A study on the equivalent electric circuit simulation model of DBD streamer and glow alternate discharge

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Abstract. This paper presents a dynamic simulating model of the dielectric barrier discharge (DBD), structured as an equivalent electric circuit of the streamer and glow discharge generated alternately in DBD. The main parameters of DBD have been established by means of analysing the structural characteristics of a single discharge cell. An electrical comprehensive Simulink /MATLAB model was developed in order to reveal the interaction of the adjacent two discharge cell. A series of simulations was carried out in order to estimate the key structural parameters that affect the alternate streamer and glow discharge mode. The comparison results of experimental and simulate indicate that there exists a close similarity of the current waveforms graphic. Therefore, we can grasp a deep understanding mechanism of the dielectric barrier discharge and optimize the plasma reactor.

1. Introduction
Dielectric barrier discharge (DBD) is a typical non-equilibrium ac gas discharge. Its experimental device generally consists of two parallel electrodes, at least one of which is covered with a dielectric material [1, 2]. Recently, much attention has been paid to DBD because of its broad application prospect in numerous industrial areas. The DBD has been previously used in different fields such as plasma display, light emitting and environmental protection [3-6]. For these reasons, accurate and reliable information of the reactive species is critical for the understanding of plasma behavior and then optimizing the plasma generation process to improve the functioning of the plasma processing reactor. Furthermore, plasma discharge parameters can be selected to optimize the production of reactive species based on the optical measurement. Several researchers have been investigated the physical mechanism of the micro-discharge in pin-to-plane DBD [7-10], combined with a macro camera. When the excitation voltage large enough, it can be found that there are two different discharge models in a current cycle which were considered to be the streamer and glow alternately discharge.

This paper sets out to present a refined modeling of the DBD electrical elements so as to afford a better understanding of the current and voltage responses during the discharge, provided that these parameters are measurable throughout the simulation process. Furthermore, this DBD model takes into account the alternative discharge of the streamer and glow model with the applied voltage above 5 kV.

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2. Modelling and analysis

2.1. The current-voltage characteristics of the streamer and glow discharge generated alternately in pin-to-plane DBD

The instrumental arrangement used for this study is shown in figure 1. It is mainly composed by the current and voltage detection and the DBD, which is supplied by a voltage source inverter coupled with a step-up high frequency. Measurements of the power source output voltage as well as of the DBD applied voltage and the discharge current is provided by a Tektronix oscilloscope. In all cases, the electric discharges are generated at atmospheric pressure.

![Figure 1. Dielectric barrier discharge experimental system.](Image)

1 High voltage electrode,  
2 Plane electrode,  
3 0.47 mm thick dielectric of aluminium,  
4 Discharge gap,  
5 Resistor,  
6 Power source,  
7 High-voltage probe,  
8 Oscilloscope.

![Figure 2. Current and voltage waveform of the pin-to-plane DBD (V >5 kV).](Image)

The pin electrode is made of brass and their dimensions are shown in figure 1. The gap clearance $d$ is adjustable up to 0.9 mm and the excitation power frequency is 10 kHz. A resistor $R$ is connected to the electrodes in series for us to measure the discharge current. A high voltage probe is used for us to measure the applied voltage between the electrodes at the same time. When the applied voltage is less than 5 kV the resulting is a typical streamer. However there will be a new type of discharge mode when the applied voltage above 5 kV. Although it still looks like a streamer discharge mode in our eyes, we can find the significant differences by a 1us macro high-speed CCD camera. According to the current and voltage waveform, as seen in figure 2, it would be the glow discharge mode.
2.2. DBD discharge equivalent circuit
An equivalent electric circuit of the pin-to-plane DBD is set up, as shown in figure 3, in order to understand the physical mechanism of the DBD and investigate the streamer and glow discharge generated alternately in pin-to-plane DBD. Thus, the electrical characteristics of such plasma discharges can be represented by a voltage-controlled current source. By this means the streamer discharge model will occur in the positive of the current waveform and the negative will be the glow. In this electric circuit the dielectric sheets between the electrodes can be represented by capacitors $C_d$. Both the gas capacitance value $C_g$ and the equivalent resistance $R_1$ depend on the applied gas composition.

![Figure 3. Equivalent circuit of single micro-discharge channel](image)

2.3. Micro-discharge dynamic simulation model
According to the analysis of DBD discharge equivalent circuit, a dynamic simulation model is established by using the simulation software of MATLAB/ Simulink [11, 12], as shown in figure 4.

![Figure 4. Dynamic simulation model of single micro-discharge channel](image)

In this model the initial state of the voltage-controlled switch $S_1$ is disconnected. The streamer discharge model process are as follows, when the air-gap voltage $V_g$ exceeds the value of the previously fixed block parameter $V_s$, then $S_1$ is switched on, output "1", $R_1$ is connected to the circuit then the streamer discharge began. However when $V_g$ is less than $-V_s$, $Vc2$ output "1", the value of the function module Fcn control the output of current source CCS to start the glow discharge.
3. Simulation process

3.1. Current waveform simulation
In order to validate the proposed-model simulation, experimental tests have been carried out with the current waveform, as shown in figure 5. It can be seen, the discharge current waveform superimpose on a large number of current pulses in the positive half cycle, showing a capacitive load characteristics, so it is a typical streamer discharge model. In the negative half cycle, there is a wide current pulse. It can be determined that there are two completely different discharge models between the positive and the negative half cycle. It must be the streamer and glow discharge generated alternately in pin-to-plane DBD. In addition, the comparison between the experimental and simulated current waveform is shown in figure 6. There exists a considerable similarity between the experimentally measured values, those produced by Simulink /MATLAB.

Figure 5. Current waveform of simulation result.

Figure 6. Current waveforms of single micro-discharge with two modes.

3.2. The impact of different parameters on DBD micro-discharge
Departing from the obtained simulation results, the two influential electrical parameters $C_d$ and $C_g$ have been considered in figure 7 to figure 10. It indicates that the performance of the DBD discharge can be improved with the increasing of the gas capacitance $C_d$ and dielectric capacitance $C_g$.

Figure 7. Micro-glow’s amplitude with different $C_d$.

Figure 8. Streamer’s amplitude and lifetime with different $C_d$. 

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4. Conclusion
There exists a close similarity between the experimental results and the predictions from the proposed DBD model. This can be considered relevant as the model goal is to provide an acceptable estimation of the electric parameters of the electrical characteristics of the high-power switches of the static converter, the intensity and frequency of the excitation voltage source, of course, the necessary power to be delivered to the charge.

A series of experiments with electric discharges in a DBD reactor has been carried out. The experimental results were satisfactorily compared with the simulation predictions of the proposed DBD reactor model. Thus, the model allows one to both predict with accuracy the discharge behaviour using the experimental parameters and verify the different discharge models of the streamer and glow discharge generated alternately in pin-to-plane DBD.

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References
[1] Leys C 2004 Contrib. Plasma Phys. 44 542
[2] Wei D D, Feng L, and Lan J Y 2009 IEEE Trans. Plasma Sci. 37 2207
[3] Tenderoа C, Tixierа C, Tristanta P, Desmaisona J, and Leprinceb P 2006 Spectrochim. Acta Part B 61 2
[4] Roth J R, Rahel J, and DAI X 2005 J. Phys. D: Appl. Phys. 38 555
[5] Fang Z, Qiu Y, Luo Y 2003 J. Phys. D: Appl. Phys. 36 2980
[6] Eden J G 2006 Proc. IEEE 94 567
[7] Radu I, Bartnikas R and Wertheimer M R 2003 J. Phys. D: Appl. Phys. 36 1284
[8] Yu. S. Akishev, A. V. Dem’yanov, V. B. Karal’nik, A. E. Monich, and N. I. Trushkin 2003 Plasma Phys. Reports 29 82
[9] Kogelschatz U 2002 IEEE Trans. Plasma Sci. 30 1400
[10] Hao Y P, Guan Z C, Wang L M, Wang X X and Li C R 2005 High Voltage Apparatus 31 59
[11] Flores-Fuentes A, Pena-Eguiluz R, Lopez-Callejas R and Mercado-Cabrera A 2009 IEEE Trans. Plasma Sci. 37 128
[12] Zhang C, Fang Z, Zhao L Z and Qiu Y C 2007 High Voltage Apparatus 43 218