Gliding arc discharge system integrating UV-LED

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Abstract: The effect of UV-LED (250 nm) irradiation on the discharge starting voltage of gliding arc discharge was investigated by changing irradiation positions and optical power of the UV-LED. Approximately 30 % of reduction rate in discharge starting voltage was confirmed by irradiating UV to at least either one of the bottom edge of electrodes. A practical setup of gliding arc system integrating the UV-LED was also proposed.

Keywords: gliding arc, UV-LED, photo-electric effect.

1. Background

Gliding arc discharge shows a transition in plasma state from thermal to non-thermal along with strong gas flow. The non-thermal state takes very serpentine plasma path repeating reconnection due to gas turbulence, which the authors name serpentine plasma. Generally, the gas temperature as well as the electrode temperature of gliding arc discharge is relatively high compared to other non-thermal plasma because electrical power consumes to make arc plasma at the shortest gap of the electrodes and keep the plasma at upward between the electrodes. Therefore, this type of discharge is suitable for applications such as gas treatment and material synthesis where most of researchers use pre-ignition discharge system to reduce discharge starting voltage and total power consumption. The further reduction of the power consumption of gliding arc discharge is necessary to drawback the thermal limitation of the usage and to apply the non-thermal state for heat sensitive targets. The authors have developed UV assisted gliding arc discharge system using a mercury lamp [1-3] to reduce discharge starting voltage and power consumption by photo-electric effect, however, the lamp consumes high power and emits unnecessary visible spectra without directivity.

In this study, an UV-LED was integrated in gliding arc discharge to reduce total power consumption. The aim of this study is investigating the dependencies of irradiating position, area, and optical power of the UV-LED on discharge starting voltage of gliding arc discharge. Then, the most suitable usage of the UV-LED from the practical point of view was proposed according to the result of the fundamental investigations.

2. Experimental setup

Figure 1 shows an illustration of experimental setup to investigate the influence of the UV-LED irradiation on the discharge starting voltage of gliding arc discharge. The gliding arc discharge system is composed of a pair of iron electrodes, a gas supply, and a chamber. The shortest gap between the electrodes was 3 mm and Ar gas was flowed with a flow rate of 20 L/min. The electrodes were irradiated by the UV-LED (THORLABS, LED250J, 250 nm) through a quartz window of the chamber. The UV-LED has higher photon energy than the work function of the electrodes and emits collimated radiation with an integrated quartz lens which realizes a viewing half angle of 7.5°. The irradiation position and area of the UV-LED are visualized using a fluorescence sheet. The position of the UV-LED was controlled by two position control stages with a spatial resolution of 0.1 mm. The optical power of the UV-LED (0.35 – 0.70 mW) was controlled by a DC power supply and estimated from current. Applied voltage and discharge current were measured with a high voltage probe and current clamp through an oscilloscope. Discharge starting voltage in this study was defined as the amplitude of sinusoidal applied voltage just before breakdown and was estimated using the applied voltage and discharge current waveforms.

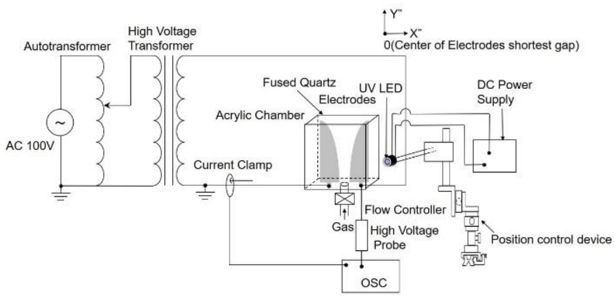

Fig. 1. Setup of gliding arc discharge system to investigate the effect of UV irradiation using LED.

3. Results and discussions

Irradiation position dependency on discharge starting voltages was examined with keeping the irradiation power (0.64 mW) and area of the UV-LED. Each irradiation position was controlled and captured by a normal digital camera. Figure 2 shows an example regarding the visualization of irradiation to the electrodes.

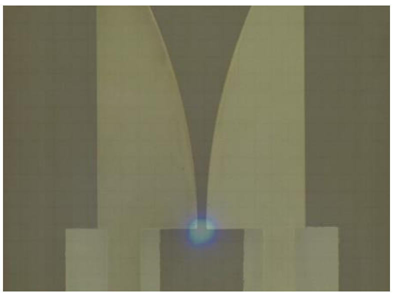

Fig. 2. An example regarding the visualization of position and area of UV irradiation.

The reduction rates of discharge starting voltages at different positons were summarized in Figure 3 where the circles correspond to the actual position and area of UV irradiation and the numbers inside mean the reduction rates of discharge starting voltages in % compared to those without UV irradiation. Each reduction rate was average value among 5 times measurements. It is clearly confirmed from the figure that discharge starting voltages decrease approximately 30 % when the area of UV irradiation ranges at least either one of the bottom edge of the electrodes where breakdown occurs. Even though further outside at the bottom line of the electrodes, 12-14 % reduction rates were confirmed. It is assumed that electrons emitted photo-electric effect from the outside of the electrodes survive and accelerate to the bottom edge due to the concentrated electric field with the strong gas flow. On the other hand, irradiating upward of the electrodes' edge and gap induces no influence on discharge starting voltage as can be imagined.

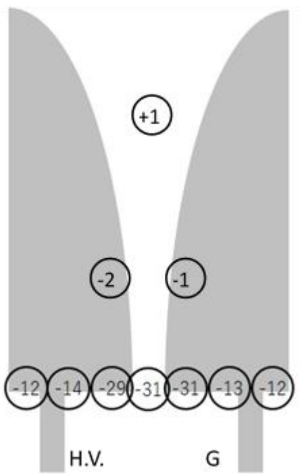

Fig. 3. Reduction rates of discharge starting voltages with UV irradiation at different irradiation positions. The circles correspond to the actual position and area of UV irradiation and the numbers inside mean the reduction rates (%) of discharge starting voltages.

Next, the optical power of the UV-LED was changed to investigate the effect of optical power density and irradiating area of the UV-LED on discharge starting voltage. The position of irradiation center was fixed at the bottom edge of the ground electrode for precise evaluation. The UV irradiated areas on the electrode at different optical powers were estimated by binarizing fluorescence images under a fixed threshold using an image software. Figure 4 shows relationship between discharge starting voltages and the optical power densities of the UV LED measured at different optical powers from 0.35 to 0.7 mW. As can be seen from the figure, the control discharge starting voltage without UV irradiation is approximately 6.5 kV, which decreases with the increase of optical power of the UV-LED, while the optical power densities show almost the same value of approximately 0.012 mW/mm^2 that means the dependence of optical power density can not be examined in this setup. Then, relationship between discharge starting voltages and irradiation areas of UV LED is plotted as shown in Figure 5. The figure shows that irradiating area increases with the optical power and which subsequently decreases the discharge starting voltages. This means the increased irradiation area of the electrode generates more electrons and results in the decrease of discharge starting voltage. However, the influence of the irradiating area is not critical to reduce discharge starting voltage. Therefore, it is concluded that irradiating at least either one of the bottom edge of the electrodes is the most important to reduce discharge starting voltage and irradiating area is not critical compared to irradiating position.

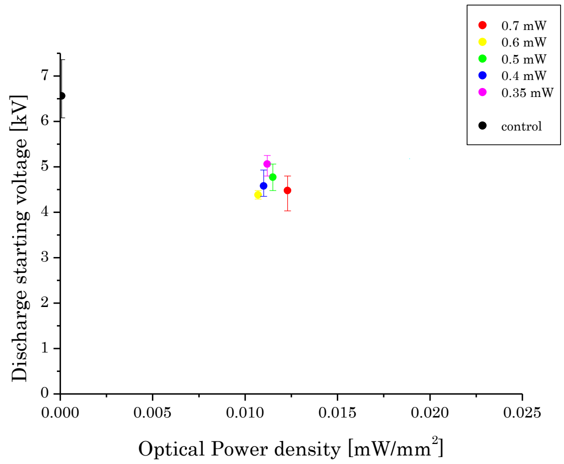

Fig. 4. Relationship between discharge starting voltages and optical power densities of UV LED measured at different optical powers from 0.35 to 0.7 mW.

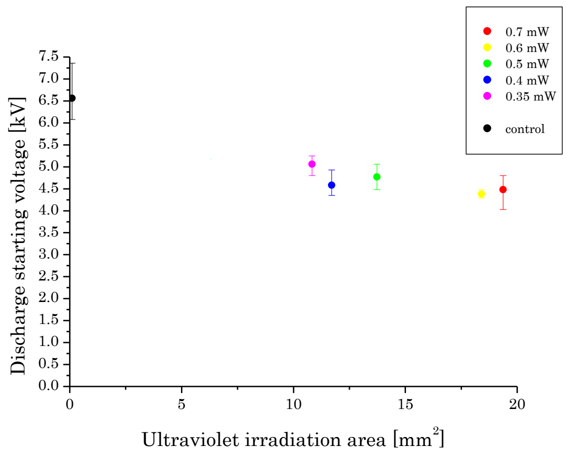

Fig. 5. Relationship between discharge starting voltages and irradiation areas of UV LED measured at different optical powers from 0.35 to 0.7 mW.

According to the above results, the authors developed an improved and more practical gliding arc system integrating the UV-LED. In the system, the UV-LED is included in the gas line and the bottom edge of the electrodes is irradiated from bottom side by using the gas line as a light guide as shown in Figures 6 and 7. Approximately 30 % reduction in discharge starting voltage was also observed in this system. Because a quartz window and the adjustment of irradiating position are not required, the authors consider this kind of system is more suitable for practical usage.

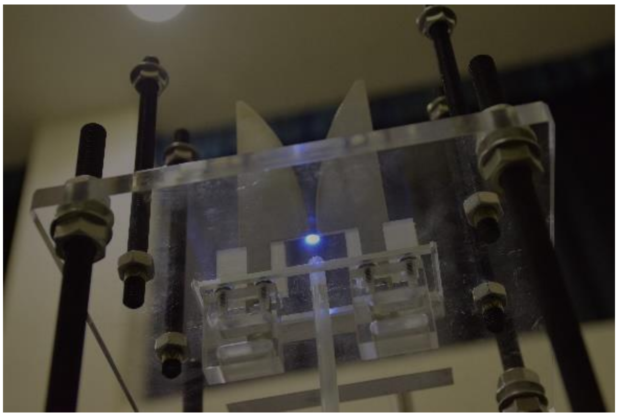

Fig. 6. UV irradiation system using gas supplying line.

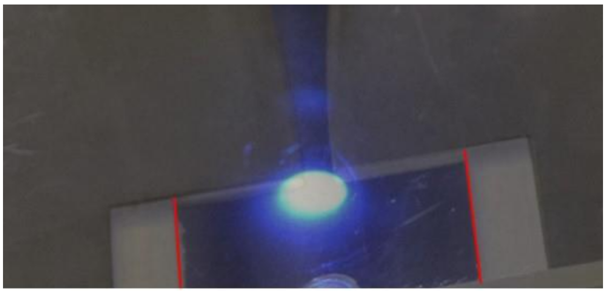

Fig. 7. UV irradiation to the bottom of gliding arc discharge electrodes.

4. Summary

In this study, an UV-LED (250 nm) was integrated into gliding arc discharge system to realize lower power, gas temperature, and electrode temperature for further applications. Approximately 30 % reduction rate in discharge starting voltage was confirmed by the UV irradiation to at least either one of the bottom edge of the electrodes. Optical power dependence was slightly observed because irradiating area increases with the optical power under a fixed optical power density, however, the influence is not so critical. Finally, more practical gliding arc system integrating the UV-LED was proposed, which uses a gas line as optical guide of the UV-LED and showed approximately 30 % discharge starting voltage reduction.

5. References

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