Detectors

Introduction

The scientific results from the synchrotron radiation facility depend on the radiation source, optics such as monochromator and mirror, detectors, and data acquisition system adopted. From the beginning of the SPring-8 project, the importance of detectors was realized and detectors were properly included in the research and development program. Detectors are adopted on the basis of specific parameters such as their size, dimensionality, detection efficiency, energy range, energy resolution, spatial resolution, dynamic range, countability, and real-time measurement capacity, and as well as on the basis of their detection technique of either photon counting or integrating type, for each research program. Many detectors exist in the X-ray region, but none of them are universal applicable and detector development has to be performed for different kinds of synchrotron radiation experiments. An important point of their development is that the program has to be carried out in close collaboration with the user groups.

At SPring-8, there have been several development programs including an imaging plate, a CCD readout two-dimensional detector and a high-spatial-resolution CCD-coupled imaging system. In this issue of SPring-8 Research Frontiers, recent developments will be touched upon. The articles concern the One-dimensional Microstrip Germanium Detector for Compton scattering experiment, a Pixel Detector and Microstrip Detector for diffraction, scattering and time-resolved XAFS experiments, and a Flat Panel Detector for imaging. Previously, SPring-8 Research Frontiers 2003, the YAP imager was rreported and in the near future a Two-dimensional Microgap Detector will be described.

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One-dimensional Microstrip Germanium Detector

Upon being absorbed in semiconductors such as silicon or germanium, X-ray photons are converted into energetic electrons through mechanisms such as the photoelectric effect and Compton scattering process. Energetic electrons lose their energies by ionizing and exciting the local lattices of the absorbing semiconductors. When a sufficiently high electric field is established across the semiconductor with a parallel-plate electrode configuration, the electrons and holes that are generated through the ionization process can be separately collected on the anode and cathode, respectively. One could determine the X-ray energy by measuring the total charge collected on either electrode, since the total amount of charge is proportional to the X-ray energy absorbed in the semiconductor. If an electrode is segmented into strips in a certain direction, one could obtain information on the X-ray photons in terms of not only their energies but also their arrival locations, thus realizing position-resolved X-ray spectroscopy.

The one-dimensional microstrip germanium detector is the one that embodies the concept explained above (see Fig. 1) [1]. The X-ray absorption medium is a planar crystal of high-purity germanium (55.5 mm × 50.5 mm × 6 mm), which is cooled down to liquid nitrogen temperature in a cryostat in order to reduce the thermal noise. On the front surface of the crystal, 128 microstrips are photochemically formed with a length and pitch of 5 mm and 350 µm, respectively, as a segmented cathode, while a single electrode is formed on the back surface as an anode. These microstrips are connected to four external application-specific ICs, each functioning as a 32-channel charge sensitive preamplifier-shaper circuit. The anode is connected to an independent charge-sensitive amplifier system to measure the total charge created by an X-ray photon over the entire volume of the crystal. When the total charge detected on the anode exceeds the predetermined threshold, there is a trigger issued to sequentially readout the positive charges detected on the microstrips.

With the one-dimensional microstrip germanium detector system, one could perform position-resolved

X-ray spectroscopy with a position resolution, an energy resolution, and a dead time of 350 μm, ~5% at 100 keV, and 110 μs, respectively. Since the detector is insensitive to external magnetic fields, one could adopt it for experiments that need to employ high magnetic fields. The detector system has been developed for high-resolution Compton scattering experiments conducted at the High Energy Inelastic Scattering Beamline (**BL08W**), and has been yielding directional Compton spectra fifty times faster than traditional single-body germanium detectors.

Fig. 1. One-dimensional Microstrip Germanium Detector.

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References

[1] M. Suzuki, H. Toyokawa, K. Hirota, M. Itou, M. Mizumaki, Y. Sakurai, N. Hiraoka and N. Sakai: Nucl. Instrum. Meth. A **510** (2003) 63.

Pixel Detector and Microstrip Detector

Position-sensitive detectors are powerful devices for use in synchrotron radiation experiments. Imaging plates are representative of them, and CCD-based detectors have become a major tool for protein crystallography recently. These detectors, however, record X-ray intensity by integrating the energy deposited by X-ray photons. Conventional Si, Ge, and NaI detectors are, therefore, still essential instruments, when fluorescence background has to be rejected by energy discrimination. In this respect, pixel and microstrip detectors are regarded as a new generation of X-ray detectors, since they possess not only position sensitivity but also energy resolving power.

The SPring-8 detector team has been developing such a pixel detector in collaboration with the *Paul Scherrer Institut* (PSI) in Switzerland [1-3], which operates a 2.4 GeV third generation synchrotron radiation source called the *Swiss Light Source* (SLS). The developed pixel detectors consist of a number of detector modules. SPring-8 introduced a *Single-Module Detector* (SMD) in September 2002 (Fig. 1), which has a silicon sensor of 300 μm in thickness with an active area of 79.4 mm × 34 mm, and 366 × 157 pixels with a pixel size of 217 μm × 217 μm,

Fig. 1. A single-module pixel detector with 366 × 157 pixels.

associated with 8 × 2 readout electronics chips. The chip has 44 × 78 pixels, each having a charge-sensitive preamp, a shaper, a single-level discriminator, and a 15-bit pseudorandom counter. An individual pixel is thus capable of being operated in a single photon counting mode. The counters can be read out digitally with a frequency of 10 MHz. These conditions result in the maximum frame rate to 30 Hz with the readout time of 6.7 ms.

The SMD has been examined at beamlines **BL38B2**, **BL44B2** and **BL46XU** of SPring-8 so far. The former two beamlines are for protein crystallography, and the last one is for instrumental R&D. Although the SMD is a prototype with about 5% dead pixels due to the DMILL process, it realizes a sufficiently high performance to allow the methodological study of its fields of applications. For protein crystallography, the major advantages of the SMD are that the readout time is much faster than that of a CCD-based detector, and that a mechanical shutter is unnecessary for definition of the exposure time. In materials science, on the other hand, its major advantage is its ability to discriminate among low-energy X-rays below a certain threshold.

The SLS detector group is currently developing an advanced pixel detector which has 60 × 97 pixels with a pixel size of 172 μm × 172 μm and 20-bit binary counters by improving the readout chips with a 0.25 μm CMOS process. The readout chips were delivered to SLS in December 2004, and no dead pixels were found in four chips selected at random. The goal of the SPring-8 and SLS collaboration is to fabricate a 6M-pixel detector for the protein crystallography beamline of the SLS and to produce a general-purpose 1M-pixel detector for SPring-8.

A microstrip detector module was also introduced from the PSI to SPring-8 in February 2004 (Fig. 2), which is a one-dimensional detector consisting of a silicon sensor with 1280 strips and 10 readout chips [2]. The strip length, the pitch, and the thickness are 8 mm, 50 μm, and 300 μm, respectively. The design concept of this readout chip is, in principle, the same as the one for the pixel detector described above, except that the counter has 18 bits. The readout time is 250 μm. Such a fast readout time allows time-resolved measurements. This single module microstrip detector has been examined at the BL46XU by carrying out powder diffraction measurements.

Now SPring-8 is introducing additional microstrip detector modules to realize time-resolved studies at a powder diffraction beamline and a dispersive XAFS beamline.

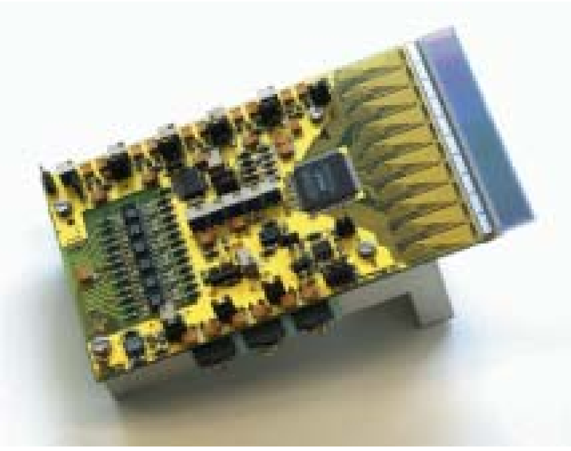

Fig. 2. A single-module microstrip detector with 1280 strips.

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References

[1] E.F. Eikenberry *et al.*: Nucl. Instrum. Meth. A **501** (2003) 260.
[2] B. Schmitt *et al.*: Nucl. Instrum. Meth. A **518** (2004) 436.
[3] Ch. Brönnimann, Ch. Bühler, E.F. Eikenberry, R. Horisberger, G. Hülsen, B. Schmitt, C. Schulze-Briese, M. Suzuki, T. Tomizaki, H. Toyokawa, A. Wagner: Synchrotron Rad. News **17** (2004) 23.

FLAT PANEL DETECTOR

A flat panel detector (FPD, C7942-CA, Hamamatsu Photonics K.K.) was installed and used for large field X-ray imaging including X-ray diffractions (Fig. 1). The FPD consists of a scintillator (needle-like CsI crystals) and a complementary metal-oxide semiconductor (CMOS) photodiode array. Its characteristics are described in Table 1.

The advantages of the FPD over other image detectors are its compactness and low cost. Its weight is about 3 kg and its thickness is about 3 cm, and, therefore, it can be positioned anywhere in an experimental setup quite easily. Its cost is at least one order of magnitude lower than that of a CCD-based detector for protein crystallography with a similar number of pixels.

The performance of the FPD was tested [1]. The tests determined the conversion gain, noise, spatial resolution, and linearity. The preliminary results are also described in the previous report. A small angle X-ray diffraction pattern of a dried tendon of chicken, a diffraction pattern of a lysozyme crystal and refraction-enhanced X-ray image of rat were reported. The experimental results showed that the FPD was already suitable for application to synchrotron radiation experiments, however, some corrections were necessary for quantitative analysis.

Table 1. Characteristics of C7942-CA.

Number of pixels	2240 × 2368
Pixel size (μm)	50
Readout time	0.44 (eight channel)
Dark current (e^- $pixel^{-1}$ s^{-1})	5900
Readout noise (R.M.S., e^-)	1100
AD converter (bits)	12
Maximum charge (e^- $pixel^{-1}$)	2.2×10^6
Electrons per ADU	500
Electrons per X-ray photon	165 @ 12.4 keV
Resolution (LP mm^{-1})	8
Phosphor	CsI:Tl
Operating temperature	Room temperature
Size (mm)	200 × 198 × 28
Weight (kg)	3.2

The FPD is used at beamline **BL20B2** for optical alignment of large size beams, topography and refraction enhanced imaging, at **BL28B2** for topography, and at **BL13XU** for X-ray diffraction.

Fig. 1. Photograph of flat-panel detector. The frame drawn in black is the detection area, which has an area of 112 mm × 117 mm.

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References

[1] N. Yagi, M. Yamamoto, K. Uesugi and K. Inoue: J. Synchrotron Rad. **11** (2004) 347.