# Streamer Branching: The Role of Inhomogeneities and Bubbles

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***Abstract*—The branching of streamers in atmospheric-pressure air, dense gases, and liquids is a common occurrence whose origins are likely found with many causes, both deterministic and stochastic. In this paper, we investigate the consequences of stochastic inhomogeneities on the propensity of branching of streamers in high-pressure gases.**

***Index Terms*—Branching, corona, streamers.**

THE BRANCHING of streamers, which is a phenomenon that occurs in nearly all high-pressure gases and liquids, is being investigated from many experimental and computational perspectives [1]. Branching likely depends on many parameters (e.g., gas or liquid type, pressure, and rate of voltage rise). However, this dependence cannot be too system specific because branching is so common. This is particularly true for streamers in liquids where branching is nearly universal. One proposed mechanism for streamer branching is inhomogeneities in the streamer path, which either divert a streamer (region of lower ionization) or produce a new branch (region of higher ionization). Such an inhomogeneity in a liquid could be a bubble, which is a subregion of significantly lower density. Bubbles are thought to provide sufficient sources of ionization to propagate the streamer [2] in an otherwise over-dense media. Bubbles being stochastically distributed in the liquid might lead to random branching.

Modeling streamers in liquids is difficult due to the lack of transport coefficients. To provide insights on how inhomogeneities might affect branching, we instead computationally investigated the role of stochastically distributed regions of low density (i.e., bubbles) in the propagation and branching of a streamer in an atmospheric-pressure humid-air ($N_2/O_2/H_2O = 79/20/1$) discharge. The model, nonPDPSIM, is similar to that described in [3]. It is a 2-D simulation performed on an unstructured mesh in which Poisson's equation for the electric potential and transport equations for charged and neutral species are solved. Radiation transport and photoionization are included by implementing a Green's function propagator.

To approximate the random bubbles that might occur in a liquid, five bubbles with diameters of 40 $\mu$m and pressures of 0.2 atm were randomly placed near the electrode tip of a point-to-plane discharge, as shown in Fig. 1. A step voltage pulse of $+15$ kV, creating a positive corona, was applied to the tip with the ground plane being 2 mm away. Although the bubbles are likely deformed by the streamer, their shapes were not changed in the simulation. The resulting electron densities ($\mathrm{cm}^{-3}$) and photoionization sources ($\mathrm{cm}^{-3}\mathrm{s}^{-1}$) are shown in Fig. 1. In the absence of bubbles, a single streamer propagates from the electrode tip. Photoionization seeds electrons a few hundred micrometers ahead of the ionization front. Only near the front is the electric field/gas number density (E/N) large enough to avalanche the seed electrons to propagate the streamer. With bubbles, photoionization seeds electrons in regions of low gas density and large E/N. For this case, the E/N in the bubbles is five times larger than the surrounding gas. The absolute rate of photoionization in the bubbles is small due to the low gas density. However, the seed electrons are produced in regions of E/N that are large enough to first initiate anode-directed, and then cathode-directed, streamers from the bubbles. The anode-directed streamer from a lower bubble intersecting the cathode-directed streamer from an upper bubble may result in what appears to be a kink in the streamer path. We found that the general propensity is for streamers to be passed between bubbles if they are sufficiently closely placed.

In conclusion, the consequences of low-density inhomogeneities (or bubbles) on the branching of an atmospheric pressure positive streamer in humid air were investigated. The large E/N in the bubbles avalanches seed electrons produced by photoionization. Each bubble then seeds both anode- and cathode-directed streamers that link with those from adjacent bubbles or the original streamer.

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Manuscript received February 7, 2008; revised March 2, 2008. This work was supported by the National Science Foundation.

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Digital Object Identifier 10.1109/TPS.2008.922434

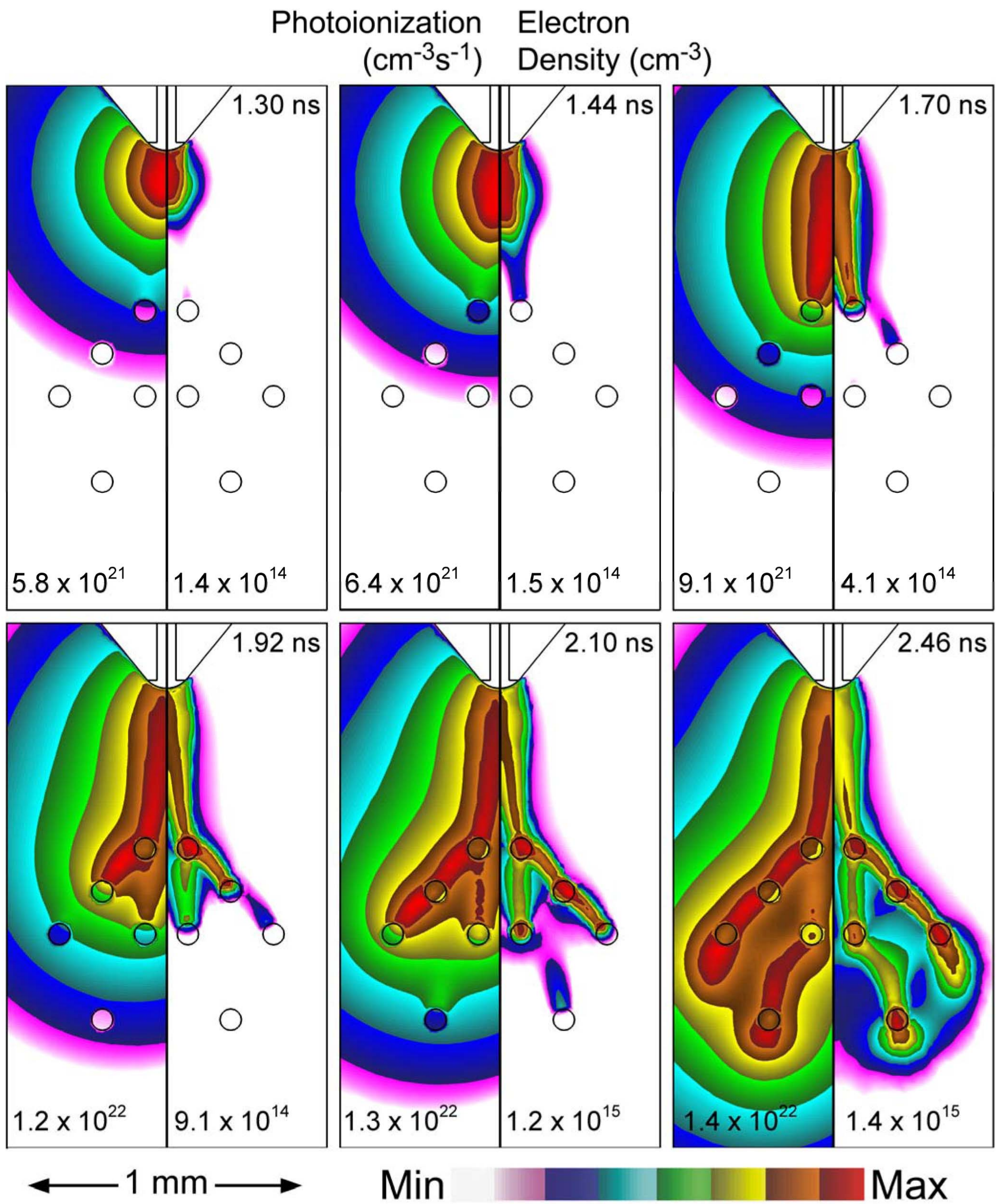


Fig. 1. Streamer development for an atmospheric-pressure-positive corona discharge with randomly placed 0.2-atm bubbles. (Left) Photoionization sources ($cm^{-3}s^{-1}$, 4-decade range) and (right) electron density ($cm^{-3}$, 3-decade range). The maximum values are shown at the bottom of each figure.