Collective motion of microdischarges driven by the buoyancy flow

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Abstract: Dielectric barrier discharge (DBD) is atmospheric pressure gas discharge, which is generated in geometric configuration with an insulating (dielectric) layer on one or both of the electrodes. This study discloses an investigation of the optical and electrical properties of microdischarge under the action of buoyancy driven convective flow. Parameters such as microdischarge collective dynamics at different discharge and dielectric layer temperatures were measured.

Keywords: Dielectric barrier discharge, microdischarge, convective flow.

1. Introduction

Non-thermal atmospheric pressure plasmas are widely used in diverse technology fields such as plasma medicine and agriculture, plasma material deposition, surface modification, and additive manufacturing, plasma catalysis, and active flow control [1, 2]. DBDs are used in a broad range of fields of applications, starting with ozone generation, and continuing many other requests of industry. The dielectric barrier discharge (DBD) is atmospheric pressure gas discharge, which is generated in configurations of electrodes with an insulating(dielectric) layer on one or both of the electrodes. Compared to other conventional atmospheric pressure plasmas sources, both (or at least one) of the DBD's insulating barrier electrodes cover the electrode surface, which prevents the glow to arc transition by limiting the current. At room conditions, DBDs visually appear as thin plasma channels, so-called microdischarges (MDs), often named filaments.

Volume DBD with symmetric-plane discharge electrodes generated by sinusoidal high voltage (HV) signal contains randomly distributed MD channels. MD channels show advanced collective phenomena and form various self -organized patterns. The collective interaction and dynamics of MD channels are very important not only for static volumetric DBD in air, but also for DBD under the influence of external factors, such as gas flow [3]. Moreover, the additional gas flow can be seen as the simplest and most economical way to achieve a uniformly diffuse DBD of air, which is highly desirable for process applications [4]. Therefore, in recent decades, various groups have focused close attention on the study of DBDs under air flow to shed light on the collective dynamics of MD channels and general changes in the operating modes of discharges.

The gas flow convection in discharge gap determines the spatial and temporal distribution of charged and excited particles, which in turn are responsible for pre-ionization in the MD channels in DBD. Pre-ionization in the discharge gap is a key factor in further evolution of individual microdischarges and formation of collective phenomena as self-organized patterns, spatial "memory effect" of microdischarge channels. Even if there is no external gas flow, there is always room for particle transport due to intense heat transfer and natural convection, since microdischarges in the dielectric gap are a local source of heat. Although the DBD is a transient thermal nonequilibrium discharge, Joule heating in a couple of chemical dissipation of energy in the discharge volume, and dissipation of part of the applied power as heat on dielectrics leads to active heating of the walls of the discharge cell. While the volume DBD behavior in an externally stimulated gas flow has been extensively studied, there are insufficient data on the impact of the natural convection gas flow on the collective behavior of MD channels and structure of the filamentary barrier discharge in air.

This study discloses an investigation of the optical and electrical properties of DBD with microdischarge. In this work, the dynamical properties of filament in dielectric barrier discharge are achieved at the convective flow of air, as continue of our previous work [7, 8]. Discharge parameters such as microdischarge and gas flow average velocities, and discharge and dielectric layer temperatures were measured. From the additional information from high-speed imaging of the discharge and Particle Image Velocimetry (PIV) analysis, the movement of the filaments is obtained and the average velocity is measured at a certain temperature of the dielectric layer. The convective flow in the interelectrode volume has been modeled using COMSOL Multiphysics.

2. Experimental part

The schematic view of the experimental setup is shown in Fig. 1. The main part of setup is DBD discharge cell. The discharge cell consists of two plane-parallel electrodes. Both electrodes are located on a quartz tile, which plays the role of dielectric (dielectric constant of quartz is 3.5). The dimensions of both quartz tiles are 60x60 mm2. The lower electrode is an aluminum plate with a length of 38 mm and a width of 33 mm, and is located on the surface of the quartz tile and connected to a high voltage power supply. The upper electrode is glass, the surface of which is coated with indium tin oxide (ITO), and it is grounded through a low-inductance shunt resistor (rated 51 ohms, with a power of 10 W). The high voltage power source composed of SDX waveform generator, Pro -Lite 5.0 power amplifier and high voltage transformer 2500S. The 30 kHz AC sinusoidal signal from waveform generator amplified by audio amplifier and enhanced to high voltage signal by transformer and applied to electrodes of volume DBD. The typical applied voltage and current are 26 kVpp AC and 100 mA, respectively. The I-V curve monitored by Wave Jet 354A oscilloscope. High voltage detected by Tektronix P6015 -1/1000 probe, while current detected by low voltage probe through low-inductance R=51 Ohm shunting resistor. The IR camera is used to detect the change of DBD quartz dielectric electrode temperature. The monochromator is used to detect the discharge spectrum, then the discharge temperature is calculated from it.

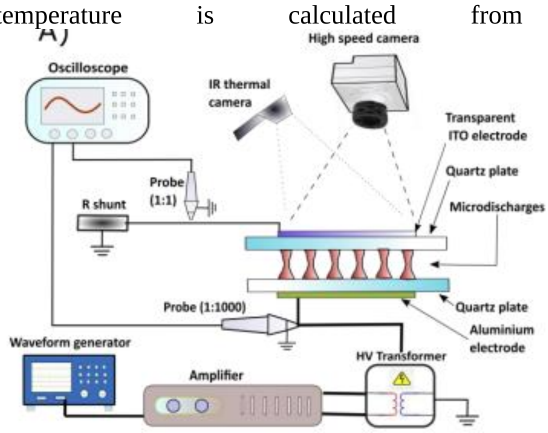

Fig. 1. General scheme of experimental setup

3. Results

The change in the temperature of dielectric quartz electrode during the 300 s operation of the discharge for both vertical and horizontal arrangement is shown in Fig. 2. The data presented corresponds to the highest quartz temperature as measured by the infrared camera images. After the plasma breakdown, the temperature of the dielectric discharge walls gradually increases.

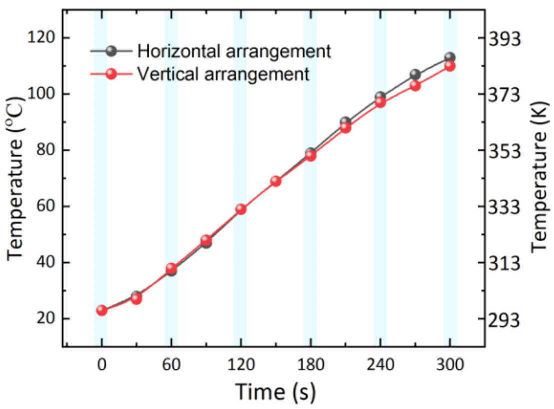

Fig. 2. The change in the temperature of dielectric quartz electrode during the 300 s operation of the discharge for both vertical and horizontal arrangement

According to the results of modeling in the Comsol Multiphysics program, the distribution of convective air flow velocity over the surface and arrays of velocity direction vectors along the discharge gap height axis are shown in Fig. 3A. And from the results of particle image velocimetry (PIV) analysis, distribution of movement of microdischarges over the surface of dielectric shown in Fig. 3B. As can be seen from the figures 3 A and B, movement of flow and microdischarges directed upward and from the figure A, the velocity distribution along the horizontal axis inside the vertically adjusted discharge gap has an inverted parabolic profile. This is expected because of the high viscosity of the flow layers near the discharge walls and the general profile for fully developed flow in a rectangular channel.

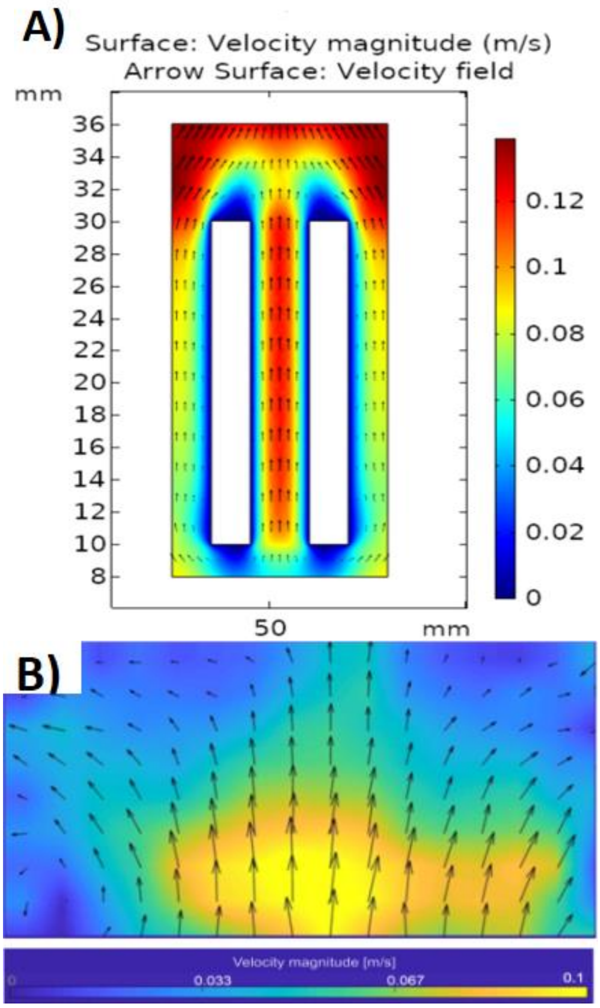

Fig. 3. The simulated convective airflow velocity distribution surface map and velocity direction vector arrays in the discharge gap height axis: A) in the Comsol Multiphysics, B) in the particle image velocimetry (PIV)

From the optical property of the discharge as a spectrum performed with a monochromator, the temperature of the discharge is calculated and compared with the dielectric temperature obtained with an infrared camera.

4. References

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