Sliding Discharge Inside Glass Capillaries

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***Abstract*—The generation of stable and homogenous plasma inside an automobile honeycomb catalyst is very difficult. This paper presents a technique to create plasma inside the thin channels of the honeycomb monolith by using a sliding discharge. The electrical and optical properties of the discharge are described.**

***Index Terms*—Emission spectroscopy, glass capillaries, honeycomb catalyst, sliding discharge.**

CAR EXHAUST emissions are important sources of air pollution. Honeycomb catalysts are commonly used in cars for the removal of toxic exhaust components. The catalyst performance depends on gas composition and temperature. The major problems represent lean fuel mixtures and engine cold starts. The improvement of the catalyst performance is possible by a combination with plasma. The generation of homogenous and stable atmospheric plasma inside the thin channels of honeycomb catalysts, as well as avoiding undesirable breakdowns of its ceramic walls, has been very difficult. This paper presents a novel approach of setting up stable discharge plasma inside honeycomb channels, utilizing a sliding discharge. The sliding discharge is a discharge generated on a dielectric surface by a combination of ac and dc powers in three-electrode geometry [1]–[4]. The discharge is a product of ac-driven barrier discharge "sliding" along the dielectrics when the dc component is applied to the remote third electrode. Louste *et al.* [1] and Sosa *et al.* [2] generated sliding on flat dielectric surfaces, whereas our approach was to generate the discharge along the inner surface of the glass capillaries. The basic characteristics of the sliding discharge inside the capillary channels, addressing the effects of the length of the capillaries and the applied voltage, are presented.

Fig. 1 shows a discharge reactor with relevant measuring systems. The reactor body consisted of a quartz tube with an inner diameter of 26 mm. A bundle of quartz capillaries with an inner diameter of 2 mm and lengths of 2 and 3 cm was packed inside the tube. The capillaries were used instead of ceramic honeycomb monolith in order to be able to visually observe the discharges inside the channels. The capillaries were placed on the top of Al_2O_3 pellet bed. The set of electrodes consisted of stainless steel rod of 6 mm diameter plugged in the middle of the bed, aluminum foil of 15 mm width wrapped around the quartz tube, and a mesh electrode of 16 mm diameter placed on the top of the capillaries. The rod was powered by an ac (50 Hz), the mesh by a negative dc high voltage, and the foil was grounded. The negative dc was chosen to ensure discharge operation of up to higher voltages without sparking. The dc line was ballasted by a series resistor of 5 MΩ to avoid the transition of the discharge into a spark. Applied voltages were measured by high-voltage probes connected to a digital oscilloscope. The pellet-bed discharge power was evaluated from Lissajous figures and the power of the discharge in capillaries as a product of dc voltage and a mean discharge current. Optical measurements were performed by an emission spectrometer, and the discharge images were recorded by a digital camera. The used gas was room air of 4.5 L/min gas-flow rate. All measurements were performed at room temperature and atmospheric pressure.

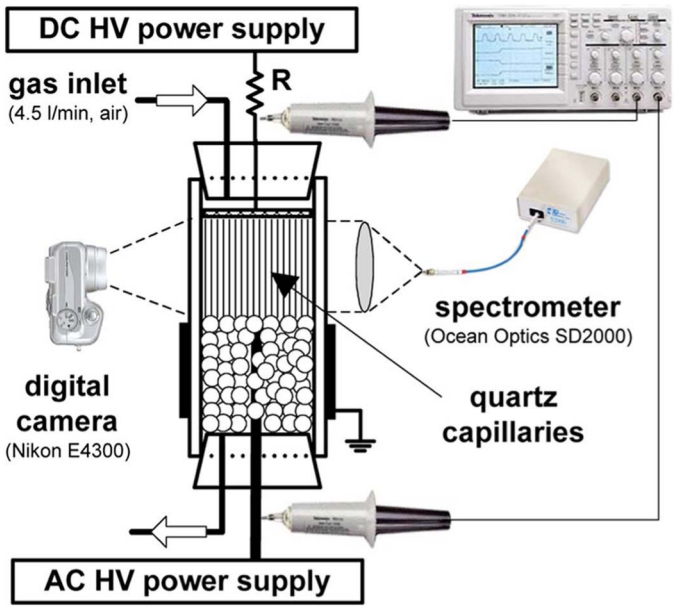

Fig. 1. Experimental setup.

The sliding discharge inside the bundle of capillaries was generated with the assistance of the pellet-bed discharge. The ac-driven pellet-bed discharge formed the plasma, which upon the application of negative dc voltage across the capillaries produced streamer development inside them. As a result, stable and homogenous plasma was produced inside the channels. Fig. 2 shows the images of sliding discharges at various ac and dc voltages. If only ac or dc voltage was applied, the packed-bed or corona discharge at the edges of the mesh electrode was observed, respectively [3]. The sliding discharge inside the capillaries occurred only when both dc and ac were applied. The images also show that the distribution of the discharges and

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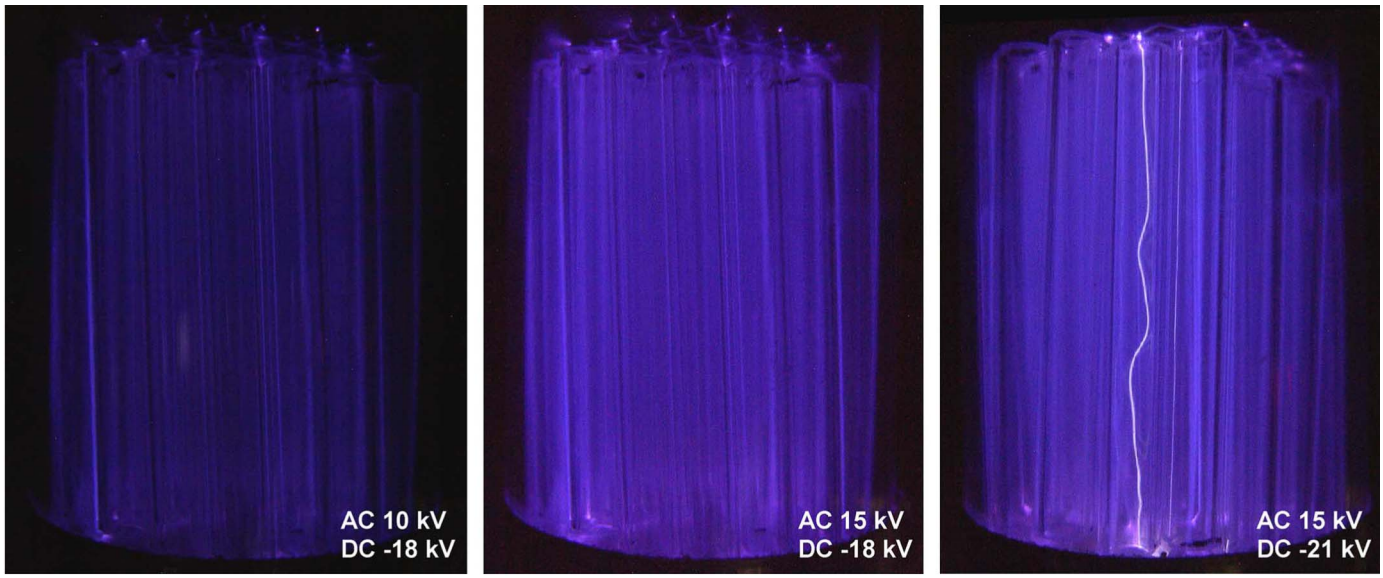

Fig. 2. Images of sliding discharge for various ac and dc voltages in 3 cm capillaries [ISO 400, f/4, and 1/4 s].

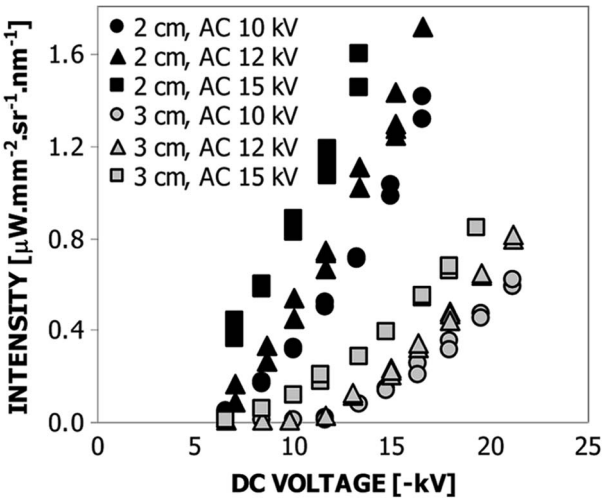

Fig. 3. Emission intensity as a function of dc applied voltage for various ac voltages and length of capillary.

the emission inside the whole capillary were relatively homogenous. At high amplitudes of the dc applied voltage, sparking occasionally occurred (the last image in Fig. 2). The discharge power increased with both dc and ac applied voltages. The effect of ac voltage, however, was almost negligible because the pellet-bed discharge power was one order of magnitude less than that of the sliding discharge. With extending the length of capillaries at a given dc voltage, the discharge current and power decreased. In contrast, the diameter of the capillary had marginal effect on the discharge power [4].

Fig. 3 shows the emission intensity of the sliding discharge based on the 0–0 spectral band (337 nm) of second positive system of $N_2(C^3\prod_u - B^3\prod_g)$, as a function of the dc voltage. The intensity increased with both dc and ac applied voltages. In contrast to the negligible effect of ac voltage on the discharge power, its effect on the discharge emission was significant. The effect of ac voltage is evident both in Figs. 2 and 3. The intensity also reflects a concentration of active species generated by the discharge. To minimize the power consumption but keep the same intensity, it seems appropriate to maximize ac and minimize dc applied voltage. The figure also shows the intensity decreased for longer capillaries, as a result of decreasing discharge current. From $N_2(C^3\prod_u - B^3\prod_g)$ spectral bands, we determined rotational (T_R) and vibrational (T_V) temperatures by using Specair software [5]. The typical measured temperatures were $T_R = 300 \pm 30$ K and $T_V = 1800 \pm 300$ K. T_R was found independent of the applied voltages. The plasma generated by the sliding discharge is cold with a high level of non-equilibrium.

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