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FLUCTUATIONS AND CORRELATIONS OF THE FORMATIVE AND STATISTICAL TIME DELAY IN NEON

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Abstract. In this paper the fluctuations and correlations of the formative t_f and statistical time delay t_s in neon studied by electrical breakdown time delay measurements are presented. The Gaussian distribution for the formative time delay, as well as Gaussian, Gauss-exponential and exponential distribution for the statistical time delay were obtained experimentally. By fitting their dependencies on the afterglow period by simple analytical models, the correlations of the formative and statistical time delay were found. Linear correlation coefficient is $\rho \approx 1$ at high electron yields and $\rho \approx 0$ at low electron yields. Thus, the formative and statistical time delay are correlated at high electron yields during charged particle decay and therefore not independent.

1. INTRODUCTION

In a recent paper (Marković et al. 2006) two new distributions of the statistical time delay of electrical breakdown in nitrogen were reported. It was shown that a distribution of the statistical time delay changes from an exponential distribution at low electron yields (i.e. rates of electron production) to Gauss-exponential and Gaussian distribution at high electron yields due to the influence of residual ionization. In paper by Marković et al. (2007a) the distribution of the formative time delay is experimentally obtained and fitted by Gaussian density distribution. Besides that, the metastable and charged particle decay in neon afterglow was studied by the breakdown time delay measurements and the memory effect in neon was explained (Marković et al. 2007b). The metastable hypothesis as an explanation of the memory effect (the long time variation of the electrical breakdown time delay on the relaxation time $\overline{t_d}(\tau)$, Bošan (1978), Bošan et al. (1986), Maluckov et al. (2004)), completely failed to explain the afterglow kinetics in neon.

2. EXPERIMENTAL DETAILS

The breakdown time delay measurements were carried out on a gas tube made of borosilicate glass (8245, Shottt technical glass) with volume of $V \approx 300\,cm^3$ and gold-plated copper cathode, with the diameter $D = 0.6\,cm$ and the interelectrode distance $d = 0.6cm$. The tube was filled with research purity neon at the pressure of $13.3\,mbar$ (Matheson Co. with a nitrogen impurity below $1\,ppm$). Prior to measurements, the

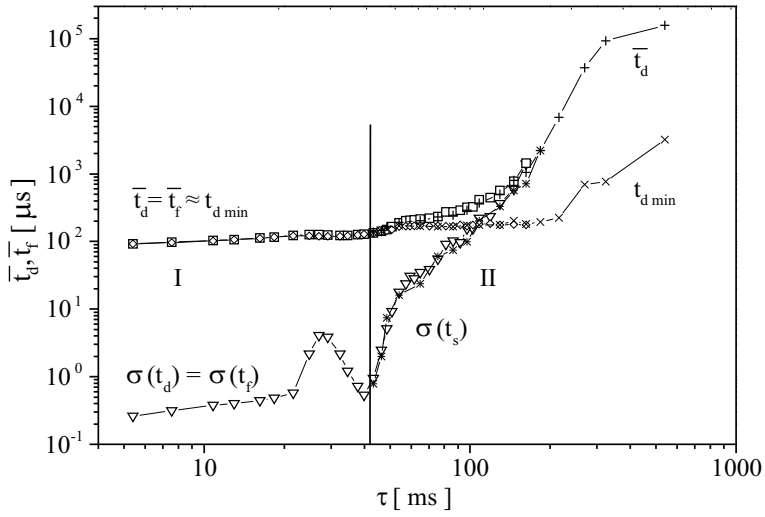

Figure 1: The memory curve, the formative and statistical time delay and their standard deviations in neon as a function of the afterglow period.

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 $U_w = 320V$ and at different afterglow periods τ . More details about the experimental procedure, measuring system and tube preparation can be found in Marković et al (2006,2007a).

3. RESULTS AND DISCUSSION

The time that elapses from the moment of applying of voltage greater than the static breakdown voltage U_s to the breakdown occurrence is denoted as the breakdown time delay t_d. It consists of the statistical t_s and formative time delay t_f, i.e. $t_d = t_s + t_f$ (Morgan 1978), where t_s is the time from the application of voltage to the appearance of a free electrons initiating breakdown and t_f is the time from this moment to the collapse of the applied voltage and occurrence of a self sustained current (Morgan 1978). The breakdown time delay dependence on the afterglow period $\overline{t_d}(\tau)$ (the memory curve, Bošan, 1978), as well as the formative and statistical time delay and their standard deviations $\sigma(t_f)$ and $\sigma(t_s)$, respectively, are shown in Fig. 1, and will be discussed on the basis of simple analytical models.

According to Kasner 1968 and Philbrick et al 1969, the molecular neon ions Ne_2^+ are dominant during the glow under given conditions. Their number density decay in the afterglow (the region I in Fig. 1) can be described by equation $dn_i/dt = -\nu\, n_i - \beta\, n_i^2$, whose solution is:

$$n_i = \frac{n_{i0}\, exp\,(-\nu\tau)}{1 + (\beta\, n_{i0}/\nu)\,[1 - exp\,(-\nu\tau)]}. \qquad (1)$$

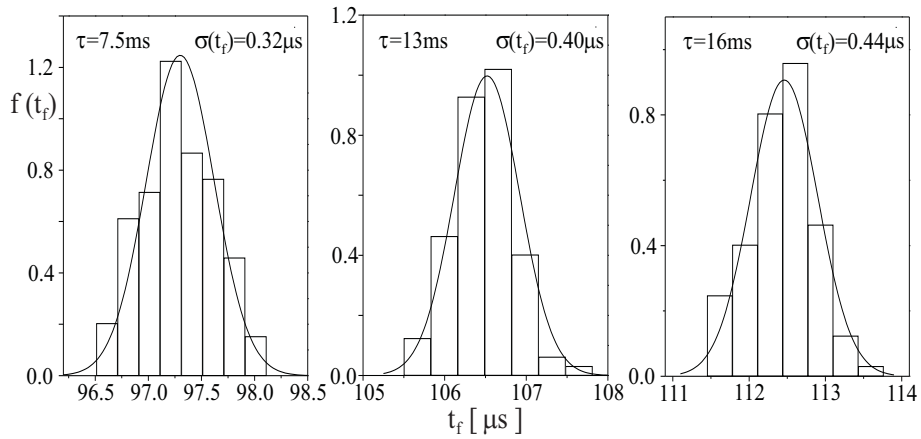

Figure 2: The density distribution functions of the formative time delay (region I).

Here, n_{i0} represents the initial number density of Ne_2^+, β is the electron-ion dissociative recombination coefficient and $\nu = D/\Lambda^2 + k_{cn}[N_2]$ is the first order decay frequency including diffusion and conversion to N_2^+ ions (reaction $Ne_2^+ + N_2 \rightarrow N_2^+ + 2Ne$). When the first order loss processes are predominant $\nu \gg \beta\, n_{i0}$, the exponential decay is obtained:

$$n_i = n_{i0}\, e^{-\nu\, \tau} \tag{2}$$

On the other side, the formative time can be expressed by (Marković et al. 2007a):

$$\overline{t_f} = \frac{q}{q-1}\frac{d}{w_i} \ln \frac{1 + (q-1)(n_{it}/n_i)}{q}, \tag{3}$$

where n_{it} is the ion number density in the Townsend's dark discharge before the collapse of applied voltage (Marković et al, 2008), n_i is the initial ion number density for the formative time, $q = \gamma\,[exp\,(\alpha\, d) - 1]$, α and γ are the primary and secondary ionization coefficients and w_i is the ion drift velocity. Inserting the exponential decay (2) into (3), it follows that the formative time is proportional to the afterglow period $\overline{t_f} \propto \tau$ (the region I in Fig. 1). Thus, the formative time delay in the ionic region (I) increases when the afterglow period (τ) increases, contrary to results in Maluckov et al (2004,2006) where the ionic region is flat.

In this case, the experimental density distribution functions of the formative time delay are obtained providing that $t_s << t_f$ and $\sigma\ (t_s) << \sigma\ (t_f)$, which can be fulfilled by measurements at high level of residual ionization in the region (I) in Fig. 1 (Marković et al. 2007a). The experimental density distribution functions of the formative time are fitted by Gaussian distributions and shown in Fig. 2, accompanied by their standard deviations. The standard deviation of the formative time delay increases with the afterglow period faster than the formative time delay (Figs. 1,2).

In the region II of the memory curve, the electrical breakdown time delay distributions are dominated by the fluctuations of the statistical time delay. According to Marković et al (2006), the three characteristic distributions of the statistical time delay are obtained when the afterglow period increases (the electron yield decreases):

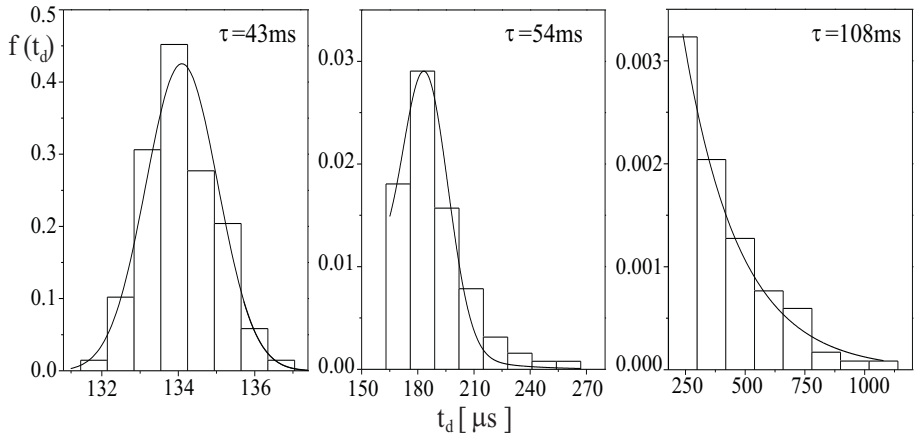

Figure 3: The three characteristic distributions of the statistical time delay (Gaussian, Gauss-exponential and exponential) in the region (II) of Fig. 1.

Gaussian, Gauss-exponential and exponential (Fig. 3). The corresponding effective electron yields are as follows : $Y_{eff} \equiv Y\,P \gtrsim 10^6\,s^{-1}$, $10^6\,s^{-1} \gtrsim Y_{eff} \gtrsim 10^4\,s^{-1}$ and $Y_{eff} \lesssim 10^4\,s^{-1}$, respectively. According to Marković et al. (2008), the linear correlation coefficient is $\rho \approx 1$ at high electron yields $Y_{eff} \gtrsim 10^{11}\,s^{-1}$ (t_s and t_f distributions are Gaussians) and decreases to $\rho \approx 0$ at low electron yields $Y_{eff} \lesssim 10^4\,s^{-1}$ (t_s distribution is exponential and t_f Gaussian). In other words, the distributions are independent if $t_s \gtrsim t_f$, which is equivalent to $Y_{eff} \lesssim 10^4\,s^{-1}$ (Figs. 1,3). Thus, the formative and statistical time delay are correlated at electron yields $Y_{eff} \gtrsim 10^4\,s^{-1}$ and therefore not independent, contrary to claims in Maluckov et al (2004,2006). It is clear that t_f follows t_s and the output from t_s is the input for t_f; therefore, the higher particle transfer means the higher degree of correlation and vice versa.

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