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THE PURPORTED TRANSITION FROM AVALANCHE TO STREAMER BREAKDOWN

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Abstract

Much effort has been exerted for many years in studying the purported transition from Townsend, or avalanche, to photoionization streamer breakdown. Calculations made with the Townsend model including space charge show detailed agreement with the experimental measurements of the alleged transition in nitrogen made by Tholl. There no longer seems to be any reason to consider gas photoionization as a dominant process in the so-called streamer breakdown in plane parallel gaps, and the use of the word transition becomes purely semantic.

Townsend developed the avalanche model of electrical breakdown in gases in the early years of this century [1]. This model is based on the primary ionization by electron collisions and the secondary ionization dominated by cathode processes, and gives accurate values of breakdown voltages. However, by the middle thirties, such short breakdown times had been measured at high gas pressures and overvoltages that the avalanche model seemed untenable under these conditions. The streamer model based on space charge distortion and gas photoionization was introduced independently by Loeb and Raether [1]. Much effort since that time has been expended in defining the transition from the avalanche to streamer breakdown. With more accurate measurements, the pressure and overvoltage claimed for this transition have steadily increased. It is the purpose of the present paper to show that the photoionization streamer is no longer needed to explain breakdown in parallel plate geometry.

The Townsend model with space charge has been used in a digital computer program to study electrical breakdown in gases [2]. The mathematical details have been published [3] and only a summary of the formulation is given here. The one dimensional continuity equations governing the growth of current in a gas in the Townsend model are

$$\partial\rho_\pm/\partial t = \alpha(x,\ t)\ J_-(x,\ t) \pm \partial J_\pm/\partial x, \tag{1}$$

where x is the distance measured from the cathode, t is the time, α is Townsend's first ionization coefficient, and $\rho_\pm$ and $J_\pm$ are the charge and current densities respectively of the electrons and the positive ions. Although diffusion is neglected in the formulation, the finite difference equations yield an almost perfect analog to particle diffusion [4]. Space charge effects are treated exactly in one dimension with Poisson's equation

$$dE/dx = [\rho_+(x,\ t) - \rho_-(x,\ t)]/\varepsilon_0. \tag{2}$$

The boundary condition on the field is determined by the external circuit, and the ion current at the anode is set equal to zero. The electron current at the cathode is determined by Townsend's secondary ionization coefficient γ, herein assumed constant.

Townsend's empirical equation for the variation of α with the field E and pressure p was used

$$\alpha = Ap \exp(-Bp/E). \quad (3)$$

Calculations have been performed to compare with the measurements made by Tholl [5] of current buildup in a N_2-CH_4 mixture at a pressure of 400 torr in a 3-cm gap. Tholl used a photomultiplier to measure the increase of discharge radiation as a function of time for various overvoltages. The discharge radiation is expected to be proportional to the current. Measurements by Hoger [6] in the same laboratory were used to evaluate the empirical constants

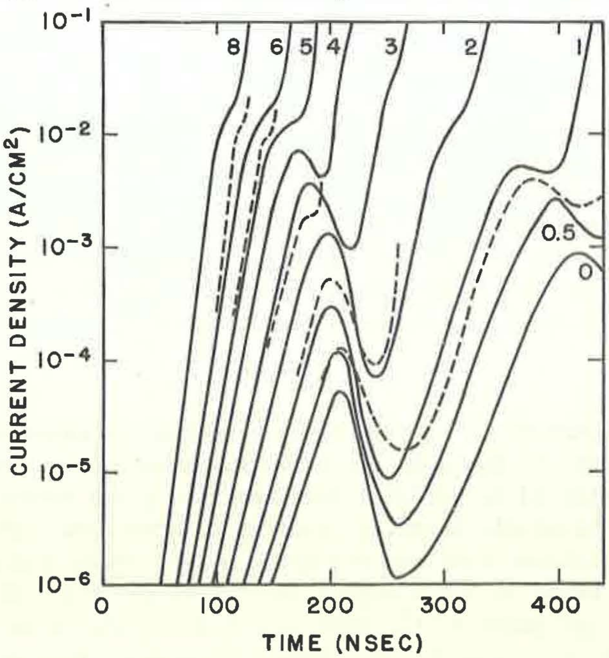

FIGURE 1

Growth of current density with time for various applied voltages. The applied voltage was 50 kv, plus the increment in kv shown for each of the calculated solid-line curves. Selected measured curves of Tholl [5] are shown as dashed curves, where the whole family is arbitrarily assigned in current magnitude.

A and B in equation (3). The values so obtained were 4 cm^{-1} $torr^{-1}$ and 242 V cm^{-1} $torr^{-1}$ respectively. The electron mobility was chosen to obtain agreement with Tholl's current growth constant $\tau_0 = (\alpha v_-)^{-1}$ in the absence of space charge. The results of one sequence of calculations with applied voltages varying from 50 to 58 kv and with $\gamma = 1 \times 10^{-5}$ is shown in Fig. 1. Also shown in Fig. 1 are measured curves of Tholl that have been arbitrarily fitted as a group to the calculated current density magnitude, since Tholl measured only the photomultiplier response.

Breakdown occurs when the avalanche is in midgap for the highest overvoltage, $\sim$ 20 percent. A detailed account of this midgap breakdown has been submitted for publication. For lower overvoltages breakdown occurs successively during the second, third, ... etc. avalanches with but little structure observed in the breakdown time versus overvoltage curves.

The agreement between the measured and calculated curves is so detailed that little doubt remains as to the sufficiency of the basic Townsend model of breakdown. In fact, one suspects that there are compensating errors in the one-dimensional calculations to give such close agreement for avalanches initiated by single electrons.

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