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Realization of DC atmospheric pressure glow discharge without external airflow

Hua Li*, De-Cha Zeng, Jun-Yu Liu, Zhen-Cheng Chen*

School of Life and Environmental Sciences, Guilin University of Electronic Technology, Guilin 541004, GuangXi, China

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A B S T R A C T

A new needle-to-cylinder electrode structure with small gap (1.5 mm) was designed to realize the stable gas discharge in ambient air. The stable corona discharge and the stable glow discharge were realized without external airflow, which was proved by the discharge waveform stored in the oscilloscope, the discharge pictures recorded by the digital camera and the voltage–current plot. The image of the glow discharge showed that there was a negative glow region, Faraday dark space, a positive column region and an anode spot. Also the experiment and the COMSOL simulation showed that the needle with a diameter of 56.4 μm can realize the glow discharge while the needle with a diameter of 626 μm can not. The reasons for the realization of the glow discharge by the small gap between the needle and the cylinder were analyzed. It also shows that the glow discharge is easily realized with the black spot on the cylinder surface and a proper ballast resistor value (larger than 2 MΩ and less than 30 MΩ). The needle-to-cylinder electrode structure is easy to fabricate by MEMS technology, which can be used in portable analytical instruments.

1. Introduction

In recent years, the glow discharge presented wide applications, such as material modification, chemical and biological decontamination, ion source, and so on [1–3]. Then, more and more efforts to generate the glow discharge were shown in the related literatures. The glow discharge is usually produced easily in low pressure. But it needs a complicated and expensive vacuum system, which is not suitable for the portable instrument. By contrast, atmospheric pressure glow discharge (APGD) is a promising technology as it provides the plasma without any vacuum system. But it is difficult to produce APGD which easily transits to an arc discharge. The challenge work attracts many researchers' attention on the item.

There are several methods to produce APGD. In early research, dielectric barrier discharge (DBD) was adopted for APGD. But the needs of inert gas and radio-frequency voltage to keep the stable gas discharge blocked its wide use [4]. After that, more attention was paid on the very asymmetric electrode structure which could produce a DC glow discharge in atmospheric pressure. Akishev et al. showed that the glow discharge was created by a negative DC pin-to-plate discharge and a pin-to-sphere discharge respectively [5,6]. Ren et al. got atmospheric pressure glow plasma in a multipin-to-plate electrode configuration [7]. Liu et al. designed a line-cylinder atmospheric glow discharge device [8]. However, a fast gas flow (air, N_2 or other gases) or a large gap distance between discharge electrodes is necessary to avoid the arc discharge in above researches. The fast gas flow needs a huge gas supply system. And the voltage used in the large gap discharge electrodes is usually above 10,000 V, which makes the volume of the power supply larger.

A novel needle-to-cylinder electrode structure was designed to realize a negative DC atmospheric pressure glow discharge in this paper. A detailed investigation and analysis about this kind of glow discharge was conducted. Current-voltage measurements, discharge voltage waveforms and visualization show that it is a real glow discharge.

2. Experimental set-up

In this study, the atmospheric pressure glow discharge has been realized by a novel needle-to-cylinder discharge electrode. The discharge setup is shown in Fig. 1. The experimental system consists of three parts, namely, a needle-to-cylinder electrode structure, a discharge circuit and a test system. The needle-to-cylinder

* Corresponding authors.
E-mail addresses: lihua@guet.edu.cn (H. Li), chenzhcheng@163.com (Z.-C. Chen).

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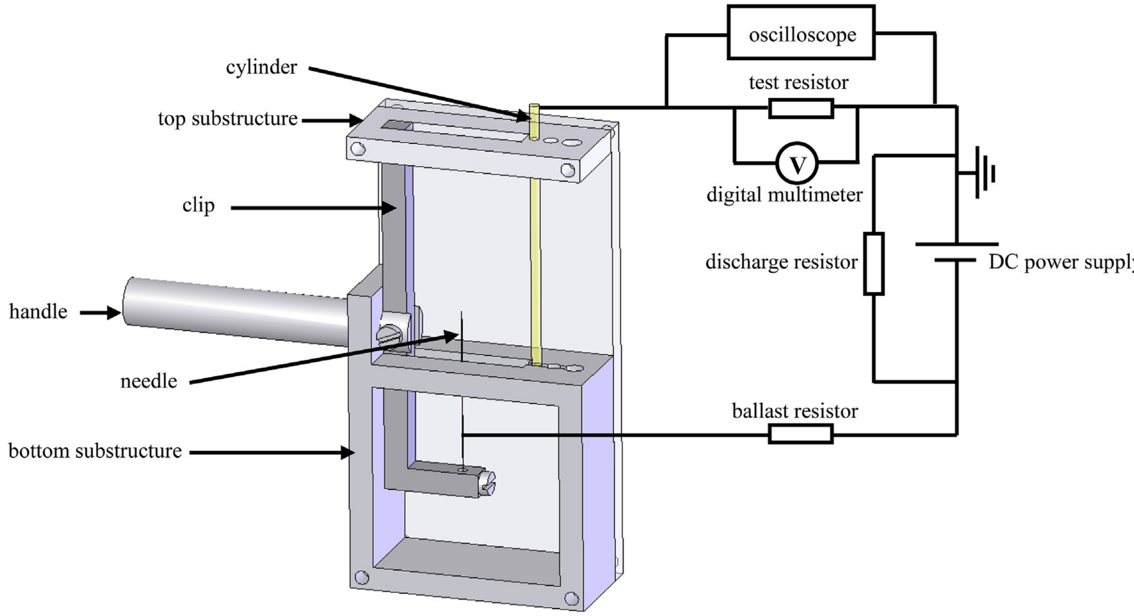

Fig. 1. Schematic diagram of experimental setup.

electrode structure includes the discharge electrodes and their fixing devices. The cathode is composed of the pin of stainless steel with tip diameter of 56.4 μm which is fixed in the clip. The anode, a copper cylinder with the diameter of 4 mm, is fixed in the holes of the top and the bottom substructures. The distance between the needle and the cylinder is only 1.5 mm, which is adjusted by the handle. The discharge circuit includes a DC power supply, a discharge resistor and a ballast resistor. The discharge is powered with a 0~-5000 V, 500 W DC power supply. The discharge resistor connected with both ends of the power supply can release the electric charge when the voltage of power supply decreases. A 12 MΩ ballast resistor is connected with the needle to prevent the arc discharge. The test system consists of TDS1002B-SC Tektronix oscilloscope and a digital camera. A 1 kΩ test resistor converts the discharge current into a voltage. The actual AC voltage is stored in the Tektronix oscilloscope and the voltage effective value is tested by a digital multimeter. The photograph of the discharge is recorded by a NIKON D300S camera.

3. Experimental results and discussions

3.1. Realization of glow discharge

On condition that the distance between the needle and the cylinder was 1.5 mm, the ballast resistor was 12 MΩ, the discharge resistor was 12 MΩ, the testing resistor was 1 KΩ, and the applied voltage of the power supply increased from 0 V to −5000 V, without external airflow, in ambient air and at room temperature, the gas discharge experiments were performed. Fig. 2(a)-(f) showed the discharge voltage waveforms of the test resistor at different external power-supply voltages. From the figure, it can be found that the discharge voltage waveforms are the typical Trichel pulses (Fig. 2(a)-(c)). This proves that the gas discharge is the corona discharge. With the external power supply voltage increasing, the Trichel pulse frequency also increases. And then DC component begin to exist in the Trichel pulse (Fig. 2(c)). With the external power supply voltage further increasing, the Trichel pulse is reduced until it wholly disappears and there is only the direct voltage in Fig. 2(d), (e) and (f). As the DC voltage discharge waveform is the characteristic of the glow discharge, it means that the discharge changes into the glow discharge now.

The applied voltage-ampere curve is shown in Fig. 3. Using Ohm's law, the current in the figure is calculated by the value of the test resistor divided by the voltage virtual value measured by the digital multimeter. In Fig. 3, segment *A*-*B* represents the corona discharge, and segment *C*-*D* shows the glow discharge. Segment *B*−*C* is the transition stage between the corona discharge and the glow discharge. In this stage, a hissing sound is heard and the discharge waveform stored in the oscilloscope is irregular. The explanation for this phenomenon is not very clear and will be studied in the later research. It also can be found that the current increases with the applied voltage increasing, and it increases more quickly in the glow discharge (*C*-*D*) than in the corona discharge (*A*-*B*).

The typical gap voltage-ampere characteristics of the discharge are presented in Fig. 4. From Fig. 1, it can be found that the gap voltage is the result of subtracting the voltage on both sides of the ballast resistor from the applied voltage (ignoring the voltage of the test resistor). Fig. 4(a) and (b) are corresponding to segment *A*-*B* and segment *C*-*D* respectively. In Fig. 4(a), the slope rate of the curve is positive, but it transforms into the negative one in Fig. 4(b). As is well known, the positive and the negative slopes of the current−voltage curve are the typical characteristics of the corona discharge and the glow discharge respectively. The results are similar to those of L X Chen and D Stack [9,10]. It is interesting to point out that the point *P* in Fig. 4(b) is not following the regular negative slope like other points. The reason is that the anode spot slides occasionally on the cylinder surface, and then the current increases irregularly at this point.

In Fig. 5, it shows the discharge emissions recorded by NIKON D300S, and the exposure time is 0.125 s, without any flashlight (the following photographs are taken in the same condition). At an external voltage of −3100 V (corresponding to Fig. 2(c)), the discharge flame is mainly located near the tip of the needle (Fig. 5(a)), while the gap between the needle and the cylinder almost has no discharge luminosity. It indicates that the ionization region is centralized at the cathode, in which the electric field is stronger than the one in other location. As the applied voltage