High-resolution Wide-band X-ray Photon-Counting Detector with Scintillator Directly-coupled Charge-coupled Device

Kazuhiro Ikegami, Michihiko Aono, Noriaki Tawa, Emi Miyata, Hiroshi Tsunemi (Osaka University)
Yasushi Ogasaka, Keisuke Tamura, Ryo Shibata (Nagoya University)
Kazuhisa Miyaguchi (Hamamatsu Photonics K.K)

We report on a new photon-counting detector possessing unprecedented spatial resolution and moderate spectral resolution for 0.1-100 keV X-rays. It consists of an X-ray charge-coupled device (CCD) and a scintillator. The scintillator is directly coupled to the back surface of the X-ray CCD. Low-energy X-rays below 10 keV can be directly detected by the CCD. The majority of hard X-rays above 10 keV pass through the CCD but can be absorbed by the scintillator, generating visible light photons. Since CCDs have a moderate detection efficiency, visible light photons can be detected by the CCD. We coupled the needlelike CsI(Tl) on the front surface of the back-illuminated (BI) CCD. We measured the hard X-ray responsivities of the newly developed SD-CCD with monochromatic X-ray beam for 20-80 keV. The excellent linear relationship is obtained between the incident X-ray energy and the peak pulse height. The energy resolution depends on the inversely square-root of energy. We will perform the balloon-born experiment of the hard X-ray observation with hard X-ray focusing telescope, Supermirror, in October 2006 at Brazil.

1. SD-CCD

Scintillator-deposited CCD (SD-CCD) is a detector which combines CCD and scintillator. Figs.1 and 2 shows a schematic view and a cross section of SD-CCD. Scintillator is directly deposited on the backside of CCD.

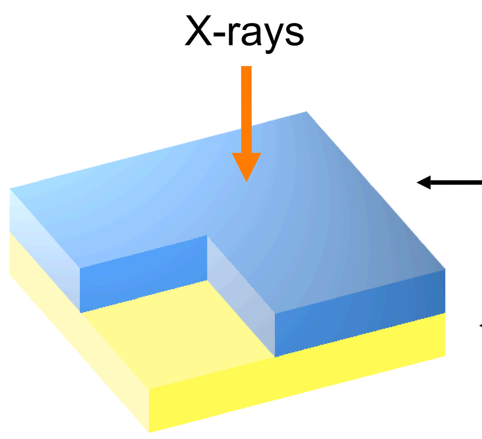

Fig.1 A schematic view for SD-CCD

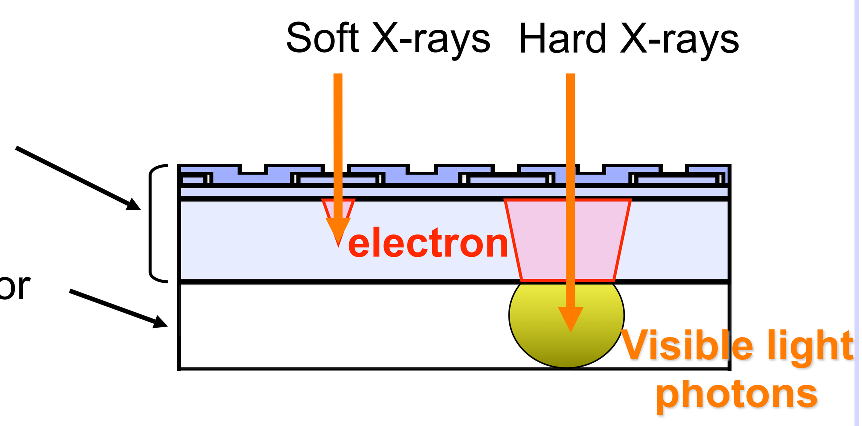

Fig.2 A cross section of SD-CCD

Principle of operation

Soft X-rays (0.5~10keV)

- Soft X-rays are directly detected by CCD

It is the same as detect on X-ray for CCD alone.

Hard X-rays (10~80keV)

- Hard X-rays transmitted off the CCD are absorbed by the scintillator, and visible light photons are generated.

Since CCDs possess high detection efficiency for visible light photons, emitted visible light photons are absorbed by CCD.

Soft X-ray are directly detect by CCD and hard X-ray are absorbed by scintillator.
The same CCD can detect visible light photons emitted from scintillator.
So we can detect X-ray from 0.1keV to 100keV !!

We use CsI(Tl) for the scintillator because

large atomic number	high detection efficiency for hard X-ray
highest light yield	high spectral capability
can form needle-like structure	can confine the lateral spread of visible light photons

2. Development of SD-CCD

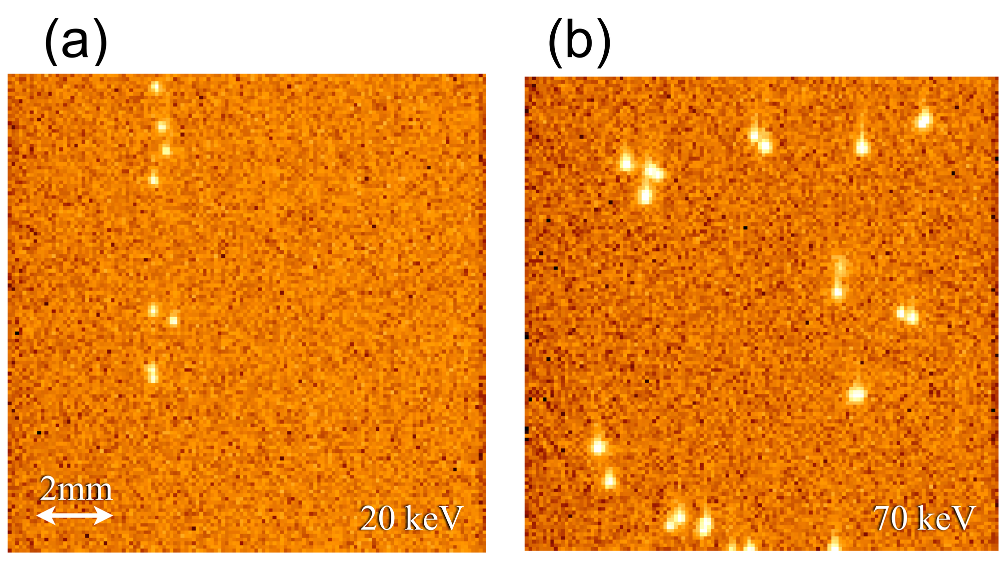

Fig.3 The image of SD-CCD for (a) X-ray beam of 20keV and (b) X-ray beam of 70 keV. Each cluster is generated by an X-ray photon absorbed CsI (Tl).

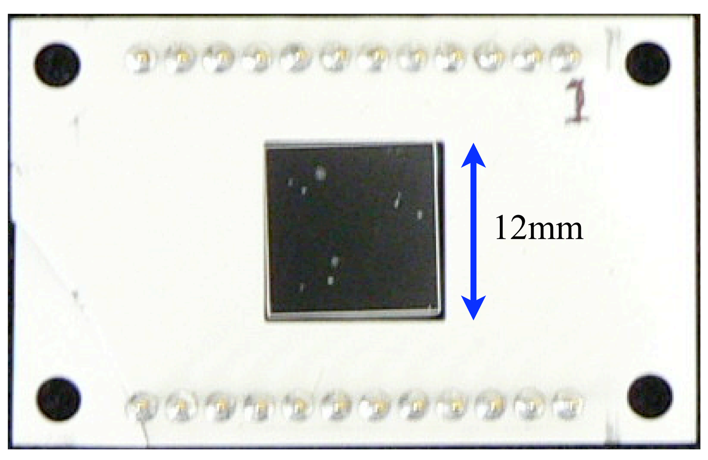

Fig.4 The picture of SD-CCD

We employ back-illuminated(BI) CCD to fabricate SD-CCD. We coupled needle-like CsI(Tl) manufactured by Hamamatsu Photonics K.K. directly on the BI CCD. Fig.4 shows a picture of SD-CCD we fabricated. The cross section of the SD-CCD is shown in Fig.5. Fig.6 shows the SEM picture of the needle-like CsI(Tl).

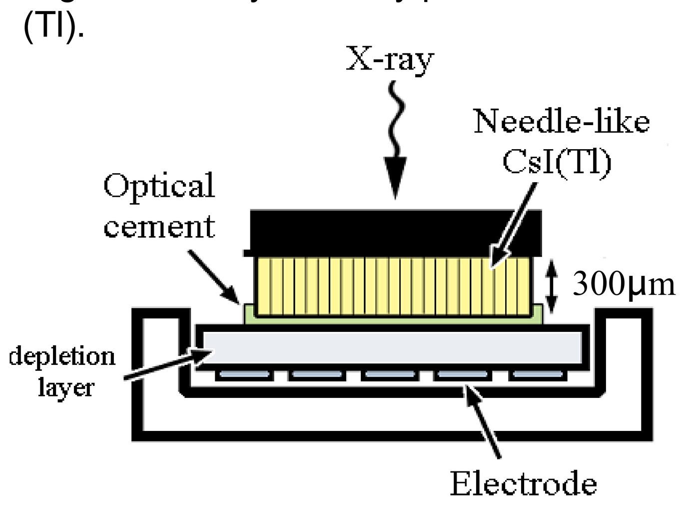

Fig.5 A cross section of SD-CCD

Specification of CCD
Hamamatsu Photonics K.K.
full frame transfer
pixel area : 24×24μm^2
number of pixels : 512×512
thickness of wafar : 35μm
fully depleted BI

Needle-like CsI(Tl) deposited on the amorphous carbon. The thickness of CsI(Tl) is 300μm.


Fig.6 SEM picture of needle-like CsI(Tl)

3. Imaging capability

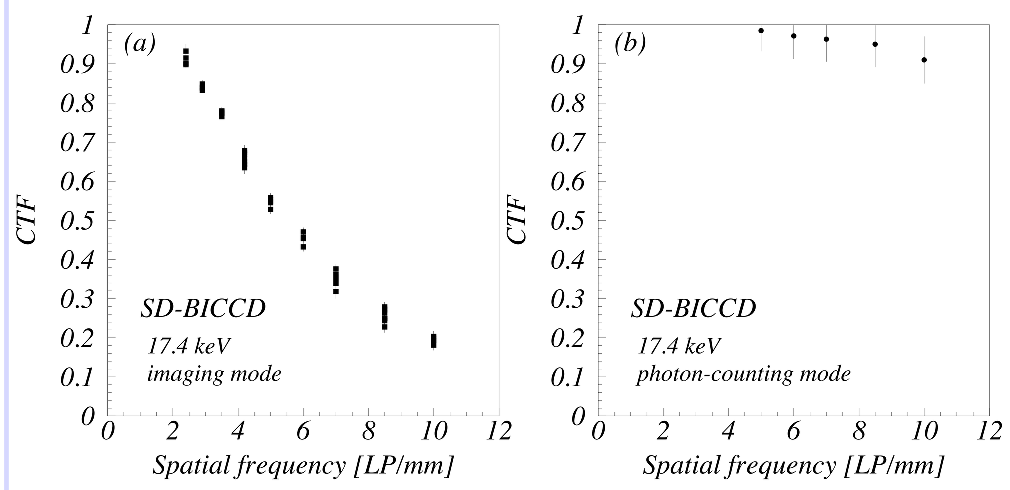

Fig.8 CTF of SD-CCD for (a) an imaging mode and (b) a photon-counting mode.

We measured CTF (contrast transfer function) to investigate an imaging capability. The imaging capability is defined by CTF of unity. Fig.8 shows CTF obtained with (a) an imaging mode and (b) a photon-counting mode. The imaging capability of SD-CCD is 10LP/mm in the imaging mode corresponding to 50μm. The imaging capability obtained with the photon-counting mode is too high to be measured with our experiment.

We then performed a demonstrative experiment. We placed two metal plates forming a V-shaped structure just in front of the SD-CCD show in Fig 9 and parallel X-ray beam having energy of 17.4keV was irradiated.
We measured an image of projection for two methods which is imaging and photon-counting mode.

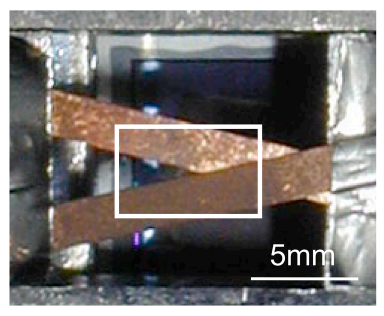

Fig.9 Metal plates cupper 200μm thick forming a V-shaped structure.

Imaging mode

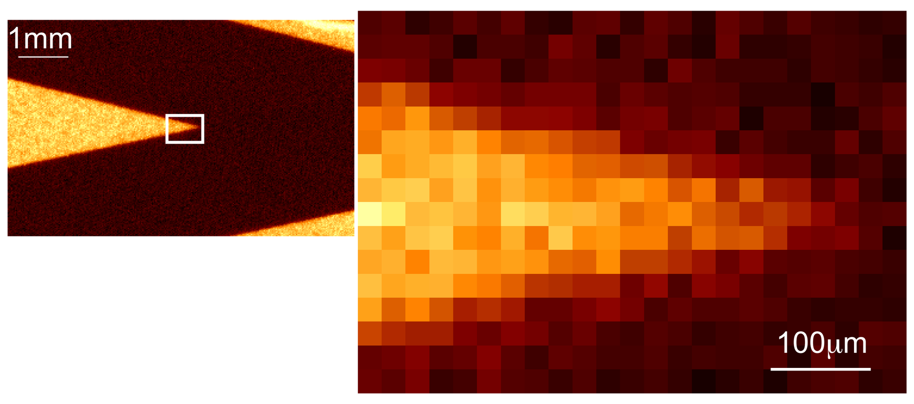

Fig.10 Left figure shows the image obtained with an imaging mode of the area marked at Fig.9. Right figure shows a close up of squared area of the left figure.

Photon-counting mode

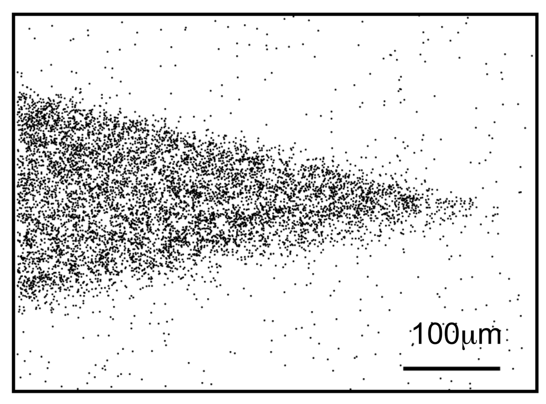

Fig.11 The image of projection of V-shaped structure for photon-counting mode. This figure is a same area of Fig.10. Each black dot is an X-ray point of interaction.

Improvement for 6 by a factor of 6

Position resolution : 61 ± 1μm (FWHM) ⇒ Position resolution : 10 ± 3μm (FWHM)

4. Experiment at SPring-8 BL20B2

We evaluated the hard X-ray responsivity of the SD-CCD at SPring-8, BL20B2. We irradiated the monochromatic X-ray beam of 20, 30, 40, 50, 60, 70, and 80keV to the SD-CCD.
Fig.12(a) shows the pulse height as a function of energy. The linear relationship between the incident X-ray energy and the pulse height can be obtained.
Fig.12(b) shows the energy resolution as a function of energy. This gave us a square-root energy dependence.

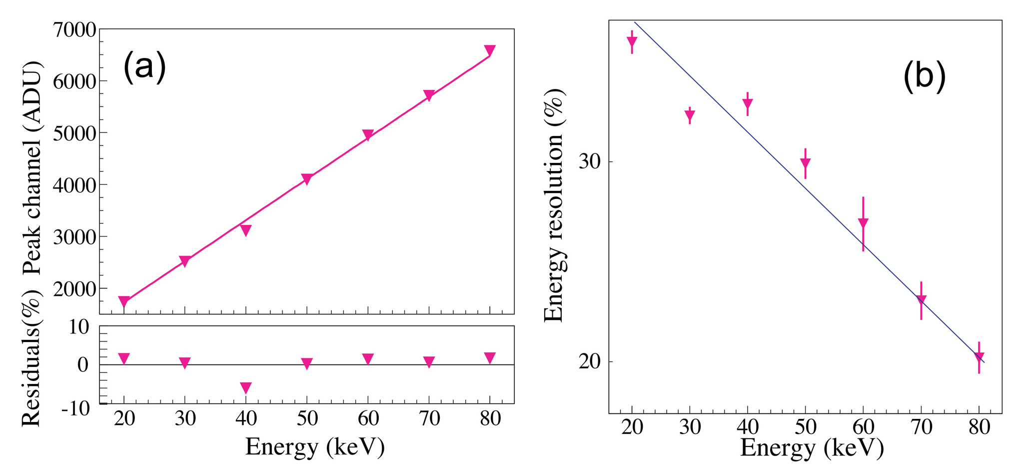

Fig.12 Energy dependences of (a) pulse height and (b) energy resolution obtained with the SD-BICCD.

We measured the on-axis image of supermirror with the SD-CCD. The supermirror is installed 8m away from the SD-CCD, which is a focal length of the supermirror We employed 40keV monochromatic X-ray with beam size of 10mm×10mm in order to obtain parallel X-ray beam.
The SD-CCD was operated in a photon-counting mode. Figure 13 shows the on-axis image of the supermirr
or at 40keV. The sharp core and the wing structure of the supermirror can be clearly imaged with the SD-CCD. This image can demonstrate the high imaging capability of the SD-CCD.

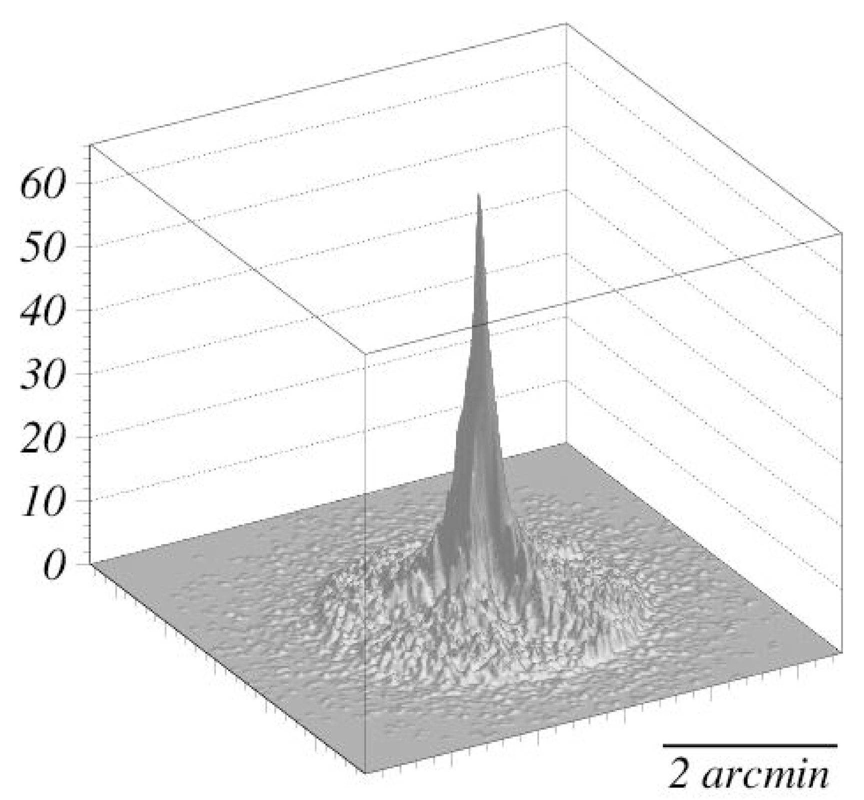

Fig13. On-axis image of the supermirror measured at 40keV with the SD-CCD

Summary

- **We have developed high-resolution wide-band X-ray photon-counting detector with scintillator directly-coupled charge-coupled device.**
- **We measured a position resolution of SD-CCD to be 61 ± 1 μm (FWHM) in an imaging mode or 10 ± 3 μm (FWHM) in a photon-counting mode.**
- **The SD-CCD can function as a spectrometer from soft X-ray to hard X-ray up to 80keV.**
- **We measured the on-axis image of the supermirror at 40keV. Both the sharp core and the wing structure can be clearly imaged with the SD-CCD.**