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Comparison of parallel and serial resonance circuits for generation of surface barrier discharges

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Two different principles of power supplies for generation of planar dielectric barrier discharges at atmospheric pressure were investigated. The comparison of parallel and serial resonance circuits has been made and the power loss mechanism in both cases has been studied. A power supply based on serial resonant circuit of plasma source has been developed.

1. Introduction

Atmospheric pressure planar dielectric barrier discharges (PDBD) are used on a large scale in industry for applications like ozone production for gas and water purification [1], film deposition and surface treatment of polymers or other materials [2]. With increasing effective area of the discharge electrode grows the need for effective and low-loss power.

Different discharge excitation principles are possible. For laboratory applications high voltage amplifiers are often used, whose output stage is operated within the active range. The disadvantage of this approach is high electrical power loss. Therefore it is unsuitable for the industrial applications. Besides, appropriate amplifiers for high voltage (several kV) and high power are very expensive. For that reason resonant power supplies are frequently used, which utilize the strongly capacitive characteristics of the plasma sources. Nevertheless also in this case the electrical losses are not negligible and this is the subject discussed in the present work.

2. Electrical characteristics of PDBD

The typical investigated system of the surface barrier discharge (SBD) [3] consists of two electrodes separated by 0.4 mm thick, high purity Al_2O_3 ceramic plate. The discharge electrode consist of 27 interconnected 1 mm wide and 45 mm long strips. On the opposite side the induction electrode is formed as a 70 mm $\times$ 50 mm rectangle. A sinusoidal signal with a frequency in the range of 5-20 kHz and voltage amplitude 2-6 kV is applied between the electrodes.

Without plasma the electrical behavior of the source is almost purely capacitive. Only a small real component of the power, caused by the dielectric losses, is to be considered. During the discharge rises this real component considerably by the power consumption of the plasma. The energy from the power supply is transferred into the plasma during partial discharges (PD). The resulting current pulses are in the range of nano- to microseconds and are superposed on the capacitive current. The voltage breaks down during the pulse duration more or less strongly (see figure 1).

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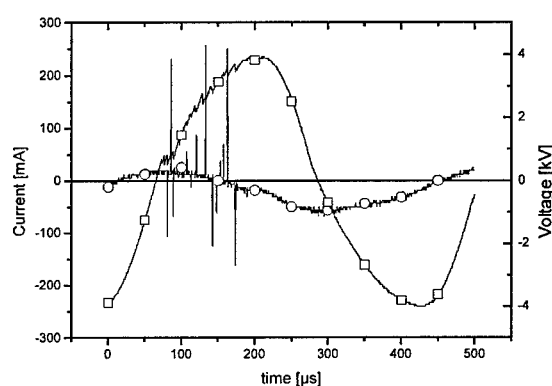


Figure 1. Typical current-voltage characteristics ($\circ$ = current, $\square$ = voltage) of a SBD-source in 80% N_2 , 20% O_2 operated with an parallel resonant power supply (Lifetech)

3. The resonant power supply

In principle two types of resonant power supply are possible: parallel and serial [4].

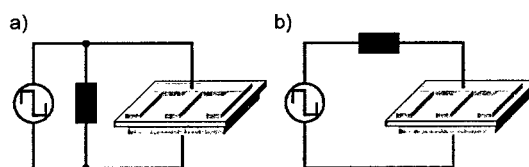


Figure 2. a) Parallel and b) serial resonant circuit.

A coil or a transformer with large main inductance or strain inductance is connected to the plasma source. The circuit formed by the inductance and the capacity of the plasma is connected to the power supply working at the resonant frequency. At higher power this excitation can be done with low electrical losses only with rectangular or pulse voltage signal.

The common way to operate a plasma source is to apply a voltage from the transformer which is connected parallel to it. In this way the plasma source and the main coil of the transformer work as a parallel resonant circuit.

When the rising time of the applied voltage is very short as in the case of rectangular or pulsed voltage the capacity of the plasma source behaves like a short cut. The strongly rising current produces high power losses in the wire resistances and in the output stage of the power supply.

The advantage of a serial resonant circuit is that the coil limits the current rise in normal operation mode but also when an accidental short cut occurs in the plasma source.

Power supply delivers energy in the resonant circuit in each half period. As long as plasma is still off, more and more energy is stored in the circuit. To ignite the plasma some energy has to be consumed, the voltage breaks down and the capacity of the plasma source changes very fast involving a change in the resonant frequency. This means that the resonant circuit is not any more stable.

In order to overcome this disadvantage two methods are proposed:

1. The energy in the circuit has to become much higher using for example capacities parallel to the plasma source. This makes the voltage drop weaker.
2. The frequency of the power supply has to be adjusted permanently to the resonant frequency of the circuit. This has been realized by the use of "current zero point detection" method.

The method 1 has the disadvantage that the parallel capacities stabilize the voltage too restrictive. More and more energy will be transferred in the plasma and this can cause the damage of the plasma source. To avoid this, a second coil L_{cpl} has been introduced in the circuit in order to adjust the coupling between plasma source and power supply. This limits the current between the parallel capacity and the plasma source.

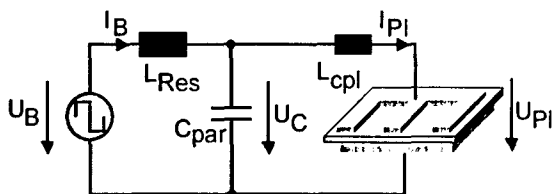


Figure 3. The resonant circuit consists of L_{Res} and C_{Par} . Coupling is realised by L_{cpl} .

4. The current synchronizing method

If an ideal serial resonant circuit is powered with a rectangular shaped voltage signal, the current reaches the zero point exactly at the moment of switching the voltage. This fact can be used to synchronize the frequency of power supply with the resonant frequency.

A technical problem is the detection of the current zero point [5] from the noisy signals produced by the plasma. This problem was solved by use of the „dynamic hysteresis“. The sensitivity of detection varies in

time. The sensitivity reaches a maximum just before the current crosses its zero level and gets the minimum immediately after this.

5. Results

With this new power supply concept it is possible to operate the atmospheric pressure plasma sources in a low loss way and with the possibility to vary the power coupled into the plasma.

Figure 4 shows the current and voltage characteristics of the plasma source with (figure 4b) and without (figure 4a) the coupling inductance L_{cpl} .

The difference is obvious. The current peaks are limited strongly. If no coupling coil is used, the lifetime of the plasma source is reduced from hundreds of hours to maximal one hour. In this last case the plasma source gets much hotter.

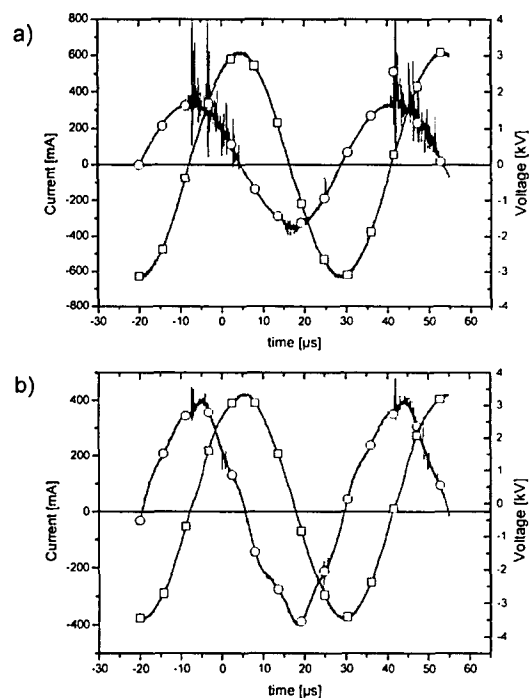


Figure 4. Current and voltage characteristics of a plasma source powered by the serial resonance voltage supply without (a) and with (b) $L_{cpl} \approx 1 \text{ mH}$ ($\circ$ = current, $\square$ = voltage).

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