Discharge Conditions of a Non-Thermal Plasma Jet in Helium, Surrounded by Flows of Nitrogen-Oxygen Mixtures of Various Proportions†

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Abstract

We present here analysis of the discharge characteristics of a non-thermal plasma jet, where the surrounding gas condition of the plasma jet is precisely controlled in open air. The mixing of the surrounding gas into the plasma jet markedly changes the discharge characteristics: the optical emission intensity of N_2^+ *linearly increases with an increase in gas flow ratio of* N_2 *to* O_2 *in the surrounding gas. Our experiments clearly demonstrate that the plasm jet could be controlled from* O_2 *main discharge to* N_2 *main discharge by changing the surrounding gas condition even in open air.*

KEY WORDS: (non-thermal plasma jet), (reactive oxygen and nitrogen species), (surrounding gas condition)

1. Introduction

Non-thermal plasma jets are of current interest in biomedical applications such as wound disinfection and even treatment of cancer tumors [1]. In a dielectric-barrier-discharge (DBD) plasma jet, the dielectric plays an important role to prevent the formation of high temperature arcs. The DBD non-thermal plasma has a relatively high electron temperature and a low gas temperature. The high-energy electrons can produce chemically rich gas-phase environments with reactive oxygen and nitrogen species around room temperature in open air. Beneficial therapeutic effects in medical applications are usually attributed to excited species of oxygen and nitrogen from air. However, to control the production of these species in the plasma jet is difficult because their production is strongly dependent on concentration of nitrogen and oxygen from ambient air into the plasma jet. In our experimental configuration we overcome this problem by producing a primary non-thermal discharge in helium, but surround this plasma with controlled flows of nitrogen and oxygen mixtures of various proportions. We demonstrate the existence of excited states of oxygen and nitrogen produced by the helium plasma by interaction with the surrounding gas flow. Our spectroscopic measurements of emissions from excited species of oxygen and nitrogen indicate the presence of these species.

2. Experimental methods

A He non-thermal plasma jet was investigated under an open-air condition [2-8]. A quartz tube was wrapped with 45- and 15-mm-wide copper metal strips as the power and ground electrodes, respectively. The outer and inner diameters of the quartz tube were 6 and 4 mm, respectively. The power electrode was set 5 mm away from the outlet of the quartz tube, and the distance between the power and ground electrodes was 8 mm. The power electrode was connected to a high positive pulse voltage with an amplitude of 8 kV in order to ignite the DBD between the power and ground electrodes in the quartz tube, where the full width at half maximum of the positive pulse voltage was about 4 μs. The repetition frequency of the positive pulse voltage was 5 kH. He gas of 1 slm was supplied into the quartz tube (inner tube) as a main discharge gas. An outer tube with 14-mm inner diameter was set around the plasma jet in order to control the surrounding gas condition of the plasma jet. N_2 or/and O_2 gases were introduced into the outer tube as a surrounding gas, as schematically depicted in Fig. 1. The optical emission spectra from the plasma jet were measured with a spectrometer with a charge-coupled device detector, where the collimating lens for collecting emission light was set 5 mm away from the quartz-tube nozzle. The diameter of the collimating lens was 4 mm.

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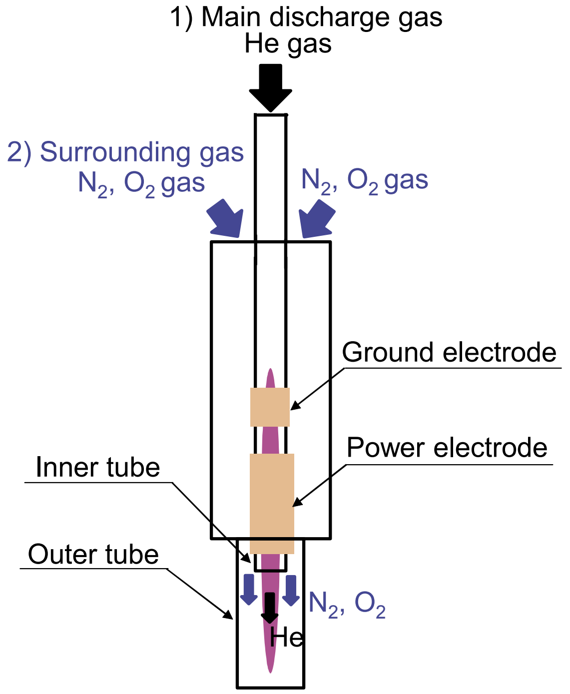

Fig. 1 Schematic of the experimental setup for a non-thermal plasma jet in open air.

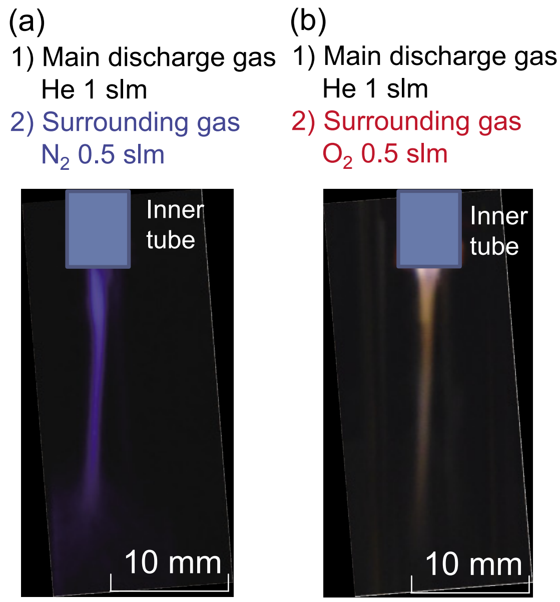

Fig. 2 Photographs of plasma jets produced under the surrounding gas conditions of (a) N_2 0.5 slm and O_2 0 slm, and (a) O_2 0.5 slm and N_2 0 slm. He 1 slm is introduced into an inner tube as a main discharge gas.

3. Results and Discussion

Figures 2(a) and 2(b) show photographs of the plasma jet under the surrounding gas conditions of N_2 0.5 slm and O_2 0.5 slm, respectively. Here, the condition of a main discharge gas in the inner tube is He 1 slm. The plasma jet as long as 20 mm was successfully produced in the open air. The color of the plasma jet is sensitive to the surrounding gas condition: the plasma jet shows a purple and orange color under the surrounding gas conditions of N_2 0.5 slm and O_2 0.5 slm, respectively. This clearly indicates that the mixing of the surrounding gas into the plasma jet markedly changes the discharge characteristics of the plasma jet. In order to investigate the discharge characteristics in detail, the optical emission spectra from the plasma jet were measured with a spectrometer. Figures 3(a) and 3(b) show optical emission spectra under the surrounding gas conditions of N_2 0.5 slm and O_2 0.5 slm, respectively. Strong optical emissions from N_2^+ are observed at the surrounding gas of N_2 0.5 slm, while optical emissions from O and He are clearly detected at the surrounding gas condition of O_2 0.5 slm. Figure 4 shows optical emission intensity of O and N_2^+ as a function of gas-flow ratio of N_2 to O_2 in the surrounding gas. Here, He 1 slm and O_2 0.2 slm are introduced into the inner and outer tube as a main discharge and a surrounding gas, respectively. A surrounding N_2 gas is changed from 0 to 0.5 slm. The optical emission intensity of N_2^+ linearly increases with an increase in N_2 flow ratio, while the optical emission intensity of O slightly decreases with N_2 flow ratio. This result shows that the plasma jet is successfully controlled

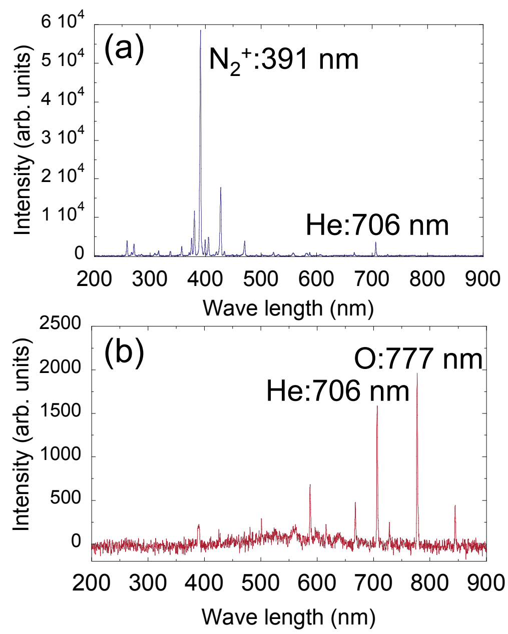

Fig. 3 Optical emission spectra of the plasma jet produced under the surrounding gas conditions of (a) N_2 0.5 slm and O_2 0 slm, and (b) O_2 0.5 slm and N_2 0 slm. He 1 slm is introduced into an inner tube as main discharge gas.

from O_2 main discharge to N_2 main discharge by changing the surrounding gas condition in tube. Our plasma-jet system with the outer tube is useful for biomedical applications, because reactive oxygen and nitrogen species could be selectively produced even in open air.

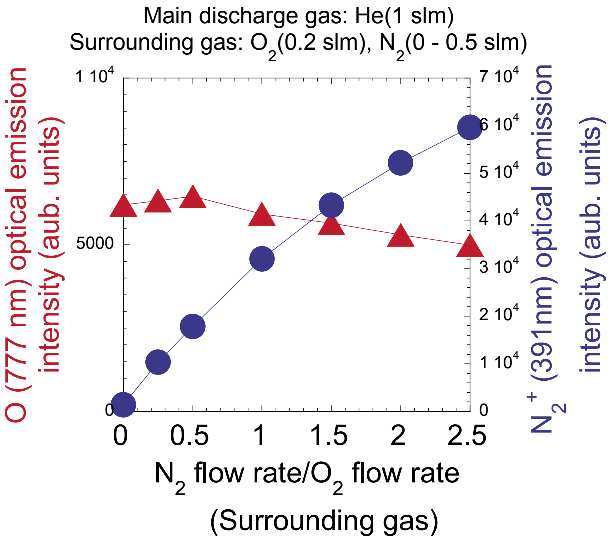

Fig. 4 Optical emission intensity of O and N_2^+ in a plasma jet as a function of surrounding gas flow ratio of N_2 to O_2 in the main gas He 1 slm and the surrounding gas O_2 0.2 slm. The surrounding N_2 gas flow is changed from 0 to 0.5 slm.

4. Summary

A non-thermal plasma jet in He, surrounded by nitrogen and oxygen, produces excited states of nitrogen and oxygen. Production of such states is frequently regarded as being beneficial in medical application such as wound disinfection. Our experiments demonstrate that the non-thermal plasma jet in He is successfully controlled from O_2 main discharge to N_2 main discharge by changing the surrounding gas condition in tube. The surrounding gas condition in the plasma-jet system is useful for the selective production of the reactive oxygen and nitrogen species in open air.

Acknowledgment

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