Measurement of OH radical in Atmospheric Pressure Plasma Driven by Nano-second Pulsed Power Generator

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1. Introduction

Non-thermal atmospheric pressure plasma has been shown to promote and catalyze various complex behaviors: disinfection, blood coagulation, wound healing, and treatment of cancer tissue [1,2]. In this study, we propose a new direct plasma treatment for living tissue with nanosecond pulsed discharge. The non-thermal plasma is driven by 8 ns and 80 ns of pulse voltage with the inductive energy storage pulse power generator. Hydroxyl radical (OH) distributions as one of radicals, which are considered to play a key role for various medical effects, are measured.

2. Experiment

Figure 1 shows the non-thermal plasma treatment device. The anode consists of a brass round bar of 3 mm diameter with hemispherical tip, and is surrounded by quartz glass tube (ID: 4 mm, OD: 6 mm) to introduce desired gas around discharge region. The cathode consists of an aluminum plate covered by a glass. Humid air (O_2 (21 %)/N_2 mixture, 20% of relative humidity) flows through the glass tube at a rate of 1 liter min^{-1}. The current through the cathode plate is measured for power calculation.

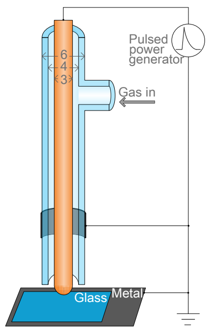

Figure 1: Plasma treatment device

Figure 2 shows two pulse voltage waveforms are shaped by the circuit parameters of the pulse power generator. Maximum values, full-width half maximums (FWHM) and rise times of the voltages are (a) short pulse: 24 kV, 7.6 ns, and 6.4 ns, and (b) long pulse: 24 kV, 80 ns, and 110 ns. The maximum voltage is determined to be between corona inception voltage and breakdown voltage.

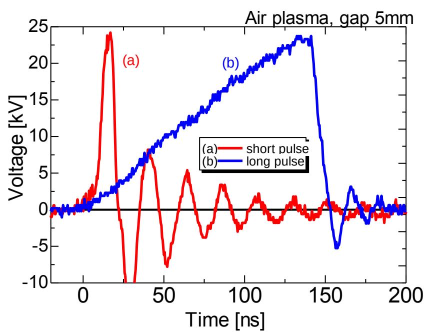

Figure 2: Waveforms of pulsed voltages.

The experimental system of laser induced

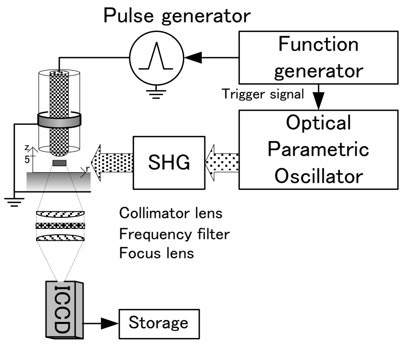

Figure 3: Schematic of experimental system.

fluorescence (LIF) is shown in figure 3. The OPO laser generates 564 nm beams which are converted to 262 nm by second harmonic generation. The incident laser beam is parallel to the glass surface, and its rectangular cross section is 5×3.5 mm^2 sufficiently large to cover the streamer area in the horizontal direction. The fluorescence in collected perpendicularly to the laser beam direction and observed as two-dimensional image by the image intensifier CMOS camera. Two optical high-pass filters (cut-off wavelength: 300 nm) stacked on the band-pass filter is applied to suppress the scatted 282 nm photon. An rz-coordinate is defined, as shown in figure 3, with its origin on the surface of glass. LIF signals depends on OH density is measured with time delay τ=3 μs after the discharge pulse for accurate measurement. Synchronized pulse repetition rate of the discharge and the laser is 10 pulses/s and the signals are averaged for 100 shots.

3. Results and Discussion

Figure 4 shows a general propagation scheme of pulse discharge. After pulse voltage is applied, the string like discharge, named primary streamer starts from the anode and propagates to the cathode [3]. After primary streamer reaches to the cathode, surface discharge remains on the surface and secondary streamer follows along primary streamer channel [4] . Secondary streamer then stops the propagation at the middle of the gap, and its propagation length generally depends on the maximum applied voltages [4]. The delivered radicals convectionally decrease with distance even though large amount of radicals are produced in secondary streamer [5]. The consumed energy by secondary streamer is efficiently utilized to heat the gas inside secondary streamer. Therefore primary streamer and surface discharge as only radical sources which produces and supplies directly at the surface is desirable, while secondary streamer which increase gaseous temperature and harmful byproducts is undesirable.

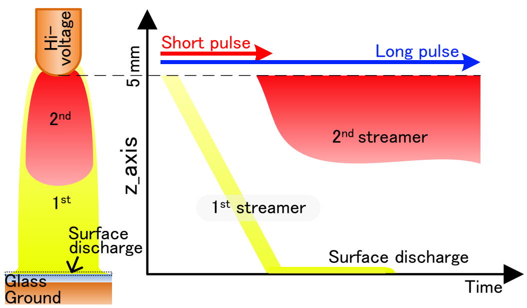

Figure 4: Schematic of discharge propagation with applying pulse voltage.

Figure 5 shows images of N_2-second

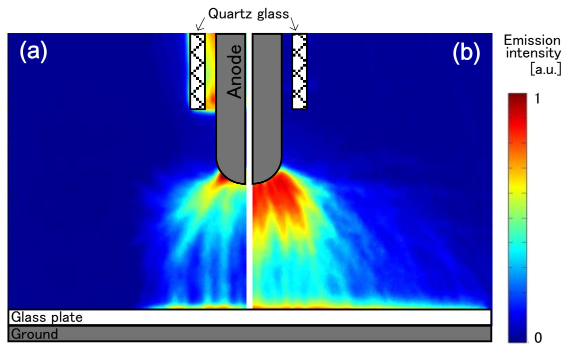

Figure 5: Distribution of N_2-SP emission with (a) short pulse and (b) long pulse.

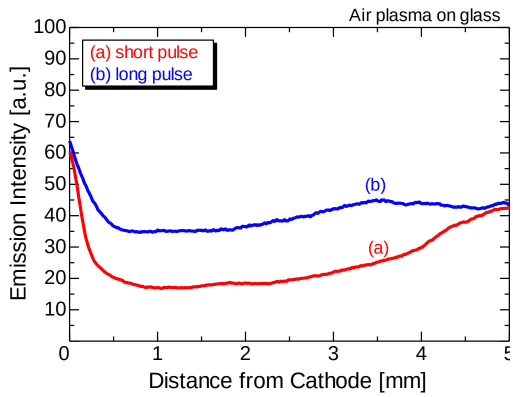

Figure 6: Vertical distribution of N_2-SP emission.

positive emission with applying voltage of (a) short pulse and (b) long pulse. In both images streamers appear between the anode and the glass surface. Discharge on the glass by long pulse spreads longer than by short pulse. Z-axial distribution by horizontally integrating N_2-second positive at each z is shown in figure 6. Emission intensities of around the cathode target surface in the cases of (a) short pulse and (b) long pulse are approximately comparable level, even if the intensity of long pulse is stronger than double for short pulse in middle area. The results are attributed to the difference of propagation length in secondary streamer by pulse width because the short pulse interrupts the propagation of secondary streamer.

Figure 7 shows two dimensional distributions of OH radical. Figure 8 represents z-axial distribution by horizontally integrating OH-LIF signal. The OH distribution in figure 7 seems the same as N_2 emission in figure 5. On the glass surface, OH radicals produced by primary streamer and surface discharge exist in a thin layer of about 0.3 mm. OH radical is generated mainly in secondary streamer channels. In figure 7, the OH production by long pulse is larger than that by short pulse, while the productions on the

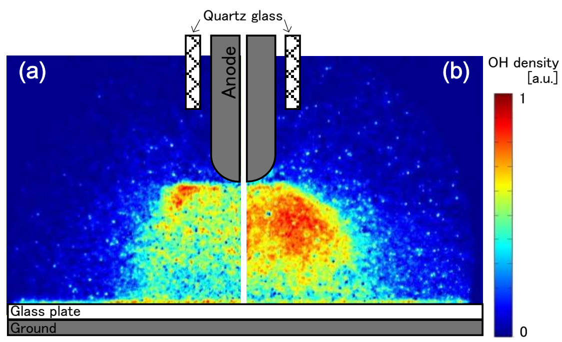

Figure 7: Distribution of OH radicals with (a) short pulse and (b) long pulse.

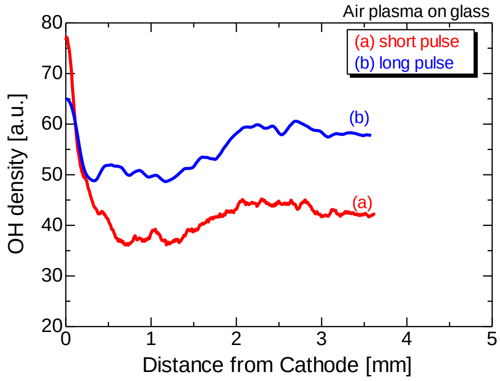

Figure 8: Vertical distribution of OH.

surface are approximately comparable levels. Additionally, the life time of OH radical is considerably short such as 10^{-5}-10^{-4} s. Therefore, the short living species such as OH radical which only generated in immediate proximity to the tissue surface, can be supplied. The nanosecond pulse discharge is available to treat living tissue with short living species and to suppress the surface heating and the byproducts.

Acknowledgments

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