Soft X-ray Ion Chamber

Chen Bo, Ma Ling, Li Futian and Chen Xingden

(State Key Laboratory of Applied Optics)

Abstract

The technique of soft X-ray ion chamber includes the measurement of the ion current as a function of rare gas pressure in the ion chamber. The true photoionization current, and hence absolute photon flux, is obtained by extrapolating ion current to zero gas pressure. This paper describes measurement of the absolute photon flux at He II25.6nm and CK_α4.47nm.

1. Introduction

Recent years, with the development of high temperature plasma physics, space astronomy, life science and X-ray laser representing the modern scientific and technological achievement, the studies on soft X-ray and vacuum ultraviolet optics are making rapid progress. To fulfill the domestic requirement on soft X-ray and vacuum ultraviolet radiation metrology an absolute detector of the ion chamber and a relative detector of the Al_2O_3 are developed in this Laboratory. This paper describes the principle and construction of soft X-ray ion chamber[1][2] developed in this Laboratory, discusses the sources of error and gives the absolute spectral radiation flux of the lines produced by hollow cathode source[3] and Henke source[4] under 30nm.

Soft X-ray ion chamber, based on gas photoionization principle, is a primary detector. The relation between the ion current of soft X-ray ion chamber and the absolute photon flux is given by the definition of the photoionization yield r as follows,

$$r=\frac{\text{(total number of ions produced)}}{\text{(total number of photons absorbed)}} \tag{1}$$

$$r=\frac{i/e}{I_0\left(1-\exp\left(-\sigma nL\right)\right)} \tag{2}$$

Where I_0 is the absolute photon flux, σ is the total absorption cross section of operating gas, n is the density of the operating gas, L is the length of the chamber, e is the electronic charge, and i is total ion current. For rara gases usedin the spectral range between 100nm and 30nm, r is equal to 1. However for shorter wavelengths the ejected photoelectrons have sufficient energy to further ionize the gas by electron-atom collision. This will give effective yield greater than unity. At still shorter wavelengths, the photons are energetic enough to cause multiple ionization in a single encounter. The threshold[5] for secondary ionization in the rare gases is 15.7nm (79.0eV) for He, 19.8nm (62.5eV) for Ne, and 28.6nm (43.4eV) for Ar. Because of the secondary and multiple ionization under 30nm, the situation becomes very complex and a special method must be introduced. The method includes the measurement of the ion current as function of the gas pressure in the ion chamber. the true photoionization current, and hence absolute flux, is obtained by extrapolating the ion current to zero gas pressure. From the definition of the basic photoionization theory the equation under the circumstance of the secondary and multiple ionization can be written as follows,

$$r = r_0\{1 + [1 - \exp(-Qnl)]Y\} \tag{3}$$

Where l is average electron free path to the collector; Q is total electron scattering cross section and Y is effective electronionization yield; r_0 is photoionization yield; n is the density of the operating gas.

2. The Construction of the Ion Chamber

The ion chamber consists of four stainless steel vacuum chambers with diameter 80mm, collecting plate and repeller plate. Because of the low operating gas pressure, the total length of the ion chamber was taken to 1 metre in order to provide a larger ion current. The backing pressure in the ion chamber can reach 10^{-6} torr in order to eliminate the effect of the residual gas. The incident radiation passes through a slit with 0.5mm height × 0.5mm width into the ion chamber. The narrower sli

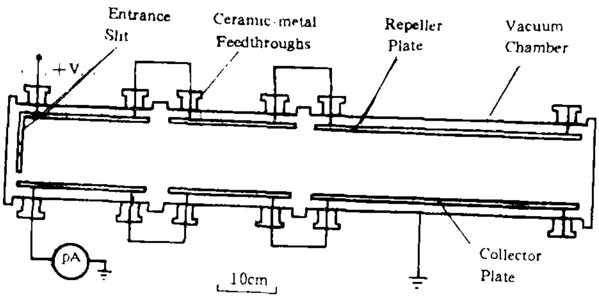

Fig.1 Construction of ion chamber

not only keeps the stable operating gas pressure but also assures that the photoionization takes places in a very weak part of electrical feild. The inlet of the operating rare gas lies in the middle of the vacuum chamber.The vacuum pumping systems are attached to the both ends of the ion chamber to make gas pressure uniform throughout the ion chamber.The ion chamber with such a construction can be also used in VUV region by means of taking two pieces of the vacuum chambers to build a double ion chamber.

3. Experimental

The radiation is produced by continuous discharge of hollow cathode sourse and Henke source.The hollow cathode source is energized by a conventionally current stabilized dc power supply with discharge current between 50mA and 400mA and corresponding discharge voltage about 2kV. The source can produce stabilized spectral radiation between 25nm and 250nm with stability of ±1%.Operating gas are He, Ne, Ar, NO, O_2 etc. depending on the wavelength of interested radiation.The radiation is dispersed with McPherson 247 grazing incidence monochromator in the spectral range frome 1nm to 250nm.The band pass used in this work is 0.05nm.The Henke source is energized by dc power supply with anode voltage 4kV and discharge current 7mA.All pressure measurements are made with a capacitance pressure sensor with the accuracy of 2% of FS. Ion current is measured with a KEITHLEY 617 programmable electrometer connected to IBM computor through IEEE —488 ihterface. To find the proper collector voltage, the ion current variation with the voltage for He and Ar is measured. Fig.2 and Fig.3 illustrates the relation

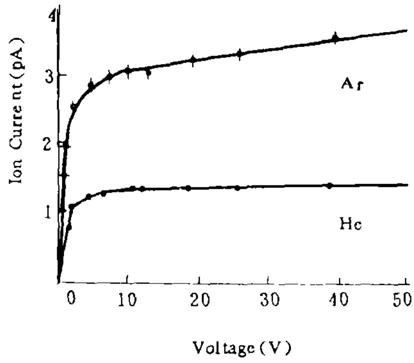

Fig.2 current as a function of operating voltage for Ar and He at 25.5nm

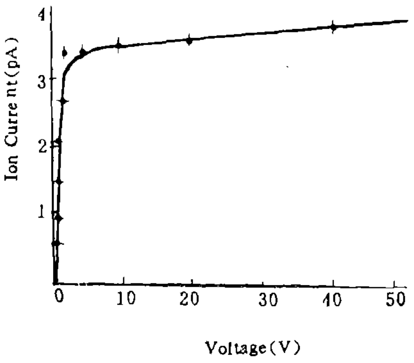

Fig.3 current as a function of operating voltage for Ar at 4.47nm between ion currentand voltage.

The experiment that indicates the relation between ion current and the pressure is performed at various pressure. The saturation can be found at high pressure and the values of the electronionization yield can be given. The results show that the curve is approximately linear at low pressure. First of all the relations between ion current and pressure are measured in Fig.4 and Fig.5. Then according to the definition of the apparent yield, experimental points are plotted in Fig.6 and Fig.7. The curves of Fig.6 and Fig.7 are obtained by means of fitting to experimental data, in wihch the intercept is equal to I_0r_0, the inital slope of the curve is equal to I_0r_0 (QYI), and the maximum of curve is equal to I_0r_0 $(1+Y)$. The wavelength of the spectral lines are HeⅡ25.6nm and CK$_\alpha$4.47nm.

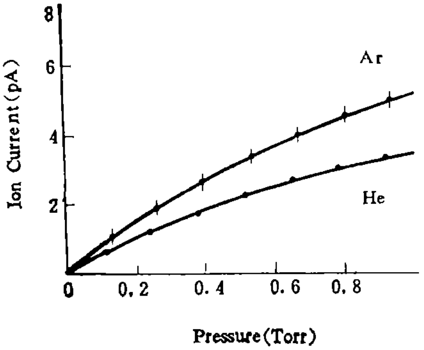

Fig.4 current as a function of operating pressure for Ar and He at 25.6nm

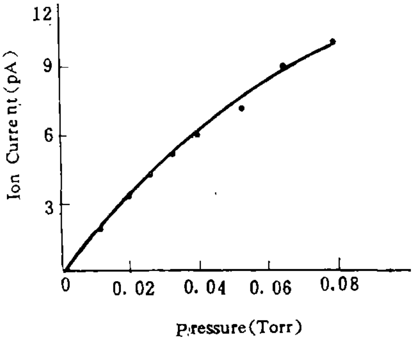

Fig.5 current as a function of operating pressure for Ar at 4.47nm

4. Discussion

Absolute flux of spectral line He II25.6nm of hollow cathode source is 1.4×10^7 photo/sec based on the above measurements. However the absolute flux of the same incidence radiation which is measured under the modle of Samson double ion chamber is 2×10^7 photo/sec. The different results arise from the multiple ionization behind 30nm. The ratio of electronionization cross sections obtained by the ratio of the slop of measurement curves at low pressure is equal to 7, but this result is 30% as small as Carlson result. 2.9×10^8 photo/sec absolute flux of the Henke source at CK$_\alpha$4.47nm can be obtained from the data in Fig.7. The remaining possible sources for error in present work are as follows: (1) the error the absolute pressure measurements at low operating pressure (2) the error of tiny ion current measurements, (3) residual gas, (4) photon scattering from the exit slit, (5) some amount of rare gas enters the monochromator, (6) energetic electrons. A few of error sources in this work can be eliminated such as the error of impurities gas which can be eliminated by lowering background pressure (10^{-6}torr) . The photon scattering may be determined at background pressure. The sum of above two errors is about 0.08pA.

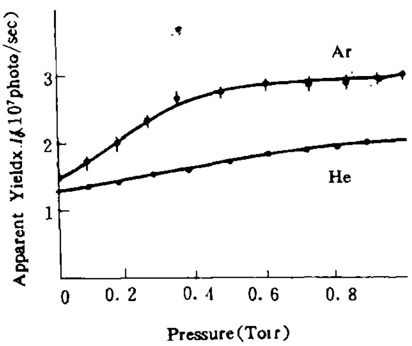

Fig.6 apparent yield as a function of operating pressure for Ar and He at 25.6nm. The linear fitted parameter I_0r_0QYI are equal to 4.73×10^7 photo/sec.torr for Ar, 0.68×10^7 photo/sec.torr for He

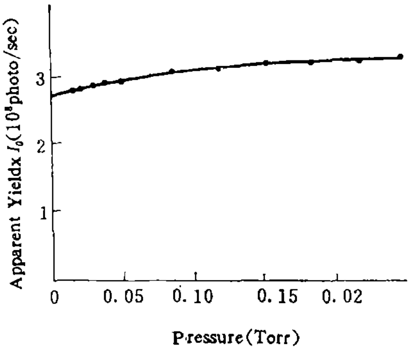

Fig.7 apparent yield as a function of operating pressure for Ar at 4.47 nm. The linear fitted parameter I_0r_0.QYI is equal 1.06×10^8 photo/sec.torr

The error derived from energetic electrons is eliminated by using proper operating voltage. The gas that enters the monochromator produces the chagne of incidence flux less than 2%. From the above analysis and measurement, main errors are due to the measurements of absolute pressure and tiny current.

For further studies on absolute measurements in soft X-ray region a plenty of research work will be carried out at synchrotron radiation facilities.

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软X射线电离室

陈波 马玲 李福田 陈星旦

（应用光学国家重点实验室）

摘要： 软X射线稀有气体电离室作为软X射线波段绝对探测器，是通过测量光电离子流得出光谱辐射强度。并详细介绍我们研制1米软X射线稀有气体电离室的工作原理及结构，测出空阴极光源辐射出的HeⅡ25.6nm离子线及Henke光源辐射出的CK_α4.47nm线的强度随电离室工作气压的变化，外推出零气压下谱线光谱辐射强度，最终得出谱线的绝对光谱辐射强度。