SPring-8 Detector Projects

1. Overview

The Station Equipment Group of Japan Synchrotron Radiation Research Institute (JASRI) has the mission of researching and developing various types of X-ray detectors to be introduced at the SPring-8 facility in the near future [1-4].

Since the X-ray beams generated at the SPring-8 facility are characterized by (i) high brilliance, (ii) high flux, and (iii) high X-ray energy, it has been the general strategy of the group to target those X-ray detectors with which SR users could profit in these three scientific directions. As described below, currently included in this framework are a multiple-CCD X-ray detector, microstrip gas chambers, and one-dimensional microstrip germanium detectors, briefly speaking, which basically correspond to the three directions, respectively.

In addition, another mission of the group is to re-investigate and improve existing X-ray detectors in order to appreciate the transcendence of the X-ray beams. Included in this work are ionization chambers and scintillating screens, whose behaviors constitute fundamental subjects in X-ray detector physics as well as in related engineering.

Besides these R&D programs, the group organized an international workshop on high flux X-ray detectors during the summer. The present report intends to update the status of the R&D projects mentioned above and convey the highlights of the scientific event.

2. On-beam Calibration of Multiple-CCD X-ray Detector

The multiple-CCD X-ray detector (MCCDX) has been installed in the RIKEN Beamline I of the SPring-8 facility for protein crystallography. As already described [5-7], the fundamental structure of the MCCDX is a 4×4 matrix of fiber optic tapers (FOTs), each element being coupled to a scientific charge-coupled-device (CCD) at its small end. Along with its matrix size, both the operation temperature of 273K and the demagnification factor of 2.2 make the MCCDX unique among FOT/CCD-based X-ray detectors. When compared with image plate systems, however, FOT/CCD-based X-ray detectors are generally considered inferior, especially in terms of non-uniformity in X-ray sensitivity and image distortion. It is, therefore, compulsory for the MCCDX system to establish a reliable procedure by which the X-ray images acquired are adequately corrected in these quantities.

Although it is well known that the non-uniformity of a given X-ray area detector can be best evaluated by irradiating it with a uniform field of characteristic X-rays, how to generate it at a beamline is still technically a central problem. In collaboration with the RIKEN structural biology group, the group operated the MCCDX system to systematically study the fields of characteristic X-rays generated with various materials by irradiating them with an X-ray beam available at the BL45XU of the SPring-8 facility. As reported elsewhere in this volume [8], the groups found that a zinc foil of 25 μm in thickness is the best with regard to the intensity of the resulting characteristic X-rays and the spectral proximity of the X-rays to the energy region of interest.

Calibration masks with fine holes that are precisely aligned two-dimensionally are commonly employed to evaluate the spatial distortion occurring in a given X-ray area detector. The spatial distortion is defined as the difference between the locations of the holes geometrically determined by the calibration mask pattern and those optically observed with a given detector. The calibration masks must also absorb the major part of the incident X-rays to ensure the contrast of the hole image to be observed. The groups found that a plate made of phosphor-bronze of 100 μm in thickness is the best candidate among the many materials, because it can achieve a location tolerance and the attenuation of X-rays of $\pm$ 20 μm and 98 %, respectively, at 1.0 Å.

During the current year, the groups experimentally confirmed that the combined use of the zinc plate and the calibration mask makes it possible to calibrate the MCCDX reliably at the beamline in the case of non-uniformity as well as spatial distortion. While proceeding in this program, it was found that the MCCDX is affected by an unidentified background noise, which deteriorates the X-ray image quality. The groups are urgently undertaking an investigation to identify the source of the noise image.

3. Improving CCD-associated Beam Monitors and X-ray Image Intensifiers

The FOT/CCD configuration is certainly not the only way of appreciating the splendid imaging capability of CCDs. The luminous images induced by an incident X-ray beam over a scintillating screen can be effectively visualized on a high resolution CCD camera with the appropriate optical component [9]. As described in detail elsewhere in this volume [10], the first model embodying this concept was produced last year for the purpose of visual beam-diagnosis. The optical coupling mechanism used for this has been further improved this year. It was experimentally confirmed that an excellent spatial resolution of 12 μm could be attained with the latest model. Since the focusing is remote-controlled in the model, it can perform not only beam diagnostics but also various types of X-ray imaging.

X-ray image intensifiers are another type of CCD-based X-ray imaging devices. The photoelectrons generated by incident X-ray photons in these devices are accelerated in a vacuum tube and impinge upon a scintillating screen yielding visible photons abundantly. Because this intensification mechanism is implemented, X-ray image intensifiers possess high sensitivity to incident X-ray photons in the energy region from 5 keV to 50 keV and are regarded as suitable devices to perform time-resolved experiments on milli-second order.

In pursuing temporal variations of X-ray images, the phosphorescence in the scintillation screens ultimately limits the time resolutions of these devices. It is, therefore, important to measure the persistence of luminous images in these devices by stimulating them with either an impulse type X-ray beam or a step-function type X-ray beam.

During the current year, the time response functions of two X-ray image intensifiers, the first one with P20 and the other P43, were carefully measured against a step-function-like termination of the incident X-ray beam [9]. As clearly demonstrated in Fig. 2 of reference [11], the luminescence of P43 quenches almost completely within a few milli-seconds while that of P20 remains at the 15 % level even 10 milli-seconds after the termination of the X-ray beam. Time-resolved X-ray imaging will benefit from using an X-ray image intensifier associated with the former scintillating screen.

4. Capillary-plate-associated Microstrip Gas Chamber

The introduction of microstructure electrodes to gaseous chambers has been revolutionizing many aspects of traditional radiation detectors. The MicroStrip Gas Chambers (MSGCs) have been the best representatives with outstanding spatial resolutions of a few tens of μm [12-17].

Nevertheless, this novel technique has long been seriously questioned as to whether a stable electron multiplication can be truly established in a realistic time-scale, since the charge gain has been reported to decrease in time due to the charge-up phenomena.

Continuing its collaboration with Tokyo Institute of Technology, the group has approached this technical issue by introducing a surface-resistively-controlled capillary plate in their MSGC. As described in detail elsewhere in this volume [18], inserting a capillary plate into their MSGC creates three functional volumes: the X-ray conversion region, the intermediate electron amplification region, and main electron amplification region. By simulating the electron trajectory in the MSGC, the electric fields applied to these three regions were determined in such a way that all the electrons generated in the conversion volume could reach the main amplification region passing through the capillary tubes.

The experimental research carried out at the RIKEN beamline I of the SPring-8 facility during the current year confirmed that the new configuration with the capillary plate drastically improves the performance of the MSGC. The charge gain achieved by this configuration exceeded 3,000 without inducing any discharge and was nearly independent of the counting rate up to 10^5 cps/mm^2. It was confirmed that the spatial resolution of the capillary associated MSGC is better than 100 μm in a xenon-ethane gas mixture. More importantly, no appreciable change in the charge gain was observed over several hours.

The results obtained with the new configuration of the MSGC during the current year encourages the group to step forward in constructing a real-time X-ray imager for SAXS experiments based on the MSGC technology.

5. Initiating on R&D Program of One-dimensional Microstrip Germanium Detectors

In order to exploit high energy X-ray potential in terms of X-ray detector technology, the group has officially started collaborating with the Compton scattering subgroup. The primary target of this collaboration is to realize a one-dimensional position-sensitive detector for Compton scattering experiments to be carried out at the BL08W of the SPring-8 facility.

Since the subgroup intends to observe electron momentum density distributions with a resolution of 0.1 atomic unit in the energy range from 70 keV to 150 keV, the spatial resolution that is required for the 1D detector becomes 200 μm under the constraints of the Cauchois-type Compton spectrometer. In addition, an energy resolution of 3 keV at 100 keV is needed to implement the background rejection capability in the 1D position-sensitive detector system. Also desired is high detection efficiency in the energy region of interest.

These conditions are imperative in the sense that there are only two detection media able to comply with them at once: germanium and CdTe. In addition, the scientific program management has directed that the construction of the final model of the 1D detector be completed within a couple of years. Given these conditions, the group reduced the question to which one of the media would be the most reliable for completing this mission within the time given. The pressing need to produce a detector medium thus became the main factor in selecting germanium, although it is still within the scope of the group's considerations to exploit CdTe and its variants such as CZT for high-energy X-ray detectors in the near future.

The interaction of the incident X-rays in this energy region with germanium is, however, known to be topologically sophisticated due to multiple scattering, and the detection process is subject to some ambiguities due to the electron diffusion and the charge splitting. Therefore, the Station Equipment Group and the Compton scattering subgroup decided to realize a final model of the 1D position-sensitive detector system by following a three-phased program.

The three-phased program was proposed to JASRI and was accepted for the first year. Two versions of the first prototype are already being fabricated. The first one has five strips with a strip width and gap of 150 μm and 50 μm, respectively, and the second one again five strips with a strip width and gap of 300 μm and 50 μm, respectively. Two single strips isolated from each other will be attached to both versions for comparison.

The collaboration team will be taking intensive research actions, not only running experiments but also performing simulations, during the next year to investigate the first models so as to extend the program to the next phase.

6. Position-sensitive Ionization Chamber

During the current year, the Station Equipment group has attempted to position-sensitize conventional ionization chambers by using backgammon-type-segmented electrodes. If the incident X-ray beam is shifted to either side, then the corresponding segment will collect more ionization charge and the other less. By detecting the difference in observed ionization currents between the two segments, it was possible to perceive the transversal shift of the beam with respect to the direction of the incident X-ray beams.

As reported elsewhere in this volume [19], it has been experimentally demonstrated that a spatial resolution better than 50 μm could be achieved by this approach. Although the spatial resolution has to be further investigated in terms of X-ray energy as well as the geometrical shape of the backgammon-type-segmented electrodes, the present system is already precise enough to incorporate into beam stabilization systems.

As described before [20-22], it is well known that the ionization currents collected on the electrodes in an ionization chamber can barely be saturated, even at the maximum rating of applied voltage, when the chamber is irradiated with an intense X-ray beam. This has been attributed to the recombination process between the charge carriers, which can proceed much faster than the charge collection process with charge densities. Therefore, the Station Equipment Group has been warning the SR community that in experiments examination should be made into whether the complete collection of the electrons/ions is established under the given applied electric field when the observed ionization current exceeds 1 μA.

From the users' viewpoint, however, it may be more convenient to have a diagram that indicates the relationships between saturated ionization currents and saturation voltages. Once these relationships are given, then the users could estimate the optimal high voltage for their experiments. Figure 2 in reference [16] corresponds to this diagram. The figure also states that ionization chambers with higher maximum ratings of high voltage are needed at those beamlines operated in a lower X-ray energy region with a higher intensity.

Extracting the physics that governs the diagram constitutes major issues such as the spatial and temporal transition of the ionization profile, which must be clearly distinguished from the beam profile. Simulation of dynamic behavior of electrons and ions should be done for this reason in parallel to further experimental studies.

7. International Workshop on High Flux X-ray Detectors

In parallel to these R&D activities related to the X-ray detectors, the Station Equipment Group decided to organize an international workshop focusing on the theme of high flux X-ray detectors during the current year as already reported [23]. Among the various motivations, the approval of a new beamline called high flux X-ray beamline at the SPring-8 facility was certainly the major driving force in organizing the workshop.

The international workshop intended to:

(1) determine the essential conditions for the detectors applied to high flux X-ray beam experiments,
(2) understand the current status of R&D programs for high flux X-ray detectors,
(3) itemize the technical problems to be solved for this purpose, and
(4) establish a strategy to realize detectors that comply to these conditions.

The International Workshop on High Flux X-ray Detectors was held at the SPring-8 facility from August 24 to 26, 1998. The organizers invited the domestic experts in this filed as well as those from USA, UK, Germany and Russia. There were more than 50 participants, not only from academic institutes but also from private companies. In order to acquire the relevant information and accomplish the above goals, the workshop covered a wide range of X-ray detectors. Discussed X-ray detectors included gaseous detectors, pixel array detectors, avalanche photodiode detectors, scintillation fiber detectors, semiconductor detectors, X-ray image intensifiers, modular CCD X-ray detectors, and image plates.

The workshop reached the conclusion that the microstructure of the electrodes in gaseous detectors and the application of CCDs to X-ray imaging devices are the two major trends in this field and the most promising candidates for high flux X-ray beam experiments. The workshop was also convinced that pixel array detectors will be available in this area in the very near future.

8. Concluding Remarks

The Station Equipment Group has been privileged to work several R&D programs related to X-ray detectors. Consequently, the group has been making the major part of the information on its activities freely accessible over the Internet and reporting these activities as much as possible to the SR community through its publications.

In this respect, the international workshop reported in the previous section became the latest example for the group where its activities have been reported to the international SR community. Given that all of the programs showed a high degree of success, next year the group will extend its activities in all of the directions described at the beginning of this report.

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