Experimental Study on Direct-current Arc Discharge Characteristics in Low-pressure Condition

R.H. Wu , S. Chai, J.Q. Liu, X. Liu, J.Y. Zhao, G. Meng, Y.N. Li and J. Li

National Key Laboratory of Science and Technology on Test Physics & Numerical Mathematics, Beijing, China

Abstract: This paper focuses on the experiment and its results analysis of direct-current (DC) arc discharge in a low-pressure environment. The experimental results show that the electron density can reach $10^{14}cm^{-3}$-$10^{15}cm^{-3}$ if the discharge voltage is from 10V to 20V and the discharge current changes between 150A and 300A under the low pressure(100–1000Pa); when the discharge current is above 300A, the plasma electron density is able to $10^{15}cm^{-3}$ or more.

Keywords: Low-pressure, DC arc discharge, electron density, experimental study

1.Introduction

Arc plasma generators are widely used in waste treatment, nanomaterials preparation, refractory metal material purification, high temperature welding, cutting, spraying, metallurgy and aerospace [1-6], and they have the significant socio-economic and military benefits. The main characteristics of arc plasma are high electron density, great power, adjustable current and voltage between the cathode and anode, etc. Under different application modes, the above parameters of arc plasma are different, which is related to arc plasma generator. Therefore, it is of great significance to study the arc plasma generator. In this paper, a DC arc discharge plasma generator was experimented in the low-pressure chamber. The results of the electron density varied with the discharge current and voltage were obtained.

2.Fundamental Theory

DC arc discharge has the characteristics of low voltage (ten volts to tens of volts), high current (several hundred amps to thousands of amps), and high electron density ($10^{14}cm^{-3}$ to $10^{15}cm^{-3}$). DC arc discharge circuit mainly includes two parts of power supply and discharge area (in Fig. 1). In Fig. 1, the power supply voltage is U_0, the internal resistance of the power supply is R_1, the voltage between the anode and cathode is U,. the plasma resistance is R_p and the discharge loop current is I. When the DC voltage between the anode and cathode is greater than the breakdown voltage of the working gas, the gas will be ionized, and plasma is generated.

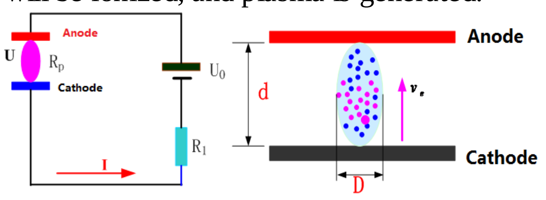

Fig. 1. Schematic diagram of DC arc discharge.

It can be seen from Fig. 1 that the relationship between the discharge current and the discharge voltage is as follows:

$$I = \frac{U}{R_p} \tag{1}$$

Where I is the discharge current, U is the discharge voltage, and R_p is the plasma resistance. According to the original definition of the resistance, the expression of R_p is:

$$R_p = \rho \frac{d}{\Delta S} \tag{2}$$

Where d is the plasma arc length, ΔS is the plasma cross-sectional area, and ρ is the resistivity, which is inversely related to the electrical conductivity σ, that is $\rho = \frac{1}{\sigma}$.The electrical conductivity σ is expressed as follows [7]:

$$\sigma = 2.26\times10^{-12}\frac{\bar{\lambda} n_e}{\sqrt{T_e}} = 2.26\times10^{-12}\frac{n_e}{nS(v)\sqrt{T_e}} \tag{3}$$

Where n is the total particle number density, $\bar{\lambda} = \frac{1}{nS(v)}$ is the mean free path and S(v) is the collision scattering cross section. The combined formula (1) to formula (3) can be obtained:

$$I = 2.26\times10^{-12}\frac{U\Delta S n_e}{nS(v)d\sqrt{T_e}} \tag{4}$$

It can be seen that when the DC arc discharge voltage is determined, the DC discharge current is proportional to the electron density, that is, the greater the electron density, the higher the discharge current.

3.Experimental method

As shown in Fig. 2, the experiment was done in a low-pressure closed chamber with a horizontal cylindrical shape, the container is Φ1.5×2.5m. The experimental anode and cathode are cylindrical metal with the size from Φ5mm to Φ10mm. The space between anode and cathode can be adjusted from 1mm to10mm. The output voltage of the DC power supply is able to regulate from 0 to 50V, and the maximum output current is 500A. When the vacuum of the closed container is better than 10^{-2}Pa, the power supply is turned on, the working gas is filled in vacuum chamber and ionized when the pressure is from 100 Pa to 1000 Pa. During discharge, the data acquisition system is used to obtain the discharge current and voltage, the electrostatic probe measurement system is obtained the plasma electron density, and the camera system is recorded the whole discharge process.

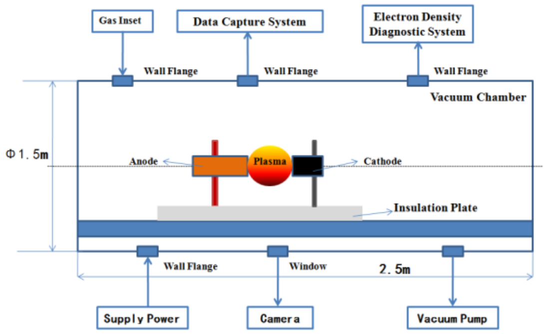

Fig. 2 Schematic diagram of DC arc discharge plasma generation experiment and measurement method.

4. Experimental conclusions

The experimental results are shown that 1) a high current pulse is formed at the moment of arcing of the working gas, and then the current drops rapidly, and the working gas flow is in an unstable state; 2)the discharge current increases with the increase of the working gas flow;3) after the gas flow reaches dynamic stability, the discharge current and discharge voltage tend to be equilibrium state, the electron density also tends to be stable state: under the low pressure(100−1000Pa), when the discharge voltage is from 10V to 20V and the discharge current is between 150A and 300A, the electron density is from $10^{14}cm^{-3}$ to $10^{15}cm^{-3}$; when the discharge current is above 300A, the plasma electron density can reach to $10^{15}cm^{-3}$ or more. According to different applications, we can select suitable discharge parameters in order to achieve various application purposes.

5.Acknowledgments

The authors gratefully acknowledge the support from the National Natural Science Foundation of China under Grant No. 61302029, Grant No. 61571031, Grant No. 61671044 and Grant No.61871018.

6.References.

[1] D. Mueller, M.G. Bell, J. Chrzanowski et al, Princeton Plasma Physics Laboratory Report Disclaimers, PPPL-4302, March, 2008.
[2] H. Zhang, G.Q Wu, H.P Li et al, IEEE Transactions on Plasma Science, **37**, 7 (2009).
[3] H. Nishiyama , K. Tsuri, H. Shimizu et al, International Journal of Heat and Mass Transfer, **52** (2009) .
[4] A.V. Vizir, E.M. Oks, M.V. Shandrikov et al, The 17th Int. Symp. on Discharges and Electrical Insulation in Vacuum, Suzhou , 2016.
[5] A.S. Anshakov, E.K. Urbakh, S.I. Radko et al, Thermophysics and Aeromechanics, **22**, 1(2015).
[6] Martin Rott, Christian Artelt, and Till Höschen, IEEE Transactions on Magnetics, **41**, 1(2005).
[7] A. Pascal, B. William, Plasma Science and Technology, **8**, (2016).