U054-030 **Room: Ocean B** **Time: May 15 14:45-15:00**

New breakthrough of CCDs

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Current X-ray observatories carry grazing incidence X-ray telescopes coated with high-Z materials (such as gold or iridium), enabling focusing of photons with energies below 10 keV. It is difficult to focus X-rays above 10 keV since the total external reflection at these energies occurs at extreme grazing incidence (less than 0.1 degree). One way to extend to the use of grazing incidence mirrors beyond 10 keV is to use a depth-graded multilayer structure in order to achieve high reflectivity in a wide energy band. Essentially, the multilayer acts as an X-ray reflector. Its periodic structure can reflect X-rays which satisfy the Bragg condition, like a crystal. These supermirrors are being developed by several groups for hard X-ray astronomy.

The focal plane detector for the supermirror is required to cover the energy range of 0.1-100 keV with an imaging capability of several arcseconds for, at least, a 15 arcmin square region. Due to their moderate spectral resolution with excellent imaging capability in the 0.1-10 keV band, charge-coupled devices (CCDs) are now widely employed as focal plane detectors on recent X-ray satellites. Since CCDs are made of silicon, the stopping power for hard X-rays significantly drops above the 10 keV energy range.

We report here a newly developed wide-band photon-counting detector for 0.1-100 keV X-rays possessing high spatial resolution, to be employed as the focal plane detector of a hard X-ray telescope: the scintillator-deposited CCD (SD-CCD). We employ the CCD itself as a soft X-ray detector. The scintillator is directly coupled to the back surface of the CCD. The majority of X-rays having energy of above 10 keV cannot be absorbed by the CCD and pass through it. However, they can be absorbed by the scintillator and emit hundreds or thousands of visible photons. The visible scintillation light photons can be absorbed by the same CCD.

The size of the charge cloud generated by X-rays directly detected in CCDs has already been investigated and is several microns below 10 keV X-rays. On the other hand, photons emitted from the scintillator expand uniformly in the first approximation and the size of their extent is expected to be roughly the thickness of the scintillator. The difference of sizes between the charge clouds generated by X-rays directly absorbed by the CCD and those by X-rays absorbed by the scintillator enables us to distinguish the two kinds of X-ray events. This suggests that the SD-CCD can function as a photon-counting detector for 0.1-100 keV X-rays. Currently, there is no other photon-counting detector available for such a wide energy band.

The thicker the scintillator, the better is the detection efficiency. However, the extent of visible photons becomes larger for a thicker scintillator, resulting in poorer identification of the X-ray point of interaction. Therefore, it is important to confine the extent of visible photons. There is a promising scintillator, CsI(Tl), which not only possesses one of the highest light yields among scintillators but also forms a needlelike fine crystal structure that resembles optical fibers. The needlelike structure significantly reduces the lateral spread of visible photons and prevents the image from being degraded, thus assuring even higher sensitivity.

We have developed the SD-CCD by coupling CsI(Tl) on the BI CCD. The X-ray performance was measured at the beamline BL20B2 of SPring-8. The linear relationship between the incident X-ray energy and the pulse height can be obtained with a maximum deviation from a linear function of 4% for 20-80 keV X-rays. We measured the energy dependence of the energy resolution of the SD-CCD and found that the energy resolution was well described by a square-root energy function. We performed an experiment with a sharp edge and obtained the spatial resolution to be 10 micron in a photon-counting operation.