WDS'07 Proceedings of Contributed Papers, Part II, 134–138, 2007. *ISBN 978-80-7378-024-1 © MATFYZPRESS*

AC Microdischarges in Porous Ceramics

M. Leštinský, M. Janda, Z. Machala, K. Hensel

Department of Astronomy, Earth Physics and Meteorology, Comenius University, Bratislava, Slovakia.

Abstract. Generation of microdischarges inside porous ceramics by AC high voltage has been investigated. Electrical and optical measurements were performed to explore the physical properties of the microdischarges. The effect of pore size, discharge power and gas mixture on the discharge properties and development is described.

Introduction

Research of various types of non-thermal plasmas generated by electrical discharges at atmospheric pressure has received a fast development in the last two decades. Streamer and pulsed coronas, and various types of dielectric or ferroelectric barrier discharges are mostly used. They are typical with nonequilibrium character and a large amount of thin filamentary channels, called microdischarges. The microdischarges produce a large density of energetic electrons and free radicals at relatively low energy consumption; therefore they represent a potential method for car exhaust cleaning [1-3].

In the recent years, there appeared a few pioneering works dealing with the generation of microdischarges in narrow cavities and capillaries of porous dielectric materials. The objective of the paper was to investigate the physical properties of these microdischarges by 50 Hz AC high voltage power supply by the electrical and optical methods.

Experimental Setup

The experimental set-up (Figure 1) includes a discharge reactor and electrical and optical circuits. The discharge reactor consisted of a porous ceramics placed between two stainless steel mesh electrodes inside the quartz cylinder. The ceramics were composed of alumina, and their diameter and thickness were 31 and 7 mm, respectively. The pore sizes of the ceramics were from 2 to 200 µm. (Figure 2). The whole reactor was placed in a Faraday cage to reduce induced noise signals.

AC regulated high voltage power supply was used to generate the discharge. The voltage on the reactor was measured by a high voltage probe Tektronix P6015A and the discharge current was measured using a current probe Pearson Electronics 2877 (1V/A), both linked to the digitizing oscilloscope Tektronix TDS2024 (200 MHz, 2.5 GS/s). The total power including power losses in the electrical circuit was measured by the digital wattmeter Metex 3860M.

Optical emission spectroscopy system consisted of a dual fiber-optic compact spectrometer Ocean Optics SD2000 with CCD detector used for fast scanning in the UV and VIS-NIR region (200-500 and 400-1050 nm). The photographs of discharge were taken by the digital camera Nikon E4300. All experiments were carried out in mixtures of nitrogen and oxygen at atmospheric pressure and at room temperature. The total gas flow rate ranged from 0.4 to 2 l/min.

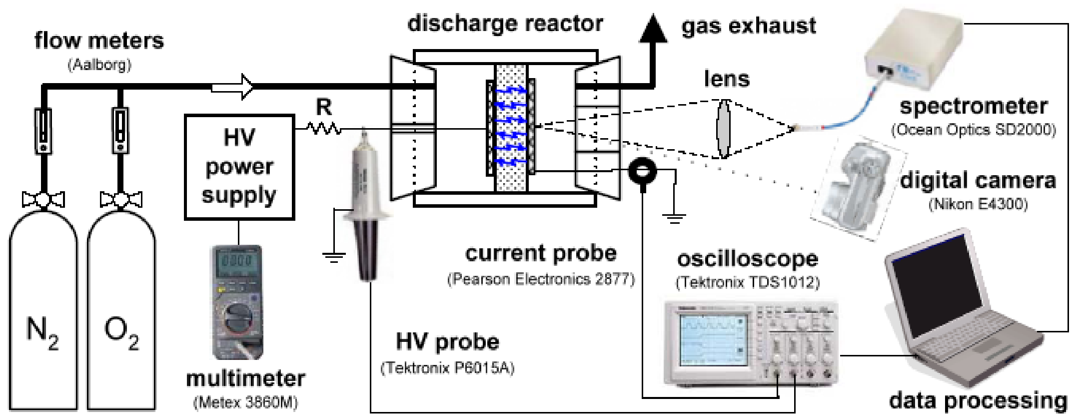

Figure 1. Experimental set-up

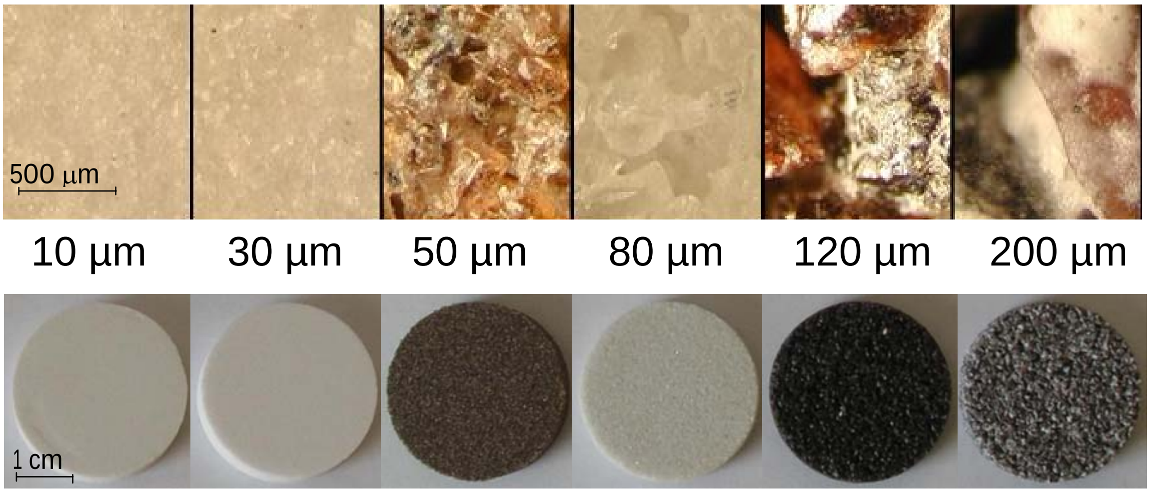

Figure 2. Structure of ceramics.

I. Formation of microdischarges

The physical mechanism generating microdischarges inside the porous ceramics is probably related to the back-corona discharge, a phenomenon often found in the electrostatic precipitators [4, 5]. It occurs when charged dielectric particles are collected on the electrode and form a porous layer of high resistivity, which the electric current must pass through. The highly resistive layer does not allow the charge to decay at a desired rate, resulting in the buildup of an excess charge on the layer. When the voltage drop across the layer exceeds a critical value, an ultimate breakdown through the layer occurs. This breakdown is observed as fine discharge channels called microdischarges. The regular pulsed microdischarges are result of repeated charge accumulations and subsequent breakdown of the dielectric layer.

II. Electrical properties

We found that the successful generation of microdischarges inside the ceramics depends on the pore size and the applied voltage. At small voltage only a surface discharge could be observed. With the increase of the applied voltage the surface discharge "leaked into" the ceramics and the microdischarges were formed inside.

Figure 3 displays the P-U characteristics after the onset of the microdischarges in three different ceramics. While the slope of the surface discharge's characteristics was independent of the used ceramics, the slope of the microdischarge characteristics increased with the pore size. The pore size determined the volume of the discharge and thus also limited the discharge current. The increase of the slope at the constant voltage was the result of the increase of the discharge current. The slope of the characteristics increased also with the content of nitrogen in the gas mixture (Figure 4), resulting from the changes in the number and the distribution of discharge channels in the ceramics.

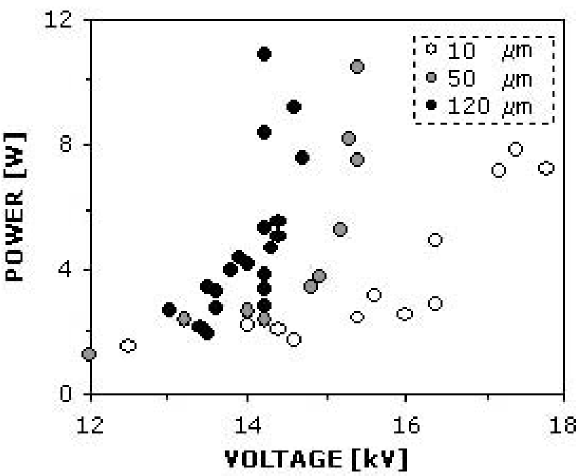

Figure 3. Discharge power as a function of the applied voltage (air).

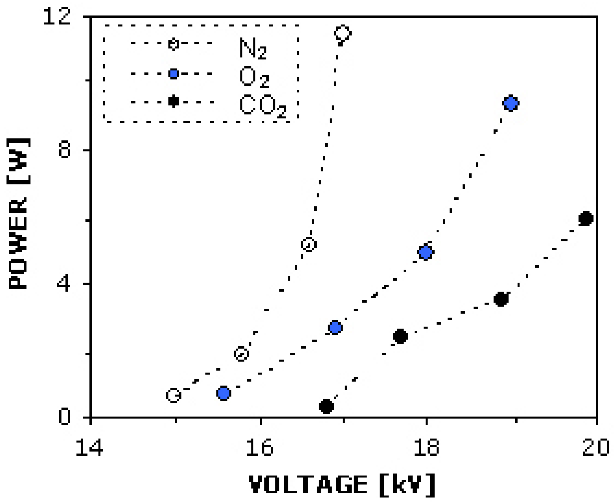

Figure 4. Discharge power as a function of the applied voltage (gas mixtures).

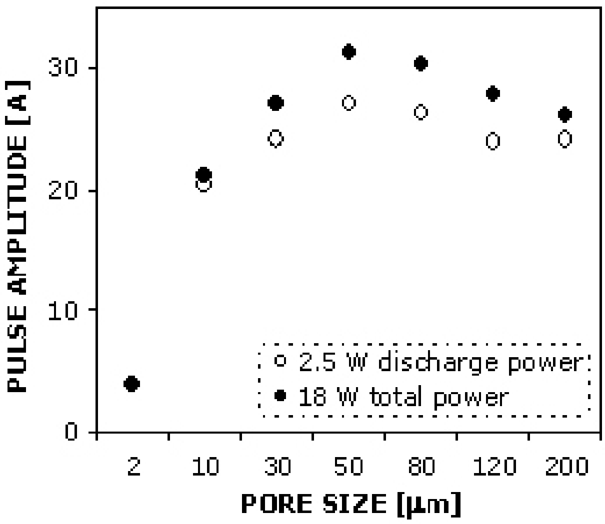

Figure 5. Current pulse amplitude as a function of the pore size (20% O_2 in N_2).

We recorded oscilloscopic waveforms of the applied voltage and the current pulses. The microdischarges occurred both in negative and positive polarity of the applied voltage. During one half-period several breakdowns were observed and they were accompanied by a voltage drop almost to zero and a sharp current pulses. The current pulses had a short duration of less than 100 ns and relatively high amplitude reaching several tenths of amps. The amplitude of the current pulses increased with the applied voltage and the pore size. At the constant power, the maximum amplitude of the current pulses was observed with 50 and 80 µm pore size ceramics (Figure 5).

III. Optical properties

We also recorded a photographs to visualize the macroscopic changes of microdischarges, depending on the gas composition and the pore size. This observations showed that the spatial and temporal distribution of the channels was not steady but randomly changed. The emission intensity increased with the discharge power resulting from the increase of the number of discharge channels and the discharge current.

We found that the increase of the oxygen amount in the gas mixture resulted in a redistribution of the microdischarge channels inside the ceramics. In nitrogen, the light emission was relatively homogenously distributed over the whole surface of the ceramics. With the increase of oxygen a gradual migration of the channels toward the rim of the ceramics occurred. Similar effect we observed also in CO_2 (Figure 6). The increase of oxygen caused also a reduction of the total number of discharge channels, which resulted in a decrease of the discharge current/power at a given voltage. Comparing all ceramics, at the given power and gas mixture, the most homogenous distribution of the channels inside the ceramics was observed for the pore size of 80 µm (Figure 7).

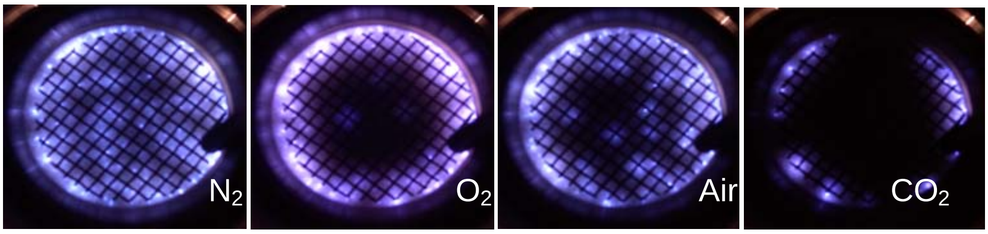

Figure 6. The effect of gas mixture (pore size 80 µm, P ~ 2-4 W).

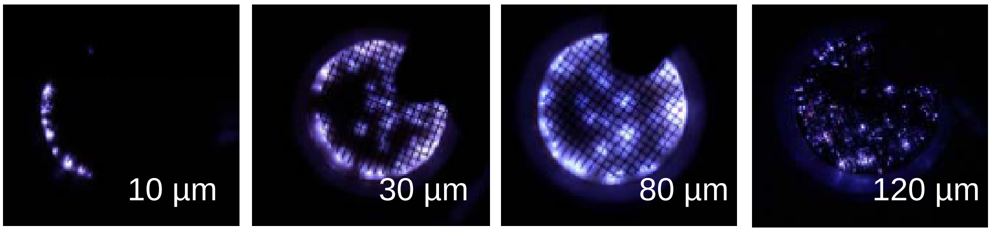

Figure 7. The effect of pore size (P = 6.4 W, 20% O_2 in N_2).

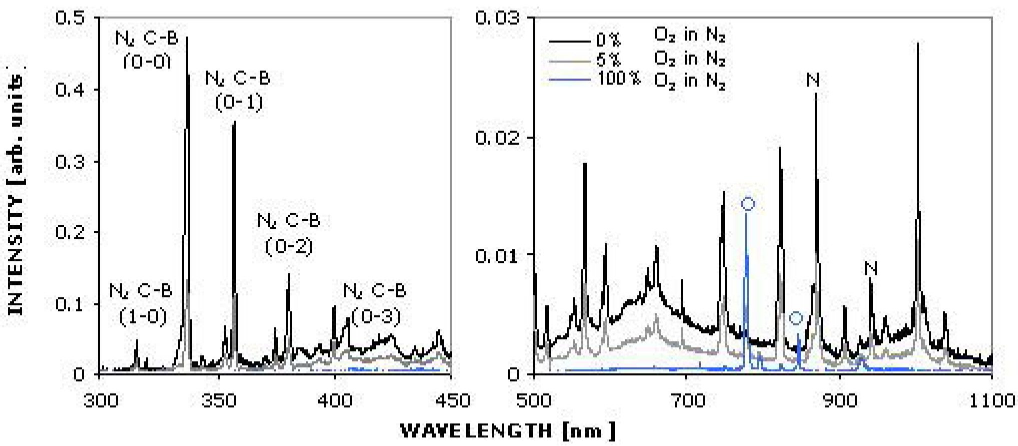

Figure 8. Emission spectra of microdischarges in UV-VIS region (pore size 80 µm, U = 16.5 kV).

Figure 8 presents the emission spectra of microdischarges in UV-VIS-NIR region taken at the constant power in mixtures with various amounts of oxygen. In nitrogen containing mixtures, the 2nd positive system of N_2 ($C^3\Pi_u - B^3\Pi_g$), the 1st positive system of N_2 ($B^3\Pi_g - A^3\Sigma_u^{\ +}$) and atomic N and O lines were observed.

Based on the spectral bands of the N_2 2nd positive system we were able to determine rotational (T_r) and vibrational (T_v) temperatures by fitting the experimental spectra with the simulated ones using Specair software for spectral simulation [6]. Owing to fast collisional relaxation at atmospheric pressure, the gas temperature T_g equals with T_r. Vibrational temperature $T_v > T_r$ indicates the non-equilibrium in the plasma. The temperatures measured for the ceramics with 80 µm pore size were the following:

N_2	$T_g \sim T_r = (300 \pm 50)$ K	$T_v = (2000 \pm 300)$ K
5% O_2 in N_2	$T_g \sim T_r = (350 \pm 50)$ K	$T_v = (2500 \pm 300)$ K
20% O_2 in N_2	$T_g \sim T_r = (400 \pm 50)$ K	$T_v = (2800 \pm 300)$ K

The temperatures increased with the increasing amount of O_2. This is because O_2 is an electronegative gas and so decreases the number of electrons by attachment under formation of negative ions. Higher energy is thus required to sustain the discharge at the same parameters than in nitrogen, thus resulting in higher temperatures.

Summary

Electrical and optical properties of microdischarges generated inside the porous ceramics by AC high voltage power have been investigated. The effects of the pore size, discharge power and gas mixture on the discharge properties were described. It was found that the onset voltage of the microdischarges decreased with the pore size, while the slope of the P-U characteristics increased with the pore size. Amplitude of the current pulses increased with the applied voltage and the maximum was observed for 50 and 80 μm pore size ceramics. In N_2, the light emission was relatively homogenously distributed over the whole surface of the ceramics, while in oxygen the microdischarges concentrated mainly at the edges of the ceramics. Emission spectroscopy showed the presence of the N_2 systems and atomic N and O lines. Overall, the optimal generation of the microdischarges and their distribution in the ceramics was observed for the ceramics with 50 and 80 μm pore size.

The microdischarge formation inside porous ceramics represents a novel way to generate large volume of stable atmospheric pressure plasmas in hybrid plasma–catalyst reactors, and can be effectively used for flue gas treatment.

Acknowledgements. The research has been supported by Slovak Research and Development Agency Grants APVT 20-032404 and SK-FR00506 and Slovak Grant Agency VEGA 1/3041/06.

References

[1] T. Oda, T. Kato, T. Takahashi, K. Shimizu, IEEE Trans. Industry Appl. 1998, 34, 268.
[2] T. Yamamoto, M. Okubo, T. Nagaoka, K. Hayakawa, IEEE Trans. Ind. Appl. 2002, 38, 1168.
[3] H.-H. Kim, G. Prieto, K. Takashima, S. Katsura, A. Mizuno, J. Electrostat. 2002, 55, 25.
[4] A. Mizuno, IEEE Trans. Dielec. Electr. Insul. 2000, 7, 615.
[5] A. Jaworek, A. Krupa, T. Czech, J. Phys. D: Appl. Phys. 1996, 29, 2439.
[6] C.O. Laux, T.G. Spence, C.H. Kruger, R.N. Zare, Plasma Sources Sci. Technol. 2003, 12, 125.