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THEORY OF DEPENDENT AVALANCHES AND THE BREAKDOWN PROBABILITY

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Fundamentals of the electrical breakdown time delay studies were laid by Zuber and von Laue in 1925 [1,2]. Zuber has proven experimentally that the breakdown time delay has a stochastic nature, while von Laue shown that its distribution is exponential. Exponential distribution for the statistical time delay was strictly derived by Kiselev [3], starting from a binomial distribution for the electron occurrence in the interelectrode space. For the transition from binomial to Poisson and exponential distribution it was implicitly assumed [3] that the rate of electron production in the interelectrode space (electron yield) Y is small or $YPt_s/m \equiv p$ is close to zero [4]. Here, P is the breakdown probability of one electron to cause breakdown, t_S is the statistical time delay and m is the number of subintervals within t_s in order to obtain at most one electron occurrence in each subinterval (i.e. independent accidents and avalanches).

However, if neither p nor $1-p$ is too close to zero, Gaussian distribution is obtained as a limiting case of binomial distribution [4]. In paper [4] it was shown experimentally and theoretically how the sum of binomial distributions for the electron occurrence goes to Gauss-exponential and Gaussian distribution for the statistical breakdown time delay in nitrogen, and also confirmed in neon [5]. Thus, beside of independent avalanches (in time) as treated in [1,2,3] ($\overline{t_d} \approx \overline{t_s} >> \overline{t_f}$, or $YP << 1/\overline{t_f}$), we have obtained dependent avalanches, also. Namely, if a new initiating electron occurred before the formative time initiated by the preceding electron is finished ($YP \geq 1/\overline{t_f}$), the avalanches are dependent (correlated) leading to the Gauss-exponential and Gaussian distribution for t_s and the correlation coefficient between t_s and t_f is determined [5,6].

The measurements were carried out on a gas tube made of borosilicate glass with volume of $V \approx 300\ cm^3$ and the cylindrical copper cathode (gold plated by vacuum deposition) with diameter $D = 6\ mm$ and gap $d = 6\ mm$. The tube was filled with research purity neon at the pressure of $6.6\ mbar$ (Matheson Co. with a nitrogen impurity below $1\ ppm$). The static breakdown voltage was $U_s = 265V$. The time delay measurements were carried out at glow current $I_g = 45\mu A$, glow time $t_g = 1s$, afterglow period $\tau = 40\ ms$ and at different working voltages U. More details about the experimental procedure can be found in [4,5].

The breakdown probability P of one electron to cause breakdown that will be applied here, was theoretically derived by Wijsman [7], considering the sequences of electron avalanches and for nonattaching gases it is given by:

$$P = \begin{cases} 1 - 1/q, & if \quad q > 1 \\ 0, & if \quad q < 1 \end{cases}, \qquad (1)$$

where $q = \gamma \exp(\alpha d)$, γ is the effective electron yield and α is the electron ionization coefficient. Experimental determination of the breakdown probability P is given in [8] by relation:

$$P(U) = \overline{t}_s^{SV} / \overline{t}_s(U) \tag{2}$$

where $\overline{t}_s$ is the statistical time delay and $\overline{t}_s^{SV}$ its saturation value at high voltages, since at high voltages $\overline{t}_s \rightarrow \overline{t}_s^{SV}$ and $P \rightarrow 1$. When $\overline{t}_f$ can be neglected, then $\overline{t}_d \approx \overline{t}_s >> \overline{t}_f$. The statistical time delay distribution is exponential, the standard deviations are $\sigma_{td} \approx \sigma_{ts} >> \sigma_{tf}$ and $\overline{t}_s = 1/YP$ [8,9]. Improved formulas for the breakdown probability P under the influence of field-assisted electron emission and surface charges on the cathode surface were derived in [10].

For dependent avalanches, $\overline{t}_s \leq \overline{t}_f$ ($YP \geq 1/\overline{t}_f$), $\overline{t}_f$ should be subtracted from $\overline{t}_d$ and equation (2) modified, according to results in [4,5,6]:

$$P(U) = \frac{\overline{t}_s^{SV}}{\overline{t}_s(U)} \approx \frac{\overline{t}_d^{SV} - \overline{t}_f^{SV}}{\overline{t}_d(U) - \overline{t}_f(U)} \approx \frac{\overline{t}_d^{SV} - t_{d\min}^{SV}}{\overline{t}_d(U) - t_{d\min}(U)}, \tag{3}$$

where $\overline{t}_f \approx t_{d\min}$ [9]. Also, $\sigma_{td} \approx \sigma_{ts} >> \sigma_{tf}$ is still valid [4,5,9], $\overline{t}_s = \kappa\sigma_{td}$ ($\kappa = 1.7$) [5] and $P = \overline{t}_s^{SV} / \overline{t}_s(U) \approx \sigma_{td}^{SV} / \sigma_{td}(U)$ is shown for comparison with eq. (3) (Fig. 1).

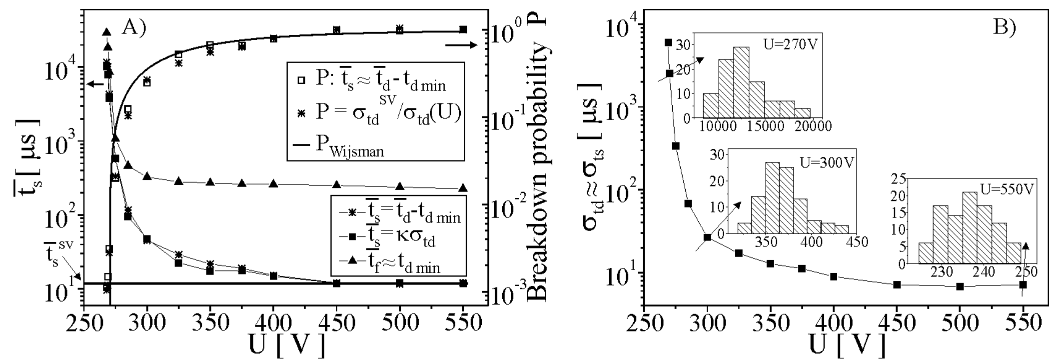

Fig. 1: A) Statistical time delay (■,∗), formative time delay (▲) and the breakdown probability (□,∗, solid line – Wijsman's formula (1)). B) Standard deviation and distributions.

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