Propagation dynamics of a room-temperature pulsed argon plasma plume through a simple dispersion-grating diagnostic method

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In this paper, a novel grating-ICCD camera dispersion diagnostic method was designed to investigate the propagation behaviors of an open-air pulsed argon plasma plume. Based on the dispersion feature of gratings, the irradiative plasma plume was dispersed into several emission-volumes corresponding to different wavelengths. And a series of high-speed dispersed emission-image sequences were captured by the ICCD camera. From these sub-microsecond emission-images at different wavelengths, the temporal and spatial propagation behaviors of excited species in the plasma plume were observed clearly.

1. Introduction

Non-equilibrium atmospheric pressure plasma jets have recently obtained increasing attention for their prospects in some emerging novel applications, like biomedical and environmental decontamination. In order to improve their application efficiency, fundamental mechanisms of open-air plasma jets are studied widely. In this paper, a novel diagnostic method was carried out to study the time-and-space resolved propagation behaviors of an open air room-temperature argon plasma plume by using two different gratings (1200 g/mm and 600 g/mm) and an ICCD camera. The argon plasma plume was generated by a simple jet device, which is almost the same with the one we reported previous except the added ground electrode in this work.[1]. The argon plasma was electrically driven by a home-made pulsed excitation source at 1 kilohertz repetitive frequency. Based on the dispersion feature of gratings, a series of dispersed emission-volumes in form of high-speed images from different excited irradiative emitters were captured by the ICCD camera. And from these dispersed emission images, the dynamic behaviors of different excited radicals in the plasma plume were observed directly.

2. Instructions

For all the experiment results in the work, the operational parameters are fixed at applied voltage V_a = 15 kV, pulse duration t_p = 800 ns, pulse frequency f_p = 1.0 kHz, and argon gas flow rate g = 140 sccm. The argon gas has an impurity of H_2O about 0.5 sccm.

Two gratings, 1200 g/mm (blazed at 500 nm) and 600 g/mm (blazed at 1000 nm) were applied for obtaining the dispersed emission-volumes of the argon plasma plume. The two grating are arranged at a same position individually with a distance of 10 cm between the vertical central axises of the gratings and the plasma jet device. The dispersed time-and-space resolved emission pattern images of the argon plasma plume were obtained by a Hamamatsu ICCD camera (C8484). The ICCD camera gating time and the discharge initiation were synchronized using a delay generation (Stanford Instrument DG535). The exposure time was fixed at 10 ns for all imaging measurements.

Figure 1 shows the time-and-space resolved image sequences of the OH and N_2 bands emissions dispersed by the grating 1200 g/mm during the (a) positive and (b) negative discharges of the argon plasma. Due to the limited efficiency of the grating 1200 g/mm (blazed at 500 nm), the OH bands emission at 308 nm was almost overlapped with the N_2 band at 315 nm, as shown in Fig. 1.

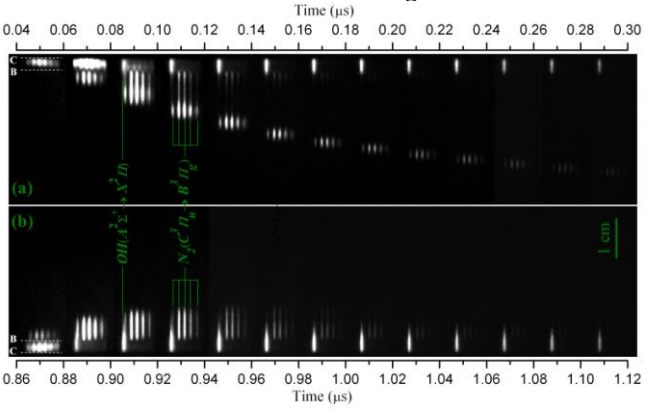

Fig. 1. The time and space resolved image sequences of the OH and N_2 bands emissions from the dispersed argon plasma plume in the open air by the grating 1200 g/mm, (a) positive and (b) negative discharges of the argon plasma. The images were acquired with a 10 ns grated ICCD camera at a time interval of 20 ns. The delay of time axis is responded to the onset of the applied voltage Va. The position of the device nozzle exit B and upper surface of the

grounded electrode C, are also shown respectively.

As can be seen in Fig. 1(a), the emission intensities from the OH and N_2 bands inside the nozzle are very strong. But after that, the N_2 emissivity inside decreased immediately while the plasma traveling out into the surrounding air. And five strong emission-volumes propagated simultaneously in the open space. It should be pointed out that the five emission-volumes are from corresponding N_2 bands at different wavelengths. The N_2 emission-volumes propagated fastly (at a high velocity about 10^5 m/s) in the surrounding air with a gradually decreasing intensity, and faded away somewhere front the nozzle. On the other side, it should be noted that the emission-volume keeping irradiating inside the nozzle was from the OH bands (308 nm). Distinct to the N_2 bands, the emission intensity of the OH bands decayed immediately while the plasma traveled out from the nozzle. As shown in Fig. 1(b), the propagation behaviors of the OH and N_2 emission-volumes during the negative discharge are similar with that of the positive case. The OH emission-volume irradiated for a relative long duration inside the nozzle, but decayed quickly while the plasma propagating into the open air.

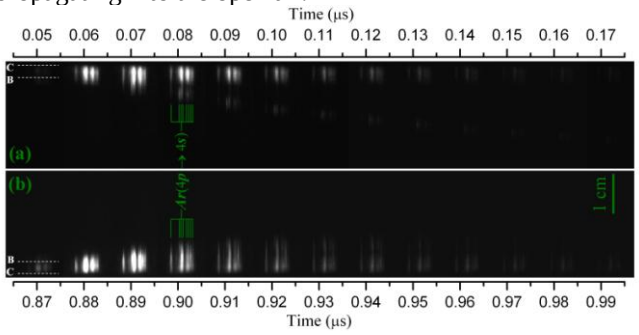

Fig. 2. The time and space resolved image sequences of the Ar emissions from the dispersed argon plasma plume in the open air by the grating 600 g/mm, (a) positive and (b) negative discharges of the argon plasma. The images were acquired with a 10 ns grated ICCD camera at a time interval of 10 ns.

The temporal and spatial resolved Ar emission-volumes in the plasma plume for positive and negative discharges are shown in Figure 2. The emission-volumes corresponding to different Ar lines were slightly overlapped with each other due to the limited resolution of the 600 g/mm grating system. For both the positive and negative discharges, the argon emission-volumes propagated with a fast decreasing irradiance intensity. The argon emission-volumes were able to propagate to a longer distance for the positive discharge (Fig. 2(a)) compared to the negative case (Fig. 2(b)), which is similar with that of the N_2 bands as shown in Fig. 1. The Ar emissivity decayed more rapidly than that of the OH and N_2 bands. These district time-and-space resolved behaviors of emission-volumes of OH and N_2 bands, and Ar lines, are attributed to the different generation and quenching mechanisms of their corresponding excited species, i.e., OH($A^2\Sigma^+$), $N_2(C^3\Pi_u)$, and Ar(*4p*).

The main generation processes for OH($A^2\Sigma^+$) under our experimental conditions are dominated by the energy transfer reaction from excited argon atoms Ar*, especially argon metastables Ar_m. The metastable levels Ar(*4s*) are resonant with Rydberg levels of water molecules, therefore collisional processes between these two species will lead a very efficient dissociative excitation of H_2O and produce a large quantity of hydroxyl radical at the $A^2\Sigma^+$ state.[2]

The long duration of OH emission inside the nozzle, is due to the long radiative lifetime of the excited OH($A^2\Sigma^+$) in our case. The quenching of OH($A^2\Sigma^+$) inside the nozzle are due to collisional process with argon atoms and the radiative de-excitation, with characteristic time in a range of 100~800 ns, which is in the same order of magnitude of the duration 400 ns of OH emissions as shown in Fig. 1.[2] However, the fast decay of OH emission for the plasma outside, is mainly attributed to the diverse effect of diffusion air.

The generation process for excited state $N_2(C^3\Pi_u)$ was also dominant by the energy transfer collisions with excited and metastables Ar_m. That is also why the Ar emission intensity decreased rapidly during the plasma propagating in the surrounding air. However, the N_2 emissions could propagate to a longer distance than that of Ar. When the Ar emissions faded away, which indicates decrease in the concentrations of excited states Ar(*4p*) and fast electrons, the continual propagation of N_2 emission-volumes in the open air are probably due to the contribution of metastables Ar_m and N_2(A). The metastables N_2(A), which has a long lifetime up to second order, can be easily produced through cascade transitions from higher levels, like N_2(C) and N_2(B), and direct collisions with low-energy electrons.[3, 4] The long lifetime metastable N_2(A) can still have a certain concentration enough to produce the excited state N_2(C) while the density of excited and metastable argon atoms and electron temperature performing a serious decrease when plasma propagated far away in the surrounding air.

Acknowledgements

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