Atmospheric Pressure Plasma Generation using Dielectric Barrier Discharge Stacked by Insulator Coated Comb-Electrodes

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Abstract. To generate volumetric atmospheric-pressure plasma, we proposed a dielectric barrier discharge system with stacked insulator-coated comb-electrodes. The large volumetric plasma was generated in each gap and surface of insulators by stacking electrodes. From the spectroscopic measurement of plasma, almost same shaped spectra were measured from 2 to 10 electrodes. In addition, the ozone concentration in plasma was estimated by the absorption spectroscopy. In this result, the constant ozone concentration was measured from 2 to 10 electrodes.

1. Introduction

Atmospheric-pressure plasma is used in various industrial applications such as material processing, environmental fields and medical fields [1-7]. The atmospheric-pressure plasma can be generated by capacitive, inductive and electromagnetic coupled methods [8-10]. One of the benefits of atmospheric-pressure plasma is that equipments for vacuum generation are not needed, exhibiting features such as the ease of creating non-equilibrium plasma, the generation of several active species, among others.

A dielectric barrier discharge (DBD) is one of the methods of an atmospheric-pressure plasma generation. The DBD consists of a pair of electrodes covered with insulator to prevent thermal damage, and a high-voltage power-supply. The DBD plasma can be easily obtained in atmospheric conditions using simple equipments and an arbitrary geometry [11-14]. Because of the concentration of different activated species between the electrodes, DBD is generally used in industrial applications such as ozonizer, surface modification, and decomposition of environmental pollutants, and so on [15-21].

Typical applications of atmospheric pressure plasma require the quantities of active species, that is, the density of active species and/or the volume of existing active species are needed to increase. Increasing the density of active species, we focus on the generation method for DBD plasma in atmosphere. To obtain large volumetric plasma, the large surface area as the electrodes and insulators is required. Thus, to obtain a relatively large volume of plasma by means of a compact device, we should produce the DBD plasma in the adjoining dielectric cavities [22]. However, the plasma parameters generated in the DBD plasma are difficult to control. To generate the large volumetric atmospheric-pressure plasma, we proposed a DBD system with stacked insulator-coated comb-electrodes and evaluating its plasma parameters.

2. Experimental Equipments

To generate the volumetric DBD plasma, we have developed a type of DBD device with stacked insulator-coated comb-electrodes. Figure 1 shows the insulator-coated comb-electrode. The electrode size is 25 mm × 45 mm. The comb-electrode is made of a tantalum of 0.8 mm of diameter, in alumina tube. Tantalum is used by reason of a high melting temperature and high corrosion resistance. The tantalum is covered by the alumina tube. The inner and outer diameters of the alumina tube are 1 mm and 2 mm, respectively. The relative dielectric constant of alumina is evaluated to be 6.9 at 45 kHz in frequency.

Figure 2 shows the schematic diagram of experimental setup. The electrodes were stacked, alternating the polarity as shown in Fig. 2. The gap distance between electrodes was fixed to 1 mm. A high-voltage power supply (IDX Co. ltd.) was used to generate the atmospheric-pressure plasma. The high-voltage power supply is an inverter system, it is contained by a boost transformer and parallel connection of two inverter circuits. The power supply can generate up to 20 kV_{pp} and 45 kHz in frequency. The voltage and current waveforms were measured using a high voltage probe (HV-P30 : IWATSU) and a current transformer (C.T. 2100 : PEARSON). To measure the active species, the spectrum emitted by the plasma was measured with a spectrometer (C12027-01 : HAMAMATSU).

The ozone, which is one of the active species, has been generated by this system. The ozone concentration in plasma was estimated by absorption spectroscopy of 254 nm wavelength generated by the mercury lamp (L937-01 : HAMAMATSU). The ozone concentration is estimated by the Beer-Lambert law, as follows [23-25];

$$C = -\frac{A}{aL}\log_{10}\left(\frac{I}{I_0}\right) \quad , \qquad (1)$$

where, C (g/m^3) is the ozone concentration, I / I_0 is the relative intensity, a (3000 ℓ/mol cm) is the

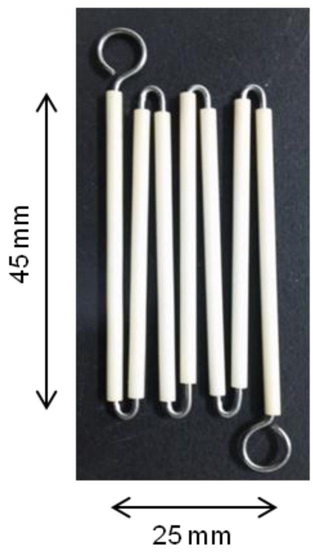

Figure 1. Insulator coated electrode

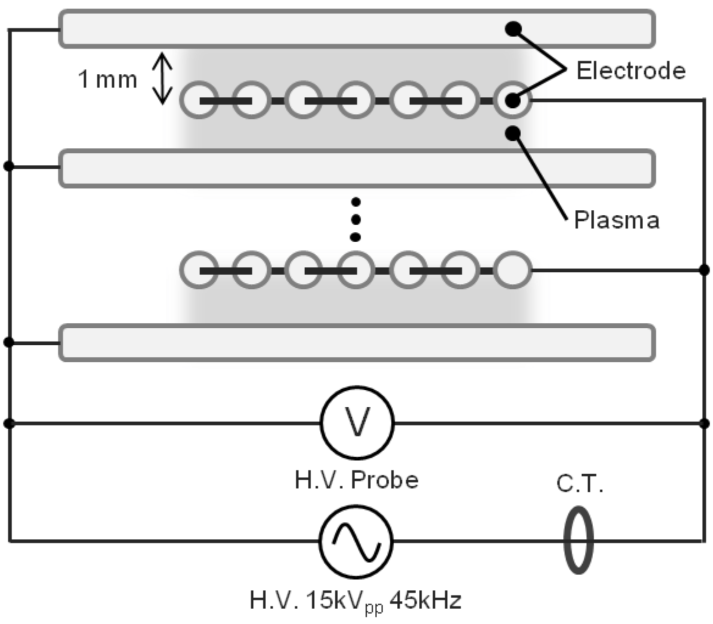

Figure 2. Experimental setup of atmospheric pressure plasma by using insulator-coated comb-electrodes

molar absorption coefficient of ozone, L (cm) is the light path length, and A (=48000) is the conversion coefficient of unit.

3. Experimental Results

To generate the DBD plasma in each gap of electrodes, the voltage of 15 kV_{pp} was applied. The DBD plasma was generated in changing from 2 to 10 electrodes. Figures 3 (a) and (b) show the photos of the generated DBD plasma in the case of stacking 10 electrodes. As shown in Fig. 3 (a), the DBD plasma was generated at the only overlapped area in alternately set electrodes, which was covered with the alumina. As shown in Fig. 3 (b), the DBD plasma was observed in each gap for stacking 10 electrodes, and it was also observed at the surface of the alumina tubes. The plasma volume was estimated by the visible emission region. In the case of stacking 2 electrodes, the plasma volume was estimated to be 6.25 x 10^2 mm^3. In the case of stacking 10 electrodes, the plasma volume was estimated to be 1.12 x 10^4 mm^3. Thus, the plasma volume was increased approximately 18 times from the comparison between the case of 2 electrodes and the case of 10 electrodes. From these results, the large volumetric plasma was obtained by using the stacking electrodes.

Figure 4 shows the typical voltage and current waveforms in the cases of stacking 2 and 10 electrodes, respectively. As shown in Figs. 4 (a) and (b), the applied peak voltage is fixed 15 kV_{pp} and the peak current is estimated to be 0.65 A_{pp} for stacking 2 electrodes, and 2.8 A_{pp} for the stacking 10 electrodes. In these results, the peak current for the stacking 10 electrodes is 4.3 times higher than that of the stacking 2 electrodes. This indicates that the peak current increases about 0.2 ~ 0.3 A_{pp} per electrode.

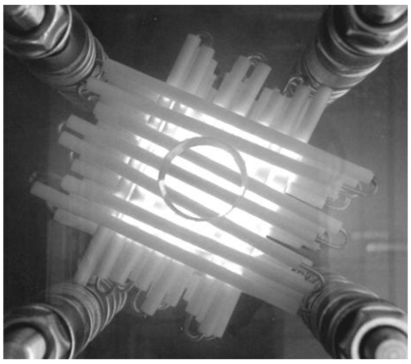

Figure 3 (a). Photo of plasma emission from top to bottom

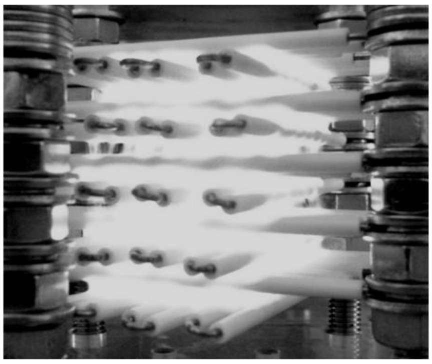

Figure 3 (b). Photo of plasma emission in each gap

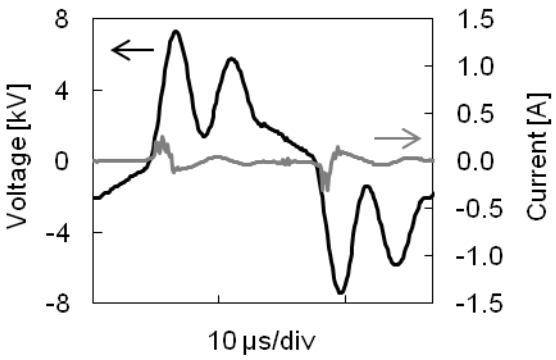

Figure 4 (a). Typical voltage and current waveforms in the case of stacking 2 electrodes

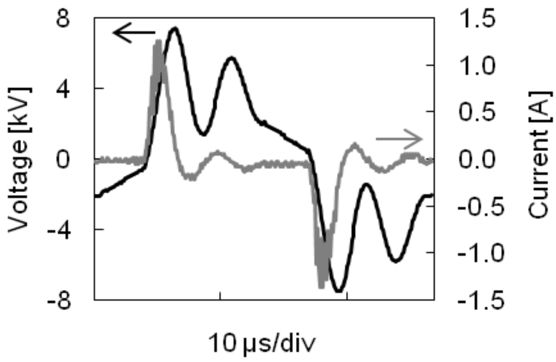

Figure 4 (b). Typical Voltage and current waveforms in the case of stacking 10 electrodes

Figure 5 shows the average input power used to generate the plasma as the function of electrode number. As shown in Fig. 5, the average input power is estimated to be 0.32 kW for the stacking 2 electrodes and 1.17 kW for the stacking 10 electrodes. The average input power to generate the DBD plasma requires 0.1 kW per electrode.

To evaluate the plasma spatial uniformity, the emission spectra from the plasma as a function of the number of electrodes were measured. Figure 6 shows the emission spectra from the generated plasma in the case of 2 and 10 electrodes. As shown in Fig. 6, nitrogen molecules, nitrogen ions, oxygen molecules, oxygen atoms and oxygen ions were observed from the emission spectra [26-27]. The spectra over 400 nm were not observed. It indicates that the UV emission was dominant. In addition, the emission spectrum was similar even in the different cases of number of stacked electrodes.

Figure 7 shows the generated ozone concentration at the central area of overlapped electrodes in the stacking direction. As shown in Fig. 7, the measured ozone concentration varied between 4.9 ~ 5.5 g/m^3 with increase of the number of electrodes. The amount of generated ozone was almost same for the different stacked cases, suggesting that the ozone generation could be increased by stacking more electrodes and by generating larger volumetric plasma.

Figure 8 shows the generated ozone concentration at each gap in the case of stacking 10 electrodes. Figure 8 shows the ozone concentration at each gap, where the upper gap is represented by gap 1, and the lower gap as gap 9, as represented in Fig. 3 (b). As shown in Fig. 8, the ozone concentration is estimated to be 3.1 ~ 3.5 g/m^3 in each gap. It means that the generated ozone concentration was almost same in each gap. In comparison with Figs. 7 and 8, the ozone concentration is different. This difference is attributed to the fact that the ozone concentration at central area of overlapped electrodes was higher than the concentration at edge area of overlapped electrodes. Therefore, the ozone concentration in each gap was lower than the concentration in electrodes stacked direction.

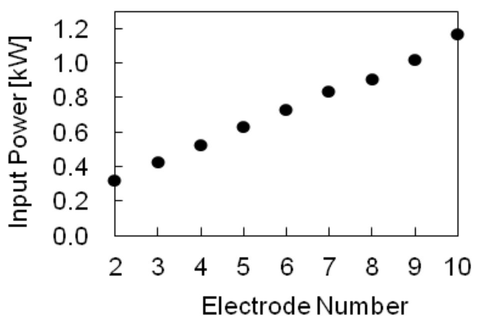

Figure 5. Input power as a function of electrode number

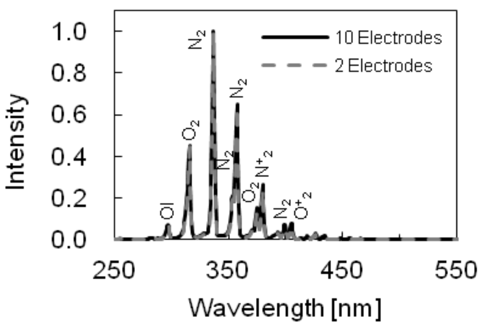

Figure 6. Plasma emission spectra in the case of stacked 2 and 10 electrodes

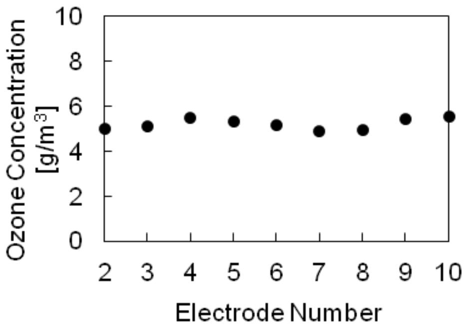

Figure 7. Ozone concentration in stacked direction of electrodes

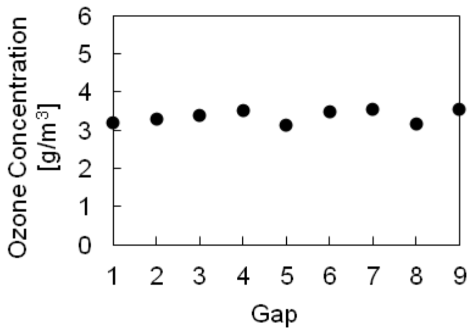

Figure 8. Ozone concentration at each gap

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4. Conclusions

To generate large volumetric atmospheric-pressure plasmas, we have developed the DBD device consists of the insulator coated comb-electrode stack. The atmospheric-pressure plasma was generated by changing from 2 to 10 electrodes in each gap and the surface of the insulators. The large volumetric plasma was generated by stacking the electrodes. From the spectroscopic measurement of plasma, almost same spectra were observed in each gap from comparison of 2 to 10 electrodes. The results indicated that the generated plasma condition is independent of the number of electrodes. The absorption spectroscopy of ozone was measured at each gap direction and electrode stacked direction. The generated ozone concentration was almost same at each electrode gap position. The uniform ozone concentration in the direction of the stacked electrodes was measured by stacking 2 to 10 electrodes. In these results, large volumetric plasma and ozone generation could be increased by stacking more electrodes.

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