SPring-8 Detector Projects

1. Introduction

This report outlines the R&D projects conducted by the *Station Equipment Group of Japan Synchrotron Radiation Research Institute (JASRI)* during 1999 around (1) a multiple CCD X-ray detector, (2) a microstrip gas detector, (3) a one-dimensional microstrip Germanium detector, (4) a position-sensitive ionization chamber, and (5) a YAP(Ce) imager.

2. Multiple CCD X-ray Detector

As reported before [1,2], we have been characterizing the multiple CCD X-ray detector (MCCDX). The fundamental structure of the MCCDX is a [4×4] matrix of fiber optic tapers (FOTs), each element coupled to a scientific charge-coupled-device (CCD) at its small end. Along with its matrix size, the operating temperature of 273K and the demagnification factor of 2.2 make the MCCDX unique among similar FOT/CCD-based X-ray detectors.

It was found in 1998 that the X-ray image quality attained with the MCCDX was seriously limited by unexpected noise. The MCCDX was, therefore, subjected to an intensive noise analysis, suspending its application to the RIKEN Beamline I of the SPring-8 facility for protein crystallography. The analysis strongly suggested that a weak emission of light existed in the FOTs assembled. One of the hypotheses was that the electrons and gamma rays emitted either from the scintillating screen of Gd_2O_2S:Eu or from the natural abundance of ^{210}Pb in glass is inducing the responsible scintillation in the FOTs. However, gamma-ray spectroscopy made with a germanium detector did not support the hypothesis [3]. Further investigations are currently under way, including a system overhaul to identify the noise source and reveal its nature.

3. Microstrip Gas Chamber

We have been also developing the two-dimensional microstrip gas chamber (MSGC) as a time-resolved X-ray imager, which has a 512 anode-, 512 cathode-, and 512 back-strips with very fine pitches of 200 µm in its detection area of 10.24 cm×10.24 cm [4-7]. In parallel, a novel high speed readout system has been developed with complex programmable logic devices on VME boards in order to realize time-resolved experiments in the µsec time domain [5,8]. During the course of the R&D program, a conductive capillary plate was additionally inserted into the MSGC structure as an intermediate electron-multiplier [9,10]. Due to the recent improvements, the present MSGC has made it possible to carry out quantitative X-ray imaging measurements. The MSGC now can be well characterized by (1) a distortion-free imaging capability, (2) an excellent uniformity in the detection efficiency over its active area, (3) a high counting rate capability up to 10^5 cps/mm^2, and (4) a high spatial resolution less than 100 µm [9, 10].

In the current year, the applicability of the MSGC to solution X-ray scattering experiments was studied at the SAXS station of the RIKEN structural biology beamline I (BL45XU) of the SPring-8 facility. The first measurement of solution X-ray scattering was carried out with a bovine serum albumin solution. The scattering pattern was similar to that obtained with a position-sensitive proportional counter and an X-ray image intensifier with a cooled CCD. The practical dynamic range of the MSGC was confirmed to be ~10^6: 1 by measuring the S^4 decay from a polystyrene latex solution. Steep troughs of scattering profile from an apoferritin solution were clearly observed without smearing effect. As the first time-resolved experiment, a pH jump of cytochrome *c* was measured, through which the unfolding process is clearly observed [11]. The time-resolving capability achieved was 500 µsec in this experiment. These advanced capabilities of the MSGC may solve the major part of the problem in synchrotron solution X-ray scattering experiments, especially those related to the experimental dynamic range available, since the MSGC realizes a much wider range than existing detectors.

4. One-Dimensional Microstrip Germanium Detector

The Compton-scattering experiment with an SR X-ray beam in the high energy region offers direct access to the momentum distributions of electrons existing in various substances. This straightforward experimental method has been embodied at the high energy inelastic scattering beamline (BL08W) of the SPring-8 facility. In this beamline, X-rays scattered by a sample will be one-dimensionally spread with three analyzer crystals, and converged on a focal plane at different positions, depending upon their energy. By scanning the focal plane with a conventional germanium detector, the intensity of the Compton-scattered X-rays as a function of their energy, *i.e.*, the Compton profile, could certainly be obtained. Even with a transcendent X-ray beam intensity at the SPring-8 facility, however, it would take month to reach a statistical accuracy of 0.1% at the observed peaks in the Compton profiles.

As already reported, we initiated an R&D program to realize a one-dimensional position-sensitive X-ray detector, with which Compton profiles could be much more efficiently measured [12]. A microstrip germanium detector becomes the primary candidate in reference to the technological mutuality. However, not only the interaction of the X-rays with the germanium crystal in this energy region could be topologically complicated, but the transportation of the charge carriers generated in the crystal could be subject to the diffusion process as well. Near the energy region of 100 keV, therefore, it is anticipated that the spatial resolution of such detectors, which must be as high as 350 μm to realize the momentum resolution of 0.1 a.u., may not be simply determined by the strip pitch. To clarify these concerns, we fabricated two prototypes with 1+1+5 strip configurations, having different pitches of 350 μm and 200 μm. These prototypes have been experimentally investigated with γ-ray radioisotopes, an X-ray generator, and the synchrotron radiation X-ray beam at the BL08W.

Computer simulations based on EGS4-lscat have been also made for the prototypes. It has become clear from these simulations that the behavior of the prototype with a strip pitch of 200 μm was not well reproduced in the simulation probably due to the enhanced hole diffusion process. On the contrary, the one with 350 μm was found to be in good agreement with the simulation.

It has been experimentally confirmed that a prototype with a strip pitch of 350 μm can attain a spatial resolution as high as 350 μm, an energy resolution better than 1.4%, and an overall detection efficiency higher than 50% at an X-ray energy of 80 keV. Owing to this successful verification of the microstrip germanium detector with strip pitch of 350 μm, the project has already entered its second stage to fabricate a new prototype with a total strip number of 128 with advanced readout electronics based on VLSI technology.

5. Position-Sensitive Ionization Chamber

The performance of an ionization chamber that has been position-sensitized with backgammon-type-segmented electrodes (PSIC) has been further investigated during the current year. It has been experimentally demonstrated that the PSIC possesses a linear range of 8 mm in determining the incident position of an X-ray beam. The position resolution was found to be better than 10 μm, probably close to the sub-μm region. Owing to its high spatial resolution, the PSIC was able to confirm that the gradual decrease observed in the X-ray beam intensity at the BL44B2 of the SPring-8 facility was mainly due to the spatial variation of the X-ray beam position in time. The work also justified the applicability of the PSIC to the feedback correction system for the beam stabilization [13].

6. A YAP(Ce) Imager

During the current year, we have initiated new international collaboration among CERN in Switzerland, the Institute for High Energy Physics in Russia, the Research Center for Nuclear Physics of Osaka University, and RIKEN in order to undertake an R&D program for a novel X-ray detector called "YAP(Ce) Imager." The imager has a [128×128] matrix of $YAlO_3$:Ce crystals, each having a volume of 1 mm × 1mm × 6 mm. Among the properties that makes a YAP crystal an excellent scintillator are its fast decay time of 30 nsec, its high density of 7.4 g/cm^3, and its high light yield of 30% relative to that in a NaI(Tl) scintillator. The scintillation light induced by an incident X-ray in a given element of the matrix will first be absorbed into wavelength-shifting fibers attached to the matrix [14]. The scintillation photons read-shifted in the fibers will be transported to a multi-anode photomultiplier located at the end of the fibers. By precisely mapping the YAP matrix with the fibers onto the multi-anode two-dimensionally, one could determine the location and arrival time of the incident X-ray photon. We are currently constructing two prototypes, one with a [8×8] and the other with [16×16] matrix, to investigate their performance in various aspects. The experimental results obtained with these prototypes will be fed back to the construction processes of the full model of YAP imager with a [128×128] matrix.

7. Prospective

Based upon the agreement made between the Swiss Light Source of the Paul Scherer Institute in Switzerland and the SPring-8 facility, the group is also about to initiate another new international collaboration with the Swiss Light Source on pixel array detector projects. Reviewing the status of those R&D projects and foreseeing these activities, the Station Equipment Group understands that it should be scientifically epochal next year to the group.

References

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