The generation characteristics of dielectric barrier glow discharge plasma in air

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Abstract. This paper focuses on how to suppress filamentous discharge and achieve glow discharge in air. In this study, glow discharge plasma was generated under low pressure by the plate electrode using dielectric barrier. Pulse supply and sinusoidal supply were adopted in this study and their influence on glow discharge were analyzed. Discharge characteristics under different air gap between the electrodes were studied. In addition, we studied the influence of dielectric barrier conditions on the glow discharge. The results show, pulse discharge, shortening the discharge gap and suitable dielectric barrier conditions, can effectively prevent the occurrence of filamentous discharge which contributes to achieve the glow discharge in air.

1. Introduction
Low temperature plasma which is chemically active contains many active particles and has light-emitting property and low temperature [1, 2]. It has a very broad prospect for industrial applications: ozone synthesis, high-power UV and VUV source, industrial waste gas treatment, wastewater treatment [3].

In general, the glow plasma is thought to be stable only in a low pressure, but it is possible to stabilize such a plasma at atmospheric pressure if three simple requirements are fulfilled: (i) use of a source frequency of over 1kHz, (ii) Dielectric barrier discharge (DBD), (iii) use of inert gas which increases costs[4]. Dielectric barrier discharge can weaken γ role and suppress the secondary electron’s emission so that stabilize glow discharge. However, DBD at atmospheric pressure in air appears as filamentous discharge whose inhomogeneity and concentration of energy density limit the prospects of its application in many industrial areas [5, 6]. The difficulty to achieve atmospheric pressure glow discharge (APGD) in air is how to suppress the occurrence of filamentous. This paper discusses how to achieve stable glow discharge in air from three aspects: power waveform, air gap, conditions of dielectric barrier in order to realizing APGD finally.

2. Experimental devices
The structure of experimental system is shown in Figure 1. We have two power supplies: pulse supply creating pulse wave of 30 kHz and 0 ~ ± 5kV whose pulse width is 1μs, sinusoidal supply creating sine wave of 20 kHz and 0 ~ ± 10kV. The electrode is in a reaction chamber which creates a low pressure environment. The discharge voltage is measured by a high voltage probe applied across the electrode and the discharge current is measured by a measurement resistor $R_0$ connected to the electrode. $Z_{eq}$ represents the equivalent resistance of the supply.
The electrode is a pair of plate electrodes made of stainless steel with thickness of 5mm and diameter of 60mm. Figure 2 is a schematic view of the electrode in different blocking mode.

3. The impact of discharge conditions on glow discharge

3.1 Supplies
The experiment was performed at $0.2 \times 10^5$ Pa and the discharge gap was 2mm. We adopted polytetrafluoroethylene (PTFE) material with thickness of 1mm in single-sided block mode. We respectively conducted pulse power discharge and sinusoidal power discharge. The experiment result was shown in Figure 3 and Figure 4.

As we can see from the discharge waveform: pulse discharge generated at 2.8kV and only one maximum crest appeared in each half cycle of current’s waveform, so it belonged to typical glow discharge; sinusoidal discharge generated at 2.4kV and multiple short pulses appeared in each half cycle, so glow discharge had been transformed to filamentous discharge[9].

Compared to sinusoidal discharge, pulse discharge can inhibit the development of the electron avalanche because it reduces the duration of the action of electric field which accelerates charged particles. Electron with smaller mass is accelerated, but ion with larger mass which mainly determine the temperature of plasma is not accelerated. Therefore the $\gamma$ role (secondary electrons emit from the cathode when struck by positive ions) is weakened, the emission of secondary electron is reduced, and then the filamentous discharge is inhibited.
3.2 Air gap
Using pulse supply, the experiment adopted PTFE with thickness of 1mm in single-sided block mode. The distance (d) of air gap ranged from 1mm to 3mm. The breakdown voltage under different air gaps and pressures is shown in Figure 5 and the discharge current when applying 3kV is shown in Figure 6. Figure 7 is the discharge pictures at $0.2 \times 10^5$ Pa under three different air gaps.

![Figure 5. The breakdown voltage](image1)

![Figure 6. Discharge current of different air gaps](image2)

![Figure 7. Discharge pictures at $0.2 \times 10^5$ Pa under three different air gaps](image3)

As we can see from the results, the discharge voltage gradually increased with the rise of air pressure. With the air gap’s decrease, the breakdown voltage and discharge current were both gradually reduced. At $0.2 \times 10^5$ Pa, filamentous discharge appeared evidently between the air gaps of 3mm and was transformed into glow discharge while the air gap decreased to 1mm.

The electric field strength of air gap can be expressed by equation (1):

$$ E_x = \frac{V_{Ed}}{l_d \varepsilon_d + l_s \varepsilon_s} \quad (1) $$

Where, $V$ represents the voltage across the electrodes, $\varepsilon_d$ and $\varepsilon_s$ respectively represents the dielectric constant of the material and the air gap, $l_d$ and $l_s$ respectively represents the thickness of the air gap and the barrier dielectric. The discharge voltage rises with the pressure’s growth which significantly increases the difficulty of discharge under atmospheric pressure [7, 8, and 11]. Against this matter, we can decrease the difficulty of discharge through narrowing the air gap which decreases the discharge voltage when the electric field strength of discharging in air is constant.

Additionally, the discharge channel is shortened when narrowing the air gap and therefore the electron avalanche is restricted. The density of charged particles generated by the electron avalanche is reduced and the discharge current decreases, so that the filamentous discharge is suppressed.

4. Discharge characteristics under different conditions of dielectric barrier

4.1 Material
This experiment used three kinds of dielectric material shown in Figure 8. Keeping other conditions constant, we only changed the dielectric material. The experimental result is shown in Figure 9.
As the experimental results show that, the breakdown voltage in descending order: PTFE > PMMA > Epoxy, the discharge current in descending order: Epoxy > PMMA > PTFE.

The discharge is more difficult when using PTFE as the dielectric. But the filamentous discharge is avoided. PTFE is an electret whose surface is easier to accumulate electric charge and it can significantly reduce the electric field strength of the air gap [5, 10]. So the current is the smallest and the glow discharge can occur through least electrons at the initial stage and will be stable.

4.2 Thickness

In this experiment, we adopted PTFE with different thicknesses: 0.5 mm, 1 mm, 1.5 mm, 2 mm, as the barrier dielectric, keeping other conditions unchanged. Figure 10 is the experimental result.

The experiment results indicated that, the barrier dielectric with the thickness of 2 mm possessed a greater breakdown voltage and exhibited a lower discharge current than that of 0.5 mm and 1 mm.

As the thickness increases, the equivalent capacitive reactance of the dielectric will be greater. Therefore the discharge current is reduced, which is conductive to suppress the filamentous discharge. However, as we can see from the equation (1), the value of voltage required to reach the discharge field strength become higher, so it’s more difficult to achieve glow discharge in air. As the thickness decreases, it’s easier to achieve glow discharge conversely. But the dielectric’s equivalent capacitive reactance decreases and the discharge current increases which is not conducive to suppress the
filamentous discharge. Therefore, a suitable thickness of the dielectric materials is of great significance to generate stable glow discharge plasma.

4.3 Blocking modes
This experiment kept the distance of air gap 1.5 mm and PTFE was adopted as the barrier dielectric with thickness of 2 mm. Discharge data is shown in Figure 11.

The experiment results indicated that, the breakdown voltage in three modes was almost the same. The discharge current was the largest in the middle block mode and the smallest in the double-sided block.

Equation 1 shows that, the total thickness of air gap and barrier is the same in the three blocking modes, so the electric field strength in the air gaps is the same and then the breakdown voltage is almost the same.

As for the middle block mode, γ role exists in the whole cycle, a large number of secondary electrons appear in the gap and so the discharge current is the largest. Compared with single-sided block mode, double-sided block can completely eliminate γ role and secondary electron doesn’t appear which contributing to suppressing filamentous discharge and achieving stable glow discharge.

5. Conclusions
This paper mainly studies the influence of power waveform, air gap and conditions of dielectric barrier on glow discharge. The results show:

1. Pulse discharge shorten the time of electric field and only accelerate electron, thereby suppressing the development of the electron avalanche, reducing the emission of secondary electrons, and then prevent the occurrence of filamentous discharge.

2. Narrowing the air gap can shorten the discharge channel, decrease the discharge voltage and current which contributing to achieving the glow discharge.

3. The electric charges are more easily accumulated on the surface of the dielectric barrier material when electret is selected. So the electric field strength of the air gap is reduced and the filamentous discharge is avoided.

4. If thicker dielectric is used the discharge voltage will increase, but the increase of current also can be avoided. So the suitable thickness contributes to achieving stable glow discharge.

5. Dielectric barrier in double-sided mode can completely avoid the emission of secondary electron which helps to achieve the glow discharge.

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