Investigation of discharge characteristics and thermal effect in atmosphere pressure plasma processing

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Abstract

The discharge characterization and thermal effect in the Atmosphere Pressure Plasma Processing (APPP) is presented. APPP is an innovative technology in advanced optics manufacturing for high material removal rate and without surface damage generated. A self-fabricated system has been developed for the plasma processing at atmosphere pressure, the spatial distribution of the chemical reactive species and the dissociation properties of SF_6 which as reactive gas have been measured by atomic emission spectroscopy technology in the plasma jet. Based on the spectral quantitative analysis and infrared temperature measurement theory, the thermal effect during discharge process has also been investigated. Temperatures have been measured under a cooling system and a normal system, the influence rules of temperature on the material removal rate were analyzed.

1 Introduction

With the rapid development of modern shorter wavelengths and the increasing requirement of high performance optics is urgently demanded. The manufacture of damage-free optics for advanced optical systems within an acceptable period of time and cost has been providing unique challenges in manufacturing [1]. Conventional methods of optical finishing relied mostly on plastic deformation and brittle fracture to cut away material from the substrate. This inevitably involved physical force at the micro scale and created damage in the subsurface of the material being treated [2]. Subsurface damage can greatly influence performance of the optical component.

APPP is a novel optical manufacturing technology, especially for brittle material [3]. Currently, the majority of plasma processing is done at low pressure and the vacuum operation is viewed as a necessary requirement. However, the expensive and complicated vacuum systems led to increased cost. The use of atmospheric pressure plasmas could greatly expand the current scope of materials processing and the cost of materials processing could be reduced substantially [4]. In this paper, the characterization of the discharge produced in APPP and the combined effects of parameters on the sample surface temperature is investigated.

2 The experiment setup

A schematic of the experimental setup is shown in Figure 1. The discharge used for this study was produced between the alumina electrode (D=3 mm) and the fused quartz (40 mm×40 mm, h=3 mm). Capacitive coupled Radio Frequency (RF) electric power at 13.56 MHz was supplied to the plasma via the alumina electrode through an impedance matching box. The electrode was placed inside a quartz tube, which was surrounded by a polytetrafluoroethylene (PTFE) cover to supply process gas to the electrode. The surface of the electrode was coated alumina by plasma spraying. Plasma gap between the electrode and the fused quartz was fixed to 2 mm. Mixed pure gases were supplied to the chamber. Flow rates of the gases were precisely monitored by independent linear mass flow meters. The optical emission of the plasma column is focused on by an entrance slit (width=50 μm) of a spectrometer (AvaSpec-2048), of which the optical fiber is fitted 5 cm from the tip of the electrode.

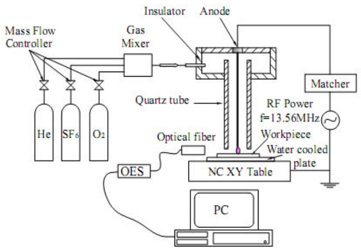

Figure 1: Schematic diagram of APPP

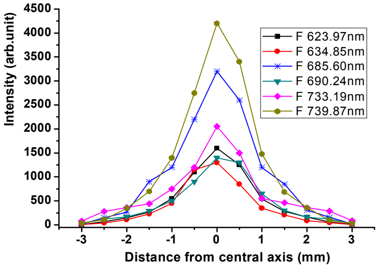

Figure 2: Radial distributions of F*

3 Reactive atoms emission spectrum

Figure 2 shows the distributions of the activated F* atoms in the radial section of the plasma jet. It is clear that, at the centre point of the jet in the radial direction, the intensity of the exited atoms emission spectrum is of the highest value, and their intensity attenuates as the distance from the centre point increases. In general, the distribution in the radial direction of the jet follows the Gaussian distribution curve.

Figure 3 shows the curves of the emission intensity of different reactive fluorine atoms at various SF_6/He ratios. The process conditions are 220 W RF power, 1.5 l/min helium flow and SF_6 volume concentration varies from 0.2~3%. It is evident from the figure that the emission intensity of reactive atoms increases with SF_6 concentration when less than 0.8%, and with more SF_6 molecules participate in this process, the electron density is decayed by the electron attachment to SF_6 molecules, which impacts the dissociation of SF_6 molecules. This emission intensity result coincides with measurement result on removal rate.

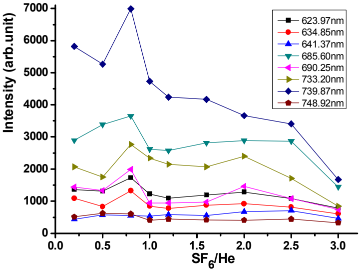

Figure 3:F* spectrums at SF_6/He ratios

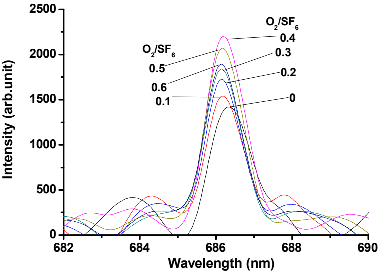

Figure 4:F* spectrums of O_2/SF_6/He plasma

A gas containing fluorine is generally used for plasma etching to move silicon dioxide components, and the removal process is performed by chemical reactions. By adding auxiliary gas O_2 in the reactive gas SF_6, it can make the reaction tend to the etching direction and then improve the removal efficiency [5]. Figure 4 shows the optical emission spectrums of the plasma generated at various O_2/SF_6 ratios.

4 Temperature on substrate

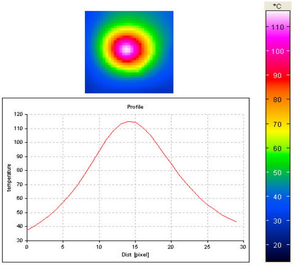

Figure 5: Temperature on substrate

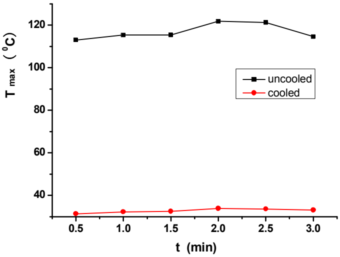

Figure 6: Temperature with/without cooling

Besides the chemical properties of active atoms, the temperature is considered as an important factor in the chemical reaction process. The temperature gradient on the substrate and the temperature profile through the maximum temperature point are shown in Figure 5. To investigate the effect of temperature in chemical reaction processing, the circulating cooling water system was designed on plasma generated equipment. Figure 6 shows the maximum temperatures on the sample surface under uncooled and cooled discharge system with the same parameters. The maximum surface temperature of sample drops from 120℃ to 33℃, but the maximum removal depths of substrate material are almost the same under two experimental conditions.

Conclusion

The spectroscopic properties of reactive fluorine atoms and the temperature gradient on substrate were investigated. The peak dissociation of SF_6 is at volume concentration 0.8%.Adding O_2 as an auxiliary gas during removal process could promote the dissociation of SF_6 molecules, and the optimal parameter is at the O_2/SF_6 ratio of 0.4. The temperature profile of the substrate follows the Gaussian curve. At the condition of cooled system, the temperature on the substrate reduce significantly compared with uncooled process, and the thermo-chemical effects do not influence the removal rate.

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