Studies of VUV Rare Gas Ionization Chamber and Al_2O_3 Photodiodes

Qian Limin, Chen Bo, Jin Lei, Li Futian and Chen Xiengdan

(State Key Laboratory of Applied Optics)

Abstract

This paper presents the design, the construction and the performance of VUV rare gas ionization chambers and Al_2O_3 photodiodes developed in this laboratory, discusses the measurement errors of the ionization chamber and the photodiode, and gives the absolute quantum efficiencies of Al_2O_3 photocathode.

1. Introduction

Recent years with the development of space science, fusion research, plasma physics and short wavelength laser techniques, the studies of soft X-ray and vacuum ultraviolet radiation metrology have made rapid progress. Several advanced industrial countries have established soft X-ray and VUV radiation source standards by means of synchrotron radiation and wall stabilized arcs, and soft X-ray and VUV radiation detector standards by means of rare gas ionization chambers.

Based on a series of fundamental research work, Samson developed vacuum ultraviolet rare gas ionization chambers[1], single ionization chamber and double ionization chamber. Afterward in 1970's, Canfield of NIST established VUV radiation detector standard between 5nm to 102nm by means of rare gas ionization chamber[2]. At present, ionization chamber is the most important method for vacuum ultraviolet radiation absolute detection.

To fulfill the domestic requirement for VUV metrology, Samson's type VUV rare gas ionization chamber and Al_2O_3 photodiode were developed in this laboratory. This paper presents the construction and the performance of VUV rare gas ionization chambers and Al_2O_3 photodiodes developed in this laboratory, discusses the measurement errors dealt with the use of the ionization chamber and the photodiode and gives the absolute quantum efficiency of Al_2O_3 photocathode.

2. Ionization Chamber and Al_2O_3 Photodiodes

Vacuum ultraviolet rare gas ionization chamber, based on gas photo-ionization principle, is a ideal absolute detector with high stability and reproducibility. The VUV rare gas double ionization chamber, developed in this lab, consists of stainless steel vacuum chamber of diameter 80mm and length 250mm, two collector plates and one repeller plate, shown in Fig.1. The collector plate and repeller plate connect with a electrometer and a stabilized DC power supply through ceramic-metal feedthroughs, which are specially designed and the leak current of which is less than 10^{-16}A. The diaphragm of the ionization chamber is slit shaped with variable width 0-2mm and height 10mm. The interaction gases are Xenon, Krypton, Argon, Neon and Helium, depending on the spectral range. The working pressure inside the vacuum chamber is 1 to 10^{-1}Pa. High purity rore gas enters the ionization chamber through two stages of micro adjustable valves.

In order to keep the pressure of the rare gas inside the ionization chamber stable and uniform, a differential pumping unit was used in front of the ionization chamber. A EMI9558QB photomultiplier sealed by sodium salicylate phosphor window was connected to the ionization chamber in order to measure VUV radiation in single ionization chamber model. Since in this spectral range the photon energies are insufficient to ionize the appropriate rare gas more than singly, and the electrons resulting from ionization events have insufficient energy to cause secondary ionization of the gas, provided that the plasma light source and grating used in this spectral range preclude the existence of 2th or higher orders from grating, then the spectral radiant flux for single ionization chamber can be expressed as

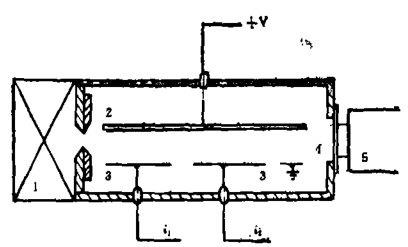

Fig.1 Schematic diagram of the ionization chamber: 1. differential pumping unit 2. repeller plate 3. collector plates 4. sodium salicylate phosphor 5. photomultiplier

$$I_0\gamma = \frac{i/e}{1 - I/I_0}$$

where

I_0 = light flux at the exit slit of the monochromator

I = transmitted flux at the end of the ionization chamber

i = ion current to collector plates 1 and 2 in amperes

γ = photoionization yield of the interaction gas. Under usual circumstances, atoms have yields of 100%, ie $\gamma = 1$.

For the double ionization chamber, the spectral radiant flux can be expressed as

$$I_0 = i_1^2 / e\ (i_1 - i_2)$$

where

i_1 = ion current to collector plate 1 in amperes

i_2 = ion current to collector plate 2 in amperes

e = the electronic charge in coulombs

I_0 = the spectral radiant flux entering the chamber in photon/sec

Because of the secondary ionization under 30nm, the situation becomes very complex and a different method must be introduced. The principle of the method involves measuring the ion current produced by a monochromatic spectral line as a function of pressure. The observed ion current is then the sum of the direct photoionization current and the secondary ion current produced by the ejected photoelectrons. Extrapolating the ion current curve to zero pressure should give the required current. According to this principle, an rare gas ionization chamber with length of 1m, suitable for soft X-ray spectral range, was constructed and the corresponding procedure for error correcting and data processing was developed.

photodiodes with Al_2O_3 photocathode are often used as soft X-ray and VUV transfer standard detectors. The Al_2O_3 photodiode developed in this laboratory includes two operating elements: the anode, which is a stainless steel hollow cylinder fixed at the PTFE body and the cathode, which consists of a quartz substrate supporting an aluminum evaporated film with thickness of about 200nm which has been anodized to an oxide thickness of about 20nm. The operating voltage of the photodiode is 60V. The output current of 10^{-12}A order is read out by a digital electrometer.

3. Instrument

Based on McPherson 247 grazing incidence soft X-ray and VUV monochromator and the rare gas ionization chamber, we have established a equipment for soft X-ray and VUV absolute calibration of detectors and quantum efficiency determination of photocathode materials (Fig.2). The hollow cathode discharge VUV source and the duoplasmatron VUV source developed in this laboratory were fixed to McPherson 247 as pla-

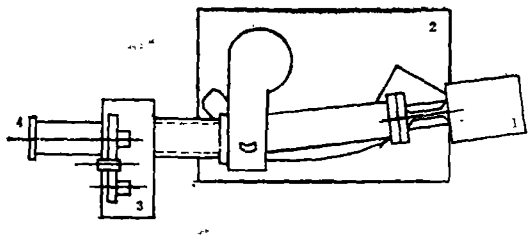

Fig.2 McPherson 247 based calibrating equipment: 1. light source 2. McPherson 247 monochromator 3.photodiodes 4.ion chamber

sma light sources. McPherson 247 used a concave grating with curvature radius 2.2m, ruling density 600 g/mm and grazing incidence angle 86°.The ionization current pf 10^{-12}A order from the ionization chamber was read out by Keithley 617 programmable electrometer and was fed to IBM-PC microcomputer through IEEE-488 interface. The wavelength scanning and filter change were controlled by the microcomputer through IEEE-488 interface and stepper motor driving unit.At the intrinsic wavelength of the hollow cathode source and the duoplasmatron source, the monochromatic radiant flux from the exit slit of McPherson 247 is alternatively measured by the ionization chamber and the photodiode and the quantum efficiencies of the Al_2O_3 photodiodes can be obtained.

4. Experimental Results

Fig.3 shows the ionization chamber currents as a function of voltage for He at 58.4nm.One of the most important precaution to take is using the proper collector voltage on the ion plates, that is we must operate in the plateau region of the ionization current versus voltage curve.In our case, it is usually fixed at 25V.

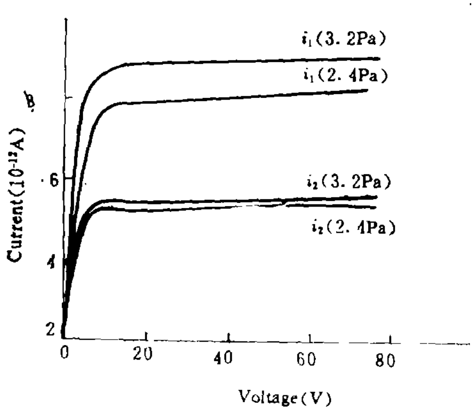

Fig.3 Ionization chamber currents as a function of voltage

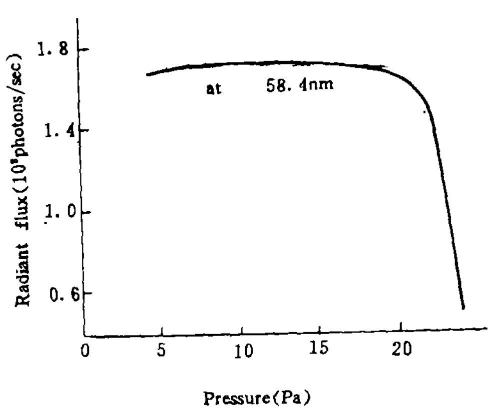

Fig.4 Measured radiant flux as a function of pressure

Since there are no windows available in this spectral region, we must take care that the main vacuum to insure that the photon intensity at the exit slit of the monochromator is the same before and after the calibrating gas is allowed to flow into the ionization chamber. Another problem is to assure that the gas is uniformly at the same pressure throughout the ionization chamber. Any presure gradients would be detrimental when using double ion chamber. Fig.4 gives the variation of the measured spectral radiant flux with the working gas pressure inside the chamber for a certain VUV radiant flux at 58.4nm.

For a constant VUV radiant flux at 58.4nm, the calibrating stability and reproducibility of the ionization chamber were tested. The measurement results show that the stability and reproducibility of the ionization chamber are better than ±2%. Table 1 gives the results.

For a constant VUV spectral radiant flux, the calibrated results were compared under single ionization chamber model. and double ionization chamber model. The agreement is better than ±1%. The difference is mainly due to the pressure inhomogeneity and the mesurement error of the residual rare gas.

Table 1

Time (min)	The measured flux ($\times 10^8$ photons/sec)
10	1.7537
20	1.7358
30	1.7779
40	1.7588
50	1.7873
60	1.7584

Table 1 The stability and reproducibility of the ionization chamber within an hour

Basde on the ionization chamber, the performance of Al_2O_3 photodiode was investigated thoroughly. The experimental results show that the stability and reproducibility of the Al_2O_3 photodiode responsivity are better than ±2% and the uniformities among the photodiodes are better than ±6%. Fig.5 shows the quantum efficiency of Al_2O_3 photodiodes. The different between the efficiency of NIST and ours is within ±10%. The calibrating errors include the instability of the VUV hollow cathode source and duoplasmatron source, the pressure inhomogeniety of the double ionization chamber, the current

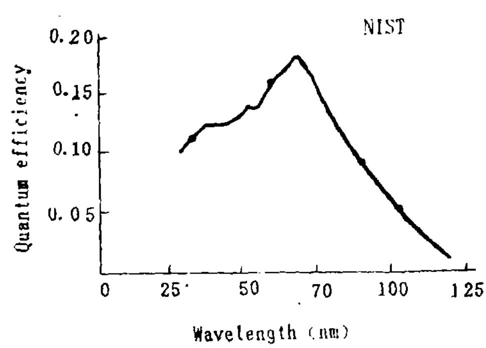

Fig.5 The spectral responsivity of the photodiodes

measurement error and so on. The total calibrating error is about ±5%.

5. Conclusion

Rare gas ionization chamber and Al_2O_3 photodiode have been developed in this laboratory. The quantum efficiencies of the Al_2O_3 photocathodes were calibrated and the calibrating errors were analyzed. Based on the above mentioned preliminary research, further work will be carried out on the synchrotron radiation facilities of this country.

References

〔1〕 J.A.R.Samson; J.O.S.A., 54, 6-15 (1964)
〔2〕 W.R.Ott et al.; Proceedings of SPIE, 689, 178-187, (1986)

VUV稀有气体电离室和Al_2O_3光电二极管的研究

钱莉民 陈 波 金 蕾 李福田 陈星旦

（应用光学国家重点实验室）

摘要：描述了应用光学实验室研制的VUV稀有气体电离室及Al_2O_3光电二极管的设计、结构和性能，讨论了电离室和光电二极管应用时的测量误差，给出了Al_2O_3光电二极管的绝对量子效率。