The breakdown in a long non-shielded discharge tube in low-pressure nitrogen.

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Electrical and optical studies of the breakdown through nitrogen in a long discharge tube are performed at pressure of about 1 Torr. The distinctive feature of the study is the absense of metal shield surrounding the tube. In these case we obtain discharge more similar to conventional one, such as used, e.g., in gas-filled lamps. It is found that the discharge characteristics (breakdown voltage, time evolution of the current, voltage, and luminosity) depend critically on polarity of the applied voltage. At positive voltage the breakdown is proceeded by ionization wave, which is not observed at negative polarity. Dependences of discharge characteristics on pulse frequency ('memory effect') and on steepness of applied voltage are different for two polarities.

Low-pressure gas discharge in long (length much larger than diameter) tubes has numerous applications, fluorescent lamps are the most evident. Investigation of discharge of this kind has a 100-year history and profound understanding of their physics has been achieved in many aspects. Ignition of such a discharge, that is the breakdown of the gas is one of the important exclusions. Breakdown in long tubes is much more complicated than in short discharge gap with large electrodes, where classical Townsend processes occur. The reason for that is essential non-uniformity of electric field before the breakdown and a crucial role of the tube wall (see [1] and references herein). Contemporary description of such a breakdown includes two essential stages, the first is breakdown between high-voltage electrode and nearest piece of the dielectric wall, and the second is propagation of ionization wave(s) along the tube. However, despite the fact that often contemporary and rather sophisticated technique [1] is used, the problem is until now far from full understanding.

It is important to note, that in previous works the discharge tube was surrounded with grounded metal shield (the Faraday cage). It was designed to exclude an environmental electrostatic influence on the breakdown. On the other hand, the metal shield produces additional finite (though definite) capacitance of the tube which could also influence the breakdown. In our experiments we used no shielding. Instead we tried to minimize possible electrostatic influence of the environment. We used dielectric tube holders, so that the distance from the tube to the nearest metal detail was 8 cm. It was proved experimentally that outer metal objects influence the breakdown if it is only closer than 1 – 2 cm.

We used a discharge tube of 2.8 cm i.d. made of molybdenum glass. The distance between two tantalum cylindrical electrodes was 40 cm. High purity nitrogen was pumped continuously through the tube. Voltage drop and current during the breakdown and following discharge pulse were measured with oscilloscope. The luminosity of gas in the tube was measured with use of optical fibers at different axial positions. One of the discharge electrodes was maintained at zero (ground) potential, the discharge voltage could be both positive and negative.

Fig. 1 shows that temporal dependences of the discharge parameters at different voltage polarity. Pulses of 3 ms duration, 5 Hz frequency were studied. Here (as well as for fig. 2) statistical time delay for the breakdown was negligible, so the pictures were reproducible. Applied voltage at leading edge of the pulse changed with time as $V_S \cdot [1 - \exp(-t/\tau)]$, where V_S is the power supply voltage, $\tau \approx 50$ µs. With the **cathode** grounded the breakdown is accompanied by the ionization wave (IW) propagating from the anode. In more precise time scale it could be seen that the breakdown occurs at the moment when IW comes to the cathode. The discharge voltage just after the breakdown drops and remains noticeably lower than that in steady-state discharge. During this (≈ 200 µs) interval there is no discharge emission ('dark phase' of the discharge [2]). This phase is followed by excitation of damping moving striations, revealed by oscillations in optical signal. For the **anode** grounded, the breakdown voltage V_B is higher by more than 300 V, and neither IW, nor 'dark phase' and moving striations are observed. Hence, change of polarity of the electrodes result in drastic changing all the characteristics of ignition of the discharge, which implies the possible existence of two different breakdown mechanisms. An influence of electrode polarity on the discharge ignition was marked

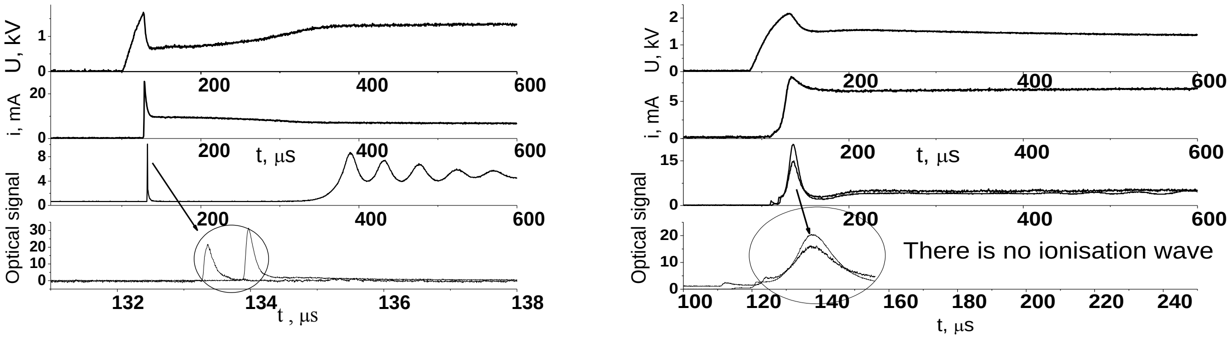

Fig. 1: Temporal dependences of discharge voltage, current and registered optical signal for a positive (left panel) and negative (right one) polarities. N_2 1 Torr, ballast resistor R_b = 520 kΩ, V_S = 2.9 kV. Two peaks in the left insert below show the ionization wave propagation by two points 12 cm apart.

in previous works [1], but it revealed only in inequality of characteristics of the IW (the latter being observed at both polarities).

Fig. 2 depicts how preceding discharge pulse influences the breakdown. The pairs of discharge pulses of 3 ms duration and 200 ms between the pairs were studied. With the **cathode** grounded, preceding discharge always increases the V_B by the value ΔV_B depending on the interpulse spacing Δt. This dependence is non-monotonous with maximum at Δt ~ 1 ms. For conditions of Fig. 2, $\Delta V_B \approx 0.4$ kV for Δt = 100 μs, but for Δt= 1 ms ΔV_B is so large that in the second pulse $V_B > V_S$, and breakdown does not occur. For larger interpulse spacing (Δt > 10 – 20 ms) the effect decays gradually. With the **anode** grounded, $\Delta V_B < 0$ for any Δt and also disappears at large Δt. Actually, the influence of preceding discharge pulse on the breakdown known as 'memory effect', has been studied before [3] but for short discharges (~ 0.1 – 1 cm) only. In those experiments the preceding discharge always promoted the breakdown (*viz*., decreased time delay of the breakdown), and influence of electrode polarity has never been marked.

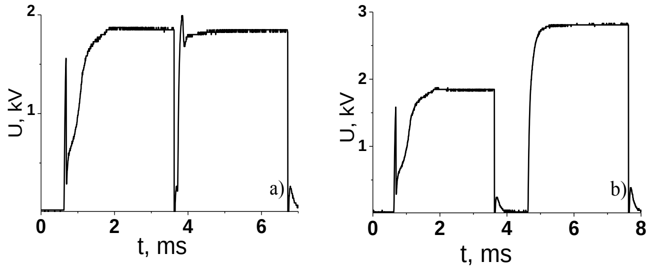

Fig. 2: Temporal dependences of discharge voltage for pair of pulses. N_2, 1 Torr, R_b =520 kΩ, V_S =2.8 kV. a) Δt = 100 μs; b) Δt = 1 ms.

In fig. 3 results of measurements of ionization wave velocity is shown as a function of the breakdown voltage V_B (the cathode is grounded). In this case single pulses with ~1 min interval and for applied voltage linearly growing with time were studied. For such rare pulses, statistical time delay of breakdown is a highly noticeable. As a result, both breakdown voltage and the IW velocity are random values. Fig. 3 depicts evident correlation between them. Moreover, all the points lay along the common line for different growth rates of applied voltage. Note that this study is the first one where the dependence of the IW velocity on V_B is obtained. In previous works its value has been found as the function of applied voltage, which noticeably exceeds V_B.

Discussion of the data obtained will be presented in the report.

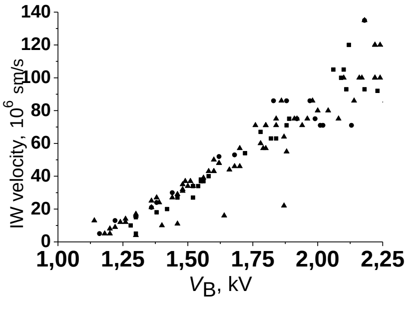

Fig. 3: Dependence of ionization wave velocity on breakdown voltage. N_2, 0.63 Torr, R_b = 260 kΩ, V_S = 3.6 kV. Applied voltage rates: $2.8\cdot10^4$ - $1.75\cdot10^5$ V/s

References

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