Irradiation Effect of UV on Discharge Starting Voltage of Serpentine Plasma

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Abstract: Photoelectric effect of electrodes irradiating an UV lamp is expected to decrease discharge starting voltage of electrical discharges. We propose assistance of UV irradiation without using a resistor for current limitation to decrease applied voltage and suppress power consumption for serpentine plasma. In this work, we studied irradiation effect of a low pressure mercury lamp and UV-LED on discharge starting voltages, electrical property and dynamic behavior of serpentine plasmas which use Fe, Al, and Carbon electrodes.

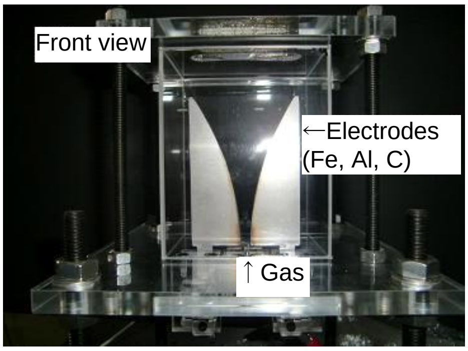
Keywords: Discharge starting voltage, Photoelectric effect, UV-LED, Serpentine plasma

1. Introduction

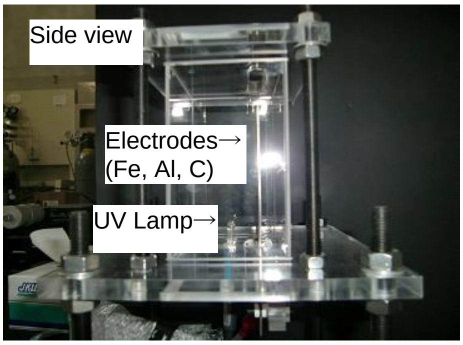
There has been much interest in gliding arc discharge plasma due to its potential for pollution control, material processing, surface treatment and biological application [1-8]. It is well known that the gliding arc discharge starts from breakdown of atmospheric gas at the shortest gap between two divergent electrodes under DC or AC power supply and it glides along the same direction as the gas flow. However, our study on simultaneous observation of the dynamic behavior of the plasma path via a high speed camera and the corresponding electrical properties revealed that the plasma path was very complicated due to gas turbulence and reconnections were repeated especially in high gas flow to maintain plasma. Moreover, the plasma impedance was not as low as that of normal arc discharge because plasma length increased with gliding [9, 10]. Therefore, we call this plasma as serpentine plasma. The serpentine plasma has possibility to realize high electron temperature, high electron density and low gas temperature which no thermal or non-thermal plasma can satisfy. 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 work, we studied irradiation effect of UV lamps (Low pressure mercury lamp, UV LED) on discharge starting voltages, electrical property and dynamic behavior of serpentine plasmas which use Fe, Al, and Carbon electrodes in different atmospheric gas of Ar, N_2 and CO_2.

2. Experimental setup

Fig. 1 shows photographs for (a) front and (b) side views of experimental setup. Two knife edge-shaped electrodes are made of Fe, Al and Carbon. 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) was applied between the two electrodes with a high-voltage transformer (VIC international, 120:1). The amplitude was adjusted with a voltage slide autotransformer (TAMABISHI, S-130-39). The applied voltage waveform during discharge was observed with a high-voltage probe (IWATSU, HV-P60). Discharge current waveform was measured by clamping a current sensor (Tektronix, TCP2020). 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 (Lecroy WaveRunner 204Xi-A) and the high speed camera were synchronized by an external trigger signal from a pulsed signal generator (Hamamatsu, C10149).



(a) Front view



(b) Side view

Fig. 1 Photographs for (a) front and (b) side views of experimental setup.

3. Results and discussion

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. The phase difference of π/2 rad. was given to obtain the maximum irradiation effect on the discharge starting voltage which means breakdown voltage at the shortest gap. On the contrary, almost no irradiation effect was expected when the applied voltage was maximum. In the case of UV-LED irradiation, the LED was driven under DC power supply.

Table 1 shows the effect of the low pressure mercury lamp on discharge starting voltage of serpentine plasmas which use Fe, Al, and Carbon electrodes in different atmospheric gases of Ar, N_2 and CO_2. The gas flow rate was 10, 15 and 20 L/min. For the influence of the gas type on the discharge, the discharge starting 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. For the influence of the kinds of the electrodes, 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. The ability of UV LED (260 nm, 150 mW, optical power = 0.3 mW) to decrease the discharge starting voltage was also investigated. As a result, the discharge starting voltage was reduced by 20 % with the UV LED irradiation of electrodes though the optical power of the LED is quite 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.

Table 1. Effect of a low pressure mercury lamp irradiation on discharge starting voltage for various electrodes, gases and flow rates.

	Lamp	Discharge starting voltage (kV)								
		10 L/min			15 L/min			20 L/min		
		Ar	N_2	CO_2	Ar	N_2	CO_2	Ar	N_2	CO_2
Fe	OFF	1.6	2.4	2.4	1.3	2.4	2.4	1.2	2.4	2.4
	ON	1.1	2.1	2.2	0.9	2.2	2.2	0.9	2.1	2.2
Al	OFF	0.9	2.7	2.5	0.8	2.7	2.5	0.7	2.6	2.5
	ON	0.8	2.3	2.2	0.7	2.3	2.2	0.7	2.3	2.2
C	OFF	0.8	2.1	2.0	0.8	2.1	2.0	0.8	2.1	2.0
	ON	0.6	1.9	1.7	0.6	1.9	1.7	0.6	1.9	1.7

Simultaneous measurements of the dynamic behavior of serpentine plasma and the corresponding electrical property were carried out. Fig. 2 and Fig. 3 show waveforms of applied voltage and current and high speed camera images during discharges in Ar at the flow rate of 20 L/min. An external signal triggered the both measurements at 0 ms. After a breakdown at the shortest gap between electrodes, a serpentine 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. During the gliding, reconnections of serpentine plasma 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. Reconnections can be seen frequently at 10.7, 13.0, 13.9, and 19.7 ms in Fig.3. 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.

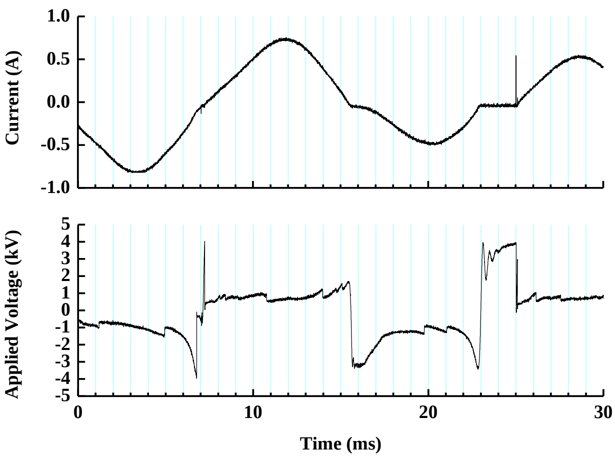


Fig.2 Waveforms of applied voltage and current between electrodes during discharge in Ar (20 L/min.). The waveforms are captured with high speed camera images shown in Fig. 3 simultaneously.

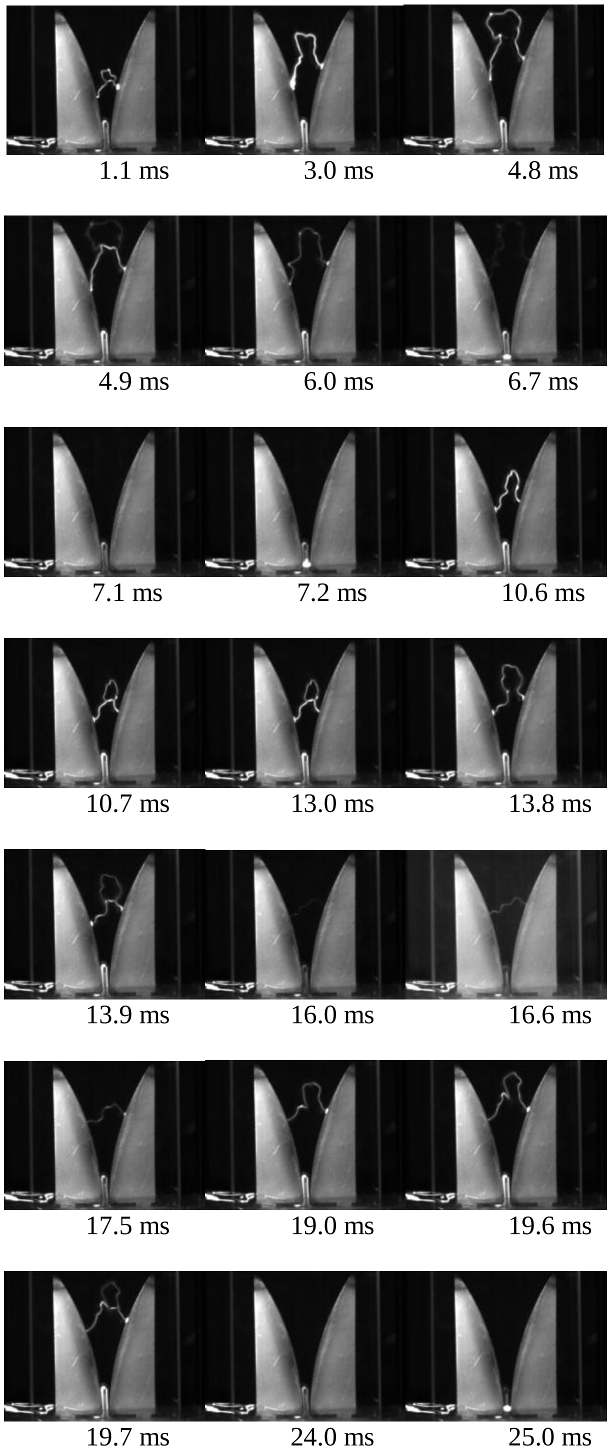


Fig. 3 High speed camera images during discharge in Ar (20 L/min.) synchronized with applied voltage and current measurements. The shortest gap between electrodes is 5 mm. An external trigger is used for simultaneous measurements of applied voltage and the high speed camera. Capturing time for each image corresponds with time in Fig.2.

4. Summary

The effect of UV irradiation of electrodes on the discharge starting voltage for serpentine 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 discharge starting 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 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 serpentine plasmas, the applied voltage and current waveforms could be analyzed with the corresponding high speed camera images. Reconnections of serpentine plasmas were observed frequently, which suppressed the increase of plasma path and impedance and maintained plasma as long as possible. The incidence of reconnections increased with gas flow rate.

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