FAST IMAGING OF STREAMER PROPAGATION

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1 Introduction

Transient discharges at atmospheric pressures are being applied nowadays in many applications [1]. Typical configurations are pulsed corona, dielectric barrier and packed bed discharges. The term transient implies here that the discharge exists only as long as it is propagating. Two ways of propagation can be distinguished: through a gas or along a dielectric. In this paper the propagation through the gas phase will be considered in a positive corona. This discharge has been studied for many years in experiments and calculations [1]. Nevertheless many aspects have not been resolved. The transient character and the small dimensions make the discharges difficult to access by measurements. Therefore parameters like electron density and energy, electric field strength and radical densities are only estimated up to now. The calculations encounter similar problems. The discharge has very strong gradients in space and time and most of the rate constants of the processes involved can only be estimated. At present the state-of-the-art of streamer simulations is a 2-D model in the hydrodynamic approach.

Recently measurement methods are becoming available to study the corona discharge in more detail. One of the most promising methods is laser-induced fluorescence to determine radical density [2, 3]. Recent improvements in CCD cameras makes it now possible to improve measurements of the discharge structure to a resolution of 1 ns in time and 10 μm in space. This paper shows the first results of the spontaneous emission of a point-to-plane corona discharge in air using such a camera. It clearly indicates that the 2-D approach for streamer propagation under these conditions is insufficient.

2 Experimental set-up

Discharging a capacitor of 0.5 nF using a triggered spark gap creates the pulsed corona studied here. The discharge is created in ambient air using four electrode configurations:

A: point-plane (point made of tungsten with a radius of 50 μm, plane made of brass)
B: point-plane (brass plane covered with dielectric)
C: point-wire (stainless steel wire directed perpendicular to the viewing direction of the camera)
D: point-wire (wire in the viewing direction of the camera)

The electrode gap is 25 mm in all cases and the power supply that charges the capacitor is always set to 25 kV. The voltage and current of the pulse are measured by probes (Tektronix P6015 and Pearson 2877). Their signals are recorded by a digital oscilloscope with a time resolution of 1 ns (Tektronix TDS380). For details see [4].

Pictures of the discharge are taken using a CCD camera equipped with a gated intensifier. This camera is (Andor Technology ICCD-452) has the following specifications:

- 1024 x 1024 pixels
- pixel size 13 μm x 13μm
- sensitivity 180-850 nm
- minimum optical gate 0.8 ns
- full width at half maximum 21 μm
- gain up to 3600

The discharge is imaged onto the camera using the Nikon UV-Nikkor 105mm f/4.5 lens. This lens is chosen because it is made of quartz. This is advantageous because almost all of the optical emission from the pulsed corona in air originates from the N_2 Second Positive System [5]. Besides this the lens has good imaging properties. The magnification is set so that one pixel of the CCD corresponds to 27 μm at the discharge gap so that the camera observes the complete gap. Pictures have been made using the shortest opening time available

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(0.8 ns) to show the movement of the streamer head and an opening time of 100 ns to give an overall impression of the streamer paths. The intensifier is set to 122x in the first situation and 30x in the second situation (according to the specifications given by the manufacturer).

3 Results

The voltage and current signals for gap A are given in fig. 1. It is seen that the voltage rise time is ~50 ns and the current duration is ~100 ns. The current amplitude is 1 A at maximum, in gap B this maximum is ~0.5 A and for gaps C and D it is 0.8 A. The total energy in one pulse is ~1.2 mJ for gap D and C. Gaps A and B give 1.5 and 0.5 mJ resp. The first peak in the figure of the current is due to capacitive charging of the gap and a geometric capacitance of ~1 pF is deduced from it. The repetition frequency of the pulses is 0.2 Hz at which no effects are observed of previous pulses.

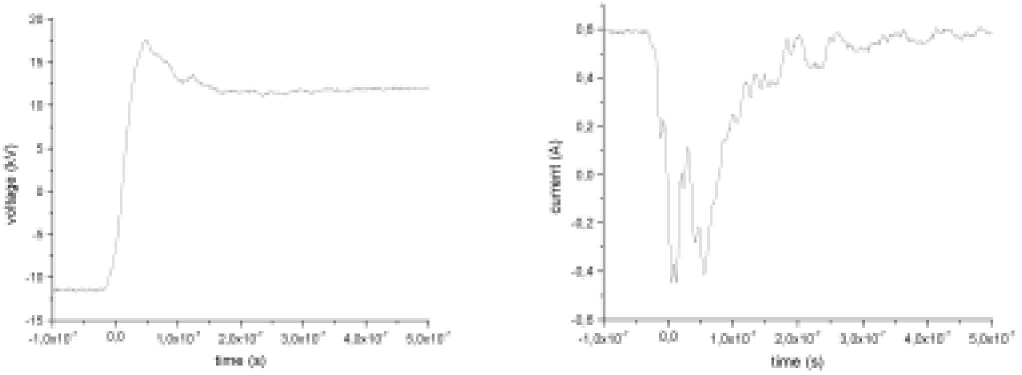

Fig. 1: Voltage and current measurement of the corona pulse in a 25 mm point-to-plane gap in ambient air

Several examples of pictures taken with the opening time of 0.8 ns are given in fig. 2. These are arbitrary shots of different pulses because the camera is a single shot device which requires several seconds to send its data to the hard disk of the connected PC. Nevertheless the pictures give the impression of “balls” that move to the cathode. The spark gap and the corona pulse both have a considerable jitter. The distance and pressure are critical parameters in this situation and the best result obtained is a total jitter of ~10 ns which is attributed mainly to the spark gap. By varying the delay of the intensifier it is found that the time for the streamers to travel from anode to cathode is ~50 ns.

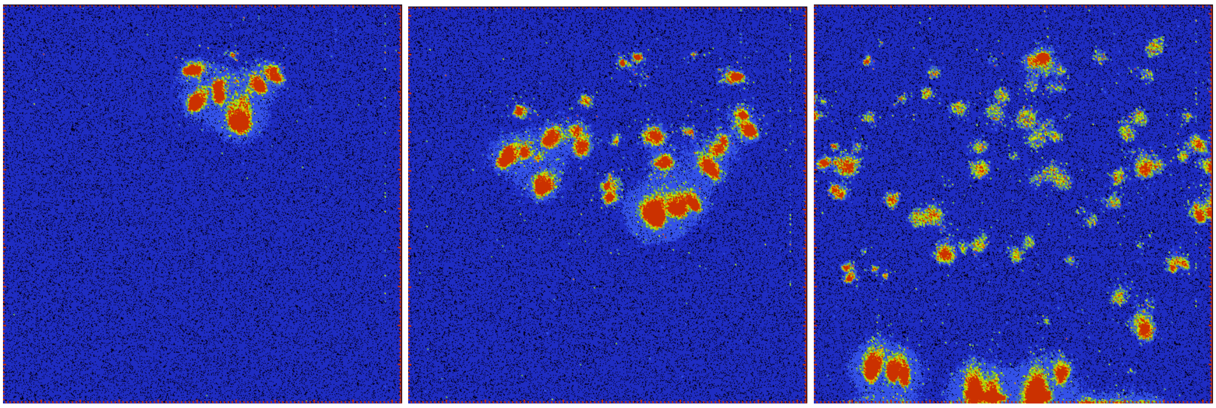

Fig. 2: Pictures of streamer propagation in a point-to-plate gap using a 0.8 ns intensifier gate

Figure 2 shows three pictures taken with an optical gate of 0.8 ns. From left to right the delay of the spark gap increases. The intensity of the radiation is unfortunately very poorly represented in a black and white image. Nevertheless the blackness is more or less a measure of it. It is observed that several rather intense spots move from anode to cathode and more vague spots appear in the region that is passed by the first discharges. The discharge always starts at the anode in one point. This point remains visible on following pictures, it becomes much more clear when the streamer hits the cathode (right picture)

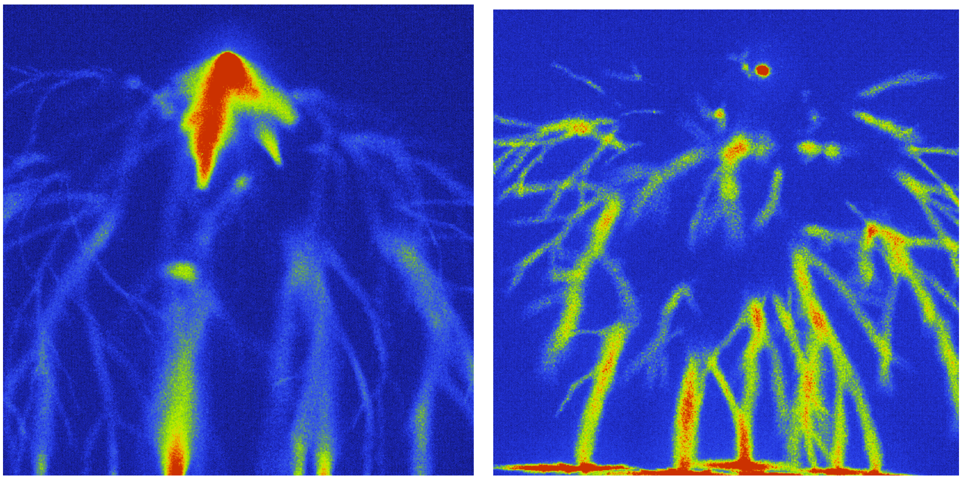

Fig. 3: Time-integrated pictures of a point-to-plate discharge with a brass cathode without (left) and with (right) a dielectric sheet

The time integrated pictures of fig. 3 show a very complicated structure of discharge channels. It is clear that a lot of branching occurs. Besides this it is remarkable that the width of the area occupied by streamers is more than the point-to-plane distance. In the right picture one can observe that the gate of the intensifier opens ~30 ns after the start of the discharge. Some of the streamers have already passed more than half of the gap. On the dielectric the discharge spreads out. This spreading out is not observed at the brass cathode in the left picture. Here a very bright light is seen at the anode which is probably the secondary streamer. One of the streamers at the cathode seems to build up a “return stroke”.

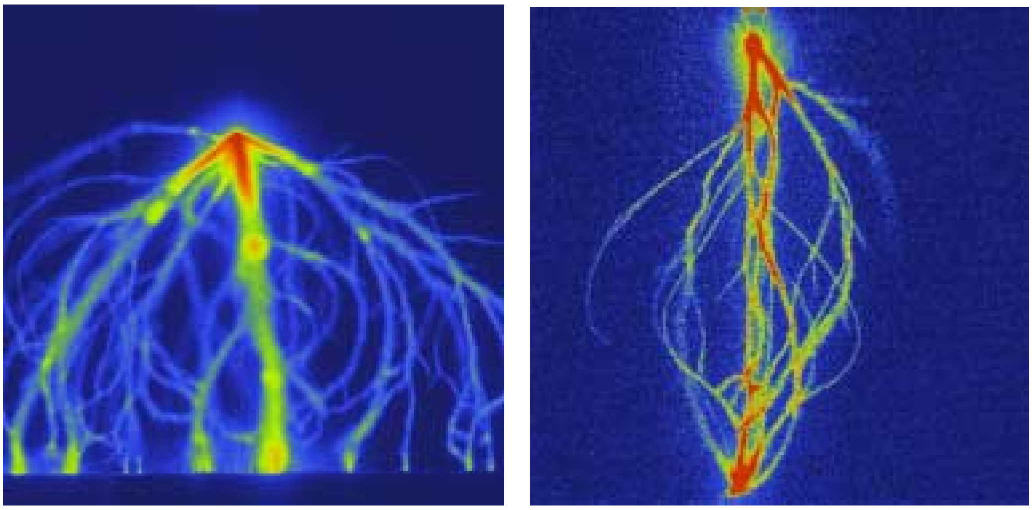

Fig. 4: Time-integrated pictures of a point-to-wire discharge, left: wire perpendicular to the viewing direction, right: wire in the viewing direction of the camera.

The point-to-wire discharge shows a structure which is quite similar to the point-to-plate case when the direction of the wire is perpendicular to the viewing direction of the camera. The left part of fig. 4 shows this case. Here the logarithm of the intensity is plotted which seems to show certain detail more clearly than a linear scale. When the wire is viewed along its direction it is observed that the streamers bend back towards the wire. The width of the area occupied by streamers in the center of the gap is almost as large as the gap distance but smaller than the width in the other direction. This last picture is used to analyse in detail the diameter of the streamer. For this purpose two rows are selected of the complete matrix: row 375 and row 900 (row 0 is the bottom of the picture just below the cathode, row 1023 is the top of the picture).

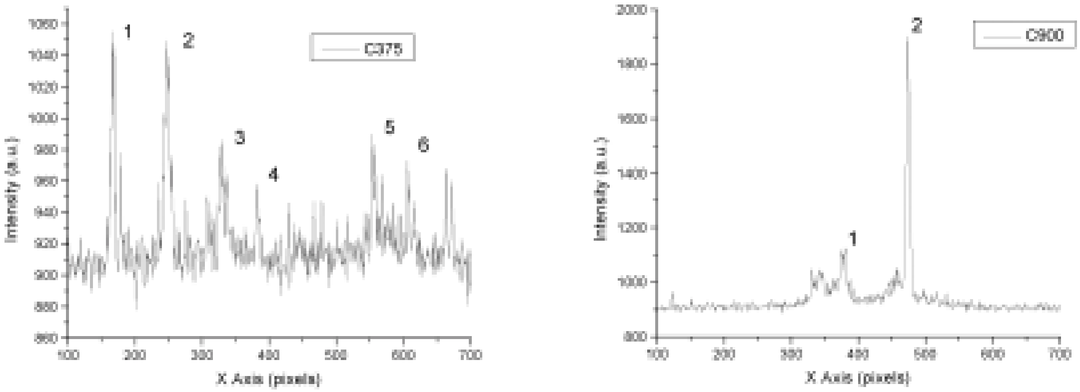

Fig. 5: Cross sections of fig. 4 showing streamer diameters close to the cathode (left) and close to the anode

The cross sections have been chosen as representative for the cases near the cathode (left) where the streamers are rather faint (peak amplitude ~100) and near the anode where the intensity is much higher (~1000). The half width of all numbered peaks is in the range 7±1 pixel. Since the resolution of the intensifier is larger than a CCD-pixel these images are somewhat broadened. The real size of the streamer is estimated to be 6±1 pixel, i.e. 160±30 μm.

4 Discussion and conclusions

The photographs shown here demonstrate in detail the streamer propagation in a corona gap in ambient air. The branching observed in figs. 2-4 shows that this is a 3-D phenomenon. The shape of the streamer head cannot be resolved with the present system. For that purpose a camera is required with at least a ten times shorter opening time. The branching of the streamer is probably beneficial for applications because it leads to a better volume treatment. This effect should be studied in more detail by varying parameters such as gas composition and pressure and voltage risetime and amplitude.

The current of individual streamers is determined to be ~0.1-0.2 A. This is lower than the value of 0.4 A found in [5] for a 35 mm gap with a 35 kV pulse. The value of the streamer diameter of 160±30 μm is close to the value of 150-300 μm reported in [5] using a system with lower resolution. This width seems to be lower than the ones found in 2-D simulations where values of 400 μm are common [1]. These diameters can, however, not be directly compared. What should be calculated is the density of the $N_2(C\ )$ state which is directly related to the SPS emission intensity. In [6] the density of this state is calculated to be 10^{10} cm^{-1}, i.e. per unit length of the streamer. Using 160 μm for diameter this leads to a $N_2(C\ )$ density of ~5 10^{13} cm^{-3}, which appears to be an acceptable value.

The explanation of the phenomena observed here will require 3-D calculations in order to understand branching. Such calculations are just beginning to appear [7]. Finally the combination of experimental and theoretical work should lead to quantitative predictions of the effects caused by pulsed discharges under conditions of practical applications.

5 References

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