Discharge propagation in ceramic foams and capillary tubes

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Discharges in spatially confined geometries, such as microcavities and micropores of various materials, present a promising method for the generation of atmospheric pressure plasma. Discharges in ceramic foams and capillary tubes are two relatively new types among them. The work describes basic physical properties and mechanisms of these discharges addressing the effects of the power supply characteristics (applied voltage, frequency and power) and geometry and properties of the dielectric material (length and diameter, number of tubes, pore size).

1. Introduction

Non-equilibrium plasmas generated by electrical discharges at atmospheric pressure are very attractive due to numerous applications, including environmental and biomedical treatments and surface modifications. The advantage of these discharges is that they can produce high densities of chemically active species at relatively low energy consumption. The apparent advantage of atmospheric air discharges is using the ambient atmosphere as an operating gas, providing very easy and cheap implementation. The most commonly used discharge types are coronas and dielectric barrier discharges. They are typical with streamer filaments, which form and propagate in the space or along the surface of dielectric materials. The discharges can be generated even inside pores and cavities of various insulating and conductive materials placed between the stressed electrodes. A number of hybrid configurations and devices have been developed and utilized in the past decades, including micro-hollow cathode discharge, capillary plasma electrode discharge, etc [1].

The presented work focuses on two other, less-known configurations: discharges in porous ceramic foams and discharges in capillary tubes. Description of their formation, propagation and physical properties based on electrical and optical measurements is presented. The effect of the applied voltage and dimensions of the pores and tubes (length, diameter and number) are addressed. The motivation to investigate these discharges is given by a demand to further improve the performance of existing conventional automobile honeycomb catalytic converters, with emphasis to resolve and overcome several existing technical limits (e.g. cold starts). It is well-known that integration of catalysts with plasma results into improved pollutant removal efficiency, excellent carbon balance, and minimal aerosol production. Therefore, to find a suitable way how to generate stable discharges inside small cavities and pores of the conventional catalysts introduces a challenge into an ongoing research.

2. Discharge in ceramic foams

Physical properties of discharges generated by DC or AC power inside the ceramic foams with pore size from 2 to 200 μm and a thickness of 3 and 7 mm were investigated [2-4]. The formation of discharges inside the pores was found possible only for a specific combination of the applied voltage and the pore size. At a small applied voltage, only a barrier discharge develops on the surface of the foam, while with further increase of the voltage it transits into capillary discharges inside the foam. The discharge inside the foam is repetitive and forms from the foregoing barrier discharge. Its formation is accompanied with a sudden increase of the mean discharge current and power, a significant voltage drop and current pulses with amplitudes of tens of amps. The light emission of the capillary discharges is also much stronger compared to the diffuse light of the surface barrier discharge. Temporarily resolved imaging reveals the discharges inside the foam were randomly distributed both in time and space, and the two consecutive discharges occur with the minimum delay of several hundreds of μs and never at the same place. The discharges are generated in the whole volume of the foam and their distribution is relatively homogeneous. The mechanism governing the capillary discharges inside the ceramic foams is related to the back corona phenomenon that occurs when a porous dielectric layer of high resistivity is present at the electrodes resulting in gradual accumulation of charges on the layer. When the number of charges exceeds a critical value, an ultimate breakdown through the layer occurs. Repetitive charge accumulations and subsequent breakdowns of the layer result in regular repetitive discharges, as we observed. The discharges inside the foams are short sparks, whose transition into an arc is avoided by a small capacity of the electrodes and connecting cables. The properties of discharges are critically determined by their interaction with the dielectric walls inside the foam, as the production of the charged particles is limited by ambipolar diffusion toward the walls of the pores and volume recombination [3].

3. Discharge in capillary tubes

The discharge in capillary tubes was investigated with a single capillary tube [5, 6], as well as in the case of bundle of several capillary tubes [7, 8]. The single capillary tube tests were essential to understand the nature and mechanism of the discharge formation and propagation, while the tests with bundle of capillary tubes were performed to assess the plasma stability, spatial homogeneity and chemical activity of the discharge. Discharge in a single capillary tube was generated by positive pulsed power supply and with capillaries of diameter of 0.2 - 2 mm and length of 5-30 mm. The spatial-temporal resolved propagation of the discharge front in the tubes was investigated with respect to the applied voltages and compared with the propagation in free space. The average velocity of the front increased with the diminishing tube diameter and was found to be of order 10^7-10^8 cm/s. The instant velocity of the discharge front from the anode to the cathode slightly decreased in time. The effect of DC bias applied in addition to the pulsed voltage was tested too. Application of the negative bias to the cathode resulted in an increase of the discharge front propagation, while positive bias slowed down the front and made it to vanish between the electrodes. We even tested various configurations of several capillaries arranged in one axis and separated by one or two porous dielectric layers. The changes in discharge front propagation velocity (delay caused by transition through a layer, propagation along the layer vs. across the layer) as function of thickness/porosity of the layer and amplitude/frequency of the applied voltage pulses was evaluated and compared to the case of a single capillary. To assess the optimal conditions for the generation of stable and homogenous plasma discharges inside honeycomb shaped automobile monolith tests with not only one but rather a bundle of capillary tubes were performed. Instead of the ceramics monolith we used quartz tubes enabling visual observation of the discharges inside. Due to unstable discharge generation with tubes placed directly between two electrodes, a system of three electrodes and two power supplies was successfully used instead. The assistant discharge in a pellet bed located at one end of the capillary tubes was ignited, while DC bias was applied on the third electrode on the other end of the tubes. The assistant discharge worked as an ionizer, producing charged particles and ionic space charges, while DC bias maintained an ionic wind toward the third electrode to form the plasma inside. The homogeneity and the stability of the plasma were largely dependent on the discharge polarity, ballasting resistor and gas mixture humidity.

The two discharges were briefly subjected to the investigations of their plasma chemical effects. The tests of ozone generation and NOx removal demonstrated the promising plasma chemical potential of the capillary discharges in porous ceramics [9]. The chemical effects of the discharge in capillary tubes were demonstrated for the collection of suspended particles and NO oxidation [10, 11]. The discharges have proven their potential in the tests directed on exhaust treatment, however their potential is expected to further improve when combined in a plasma-catalytic system.

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4. References

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