

An Atmospheric Pressure Nonequilibrium Plasma Jet Device

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Abstract—In this paper, a specially designed atmospheric pressure nonequilibrium plasma jet device is reported. The device is a modified dielectric barrier discharge. It is capable of generating a plasma plume that is up to 10 cm long in the surrounding air. Using helium as the operating gas, the plume can be touched by bare hands without causing harm. There is no risk of arcing with this device. The gas temperature of the plume is close to room temperature. Therefore, this device may be used for applications such as the decontamination of temperature-sensitive materials, surface modification, teeth cleaning, etching, etc.

Index Terms—Atmospheric pressure plasma, decontamination, dielectric barrier discharge, nonequilibrium plasma, nonthermal plasma, plasma jet, surface modification.

ATMOSPHERIC pressure nonequilibrium plasmas, which have an electron temperature that is much higher than gas temperature, have recently come to play an increasing role in several novel applications, such as biological applications. The high electron temperature is favorable for enhancing the plasma chemistry, and the low gas temperature (close or at room temperature) makes them suitable for applications where gas temperature that is close to or at room temperature is required. On the other hand, for biological applications, such as wound healing and teeth cleaning, atmospheric pressure nonequilibrium plasma jet devices are needed. Because of the merit of the plasma jets devices [1]–[8], which generate plasma plumes in surrounding air rather than only in discharge gaps, it has recently attracted great attention. However, most of the known plasma jet devices have their own shortcomings. Either the length of the plasma plume is only few millimeters, the gas temperature of the plume can reach tens of degrees Celsius, or the risk of arcing is not completely avoided.

Recently, we reported a specially designed room temperature plasma jet device [9]. The device is basically a modified dielectric barrier discharge. Fig. 1(a) shows a schematic of the setup. The high-voltage (HV) wire electrode is inserted into a glass tube with one end closed. Thus, the risk of arcing is completely avoided. The ground electrode is attached to the outer surface of the quartz tube. The distance between the tip of the HV wire electrode and the ground electrode is about

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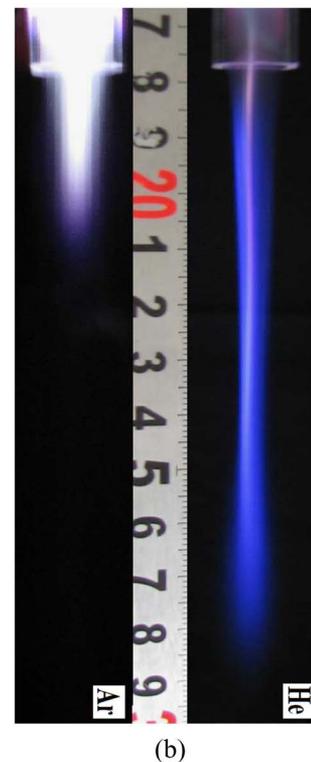
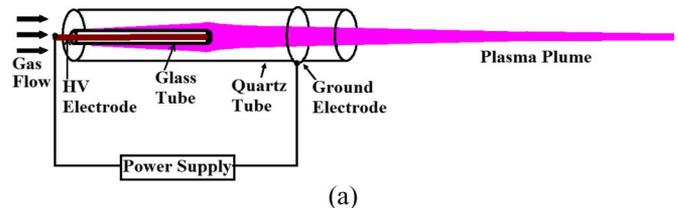


Fig. 1. (a) Schematic of the experimental setup. The HV electrode, which is made with copper wire, is inserted into a glass tube with one end closed. The copper wire has a diameter of 2 mm. The inner and the outer diameters of the glass tube are 2 and 4 mm, respectively. The aluminum foil made into a ground electrode is attached on the outer surface of the quartz tube, which has inner and outer diameters of 8 and 10 mm, respectively. The distance between the tip of the HV electrode and the ground electrode is about 2 cm. (b) Photograph of the plasma plumes [ac frequency of 40 kHz and applied voltage of 5 kV (rms)].

2 cm. Operating gas such as helium, argon, nitrogen, or air, can be used with this device. When the operating gas is flowing into the quartz tube from the left end and a 40-kHz ac voltage is applied to the electrodes, a plasma plume is generated in the surrounding air, with its length up to 10 cm long. The length of the plasma plume depends on the applied voltage, gas flow rate, and gas mixture. When helium or argon is used as the operating gas, the gas temperature of the plasma plume is

close to room temperature. Fig. 1(b) shows the photograph of the plasma plumes, which is taken by a Canon digital camera, for the working gases He and Ar. When helium is used, the rotational temperature of the plasma plume is about 2300 K [9], which is determined from the emission spectra of a nitrogen second positive system. Therefore, the plasma plume is under an extremely nonequilibrium condition, which is favorable for an enhanced plasma chemistry.

In addition, several of these plasma jet devices can be operated in parallel with a single power supply. Hence, it is possible to generate a large-volume atmospheric pressure plasma plume in the surrounding air.

Furthermore, as mentioned before, this device can be operated by using air as the working gas. Therefore, this device may be used to generate large-volume air plasma for applications such as aerodynamics (drag reduction and shock wave mitigation) and radar communications (absorption and reflection of microwaves).

The gas temperature of the plasma plumes is determined by analyzing the rotational structure of the nitrogen second positive system emission. With helium as the working gas, the gas temperature is about 30 °C for the ac frequency of 40 kHz, applied voltage of 5 kV (rms), and helium flow rate of 15 l/min.

Optical emission spectra show that excited OH, O, N₂, N₂⁺, He, NO, etc., are present in the plasma plume. It is well known that radicals, such as OH and O, are very reactive; therefore, this device is also suitable for applications in fields such as

the surface modification and decontamination of temperature sensitive material, teeth cleaning, etc.

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