Detectors

Requirement for New Detectors in SPring-8: an Overview

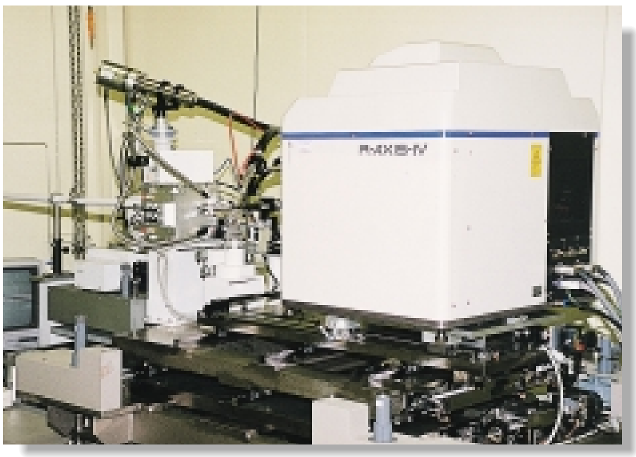
SPring-8 is a third generation storage ring characterized by its low emittance of radiation. The detectors in SPring-8 have to match this characteristic of the source. The detectors currently used at SPring-8 are mostly those, that have been used in other synchrotron radiation facilities and even with laboratory X-ray sources, such as ionization chambers, scintillation counters, solid-state detectors and image plates. These detectors are useful in many experiments and their best advantage is that users are familiar with them. However, in order to make full use of the synchrotron radiation from SPring-8, it is clearly desirable to find and develop detectors that match the characteristic of SPring-8.

The low-emittance X-ray radiation of SPring-8 is currently posing two requirements on area detectors: fast readout and high spatial resolution. The former has partially been fulfilled by the use of CCD as a readout device: although the readout time of CCD is slower than most photon-counting detectors, it is probably the fastest among integrating detectors such as an image plate. The latter problem has also been partially solved by the use of CCD: the pixel size of CCD is small enough for most purposes. SPring-8 also provides high photon flux which is hard to handle with photon-counting detectors. Since CCD is an integrating-type detector, it is suitable for SPring-8 for this point, also. As an X-ray detector, CCD is versatile and easy to use, which has been demonstrated by its popularity among users of many fields.

Current Status of Area Detectors

R-AXIS IV

As an area detector, an image plate is still the most widely used detector in SPring-8. In diffraction experiments in both biological and non-biological fields, RIGAKU R-AXIS IV is the detector most often. At the moment, BL10XU, BL24XU, BL41XU, BL44B2 and BL45XU are equipped with it. Among these beamlines, all except BL10XU are for protein crystallography: in fact, all protein crystallography beamlines are using R-AXIS IV at the moment. R-AXIS IV has two plates of 30x30 cm so that when one is scanned by a laser for readout, the other can be exposed.



RIGAKU R-AXIS IV detector.

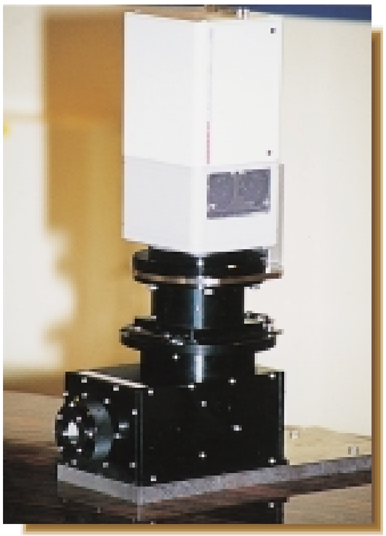
This choice of R-AXIS IV is generally welcomed by users because most of them use the same detector with their laboratory X-ray source. On the other hand, since this detector was for laboratory use, it is designed for a long exposure time and so the readout takes 5.5 minutes. For beamlines in SPring-8 where an exposure is typically 5-60 seconds, this is unreasonably long.

X-ray image intensifier and fast CCD

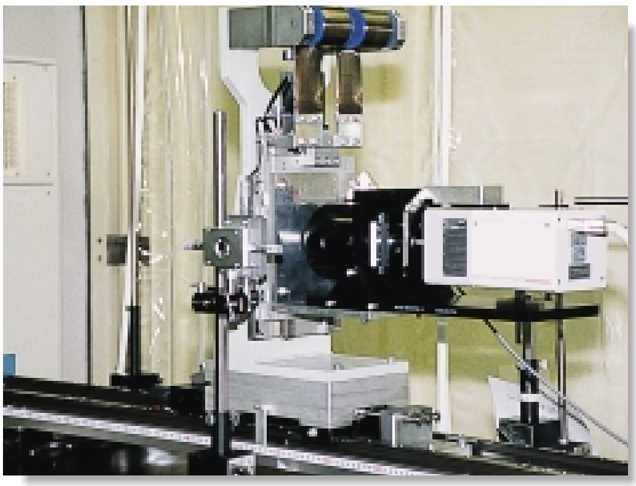
For the fast time-resolved recording of images, a fast CCD is used with an X-ray image intensifier. The X-ray image intensifier with a beryllium window was developed in a SPring-8 R&D program in collaboration with Prof. Amemiya of Tokyo University and Hamamatsu Photonics. At the BL45XU small-angle station, this combination is used extensively in both the time-resolved and static measurements of X-ray diffraction and scattering from biological specimens. To improve the time-resolution, the phosphor in the exit window of the image intensifier is P43 which has a persistence shorter than 3 msec. The CCD is Hamamatsu C4880-80-14A with air-cooling to 0˚ C and a frame rate of 28 per second with 656x494 pixels. The ADC is 10 bits with a noise level within one bit. By reducing the number of lines in each frame, the rate can be increased to 500 frames per second with 656x15 pixels. So far, time-resolved experiments on skeletal and cardiac muscles and purple membranes have been made using this detector. It has also been used at BL44B2 to record time-resolved white Laue diffraction.

Beam monitor

High-resolution imaging detectors are becoming increasingly important because the low-emittance of the SPring-8 radiation provides a smaller and parallel X-ray beam. This makes it possible to observe the interference or refraction of X-rays that appear as fringes of a few microns to a few tens of microns. As this is probably one of the most adequate applications of the low-emittance beam of SPring-8, detectors targeted for this purpose have been developed. Currently, the detector most widely used is called the "beam monitor" since it was designed to observe a monochromatized direct X-ray beam in an undulator beamline. In its design, it is capable of recording a beam whose flux is as high as on the order of 10^{12} per mm^2. It is composed of a phosphor (P43) and a tandem lens, and a reflecting mirror. In order to reduce the radiation damage in the optic system, a pair of lead glasses is placed behind the phosphor. The present design uses a 1000x1014 pixel cooled-CCD (Hamamatsu C4880-10-14A) as the camera. The spatial resolution is about 25 µm. It has been used in most of the imaging experiments done at BL47XU. For time resolved experiments with a high spatial resolution, the camera can be replaced by a fast CCD (C4880-80-14A).



"Beam monitor".

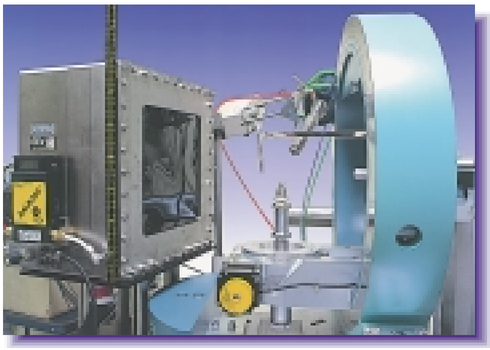


"Beam monitor" detection system at BL47XU.

Future Prospects

CCD detectors for protein crystallography

Although R-AXIS IV is widely used, some beamlines for protein crystallography will also be equipped with a CCD detector with tapered fiber optics. For the BL45XU protein crystallography station, a detector with 4x4 CCDs (1242x1152 pixels each) has been developed. It will be installed when the data processing software to be used becomes ready. The readout is 6 seconds. This will be short enough to match the typical exposure time in the undulator beamline.



MCCDX detector system.
Ref. Suzuki et al., Nucl. Instrum. Meth. Phys. Res. A (1999) - in press.

Shortening the readout of R-AXIS IV

Improving R-AXIS IV to reduce the turn-around time to shorter than 1 minute has been discussed with RIGAKU and prototypes will be manufactured in 1999. As there will be no change in the basic design, it will remain friendly to users. On beamlines that provide a moderately strong beam, it may remain as the user's best choice.

Improving the resolution of CCD detectors

For high resolution imaging, CCD detectors must be improved to achieve a higher resolution. In principle, by using optics similar to that in a microscope, it is possible to achieve spatial resolution of a few microns. However, attention should be paid so as to avoid radiation damage on the optical components by the intense X-ray beam. Discussions on new designs for CCD detectors are currently underway with Hamamatsu Photonics who will be manufacturing detectors for tests.

High energy X-ray detector

One important feature of SPring-8 is that it is a high energy storage ring that can produce X-rays of high energy (>100 keV). Since this energy range has not been available in most synchrotron radiation facilities to date, detectors have not been developed extensively. Actually, this range will be the region of exploration in SPring-8. CdZnTe is an obvious candidate in such an energy region because of its high photon stopping power. However, considerable R&D will be required to achieve detectors that are usable in actual experiments.

Fast detectors

Since CCD is now widely used in commercial products, its technical development has been rapid. Along that line, it will be feasible to make a very fast CCD camera with a frame rate higher than 1000 per second. A time resolution higher than this can be obtained by using photon counting detectors. A wire detector using microstrip technology has been developed for the BL45XU small-angle station by Dr. Tanimori of the Tokyo Institute of Technology, but it is still not usable in actual experiments. Typically, the requirement for a high time resolution accompanies that for a high counting rate since a certain number of photons are required in recording an image or a diffraction pattern of an acceptable quality. Most wire detectors can handle only less than 3 million photons per second, which is not sufficient. Therefore, more sophisticated electronic equipment is required to solve this problem.

Naoto Yagi
SPring-8 / JASRI