VISUALIZATION OF NANOSECOND SURFACE DIELECTRIC BARRIER DISCHARGE AT HIGH PRESSURES

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ABSTRACT

Surface nanosecond dielectric barrier discharge in air has been studied in a pressure range 1–6 bar in coaxial geometry of electrodes for positive and negative polarity of high–voltage pulses. High-voltage pulses of 20–60 kV amplitude on the electrode, 20 ns duration, 0.5 ns rise time were used to initiate the discharge. ICCD images of the discharge development have been taken with 2 ns gate. It was found that at certain combinations of pressure and applied voltage the discharge becomes significantly filamentous

1. INTRODUCTION

Nanosecond surface dielectric barrier discharge has been intensively studied recent 10 years due to increased interest to plasma applications in flow control and combustion [1-3]. The pioneering experiments based on the known influence [4] of the sinusoidal power DBD discharge on the flow, demonstrated extremely high efficiency of the nanosecond DBD in control of laminar–to–turbulent transition in subsonic flows. The peculiarity of a nanosecond power supply is that the streamers start from the high voltage electrode and propagate synchronously (within 0.2 ns at atmospheric pressure) in the direction perpendicular to the electron edge. Synchronous start of the streamers leads to the initiation of a cylindrical shock wave on the electrode edge. The shock wave, even at low energy input to the discharge, causes a laminar-turbulent transition and subsequent flow reattachment to the surface. One of the most complicated questions for SDBD discharges at elevated pressures is the question about energy distribution in the discharge region. At atmospheric pressure, discharge develops as a set of streamers of a relatively big diameter (about 0.1 mm), starting synchronously from the high voltage electrode. This provides a picture of quasi-uniform 2D structure. This approximation, of a plasma layer, is often used for numerical modeling. To use this approach for higher gas densities, typical for combustion initiation in engines, gas uniformity with pressure must be studied. In this work nanosecond SDBD spatial structure is studied for discharges of negative polarities at ambient temperature and elevated,
1-6 atm, pressure.

2. EXPERIMENTAL SETUP

A coaxial electrode system, 10 schematically represented by figure (1), has been developed to obtain a quasi–uniform 2D discharge that propagates along the surface in a radially symmetrical geometry. The thickness of the plasma layer in the direction perpendicular to the dielectric plane is about 1 mm. The central coaxial high voltage (HV) electrode is ended by a beveled–edged copper disk, 2 mm in thickness and 20 mm in diameter. The low voltage electrode is made of aluminum. The inner diameter of the low voltage electrode is equal to the outer diameter of the HV electrode, and the outer diameter of the low–voltage electrode is equal to 46 mm. A dielectric layer of PVC 0.3 mm in thickness is located between the electrodes. The discharge starts from the edge of the high voltage electrode and propagates radially along the surface of the PVC layer.

The SDBD electrode system was installed into the port of the high pressure discharge cell, so that one optical window was situated opposite to the electrode system and two others allowed to observe the discharge from the side. The high voltage electrode was connected to the high-voltage generator via a 30 m coaxial 50 Ω cable. The high–voltage (HV) pulse generator (FID Technology, FPG20–03NM) used in experiments provides the following parameters: 0.5 ns pulse front rise time, 20 ns pulse duration on the half–height and ± (12–30) kV voltage range in the cable. All discharge SDBD experiments presented in this paper were performed in single shot regime without a gas flow.

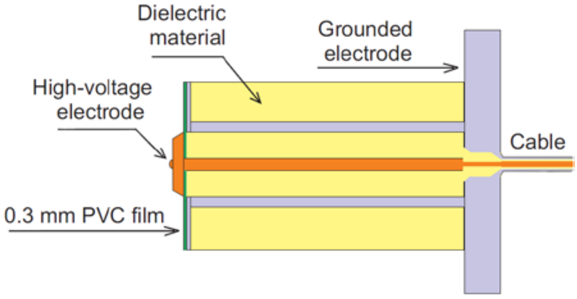

Fig.1. Cylindrical electrode system.

Two calibrated back current shunts (BCS) were installed into the cable: one, BCS1, in the middle of the cable and another one, BCS2, 1 m apart from the HV generator. BCS1 was used to measure the voltage on the electrodes, the current through the electrodes and the deposited energy, and the BSC2 was used to synchronize the ICCD camera with the discharge. The signals from the BCSs were registered by a LeCroy WaveRunner 600 MHz oscilloscope. To study the spatial structure and the development of the surface discharge, a 2D map of emission integrated over the wavelength range 300—800 nm was recorded by ANDOR iStar DH734 ICCD camera. The camera gate was equal to 2 ns. The camera was triggered at different time delays from the beginning of the applied pulse to get the images of the discharge evolution.

The monochromator ANDOR 500i combined with ANDOR iStar DH734 ICCD camera was used to study the rotational structure of the second positive systems of nitrogen. The resolution reached in experiments with the grating 2400 l/mm and 100 μm input slit width was 0.11 nm.

3. EXPERIMENTAL RESULTS

Two different modes of the discharge can be distinguished at the given experimental conditions and this is illustrated by figure (2)

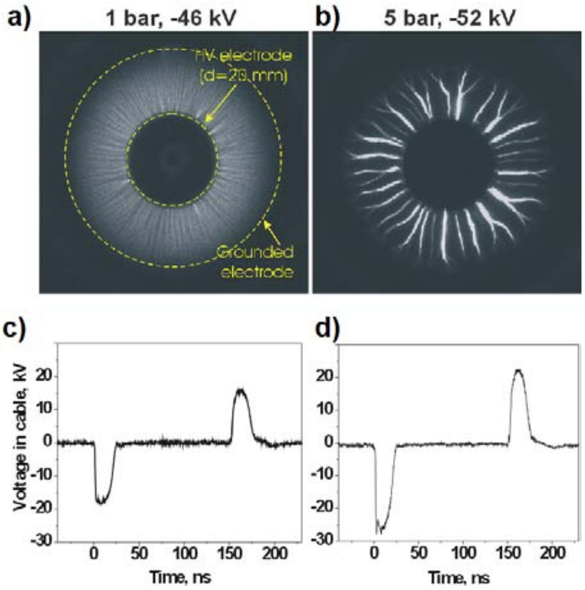

Fig. 2. Result of ICCD imaging and BCS oscillograms. Camera gate is 2 ns.

representing the ICCD images of the discharge taken with a 2 ns camera gate. A discharge, similar to observed in a classical plane–to–plane geometry at atmospheric pressure air, is obtained at relatively low voltages on the high–voltage electrode (see figure (2a)). This mode will be further called “quasi–uniform” although the discharge consists of a lot of radially propagated emitting channels (streamers) with an optical diameter equal to −0.3 mm. A typical observed number of streamers is 150–200. Depending upon the conditions, they are more or less pronounced or even merged together giving the impression of the uniform plasma layer propagating from the high-voltage electrode.

The second, filamentary mode of the discharge is observed at high pressures at high voltage amplitude of negative polarity of the voltage pulse. A typical ICCD image of this mode is given by figure (2b). The number of filaments is at least 4 − 6 times lower than the number of streamers in the uniform mode, the optical diameter of the filaments is 1 − 3 mm. It is worth noting that both modes are low current modes, and that there is no spark formation in the filamentary mode. This fact is confirmed by the signals from the back current shunt BCS1 in the center of the cable, taken for quasi–uniform (figure (2c)) and filamentary (figure (2d)) regimes. It is clearly seen that, for both modes, a reflected current pulse has an opposite polarity relative to the incident pulse. This means that the reflection takes place from the open edge, no closing of the discharge gap is observed.

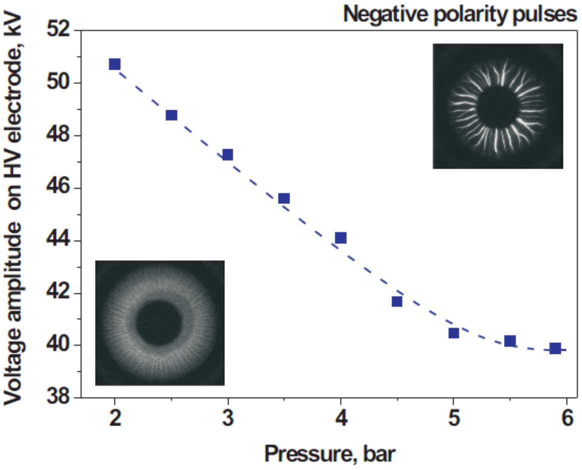

Fig. 3. The combinations of pressure and voltage corresponding to the transition mode.

To find the field of the parameters, corresponding to uniform–to–filamentary mode transition, an additional set of experiments has been carried out. The discharge chamber was filled by a synthetic air at a given pressure. The emission from the discharge was controlled by ICCD with 2 ns camera gate, synchronized to the beginning of the high voltage pulse with an adjustable delay. The voltage increased until the first filaments were observed. The experiments were performed in a single-shot regime without changing the gas between the experiments. To check the absence of the hysteresis, the experiments were repeated at increasing and then at decreasing voltage. The results are given by figure (3). The curve corresponds to the combinations of pressure and voltages when the quasi–uniform discharge transforms into the filamentary. The higher the pressure, the lower is the transition voltage, although it is always in the range of 40–50 kV on the electrode for the pressure range 1 − 6 bar.

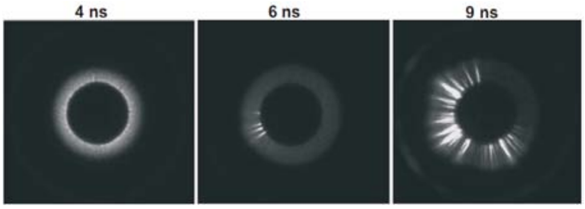

Fig. 4. ICCD imaging of transition process, P=3 atm, U=-47 kV. Camera gate 2 ns.

The details of the transition to filamentary mode at P=3 bar and U=-47 kV are given by a set of ICCD images in figure (4). First, the discharge starts from the high–voltage electrode and propagates as the quasiuniform discharge, that is as a set of streamers with relatively low emission intensity. Streamers start from the electrode with a velocity a few mm/ns and slow down practically to zero velocity during a few nanoseconds (about 5 ns for the given experimental conditions, this time instant corresponds to the plateau of the high-voltage pulse). At this moment, the emission intensity drops down, and on the week background of the “streamer” emission, a few bright channels develop from the high–voltage electrode with a typical velocity of about 5 mm/ns. The number of bright filaments increases rapidly, and at the end of the pulse they represent already a regular structure. If the voltage is higher than a transition voltage, a regular structure appears within first 1 − 2 ns.

4. DISCUSSION

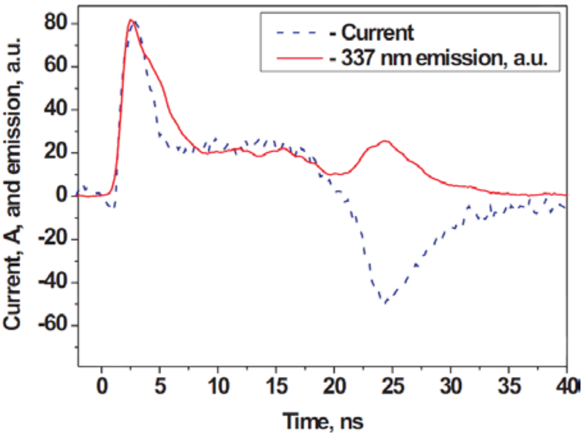

Fig. 5. Comparison of discharge current and emission intensity at 337.1 nm. Transition regime at P=3 atm, U=-47 kV.

Comparison of the shape of electrical current and emission of 2+ system of molecular nitrogen for the regime corresponding to “quasi-uniform”–to–filamentary transition, is given by figure (5). It is seen that the shapes of emission intensity and the current presented in figure (5) are rather similar.These data allow to estimate the fact that at our conditions the electric field in streamer channel is constant during first 20 ns which allows to perform the numerical modeling at constant field. The modeling was performed with the extended kinetic scheme [4]. The kinetic curves obtained with the numerical model are presented in figure (6). The current obtained experimentally and calculated numerically on the base of experiments is presented in figure (7). The results presented in this figure demonstrate reasonable agreement between experiment and theory.

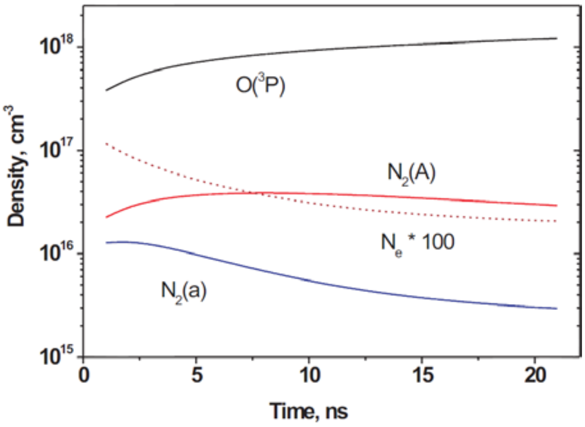

Fig. 6 Kinetic curves of main active species. E/N=100 Td, P=3 atm, T=300 K. Synthetic air.

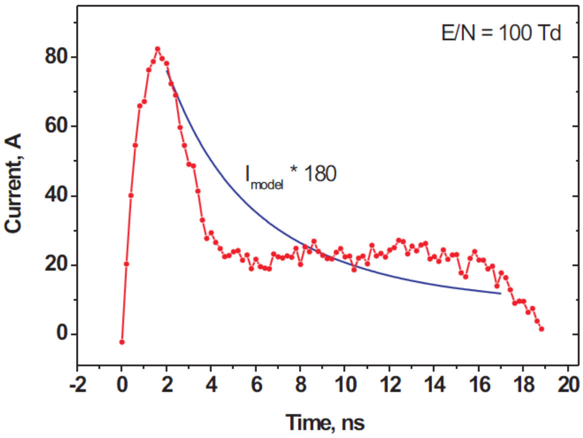

Fig. 7. Discharge current at E/N=100 Td, P=3 atm, T=300 K. Dash-dot curve – experimental results, solid curve – numerical results.

The process of filamentation presented in fig. (4) can be considered as thermal instability in cathode layer [4].

5. CONCLUSIONS

Development and propagation of a pulsed nanosecond surface dielectric barrier discharge has been studied in synthetic air for radially symmetric and for planar geometries for a range of pressures 1-5 bar at ambient temperature. It was shown that, at low voltages, discharge consists of a few hundreds of thin streamers, filling in a "quasi–uniform" manner the dielectric surface. Starting form a certain values of voltage and pressure, in the negative polarity discharge the streamers slow down and stop; and the discharge transforms into a regular filamentary structure. The parameters of the structure (number of filaments, distance between them) practically do not change in the considered range of parameters. No significant changes of the current and electric field are observed at transition point. The results of numerical analysis based on experimental results and extended kinetic scheme demonstrate reasonable agreements between theory and experiment.

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