Filaments in a Surface Dielectric Barrier Discharge Operating in Altitude Conditions

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***Abstract*—Positive and negative discharges occurring in a surface dielectric barrier discharge are investigated for different altitude conditions. Fast imaging reveals the expansion of the glow zone and streamer when the altitude increases from ground level up to 9000 m which corresponds to cruising altitudes of commercial flights.**

***Index Terms*—Actuators, fluid flow control, plasma devices, surface discharges.**

CURRENTLY, SURFACE plasma discharges are under investigation as innovative flow control devices [1]. It is assumed that these actuators may eventually replace mechanical systems mounted on actual aircraft. In this perspective, it is essential to evaluate how realistic environmental conditions affect their operability. A preliminary effort has been conducted to characterize the multiphysics transduction of a dielectric barrier discharge actuator operated at an altitude of up to 10 000 m, with a particular attention to the electromechanical conversion [2]. This paper focuses on the visualization of the plasma sheet by fast imaging, with the discharge being operated for combinations of temperature and pressure representative of altitudes from ground level up to 9000 m.

The plasma actuator consists of a single DBD mounted on a flat plate (4-mm-thick PMMA as dielectric barrier). The electrodes are made of thin aluminum foils (span length of 100 mm). These electrodes are asymmetrically stuck on the plate (interelectrode distance of 5 mm). The high voltage (HV) electrode is 15 mm long when the grounded one is 40 mm long. The grounded electrode is insulated with a thick layer of epoxy resin (15 mm) to prevent the formation of a plasma discharge on this side. Altitudes from the ambient level up to 9000 m (see Table I) are reproduced by using an altitude test chamber (Sapratin FCH 350). The HV amplitude of 16 kV is produced by using a Trek amplifier (20/20 A) (sine waveform at 1 kHz). Image collection is performed by a fast gateable ICCD camera (Andor, iStar DH734) with a 1024×1024 pixel^2 matrix in this paper. The field of view (45×45 mm^2, with a resolution of about 45 μm/pixel) is obtained by using a 105-mm macro lens (Sigma). A triggering system is deployed to separately investigate the contribution of plasma filament formation during positive and negative alternance half cycles. Series of images are acquired at times $t = 125$ μs and $t = 625$ μs to access anode and cathode half cycles, respectively (exposure time fixed at 125 μs). The investigated time segments correlate with the occurrence of current pulses at atmospheric pressure [2].

TABLE I
PRESSURE AND TEMPERATURE COMBINATIONS FOR FOUR ALTITUDES

Altitude (m)	Pressure (hPa)	Temperature (°C)
0	980	15
6000	470	-24
9000	300	-43

Fig. 1 shows filaments appearing at the surface of the actuator for cathodic and anodic half cycles, respectively. Filaments are randomly spread over the surface, with a bright spot zone in contact with the active electrode (corona zone) and an extension from this spot towards the dielectric (streamer propagation). The spot brightness is not sensitive to the considered half cycle, but the extension shape is dramatically different between both half cycles. During the cathodic half cycle, the extension has a plume shape, enlarging from the spot to the dielectric. However, during the anodic half cycle, the extension is branched over several filaments with erratic propagation paths. Anodic filaments extend further than cathodic filaments.

Variation of altitude level does not change the plasma structure so much. It modifies the diameter and length (increase with altitude) of the spots distributed along the active electrode edge. This indicates that the corona part is enhanced when the altitude increases. The shape of the filament propagation is more affected by the altitude conditions. During the cathodic half period, the plume extension loses its coherency at 9000 m and finally forms a nearly homogeneous weakly ionized gas over the dielectric surface. In time-dependent current waveforms observed in [2], negative pulses occurred more probably in the second half of the positive period at high altitude. It is highly suspected that the trace of the larger negative current peaks cannot be viewed in the time frame used here. The intense filaments observed in the anodic half period extend further downstream with an increasing altitude. The streamer gradually expands on the dielectric surface to finally reach the end of the grounded electrode at 9000 m. Initially having a visual emission

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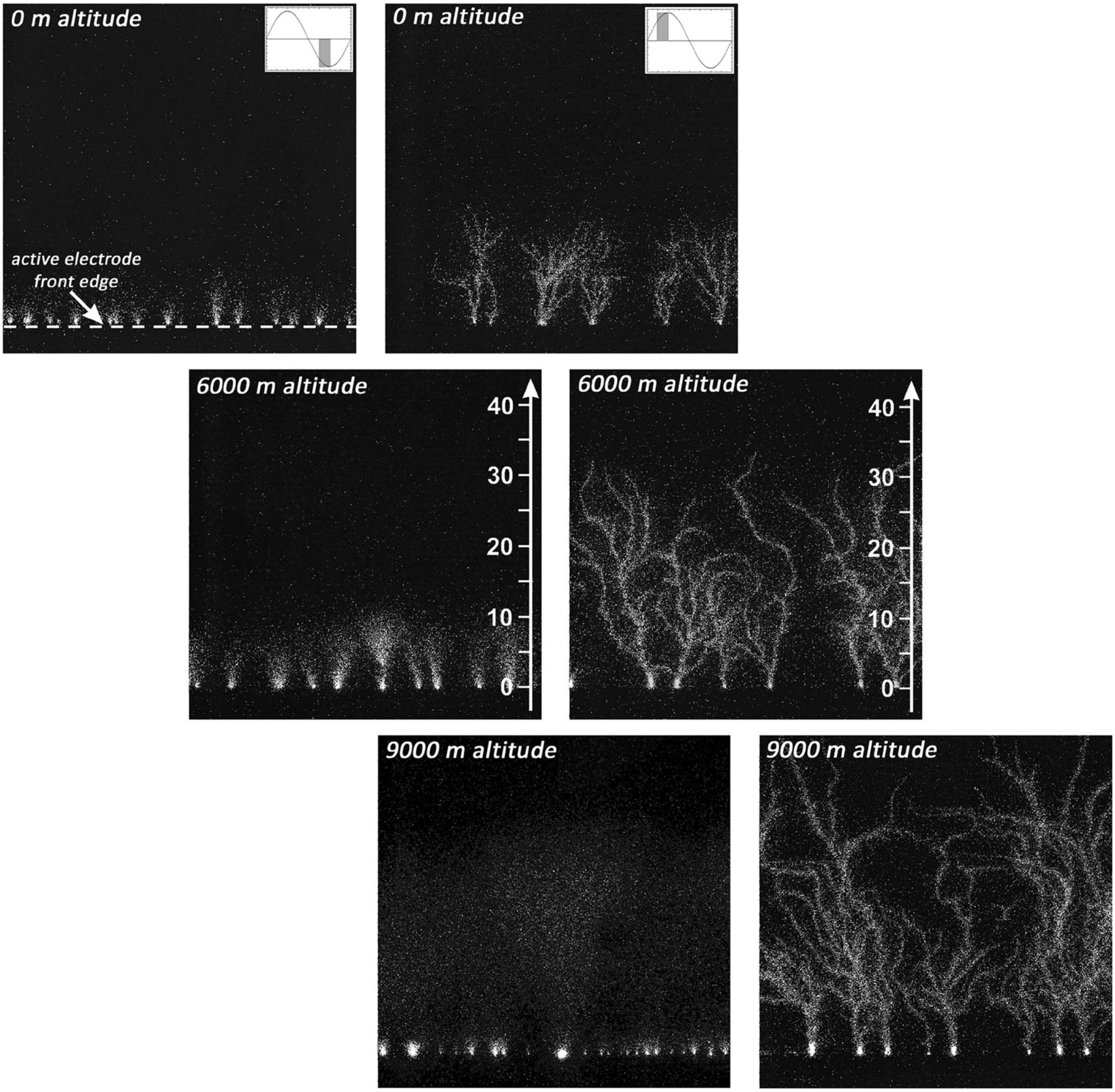

Fig. 1. Development of surface filaments during the (left plots) cathode and (right plots) anode half period of a DBD operating at different altitude conditions (scale in millimeters).

with a diameter of about 0.5 mm, the luminous trace of the streamers can expand up to 1 mm and subsequently can increase in altitude up to 9000 m. This supports the large increase in positive current peak amplitude observed at high altitude [2], if a constant current density is considered.

The change in the filament propagation according to the altitude can be interpreted by the increase of species mean free paths when pressure drops. However, as a temperature drop has a reverse effect on the mean free paths, it may counter the effect of the pressure drop, but as already discussed in [2], this latter seems to be dominant.

References

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