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Strong Density Gradients in Postdischarges in Argon and Air

Z. Liu, E. M. van Veldhuizen, E. J. M. van Heesch, and A. J. M. Pemen

Abstract—High current sparks are created in argon and air using a high-voltage pulse of 16-ns duration. Shadowgraphy is applied to image density fluctuations. Shock waves become visible ~ 100 ns after the pulse; they expand with a velocity somewhat higher than the speed of sound. The filamentary core of the discharge shows heating that diffuses outward slowly and develops into microturbulences. They remain visible up to 3 ms. In air, the current remains lower than that in argon, and shocks only emerge from the electrodes. No indication of absorption is found; probably gas heating is observed near the electrodes.

Index Terms—Microturbulence, overvolted pulsed discharge, shadowgraphy, shock waves.

VOLTAGE PULSES with a 7-ns rise time and a 16-ns FWHM have been applied to two opposing arrays of eight points. The vertical distance between the anode and cathode points is 14 mm; the horizontal distance between the points is 9 mm. The amplitude of the voltage pulse is ~ 60 kV, so the gap is strongly overvolted. Due to this high voltage, the initial streamer travels at ~ 3 – 10 mm/ns [1]. This implies that the gap is bridged well within 16 ns of the pulse duration. After bridging, the discharge goes over into a spark, and the current goes up to as much as the power supply can deliver. The present power supply has inductive storage with a diode opening switch [2] and is able to deliver a current of up to 200 A in argon and 100 A in air. The total energy per single discharge is ~ 10 mJ in argon and ~ 5 mJ in air. In [3], a current of 2 kA is reported for a pulse in air with 60 kV in a 50-mm gap. Due to the high current, the optical emission is sufficient for direct imaging using a CCD camera without an intensifier (SBIG STC-10). These time-integrated pictures are made, with a resolution of $1\,600 \times 1\,200$ pixels.

The top row of Fig. 1 shows the discharge in argon at 1 bar. It is seen that the paths are far from straight, the intensity per pin is varying significantly, and, most surprisingly, each

discharge channel consists, unexpectedly, of very fine filaments. The thinnest channels seen in Fig. 1 have an estimated FWHM of $100\ \mu\text{m}$. The lower left of Fig. 1 shows two discharge channels in air at 1 bar; the intensity in the bulk of the channels is, on average, 30 times lower than that in argon. It can be seen that the discharge in air is more diffuse; occasionally, two channels occur, and there is always a contraction in the center of the gap.

The middle row of Fig. 1 shows the shadowgraphs made with UV laser pulses of 8 ns. The SBIG camera records the light from a fluorescent plate 10 cm behind the discharge. A series of photographs taken with different delays after the start of the voltage pulse is shown. Before $0.16\ \mu\text{s}$, almost nothing is seen, and from that time, the discharge and a corresponding shock wave develop. The shock wave travels at ~ 400 m/s, slightly faster than the sound velocity in argon (323 m/s). The central channels broaden with a speed of ~ 100 m/s until $5\ \mu\text{s}$. From that moment, this speed decreases rapidly, and at 1 ms, it is down to ~ 1 – 2 m/s. This transition appears to coincide with the formation of “bubbles”; they are also called microturbulences. At 3–4 ms, all density variations have disappeared. Shadowgraph photographs of pulses in air are far less spectacular. Almost nothing is seen of the central channels, but the circular shock waves starting at the points are more pronounced. These shocks expand with ~ 360 m/s, again slightly faster than the sound speed in air (343 m/s).

The pictures of the shock waves in air show faint gray stripes going from the cathode almost to the middle of the gap. In [4], such effects are attributed to absorption by ozone created by the discharge. The amount of absorption in the center of the gap could not be quantified, and in the measurements shown here, it disappears in the noise. Near the electrode tips, white edges can just be seen around darker areas. This points to density gradients, probably due to gas heating. This may be the reason why we do not observe ozone absorption.

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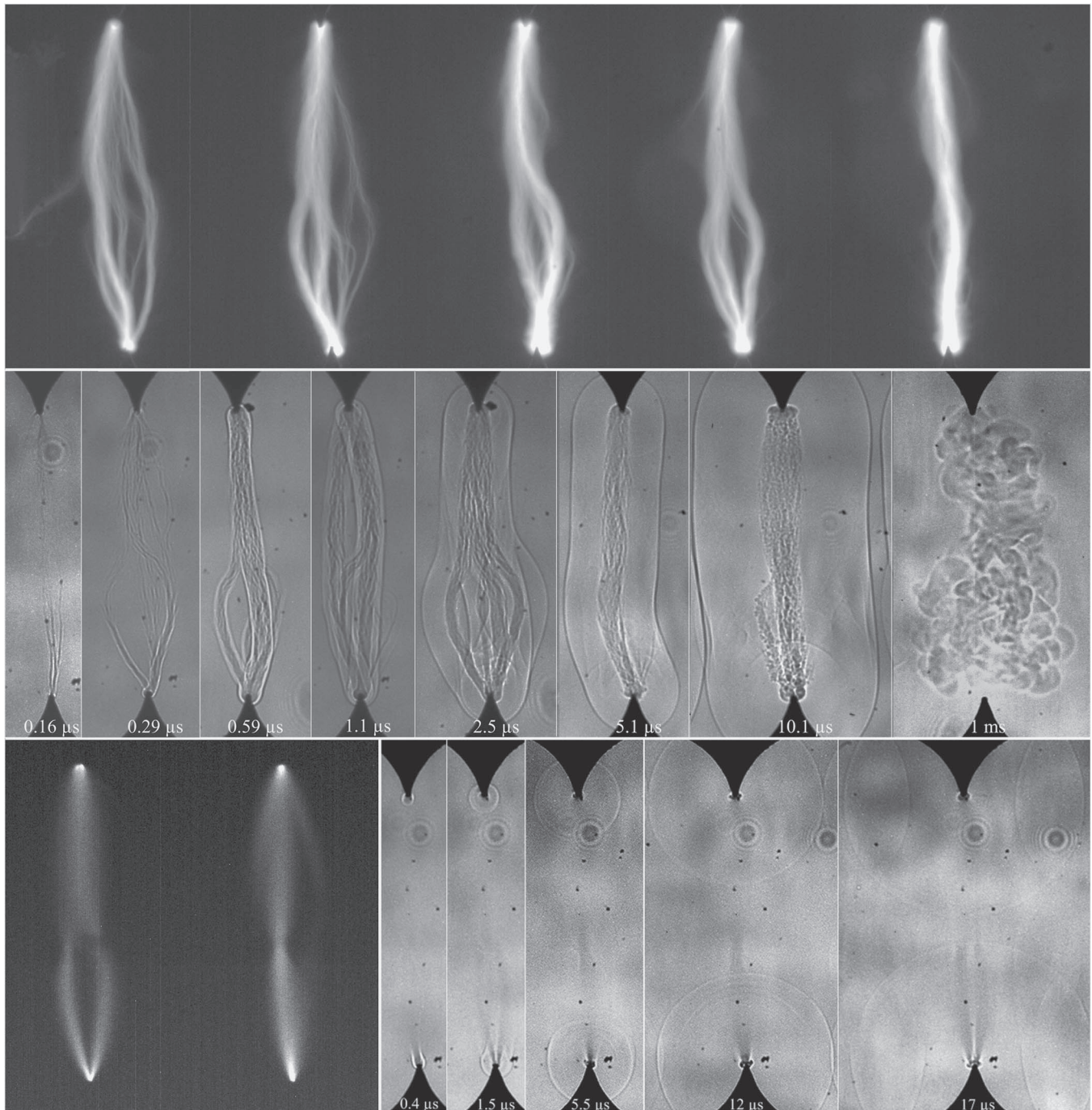


Fig. 1. In all images, the cathode is at the bottom, and the anode is at the top. The current per pin is ~ 25 A in argon and ~ 12 A in air. Note that, usually, most details are seen using a digital document and a computer screen. (Top row) Direct optical emission of sparks in argon. This emission has the same duration as the current, i.e., 16 ns. The electrodes have eight pins of which five are displayed in this photograph. Most remarkable are the very thin filaments in combination with two or three thicker and more intense cores. (Middle row) Shadowgraphs in argon with delayed exposure times as indicated at the lower electrode. Shock waves develop around the discharge channels and much more faintly at the electrode tips. The central channel disintegrates into microturbulences. (Lower left row) Direct optical emission of sparks in air; here, only one or two diffuse channels appear. The contraction in the center is always observed. (Lower right row) Shadowgraphs in air: Circular shock waves develop only from the cathode and anode tips. The tiny circles at the electrodes and the faint stripes from the cathode to the middle of the gap are attributed to gas heating.