A position-sensitive ionization chamber for XAFS studies at synchrotron sources

Kazumichi Sato[a*]

[a]*SPring-8/JASRI, Japan.*
Email:kazusato@spring8.or.jp

A position-sensitive ionization chamber has been developed with backgammon-type-segmented electrodes. This novel detector possesses a linear range of 8 mm for determining the incident position of the X-ray beam incoming. The position resolution was found to be less than 10 um, probably close the sub-micrometer region. Owing to its high spatial resolution, the position-sensitive ionization chamber was able to commit that the gradual decrease observed in the X-ray beam intensity at a SPring-8 beamline was mainly due to the spatial variation of the X-ray beam in time. The present work also confirmed the applicability of the novel detector to the accurate monochromator adjustment for experiments using diamond anvil cells.

Keywords: ionization chamber; position-sensitive detector.

1. Introduction

Spacial variations of fine X-ray beams which are used in synchrotron radiation experiments, including XAFS, are very important because it causes deterioration in experimental data. There are some rumors about spacial variation but, first, we have to evaluate it quantitatively.

One method to do this is to adopt segmented electrode ionization chamber (Tischler et al., 1980). Those with triangular electrodes had been developed (Hettel, 1983 and Koyama et al., 1989). In this electrode configuration, the ions generated along the pass of the X-ray beam drift towards the segmented electrodes under the influence of an applied electric field. The ionization currents from these electrodes depend upon the beam position and we can measure the beam position by measuring these currents.

The stability, however, is not adequate since the incident beam exponentially attenuates along its incident direction and causes systematic error in output currents. Even if the beam was absolutely in the center of the electrodes, a position calculated with ionization currents has an offset, which depends on the absorption condition of the gas, such as X-ray energy, gas pressure or gas purity. As a result these position monitors have two disadvantages; instability in long term operation and dependency upon absorption condition.

In the present work, to improve this condition, a zigzag-shape of segmented electrode called “backgammon-type electrode” has been developed.

2. Conceptual Design and Operation Principle

Each current from triangular segmented electrode can be expressed by the following equations:

$$SigA \propto 1-\exp\left(-\frac{L}{2\lambda}\right),$$

Table 1
Energy dependence as a function of Ntri.

Ntri	L[cm]	Position @8keV	Position @14keV	Displacement[um]
1	3.3	37.4	7.15	30.3
2	1.65	18.7	3.57	15.1
3	1.1	12.5	2.38	10.1
4	0.825	9.35	1.79	7.57
5	0.66	7.48	1.43	6.06
6	0.55	6.24	1.19	5.05
7	0.471	5.35	1.02	4.33
8	0.413	4.68	0.893	3.78
9	0.367	4.16	0.794	3.36
10	0.33	3.74	0.715	3.03
11	0.3	3.40	0.65	2.75

$$SigB \propto \exp\left(-\frac{L}{2\lambda}\right)\left\{1-\exp\left(-\frac{L}{2\lambda}\right)\right\},$$

where SigA and SigB denote the currents measured on the segmented electrodes A and B, respectively. Here, λ denotes the X-ray attenuation length and L the length of the electrodes.

Assuming the triangular electrodes are shrinked and constructs the backgammon segmented electrode as shown in Fig. 1, the systematic error was calculated with these equations. Table 1 summarizes the systematic errors at X-ray energies of 8keV and 14keV as a function of the total number of the triangle in the backgammon segmented electrode where Ntri denotes the number of triangles. The filling gas was assumed to be a 1 atm nitrogen. The variation of energy causes error of more than 30 microns but with 11 triangles, it is less than 3 microns.

Following to the energy dependence, the position resolution was confirmed (Sato et al., 1999). With error propagation law, the current reading accuracy of about 10^{-4} corresponds to the position

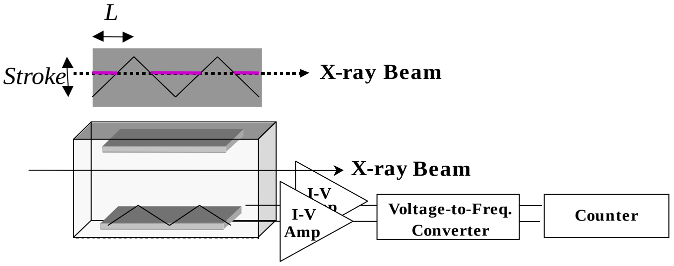
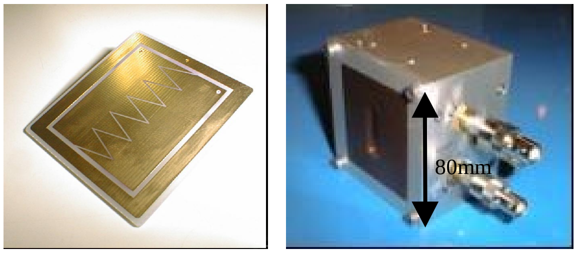


Figure 1
Schematic Diagram of PSIC.



(a) (b)

Figure 2
Photographs of the backgammon-type-segmented electrode (a) and the PSIC built (b).

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reading accuracy of 1 micron. This current reading accuracy is adequately achievable in usual XAFS beamlines, thus position resolution of 1 micron can be obtained.

The linear output range of the beam position was also confirmed. Factors are the electrode stroke, spread of the ionization and the beam size. Spread of the ionization was calculated with EGS4 calculation code (Nelson et al., 1985). With the electrode stroke of 10 mm, it can be proved that the position determination over 4.4 can be done even if beam size is 1 mm.

3. Experimentals and Discussion

The backgammon-type-segmented electrodes were formed on a printed circuit board as shown in Fig. 2a. The electrodes have an identical triangular pattern with a repetition of 11 times. The position-sensitive ionization chamber (PSIC) has been built as shown in Fig. 2b and installed into the diffraction experiment station of the BL44B2 (RIKEN Beamline II) at the SPring-8 facility. Before reaching the sample position, the monochromatized X-ray beam on the sample position is collimated with an X-ray collimator of 100 um in opening. The intensity of the X-ray beam after the collimation was monitored by an ionization chamber, IC2. Also the position of the beam before the collimation was monitored by a PSIC.

In order to measure the linearity range realized, the PSIC was first moved vertically on a stepping motor stage with an interval of 400 um over a distance of 10 mm. The ionization current was integrated for 1 sec. Figure 3a shows the ionization current observed on the two-segmented electrodes. Since the ionization region is more extended than the beam profile measured due to the range of the secondary electrons, it is reasonable to observe the precursor in the ionization current.

In order to determine its spatial resolution attainable, the PSIC was moved with much finer interval of 10 um. The PSIC system employed in the present work has succeeded in precisely responding the increment of this fine interval as can be seen in Fig. 3b, strongly suggesting that its spatial resolution is much less than 10 um under the present conditions.

During the course of proceeding in the present work, it was decided to employ the PSIC for the purpose of investigating the nature of the drift of the beam position. Having located the PSIC in the same position as before, the vertical position and the intensity of the X-ray beam were continuously monitored over 60 minutes with 10 seconds integration as shown in Fig. 4a. It is clearly seen in this figure that the position variation observed with the PSIC is almost identical to the ionization current observed with the ionization chamber. This experimental observation can be regarded as evidence for the vertical moving of the X-ray beam at the beamline. Also suggested in this observation was the possibility that the ultimate position resolution of the PSI C reached sub-micron level, since it succeeded in resolvin g the fine structure of 1 um level appearing on the drift curve. The two PSIC output s are added and shown in Fig. 4b in order to check a spurious dependence of PSIC on incident intensity. Although the beam intensity should depend on the beam position by beamline optics, the PSIC position output is more similar to the IC2 output.

One should keep in mind that the position resolution strongly depends on the integration time of the PSIC system. Increasing the integration time will improve the S/N ratio of the system, but will degrade the time response of the system.

Figure 5 shows a result of an accurate monochromator adjustment using PSIC for XAFS experiment at BL01B1 XAFS beamline in SPring-8. The monochromator crystal was silicon (311). Since it is necessary to put the beam onto a small entrance window of a diamond anvil cell, horizontal adjusting of the beam position was important. In this figure, the monochromator adjustment was performed using the PSIC output. As a result, the beam position was fixed with the positioning accuracy of less than ±20 microns over the bragg angle range of 10 degrees after monochromator adjustment compared to previous ones.

4. Conclusion

We have developed the position-sensitive ionization chamber which can monitor not only the X-ray beam intensity without beam destruction during user experiments, but also the X-ray beam position. The use of the backgammon-type-segmented electrodes should result in making the system independent from the X-ray energy and in improving the long-term system stabilization.

The present work experimentally confirmed that the spatial resolution of the PSIC is definitely less than 10 um. The PSIC provided that the gradual decrease in the X-ray intensity observed with the ionization chambers was mainly caused by the spatial drift of the X-ray beam. Since the PSIC was capable of reproducing the detail structure of the variation in the X-ray intensity, it is likely that the spatial resolution of the PSIC is already in the region of sub-micrometer. It was also experimentally confirmed that the PSIC possesses a linear range

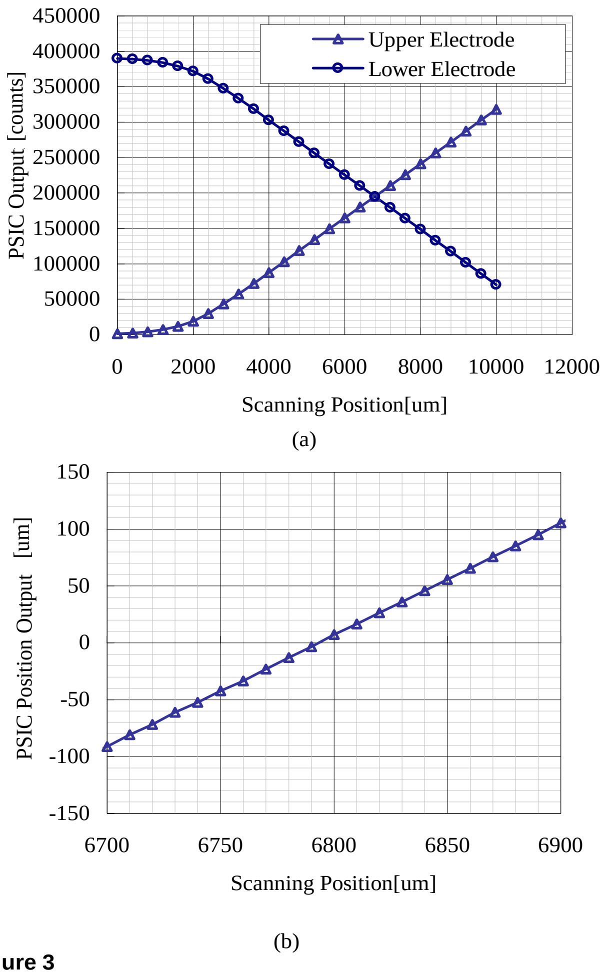

Figure 3
Response of the PSIC to the stage scanning; 400um step in AD unit (a) and 10um step in position unit (b).

close to 8 mm for position determination over 10 mm stroke as the design expected.

In addition, the PSIC can be useful for adjusting X-ray beams in beamline optics. The PSIC can also be applied to experiments in which the center of gravity of X-ray beam is requested to irradiate on a fixed position of the sample precisely such as in XAFS experiments using diamond anvil cells.

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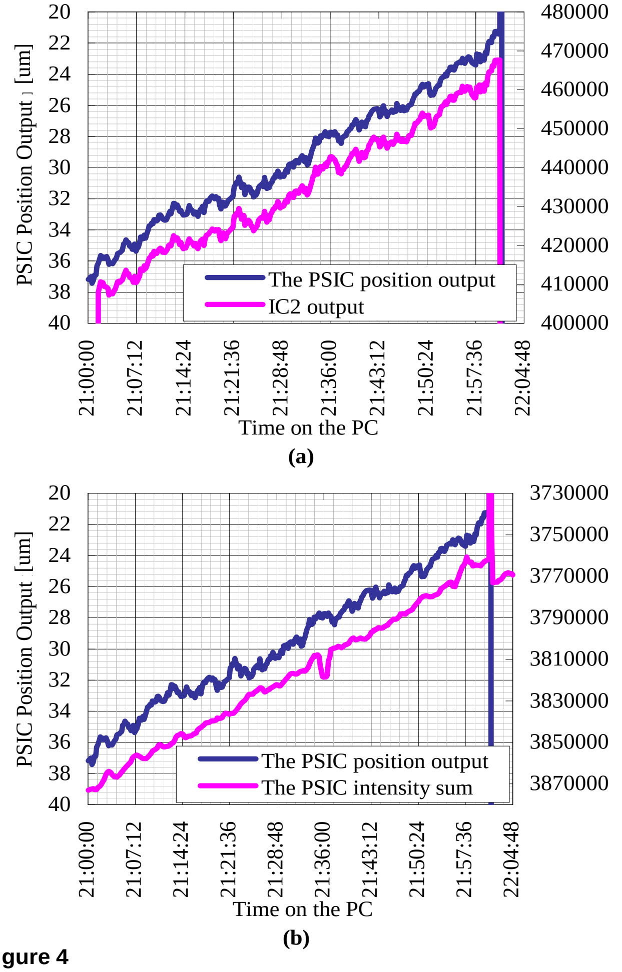

Figure 4
Comparison of the detector signals; time variance of the PSIC position output and IC2 output (a) and the PSIC intensity sum (b) .

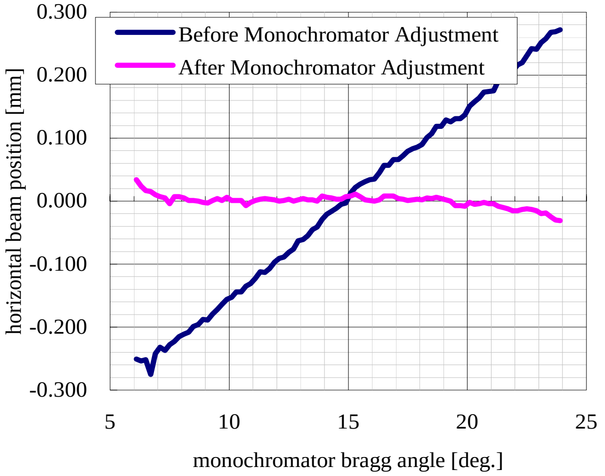

Figure 5
The result of an accurate monochromator adjustment using the PSIC.

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