Gas Composition Analysis in Atmospheric Pressure Plasma Jet Using Mass Spectroscopy with Differential Pumping
差動排気質量分析法による大気圧プラズマジェットのガス組成分析

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Atmospheric pressure plasma jet of He core with the sheath gas flow has been developed for precise control of chemical reaction in the atmosphere. By wrapping the He core jet for discharge with the sheath gas at the same velocity, plasma plume was extended even at a small gas flow rate for He. The spatial profile of gas composition with and without the sheath gas was analyzed using quadrupole mass spectrometer through a thin glass capillary tube. At the end point of plasma plume, oxygen concentration rapidly increased due to turbulence and mixture with ambient air.

1. Introduction

Medical, biotechnology and agricultural applications of atmospheric pressure plasma[1] have been energetically studied by many researchers. Atmospheric pressure plasma jet (APPJ) of helium (He) or argon (Ar) gas can be operated using a simple apparatus consisting of a discharge tube, electrodes, and a conventional high voltage source at low frequency AC sinusoidal wave or pulse. Reactive oxygen and nitrogen species (RONS) are generated in APPJ from ambient air and transported to the target of living tissue[2]. The irradiation of RONS to the target surface will result in various chemical reactions with biological effects.

When the jet of discharge gas is injected into the atmosphere, turbulence occurs at the boundary between the jet and the surrounding gas. Due to the turbulence, the reaction process between the plasma in the discharge gas jet and oxygen and nitrogen in the ambient air is quite complicated as investigated by Schlieren imaging method. In this work, using a quadrupole mass spectrometer with differential pumping through a thin glass capillary, composition of atmospheric gas around He APPJ has been studied. It can be expected to clarify the gas flow profile around the APPJ affecting the RONS generation and transportation.

2. Experimetal

The He core jet with the sheath gas flow was ejected from coaxial double tubes made of Pyrex glass as shown in Fig.1. The inner tube was used for He APPJ excited by an electrode wound on the surface. The outer tube was used for supplying the sheath gas of N_2. The inner and outer diameters of the inner tube were 3.2mm and 4.0mm, and those of the outer tube were 8.0mm and 10mm, respectively. A dielectric barrier discharge was operated in the inner tube by 30 kHz sinusoidal wave of 7kVp-p.

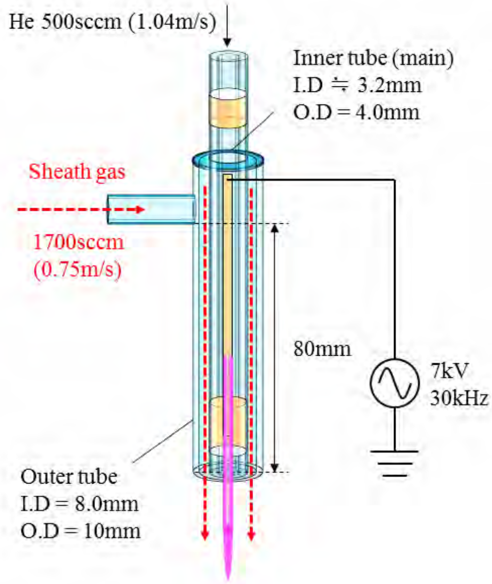
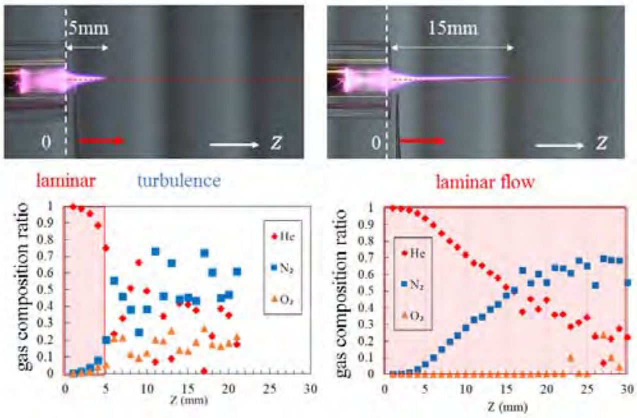


Fig.1. Experimental setup

The He flow rate was 500sccm. The N_2 flow rate was tuned to extend the plasma plume and finally determined at 1,700sccm. At the flow rates, the velocities of gases became an almost same value about 1 m/s. The gas composition around the jet was analyzed in a vacuum chamber using a quadrupole mass spectrometer (M200QA-M, ANELVA) with sampling through a thin glass capillary of 35 µm inner diameter and 150µm outer diameter vertically inserted into the gas jet. The sampling position was scanned using a precision stage in z and r axes where z was distance from gas nozzle and r was distance from the central axis. As the composition, concentrations of He, N_2, and O_2 were evaluated from the mass spectra.

3. Results and Discussion

Photographs of plasma plumes and the spatial profiles of gas composition were shown in Fig.2 and Fig.3. The gas composition profiles were measured without discharge. By using sheath gas of N_2, plasma plume was extended from 5 mm to 15 mm. The plasma plume with N_2 sheath gas looked thin and straight.



(a) (b)

Fig.2. Spatial profile of gas composition with z (a) w/o sheath gas flow and (b) with sheath gas flow.

Fig.2 shows gas composition at the center of gas jet with variation of z. Without the sheath gas, He gas was suddenly mixed with air at z=5mm due to turbulence where the plasma plume was terminated. As shown in Fig.2(b), by using the sheath gas flow, He jet was gradually mixed with N_2 due to mutual diffusion at the boundary of laminar flow. The plasma plume ended at z=15mm where the N_2 concentration exceeded 50%. By the sheath gas flow, O_2 was completely excluded from the plasma plume in the core jet until the 25mm from the nozzle.

Figs.3 show the radial profiles of gas composition at z=1, 8, and 15mm. Near the nozzle, the core jet was pure He gas. As shown in Fig.2(b), the N_2 sheath gas gradually diffused into the core jet. At z=8mm, the center of the core jet included 30% of N_2.

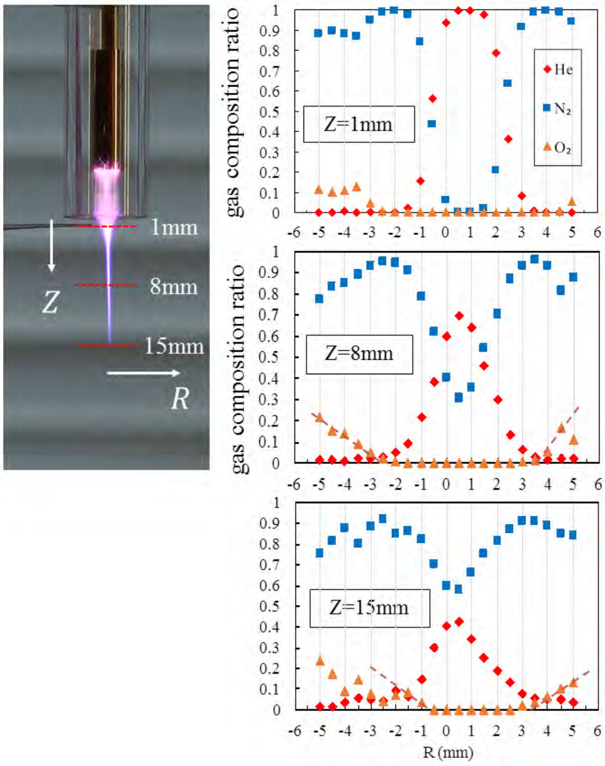


Fig.3. Radial profile of gas composition with sheath flow at z=1, 8, and 15 mm.

The sheath gas flow is not only to replace the ambient gas but also to extend laminar flow of discharge gas by avoiding turbulence. It has been also supported from the result that velocity matching at the boundary between core gas jet and sheath gas flow was critical condition for extension of plasma plume. In the conventional He APPJ, the chemical reactions for RONS production was complicated due to turbulence between He jet and ambient air. The results indicate that chemical will be well controlled in the laminar flow between the He jet and the sheath gas flow. It is also expected to include any reaction gas in the sheath gas for intentional reaction control.

4. Summary

Plasma plume of He APPJ was extended by N_2 sheath gas at matched velocity. Gas profile of laminar structure between core He jet and N_2 sheath gas was elucidated by QMS measurements.

References

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