Introduction to detectors for synchrotron radiation detection and application

Hyun-Joon Shin
Pohang Light Source, Pohang Accelerator Laboratory, POSTECH, Pohang, 790-784, Korea
shj001@postech.ac.kr

1. Introduction

Pohang Light Source (PLS), a third-generation synchrotron radiation facility, has been operational from 1995 [1]. One of the main purposes of the synchrotron radiation facility is to generate high quality x-rays with an aim to investigate physical and/or chemical properties of samples based on light-matter interaction mechanisms. X-rays are generated from high-speed (~speed of light) electron-bunches that are circulating inside a storage ring and are delivered to a sample position through beamline optics. In the beamline and in the sample position, we employ various kinds of detectors in order to characterize the x-rays and to investigate sample responses caused by the incident x-rays. In this presentation detectors for these purposes are introduced.

2. Detector types for synchrotron radiation facility

Synchrotron radiation facilities generate x-rays: soft x-rays and hard x-rays. When x-rays are incident on a sample, light-matter interaction occurs, and based on the interaction mechanisms, such as x-ray absorption and partial transmission specifically at the near- and/or extended- absorption edge, x-ray diffraction, x-ray scattering, x-ray emission, x-ray induced photo-electron generation, etc., as shown in Fig. 1, one can investigate sample's atomic structure, crystal structure, elemental composition, chemical states, electronic structure, and so on [2-3].

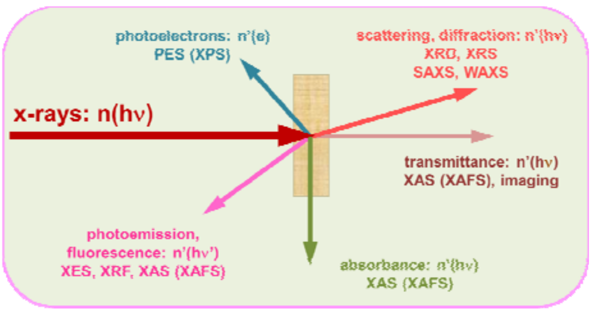

Fig. 1. When x-rays are incident on a sample, they are being (partially) absorbed or transmitted, scattered, or generating luminescence and photoelectrons. PES: photoelectron spectroscopy, XPS: x-ray photoelectron spectroscopy, XRD: x-ray diffraction, XRS: x-ray scattering, SAXS or WAXS: small or wide angle x-ray scattering, XAS: x-ray absorption spectroscopy, XAFS: x-ray absorption fine structure, XES: x-ray emission spectroscopy, XRF: x-ray fluorescence.

It is important to monitor the x-ray position and intensity and the sample responses and diverse kinds of detectors are used in the beamline. As an example, we may categorize detector types as shown in Fig. 2; (i) x-ray position measuring detectors, (ii) x-ray intensity measurement detectors typically located before sample position, (iii) x-ray induced sample response detectors at, in front of, or after the sample. In these detectors, basic detection mechanism is photoelectron generation from solid, photoionization of molecules, and electron-hole pair generation in semiconductor. In the case of low x-ray flux, counting detectors, such as gas proportional counter, phosphor screen employed PM tube, etc., are practically used. In the case of intense x-ray flux on a sample position, current measurement from a sample in total electron yield mode or in partial electron yield mode, ion chamber, gas cell, photo-diode, photoelectron measurement detectors (electron analyzer), and x-ray fluorescence measurement detectors are used.

2.1 X-ray position monitoring detectors

The spatial profile of X-rays is typically Gaussian in the plane perpendicular to the direction of x-ray. By putting pair of metal blades near the tail of the Gaussian profile, one can monitor the x-ray position. Two or four metal blades are typically used and called as photon beam position monitor (PBPM). One can also measure x-ray source size and divergence with two sets of PBPM detectors placed at different positions. Recently, quadrupole photon beam position monitor (QBPM), that detects x-ray induced luminescence from an x-ray passing window or filter, is devised to monitor x-ray position as well as relative intensity.

2.2 X-ray intensity measurement detectors

Measuring the intensity of x-rays before sample, Io measurement, is needed to normalize any spectrum or response obtained from a sample. For this purpose, partially (80~90%) transparent mesh, ion chamber, QBPM are typically used.

Mesh current: when x-rays hit metal of the mesh, photoelectrons are generated from the metal surface and charge compensating electrons flow from the ground to the mesh. Typically total electron yield (TEY) mode is used in this case. Similar method is used to measure photoelectron yield current from a reflecting mirror in the beamline. Photoelectron yield measurement method is efficient in (ultra-)high vacuum and typically used for soft x-ray beamlines.

Ion chamber: when x-rays are incident into ion chamber, x-rays ionize gas molecules and the electrons and ions are collected through biasing electrodes. By measuring this current, one can measure relative x-ray intensity. This is typically used for hard x-ray beamlines.

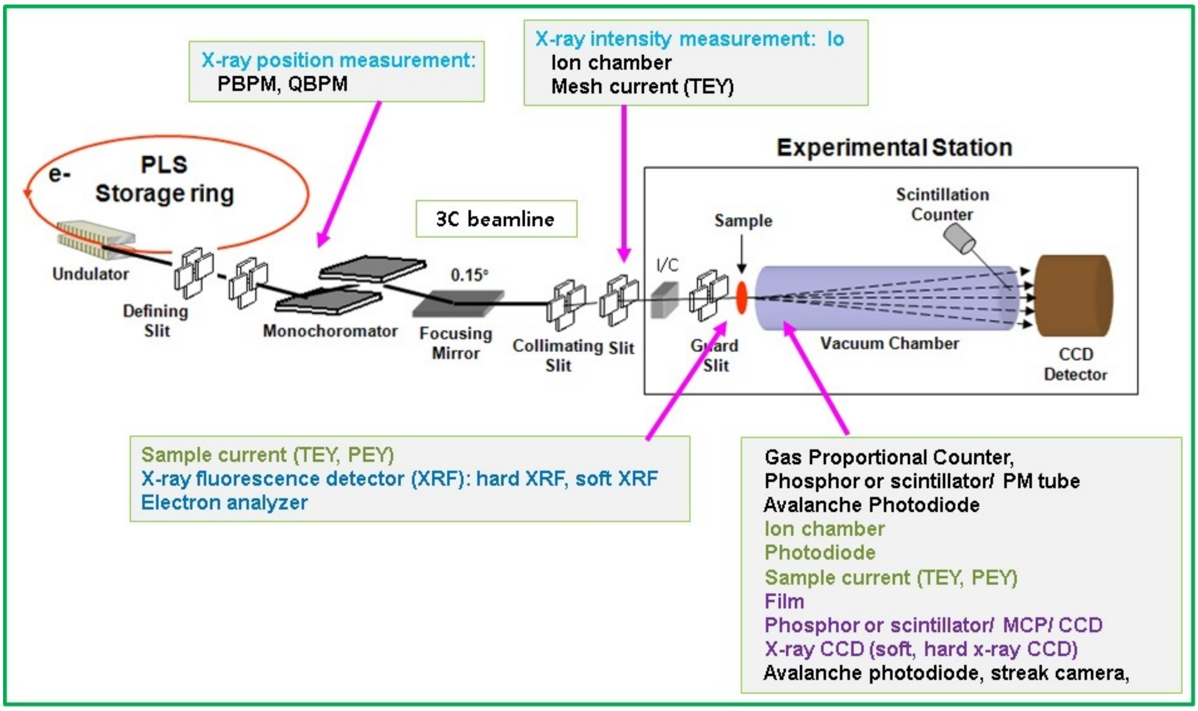

Fig. 2. Schematic of detector type category: x-ray position measurement detectors, x-ray intensity measurement detectors, and x-ray induced sample response measurement detectors.

QBPM: recently this device is used for x-ray position and intensity measurement, as explained above.

2.3 Sample response measurement detector

When x-rays hit samples, different kinds of responses are occurring based on the light-matter interaction as shown in Fig. 1, and correspondingly different kinds of detection techniques have been devised.

2.3.1 Detectors at or in front of the sample

Sample current: as stated above, this measures the amount of x-ray induced photoelectrons. Typically sample current is measured without bias, TEY mode. If one wants to select specific energy range of electrons, biasing is applied, partial electron yield (PEY) mode.

X-ray fluorescence: when x-rays hit sample, x-rays are generated (photoluminescence) as excited electrons or upper level lying electrons recombine into the empty lower energy holes. This x-ray fluorescence can be detected with solid state detectors. When the detectors are specifically designed, they can also provide energy information of the fluorescent x-rays.

Electron energy analyzer: when x-rays hit sample, x-ray induced photoelectrons are generated and escape from the sample surface into vacuum. When one collects the photoelectrons and measures the kinetic energy of the photoelectrons, then one can obtain binding energy and the occupied density of states of the sample. This electron analyzer has become very powerful for the investigation of electronic structure. Advanced setup of the electron analyzer can detect the momentum of photoelectrons, and one can obtain band structure of the sample. Hemispherical sector analyzer is commonly used for this purpose.

2.3.2 Detectors after the sample

Ion chamber: as stated above, this measures the intensity of x-rays passing through the sample.

Photodiode: this utilizes electron-hole pair generation by the incident x-rays. By measuring the photocurrent, one can measure the relative intensity of x-rays.

When x-ray flux is low, counting mode detectors are used; gas proportional counter, phosphor or scintillator implemented PM tube, or avalanche photodiode are in this catagory.

2.3.3 Detectors for scanning microscopy or full field microscopy

In order to obtain element specific, chemical state specific distributions within a sample or to obtain structural or spectroscopic information from a local area, spectro-microsocpy/-nanoscopy has been developed [4].

Microscopy type can be categorized by two techniques: sample scanning technique and full field recording technique. For the scanning type, 0-dimensional fast responding detectors, such as avalanche photodiode or phosphor/scintillator based PM tube, are used (Fig. 3). For the full field recording type (for microscopy or for diffraction pattern recording), films, phosphor/ scintillator based MCP combined with an optical CCD, and x-ray CCD in back illuminated mode or in front illumination mode are used.

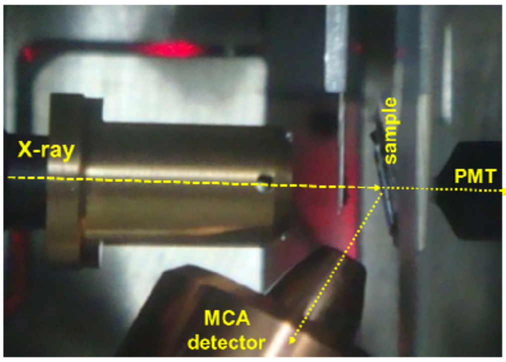

Fig. 3. In transmission x-ray microscopy, a PM tube (PMT) and (or) a MCA detector are used to measure transmitted x-ray intensity and x-ray induced fluorescence.

2.3.3 Detectors for fast timing pump-probe experiment

For fast timing pump and probe experiment, streak camera has been successfully developed to provide time resolution of a few hundreds of fs to ~ns [5]. In this case, photoelectrons are generated from a thin metal foil in transmission geometry or from metal surface in reflection geometry, (photocathode in the figure) and the photoelectrons are accelerated towards MCP (Fig. 4). In the process of photoelectron generation, electron bunch profile forms sequentially depending on the arrival time of x-rays. During the flight to MCP, the electrons are deflected by transient electric field in order to differentiate sequence of x-ray arrival time and are spatially expanded in the plain of detector, MCP, which is then monitored by an optical CCD [5].

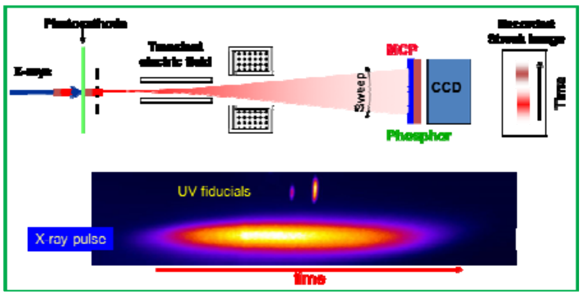

Fig. 4. Schematic of streak camera setup for x-ray pulse measurement.

3. Summary

Different kinds of detectors for the measurement of x-ray position, intensity, and sample responses have been introduced. Basically x-ray generated photoelectrons, ions and electrons from gas molecules, and electron-hole pairs inside semiconducting devices are monitored by electronics as signal. Since better performing detectors can provide better statistics and liability of the experimental data, lots of efforts on the realization of better detectors are still being made in the synchrotron radiation community.

Acknowledgement

The author would like to acknowledge the support by the Basic Science Research Program (NRF-2015R1A5A1009962) through the National Research Foundation of Korea (NRF) funded by the Korea government Ministry of Science, ICT and Future Planning (MSIP).

REFERENCES

[1] Pohang Light Source upgraded to PLS-II in 2011.From 2012 PLS is called as PLS-II. www.pal.postech.ac.kr..
[2] Introduction to Synchrotron Radiation, Giorgio Margaritondo, Oxford University Press, New York, Oxford, 1988.
[3] Photoelectron Spectroscopy: Principles and Applications, Stefan Hufner, Springer Series in Solid-State Sciences Edited by Manual Cardona, 1996.
[4] International conferences on x-ray microscopy: XRM2016, XRM2014, XRM2012, XRM2010, etc.
[5] J. Feng, et al., Nuch. Instrum. Meth. Phys. Res. A. 582, 248-251 (2007). J. Feng, et al., Appl. Phys. Lett. 91, 134102 (2007).