ISBN: 978-3-95450-250-9 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2023-TUPYP032

AN ARGON-OXYGEN OR ARGON-HYDROGEN RADIO-FREQUENCY PLASMA CLEANING DEVICE FOR REMOVING CARBON CONTAMINATION FROM OPTICAL SURFACES

Hongjun Yuan†, Xuewei Du, Qiuping Wang, National Synchrotron Radiation Laboratory, University of Science and Technology of China, 230026 Hefei, China

Abstract

Due to synchrotron radiation, carbon contamination on the surfaces of optical elements inside the beamlines, such as mirrors and gratings, remains an issue. Future beamline designs will select more optical element surface coating materials according to the specific needs, including gold, platinum, chromium, nickel, and aluminum, and a single cleaning method will not be able to adequately address the demands. We have studied the radio-frequency (RF) plasma cleaning of optical elements. After the Ar/O_2 or Ar/H_2 gas mixture was injected into the chamber, glow discharge was carried out, and the carbon on the surface of the inert metal-coated optical element and oxidation-prone metal-coated optical element was removed by the oxidation or reduction reaction of radicals. In order to optimize the discharge parameters, it utilizes a differential mass spectrometry system and an optical emission spectrometer to monitor the cleaning process. This poster introduces the principles of the two cleaning methods as well as our existing cleaning device.

INTRODUCTION

Carbon contamination is a typical issue for high flux optical elements in synchrotron radiation beamlines. Shortwave light irradiation cracks the hydrocarbons, which then deposit a layer of carbon deposition on the surface of the optical element. This causes a decrease in reflectivity in the vacuum ultraviolet and soft X-ray regions as well as a loss of photon flux.

More varieties of coated mirrors and gratings will be chosen for the Hefei Advanced Light Facility (HALF) beamline in order to attain high performance. When the mirror coating is made of inert metal, such as Au or Pt, the carbon contamination could be removed using Ar/O_2 RF plasma cleaning. However, the reflectivity in the soft X-ray area may be decreased due to oxidation of the metal surface when the coating material is readily oxidized metal, such as Ni, Cr, or Al. The RF plasma cleaning approach using Ar/H_2 was suggested to clean optical elements in order to prevent the loss of reflectance by the oxidation of coating materials [1-3].

Based on the aforementioned reasons, Ar/O_2 and Ar/H_2 RF plasma cleaning system is constructed, equipped with cleaning parameter optimization system, which can achieve the optimal cleaning rate under varied operating conditions.

EXPERIMENTAL SETUP

Figure 1 shows the principle of cleaning carbon contamination with RF plasma. Under the influence of RF discharge, the mixed gas produces active free radicals that oxidize or reduce the carbon on the surface of the optical element to produce the volatile gas, such as CO_2, or CxHy, which could be removed by the vacuum pump.

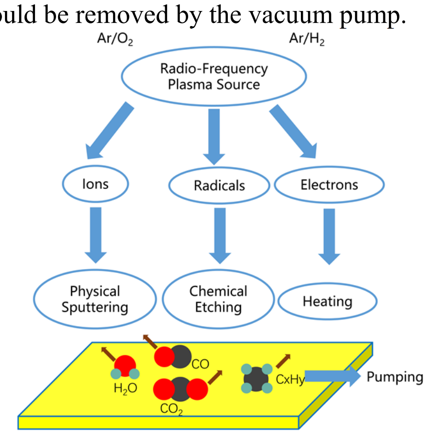

Figure 1: Schematic diagram of cleaning carbon contamination with RF plasma.

As seen in Fig. 2, the experimental device utilizes the laboratory's current RF plasma cleaning technology. The experimental equipment includes: cleaning chamber, gas mixing chamber, RF power supply and RF matching device, vacuum pumping system, etc. Ar/O_2 or Ar/H_2 enter the gas mixing chamber with a certain ratio through the mass flow meter. The mixed gas enters the cleaning chamber through the needle valve. By adjusting the needle valve and the pumping speed of the molecular pump unit, the cleaning chamber is maintained at a certain pressure. Turn on the RF power supply, adjust the RF matcher to find the appropriate discharge power, and perform glow discharge.

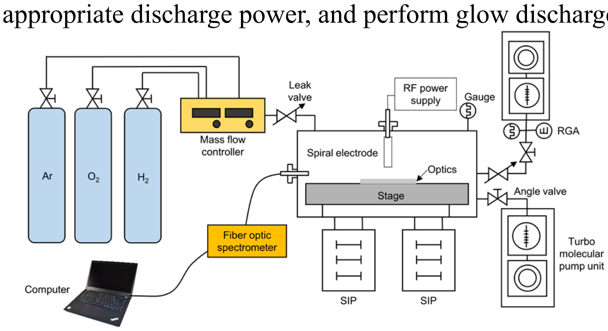

Figure 2: Setup for carbon contamination cleaning with RF plasma.

† yuanhj@mail.ustc.edu.cn

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OPTIMIZATION OF CLEANING PARAMETERS

A cleaning parameter optimization system based on a fiber optic spectrometer and quadrupole mass spectrometer was constructed, as shown in Fig. 2, in order to study the optimization of cleaning parameters for cleaning synchrotron radiation optical elements using RF plasma.

Previous research has demonstrated that chemical etching of active O or H atoms rather than physical sputtering of active Ar atoms plays a more significant role in the cleaning process. Indirectly, the rate of cleaning of the carbon contamination is seen with the concentration of O or H atoms. A CF35 fiber feeding flange is installed on the side of the cleaning chamber, connect the optical fiber to couple the spectral signal into the fiber spectrometer, and then detect the RF electrode discharge to see how the intensity of the O I (777.2 nm), H I (656.2 nm), and Ar I (750.3 nm) light emission spectral lines changes.

Ar/O₂ Plasma Cleaning Parameter Optimization

The gas mixing ratio has a greater influence on the cleaning rate, and is first controlled as a variable. The reading of the vacuum gauge is 5 Pa, the integration time of the spectrometer is 200 ms, and the flow indicator is changed. The gas mixing ratio is controlled by the Ar/O_2 flow. Spectral detection of the glow discharges generated under different gas ratios was carried out, and the curve of change rule of O atom intensity at 777.2 nm was obtained. The collected spectral information is shown in the Fig. 3.

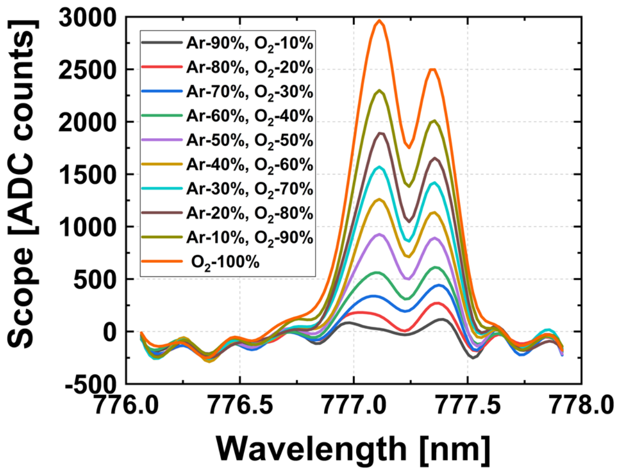

Figure 3: O atom intensity (@777.2 nm) at 5 Pa with different Ar/O_2 ratio.

In Ar/O_2 plasma cleaning, although 100 % oxygen produces more reactive oxygen species, the total number of ions in the chamber will be less, as shown in the Fig. 4. Considering the physical sputtering effect during cleaning, the argon-oxygen cleaning ratio will be adjusted to 30 %-70 %.

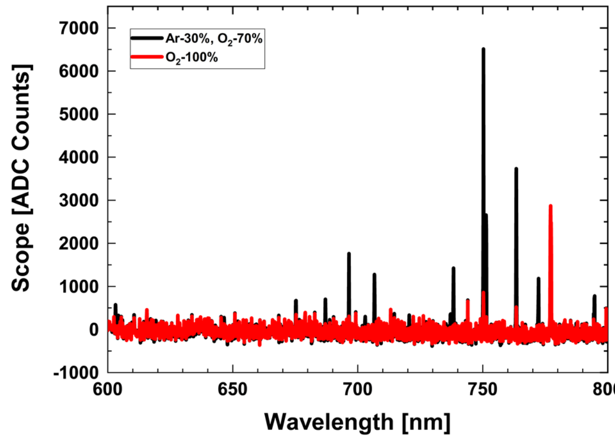

Figure 4: Optical spectrum when Ar/O_2 is 30 %:70 % and 100 % oxygen.

The working pressure also has a great influence on the cleaning rate, which is controlled as a variable. The Ar/O_2 flow ratio of the flow indicator is 30 %-70 %, the integration time of the spectrometer is 200 ms. Changed the indication of the vacuum gauge from 0.2 Pa to 10 Pa. Spectral detection of the glow discharges generated under different pressures was carried out, and the curve of change rule of the oxygen atom intensity at 777.2 nm was obtained, as shown in the Fig. 5.

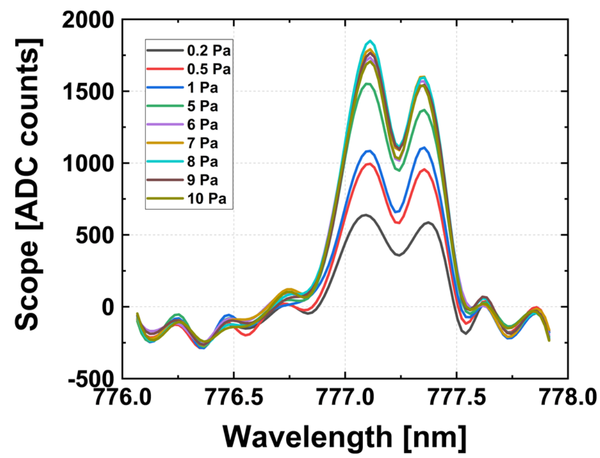

Figure 5: O atom intensity (@777.2 nm) at 5 Pa with different working pressure.

Ar/H₂ Plasma Cleaning Parameter Optimization

The same technique was applied to optimize the Ar/H_2 plasma cleaning parameters, and the spectral intensity at the H atom (656.2 nm) was observed. Figures 6 and 7 show the results of tests on the mixing ratio and working pressure, respectively.

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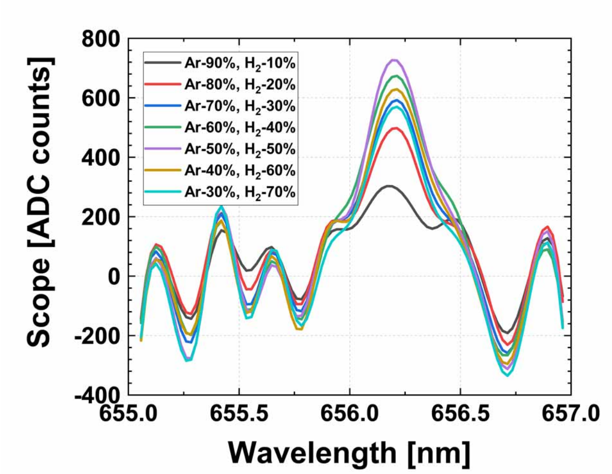

Figure 6: Hydrogen atom concentration (@656.2 nm) at 5 Pa with different Ar/H_2 ratio.

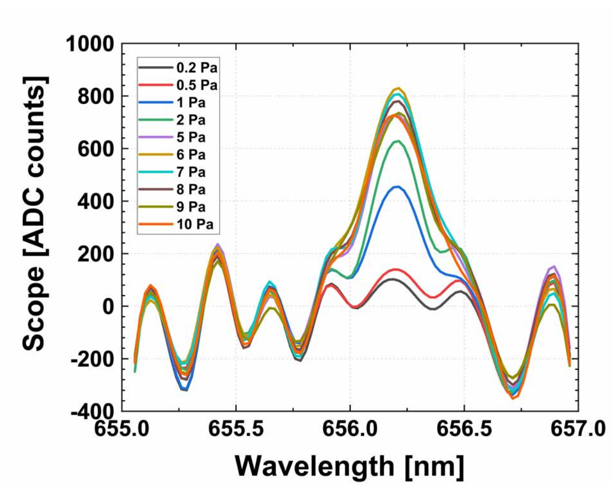

Figure 7: H atom concentration (@656.2 nm) at 50 %:50 % with different working pressure.

Results

The results of cleaning parameter optimization are shown in Table 1.

Table 1: Results of Cleaning Parameter Optimization

Plasma Type	**Ar/O₂**	**Ar/H₂**
Mixing Ratio	30 %:70 %	50 %:50 %
Working Pressure	8 Pa	6 Pa

EXPERIMENT

The carbon-contaminated Au-coated grating was cleaned with Ar/O_2 plasma for 6 h, the cleaning pressure was 8 Pa, and the Ar/O_2 mixing ratio was 30 %-70 %. The cleaning effect was shown as Fig. 8.

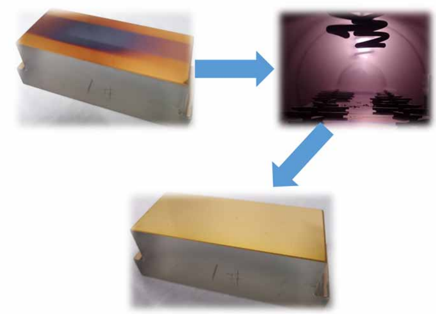

Figure 8: Cleaning of Au-coated grating with Ar/O_2.

The carbon-contaminated Al-coated mirror was cleaned with Ar/H_2 plasma for 4 h and 9 h, the cleaning pressure was 6 Pa, and the Ar/H_2 mixing ratio was 50%-50%. The cleaning effect was shown as Fig. 9.

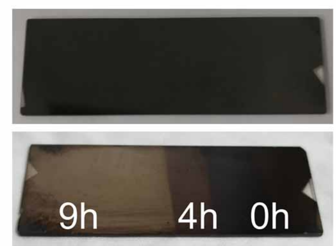

Figure 9: Cleaning of Al-coated mirror with Ar/H_2.

CONCLUSION

A system for RF plasma cleaning with Ar/O_2 and Ar/H_2 was constructed, and optical and mass spectrometers were used to optimize the discharge parameters and determine the cleaning cutoff point. The system can be used to remove carbon contamination from the surface of optical elements coated with easily oxidized or inert metal in the beamlines, enhance reflectivity, and boost photon flux. To create an ultra-clean, ultra-high vacuum environment, the method can also be used to clean superconducting RF cavities and storage rings.

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