Measurement of vacuum ultraviolet light emitted from AC excited atmospheric pressure Ar plasma jet in ambient air

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The AC power excited atmospheric pressure plasma jet (APPJ) with pure Ar gas was generated under open air condition, and vacuum ultraviolet (VUV) emission spectra was measured by using a VUV monochromator. The spectra of atomic species such as O (wavelength: 130.4 nm), N (120.0, 174.3 nm), and H (121.6 nm) were observed. The emission intensity of N atom at a wavelength of 174.3 nm in the plasma remote region exponentially decreased with increasing the distance from the plasma jet. The absorption coefficient was estimated to be 1.8 cm^{-1}, over 20 mm distance from the plasma jet, the coefficient increase to 4.2 cm^{-1} which is almost same with value due to atmosphere. The behaviors of reactive species and high energy photons emitted from the AC excited Ar APPJ were discussed on the basis of the results measured by VUV spectroscopy.

1. Introduction

Recently, atmospheric pressure plasma jet (APPJ) has been applied to bio and medical fields. The plasma biomedical applications have attracted us much attention as new application of low temperature plasma. In our group, plasma applications to biomedical fields have been investigating, and the selective killing of cancer cells [1], inactivate spores of *Penicillium digitatum* [2], etc. have been successfully realized by non-equilibrium APPJ with ac power supply [3].

In the applications, reactive species generated in gas phase affect to biomedical samples. However, in the open air condition, many kind of reactive species and high energy photons are generated in gas-phase due to entrainment of ambient air. Therefore, the reactions between the plasmas and the samples are very complex and it is more difficult to understand the mechanism compared with those in low pressure plasma. However, to develop the plasma bio and medical applications, it is important to diagnose those behaviors. High density NEAPPJ developed in our lab can offer electron density as high as 10^{15} cm^{-3}.[3,4] Moreover, the behaviors of atoms generated by the plasma jet were measured by using spectroscopic methods.[3] However, in the bio-medical applications, high energy photons are also important factor to affect to treatment of biomedical samples. In this study, the behaviors of high energy photons in the vacuum ultraviolet (VUV) region emitted from the ac excited APPJ with pure Ar in open air have been measured by optical emission spectroscopy in the VUV region.

2. Experimental setup

The Ar NEAPPJ was generated between two metal electrode tips, to which a 60 Hz alternating voltage was applied, on the condition of the Ar gas flow rate of 2 slm. The ac power supply provided a peak-to-peak voltage of around 18.0 kV, adjustable using a transformer. The current was limited to 20 mA in order to prevent the formation of an arc discharge. A plasma jet was generated as a glow discharge and emitted from square-shaped exit slit (20×0.3 mm) along the gas flow direction with a length of up to about 8 mm.

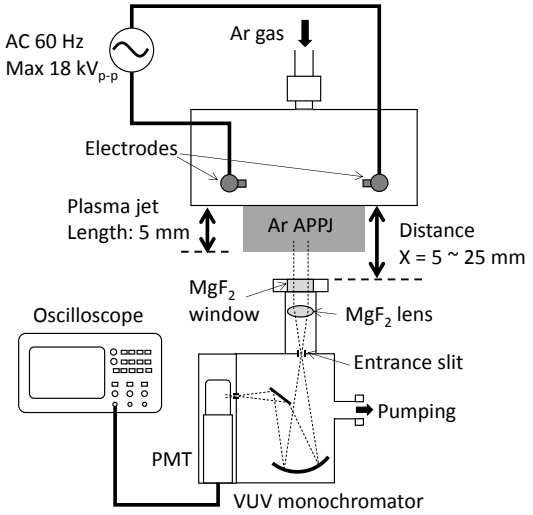

Fig. 1 Experimental setup of VUV optical emission spectroscopy for diagnosing AC excited Ar APPJ.

Figure 1 shows an experimental setup for VUV radiation emitted from AC excited Ar APPJ. VUV monochromator was set at down flow region and evacuated by a vacuum pumping system. VUV light emitted from the Ar APPJ went through the MgF_2 window and focused on the entrance slit of VUV monochromator. And then, the VUV light was dispersed by a grating and detected with a PMT.

In this study, the experiment was carried out in open air condition and the distance between the plasma head and the entrance window of VUV monochromator was changed from 5 to 25 mm along the gas flow direction and. From results, influence of ambient air entrainment on the behavior of high energy photon in VUV region is discussed.

3. Results and discussion

The Ar APPJ was generated under open air condition, and VUV emission spectra was measured by using a VUV monochromator. Figure 2 shows emission spectra of AC excited Ar APPJ at the wavelength region between 115 to 200 nm. In the experiment, the distance between the plasma head and the entrance window of monochromator was set at 5 mm. As shown in Fig. 2, the spectra of atomic species such as N atom (wavelength: 120.0 nm, 174.3 nm), H atom (121.6 nm), and O atom (130.4 nm) were observed. These species were generated by the entrainment of ambient air.

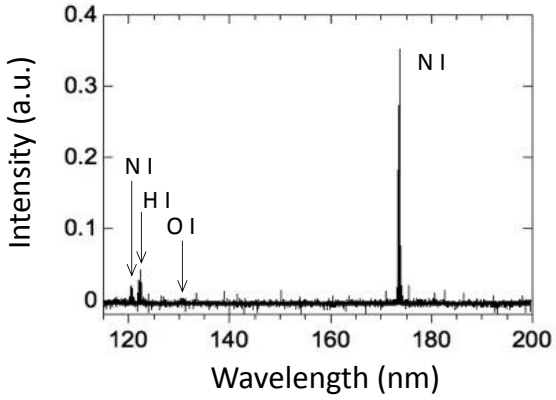

Fig.2 VUV emission spectra from Ar APPJ in open air condition.

Figure 3 shows the behavior of the optical emission intensity of N atom at 174.3 nm as a function of distance from plasma head. As the distance increases, the emission intensity of N atom decreased drastically. The length of Ar plasma jet from the exit slit was about 5 mm. From this result, the VUV light emitted from the plasma jet was strongly absorbed by atmospheric gases such as oxygen molecules. In the AC excited APPJ, strong influence of ambient air entrainment in the remote region of plasma jet could be considered.

By fitting the emission intensity as shown in Fig. 3 with Beer–Lambert law, two fitting curves are confirmed. The absorption coefficients of each part are estimated to be α_1=1.8 cm^{-1} in the region between 5 and 20 mm and α_2=4.2 cm^{-1} at the region between 20 and 25 mm. The theoretical value of absorption coefficient at the wavelength of 170 nm in pure O_2 gas at atmospheric pressure is about 20 cm^{-1} [5]. The atmosphere is roughly 80% of nitrogen and 20% of oxygen with small amounts of moisture, argon, carbon dioxide, and other gases. Therefore, the absorption coefficient under the air condition at atmospheric pressure is about 4.0 cm^{-1}. The value is equal to α_2, approximately. In conclusion, from the distance of 20 mm, the VUV light emitted from the plasma was strongly absorbed by oxygen molecules in ambient air. From results, in the remote region of plasma jet, the effect of high energy photon on the treatment of biomedical sample is considered to be decrease rapidly with increase in the distance.

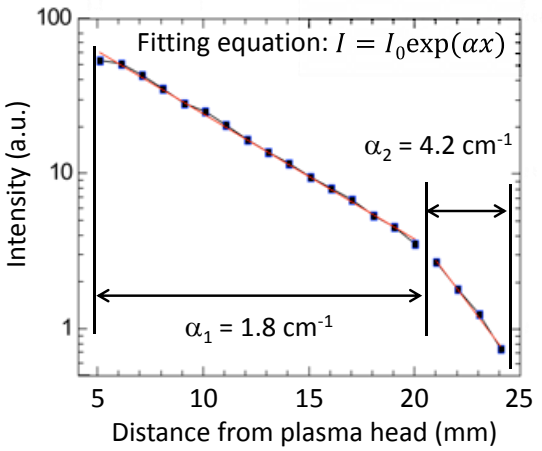

Fig. 3 Emission intensity of N atom at 174.3 nm as a function of distance from plasma head.

4. Acknowledgment

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5. References

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