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Efficient Sustainment of a DC Atmospheric Pressure Glow Discharge by use of an Auxiliary Gas Flow in Pin-Plate Electrodes

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Abstract

We investigated experimentally characteristics of an atmospheric pressure glow discharge (APGD) produced by cathode-pin and anode-plate electrodes with a flowing gas between the electrodes. An APGD is sustained by DC voltage applied between these electrodes with main and auxiliary gas flow. The nozzle position of the auxiliary gas flow is varied between the two electrodes. It is found at first time that the glow discharge current increased significantly when the auxiliary nozzle is set near the anode plate. This finding is very important to clarify the mechanism of a flow-stabilized APGD.

1. Introduction

An atmospheric-pressure glow discharge (APGD) provides a non-equilibrium plasma without any vacuum system and is expected to enhance an efficiency in the environmental treatment and material processing.^[1-9] The APGD is usually produced by several methods, such as an AC-biased dielectric barrier discharge^[10], micro-plasma discharge^[11], and flow-stabilized pin-plate discharge.^[12-14] It is one of the simplest APGD plasma production methods to sustain an APGD by using pin-plate electrodes. It is known that the APGD can be maintained by a DC high voltage applied between the pin and plate electrodes, when a gas is forced to flow between the electrodes to prevent a transition from a glow discharge state to an arc one. The roll of the flowing gas in the APGD production, however, is not investigated in detail. Especially, effects of a spatial profile of the gas flow are not clarified yet. In this paper, experimental results are reported on the effects of the main and auxiliary gas flow driven through the discharge region. An attempt to the surface treatment by the APGD plasma is also described.

2. Experimental setup

The experimental setup is shown in Fig.1. The pin-plate electrode system is located in the rectangular gas flow channel. The cross section of the flow channel is 6mm in width and 10mm in height. The cathode pin (0.43mm in diameter) and the anode plate (6mm in width, 85mm in length) are made of stainless steel. The distance between the pin and the plate is fixed at 5mm. A DC high voltage up to 8kV is applied between these electrodes. In this experiment, a main gas flow is driven through the discharge region across the discharge current channel. In order to modify the gas flow field and to investigate effects of gas flow on the sustainment of APGD, an auxiliary gas flow is added to the main flow in a localized region by using a tiny nozzle. The nozzle is 0.8mm in inner diameter and 1.2mm in outer diameter. We can choose air, helium,

argon and their mixture as the main and auxiliary working gases. The nozzle position is varied between the two electrodes. A flow velocity is calculated by using a mass flow rate and the cross section of the flow channel.

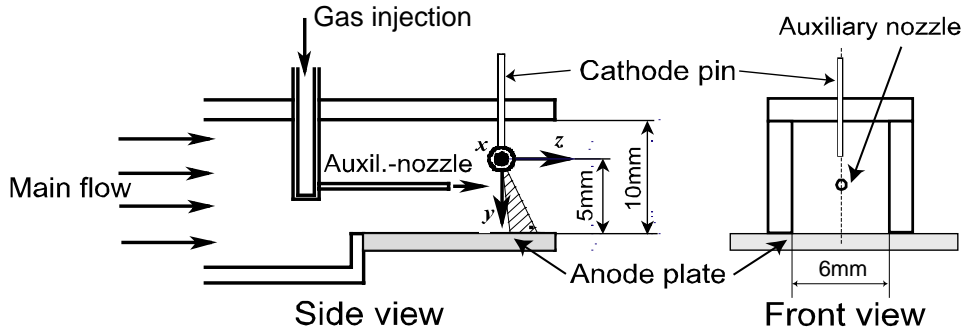


Fig.1. Experimental setup

3. Experimental results and discussion

3-1 Effect of main and auxiliary gas flow on the APGD

Figure 2 shows effects of air gas flow and polarity of the electrode on the discharge. When the pin electrode is biased positively to the plate electrode, a spark discharge suddenly occurs following a corona discharge without any glow discharge state. When the polarity of the electrodes is reversed, a glow discharge at atmospheric pressure (APGD) appears between the electrodes. The APGD is sustained only when the pin-electrode is negative in addition to the main air gas flow. A transition current from a glow discharge to a spark one increases with an increase of the velocity of the main gas flow.

In order to investigate effect of a gas flow profile on the sustainment of APGD, we have added an auxiliary gas flow to the main flow in a localized region between the electrodes by using a tiny nozzle. The tiny nozzle outlet is fixed at 10mm upstream of the pin electrode. An increase of the transition current is observed in a case with the auxiliary gas flow.

When the nozzle position is varied in the vertical direction and is set near the anode plate, the transition current increases remarkably as shown in Fig.3. The higher transition current means that an APGD can be maintained up to a higher density. This result shows that a fast air flow near the anode plate is most effective to maintain a stable APGD with pin-plate electrodes.

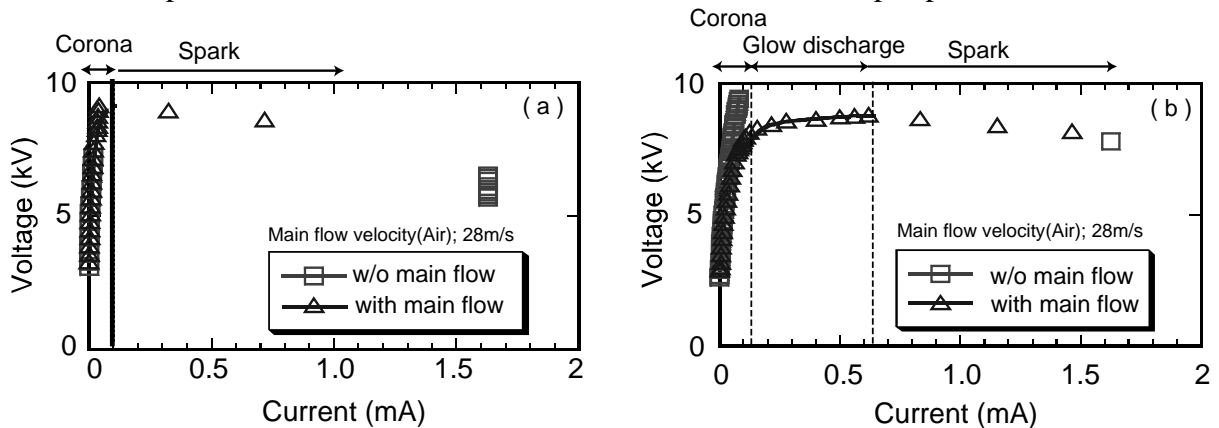


Fig.2 Discharge characteristics in different polarity of the electrodes.

(a) The pin electrode is positive, the plate one is negative.

(b) The pin electrode is negative, the plate one is positive.

Main air flow velocity is fixed at 28 m/s.

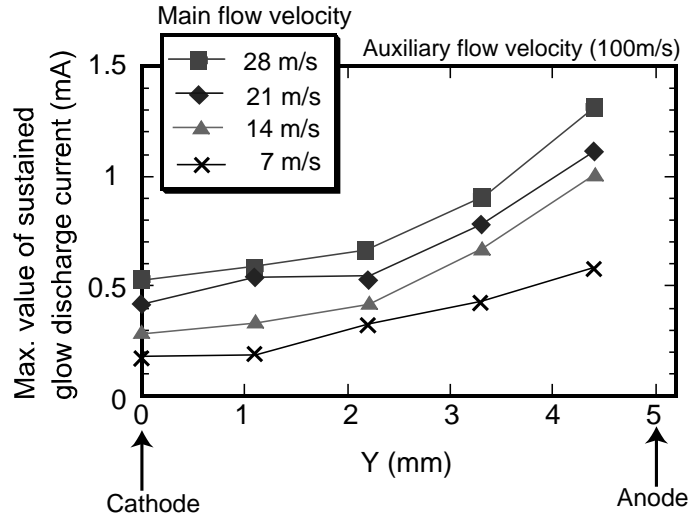


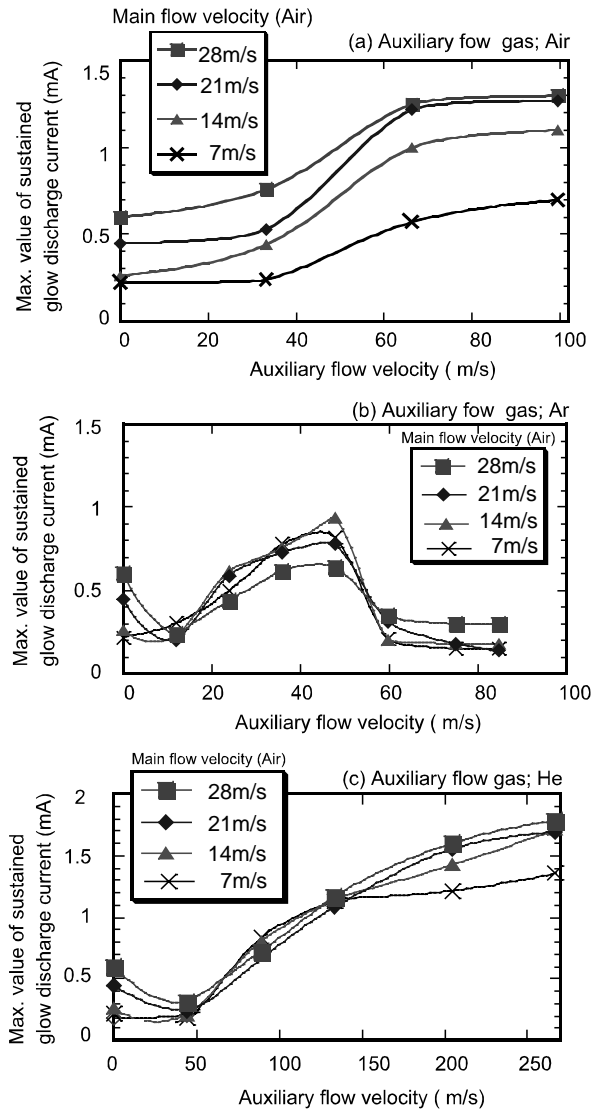
Fig.3 Relations between the position of auxiliary nozzle and the glow discharge current. (Auxiliary flow velocity is fixed at 100m/s. Cathode pin and anode plate are located at $y=0\text{mm}$ and 5mm , respectively.)

Though the auxiliary flow velocity is fast at 100m/s, total amount of the auxiliary gas flow is very low with a few percent of the main gas flow. The maximum current of APGD increases twice by adding the auxiliary gas flow only with the flow rate of 3% of the main flow.

A number of nozzles are arranged parallel to the anode plate surface. The glow discharge current increases as the number of the auxiliary nozzle increases. It is noteworthy that the APGD is maintained without any main gas flow when the number of auxiliary nozzles is increased.

We changed gas species of the auxiliary flow. These experimental results are shown in Fig.4. In these experiments air gas is used as a main gas and air, Ar or He is used as an auxiliary gas, respectively. The auxiliary nozzle is fixed on the anode surface. As the Ar-gas flow velocity increases, the discharge current increases, but it decreases when the flow velocity increases more than 50m/s (Fig.4 (b)). In an auxiliary gas of He, a higher velocity of He gas is necessary to sustain the glow discharge (Fig4(c)).

Fig.4. Dependence of the discharge current on the auxiliary flow velocity. In all cases, the main flowing gas is air. Auxiliary flowing gas species are (a) Air, (b) Ar and (c) He, respectively.



The reason why the localized flow is more effective to sustain the glow discharge is considered to be due to the suppression of thermal instability. It is reported that thermal instability plays an important role in the transition process from a glow discharge to a spark discharge.^[15] An air gas flow between the electrodes reduces an increases of gas temperature associated with the glow discharge and prevents the occurrence of thermal instability. The reason why the most effective position of a gas flow is the anode surface is not well known yet. Further experimental study should be necessary to understand these transition phenomena.

3-2. Application to surface treatment

A surface treatment of a sodium silicate glass is performed as one of applications of the present APGD. These experimental results are shown in Fig. 5. An irradiation of the APGD plasma for a few seconds provides an excellent hydrophilic property on the glass surface. Water contact angles of the treated glass surface are less than a few degrees with only a few seconds of the APGD plasma irradiation time. The treated glass surface keeps this property for several days in the atmospheric circumstance.

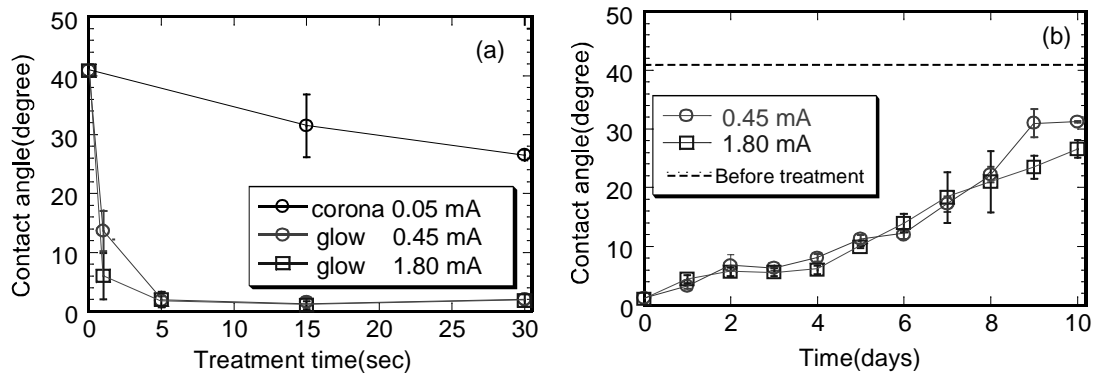


Fig.5 Surface treatment of sodium silicate glass plate by the APGD.
 (a) Effect of the treatment time(The relative humidity is 30%.)
 (b) Daily variation of the hydrophilic property(The relative humidity is 30%.
 The treatment time is one minute.)

4. Conclusion

We investigated experimentally characteristics of the APGD produced by pin-plate electrodes with a gas flow. The glow discharge is sustained by using main and auxiliary air flow across the discharge current channel. The maximum current of the glow discharge increases with an increase at the air flow velocity. The current significantly increases when the auxiliary tiny nozzle is set near the surface of the anode plate and the auxiliary gas flow covers the glow discharge area.

A surface treatment of a sodium silicate glass is performed by using the APGD plasma. An excellent hydrophilic property is observed with only a few seconds irradiation of the plasma and continues for several days.

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