Study on dielectric barrier discharge in nanostructured electrode materials

Dongpeng Zhang1,2
1 National Key Laboratory of Science and Technology on Micro/Nano Fabrication, Department of Micro/Nano Electronics, School of Electronic Information and Electrical Engineering, Shanghai Jiao Tong University, Shanghai 200240, P. R. China
2 e-mail: sju410629983@sina.com

Abstract. In order to conduct dielectric barrier discharge experiments under normal pressure and low voltage (less than 15000V), an ac high-voltage differential power supply based on series-parallel LCC-type (inductor L and capacitor Cr,Cp are connected in series and parallel structure) resonant converter is designed. The designed power supply prototype has the advantages of small size, light weight and easy operation. The power supply prototype has been tested on loads for many times. Its output repeatability is good and it can continuously output stable sinusoidal ac voltage. At the same time, the prototype also has a strong ability to resist electromagnetic interference. Moreover, the dielectric barrier discharge experiment is carried out using copper electrode with zinc oxide nanowires and copper electrode without zinc oxide nanowires. The experimental results show that the starting voltage of the test group with nanostructures growing on the surface is smaller, about 2500V lower than that of the latter under the same dielectric conditions and discharge spacing. In terms of the discharge phenomenon, the former has a better discharge process consistency, the non-nanostructured electrode discharge is unstable, and the difference in the discharge process is obvious.

1. Introduction
At present, high voltage ac power supply is widely used in some occasions where high voltage output is required[1]. The resonant converter participates in power transformation with parasitic parameters in its own circuit, which not only improves the efficiency of the converter, but also greatly simplifies the circuit structure and makes the power supply as small as possible[2]. Resonant converter has three main circuit structures: series resonance, parallel resonance and series-parallel resonance. LCC series and parallel resonance combines the advantages of high frequency, low power consumption and small volume. For applications of high voltage such as electrostatic dust removal and X-ray, LCC resonant converter is a better choice[3]. In this paper, LCC resonant transformation technology is used to design a high frequency and high voltage power supply prototype, and it is applied to dielectric barrier discharge experiment. Dielectric barrier discharge (DBD) has been applied to plasma active flow control in recent years and has been widely used to inhibit flow separation. Dielectric barrier discharge can produce uniform discharge with low power consumption, which is of special significance in the fields of pollution gas prevention and gas cleaning[4]-[6]. Ma et al.[7] used the designed porous dielectric barrier discharge system to produce hydroxyl radicals and active substances in water, thus achieving the purpose of removing pollution and purifying water. Liu[8] improved the photocatalytic performance of titanium dioxide particles by applying plasma to the surface of the particles in a dielectric barrier discharge plasma-assisted ball-milling process. In the literature [9], bisphenol A (BPA)
was eliminated by using nanoscale zinc oxide with multiple catalytic effects and dielectric barrier discharge plasma system. And the experimental results showed that the system had a 100% efficiency of BPA degradation. Therefore, dielectric barrier discharge is very important in many applications.

In this paper, the differential high voltage power supply is used as the excitation source to explore the effect of dielectric barrier discharge under different electrode materials. Under the same conditions, the starting voltage required by nanomaterial electrode and non-nanomaterial electrode in the experiment was compared, so as to explore the possibility of conducting dielectric barrier discharge at lower voltage under normal pressure. In addition, the digital camera was used to capture the process under the condition of two different discharge structures. This study provides theoretical basis and novel ideas for the application of dielectric barrier discharge in more fields.

2. Experimental design

The dielectric barrier discharge and measurement system in this experiment consists of differential high voltage power supply, DBD load, oscilloscope, high voltage rod and test resistance. The DBD load in the experiment was composed of a square porous copper electrode and a ceramic dielectric plate. The side length of the square porous copper electrode was 10mm and the thickness was 1mm. The thickness of ceramic dielectric plate was 1mm, and the distance between the two electrodes was 4mm. The two output voltage amplitudes of the differential power supply were the same with a phase difference of 180°. The DBD load was connected to the two output terminals of the power supply through a resistor with a resistance value of 15 kiloohms to form a closed loop. Both ends of the DBD load and the power output connected with the resistance were connected to the oscilloscope through the high voltage probe to display the voltage values of the three potential points, as shown in Figure 1.

![Figure 1. Schematic diagram of dielectric barrier discharge system](image_url)

2.1. Differential power supply design

The differential power supply used in the dielectric barrier discharge experiment was composed of full-bridge inverter network, LCC resonance circuit, boost transformation part and control circuit. The control circuit was based on the chip STM32F343. The DC voltage of the input terminal was adjustable within the range of 0–24V, which was converted into square wave through the inverter network, and then sinusoidal voltage was obtained through LCC resonant transformation. Finally, it went through the boost transformer to output the AC high voltage required by the load. Since the load capacitive reactance was relatively large, and the transformer of the power supply itself had leakage inductance and distributed capacitance, these added uncertainty to the matching test of high-frequency power supply and DBD load in the on-load experiment. In addition to simplifying the circuit model to calculate the LCC resonance parameters and resonance frequency in the experiment. In the actual
debugging process, it was also necessary to repeatedly test around the theoretical value to find the optimal operating frequency point.

In the design of high voltage circuit, the principle of LCC resonance transformation was used for AC power transformation. Figure 2 is the actual differential power supply diagram designed in this experiment, and Figure 3 is the circuit schematic diagram of the LCC series and parallel resonant converter. The LCC resonant converter in the circuit is composed of four resonant elements, namely the resonant inductor $L_r$, the transformer leakage inductor $L_{\text{leak}}$, the resonant capacitor $C_s$ and the equivalent capacitor $C_{ps}$ on the secondary side of the transformer. In the schematic diagram, $S_1$~$S_4$ are switch tubes, which constitute the bridge inverter circuit. The output voltage of the inverter $V_{AB}$ is obtained through the resonant network. The high-frequency transformer $T_r$ (transformation ratio: $1: n$) are connected to the resonance network to boost the sinusoidal AC voltage.

![Figure 2. Physical picture of differential power supply.](image1)

![Figure 3. Schematic diagram of single high voltage output.](image2)

2.2. DBD load
In the experiment, two sets of DBD load were tested. The two kinds of loads had the same structure except for the different electrode materials. The first copper electrode pair was made of ordinary PCB board material filled with copper, with a number of holes on the surface. The second copper electrode grew zinc oxide nanowires on the surface of the copper electrode. Therefore, the discharge experiment was divided into two groups. In the first group, the copper electrode without nanomaterial structure was used to prepare DBD excitation. The two copper electrodes were separated by an insulating ceramic plate. In the second group of experiments, copper electrodes with zinc oxide nanowires were used as DBD excitation poles. The materials and specifications of the dielectric plates used and the gap distance between the two electrodes were exactly the same as the first group.

3. Dielectric barrier discharge experiment

3.1. Electrode discharge experiment without nano materials
The two outputs of the differential power supply were connected to the non-nanostructured DBD load through series resistor to form a discharge circuit. The output frequency of the differential power supply was adjusted to 70KHZ, and the current-limiting value of the power supply was set. The input voltage of the power supply was gradually increased, and the output voltage was linearly increased accordingly. In the experiment, it was observed that when the terminal voltage of load reached 17KV, discharge started on non-nanostructure DBD loads. As the voltage continued to increase, the voltage waveform on load was stable sine. When the output voltage was greater than 17KV, the discharge phenomenon became more intense than before, making it more difficult to control the discharge range.

![Second group of images in Figure 4](image3)

The second group of images in Figure 4 shows the discharge conditions at 17KV, $t=10s$, $t=30s$, and $t=60s$, respectively. It could be seen that with the continuation of the discharge process, the discharge brightness and range increase significantly, resulting in poor consistency of the discharge phenomenon. After 6 repeated experiments, the starting voltage and loop current of each load discharge were obtained as shown in table 1.
Table 1. Turn-on voltage and current of non-nanostructured electrode experiment

| Experiment number | Turn-on voltage (KV) | Loop current (mA) |
|-------------------|----------------------|-------------------|
| 1                 | 17.0                 | 78                |
| 2                 | 17.3                 | 79                |
| 3                 | 17.0                 | 78                |
| 4                 | 17.0                 | 78                |
| 5                 | 17.3                 | 79                |
| 6                 | 17.0                 | 78                |

Figure 4. Three-time discharge diagrams under the same conditions for two different discharge loads. Group 1: Electrode discharge diagram of nanomaterials; group 2: Non-nanomaterial electrode discharge diagram.

3.2. Electrode discharge experiment with nano materials

The discharge load without nanostructure was replaced by nanostructure DBD load in the same way as in 3.1, and the discharge circuit was formed. The same power supply parameters were set. In the experiment, it was observed that when the voltage at the end reached about 14.5KV, the discharge between the two electrodes of the nanostructure DBD load began. The voltage continued to increase near 14.5KV, and the voltage waveform at the end of the load was stable. The first group of images in Figure 4 showed the discharge pictures at 14.5KV, t=10s, t=30s and t=60s, respectively. It could be seen that with the continuation of the discharge process, the discharge brightness and range did not change much, and the discharge phenomenon was consistent. After 6 repeated experiments, the starting voltage and loop current of each load discharge were obtained as shown in Table 2.

Table 2. Turn-on voltage and current of nanostructured electrode experiment

| Experiment number | Turn-on voltage (KV) | Loop current (mA) |
|-------------------|----------------------|-------------------|
| 1                 | 14.7                 | 77                |
| 2                 | 14.8                 | 77                |
| 3                 | 14.6                 | 76                |
| 4                 | 14.6                 | 76                |
| 5                 | 14.5                 | 75                |
| 6                 | 13.5                 | 72                |
4. Conclusions
A self-developed differential power supply for DBD discharge of porous copper electrode plate is introduced. The conclusion is as follows:

(1) Under the same experimental conditions, compared with the ordinary porous copper electrode DBD discharge, the opening voltage of the porous copper electrode DBD discharge growing with nano-structure is smaller, about 2500V less than the former.

(2) DBD discharge is carried out by the two structures at their respective turn-on voltages, and DBD load discharge of the nanostructure is more stable and the discharge consistency is better.

(3) The developed differential power supply prototype has good compatibility with the porous copper electrode load, can work stably for a long time, and meets the basic requirements of such DBD discharge preliminarily.

At the same time, the good step-down effect of DBD discharge by introducing nanostructured materials in this paper also provides theoretical experimental support for the application of dielectric barrier discharge in other fields, and broads the selection range of DBD discharge materials and structures.

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