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Concentration Distribution of Reactive Oxygen Species Supplied on Liquid Target by Non-thermal Plasma Jet
大気圧プラズマジェットが液状ターゲット表面に供給する活性酸素の濃度分布

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In this paper, the distribution of ROS supplied on a target by a plasma jet was studied using the gel visualization reagent originally prepared in our laboratory. Additionally, relative concentration distribution was numerically obtained by an absorbance measurement of the results using this reagent. The relationship between the plasma irradiation distance and ROS distribution became clear visually and numerically. The experiment with the water layer on the reagent was also conducted in order to study the production and transport of ROS through water. The interesting ROS distribution patterns in the bottom of water were visually obtained using the reagent underwater.

1. Introduction

An atmospheric pressure plasma jet has attracted special interest all over the world because it has physical and chemical special features [1]. Recently, the plasma jets have been actively studied and developed for biomedical applications because it can be directly irradiated to liquid targets including the human body and biological tissue [2]. However, there are many questions regarding the interactions between plasma and such liquid targets. Therefore, the spatiotemporal generation and distribution of the various reactive species have been studied by optical and chemical measurements [3].

In this study, the distribution of ROS supplied on the target by a plasma jet has been studied using the gel visualization reagent originally prepared in our laboratory [4, 5]. In this paper, the influence of the irradiation distance on the ROS distribution was reported using the gel visualization reagent in atmospheric air. The experiments with the water layer between the generator and the reagent were also conducted in order to visualize the ROS distribution in the bottom of water. The relative concentration distribution was also obtained by an absorbance measurement.

2. Experimental Setup

The plasma jet generator was made of a glass tube (OD: 8 mm, ID: 2.5 mm) with wrapped high voltage and grounded electrodes (width: 13 mm) separated by 20 mm on the tube. A high voltage electrode was located at 10 mm from the open end. A sinusoidal 16 $kV_{p\text{-}p}$ high voltage (frequency: 3 kHz) was applied to the electrode. Helium (He) gas was supplied into the glass tube at a flow rate of 5.6 L/min. The visualization reagent inducing iodine-starch reaction (a kind of color reaction) with ROS was prepared before use as a target. This reagent was gelled by adding agarose in order to fix the color reactions. An absorbance proportional to concentration was also measured for the relative ROS concentration distribution. The experiments with water layer on the target were also conducted.

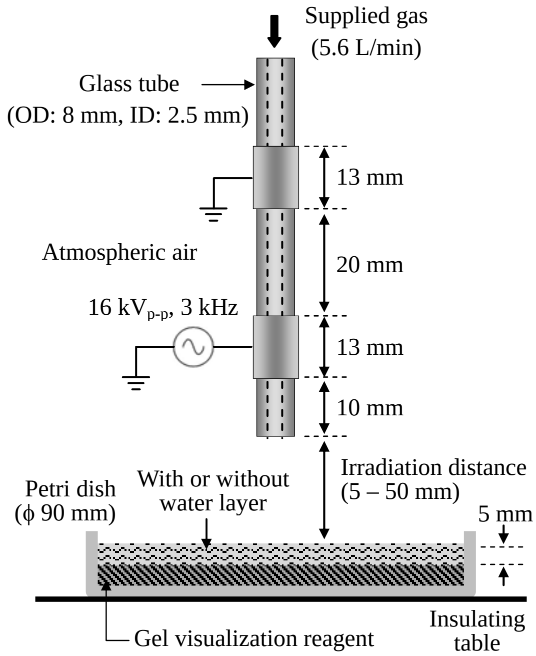

Fig. 1. Schematic diagram of experimental setup.

3. Results and Discussions

Figure 2 shows the influences of the irradiation distance (a) 5 mm, (b) 20 mm and (c) 40 mm on the plasma jet and the resulting ROS distribution. Irradiation time was 10 s. The plasma jet fully reached to the reagent at 5 mm and 20 mm. At 40 mm, only the tip of the plasma jet slightly contacted with the reagent. Such conditions had a great influence on ROS distribution. The visualizations at 5 mm and 20 mm indicate that ROS was radially distributed from the boundary between the plasma jet and surrounding air, with the unreacted area located at the center. Although the results are not shown in this paper, the color reactions are not induced when the plasma jet do not contact to the reagent (irradiation distance is more than about 50 mm). It is assumed that the color reactions in this case are dominantly induced by ROS generated at a contact point between the plasma jet and the reagent with mixing the surrounding air.

Figure 3 shows the relative ROS concentration distribution numerically obtained by an absorbance measurement of the color reactions. The maximum concentration at a distance of 30 mm was about 2.5 times larger than those of 5 mm and 10 mm. It became clear that the concentration distribution of ROS supplied to the target by the plasma jet significantly depends on the irradiation distance.

It is said that the understanding of the behavior of ROS generated by the plasma-water interaction is very important. ROS may be transported with chemical reactions in the water. In this study, ROS distribution in the bottom of water was also studied using the gel visualization reagent underwater. Fig. 4 shows the typical plasma jet irradiated to water and the resulting ROS visualization in the bottom of water. In this presentation, the results on the ROS distribution in the water will be reported in detail.

Acknowledgments

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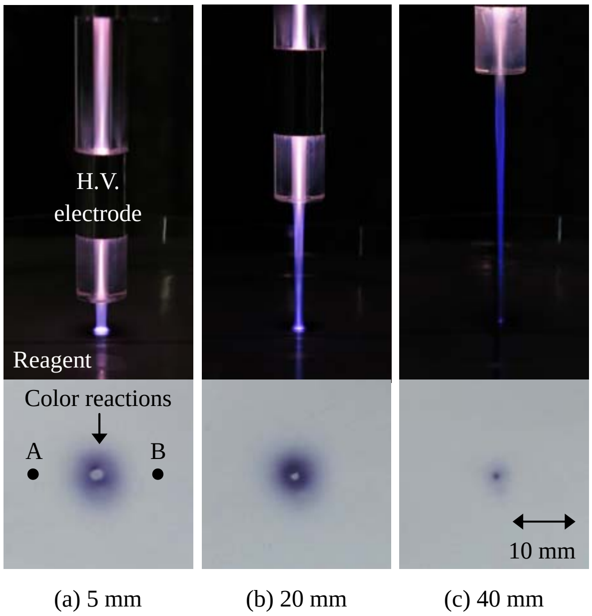

Fig. 2. Influence of the irradiation distance (a) 5 mm, (b) 20 mm and (c) 40 mm on the plasma jet and the resulting ROS distribution. Points A and B are used in Fig. 3.

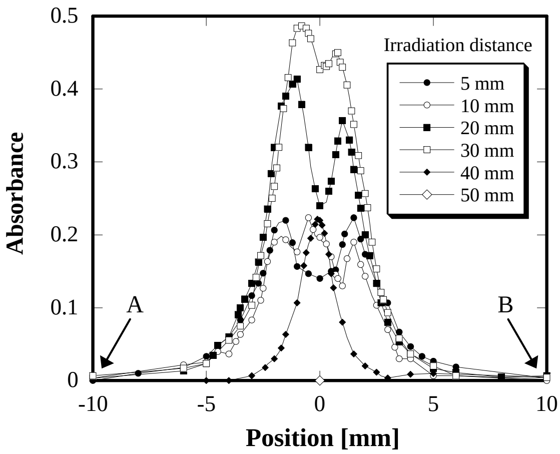

Fig. 3. Relative ROS concentration distribution obtained by an absorbance measurement along the line AB shown in Fig. 2. The center of the contact point by plasma jet is zero point (0 mm).

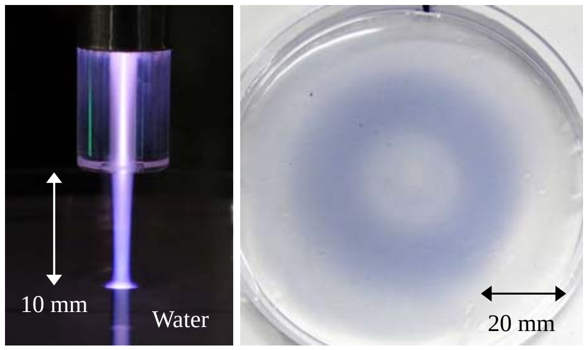

Fig. 4. Plasma jet irradiated to water and the resulting ROS distribution in the bottom of water. The irradiation distance and time were 10 mm and 60 min, respectively.