The discharge characteristics of atmospheric-pressure radio-frequency discharge with and without dielectric barriers

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Abstract In this paper, the characteristics of argon discharge in radio-frequency (RF) atmospheric pressure glow discharges (APGD) and RF dielectric barrier discharges (RF-DBD) have been compared. Discharge characteristics of I-V curves, the optical emission spectrum in Ar discharge were also measured. And the electron density was calculated based on the measurement results.

Key words: atmospheric-pressure plasma, radio-frequency DBD, characteristics

Introduction

Atmospheric pressure glow discharges (APGD) represent one of the hot points in low-temperature plasma physics, primarily because they offer a low voltage and chamber-less route to numerous industrial and biomedical applications. Free from the constraints of a vacuum chamber, APGD can be used to modify surface properties [1], deposition, and ozone generation. In order to get more active particles in atmospheric pressure glow discharge, recently RF-DBD has attracted more and more people attention. [2-5]

Experiment

RF APGD system employs two parallel square copper electrodes, whose area is $10\times10\text{cm}^2$, the surface is bare and cooled by cycle water, and the gas gap is fixed at 1.1mm or 1.64mm. The RF (13.56MHz) supply is powered on bottom electrode and the top electrode is grounded. Teflon spacers are used to seal the gas gap on the both sides.

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The generator is housed within an aluminum box which is grounded and tightly fixed with the matching box. A square hole is leaved in the front of box for viewing and measuring, which is covered by a copper net to shield radio frequency radiation. The current and the voltage across the electrodes were measured by a wide band current probe (Tektronix6021AC), a wide band voltage probe (Tektronix P6015A), and a digital oscilloscope (Tektronix DPO4104). A digital camera (Sony DSC-H5) with exposure time 1/600 s was used to take the images presented in this paper. Optical emission spectrum was obtained using a spectroscopy (Avantes Avaspec 2048) with resolution of 0.12nm and a grating of 1800 or 2400 grooves/mm.

Results and discussion

![Graph showing RMS Current dependence on the RMS applied voltage in the argon atmospheric pressure glow discharge (APGD) without dielectric. The inset photo was taken at the point A.](image)

Figure1. RMS Current dependence on the RMS applied voltage in the argon atmospheric pressure glow discharge (APGD) without dielectric. The inset photo was taken at the point A

Figure1 shows that the current have an initially linear relationship with the applied voltage in different gas gap, both straight lines go through the origin, but the slope of 1.64mm gas gap APGD is greater than that in the smaller gap (1.1mm). They represent the pre-breakdown regime for the two discharges. The reason is that the larger gas gap supplies a larger capacitance and need a higher breakdown voltage. The points after the breakdown show that in relatively smaller gas gap a larger current density was obtained in the same applied voltage. The larger current density can also be observed in the small gas gap before it transfers to γ mode.

From the flowing equation, the electron density can be calculated:

\[ n_e = -\frac{J_{rms}}{e \mu_e E_{plasma}} \]  

More details could see reference [6], where \( J_{rms} \) is the RMS current density, \( e \) is the unit charge; \( \mu_e \) is the electron mobility, which is 0.0458 m²/Vs for argon at 960 hPa [7]. In our work, based on calculation of the
equation (1), the max $n_e$ in 1.1mm gas gap between bare electrodes is $7.375 \times 10^{11}/\text{cm}^3$, and it is $5.962 \times 10^{11}/\text{cm}^3$ in 1.64mm gas gap.

It is worth noting that in the condition of the large gas gap (1.64mm), a stable $\alpha$ mode glow discharge was very difficult to get after the Ar was broken down, it was always discharged in $\alpha$-$\gamma$ coexisting mode. There were two methods to obtain the stable $\alpha$ mode discharge, one was increase the flowing effluent firstly then after stable, the flow effluent was decreased gradually; other way to obtain the stable $\alpha$ mode discharge is to reduce the input power. In Fig.1, the stable $\alpha$ mode discharge at 1.64mm gap was obtained based on the aforementioned methods.

![Figure 2](image)

**Figure 2.** RMS Current dependence on the RMS applied voltage in the argon atmospheric pressure dielectric-barrier discharge (DBD). The inset photo is taken at the point B.

Figure 2 shows RMS Current dependence on the RMS applied voltage in the argon atmospheric pressure RF-DBD. To compare with bare electrodes, the same gas gaps are fixed in the RF DBD. Apparently, because of the added dielectric (quartz, $10 \times 12 \text{cm}^2$, 1.0 mm in thickness, 3.7 in relative permittivity), the maximum RMS currents before transferring to $\gamma$ mode were increased 2.9A and 3A, comparing to 2.0A and 2.5A in bare Cu electrodes in 1.64mm and in 1.1mm gas gap, respectively. The reason is that the dielectric can mitigate plasma constriction in RF-DBD [8]. Under the power limit of the $\alpha$ mode, no mater the dielectric was placed between the electrodes or not, both the current and the voltage exhibited sinusoidal waveforms with the current leading the voltage by more than 80°. It is suggest that there can’t be much filament existing in the discharge. So a large area glow discharge in a higher current density can be obtained by adding the dielectric between electrodes.
Figure 3. Optical emission spectrum of the argon RF APGD in gas gap 1.1mm, and input power 40w

Optical emission spectrum measurement was also performed in Ar RF APGD in gas gap 1.1mm, and input power 40w as shown in Fig.3. It is noticed that some atomic oxygen lines can be seen at 777nm and 844nm. This is because the discharge generated in the atmospheric environment, oxygen and nitrogen atoms in the air can diffused into the discharge area.

Figure 4. Dependence of relative line intensity at 706nm, 738nm, 751nm and 794nm for Ar I on the input power with and without dielectric between electrodes, gas gap 1.1mm, Ar 2slpm

Figure 4 show that almost all the relative intensity of argon atomic lines were increase with the increase of input power, and the slop of all four lines in DBD and bare Cu are identical. But there still exist some differences between the curves, and in RF DBD the intensities were always higher and rising faster than that in bare Cu electrodes. It means that the adding dielectric barriers shall be benefit for more active particle generations.
Conclusion

In conclusion, we demonstrated that the introduction of dielectric barriers can critically enable the generation of large-area and stable RF glow discharges in atmospheric argon over a large range of the discharge current. Calculated results show that a larger current density can be gotten in the small gas gap. The results of optical emission spectrum show that RF-DBD can generate more active chemistry particles, which shall be very useful for plasma chemical reaction.

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References