Published in final edited form as:

IEEE Trans Plasma Sci IEEE Nucl Plasma Sci Soc. 2011 May 2; 39(11): 2060–2061. doi:10.1109/TPS.

Self-Organization and Migration of Dielectric Barrier Discharge Filaments in Argon Gas Flow

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Abstract

Observations of atmospheric-pressure dielectric barrier discharge are conducted through a water-filled electrode in atmospheric-pressure argon gas flow. Quasi-symmetric self-organized discharge filaments were observed. The streamers moved with the gas flow, and the migration velocity increased with increasing gas velocity.

Keywords

Argon; atmospheric pressure; dielectric barrier discharge (DBD); plasma filament; self-organization

Dielectric barrier discharges (DBDs) are widely used for various applications, including polymer treatment, lighting, and ozone production. Recently, biocidal properties of atmospheric-pressure DBDs have made them potentially a favorable system for the disinfection of living surfaces [1], [2]. Depending on specific applications, plasma may be varied from diffuse to strongly filamentary mode. The latter may lead to the formation of complex spatial patterns, where self-organized arrangements were observed [3].

The filamentary mode is usually characterized by a large number of microdischarge channels. As the average input energy increases, a concern about the uniformity of DBD plasma treatment emerges as the strongly filamentary pattern may lead to inhomogeneous energy deposition and subsequently damage to samples. Takaki *et al.* [4] show that the gas flow velocity affects the arrangement of the filaments in atmospheric-pressure helium, and the transition from filamentary to homogeneous structure appears at high flow velocity. In this paper, we report observations of the pattern of self-organized discharge filaments in atmospheric-pressure argon and their migration with gas flow.

DBD was generated between a grounded mirror-polished stainless steel plate and a flat 25.4-mm-diameter water-filled electrode (Fig. 1). Regular tap water was degasified by boiling/cooling cycles and circulated in the upper transparent electrode as both conducting and cooling media. A fused polished 1-mm-thick quartz plate was used as the dielectric material. The water electrode was separated from the grounded plate by a 2-mm polyethylene spacer. The water-filled electrode was connected to an 11-kHz sinusoidal power source. Argon was fed into the space between the two electrodes through a mass flow controller. The average gas flow velocity v was calculated by $v = Q/S$, where Q is the gas flow rate and S is the maximum cross-sectional area of the discharge chamber (25.4 mm $\times$ 2 mm). Gas flow rates ranging from 0 to 3 slpm were used, corresponding to average velocities from 0 to 0.35 m/s. A Nikon CCD camera was mounted above the water electrode to characterize the plasma spatial uniformity at a shutter speed of 10 ms.

Fig. 2 shows the typical current and voltage waveforms. The sharp current pulse in each half-period corresponded to the simultaneous formation of filamentary discharges.

Fig. 3 shows the steady filaments arranged in a quasisymmetric self-organized pattern at zero gas flow rate. Fig. 4 shows the pattern of the filaments at different gas flow velocities. The spatial structure of the filaments changed to a nonstationary pattern. The trails left by the filaments were not continuous but showed a discrete pattern, possibly due to the fact that the camera gate time was much longer than the period of the high voltage pulse, leading to multiple cycles of extinguish and reignite of streamers captured in each single exposure. The average velocity of the streamers u was calculated by $u = L/(n \cdot \Delta t)$, where L is the total length of the streamer movement, n is the number of streamers, and Δt is the shutter speed of the camera. For gas flow with a velocity of 0.18 m/s, the migration velocity of the filaments was 0.15 m/s. When the gas flow velocity increased to 0.35 m/s, the migration velocity of the filaments increased to 0.28 m/s.

The formation of the filaments is a complex process. Avalanches are first initiated, followed by cathode-oriented streamers bridging the gap. They form conducting channels of weakly ionized plasma until the local electric field is collapsed caused by the charges accumulated on the dielectric surface and ionic space charge. After electron current termination, there is still a high level of electronic excitation in the channel volume, along with charges deposited on the surface and ionic charges in the volume, allowing this region to be separated from the rest of the volume. This region is usually called a microdischarge remnant, which will facilitate the formation of a new filament in the same location as the polarity of the applied voltage changes. The fact that the remnant is not fully dissipated before the formation of the next microdischarge is called memory effect [5], which may lead to the steady pattern formation of the barrier discharges. The close coupling between the average flow velocity and the migration velocity of the streamers suggests that the movement of the filaments was probably associated with the momentum transfer from the neutral gas molecules to charged and excited species left over from the previous half cycle. This process pushes the discharge remnant region in the direction of gas flow and subsequently causes the displacement of streamers in the next cycle.

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Fig. 1.
General schematic of the experimental setup.

Fig. 2.
Voltage and current waveforms at zero gas velocity.

Fig. 3.
Pattern of the filaments observed at zero gas velocity.

Fig. 4. Migration of the filaments observed at average gas velocities of (a) 0.18 m/s and (b) 0.35 m/s.