Uniform glowlike plasma source assisted by preionization of spark in ambient air at atmospheric pressure

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The ultraviolet radiation produced by spark discharges is employed to supply preionization for the dielectric barrier discharge in ambient air at atmospheric pressure. The effect of ultraviolet preionization and overvoltage on improving the uniformity of the dielectric barrier discharge is investigated experimentally. Based on the emission spectra and voltage-current wave forms, the optical and electrical characteristics of the discharge are discussed. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2356894]

Recently, much attention has been paid to dielectric barrier discharge (DBD) due to its numerous potential industrial applications, such as pollution control, generation of ozone, polymer modification, thin film deposition, sterilization, etc.[1–5] In DBD device, the uniform glow discharge is usually realized by making use of noble gases, such as He, Ar, and Ne.[6–8] There exist some obstacles in obtaining the uniform discharge plasma in ambient air because it is difficult to control the stability of discharge in air with the pressure increasing. According to the experimental and theoretical results by Palmer[9] and Levatter and Lin,[10] the generation of a uniform glow discharge is attributed to "multiple avalanche coupling." If the density of seed electrons just prior to the discharge occurrence can reach a high level, usually of the order of 10^6 or 10^7 cm^{-3},[11] the avalanches are liable to overlap each other and coalesce in lower electric field, thereby smoothening out the field gradients resulting from space charges, which is responsible for the formation of atmospheric pressure glow discharge. The spark discharge employed as an ultraviolet (UV) preionization source to improve the uniformity of the discharge in mixed gases has been studied in CO_2 laser.[12] Moreover, other studies show that a high overvoltage is the other significant factor for forming spatially homogeneous discharge.[13,14] In this letter, we generated a uniform glowlike discharge in air at atmospheric pressure by making use of the spark discharge as a preionization source.

A schematic setup of the experimental discharge system is shown in Fig. 1. The copper pins and DBD reactor are connected in series to compose a feedback system. DBD reactor plays the role of restraining the arc discharge occurring between pin-to-pin gap; on the other hand, the discharge between pin-to-pin gap imposes influence on the voltage applied on DBD (V_{DBD}). The UV radiation produced by spark discharge between two pins is coupled to the DBD's gap through one transparent electrode made of a quartz plate deposited with indium tin oxide film. The pin-to-pin distance ($d_{pin\text{-}pin}$) is 12 mm, the spacing distance of the discharge gap in DBD (d_{DBD}) is 4 mm, and the vertical distance from the tips of pins to the transparent electrode is 5 mm, respectively. The dual discharge device is driven by one sinusoidal power supply, the frequency varies from 300 Hz to 10 kHz, and the peak-to-peak value of the voltage ranges from 0 to 40 kV. The discharge current, measured with a current probe (Tektronix, TCP202), is input into one channel of a storage oscilloscope (Tektronix TDS3032B) and the discharge voltage, measured with a high voltage probe (Tektronix, P6015A), is fed into the other channel. A digital camera (Fuji, s602z) is used to take the images of the visible emission of the discharge with the exposure time of 1/1200 s. The emission spectra from the discharge are obtained through a spectrometer with a charge-coupled device detector (Acton 2500i).

For a given applied voltage across the device, the electric field near the pins is much higher than that in DBD. The discharge between the pins is ignited first and then the discharge in DBD is "turned on." Figures 2(a) and 2(b) are the side views of the images of the discharges. It is shown in this experiment that the applied frequency plays an important role in controlling discharge characteristics in the pin-to-pin gap. If the frequency is lower than 4.250 kHz, the discharge in the pin-to-pin gap is a spark discharge, as shown in Fig. 2(a). Otherwise, the discharge between two pins is an enhanced-corona one, characterized by the brightest regions appearing near the tips of pins, which is illustrated in Fig. 2(b). Comparing the two pictures of discharges in DBD reactor, it is obvious that the discharge between two pins, spark or enhanced corona, imposes great influences on the DBD. Evidently, the spark discharge is more helpful for improving the uniformity of DBD than the enhanced-corona one.

The emission spectra of the discharge in pin-to-pin gap are illustrated in Fig. 3(a). The UV radiation lines in both spark and enhanced-corona discharges are observed at the wavelengths of 225.802, 235.483, 246.203, and 257.699 nm,

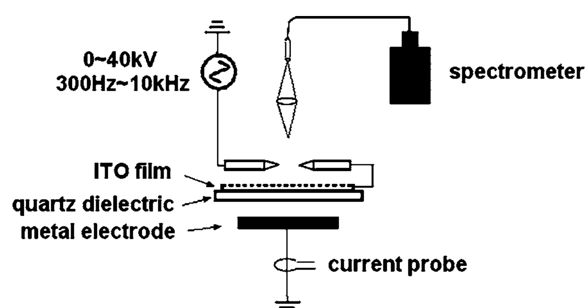

FIG. 1. Schematic of the experimental setup.

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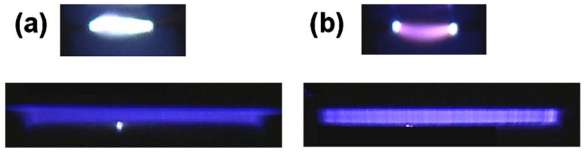

FIG. 2. (Color online) Side view images of the dual discharge are taken at the exposure time of 1/1200 s. (a) The peak-to-peak value of V_{DBD} is 16 kV at the operating frequency of 3.573 kHz and (b) the peak-to-peak value of V_{DBD} is 26 kV at 5.460 kHz, in which the upper images are the discharges between the pins and the lower images correspond to the discharges in DBD.

respectively. Since the UV absorption peaks of the nitrogen fall in the range of 120–145 nm (Ref. 12) and the CO_2 strongly absorbs radiation below 115 nm,[15] the nitrogen and CO_2, as two chief components of air, are difficult to be directly photoionized by the UV irradiation in our case. As for O_2, the molecule can be dissociated easily into atoms by UV irradiation. However, the direct ionization of oxygen atom is impossible since each oxygen atom has a much higher ionization potential than the highest photon energy of 5.3 eV. Hence, the photoionization of oxygen atoms is believed to be realized by a two-photon ionization process with 845 and 777 nm emission lines.[16] The two emission lines shown in Fig. 3(b) justify the conclusion.

The voltage wave forms of the output of the power supply (V_{output}), the voltage component applied across DBD (V_{DBD}), and the component applied across two pins ($V_{pin\text{-}pin}$), when the operating frequency of the power supply is 3.573 kHz, are illustrated in Fig. 4(a). The figure shows that a spark discharge ignites once the $V_{pin\text{-}pin}$ is higher than 10 kV, then $V_{pin\text{-}pin}$ drops to 2.5 kV lasting for about 50 μs during the first half-cycle, and a similar process evolves at the second half-cycle in the opposite direction. It is indicated that the discharge gap between two pins is characterized by a low impedance after sparking, while the capacitance of DBD (C_{DBD}) in series is charged up in the meantime. Consequently, the overvoltage falls on DBD with the rapid rise time of about 40 ns. The voltage and current wave forms of DBD corresponding to the circumstance in Fig. 4(a) are shown in Fig. 4(c) for three cycles. When the negative V_{DBD} is applied across the DBD gap, the displacement current manifests itself as an oscillating pulse train with the rising time of 40 ns and a current discharge pulse in DBD follows with a long duration of 30 μs, which are shown in Fig. 4(e) for clear demonstration. Due to enough seed electrons yielded by spark preionization and the adequate overvoltage applied on DBD gap, the ionization process evolves into a uniform glowlike discharge. Figure 4(b) depicts the circumstance where the operating frequency of the applied voltage is 5.460 kHz. The discharge between two pins is ignited at a relatively low breakdown voltage of about 2 kV and the discharge voltage is maintained at about 1 kV for the duration of 64 μs in each half-cycle. The corresponding voltage and current wave form of DBD for this circumstance is illustrated in Fig. 4(d). The V_{DBD} is sinusoidal with a little distortion, even though the pin-to-pin discharge occurs, and the current spikes erratically appear on the temporal abscissa and the average duration of these current spikes is only about 90 ns, as shown in Fig. 4(f). This discharge is a typical filamentary discharge.

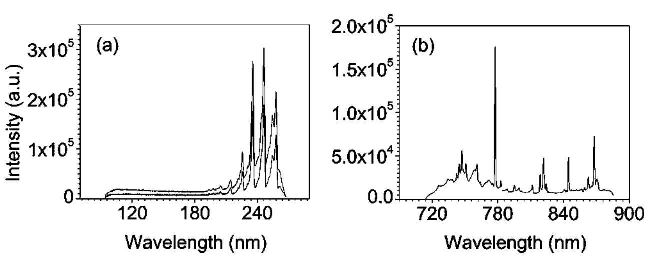

FIG. 3. Emission spectra of the spark and enhanced-corona discharges in the pin-to-pin gap are illustrated. (a) The UV radiation spectra for two discharge modes, in which the stronger emission spectrum is produced by spark discharge and (b) the long wavelength spectrum of the discharge is produced by spark.

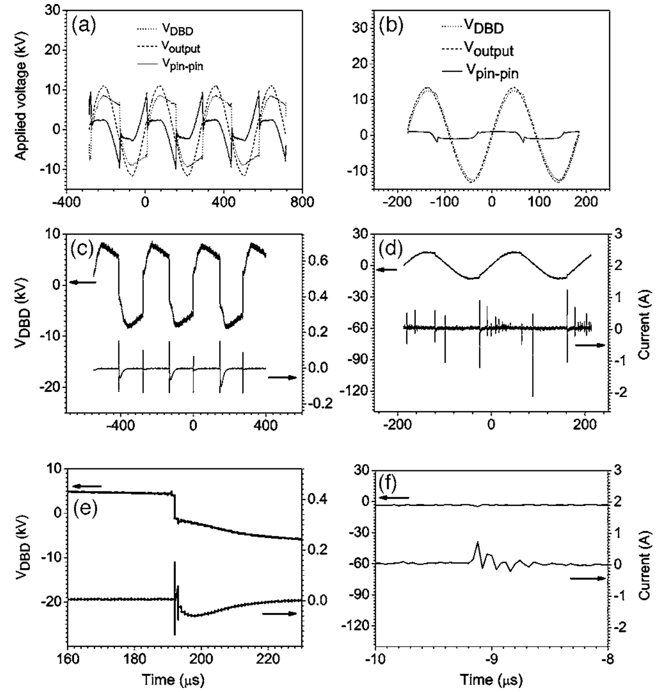

FIG. 4. Wave forms of V_{output}, V_{DBD}, and $V_{pin\text{-}pin}$ at the operating frequency equal to 3.573 kHz are shown in (a) and that at 5.460 kHz in (b), The voltage and current wave forms of DBD in the case of (a) are illustrated in (c) and that of (b) in (d); the wave forms in (e) and (f) correspond to those in (c) and (d), respectively, after the time expansion of the temporal abscissa is done.

In conclusion, we generated a uniform glowlike plasma in air with a dual discharge device driven by one power supply. The discharge in DBD is assisted by the UV illumination from the spark discharge between two pins in series with DBD. The preionization by the UV irradiation lowers the breakdown voltage of DBD by yielding the adequate seed electrons, which is crucial for obtaining the uniform glowlike discharge. And it is also found that the quick rising time of V_{DBD} is the other factor in improving the discharge uniformity of DBD.

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