February 1996

High-Temporal-Resolution, High-Sensitivity Imaging of Streamers in a Long Atmospheric Pressure Gap

W. J. Yi
University of Nebraska - Lincoln

B. J. Hankla
University of Nebraska - Lincoln

P. F. Williams
University of Nebraska - Lincoln, pfw@moi.unl.edu

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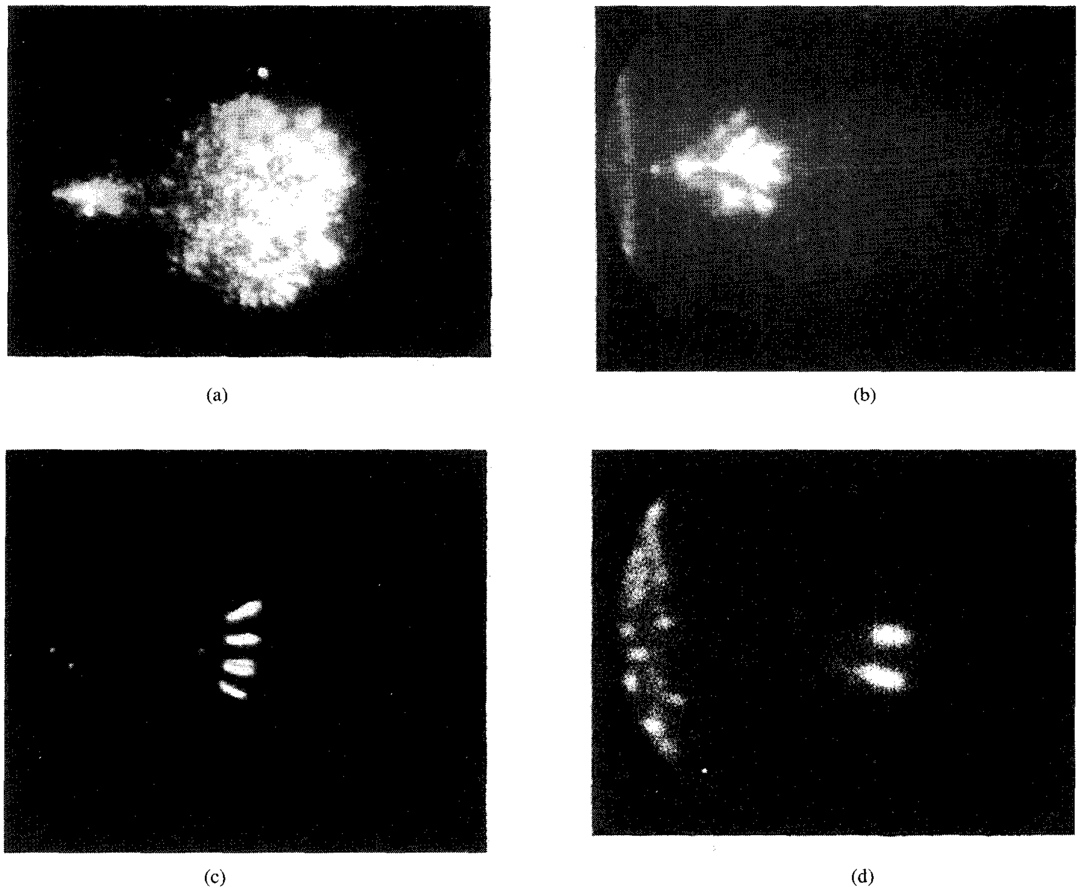

Fig. 1. Figure showing streamers in pure N_2, (a) and (b), and mixtures containing 15%, (c) and 1%, (d), O_2. Streamers in (a) and (c) are propagating toward the cathode, those in (b) and (d) toward the anode. In all cases, the initiating point is at the left of the photo. The total horizontal distance shown varies a little between photos and is about 16 cm. The features at the far left in (b) and (d) are due to streamers initiated at the edge of the charged electrode.

***Abstract*— We present time-resolved shutter photographs of streamers in a 13-cm gas-filled atmospheric pressure gap. The photographs show that in pure N_2, the streamers split readily in two. In mixtures containing O_2, on the other hand, this bifurcation is substantially reduced.**

RAETHER [1], [2], Loeb [3], [4], and Meek [5] independently proposed similar mechanisms to explain the breakdown of relatively long gas-filled atmospheric pressure gaps. These mechanisms are based on the formation and propagation of phenomena which have come to be called streamers. Since that time, streamers have attracted sporadic attention in the literature, on both empirical and theoretical planes. We have obtained a large volume of time-resolved photographs of streamers propagating in a 13-cm N_2-filled gap. These data provide new information about streamer formation and propagation. In this paper, we limit ourselves to the stability of streamers to bifurcation and the effect of gas composition on this stability.

The experimental setup consisted of a 0.7-m diameter 1-m long cylindrical tank containing two near-constant-field electrodes separated by about 13 cm. This cylinder can be evacuated and then backfilled to any pressure up to about 2 atm. A short pointed tip extended about 1 cm outward into the

Manuscript received July 17, 1995.
The authors are with the Department of Electrical Engineering, University of Nebraska–Lincoln, Lincoln, NE 68588-0511 USA.
Publisher Item Identifier S 0093-3813(96)02242-4.

gap from the charged electrode to seed streamer formation. Voltage pulses with 40-ns risetime and magnitude up to 150 kV were applied to the gap.

Both shutter and streak photography were used to observe the formation and propagation of streamers in the gap. In this paper, we present only shutter photographs. The shutter camera was locally constructed and based on an ITT F4144 gated microchannel plate intensifier. The camera is capable of near-single-photon sensitivity, and provides time resolution down to about 5 ns.

Fig. 1(a) shows a typical shutter photograph of cathode-directed streamers obtained with a voltage pulse of 120 kV in pure N_2 at 760 torr. From the photo, it appears that one or a few streamers were launched from the sharp tip, and that these matriarch streamers then split into many generations of daughter streamers, in an expanding roughly spherical front. Fig. 1(b) shows a typical shutter photograph of anode-directed streamers obtained in pure N_2 at 760 torr and 150 kV. The multiple branching seen with cathode-directed streamers is evident in this photo, but the individual streamers seem a bit thinner. This behavior is opposite to what one might expect, considering the direction of the electric field near the streamer tip. For a cathode-directed streamer, the field pulls electrons inwards towards the tip, whereas for an anode-directed streamer, the field pushes electrons outward.

The strong tendency of streamers of both polarity to split into many daughter streamers was commonly observed with a pure N_2 fill. The addition of a small amount of O_2 dramatically changes this tendency. Fig. 1(c) shows a photograph of cathode-directed streamers obtained in an 85/15 N_2/O_2 mixture. The pressure was 760 torr, and the voltage 110 kV. Fig. 1(d) shows a photo of anode-directed streamers obtained under similar conditions. The mixture was 99/1 N_2/O_2, the pressure 760 torr, and the voltage 150 kV. The difference in appearance between streamers in pure and O_2-containing mixtures is striking. In the mixtures, only a few well-defined streamers are formed, and they propagate across the gap with little splitting, whereas in pure N_2, the streamers are continuously splitting in two.

It is not clear what the reason is for the difference in streamer behavior. One possibility is that O_2 is an attacher of low-energy electrons, but N_2 is not. If bifurcation requires an initial electron ahead of the streamer in the right place, then this difference might be responsible for the differing streamer behavior. We have a limited volume of data on streamers in N_2/SF_6 mixtures which is consistent with this hypothesis. SF_6 is a strong electron attacher, and the appearance of streamers in these mixtures is similar to that in O_2-containing mixtures.

We believe, however, that a more likely explanation is the difference in photoionization characteristics. Penney and Hummert [8] have published data showing the photoionization efficiency of pure N_2, O_2, and air. For both pure O_2 and air, the photoionization efficiency falls off more slowly with distance than it does in N_2. Preliminary numerical calculations suggest that bifurcation in pure N_2 occurs because the streamer profile becomes increasingly flat and square-cornered. The peak field then moves off the streamer axis, and the streamer veers away from the initial propagation direction. The increased photoionization efficiency in O_2-containing mixtures would be expected to reduce the peak field required to produce a propagating streamer, and might reduce the squaring-off effect observed in calculations for pure N_2.

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