DC Microdischarges Inside Porous Ceramics

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***Abstract*—The hybrid plasma-catalyst system represents an effective method for the pollutant abatement from car exhaust. A problem, however, is a limited volume of the generated plasma, and a pressure drop across the catalyst layer. A new approach on the generation of microdischarges inside porous ceramic materials is reported. The results show that the stable generation of microdischarges can be observed only in ceramics with specific pore size.**

***Index Terms*—Car catalyst, microdischarge, nonthermal plasma, porous ceramics.**

ATMOSPHERIC pressure nonthermal plasmas provide many uses in environmental, biological, and other applications, including abatement of atmospheric pollutants from air and car exhaust. The plasmas are typically generated by streamer and pulsed coronas, and various types of dielectric or ferroelectric barrier discharges. These discharges are characteristic by their nonequilibrium character and a large amount of thin filamentary channels called microdischarges. The chemical effect can be enhanced if the plasma is combined with a catalyst. The hybrid plasma–catalyst system is very effective for gas exhaust abatement applicable even at low temperatures. The drawback is, however, a limited volume of the generated plasma and a pressure drop across the catalyst layer. This problem can be solved by using a honeycomb-like catalyst, which has a large surface area, acceptable pressure drop, and is preferred for practical use. The plasma generation inside a honeycomb monolith and its use for the abatement of nitrogen oxides and hydrocarbons have been reported in [1], [2]. These experiments show that the plasma uniformity inside the narrow holes, as well as the insulation failure of the ceramic wall, appear to be a serious problem. Therefore, we used porous ceramic material instead of honeycomb to generate the discharge plasma. Our goal was to determine the conditions of a stable and uniform discharge generation with respect to the pore size of the ceramic material.

Our experimental setup consisted of ceramics placed between two stainless steel mesh electrodes. The ceramics were sintered from alumina and cordierite and their diameter and thickness were 28 and 3 mm, respectively. The pore sizes of the ceramics were 0.8, 15, and 90 μm. The experiments were performed in dry air flowing perpendicular to the ceramics layer. The discharge photographs were taken by the digital camera (Nikon, E4300).

Direct current (dc) regulated high-voltage power supply of positive polarity was used to drive the discharge reactor. Although alternating current (ac) or pulsed high-voltage power is typically needed if a dielectric barrier is present, we observed a successful generation of a pulsed discharge using dc excitation voltage. The pulsed behavior resulted from the phenomenon known as the back corona discharge [3]. The back corona is observed when a dielectric layer of high resistivity covers the electrode surface. In such case, the charge emitted from the electrode is accumulated on the dielectric surface and intensifies the electric field across the dielectric layer. If the amount of the charge accumulated on the surface becomes critical, the breakdown through the dielectrics occurs. This breakdown is observed as fine discharge channels called microdischarges. The regular pulsed discharge is a result of repeated charging and subsequent breakdown of the dielectric. The effective generation of microdischarges inside porous ceramics utilizing the back corona discharge is possible, however, only for a specific pore size and discharge power.

In Fig. 1, the photographs of the discharge using porous ceramics with pore sizes of 0.8 μm (top row) and 15 μm (bottom row) are shown. The pictures demonstrate the development of the discharge visual character at increasing power. The exposure time for all photographs was 8 s.

When using ceramics with very small pores (0.8 μm), the discharge developed on the dielectric surface (surface discharge). The breakdown through the dielectric did not occur and no discharge inside the porous ceramic was observed. The discharge current increased with the voltage relatively slowly (less than 10 μA/kV), as can be seen from the I-V characteristic (Fig. 2). Raised discharge power only caused the area covered by the surface discharge to expand.

When using ceramics with larger pore size, the change of the discharge mode was observed. It occurred either above the threshold voltage (with 15-μm pores) or at the discharge onset (with 90-μm pores), as shown in Fig. 2. The slope of the I–V characteristic suddenly increased as the surface discharge "leaked into" the ceramics and microdischarges inside the material were observed. Typical blue color of the surface discharge changed to the intense white emission of randomly distributed microdischarges. The amplitude of the current pulses was high compared to the surface streamers. The frequency of the pulses, which increased with the mean discharge current but appeared to be independent of the pore size, was on the order of kilohertz. The obtained results are in a good agreement with the estimates from the Paschen's law, which determines the breakdown voltage as a function of the pressure-gap length product. In atmospheric pressure air, the Paschen's minimum

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Manuscript received July 3, 2004; revised November 25, 2004. This work was supported by the 21st Century COE Program on "Ecological Engineering for Homeostatic Human Activities", Ministry of Education, Culture, Sports, Science, and Technology, Japan.

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Digital Object Identifier 10.1109/TPS.2005.845389

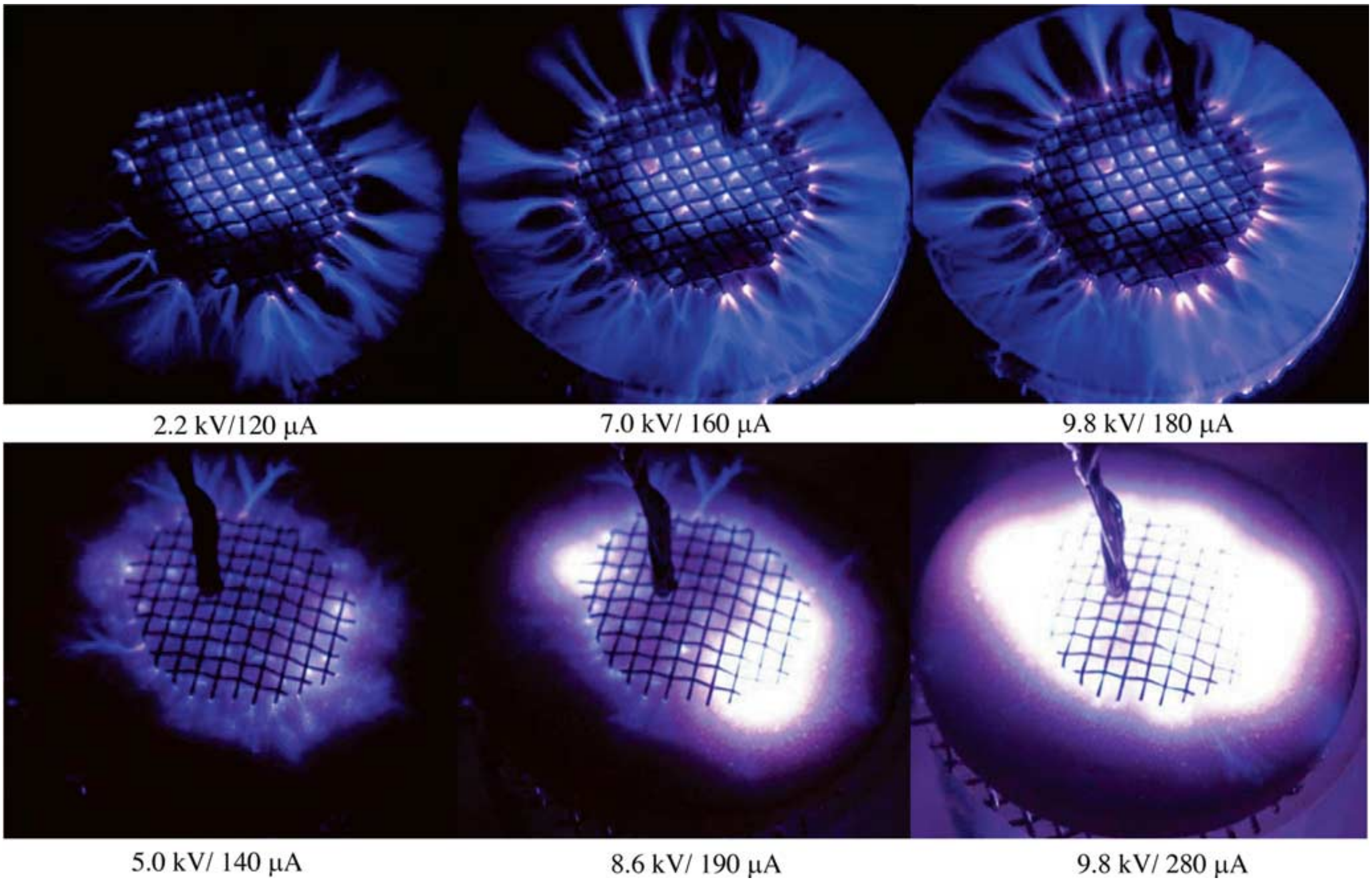

Fig. 1. Discharge generation using porous ceramics. The photographs represent the discharge development using ceramics with pore sizes of 0.8-μm (upper row) and 15-μm (lower row). With 0.8 μm pores, surface discharge mode is established, while with 15 μm pores, microdischarges are generated inside the ceramic material.

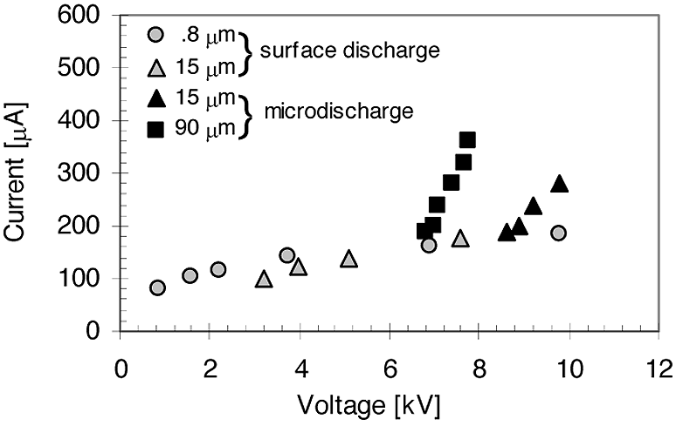

Fig. 2. Discharge I–V characteristics for ceramics of various pore sizes.

corresponds to several micrometers, which is about the pore size of the ceramics where microdischarges were generated. The generation of microdischarges inside the ceramics can be explained by the back corona discharge phenomenon. There is a small difference since the back corona is usually associated with excessive sparking. This sparking is due to gas heating in the discharge channel that reduces the gas density sufficiently to increase the E/n above the critical value so that the ionization increases. In microdischarges, the sparking effect is suppressed because the gas expansion inside the fine pores of the ceramic is limited, not to mention that the material is a high thermal shock resistive cordierite. When a ceramic with larger pore size is used, its surface can not be effectively charged, and thus instead of microdischarges, a rapid spark breakdown occurs.

The discharge formation inside porous ceramics presents a novel way to generate large volume stable atmospheric pressure plasmas in hybrid plasma–catalyst reactors.

REFERENCES

[1] H. H. Kim, "Application of Nonthermal plasma in environmental protection," Ph.D. dissertation, Dept. Ecological Eng. Toyohashi Univ. Technol., Toyohashi, Japan, 2000.

[2] C. Ayrault, J. Barrault, N. Blin-Simiand, F. Jorand, S. Pasquiers, A. Rousseau, and J. M. Tatibouët, "Oxidation on 2-heptanone in air by a DBD-type plasma generated within a honeycomb monolith supported Pt-based catalyst," *Catal. Today*, vol. 89, pp. 75–81, 2004.

[3] A. Jaworek, A. Krupa, and T. Czech, "Back-corona generated plasma for decomposition of hydrocarbon gaseous contaminants," *J. Phys. D, Appl. Phys.*, vol. 29, pp. 2439–2446, 1996.