Design, construction, and testing of a rarefied-gas ionization chamber

A.M. Pyzyna, A. McPherson, S.D. Shastri, and D.R. Haeffner
Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439 USA

Introduction

An ideal ionization chamber will produce a current that is directly proportional to the flux of a monochromatic x-ray beam that passes between its electrodes. In order to approach this result, we must ensure that a sufficient voltage is applied to the electrodes such that nearly all photoelectrons produced by the beam are collected. When the applied voltage is below this value, electrons and ions are more likely to recombine before they reach their respective electrodes. In effect, the current measured grows as a function of applied voltage until the "plateau" voltage is reached. Further voltage increases will not lead to an increase in current until we reach such a high voltage that secondary ionization is initiated [1]. Only in the plateau region can the current be taken as proportional to the amount of ions created.

The standard style of ionization chambers used in sector 1 of the SRI-CAT utilizes a flowing supply of nitrogen at slightly greater than atmospheric pressure. These devices work reasonably well with high-energy monochromatic x-rays, for which nitrogen has small photoelectric and Compton scattering cross sections. However, as the x-ray energy is decreased, and ionization is subsequently increased, we find that an ever-increasing voltage is required to collect all of the liberated electrons. Figure 1 shows that with the Si(111) monochromator and undulator optimized at 7.46 keV, our power supplies cannot produce a high enough voltage to reach the constant current plateau.

The standard ionization chambers work better at high energies because smaller cross sections result in less ionization. Since there are many fewer electrons and ions per unit volume present, interactions that lead to recombination are greatly reduced. The purpose of this project was to design, build, and test an ionization chamber that has a low plateau voltage even when used with low-energy x-rays. This chamber will serve as a permanent beamline component, residing in the 1-ID-B station (see Figure 2).

Methods and Materials

The rarefied-gas ionization chamber was designed to produce less ionization at low energies than the standard ionization chambers. By filling the chamber with nitrogen to approximately one-eighth atmospheric pressure, we proportionally reduce the amount of molecules available for ionization.

The chamber was designed and constructed as a stainless-steel box embedded in a portion of stainless-steel tube. The tube, which has conflat-style flanges on either end, can be connected to other high-vacuum components in the beamline. The box is positioned within the tube such that the monochromatic beam will pass through it via two beryllium windows. The white beam, however, will pass through the tube but under the box. The stainless-steel

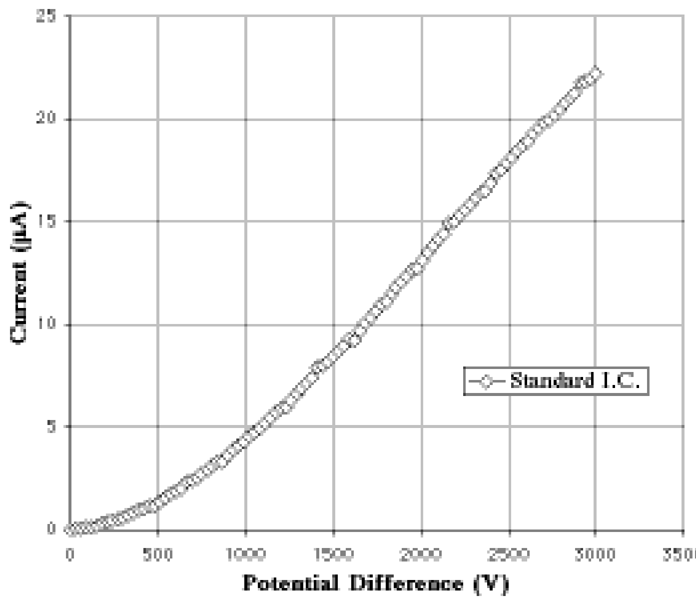

Figure 1: Response of a standard ionization chamber to a 7.46 keV beam. The current continues to increase as a function of applied voltage.

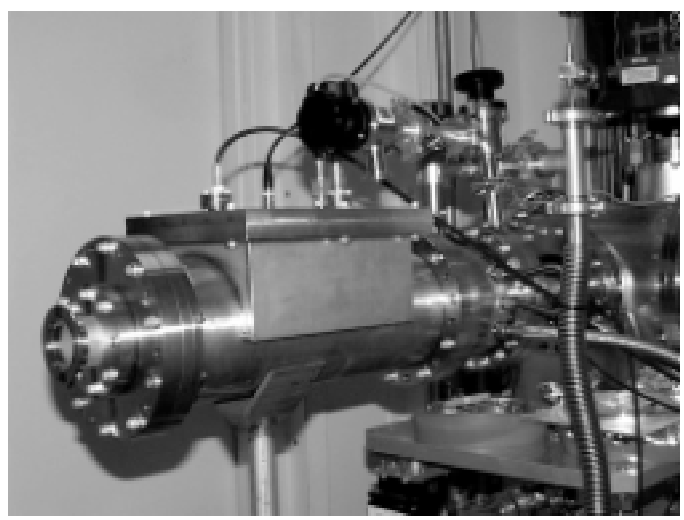

Figure 2: The ionization chamber is shown installed at the downstream end of the 1-ID-B hutch.

electrode plates, which are housed in the box, are supported by a polycarbonate structure. They are separated such that the active region between them measures 120.7 mm long by

50.8 mm wide by 14.7 mm high. This structure, as well as gas valves and electrical feed-throughs, are attached to a lid. An O-ring seal between the box and the lid maintains the nitrogen pressure inside.

The rarefied-gas ionization chamber was filled with nitrogen to 101 torr and placed in 1-ID-C for testing. Two standard ionization chambers were also placed in the hutch to serve as references. The white-beam slits were opened to 3 mm (horizontal) by 2 mm (vertical). The response from the rarefied-gas ionization chamber and a standard ionization chamber was then measured as a function of voltage. The chambers were tested with 7.46 keV, 13.00 keV, and 18.00 keV x-ray beams. The applied voltage varied from 0 V to –1320 V. The average ring current was approximately 86 mA.

Results

At all three energies tested, the rarefied-gas ionization chamber reached a current plateau. As shown in Figure 3, the plateau voltage for the rarefied-gas ionization chamber is about –330 V when used with a 7.46 keV beam. When it is used with 13.00-keV and 18.00-keV beams, the response becomes constant at about –160 V and –100 V, respectively.

The response from the standard ionization chamber, however, did not plateau when used with 7.46-keV and 13.00 keV beams. Only when the ionization chamber was used with an 18.00 keV beam did its current begin to level off.

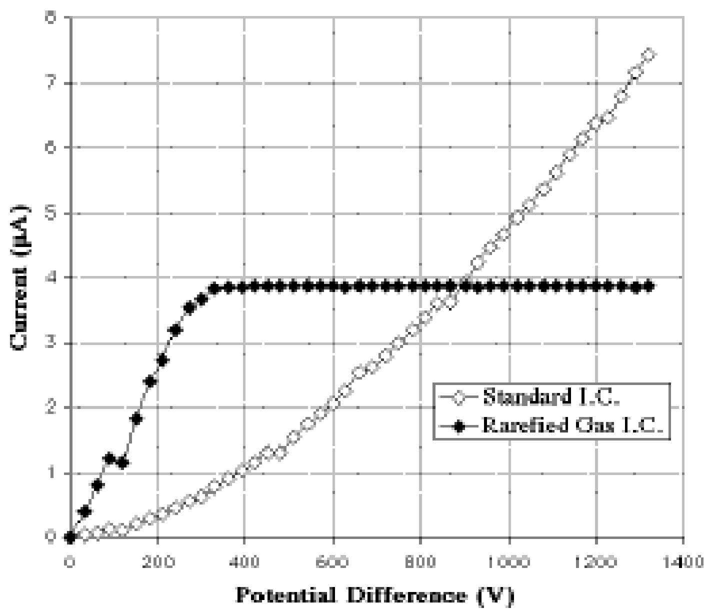

Figure 3: Response of both the rarefied-gas and standard ionization chambers to a 7.46 keV beam. (Note that the actual applied voltages were of negative potential.)

Discussion

The rarefied-gas ionization chamber proved to work well at all energies tested. This result is especially important at low energies, where the standard ionization chambers were unable to collect all of the electrons and ions before recombination.

Acknowledgments

The authors thank Ali Mashayekhi for his input and assistance with this project.

Use of the Advanced Photon Source was supported by the U.S. Department of Energy, Basic Energy Sciences, Office of Science, under Contract No. W-31-109-Eng-38.

Reference

[1] C.L. Hemenway, R. W. Henry, and M. Caulton, *Physical Electronics,* Second Edition, (John Wiley and Sons, Inc., New York, NY, 1967) 183–184.