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Glow and pseudo-glow discharges in a surface discharge generator*

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The glow discharge in flowing argon at one atmospheric pressure is realized in a surface discharge generator. The discharge current presents one peak per half-cycle of the applied voltage. The duration of the discharge pulse is more than 1μs when the frequency of the applied voltage is 60kHz. For the glow discharge in argon, the power consumption increases with the increase of voltage or the decrease of gas pressure. This relation is explained qualitatively based on the theory of the Townsend breakdown mechanism. In contrast, the discharge current in one atmospheric pressure air gives many spikes in each half-cycle, and correspondingly this kind of discharge is called pseudo-glow discharge. Every current spike oscillates with high-frequency damping. The pseudo-glow discharge in one atmospheric pressure air might result from the streamer breakdown mechanism.

Keywords: atmospheric pressure glow discharge, pseudo-glow, Lissajous figure
PACC: 5280H, 5280P

1. Introduction

Experimental and theoretical studies of one atmospheric pressure discharge are motivated by its numerous potential applications such as thin-film deposition,[1−3] surface treatment,[4] the reduction of thin oxide layers, ozone formation, and the sterilization of biological samples.[5] The discharge at one atmospheric pressure appears usually in the form of many very rapid, randomly distributed narrow current filaments, but the atmospheric pressure glow discharge seems to win an advantage over the filamentary discharge in such applications with a requirement for uniform plasma as the deposition of uniform thin films or the surface treatment.[6] In the filamentary discharge mode, intensive high-density spots on the surface can result in inhomogeneous treatment or even cause local damage in the deposited thin film. Therefore, in the case of a uniform surface treatment or thin-film deposition, a homogeneous discharge is very desirous.[7] During the past decade, it has been demonstrated that atmospheric pressure glow discharge can be generated in the volume discharge in a dielectric barrier discharge generator under certain conditions,[8,9] but there are few reports about atmospheric pressure glow discharge produced by the surface discharge generator.[10,11]

In this paper, we report the features of atmospheric pressure glow discharge in flowing argon. Electrical and optical measurements are used to characterize this discharge. In order to well understand the surface discharge, the pseudo-glow in one atmospheric pressure air is also investigated with the same experimental setup.

2. Experimental setup

The experimental apparatus with simplified surface discharge configuration is schematically shown in Fig.1. One stripe with a width of 1mm and length of 30mm is covered on a rectangular ceramic dielectric plate (36mm×16mm) with a thickness of 1mm, the other side of the dielectric plate is a rectangular metallic layer (25mm×9mm). The stripe electrode is covered with a protective dielectric layer. An ac power supply with a maximum peak voltage of 10kV at a frequency of 60kHz is connected with the rectangular metallic electrode. A high voltage probe (Tektronix P6015A, 1000X) is used to measure the applied

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voltage. The discharge current is measured through a small resistor (R=50Ω) in series with the grounded electrode. When the charges flowing in the discharge are to the measured, the resistor is replaced by a capacitor (5600pf). The light emitted from the discharge is detected by two photomultiplier tubes (Hamamatsu H7826-01) which are placed in the imaging plane of a lens, and recorded with an oscilloscope (Tektronix TDS3054, 500MHz). A digital camera (Canon Powershot G1: 1024×768 pixels, minimum exposure time 1ms) is used to record images of the discharge. The chamber is evacuated to the limit vacuum by a mechanic pump, and then filled with argon. The gas pressure can be controlled in 1 atm by adjusting the pumping speed.

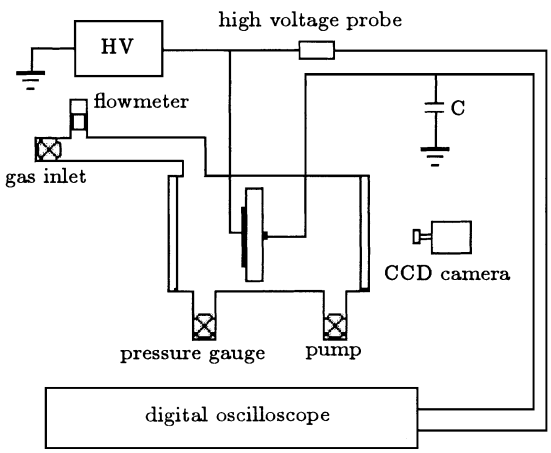


Fig.1. Experimental setup.

3. Results and discussion

Raising the voltage of the power supply, a homogeneous discharge can be realized in argon, and no filaments can be discerned in this discharge, as shown in Fig.2(a). The discharge is very diffuse and almost covers the whole plane electrode. In contrast, the discharge in air under the same experimental condition is restricted in a narrow region near the stripe electrode, as shown in Fig.2(b). In addition, the colour of the discharge is different in different gases: it is purple in air discharge, but white in argon discharge. The peak value of the applied voltage U is 1400V and the exposure time is 10^{-3}s.

The conventional atmospheric pressure glow discharge indicates that only one current pulse appears during each half-cycle of the applied voltage.[12] A group of typical oscillograms of the voltage, the current and the light emission from this homogeneous discharge is shown in Fig.3. It is obvious that the current has only one peak per half-cycle, from which we can conclude that the atmospheric pressure glow discharge is realized in our experiment.

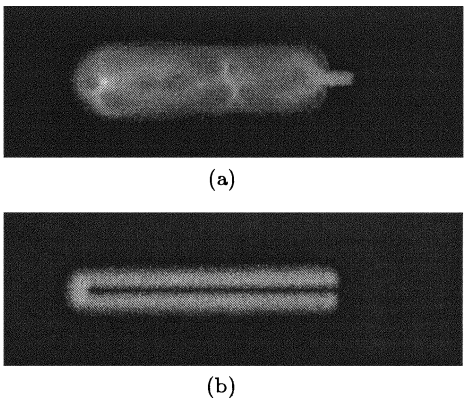


Fig.2. Glow and pseudo-glow discharges respectively in (a) argon and (b) air under atmospheric pressure (U=1400V and t_{exp}=10^{-3}s).

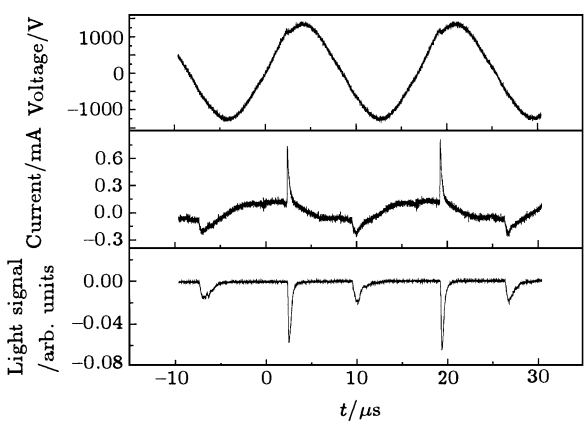


Fig.3. Applied voltage, total discharge current and light signal waveforms in atmospheric glow surface discharge in flowing argon.

During the discharge current pulse, charges accumulated on the dielectric can reduce the net electric field and lead to the extinction of the discharge. In the next half-cycle, the voltage reverses and a current pulse of opposite polarity appears when the net electric field exceeds the breakdown threshold. Under our experimental condition, the durations of discharge current pulses are found to be different in the positive and negative half-cycles. The pulse duration is a little more than 1μs in the positive half-cycle, but it is about 2μs in the negative half-cycle. Furthermore, their amplitudes are also different in the two half-cycles as shown in Fig.3. These differences in pulse duration and amplitude between the two different half-cycles might result from the asymmetric configurations of the electrodes.

With the voltage increasing continuously, two or more peaks appear per half-cycle of the applied voltage. The number of discharge current pulses in the first quarter of each half-cycle increases with applied voltage. When the applied voltage further increases, the leading discharge pulse, followed by a few of the most proximate adjacent discrete pulses in the discharge sequence, begins to gradually shift (with respect to the phase of the applied voltage wave) towards the zero voltage and finally enters into the preceding half-cycle. The discharge seems to be still homogenous, therefore a high-speed camera is necessary to be used to distinguish the types of the discharges.

A Lissajous figure can be used to measure the power consumption in the discharge. By calculating the area enclosed by the curve, the power consumption for glow discharge in argon can be obtained. The variations of power consumption with voltage and pressure are shown in Fig.4 and Fig.5, respectively. It is shown in Fig.4 that the power consumption is fairly low before the gas breakdown, but increases abruptly when the voltage reaches the breakdown threshold (1400V), and still increases with the increase of applied voltage after the gas breakdown. However, when the voltage decreases down to the breakdown threshold the discharge is still maintained and it is not extinguished until the voltage is below 1000V. It is obviously shown in Fig.5 that the power consumption increases with decreasing pressure when the applied voltage is kept constant.

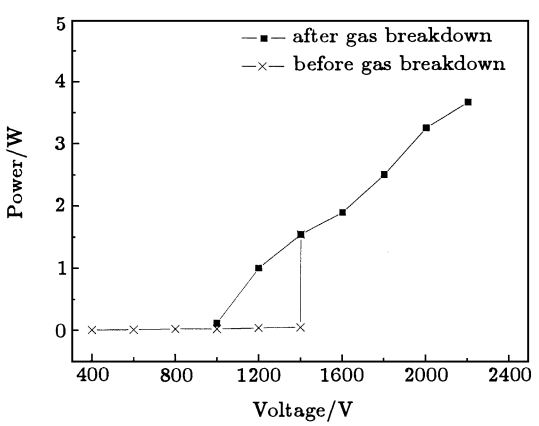


Fig.4. Relation between applied voltage and power consumption in surface discharge in argon when the gas pressure is kept constant.

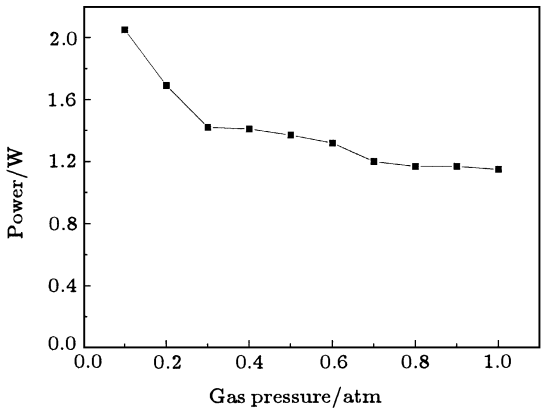


Fig.5. Dependence of power consumption on argon pressure when the applied voltage is kept constant.

The physical meaning of power consumption related to the voltage and the pressure can be explained below. The net electric field to sustain the discharge at one atmospheric pressure is constant. Therefore, when the voltage is increased more charges should be transported to and accumulated on the dielectric plate so that the discharge can be extinguished in each half-cycle. Transportation of charges between the two electrodes would consume some energy; the more charges are transported, the more energy will be consumed in the discharge. Consequently, the power consumption increases with the voltage increasing. The relationship between power consumption and voltage can also be explained from the duty ratio of discharge current. As mentioned above, at a constant frequency, the number of discharge current pulses in the first quarter of each half-cycle increases with applied voltage, that is to say, the duty ratio of discharge current increases with the increase of applied voltage. The power consumption also increases with duty ratio, consequently, the power consumption increases with voltage. When the voltage is kept constant but the gas pressure is decreased, both the threshold of electric field for gas breakdown and the sustaining electric field may be decreased according to the theory of Townsend breakdown, so more charges should transport between the electrodes in each half-cycle. Accordingly, the power consumption will increase when the pressure decreases.

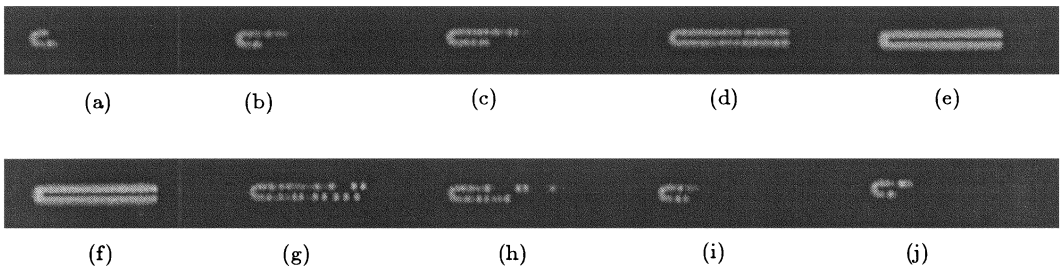


Fig.6. Surface discharge in one atmospheric pressure air under different voltages, from (a) to (e) the voltage is increasing from 1300 to 1400V, and from (f) to (j) the voltage is decreasing from 1400 to 1300V.

When the working gas is air at very low pressure (for example, 1.33×10^3Pa), its discharge current waveform is similar to that in one atmospheric pressure argon. However, the type of discharge in one atmospheric pressure air is quite different from that in one atmospheric pressure argon. Raising the voltage of power supply slowly, the discharge can be ignited in one atmospheric pressure air when the electric field reaches the threshold. When the voltage is slightly above the threshold, the discharge does not take place on the whole area, as shown in Fig.6. This phenomenon results from the stronger electric field near the tip of the stripe electrode. Further increase the voltage slowly, the discharge will soon take place on the whole area near the stripe electrode. The discharge shown in Fig.6(e) looks also homogeneous. As the voltage decreases, the discharge disappears little by little as shown from Fig.6(f) to Fig.6(j). In Fig.6, filaments can be easily seen and the colour of the discharge is light purple, but it is white in argon discharge.

The voltage and current waveforms in one atmospheric pressure air discharge with homogeneous features are shown in Fig.7(a). It is obvious that the sinusoidal current waveform are superimposed with many spikes that correspond to the discharge currents of different filaments, and the sinusoidal part of current results from the capacitance of the surface discharge generator. The amplitude of current in air discharge is much larger than that in argon discharge as shown in Fig.3. Figure 7(b) shows the magnification of part of the discharge current. The discharge current is of damping oscillation with a period of about 20ns. The duration of the filament current should be about 20ns. In such a short time, the ions almost keep stationary, so the discharge cannot be explained by the Townsend breakdown theory. Actually, the threshold field for breakdown in one atmospheric pressure air is quite high, therefore the electron avalanche develops very rapidly and the electron density at the head of the avalanche reaches a threshold value very quickly. The strong electric field near the head of the avalanche leads to the formation of a streamer discharge. Therefore, the discharge is not uniform in space microscopically because it consists of many narrow discharge filaments, though it seems to be homogeneous macroscopically.

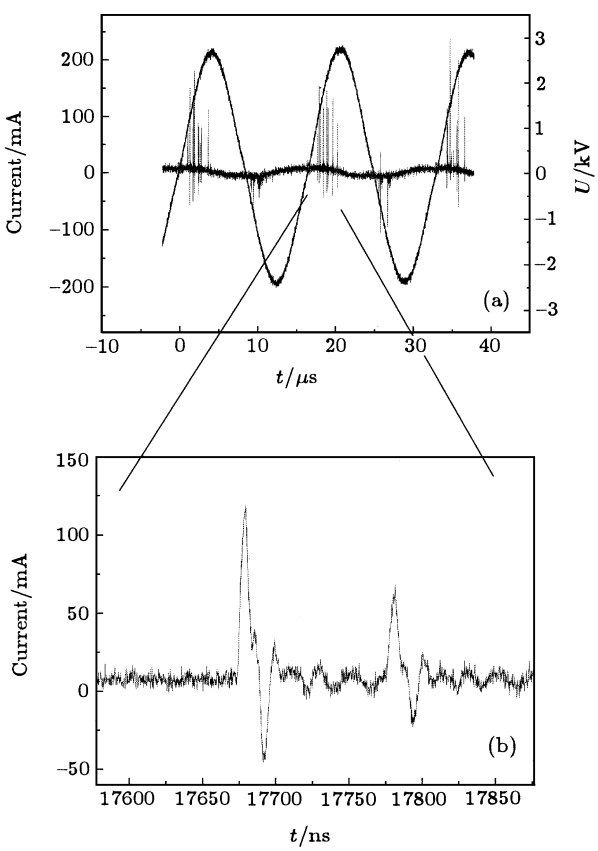


Fig.7. Characteristics of surface discharge in one atmospheric pressure air: (a) the current and voltage waveforms, (b) magnification of part of current waveform.

4. Conclusion

We present a one atmospheric pressure glow dis-

charge in argon with a surface discharge generator. The discharge generates a current with only one pulse per half-cycle of the applied voltage with the pulse duration being more than 1 μs. The duration is different in the different half-cycles. The surface discharge in one atmospheric pressure air is a kind of pseudo-glow discharge. The current waveform for air discharges at one atmospheric pressure is superimposed with many spikes, which are in the form of high-frequency damping oscillation. The current waveform in one atmospheric air discharge has an amplitude much larger than that in one atmospheric pressure argon discharge, and a duration much shorter. Therefore, we think, the pseudo-glow discharge in one atmospheric pressure air results from streamer breakdown while the discharge in argon is attributed to the Townsend breakdown. The power consumption in argon discharge for different voltages and different gas pressures is also discussed, and the results can be explained qualitatively.

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