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Effect of UV light on Breakdown Voltage of atmosphere air

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The effect of UV irradiation of electrodes on the discharge starting voltage for arc discharge plasma was studied using a low pressure mercury lamp and an UV-LED. The reduction of breakdown voltage via the photoelectric effect of the low pressure mercury lamp and UV-LED was confirmed because the photon energy of the UV lamps exceed the work function of electrodes. The reduction effects depend on the gas, electrode material electrode shape. The reduction rate of about 30 % was realized in the case of Fe electrodes. Especially, the UV-LED is potential alternative to conventional pre-ignition discharge because it can suppress the total energy consumption of the system drastically.

Key words: Breakdown Voltage, Photoelectric effect, UV light

1. INTRODUCTION

There has been much interest in discharge plasma on the atmospheric pressure due to its potential for pollution control, material processing, surface treatment and biological application [1-8]. In special, sterilization in the atmospheric pressure plasma has been much attention in the medicine field, and there are a lot of researches recent year [1-8].

It is well known that the discharge starts from breakdown of atmospheric air gap between two divergent electrodes under DC or AC power supply. In the atmospheric air, high voltage of several tens kV needs for the breakdown in general, for example, 30kV/cm in uniform electric field. However, sustaining voltage were low after the breakdown. Therefore, one of the key techniques is how to suppress the applied voltage and the power consumption. Almost all gliding arc discharge systems use the assistance of pre-ignition discharge and a resistor for the current limitation which causes the increase of the total power consumption, while, we propose assistance of UV irradiation of electrodes without using a resistor to decrease applied voltage and suppress power consumption due to the photoelectric effect.

In this study, we studied irradiation effect of UV lamps (low pressure mercury lamp, UV LED) on discharge starting voltages which use Fe, Al, and Carbon electrodes in different atmospheric gas of Ar, N_2 and CO_2. In addition, dynamic behavior of the plasmas were observed by high speed camera[9-15].

2. EXPERIMENTAL

Fig. 1 shows schematic diagram of a dynamic measurement system of experimental setup. Two electrodes are made of Fe, Al and Carbon. The shape of the electrodes were knife-shape and sphere. Their shortest gap was 1 mm when effect of UV irradiation on discharge starting voltage was investigated and was 5 mm for high speed camera observation. The electrodes were set inside an acrylic chamber to investigate the influence of gas type. Outlet of a gas supply was placed at the bottom of the acrylic chamber. The gas flow rate was controlled by a digital flow instrument. High voltage (sine wave, 60 Hz) with a high-voltage transformer (VIC international, 120:1) was applied between the two electrodes. The amplitude was adjusted with a voltage slide. Discharge current and voltage waveform was measured by digital oscilloscope (Lecroy WaveRunner 204Xi-A) with clamping a current sensor and a high-voltage probe. A low pressure mercury lamp (Hamamatsu, L937-01) was set in front of the shortest gap of the electrodes as shown in Fig.1(b). Both waveforms of applied voltage and current were captured with a digital oscilloscope Time-resolved digital photographs for plasmas were recorded by a high speed digital camera (DITECT, HAS-D3) with the frame rate of 10,000 frames per second and the effective pixels of 320 x 240. The observation time for the digital oscilloscope and the high speed camera were synchronized by an external trigger signal from a pulsed signal generator (Hamamatsu, C10149).

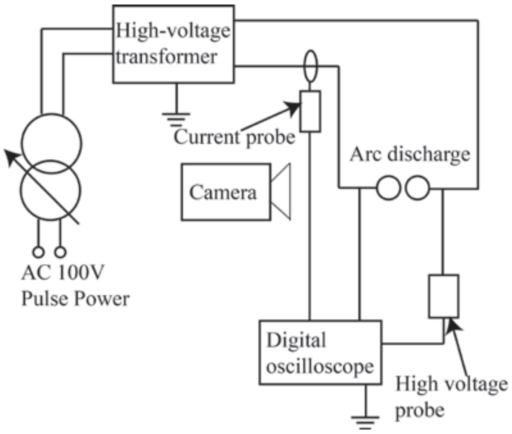

Fig. 1 Experimantal setup.

3. RESULTS AND DISCUSSION

3.1 Effect of the UV light for breakdown voltage

Relationship for phase difference between a low pressure mercury lamp and applied voltage was confirmed comparing waveforms from a photodiode and a high voltage probe. In the case of UV-LED irradiation, the LED was driven under DC power supply.

Fig. 2 shows the effect of the low pressure mercury lamp on breakdown voltage of arc discharge which use Fe electrode in different atmospheric gases of Ar, N_2 and CO_2. The gas flow rate was 10, 15 and 20 L/min. The effect of the gas type on the discharge, the breakdown voltage in Ar was about half of that in N_2 and CO_2 for all electrodes regardless of the low pressure mercury lamp irradiation.

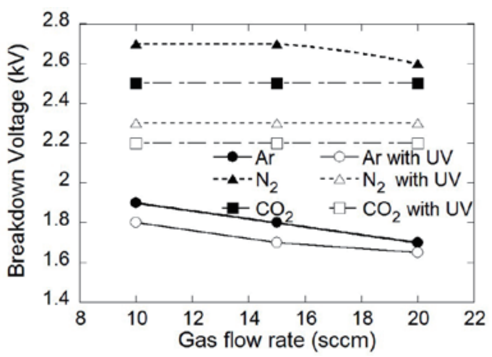

Fig. 2 The effect of the low pressure mercury lamp on breakdown voltage of arc

Dependence of the breakdown voltage on electrode material were shown in Fig. 3. As the results, higher applied voltage was required for Fe without irradiating the low pressure mercury lamp because the work function of Fe is larger than that of Al or Carbon. Because the main spectrum of the low pressure mercury lamp is 254 nm of which the photon energy (4.9 eV) is higher than work function of the electrodes, remarkable reduction of the discharge starting voltage was observed for all electrodes in different gases. The reduction rate of approximately 30 % for the discharge between Fe electrodes was the largest among these three electrodes, the result had relation to the work function of the electrodes.

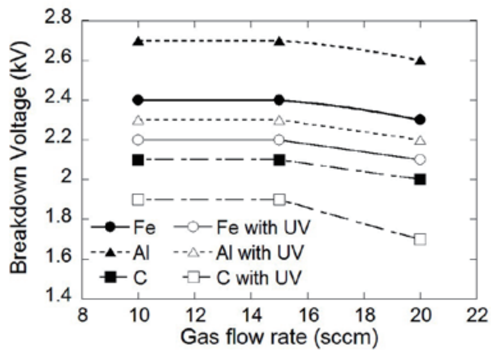

Fig. 3 Dependence of the breakdown voltage on electrode material discharge

Fig. 4 shows breakdown voltage using sphere shape and knife shape electrodes. As the result, breakdown voltages of the sphere shape electrode were higher than that of knife shape. This may be due nonuniform electric field. In addition, breakdown voltages with UV light were lower than that without UV light. The reduction rate of knife shape electrode (20%) were higher than that for sphere shape (10%), however absolute reduction voltage were almost same (~400V).

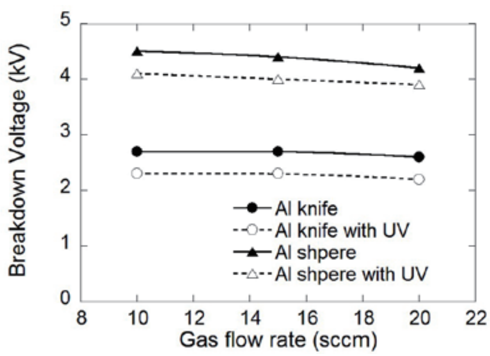

Fig. 4 Breakdown voltage using sphere shape and knife shape electrodes.

The ability of UV LED (260 nm, 150 mW, optical power = 0.3 mW) to decrease the breakdown voltage was also investigated, shown

Fig. 5. As a result, the breakdown voltage was reduced by 20 % with the UV LED irradiation of electrodes though the optical power of the LED is small. It was revealed that the UV irradiation which has higher photon energy compared to the work function of electrode was available to assist the ignition of discharge and to suppress the power consumption of serpentine plasmas, especially the UV-LED is potential alternative to conventional pre-ignition discharge because it can suppress the total energy consumption of the system drastically.

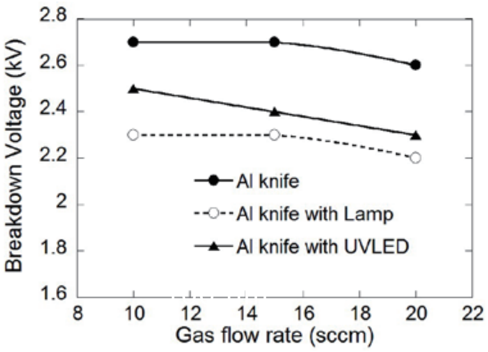

Fig. 5 Deposition rate of the film prepared using powder and bulk targets.

3.2 Dynamic behavior of arc plasma

Simultaneous measurements of the dynamic behavior of plasma and the corresponding electrical property were carried out. Fig. 6 shows waveforms of applied voltage and current during discharges in Ar at the flow rate of 20 L/min. An external signal triggered the measurements at 0 ms. After a breakdown at the shortest gap between electrodes, plasma glides along the direction of the gas flow until the next breakdown at 6.7 ms. Because the plasma path and the impedance increases with gliding, the applied voltage increases gradually with gliding. The applied voltage is recovered when the plasma disappears at around 6.0 ms, subsequently, the next breakdown follows.

Fig. 7 shows high speed camera images during discharges in Ar at the flow rate of 20 L/min. As shown in this figure, reconnections of plasma passes during the gliding are observed at 1.1 ms and 4.9 ms where small and sudden applied voltage drop is confirmed at the same time. Almost no influence of the reconnection on the current waveform is observed since the current probe has little sensitivity to such high frequency current. It is considered that reconnections play an important role to reduce plasma impedance and maintain plasma as long as possible. It was revealed from high speed camera images for various gas flow rate that the incidence of reconnection increased with gas flow rate. A breakdown occurs even at the middle of the electrodes (16.6 ms) when the period of plasma gliding is longer than that of applied voltage because residual ionized seeds around the previous discharge makes generation of next breakdown easier even though the gap becomes wider at the middle of the electrodes. When there is no plasma, no current flows (24.0 ms) until the next breakdown at 25.0 ms. These behavior was observed repeatedly.

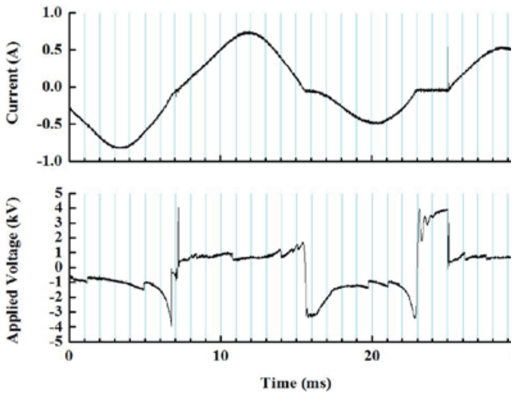

Fig. 6 Waveforms of applied voltage and current during discharges.

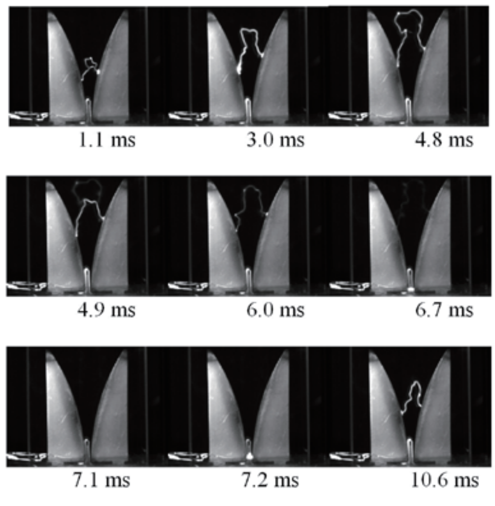

Fig. 7 High speed camera images during discharges

4. CONCLUSION

The effect of UV irradiation of electrodes on the discharge starting voltage for arc discharge plasma was studied using a low pressure mercury lamp and an UV-LED. Moreover, simultaneous observation of time-resolved dynamic behavior and electrical property were also carried out under UV irradiation. The reduction of breakdown voltage via the photoelectric effect of the low pressure mercury lamp and UV-LED was confirmed because the photon energy of the UV lamps exceed the work function of electrodes. The reduction effects depend on the gas, electrode material electrode shape. The reduction rate of about 30 % was realized in the case of Fe electrodes. Especially, the UV-LED is potential alternative to conventional pre-ignition discharge because it can suppress the total energy consumption of the system drastically. For the dynamic observation of plasmas, the applied voltage and current waveforms could be analyzed with the corresponding high speed camera images. Reconnections of plasmas path were observed frequently, which suppressed the increase of plasma path and impedance and maintained plasma as long as possible.

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