Analysis of plasma flow at gas-liquid interface for biological interaction

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ABSTRACT

The usage of atmospheric plasma in biomedical applications has become more popular recently. It is important to understand a mechanism of the interaction between plasma discharge and liquid surface because treated substance is often covered by liquid when living tissues are treated. In this paper we briefly demonstrate a gas transport induced by the plasma discharge between a metal electrode and water surface. The measurement shows that the plasma produced a flow toward the water surface and it is important to understand a mixing mechanism between the water and chemically active agents produced by the plasma.

1. Introduction

Research in the field of biomedical applications using low-temperature atmospheric plasmas has received growing attention because such plasmas have a bactericidal/fungicidal property [1-4]. Moreover, the usage of the atmospheric plasma allows us to treat substances which are not resistant to vacuum, e.g. living tissues. Such plasmas can be used in medicine for the living tissue disinfection and regulation of cellular processes as a source of biologically active agents, e.g. reactive species, charged particles and ultraviolet light. It is crucial to understand the interaction between these active agents and living tissues in order to define possible areas of plasma applications and optimize plasma conditions depending on purpose.

As an example, there are requirements for wound disinfection that the plasma should reduce bacteria density and should not give any negative effect on human cell viability. It is important to identify a role of the plasma agents which have different effects on bacteria and mammalian cells in order to design the plasma.

In this study, for the first step, measurements of the interaction between plasma and liquid surface were carried out. In many applications, living tissues are covered with liquid. Therefore, it is beneficial to understand the mechanism of the interaction. In this paper, we concentrate on the measurement of the flow in the gas phase driven by the plasma ignition.

2. Experimental setup

An atmospheric plasma was produced by a principle of ‘dielectric barrier discharge” as shown in fig. 1. The electrode system consists of a platinum rod of 0.3 mm in diameter with a rounded edge, pure water in a glass cell of 10 mm × 20 mm × 8 mm, and an electrically grounded metal plate below the cell. Water of 1.6 ml was poured in the glass cell so that the water level is as high as the height of the cell. The platinum electrode was placed 1 mm above the water surface vertically. By applying high voltage of 7.5 kV_{0p} with square wave at 5 kHz with respect to the electrical ground, the plasma discharge was produced between the tip of the platinum electrode and the water surface. The applied voltage and current were monitored by a voltage monitor on the amplifier and a current probe, respectively. The input power was about 12 W estimated by the Lissajous method. A video image of density gradient in gas was measured using the Schlieren flow visualization technique. This system consists of a video camera, collimators, a knife-edge, and a light source with a pin-hole.

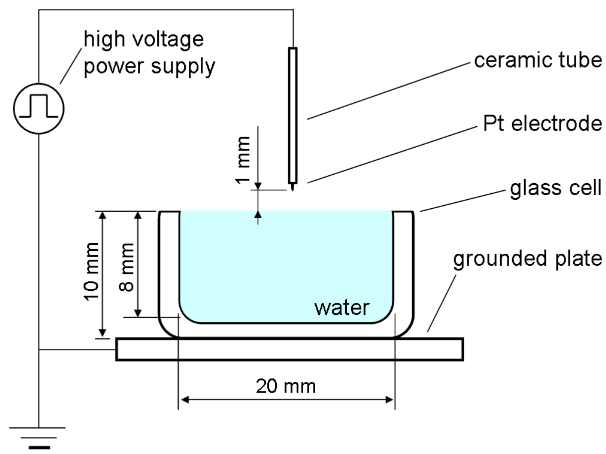

Fig.1. Experimental setup. Pt electrode was placed 1 mm above the water surface and discharge was produced between the Pt electrode and water surface.

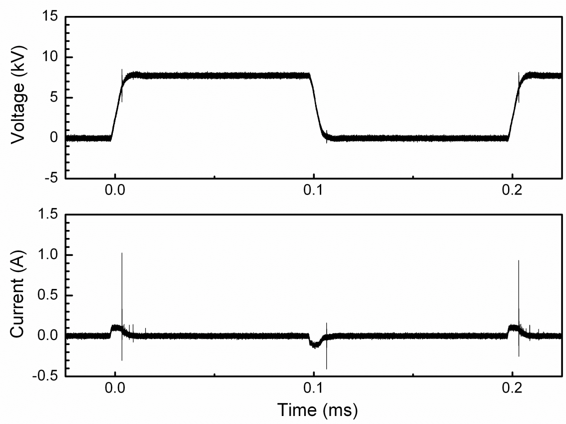

Fig. 2. Typical waveforms of the voltage and current.

3. Experimental Results and Discussion

Typical waveforms of the voltage and current are shown in fig. 2. When the applied voltage reaches the breakdown voltage, the current grows rapidly to ~1 A and the plasma discharge is produced. During the discharge, charge is accumulated on the water surface, terminating the discharge. Due to this termination, the discharge time is limited and the gas is not heated very much. After the high current pulse of ~1 A, small current pulses follow. Theses pulses are mainly due to the discharges between a lower part of the cell and the metal plate. When the applied voltage drops down to 0 V, again a sharp peak in the current waveform was observed.

The Schlieren visualization gives us the density variation in the plasma as shown in fig. 3. Because the signal is very faint, a difference between an image and the previous image was calculated for all the frames in order to emphasize the signal. At t=0 s, the plasma discharge was ignited and every 16 μs the images are shown. In these images a temperature field is shown since the pressure is constant at atmosphere in this experiment. Note that this plasma was produced in an open air at atmosphere. Firstly a hot region in a rod shape between the electrode and water surface was created. Neutral gas in the plasma discharge was heated locally. Following that a hot region in a crescent shape was produced and transported toward the water surface. We suppose that this transport was driven by accelerated ions in the electric field, producing a flow. This flow is quite important because it can induce a flow in the water and affect a mixing of chemically active agents in the water.

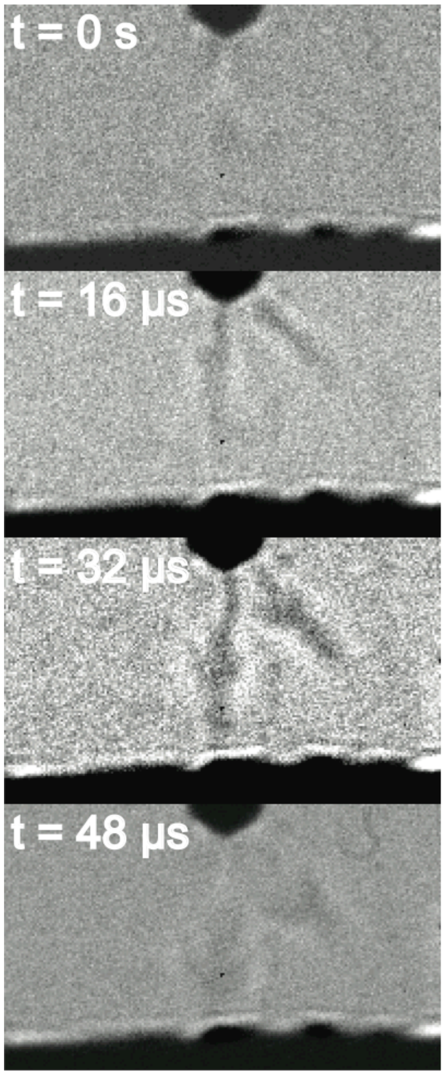

Fig.3. Density variation in the plasma discharge observed using Schlieren visualization technique.

4. Summary

The density variation in the dielectric barrier discharge between the metal electrode and water surface was investigated using the Schlieren visualization technique. The measurement shows that firstly the gas in the plasma discharge was heated locally and afterwards a hot gas region is transported toward the water surface. This transport can produce a flow in the water and enhance a mixing between the water and chemically active agents produced by the plasma. In the next step, we carry out a measurement of flow as well as transport of chemical species in the water.

References

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