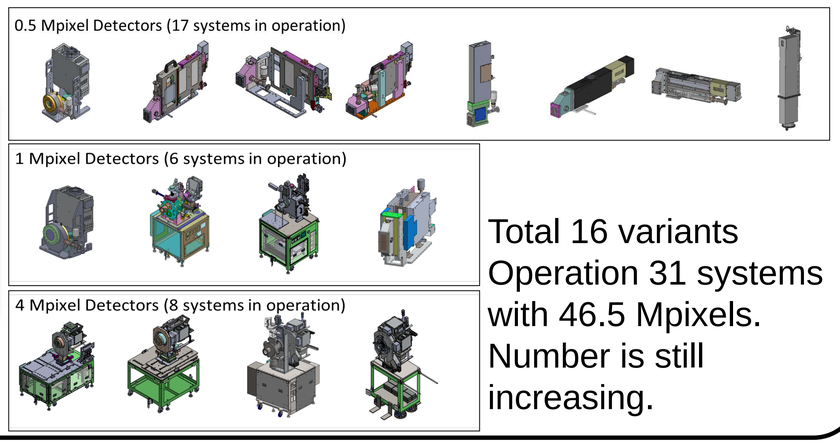


Octal sensor detector for crystallography experiments



First light data[2]

Detector



Total 16 variants
Operation 31 systems with 46.5 Mpixels.
Number is still increasing.

Summary

- MPCCD detectors have operated for seven years with successful scientific outcome at SACLA.
- We developed and mass-produced MPCCD sensors including sensors with high sensitivity suitable for SACLA.
- Compact camera system enabled 60 Hz operation and enhanced the data accuracy.
- Modular design enabled developments of 16 mechanical variants in short lead time.

Acknowledgement and Reference

The authors are grateful for the cooperation of Teledyne e2v on the development of the MPCCD sensors. This work was partly supported by X-Ray Free Electron Laser Priority Strategy Program (MEXT) and JSPS KAKENHI grant 13321217.

[1] T. Kameshima et.al., Review of Scientific Instruments 85, 033110 (2014)
[2] C. Song, et.al., J. Appl. Cryst. (2014). 47, 188–197.
[3] References in the review, T. Hatsui and H. Graafsma IUCrJ, Vol. 2, p. 371 (2015).
[4] Publications can be found at http://xfel.riken.jp/eng/research/indexnne.html