ICCD Camera Imaging of Discharges in Porous Ceramics

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Abstract—**The microdischarges generated inside porous ceramics represent a novel way to create stable atmospheric pressure plasmas. Hybrid plasma-catalytic system utilizing ceramics loaded with catalysts may be very effective for flue gas treatment. This paper presents the images of the discharges in porous ceramics generated by an ac high voltage and visualized by intensified charge-couples device (ICCD) camera system.**

Index Terms—**Atmospheric microdischarges, intensified charge-couples device (ICCD) camera imaging, porous ceramics.**

ATMOSPHERIC PRESSURE plasmas are often used for various environmental applications. The efficiency and selectivity of the plasma chemical process can be improved when the plasma is combined with a catalyst. Materials of various shapes (e.g., pellet bed, foams, and honeycomb) and composition (e.g., TiO_2, Pt/Al_2O_3) are used as catalysts. The investigation of plasmas generated inside small cavities and capillaries of various materials and their physical properties has been a subject of many recent papers [1]–[4]. It was found that depending on the applied voltage and pore size, two types of discharges—barrier discharge on the surface and capillary microdischarges inside the ceramics—can be observed [3], [4]. This paper presents the images of ac discharges recorded by intensified CCD camera. The camera was synchronized with the high-voltage power supply. The effects of camera gate time and pore size are reported.

The discharge system consisted of porous ceramic disks placed between two mesh electrodes. The disks were made of alumina–silica mixture, and their diameter and thickness were 31 and 7 mm, respectively. The pore size of the used ceramics was 10 and 80 μm. The discharge was generated by ac high-voltage power supply (50 Hz), and the discharge voltage was measured by a high-voltage probe Lecroy PPE20KV linked to the digitizing oscilloscope Lecroy LT374L (500 MHz; 4 GS/s). The optical system consisted of a digital camera Atmel Camelia 4M (black/white; resolution of 2048 $\times$ 2048 pixels) equipped with intensifier fragment Optronis (exposure time of 3 ns to 110 ms; spectral sensitivity of 400–700 nm). The camera system was synchronized with the applied high voltage. The images of the discharge were taken perpendicularly to the surface of the ceramics. The experiment was carried out in dry nitrogen with a gas-flow rate of 1 L/min at atmospheric pressure and room temperature.

The temporal development of discharge emission along the ac applied voltage signal was observed, and corresponding images were recorded by the camera. At a given voltage, the images showed the intense light emission in the region around the maximum amplitude of the applied voltage and the substantially smaller intensity beyond the region. The emission of the small intensity is attributed to the surface barrier discharge, which develops on the surface of the ceramics and is typical with pulses of amplitudes of several tens of milliamperes and an insignificant voltage drop. As the amplitude of the applied voltage increases, the surface discharge may transit into the repetitive capillary microdischarges inside the ceramics. Then, much more intense light emission is observed, which is accompanied by sharp current pulses with amplitudes reaching several tens of amperes and a significant voltage drop. The microdischarge is a spark discharge, whose transition into an arc is avoided by a small energy stored in the capacitor represented by the capacity of the electrodes and connecting cables. During the microdischarge, the production of the charged particles is limited by ambipolar diffusion toward the walls of the pores and volume recombination. The ceramics have high thermal shock resistance and effective heat dissipation. The erosion of the ceramics by the microdischarges was therefore found to be very slow, particularly when using ac power supply instead of dc. The detailed description of the physical properties of microdischarges can be found in [4].

Fig. 1(a) shows one period of the applied voltage waveform. The marked area of the waveform is zoomed below, showing the details of voltage and current waveforms and the camera gate signal. Fig. 1(b) shows the image for 10-μm pore-size ceramics recorded during the corresponding camera gate time. A comparison with the waveform shows that the number of voltage drops matches with the number of the spots in the image, i.e., each microdischarge is accompanied by a light emission and a voltage drop. Fig. 1(c) shows the image recorded during the following cycle of the applied voltage. The comparison of the discharge patterns of the two images shows that the microdischarges are randomly distributed both in time and space and the consecutive microdischarges do not occur in the same point. The delay between the microdischarges decreased with the amplitude of the applied voltage. With delay shorter than approximately 180 μs, a chance that two consecutive breakdowns occur in the same point increased. In such case,

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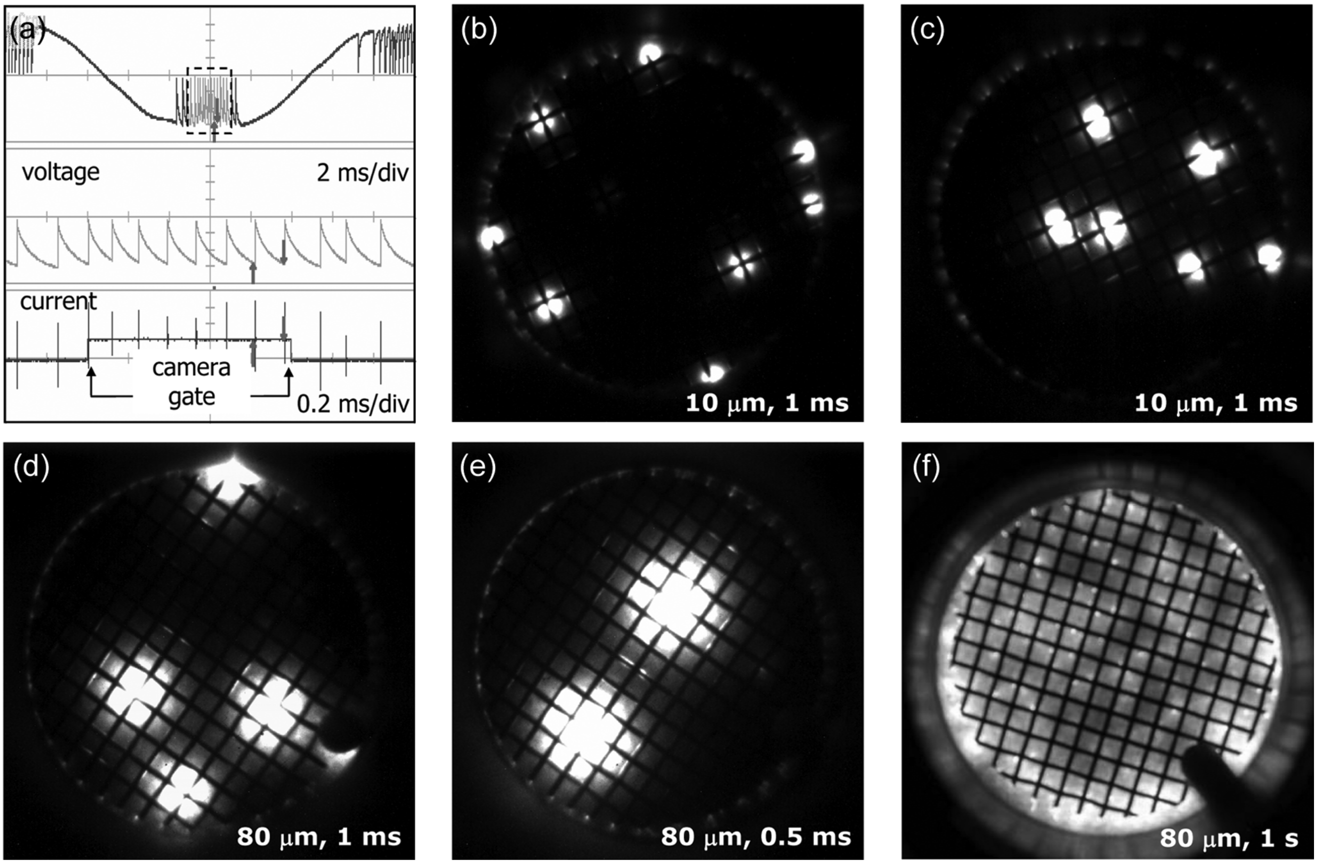

Fig. 1. (a) Voltage and current waveforms and (b)–(c) images of microdischarges in 10-μm pore-size ceramics during two different cycles of the applied voltage [gate time of 1 ms and camera sensitivity of 420]. (d)–(e) Images of microdischarges in 80-μm pore-size ceramics at two different camera gates [gate time of 1 and 0.5 ms and camera sensitivity of 420 and 470, respectively]. (f) Image taken by a digital camera [exposure time of 1 s, ISO 100, and f/4]. All images were taken in nitrogen at an applied voltage of 16 kV.

less emission spots than the number of voltage drops were observed. We assume that it is the result of the "memory effect" of residential heat or charge trapping due to a short relaxation time between the two breakdowns.

Fig. 1(d) shows the image of the microdischarges in the ceramics with 80-μm pore size, which was taken with the same camera settings and the applied voltage as Fig. 1(b) and (c). The comparison of the images shows that the diameter of the emission spot increased with the pore size. The diameter of the spot is determined by the diameter of the microdischarge channel and corresponding discharge current. At the given voltage, the discharge current and the amplitude of the current pulses were found higher with 80-μm pore size [4]. If the gate time was reduced to half, the number of the spots correspondingly reduced [Fig. 1(e)]. Finally, Fig. 1(f) shows the image of the microdischarges taken by a conventional digital camera at a time exposure of 1 s. The long exposure image shows that the microdischarges are generated in the whole volume of the ceramics. The most intense emission is observed at the sharp edges of the mesh electrode, because the electric field intensity is highest here.

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