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Formative time delay distributions for multielectron initiation and Townsend breakdown in neon (II)

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1. Introduction

Study of electron avalanche multiplication is important for the electrical breakdown of gases (Raether 1964, Meek 1978), as well as for the operation of radiation and particle detectors (Sauli 2014, Titov 2012). By studying the fluctuation phenomena in the passage of electrons through lead and gases, Furry 1937 and Wijsman 1949 derived the electron number distributions of avalanches initiated by one particle, which for a large number of electrons are approximated by the exponential distributions. As for our studies in the field of avalanche statistics, the statistical analyses and Monte Carlo simulation of the size distribution of electron avalanches were carried out in Jovanović et al. 2019, Stamenković et al. 2018, 2020, and Marković et al. 2019. In Jovanović et al. 2019, the experimental results for the single electron initiation from, were modeled using the Monte Carlo simulation, and the shape of the distribution under different conditions was discussed. A generalization of the primary electron avalanche statistics for multielectron initiation based on the negative binomial distribution (NBD) and the continual Gaussian approximation was proposed in Stamenković et al. 2018. Besides that, when the emission of initiating electrons is a homogeneous (stationary) and an inhomogeneous (non-stationary) Poisson process, the weighted mixtures of NBDs for electron avalanche statistics are applied in Marković et al. 2019. In Stamenković et al. 2020, the statistics of secondary electron avalanches with ion-induced electron emission in air was based on NBD and its mixtures, as well as on their Gaussian continual approximations.

On the other hand, it is well known from early breakdown studies that there is a time interval between the moment of voltage application to the spark gap and the electrical breakdown. This time interval is referred as the breakdown time delay t_d and consists of the statistical time delay t_s and the formative time delay t_f (Meek 1978). The time which elapses between the application of a voltage greater than the static breakdown voltage U_s and the appearance of a free electron initiating breakdown is the statistical time delay and from this moment to the collapse of the applied voltage and occurrence of a self-sustained current is the formative time delay (Meek 1978). By measuring the statistical time memory curve $t_s(\tau)$, the formative time memory curve $t_f(\tau)$ and the dynamic breakdown voltage memory curve $U_b(\tau)$, (τ is the afterglow period or relaxation time), the transition regimes of gas discharges have been studied (Marković et al. 2009, 2005a, 2005b). The memory effect in nitrogen and nitrogen mixtures was observed with different voltage pulses (DC, RF, linearly rising or ramp voltage pulses and others) (Huo et al. 2014, Dyatko et al. 2018, Marković et al. 2018), as well as in RPC and Compass RICH (Fonte et al. 2008).

In this paper, we compared the experimental formative time distributions with theoretical distributions for multielectron initiation and Townsend breakdown mechanisms in neon. The paper is organized as follows. In Section 2, the experimental details for the breakdown time delay measurements are shortly quoted, while in Section 3, the experimental formative time distributions in neon are compared with derived theoretical distributions.

2. Experimental details

The breakdown time delay measurements were carried out on a gas tube made of borosilicate glass (8245, Shott technical glass) with volume of $V \approx 300\ cm^3$ and gold-plated copper cathode, with the diameter $D = 0.6\ cm$ and the gap distance $d = 0.6\ cm$. The tube was filled with research purity neon at the pressure of $p = 13.3\ mbar$ (Matheson Co.) with a nitrogen impurity below 1 ppm. Prior to measurements, the cathode surface was conditioned by running a glow discharge and several thousands breakdowns. The static breakdown voltage was $U_s = 271\ V$ DC. The time delay measurements were carried out by applying step pulses, at glow current $I_g = 0.1\ mA$, glow time $t_g = 1\ s$, working voltage $U_w = 320\ V$ and at different afterglow periods τ. The personal computer with interface was used to control the value of afterglow period and other basic parameters of the experiment, as well as for collection and analysis of data, achieving the voltage rise time and resolution limit below 0.2 microseconds. During the measurements the tube was protected from external light. More details about the experimental procedure, measuring system and tube preparation can be found in Marković et al. 2009, 2005a, 2005b.

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3. The formative time delay distributions for multielectron initiation in neon

According to I, the formative time delay distribution for streamer breakdown mechanism as a function of number of initiating electrons k is given by:

$$\rho_T{}^{str}(t_f) = \frac{\alpha w_e}{\Gamma(k)}\left[\frac{n_c}{\exp(\alpha w_e t_f)}\right]^k \exp\left(-\frac{n_c}{\exp(\alpha w_e t_f)}\right), \qquad (1)$$

where α is the Townsend first electron ionization coefficient, w_e is the electron drift velocity and $n_c \approx 10^8$ is the critical number of electrons. For Townsend breakdown mechanism, the formative time delay distribution when the number of initiating electrons k is high, is given by similar relation:

$$\rho_T^{Town}(t_f) = \frac{\alpha\gamma w_i}{\Gamma(k)}\left[\frac{n_T}{\exp(\alpha\gamma w_i t_f)}\right]^k \exp\left(-\frac{n_T}{\exp(\alpha\gamma w_i t_f)}\right) \qquad (2)$$

where γ is the secondary ionization coefficient, w_i is the ion drift velocity and n_T is the critical number of electrons for Townsend breakdown, before the fast super-exponential current rise (Marković et al. 2007, 2008).

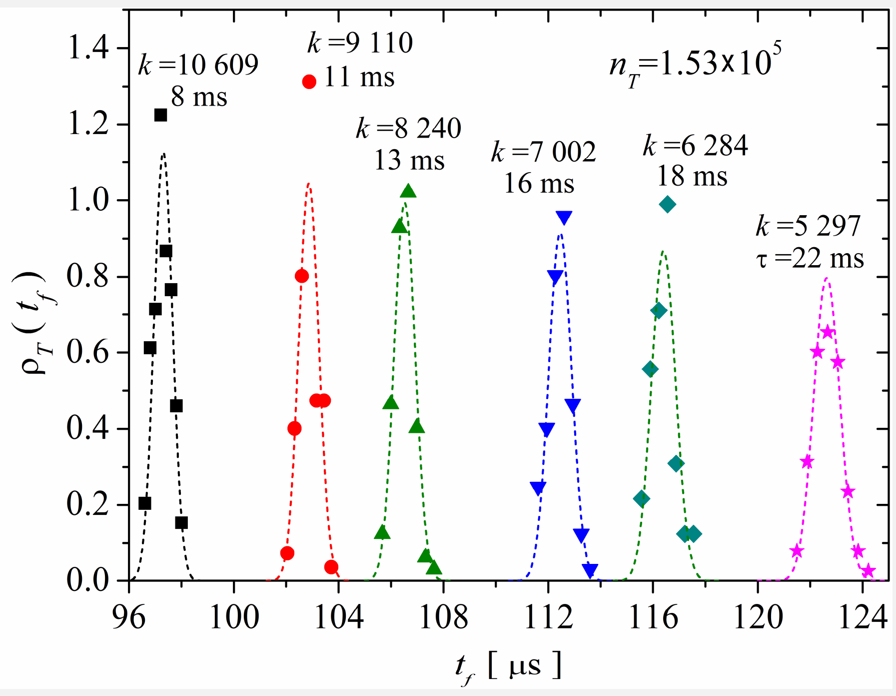

Figure 1: The formative time delay distributions for the Townsend breakdown mechanism in neon fitted by the theoretical distributions (2) with different number of initiating electrons k.

The memory effect in atomic and molecular gases was studied by measurements of the statistical time memory curves, the formative time memory curves, as well as the breakdown voltage memory curves (Marković et al. 2009, 2005a, 2005b, 2018, Huo et al. 2014, Dyatko et al. 2018). While studying the memory effect in neon (Marković et al. 2009), the statistical and formative time delay distributions were measured at different preionization levels (afterglow periods). The derived theoretical distributions (2) are compared to the experimental distributions measured in neon, taking into account that $\bar{t}_f = \ln(n_T/k)/(\alpha\gamma w_i)$ (Marković et al. 2008), and a good agreement was found with $\gamma = 2.2 \times 10^{-2}$, $w_i = 1.62 \times 10^5\ cm/s$ and $n_T = 1.53 \times 10^5$ (Figure 1).

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