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Telescope Mirror Cleaning Using Atmospheric Pressure Multi-Channel Radio Frequency Plasma Jet

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Abstract

In this work, the surface of the telescope’s mirror is cleaned using an atmospheric-pressure radio frequency plasma jet (APRFPJ), which is generated by Argon gas between two coaxial metal electrodes. The RF power supply is set to 2 MHz frequencies with three different power levels: 20, 50, and 80 W. Carbon, that has adhered to the surface, can be effectively removed using the plasma cleaning technique, which also modifies any residual bonds. The cleaned surface was clearly distinguished using an optical emission spectroscopy (OES) technique and a water contact angle (WCA) analyzer for the activation property on their surfaces. The sample showed a super hydrophilic surface at an angle of 1° after 2.5 minutes of plasma treatment, as determined by the WCA technique, and an analysis of its optical properties showed that its reflectance had increased from 75% before cleaning to 98% after cleaning. Using the OES technique, the RF plasma jet's spectrum can be observed to contain the ArI, ArII, and NI lines.

Keyword: RF plasma jet, telescope’s mirrors, WCA, OES, optical properties.

تنظيف مرآة التلسكوب باستخدام بلازما النفث ذو الترددات الراديوية متعدد القنوات عند الضغط الجوي

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الخلاصة

في هذا العمل، يتم تنظيف سطح مرآة التلسكوب باستخدام بلازما النفث ذي التردد الراديوي عند الضغط الجوي، والتي يتم توليدها بواسطة غاز الأرجون بين قطبين معدنيين متحدا المحور. تم ضبط مصدر طاقة التردد الراديوي على تردد 2 ميجاهرتز وبثلاثة مستويات طاقة 20 و50 و80 واط. يمكن إزالة الكربون الملتصق بالسطح بشكل فعال باستخدام تقنية تنظيف البلازما، والتي تعدل أيضًا الروابط المتبقية. تم تمييز السطح النظيف بوضوح باستخدام تقنية التحليل الطيفي للانبعاثات البصرية ومحلل زاوية ملامسة الماء لخاصية التنشيط على السطوح. أظهرت العينة سطحًا فائقًا للماء بزاوية 1 درجة بعد 2.5 دقيقة من المعالجة بالبلازما، كما هو محدد بتقنية زاوية ملامسة الماء، وأظهر تحليل خواصها البصرية أن انعكاسها قد زاد من 75٪ قبل التنظيف إلى 98٪ بعد التنظيف. وباستخدام تقنية التحليل الطيفي للانبعاثات الضوئية، يمكن ملاحظة طيف بلازما النفث الراديوي وظهور خطوط ArI و ArII وNI.

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1. Introduction

The fourth state of matter is commonly referred to as "plasma", which is composed of electrons, ions, and neutral particles, in the physical sciences, whilst in biology it refers to the yellowish liquid that is the blood's non-cellular component. American chemist Irving Langmuir, winner of the Nobel Prize, coined the phrase "plasma" in 1927 to define an ionized gas, an electrified fluid carrying electrons and ions, similar to the biological plasma carrying blood corpuscles, pathogens, etc. [1]. Plasma can be generated in a diverse range of ways and can exist in a variety of forms. It is estimated that plasma makes up more than 99% of the visible universe. Our sun is an example of plasma that we see far away from us, along with the twinkling of stars, nebulas, and auroras in the night sky [2]. Typically, cold and thermal plasma are the two categories into which plasma is separated based on its temperature [3]. In a high temperature plasma, such as a strong or fully ionized plasma, the temperature of the electrons and ions is the same; consequently, they are in thermal equilibrium with one another because of thermal motion [4]. Cold plasma has become widely used recently for a variety of purposes, including material fabrication, chemical water treatment, semiconductor device manufacturing, and industrial disinfection. The plasma generator supplies ionized species for surface preparation, deposition, and removal during the manufacturing process. Predictable and repeatable traits define the final product's quality [5, 6]. Plasma jets, also known as plasma plumes, are a common type of gas discharge in which the plasma discharge extends outside the area of plasma formation into the surrounding atmosphere. Non-equilibrium plasma jet devices are remote plasma sources that function under non-equilibrium plasma conditions at atmospheric pressure and cool gas temperatures. Non-thermal or cold plasma torches are some of the names used for them [7]. Atmospheric-pressure plasmas have been developed in recent decades as a consequence of extensive study, which eliminates the drawbacks of vacuum operation. A new set of difficulties arise as a result of how difficult it is to maintain a glow discharge in these circumstances. At 760 torr, higher voltages are needed for gas breakdown, and this frequently results in arcing between the electrodes. Arcing is purposefully sought in some applications, like plasma torches. However, several techniques, including the usage of pointed electrodes in corona discharges [8] and insulating inserts in dielectric barrier discharges [9], have been developed to stop arcing and reduce gas temperature. Because the plasmas are not consistent throughout the volume, these sources get this drawback. Recently, a plasma jet that uses flowing helium and a unique electrode design to prevent arcing has been developed [10]. This source may be appropriate for a variety of applications because it can deposit materials and etch them at low temperatures [11]. The ability to generate a cold plasma plume at atmospheric pressure in air has been demonstrated by several devices in recent years. For potential use in medical applications and their capacity to treat heat-sensitive surfaces, various designs have been investigated [12].

The possibility of processing materials that are not resistant to high vacuum is another significant benefit of using atmospheric plasmas. There are numerous examples of these materials, mostly in the organic realm. Fine surface processing among some polymers, foods, and even living things is a new and quickly developing field of plasma applications [13].

Over the past few years, atmospheric pressure plasmas (APP) have proven to be an effective tool for cleaning hydrocarbon contamination off glass surfaces. Plasmas offer a variety of usable species for this purpose, including radicals, free electrons, ozone, and a specified amount of ultraviolet radiation [14]. Due to their in-line process capabilities, low costs, and minimal requirements for environmental and personal safety, plasma jets are an intriguing alternative to other pre-treatment methods (such as low-pressure plasma or wet chemical treatment). Since the substrates must have a clean surface and be free of contamination before moving on to another process, cleaning is an essential step in the production of semiconductors, medical devices, and even industrial sector [15]. Since the early 1990s, APRFPJ have gained popularity because of their special abilities to generate highly reactive gas in an open environment. The primary reactive atoms and ions appear at a relatively low working temperature of between 30°C to 50°C, which makes APRFPJ a superior candidate for material processing such as surface modification, deposition, and cleaning processes [16].

High-tech materials include glass, whose characteristics can be tailored in a variety of ways, such as by changing its composition, to meet specific requirements for the intended application. Fabricating optical elements like mirrors, lenses, or other equipment, requires the use of specialized technical glass. Surface machining procedures must be able to provide adequate surface quality throughout the complete range of spatial surface wavelengths because application-related interaction of surfaces with light necessitates extremely accurate surface topography properties [17].

Atomic particle beam-based surface machining methods like ion beam smoothing, ion beam figuring, and plasma jet machining are frequently used to produce ultra-precise optical surfaces. These techniques are very beneficial for correcting and finishing surfaces, such as freeform surfaces, aspheric lenses, and mirrors [18].

An ultraviolet-visible spectrophotometer was used to measure the reflectance of telescope mirrors and examine the optical properties [19]. Optical emission spectroscopy is one of the techniques for plasma diagnosis. It is employed to gather data on the species, chemical make-up, and nature of plasma. Examples include plasma density and electron temperature [20].

The wettability and cleanliness of a surface can be determined by measuring the WCA of a deionized water droplet on that surface. In this work, an instrument similar to the optical contact angle measuring system OCA-20 has been used, which is the most flexible instrument for measuring and analyzing contact angle and drop shape.OCA-20 Data physics WCA measuring instrument is used to measure the wettability of the telescope’s mirror before and after atmospheric plasma treatment. Organic contamination that occurs accidentally decreases surface energy and raises the WCA. Consequently, the contact angle is reduced when this contamination is removed. A significant spread of the water droplet with a very low contact angle is indicative of a highly activated surface. WCA measurements have been taken repeatedly over time to track the rate at which advective carbon from the atmosphere re-contaminates the surface [21, 22].

2. Experimental Method

Atmospheric pressure RF plasma jet cleaning was investigated on silver-coated telescope mirrors (diameter: 60 mm, thickness: 3 mm). It is demonstrated that ageing causes the adhesion of carbonaceous contaminations and a decrease in mirror reflectance. Figure 1 illustrates the longitudinal position of the APRFPJ.

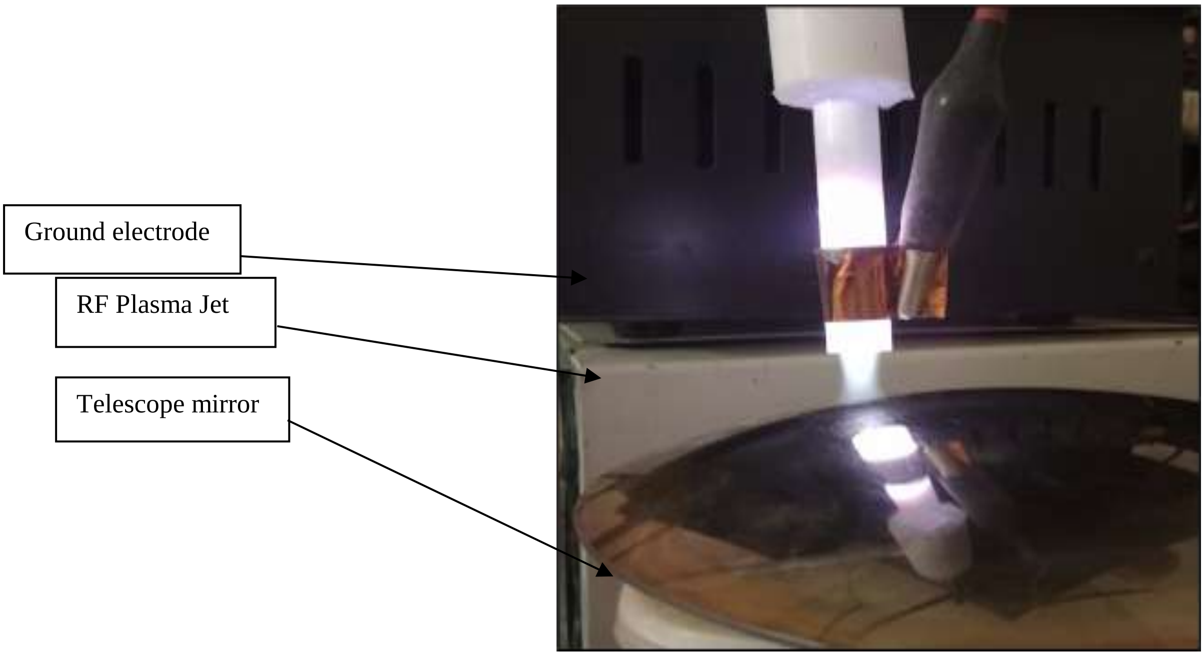

Figure 1: RF plasma gets during cleaning process.

The plasma jet system consists of a glass tube that serves as a dielectric barrier with an outer diameter of 5 mm and an inner diameter of 3 mm (see Figure 2). The positive electrode is placed in the center of the tube in a longitudinal manner with a length of 10 cm, and the second electrode is wrapped at the end of the tube as a negative electrode. The electrical wires are connected to the radio frequency high voltage source where the negative electrode is grounded. The RF power supply is set to 2 MHz, with power of 20, 50 and 80 watts.

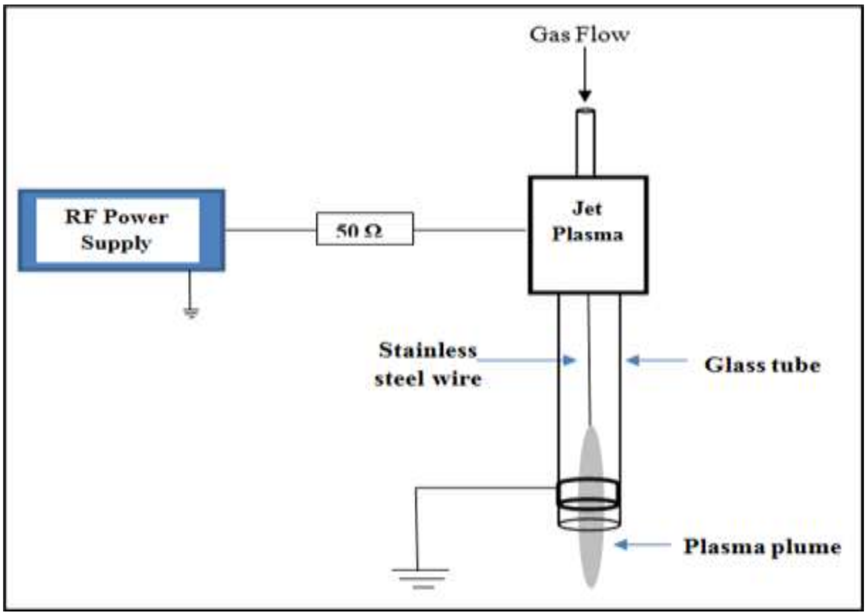

Figure 2: Schematic diagram of plasma jet system used in this work.

This work includes three experimental tests of three RF power values to clean the telescope's mirror using an RF plasma jet, and each test underwent 6 measurements over 6 different treatment times. A sample of 0.5 µL of deionized water was dispensed for each measurement as displayed in Figure 3.

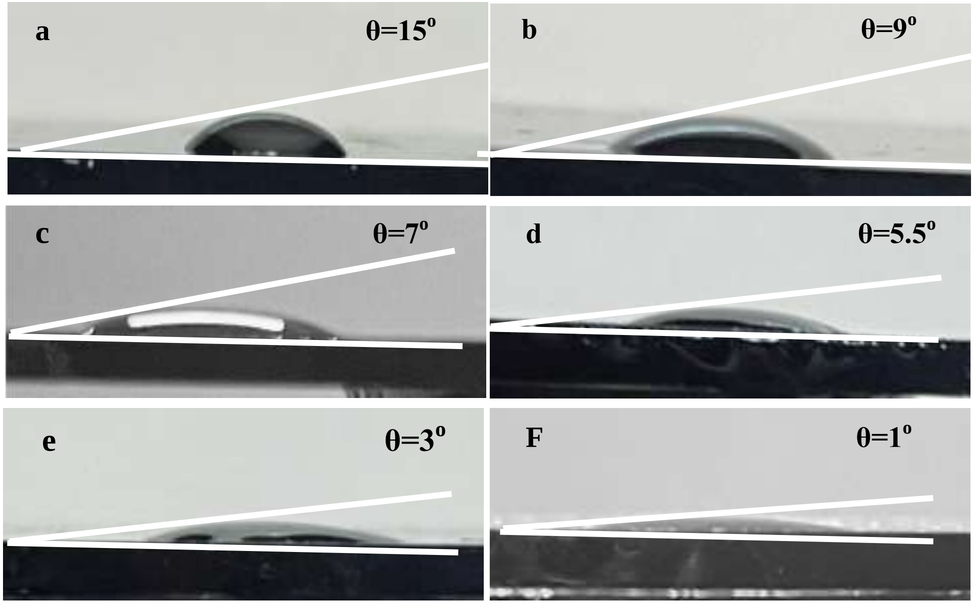

Figure 3: WCA images of the telescope’s mirror before cleaning (a) and after cleaning (b, c, d, e, f) at (0.5, 1.5, 2, 2.5) minutes respectively.

Argon (Ar) gas is utilized with high purity (99.99%) and is stabilized at 50 L/min under manual flowmeter control during the working duration. The jetting plasma column is about 20 mm thick, and the distance from the mirror to the jetting nozzle is 9 mm (see Figure 1). The droplet contact angle was used to analyze the surface properties and measure the cleaning efficacy of each process (the droplet fluid used is DI water).

3. Results and Discussion

Figure 4 shows the effect of RF plasma cleaning at atmospheric pressure on the WCA of the telescope’s mirror (silver/glass). The figure displays the increase in sample surface wettability with increasing cleaning time.

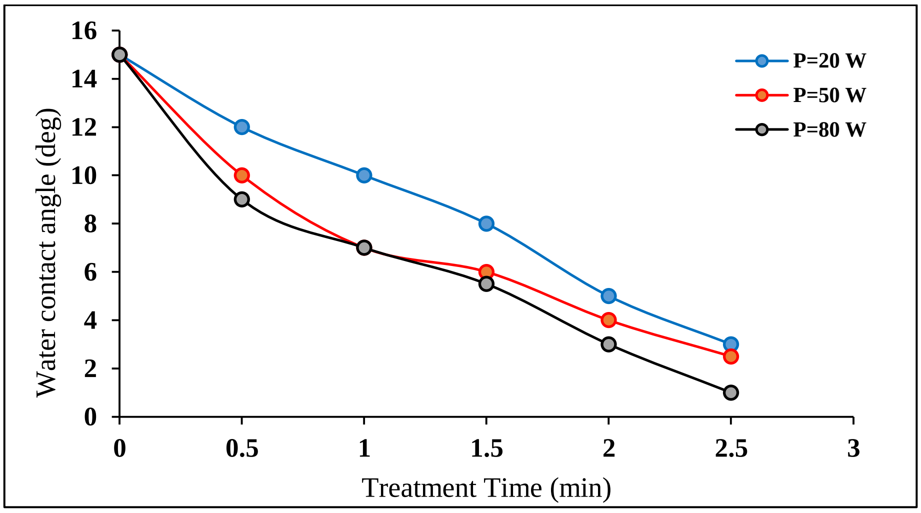

Figure 4: WCA measurements against time show the ageing effect of the atmospheric-pressure treatment on telescope mirror surfaces at various values of power.

The hydrophilic surface transformed into a superhydrophobic surface with a longer curing exposure time, which is consistent with [23]. The low wettability of the mirror before plasma treatment (WCA =15°) was significantly improved by atmospheric radiofrequency plasma cleaning, which reduced the WCA to less than 3° at 20 W, 2.5° at 50 W, and 1° at 80 W, respectively.

The reflectance of the telescope’s mirrors can be increased as shown in Figure 5 by using atmospheric pressure RF plasma to clean the mirrors' surfaces. The typical wavelengths measured here range from 300 to 1000 nm. Due to carbon contamination, significant changes in the reflectance have been noticed. It approaches the initial pre-aging reference value of 98.0%.

After 0.5 minutes of plasma treatment, the mean reflectance is 75%, and it rises to 98% after 2.5 minutes. The regular plasma cleaning may be able to avoid severe surface contamination that occurs after longer periods of aging or use. Moreover, the removal of carbon or hydrocarbons from optical surfaces allows for increased laser efficacy of mirrors used in optical devices, which is consistent with [24].

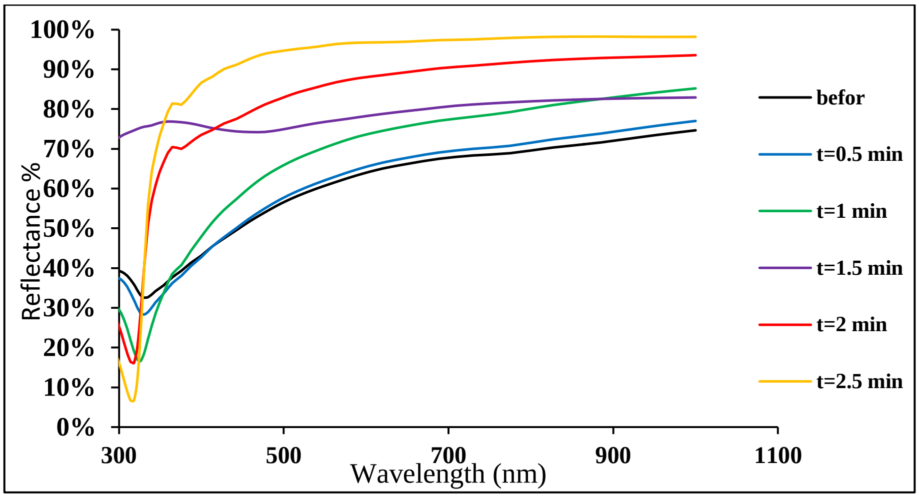

Figure 5: Reflectance against wavelength for the telescope’s mirror before and after cleaning at 80 W.

Figure 6 displays Ar I lines observed at 696.5431, 706.7218, 727.2936, and 738.398 nm at energies of 20, 50, and 80 W from spectral analyses of the plasma jet generated by the radio frequency power source at atmospheric pressure. Cleaning can reveal Ar I, Ar II, and NI.

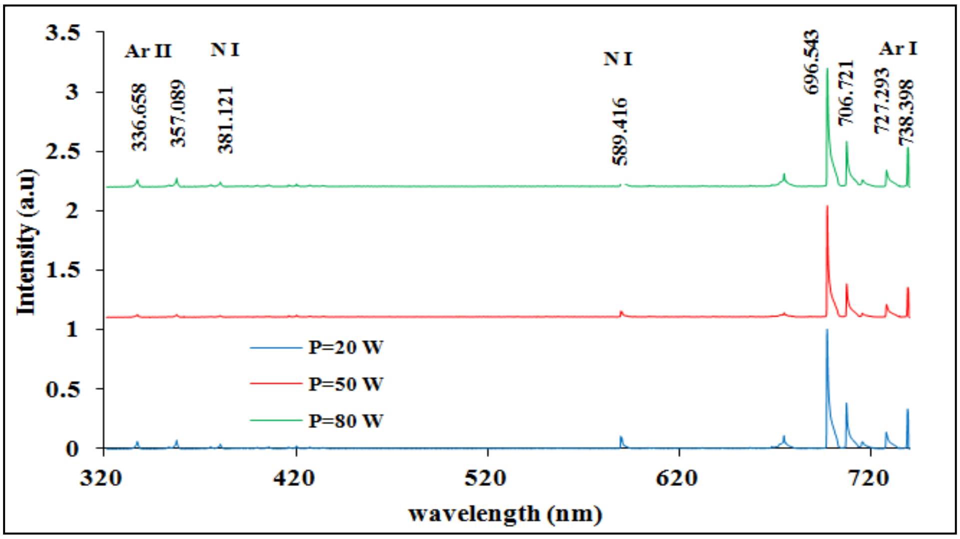

Figure 6. The Spectrum of Ar I lines 696.5431, 706.7218, 727.2936 and 738.398 nm for RF plasma jet at various powers (20, 50, and 80 W).

4. Conclusion

The plasma cleaning process allows for the effective removal of carbon adhering to the surface and changes the remaining bonds. The reflectance is increased during this process, almost restoring it to its original value before aging. Without using chemical cleaners, the telescope's mirror was successfully cleaned by an atmospheric pressure RF plasma jet. After 2.5 minutes of plasma treatment, the sample displayed a super hydrophilic surface at an angle of 1° as determined by the WCA technique, and an examination of its optical properties revealed that its reflectance had increased from 75% before cleaning to 98% after cleaning. The ArI, ArII, and NI lines can be seen in the RF plasma jet's spectrum when using the OES technique.

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