Experimental investigation of correlation between net charges in plasma jet and decomposition of methylene blue solution

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Abstract: Here we investigated how plasma bullet currents are affected by frequency of bipolar high voltage. A wide range of frequency between 2.5 and 70 kHz was investigated for the helium microplasma jet which has a tapered nozzle exit. From the plasma bullet current measurements, larger net charges in both positive and negative were calculated at lower frequency per discharge cycle. Similar trend of MB decomposition was also confirmed by a conventional spectrophotometry.

Keywords: plasma bullet currents, dc-pulse, methylene blue.

1. Introduction

Non-thermal atmospheric pressure plasma (APP) technologies are widely used in biological and biomedical applications. It is strongly considered that the short-lived and highly reactive oxygen species (ROS) are the most important to induce biological reactions. Hydroxyl radicals (OH•), superoxide anion radicals (O_2^{-}•), singlet oxygens ($^1O_2$) and atomic oxygens are well-known short-lived and highly reactive ROS in plasma. Non-thermal atmospheric-pressure plasma jet is a well-known method to generate such ROS and to supply to biological target without thermal damage. In our previous study, we showed dc-pulse driven helium plasma jets could modulate the chemical components in plasma activated water.

In this study, we investigated how dc-pulse affected on production of net charges and decomposition efficiency of methylene blue solution.

2. Experimental

Figure 1 shows non-thermal atmospheric-pressure helium microplasma jet employed in this study. It consisted of a 150 mm long glass tube tapered from an inner diameter of 4 mm to 680 μm at the nozzle. The glass tube (borosilicate, Pyrex) has a 15 mm long metallic external ring electrode wound onto the glass tube at 50 mm from the end of the nozzle. Helium gas (99.98%, industrial grade) was fed into the glass tube with a fixed gas flow rate of 2.0 L/min. A capillary microplasma dielectric barrier discharge (DBD) was generated using a high voltage bipolar pulse of 8.9 $kV_{p\text{-}p}$ (peak-to-peak) applied to the external electrode. Frequency was varied between 2.5 and 70 kHz in a wide range.

High-voltage DC-pulses were applied to the external electrode with a commercial power supply (Haiden-SBP-10K-HF, Haiden Lab, Akashi, Japan). The high-voltage DC-pulse and plasma bullet currents were measured employing a high-voltage probe (PPE 20 kV, LeCroy,) and a conventional current monitor (Pearson 2877, Pearson Electronics), respectively. Current monitor was fixed at the below 5 mm from the nozzle exit. The voltage and current waveforms were recorded with a digital oscilloscope (WaveJet 300A, LeCroy). The length of the plasma jet, as seen with the unaided eye and measured with a ruler, was varied between 5 and 15 mm in the frequency range mentioned above.

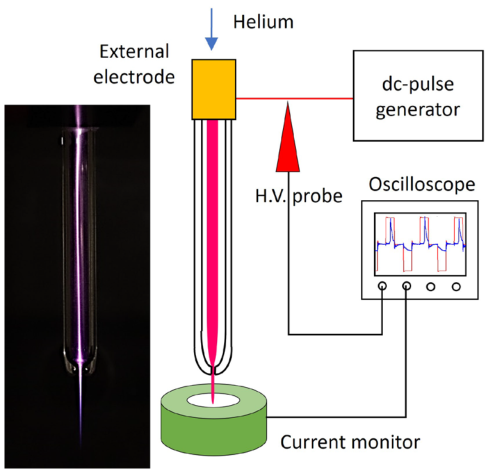

Fig. 1. Schematic diagram of plasma bullet current measurement and a picture of atmospheric-pressure helium microplasma jet used in this study.

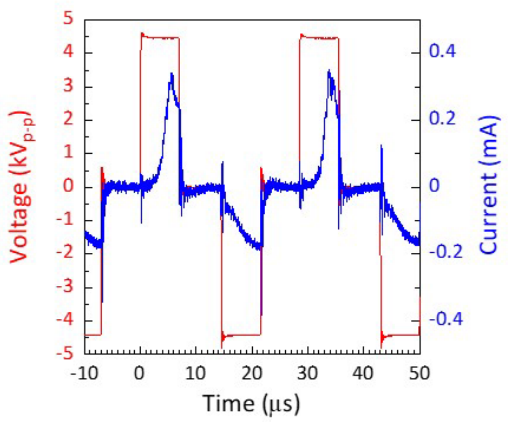

Fig. 2. Bipolar high voltage pulse at 35 kHz and plasma bullet current waveforms were measured.

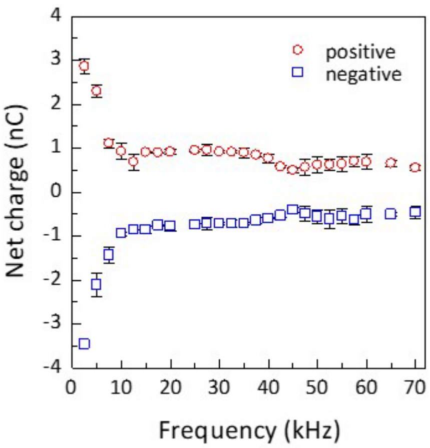

Fig. 3. Positive and negative net charges calculated from the measured bullet currents.

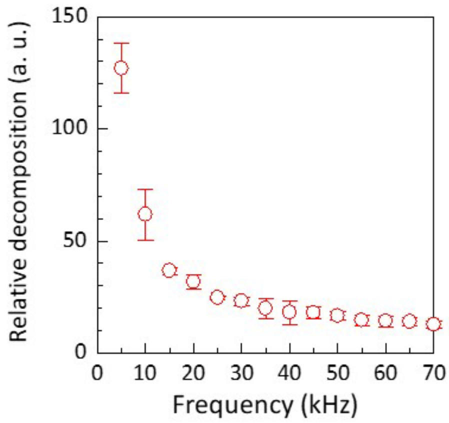

Fig. 4. Effect of MB decomposition on the frequency.

Methylene blue (MB) solution was used to estimate the production of highly reactive oxygen species such as a hydroxyl radical (OH•). UV-vis-NIR spectrophotometer (UV-1900, Shimadzu) was employed to investigate the concentration of MB in solution.

3. Results and discussion

Figure 2 shows bipolar high voltage pulse at a frequency of 35 kHz and plasma bullet current (I_b) waveforms. Regarding of plasma bullet current in the pulse discharge, positive bullet current could be measured during the positive pulse on-time, while negative bullet current could be measured during the negative pulse on-time. Current peaks are 3.5 mA for positive bullet current and -1.8 mA for negative, respectively. Interestingly, a few µs delay was observed only in case of positive bullet current.

Figure 3 shows both positive and negative net charges (Q_n) per a discharge cycle. The net charges were calculated using equation 1 with the positive and negative bullet currents, respectively.

$$Q_n = \int_0^T |I_b| \, dt \qquad (1)$$

It could see the largest net charges are measured at lowest frequency at 2.5 kHz. It rapidly decreased as an increase of frequency up to 10 kHz and gradually decreased afterward. This trend was compared to the decomposition rate of MB. Figure 4 shows how MB decomposition was affected by the plasma at the different frequency. It seems that there is a very strong correlation between the net charge and decomposition rate of MB.

Considering the situations of plasma bullet current measurement using current monitor at 5 mm below the nozzle exit and MB decomposition at 17 mm below it. At this distance, charged species are hardly to detect and neutral reactive species are mainly existed. Interestingly, however, we see the same trend in both net charge and MB decomposition.

4. Conclusions

In this study, we have investigated how plasma bullet currents are affected by frequency in a range between 2.5 and 70 kHz for the helium microplasma jet which has a tapered nozzle exit. From the measurements, larger net charges were calculated at lower frequency per discharge cycle and decrease as an increase of frequency. Similar trend of MB decomposition was also investigated.

Acknowledgement

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