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DEVELOPMENT OF BEAM INTENSITY MONITORS FOR INTENSE UNDULATOR X-RAYS IN SPring-8

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Abstract

Saturation characteristics of Si photodiode(Hamamatsu S5377), free air ionization chamber(FAIC) and BGO scintillator for intense synchrotron radiation beam were measured with varying the thickness of Al absorber at the undulator beamline BL46XU in SPring-8. The FAIC showed serious saturation owing to the recombination when the beam intensity exceeded about 1×10^{11} photons/s for 15 keV X-rays and 1.0 mm$\times$0.5 mm beam size, while no tendency of the saturation was observed in case of the Si photodiode.

1 Introduction

Recently, very high intense X-ray beam from undulator is available at the 3rd-generation synchrotron radiation(SR) facilities such as SPring-8, ESRF and APS. Ionization chambers have been widely used for monitoring beam intensity at the SR facilities but X-ray beam from the undulator is so intense that the absolute intensity of the X-ray beam cannot be determined by using the ionization chamber because of the loss of ions by recombination. Therefore other new beam intensity monitors are needed in order to measure the absolute intensity of the undulator X-ray beam.

The prospective monitors for the measurement of absolute intensity of the undulator X-ray beam are following : Si photodiode, BGO scintillator, gas scintillator, CdTe semiconductor detector and secondary electron collecting vacuum chamber. In the present work, Si photodiode and BGO scintillator were irradiated at the BL46XU undulator beamline in SPring-8 for checking the saturation characteristics of these monitors. The other monitors are also intended to be tested at the same beamline in SPring-8.

2 Experimental

2.1 Calibration of monitors

A free air ionization chamber(FAIC) has been already calibrated by the total absorption microcalorimeter at the KEK PF 14C vertical wiggler beamline[1]. In our previous works, Si photodiode[2] and BGO scintillator have been also calibrated with the FAIC at the same beamline in KEK PF.

Fig.1 shows the schematic drawing of the experimental arrangement. The FAIC was located upstream of the Si photodiode or the BGO scintillator, which was used for obtaining the intensity of incident X-ray beam and calibrating the detectors. X-ray beam which was scattered by thin Be foil was detected by the HPGe detector. Incident X-ray beam energy and contamination of higher harmonic component are checked by measuring the coherent and incoherent scattering photon energy spectra using the HPGe detector.

Si photodiode : The wafer thickness of the Si photodiode was 300-μm and the Si photodiode was operated as a ΔE counter. The induced photocurrent of the Si photodiode was measured with an electrometer (Keithley 6517A).

BGO scintillator : A cubical BGO crystal (12 mm$\times$12 mm$\times$12 mm) was mounted on a Si photodiode (Hamamatsu S1227-1010BR) with polished face. The other sides of the crystal were not polished. The crystal and photodiode were settled in an aluminum case, which had a window of Be foil in 100-μm thickness for shading. The photocurrent of the scintillation light was also measured with the electrometer (Keithley 6517A).

(1) Calibration result of the Si photodiode

The Si photodiode(Hamamatsu S5377) was calibrated by the FAIC many times and the stability was confirmed. Table 1 shows the measured and calculated photocurrent of the Si photodiode per incident photon. Energy deposition in the total thickness of the Si photodiode was calculated using EGS4[3] or the mass energy absorption coefficient μ_{en}/ρ[4] of Si. The equation[5] that was used for calculation of absorption energy in Si using μ_{en}/ρ is

$$\text{absorption energy} = E \times (1 - \exp(-\mu_{en}/\rho \times \rho \times d))$$

where E is the energy of photon, ρ is the density of Si and d is the thickness of Si. Photocurrent was determined by using the results of these calculations and the value of W of Si that is 3.68 eV[6]. The differences between the measured and calculated photocurrents were almost within 1 %.

(2) Calibration result of the BGO scintillator

Table 2 shows the measured photocurrent per incident photon of the BGO scintillator, K,L X-ray and electron escape ratio from the crystal surface and the response per unit absorbed energy of the BGO scintillator. The BGO scintillator was a black detector but the measured photocurrents were not proportional to the incident photon energy. The BGO scintillator was operated in current mode and one reason of this non-proportionality was owing to the escape of characteristic X-rays and electrons from the crystal surface. Ratio of energy loss by escape of K,L X-rays and electrons from the BGO crystal surface was calculated by EGS4 and the result was shown in Table 2. After correction for the escapes of K,L X-rays and electron from crystal surface, the non-proportionality still remained.

Fig.2 shows the measured response of the BGO crystal for unit absorbed energy. Considerable non-proportionality was observed near L absorption edge of Bi (16.4 keV) and slightly near K absorption edge of Ge (11.1 keV). The relative response of the BGO crystal around 15 keV is about 20 % less than that of 40 keV. In this energy region, particularly near X-ray absorption edges, the non-proportionality of the scintillation responses of alkali halide crystals are well known[8] and a few authors have observed the non-proportionality of BGO crystal[9,10]. The present result was in good agreement with that of ref[10] in the whole energy region.

(3) EGS4 calculation of BGO scintillator response

The non-proportional response of BGO scintillator for photons under several hundreds keV energy region was induced by non-proportional response for electrons. Fig.3 shows the electron response of BGO crystal, which was measured using a Compton spectrometer[11]. The BGO response for electrons was nearly proportional to electron energy above 70 keV and decreased slightly as electron energy decreases. For calculation of BGO response for photons, energy spectrum of primary electrons, which was generated by photoelectric effect, Auger effect and Compton scattering in BGO crystal, was calculated using EGS4. One of the problems of this electron energy spectrum calculation by EGS4 was that the emissions of the low energy Auger electrons and characteristic X-rays from M and the higher shells were not able to be treated and the energy deposited in the very small area in the EGS4 calculation. This was significant for the response calculation of BGO crystal because such locally deposited energy by a vacancy of electron in M and the higher shells was not negligible for the calculation of photons of which the energy was under several tens keV. Therefore a rough assumption was made that all of the deposited energy by such an electron vacancy in M and the higher shells were assumed to have equivalent response of electrons of which the relative response was 0.5(see Fig.3). Fig.4 shows the calculated scintillation response of BGO crystal for photons using the result of electron energy spectrum calculation by EGS4 and measured BGO response for electrons. The calculated response was found not to be so different from the experimental result.

2.2 Saturation characteristic measurement

The saturation characteristics of the Si photodiode, the FAIC and the BGO scintillator for intense undulator X-ray beam were measured at BL46XU in SPring-8 with varying the thickness of Al absorber. The experimental setup was the same as made at KEK PF 14C. The X-ray beam size was 1.0 mm$\times$0.5 mm and the energy range was 15-20 keV at BL46XU. The Al absorber was placed in front of the first collimator to attenuate the incident X-ray beam. The attenuation ratio was calculated using the mass attenuation coefficient μ/ρ[4]. The saturation of monitors was able to be checked by comparison between this calculated attenuation ratio and the measured attenuation of beam intensity by the monitors.

3 Results and Discussions

Fig.5 shows the experimental result of simultaneous measurement of undulator X-ray beam using the Si photodiode and the FAIC. The X-ray energy was 15 keV. The FAIC saturated obviously when the beam intensity exceeded about 1×10^{11} photons/s. No tendency of saturation, however, was observed in case of the Si photodiode. Fig.6 shows the ratio of recombination loss of the FAIC for the undulator X-ray beam. The value of X-ray beam intensity on the horizontal axis of Fig.6 was measured by the Si photodiode. The charge loss by recombination decreased to 70 % at the beam intensity of 1×10^{12} photons/s. These results indicate the difficulty of the measurement of the absolute intensity of the undulator X-ray beam using the ionization chamber. The Si photodiode and the BGO scintillator were also operated in the same way and the result is shown in Fig.7. The measured intensity of the BGO scintillator became by about 3 % less than that of the Si photodiode when no Al absorber or 1mm thick Al absorber were used. One of the supposed reasons of these differences between the BGO scintillator and the Si photodiode was owing to the thermal dependence of the BGO scintillation response. The response of BGO scintillator extremely depends on the thermal condition[12]. The rise of 1 °C temperature of BGO crystal causes about 1 % decreasing of the response. It was considered that the temperature rising of BGO crystal was induced by the intense X-ray beam.

4 Conclusion

The Si photodiode was capable of absolute intensity measurement of undulator X-ray beam. The FAIC showed serious saturation by recombination when the beam intensity exceeded about

1×10^{11} photons/s while no tendency of saturation was observed in case of the Si photodiode. The BGO scintillator had difficulties in measuring absolute intensity of undulator X-ray beam because of its thermal dependence of the response and non-proportional response near absorption edges. For more precise measurement, comparison between the Si photodiode and the total absorption microcalorimeter[1] is planned.

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Table 1. Measured and calculated photocurrent (Coulomb/incident photon) of the Si photodiode.

X-ray energy(keV)	Measured value	Calculated by EGS4[7]	Calculated using μ_{en}/ρ
10	3.88e-16	3.91e-16	3.92e-16
15	3.21e-16	3.23e-16	3.24e-16
20	2.13e-16	2.15e-16	2.16e-16
30	1.01e-16	1.01e-16	1.02e-16
40	5.67e-17	5.7e-17	5.73e-17

Table 2. Measured photocurrent (Coulomb/incident photon) and response per absorbed energy of the BGO scintillator.

X-ray energy (keV)	Measured photocurrent (C/photon)	K,L X-ray and electron escape ratio by EGS4 (escape energy/total energy)	Response per unit absorbed energy (C/keV)
9	2.57e-18	3.327e-3	2.87e-19
10	2.98e-18	3.832e-3	2.99e-19
11	3.40e-18	4.312e-3	3.10e-19
12	3.66e-18	2.240e-2	3.12e-19
13	4.02e-18	1.899e-2	3.15e-19
14	4.04e-18	4.131e-2	3.01e-19
15	4.36e-18	3.548e-2	3.01e-19
20	6.11e-18	2.989e-2	3.15e-19
30	1.07e-17	1.241e-2	3.61e-19
40	1.49e-17	8.627e-3	3.76e-19

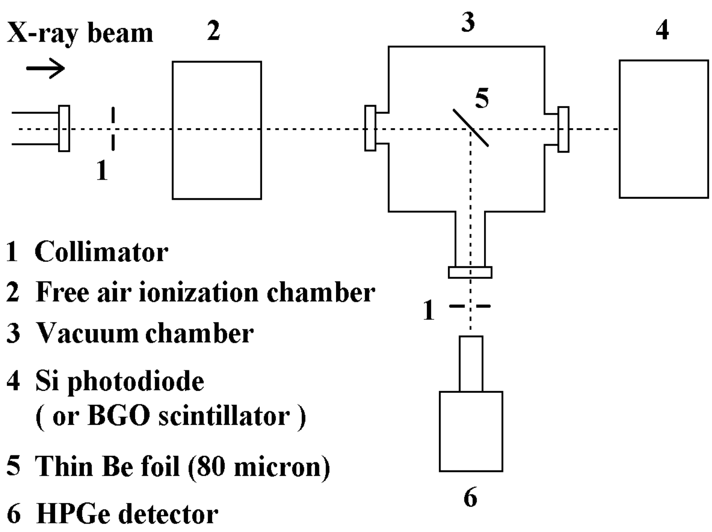

Figure 1: Schematic drawing of the experimental arrangement.

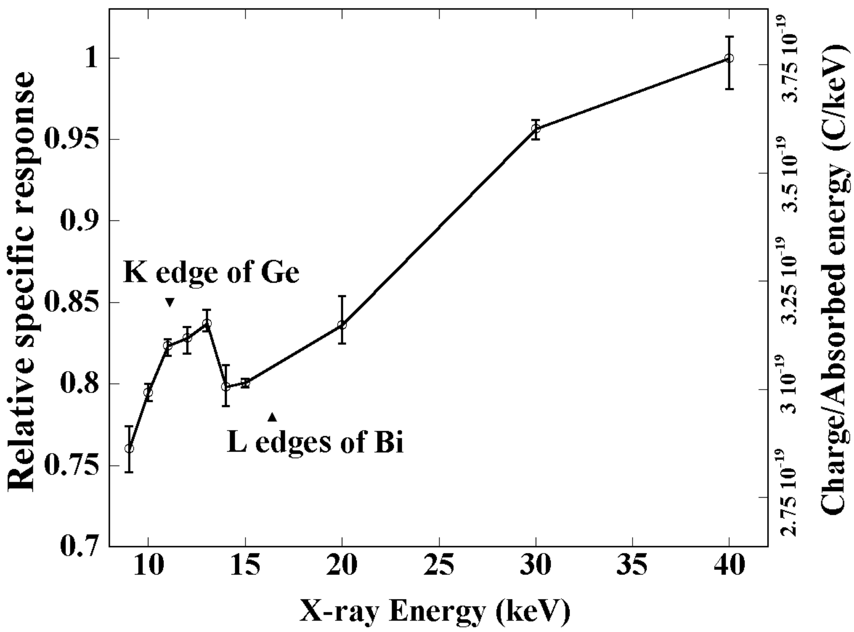

Figure 2: Measured response of the BGO scintillator for photon per unit energy deposited in the scintillator. The values are normalized to unity at 40 keV.

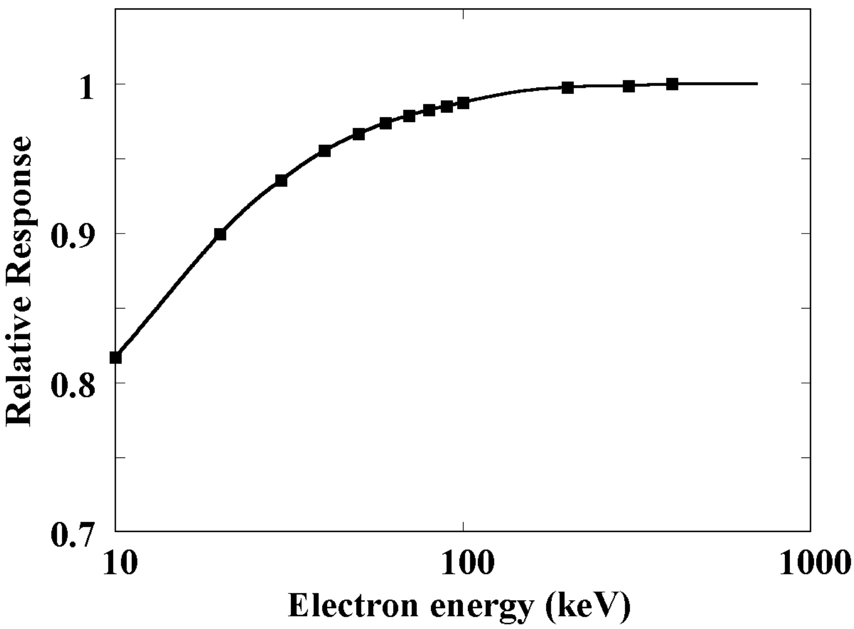

Figure 3: Scintillation response of BGO crystal for electrons measured by Compton spectrometer[10].

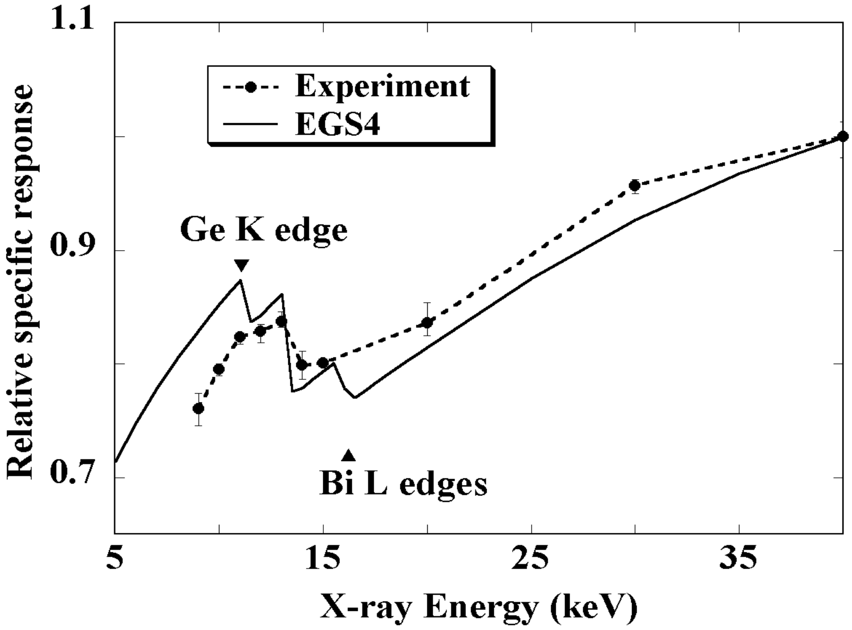

Figure 4: Measured and calculated BGO response for 8-40 keV X-rays. The values are fitted at 40 keV.

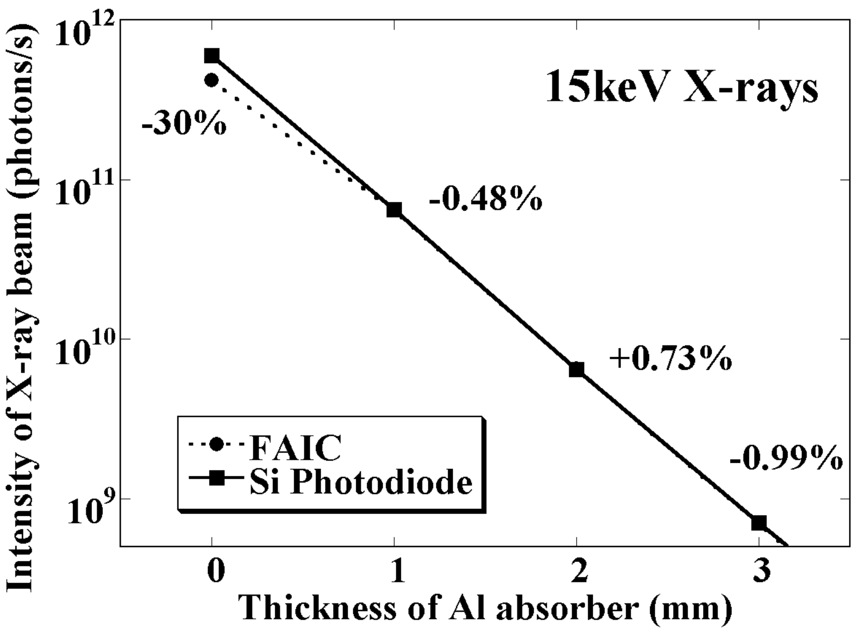

Figure 5: Saturation characteristics of the FAIC and the Si photodiode for undulator 15 keV X-ray beam at SPring-8 BL46XU. The values in the figure denote the difference between the FAIC and the Si photodiode.

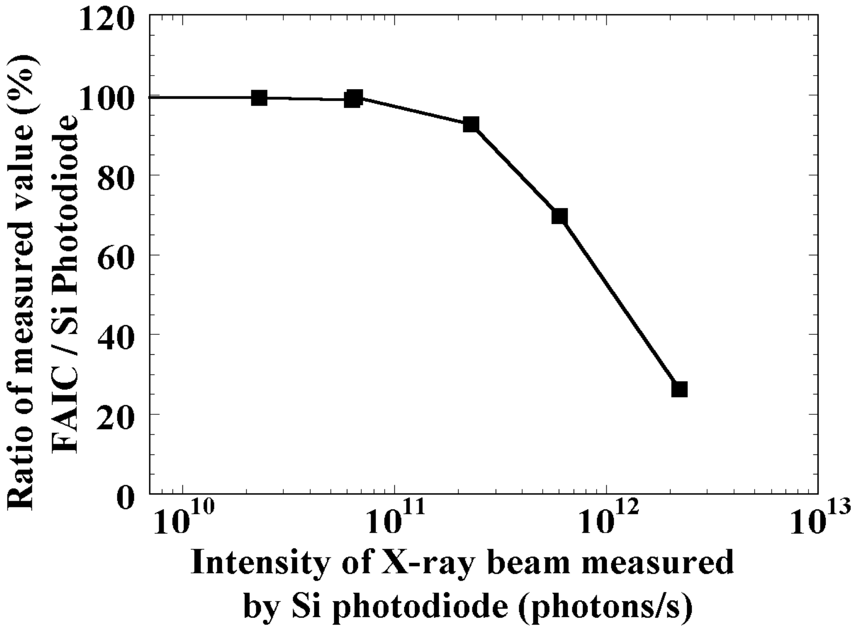

Figure 6: Recombination loss of the FAIC for undulator 15 keV X-ray beam at SPring-8 BL46XU in comparison with the Si photodiode.

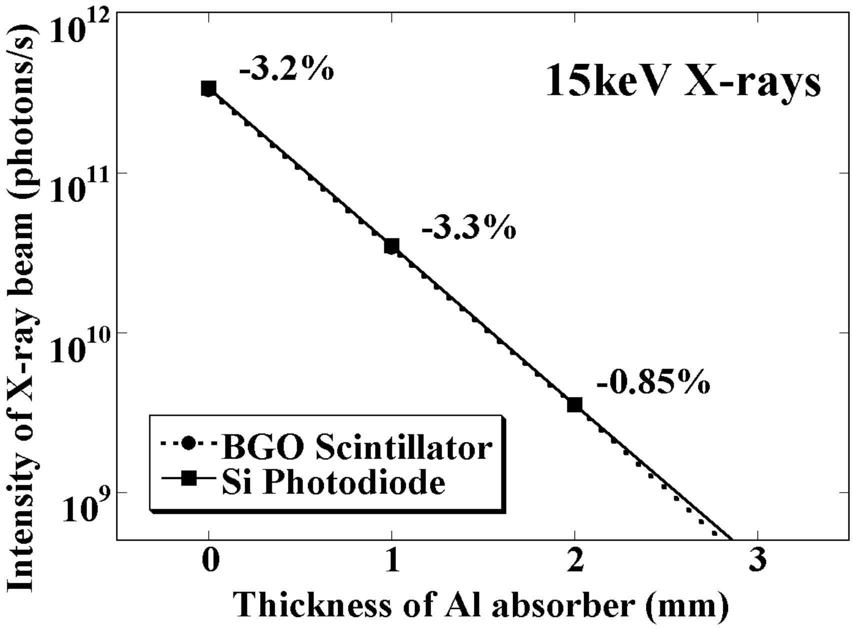

Figure 7: Saturation characteristics of the BGO scintillator and the Si photodiode for undulator 15 keV X-ray beam at SPring-8 BL46XU. The values in the figure denote the difference between the BGO scintillator and the Si photodiode.