The Behavior of Ionization Chambers under the Irradiation of High Flux X-Ray Beam

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1. Introduction

Ionization Chambers are widely in use as X-ray beam intensity monitors in synchrotron radiation experiments. It makes full use of the proportionality of an ionization current generated in an ionization chamber and the incident X-ray beam intensitiy.

Typical ionization chambers are constructed with the parallel plate geometry as illustrated in Fig. 1, where the applied voltage is denoted as V, the gap width d, and the ionization current *I(V)*, respectively [1]. The current-voltage characteristics observed in such chambers is also schematically shown in Fig. 2. As the voltage is increased, the resulting electric field begins to separate electron-ion pairs generated by ionizing radiation more rapidly, and the recombination process between the electrons and the ions are diminished. At a sufficiently high applied voltage, the electric field becomes strong enough to suppress the recombination process to a negligible level, and all the charges initially created through the ionization process contribute to the ionization current. Under these conditions, the current measured in the external circuit can be regarded as a true indication of the formation rate of all charges due to ionization by the incident X-ray photons.

In case of charged particle beams, however, it has been known that the proportionality breaks in high ionization current region (higher than 1μA) because of (1) the high concentration of electron and ion pairs that enhances the recombination process (volume recombination), and (2) the space charge effect which shields the external electric field resulting in enhancing the recombination further (columnar recombination) [2]. It is quite natural to anticipate that ionization chambers would also cease to function if a high ionization current is generated with an intense X-ray beam. However, there is few experimental research reported on this subject as far as we know, preventing us from justifying the use of ionization chambers under irradiation of high flux X-ray beams.

Based upon this understanding, we carried out an experimental study on an ionization chamber first at the BL01B1 (XAFS Beamline) [3] where the X-ray beam with the bending magnet will generate a lower ionization current, and subsequently at the BL47XU (R&D Beamline I) [4] where the X-ray beam with the undulator will generate a higher ionization current.

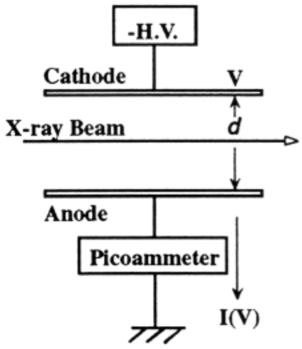

Fig.1 Structure of typical ion chamber

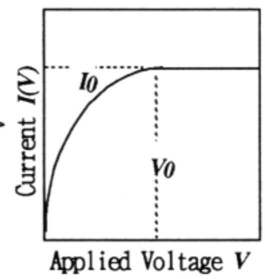

Fig.2 Saturation curve

2. Experimentals

The ionization chamber used (S-1194B1, Ohyo Koken Kogyo Co., Ltd) has a pair of electrodes, 140 mm long and 12.5 mm separated. The electrode collecting ionization current is associated with guard rings. This model is commonly used as a beam intensity monitor at SPring-8 beamlines. The maximum rating of the applied high voltage is 2000 V when air is filled. In the present study, the applied voltage was supplied to the ionization chamber from a high voltage stabilized power supply (ORTEC, model 556), and the ionizing current was measured with a high sensitivity picoammeter (Keithley, model 486). Aluminum absorbers were used so as to vary the incident beam intensity.

The X-ray beam intensities at the position between the absorbers and the ionization chamber were evaluated by using the following equation

$$\phi_0 = \frac{I}{e}\frac{w}{E_{x-ray}}\{1-\exp(-\mu x)\}^{-1},$$

where the absolute intensity is denoted as ϕ_0 [X-ray photons/sec], the measured ionization current I [A], the *W-value* of the filling gas w [eV/e-i pair], the incident X-ray energy E_{x-ray} [eV], the line absorption coefficient of the filling gas μ [cm^{-1}] and the electrode length x [cm], respectively. The dead volume correction is not included in the above expression for simplicity.

The filling gases used were argon gas for the BL01B1 experiment, and air, nitrogen, argon and krypton gases for the BL47XU experiment, all at 1 atm. Air is conventionally used as a filling gas among the SPring-8 beamlines, and the other gases are particularly useful for XAFS experiments in which X-ray absorption efficiency of the ionization chambers is important.

In the BL01B1 experiment, the synchrotron radiation beam from the bending magnet is monochromatized to 19.5keV X-ray beam, whose intensity was reported to be about 108 photons/sec during the period of the initial beamline commissioning with a storage ring current of ~ 1 mA [3]. The saturation of the ionization current was clearly observed at the electric field of 8 V/mm as shown in Fig. 3, verifying the function of the ionization chamber.

The configuration of the BL47XU experiment is schematically shown in Fig. 4. The storage ring current was about 20 mA, and the energy of the first order X-ray beam was 14.3 keV. The incident beam size was set to be 0.6 mm horizontally and 0.5 mm vertically with the front-end X-Y slits. The saturation characteristics measured under these conditions are shown in Fig. 5(a)-(d).

3. Discussion

As shown in Fig. 5(a), the saturation voltage observed is as high as 500 V without absorbers for nitrogen gas, while it is as low as 50 V with 2 mm absorber. The applied voltage needed for complete saturation became higher as the incident beam intensity increased.

The saturation voltage in argon gas were 100, 300 and 1000 V with the Al absorber thickness of 3, 2 and 1 mm, respectively, as shown in Fig. 5(b). The dependence of the saturation voltage on the incident beam intensity was larger in argon in argon than that in nitrogen. Without absorbers, the complete saturation was not confirmed. The relations between the saturation voltage and the absorbers, *i.e.*, the incident beam intensity, is shown in Fig. 6. In this figure the solid lines are eye-guide lines connecting the measured points. The figure indicates that the incident beam intensity based on the ionization current can result in an erroneous underestimation if the ionization current saturation is incomplete.

The saturation characteristics in krypton gas was similar to that of argon gas as shown in Fig. 5(c). Although the ionization current in air seems saturated in the present range of the applied high voltage as shown in Fig. 5(d), more accurate measurements at higher applied voltages should be done to confirm its saturation.

Taking the absorbers' effect into account, as shown in Table 1, the absolute intensities of the X-ray beams were estimated to be about 1012 photons/sec in all the gases except krypton gas. The ionization current generated in krypton gas is presumably larger than that in argon gas owing to its smaller *W-value*. However, this seems not the case, since the ionization current observed at 2400 V is less than that in argon gas. This may imply that the recombination process is not fully suppressed in krypton gas even at the applied voltage of 2.4 kV because of its larger ionization density.

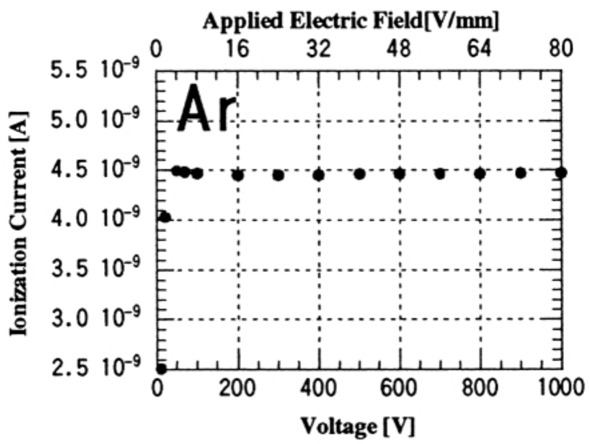

Fig.3 Saturation Curve at the Bending Magnet Beamline (BL01B1, 19.5keV)

Table 1. The absolute intensities

Gases and absorbers	W-value [eV]	Estimated absolute intensities [photons/sec]
Air	33.8	2.00×10^{12}
N2 N2-Al2mm	34.8	1.40×10^{12} 1.07×10^{12}
Ar Ar-Al1mm Ar-Al2mm Ar-Al3mm	26.4	1.20×10^{12} 1.30×10^{12} 1.20×10^{12} 1.13×10^{12}
Kr Kr-Al1mm Kr-Al2mm Kr-Al3mm	24	2.03×10^{11} 4.19×10^{11} 4.57×10^{11} 8.28×10^{11}

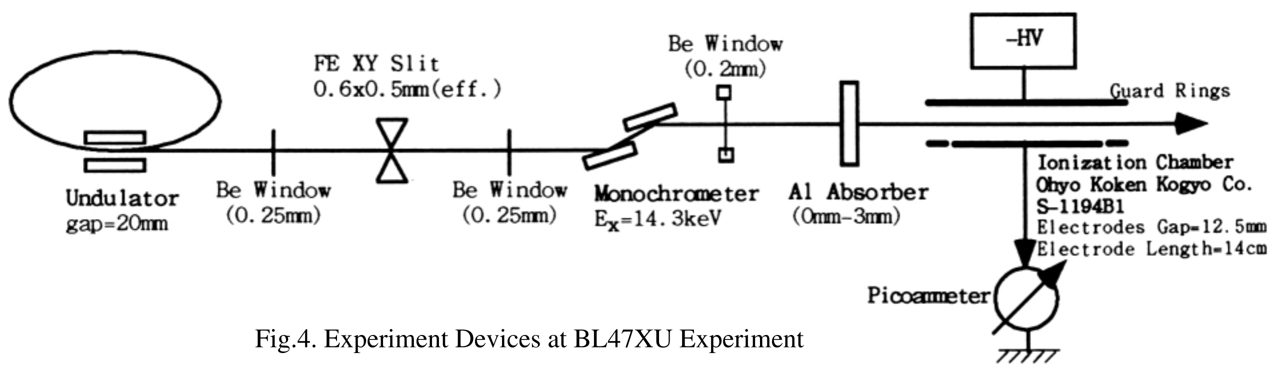

Fig.4. Experiment Devices at BL47XU Experiment

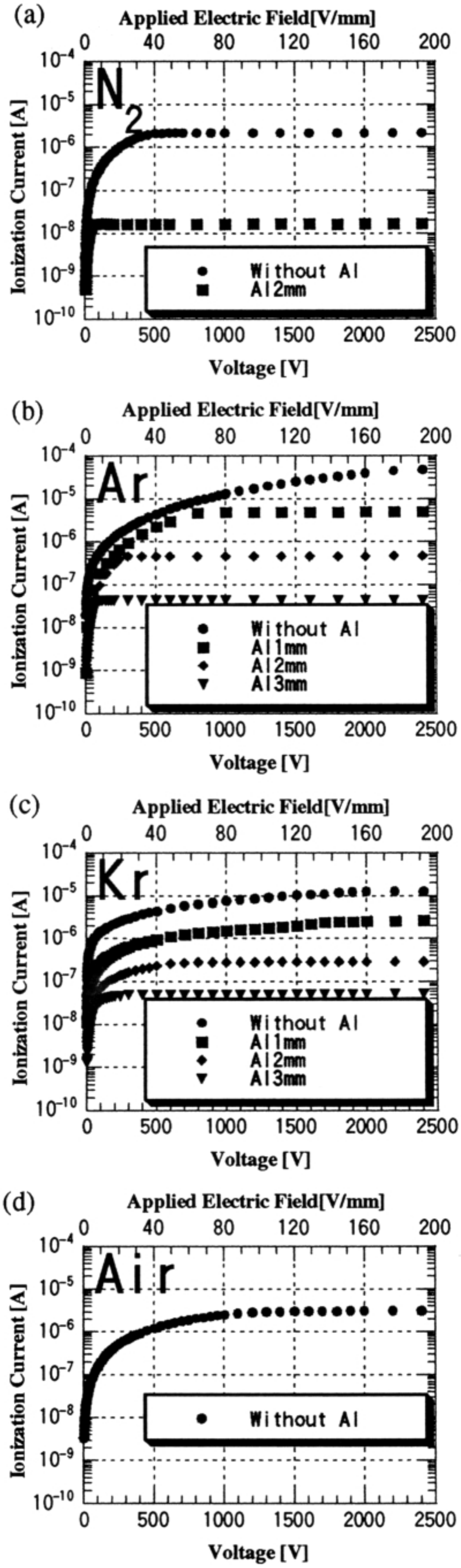

Fig.5 Saturation Curves at the Undulator Beamline (BL47XU, 14.3keV)

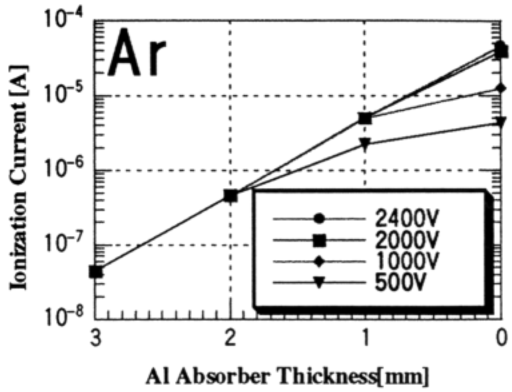

Fig.6 Relation between the saturation voltage and the absorbers

4. Concluding remarks

From an application point of view, it should be emphasized that the proportionality between the incident X-ray beam intensity and the observed ionization current in an ionization chamber is not guaranteed under high flux X-ray beam experiments. When the SPring-8 storage ring is in its full operation with a ring current of 100 mA, even nitrogen gas may no longer be an appropriate filling gas in those beamlines where focusing devices are utilized. Basic strategy towards this problem is probably to use lighter gases in ionization chambers. In this respect, helium gas could be promising, since it is the lightest gas in practice. However, adding some molecular gas component could be required in order to suppress Penning effect in helium gas which changes the *W-value* and to shorten the photoelectron range. Helium-nitrogen gas mixture could, therefore, be one of the most attractive gas combination, provided that the gas concentration is precisely controlled.

Since, in addition, there exists an ambiguity in the ionization current measurement due to the higher-order-harmonics contained in the X-ray beam, their elimination should be well managed in further experiments by, for example, detuning the double crystal monochromator.

References

[1] G. F. Knoll, "Radiation Detection and Measurement", (1989) 136.

[2] C. A. Colmenares, Nucl. Instrum. Meth, 114 (1974)269.

[3] K.Sato et al., Internal Note 1997/09/25_DG/97/02, 1997 (in Japanese).

[4] K.Sato et al., Internal Note 1998/02/10_DG/98/01, 1998 (in Japanese).