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Absolute soft X-ray measurements using an ion chamber

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Measurements of soft X-ray absolute intensities have been carried out using a double ion chamber and monochromated synchrotron radiation. The chamber is cylindrical and 1.3 m long. The soft X-ray beam enters the chamber at a position off the central axis, and the produced ions are collected with electrodes on the opposite side to the photon entrance. An index constant for rare gas, the γ-value, which is the average number of electrons emitted from an atom having absorbed a photon, was used for obtaining the absolute photon intensity. The obtained intensity ranges from 1 Gphotons s^{-1} to 25 Gphotons s^{-1} in the energy range 72–800 eV. The estimated uncertainty is about 5–20% depending on the intensity and the spectral purity of the soft X-rays.

Keywords: soft X-rays; absolute intensity; double ion chamber; γ-values.

1. Introduction

The utilization of soft X-rays is currently making advances into micro-fabrication techniques, characterization of different materials and micro-analyses of biological samples with the efficient use of a number of synchrotron radiation facilities (Saisho & Gohshi, 1996). Much basic research needs a monochromatic beam with high resolution, but some studies require absolute intensity of the photon beam, *e.g.* quantitative characterization of irradiation effects and impurity analysis of several elements. Synchrotron radiation has a standard-light-source capability in the UV to X-ray region, because the intensity and characteristics of the radiation can be calculated (Krumrey & Tegeler, 1992; Madden *et al.*, 1985; Sakurai *et al.*, 1989; Suzuki & Saito, 1986, 1993). However, this radiation has a wide energy spectrum and thus it is usually necessary to employ some focusing and monochromatizing optical elements. Since these elements have unknown efficiencies on photon transfer, the photon beam at the experimental point is not of a standard whose intensity and energy width are well determined. Therefore it is necessary to develop a technique for measuring the absolute intensity of the soft X-ray beam. In the present study, a double ion chamber has been developed, with which the absolute intensity of the soft X-ray beam is obtained with the aid of an index constant for rare gas on multiple photoionization.

2. Methods for absolute measurement

A proportional counter and an ion chamber with a single electrode have been used for the absolute measurement of X-rays for many years (Caruso & Neupert, 1965), but they have the serious drawback of limited counting rate or of no available data on the *W*-values in the soft X-ray region (Saito & Suzuki, 1986; Wyckoff, 1979). A double ion chamber including a rare gas is well known to work effectively as the absolute detection device in the vacuum ultraviolet radiation region (Saito, 1994; Samson, 1967). Since singly charged ions of rare-gas atoms are dominantly produced in this energy region, the photon intensity is given by

$$I = i_1^2/e(i_1 - i_2), \tag{1}$$

where i_1 and i_2 denote the ion currents collected with the first and second electrodes, respectively, and e indicates the elementary charge. Since multiple photoionization takes place significantly in the soft X-ray region (Holland *et al.*, 1979; Saito & Suzuki, 1992, 1997), an index constant, the γ-value (the average number of electrons emitted from the atom having absorbed a single photon), should be multiplied to the denominator of (1). Since available γ-value data were limited to only those near 100 eV, the γ-value had to be measured at the initial stage of the present work.

3. Experimental

Monochromatic soft X-rays were obtained by dispersing synchrotron radiation from the electron storage ring at the Electrotechnical Laboratory. The soft X-ray beam passed through a differential pumping stage and entered a chamber including a time-of-flight (TOF) mass spectrometer for measurements of the γ-values of Ne, Ar, Kr and Xe. In the absolute measurement, the photon beam was introduced to the cylindrical-shaped double ion chamber (see Fig. 1). The window, a thin VYNS foil (Manson type 'F' filter), for the incident photon is positioned at 15 mm from the central axis, and electrodes for collecting the produced ions are fixed at 22 mm from the axis. A positive potential is applied to the outer cylindrical electrode, of diameter 65 mm, for the collection of ions. The set of other electrodes is composed of six cylinders of diameter 5 mm; their lengths are shown in Fig. 1. Each Au-plated electrode is electrically separated with Teflon insulators. The ion chamber was evacuated with a 280 l s^{-1} turbo-molecular pump just before measurements, and supplied with a rare gas at about 10^{-2}–10^3 Pa for obtaining ion currents. The ion current at each electrode was led to a pico-amperemeter and transferred to a personal computer. The gas density was detected with a capacitance monometer (Baratron 690) and controlled with an automatic valve system. The size of the soft X-ray beam was defined using a circular aperture of diameter 1 mm.

4. Results and discussion

Branching ratios for multi-charged ions from rare-gas atoms were measured over the soft X-ray range using a pulse electric field

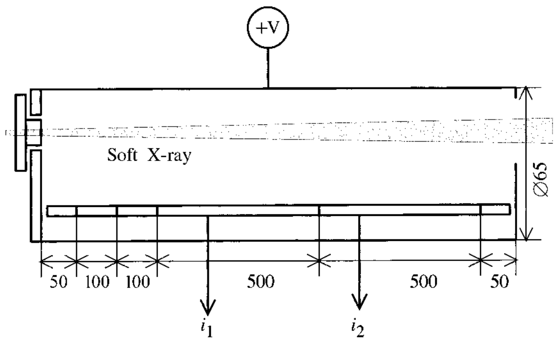

Figure 1
Double ion chamber using a γ-value. The size of the chamber is denoted in units of mm.

applied to the TOF mass spectrometer. The γ-value was derived from the measured ratios. The γ-value data for Ne, Ar, Kr and Xe are reported elsewhere (Suzuki & Saito, 1993). In selectiing adequate species of atoms, a large cross section and little variation in the γ-value are important factors in the energies of interest.

The performance test of the double ion chamber was carried out using Ne at a photon energy of 72 eV. Fig. 2 shows collected ion currents for the second through to the fifth electrode as a function of the voltage applied to the outer cylinder at a gas pressure of 53.2 Pa. The currents increase linearly with voltage below 0.8 V and approach saturation plateaus near 5 V. Since the electrodes are positioned off the central axis, calculations indicated that a strong electric field is not formed even with high applied voltages.

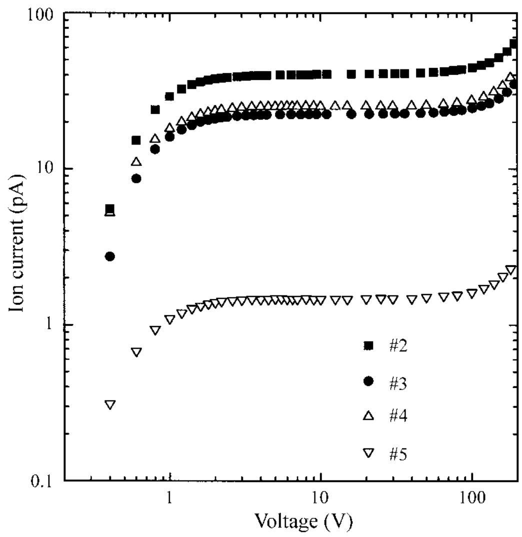

Figure 2
Collected ion current as a function of the applied voltage. The energy of the photon is 72 eV and the gas used is Ne. Filled squares, filled circles, triangles and inverted triangles denote the ion currents measured at the second, third, fourth and fifth electrodes, respectively.

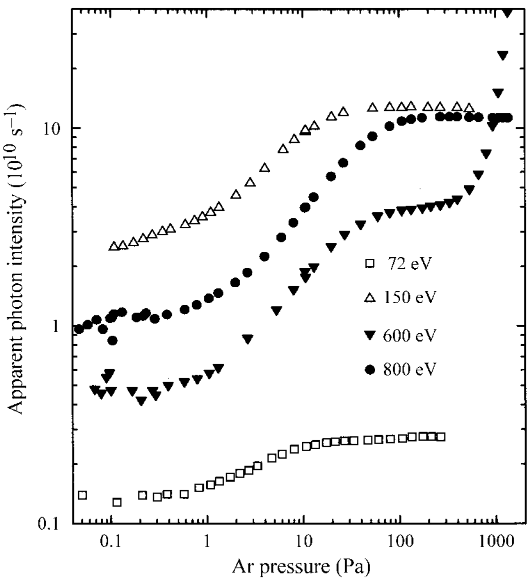

Figure 3
Observed photon intensity as a function of the supplied gas density. Squares, triangles, inverted filled triangles and filled circles denote the results at photon energies of 72, 150, 600 and 800 eV, respectively. The gas used is Ar.

Table 1
Measured absolute intensities of soft X-rays and W-values for Ar.

The photon size is 1 mm diameter and the electron beam current in the storage ring is assumed to be 100 mA.

Photon energy (eV)	Intensity (Gphotons s^{-1})	γ-value	Effect of secondary ionization (N)	W-value (eV)
72	1.4	1.17	2.2	28
150	25	1.19	4.7	27
600	4.4	2.41	8.6	29
800	10	2.47	11.0	29

Apparent photon intensities at photon energies of 72, 150, 600 and 800 eV are plotted as a function of the Ar gas pressure at the applied voltage of 15 V in Fig. 3. Data points denote the experimental results when the ion current for the fourth electrode, of length 500 mm, was used as i_1 and that of the fifth electrode was employed as i_2 in equation (1). An Au photon-intensity monitor was used during these measurements. Data were normalized with an electron beam current of 100 mA in the storage ring. Real photon intensities have been obtained through extrapolation to zero gas density. The data for 600 eV were seriously affected by higher-order light, which induced a sharp increase in intensity above 500 Pa.

The ratio between the apparent photon intensity at sufficiently high pressure and that at almost zero pressure, N, indicates the effect of secondary ionization through collisions of the electron ejected from the atom with other ambient atoms. The W-value has been obtained as

$$W = E/N\gamma. \tag{2}$$

Table 1 lists measured absolute intensities of the soft X-rays (fluence rate) in the Ar sample gas, as well as the W-values. The uncertainties range from 5% to 20%. The main source of uncertainty originates from the estimation of a crossing point at the ordinate extrapolated from apparent photon intensities. The uncertainty of the γ-value used is about 1% at the present photon energies. The obtained W-values are close to those for low-energy electrons (Combecher, 1980), suggesting that the present ion chamber has been correctly operated. Measurements using other rare gases were tentatively carried out, which yielded similar fluence rates of the soft X-rays to the values listed in Table 1.

5. Summary

A trial determination of the fluence rate of soft X-rays in the energy range 72–800 eV has been made using a double ion chamber and the γ-value for Ar. Obtained absolute values of the fluence rate are comparable with those expected from the Au monitor. Uncertainties are not small and thus a decrease in noise currents is necessary for establishing a standard soft X-ray field of high quality.

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