Discharges in ceramic honeycomb monoliths and glass capillary tubes

K. Hensel, S. Kukura, R. Cimerman, M. Janda

Faculty of Mathematics, Physics, and Informatics, Comenius University Bratislava, Slovakia
e-mail: hensel@fmph.uniba.sk

Abstract: Properties of discharges generated in ceramic honeycomb monoliths, in a bundle of glass capillary tubes as well as a single capillary tube was investigated. Electrical and optical characteristics of the discharges were recorded and analysed, and their chemical activity was briefly evaluated.

Keywords: honeycomb catalyst, glass capillary tubes, electric and optical diagnostics, gas analysis

1. Introduction

Atmospheric pressure cold plasmas generated by electrical discharges are widely attractive due to their numerous applications. Among their environmental applications, the gas cleaning for air pollution control has attracted a lot of attention in past decades. The commonly used discharge types for air pollution control are corona and dielectric barrier discharges, in devices where the discharge is generated in a gas volume or propagates along the dielectric surface. The discharge can be also generated inside cavities and pores of various dielectric material placed between the electrodes, e.g., porous ceramic foams, pellets and beads, or capillary tubes. These discharges are very interesting from the point of view of plasma catalysis when a dielectric material is supported by various catalysts. The interaction of the plasma with the catalytic material affects properties of the generated plasma as well as catalyst activity and selectivity. It may lead to various synergistic effects that often result in enhanced efficiency of desired chemical processes.

This contribution summarizes the results on generation of discharges in a single quartz glass capillary tube, a bundle of capillary tubes as well as ceramic honeycomb monolith [1-4]. All tested systems were of point-to-plane reactor geometry. Electrical and optical measurements have been performed in capillary tubes and honeycomb monoliths of various geometry (diameter, length, and cpi), feed gases (air, N_2, O_2, H_2O), using various power supplies (AC, DC, pulsed) of both polarities. Electrical diagnostics included current and voltage oscilloscopic measurements and power consumption evaluation. The optical diagnostics included discharge photography, optical emission spectroscopy as well as photomultiplier and ICCD camera measurements to track the discharge propagation in capillary tubes. Chemical activity of the discharges was also briefly investigated by monitoring various gaseous species by absorption FTIR spectroscopy.

2. Discharge in a single capillary tube

The discharge in a single capillary tube (diameter of 0.2-2 mm, length 1-2.5 cm) was investigated to understand a fundamental mechanism of the discharge formation and propagation [2]. It was generated by pulsed high voltage, AC high voltage (50 Hz–1kHz) or their combination. A velocity of the discharge generated by pulsed power was enhanced or suppressed by AC bias. For instance, with a capillary tube of 1 mm diameter and 20 mm length, high voltage pulse of +15 kV, and AC bias of -13 kV a discharge propagation velocity was found in a range of 7–10x10^7 cm/s (**Fig. 1**).

Application of the negative AC bias increased the discharge velocity, while positive AC bias slowed down the discharge front and made it to vanish between the electrodes. The propagation velocity increased with the decreasing tube diameter. It was found 4.3x10^7 and 9.9x10^7 cm/s for 1 and 0.2 mm diameter, respectively. Onset and breakdown voltages increased with the decreasing tube diameter, while stable discharge generation was improved by extending the discharge gap. Further the amplitude of current pulses was higher for smaller tube diameters and smaller oxygen content. Propagation velocity of the discharge was higher for smaller tube diameters and higher oxygen content.

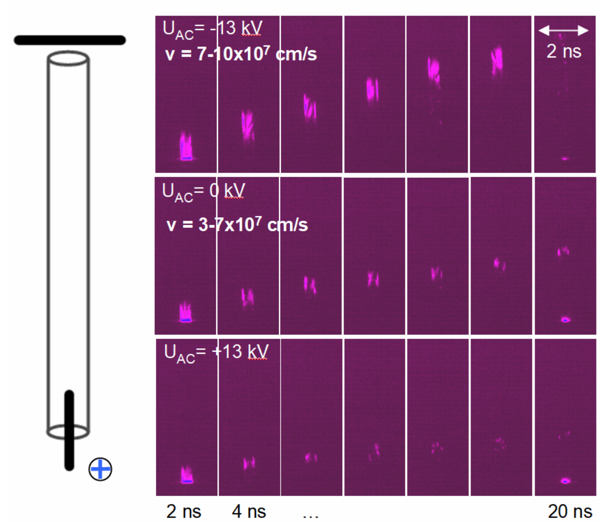

Fig. 1. Propagation of a discharge generated in capillary tube by pulsed high voltage as function of U_{AC} bias [tube ∅ 1 mm, d_{gap} 20 mm, U_{pulse} +15 kV, air].

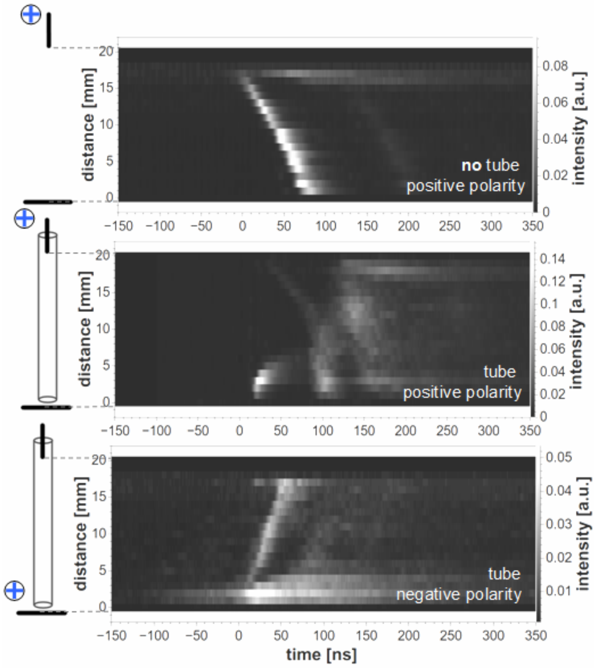

Fig. 2. Propagation of a discharge generated with/without capillary tube by AC high voltage in both polarities visualized based on PMT measurements [d_{gap} 20 mm, U_{AC} 18 kV, air].

Besides using ICCD camera to track the discharge front propagation in time (**Fig. 1**), discharge propagation in both polarities was also visualized based on photomultiplier (PMT) measurements in both polarities, first without and then with capillary tubes (**Fig.2**) As the figure shown several lights trails in one sequence were observed and discharge propagation was faster for negative polarity.

3. Discharge in a bundle of capillary tubes

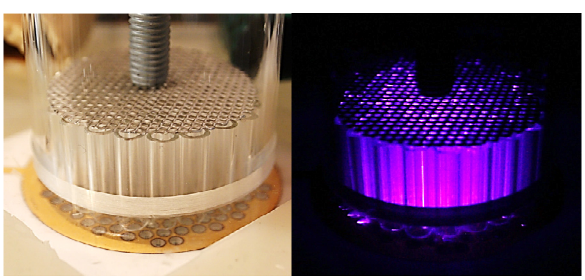

Fig. 3. Discharge generated in a bundle of capillary tubes assisted by AC driven multi-hollow dielectric barrier discharge [d_{gap} 20 mm, U_{AC} 4 kV, 1 kHz, U_{DC} +14 kV, air].

Tests with a *bundle of capillary tubes* were performed to assess the overall stability and spatial homogeneity of the discharge. The quartz tubes were used instead to be able to perform the optical emission spectroscopy of the discharge and monitor the discharge propagation inside the channels. The discharges were generated by a DC high voltage in a point-to-plane geometry, eventually assisted by an auxiliary AC driven discharges either in a pellet bed [1] or in a multi-hollow dielectric barrier discharge [4] (**Fig. 3**). The auxiliary discharges served as ionizers, while DC bias maintained the ionic wind and extended the discharge inside the capillary tubes. The homogeneity and the stability of the plasma were largely dependent on the discharge polarity, ballasting resistor, and feed gas humidity.

4. Discharge in honeycomb monoliths

At last, the discharges generated directly in *ceramic honeycomb monoliths* of various geometry (diameter of 77 mm, length 12–24 mm, 64–300 cpi) were tested (**Fig. 4**). They were also briefly subjected to the investigations of its plasma chemical activity. The generation of O_3 and NOx removal was monitored by FTIR spectrometry. Tentative results were promising and are expected to be further improved in systems with honeycomb monoliths supported by various metallic catalysts.

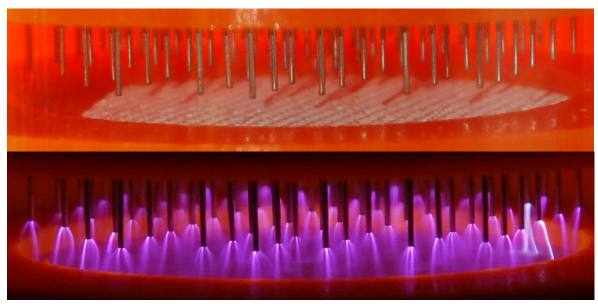

Fig. 4. Discharge generated in honeycomb catalyst in point-to-plane geometry by DC high voltage [d_{gap} 17 mm, U_{DC} 21 kV, 200 cpi, air].

Acknowledgment

The work was supported by Slovak Research and Development Agency grants no. APVV-20-0566 and by Scientific Grant Agency VEGA grant no. 1/0822/21.

References

[1] K. Hensel, Eur. Phys. J. D 54 (2), 141-148 (2009)
[2] K. Hensel, M. Janda, Z. Machala, V. Martišovitš, P. Adda, P. Le Delliou, P. Tardiveau, S. Pasquires: *Discharge propagation in ceramic foams and capillary tubes*, 32nd International Conference on Phenomena in Ionized Gases XXXII ICPIG, Iasi (Romania), July 26-31 (2015)
[3] H.-H. Kim, A. A. Abdelaziz, Y. Teramoto, T. Nozaki, K. Hensel, Y.-S. Mok, S. Saud, D. B. Nguyen, D. H. Lee, W. S. Kang, Int. J. Plasma Environ. Sci. Technol. 15 (1), e01004 (2021)
[4] R. Cimerman, K. Hensel, Int. J. Plasma Environ. Sci. Technol. 15 (1), e01003 (2021)