Evolution of filamentary pattern in glow dielectric barrier discharge system

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We investigate the filamentary patterns evolving with the applied voltage in a planar dielectric barrier discharge (DBD) system driven by square-wave voltage of several tens kilohertz. The homogeneous glow discharge can develop into filamentary patterns according to the conditions of the gas pressure, the applied voltage and frequency. The patterned DBD starts with some filaments which increase in number and form various patterns as the voltage increasing, until reaches uniform state at very high voltage. It is found that there are two series of patterns at moderate frequecny and pressure, while there is only one series at higher frequency and pressure.

Dielectric barrier discharge (DBD) systems are capable of generating non-equilibrium plasma at various pressures up to atmosphere and have been widely used in many industrial applications for the production of ultraviolet radiations and reactive species [1]. The DBD is also one of the nonlinear systems which can achive various self-organized patterns according to the conditions of the gas and exciting voltage. Even if in glow regime, the DBD plasma is homogeneous only in some very strict conditions. In most cases, the DBD usually composes of filaments or stripes which are random or in space, synchronized or not in time [e.g., Ref.2 and references therein]. The goal of this paper is to study the evolution of patterned DBD under different conditions.

The DBD system consists of two electrodes in diameter of 50 mm, each covered by 1mm-thick glass and separated by gas gap of 2 mm. One of the electrodes (upper) is made of transparent indium-tin-oxide (ITO) which makes it possible to record the light emission from top-view and the bottom electrode is of aluminum foil. The filling gas is pure argon at various pressures of p. A square-wave voltage is applied between the two electrodes with frequency of $f = 1 \sim 100$ kHz and amplitude up to 1000 V. A non-inductive resistor R is connected in series with the cell to sample the discharge current. The applied voltage and the current are measured by an oscilloscope (Tektronix TDS-3054B). A digital CCD camera (Canon 500D) was used to record the time-averaged images of the discharge emission from top-view.

Generally, a uniform DBD can sustain at lower pressure and/or frequency, while the patterned DBD appears above critical values. Increase of gas pressure p or driving frequency f leads to the similar tendency for the pattern at various voltages. The critical priduct of pressure and frequency is $pf \sim 50$ Torr s^{-1} in the present conditions.

At moderate pressure of 7.5 Torr and frequency of 20 kHz, the DBD starts with a single filament under minimum sustaining voltage of 200 V after the gap breaks down at voltage of 290 V. The evolution of the DBD is shown in Fig. 1 (a, the left one). The filaments develop into various net-shaped patterns as the voltage increasing, until reaches uniform state around 250 V. The discharge in this stage is generally weak, with lower discharge current and smaller charge-transfer during a pulse. Then, increase of the applied voltage results in the appearance of bright spots (or the second series of pattern) in the background of weak glow. The spots increase in number as the voltage rising and may self-organize in the active area. At voltage higher than the breakdown threshold (i.e. 290 V), the glow DBD becomes uniform over the whole electrode. At very high voltages, the discharge glow may overflow out the electrode boundary, with a ring of uniform corona surrounding the boundary.

At higher pressure of 30 Torr and frequency of 50 kHz, the DBD also starts with one or several filaments under the minimum voltage of 300 V after the DBD breakdown at voltage of 420 V, but the discharge glow is much stronger than that at moderate pressure and frequency. The evolution of the DBD is shown in Fig. 1 (b, the right one). The filaments are moving in random manner at beginning. The filaments increase in number as the voltage increasing. These filaments can self-organize in space when the number is large enough, typically in shape of hexagon. The self-organized patterns may be distorted due to being redundant or lack of filament. At higher voltages greater than 440 V, the DBD tends to be uniform. The DBD glow can overflow out of the electrode edge at very high voltage. Different from the case of moderate pressure, the outer is radial pattern instead of uniform corona.

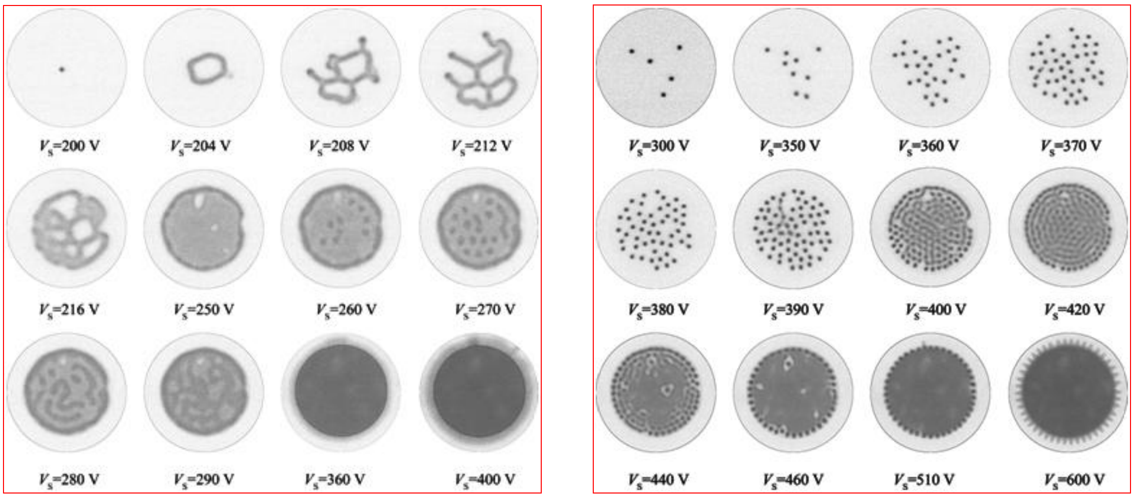

Fig. 1: The images of the DBD pattern from top-view at increasing voltages for (a) the left: p = 7.5 Torr, f = 20 kHz and (b) the right: p = 30 Torr, f = 50 kHz. The exposure time is 1 s.

The new-born filaments can be created by the splitting of a single one, or producing at isolated position when the voltage rising. The filament can also be quenched by the collapse of a pair of filaments if the voltage drops down. This spliting and auenching processes are shown in Fig. 2.

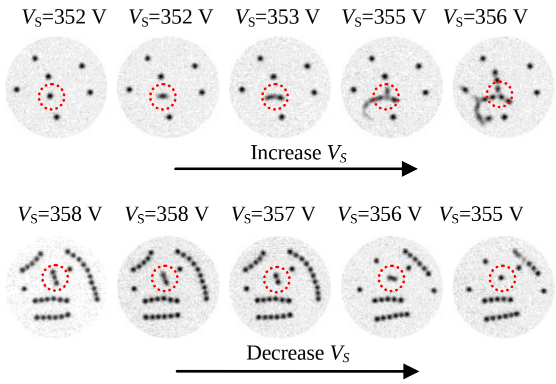

Fig. 2: The process of splitting of a single filament (the upper, incerasing voltage) and quenching of filaments (the bottom, decerasing voltage) at p = 30 Torr and f = 50 kHz.

The DBD patterns appear only when the pf is greater than a critical value which depends on the configuration and the gas mixture. It is associated with the diffusions of the ions/electron in plasma which determines the plasma decay during afterglow. Only when the afterglow plasma would not reach uniform state under moderate or higher pf, the patterns can form in DBD system. Meanwhile, a moderate voltage is also important for the pattern formation. A very high voltage (or applied field) will destroy the DBD patterns in all the cases. It is suggested that the development of DBD patterns relate to the lateral inhibition of non-uniform electron density [3]. The distribution of the remaining free electrons in the space in each period of the voltage pulse plays a key role for the DBD structure, and the applied voltage (or field in gap) determines the strenghth of the inhibition.

References

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