Measurements and determination of breakdown voltage in DC discharges at low pressure

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1. Introduction

Non-equilibrium plasmas in gases and vapors are of interest due to multiple application possibilities, from nanotechnology, electronics, biomedicine, energetics to ecology and environmental protection. The development of various new applications is closely related to the knowledge and research of the elementary properties of discharge regarding breakdown, operating regimes, discharge structure, etc. Having breakdown voltage data (Paschen curve) for a wide range of the reduced electric fields E/N (E – electric field, N- gas density) is, in some cases, of great importance if we take into account the fact that the operation of some applications directly depends on the conditions of the breakdown. Also, breakdown measurements are crucial in providing insight into elementary processes such as ionization, secondary electron emission, and surface interactions that participate in discharges.

In our experiment, the breakdown voltage is determined by igniting discharge in a low-current regime and extrapolating the Volt-Ampere characteristic to zero-current [1-3]. While the advantage of this technique is in the elimination of overvoltage in the pre-breakdown, it can have limitations under certain conditions due to oscillations of voltage and current in the Townsend regime of the discharge. In principle, it is possible to suppress oscillations by adjustments of circuit elements, according to the model developed by Phelps, Petrović and coworkers [4,5]. However, with an increase in pressure, the negative slope of the Volt-Ampere characteristics in Townsend discharge also increases, making the discharge less stable. After a certain point, it is no longer possible to stabilize the discharge by varying circuit elements, while keeping the discharge currents sufficiently low.

We have developed a technique of estimation of the DC breakdown voltage from relaxation oscillations in the Townsend regime of discharge [4,5], with the aim of extending the range of breakdown measurements to higher pressures and gaps, i.e. lower E/N-s. In this paper, we illustrate the technique for an example of water vapour discharge at pd = 1.1 Torr cm (p-pressure, d-interelectrode distance).

2. Experimental setup

Figure 1 presents a schematics of the experimental setup and the electrical circuit used in the measurements. The breakdown is achieved between a plane cathode made of copper and a flat quartz window with a deposited thin platinum film that serves as an anode. The diameter (2r) of electrodes is 5.4 cm, while the interelectrode distance is variable. For these measurements, it was 1.1 cm. The plane-parallel electrode system is placed inside a tight quartz tube, to prevent long-path breakdown. Vapor is obtained from bi-distilled deionized water and introduced into the discharge chamber at a slow flow rate. Before measurement, a moderate pressure of water vapor is maintained in a chamber for 1-2 hours in order to achieve saturation of chamber walls [1,2].

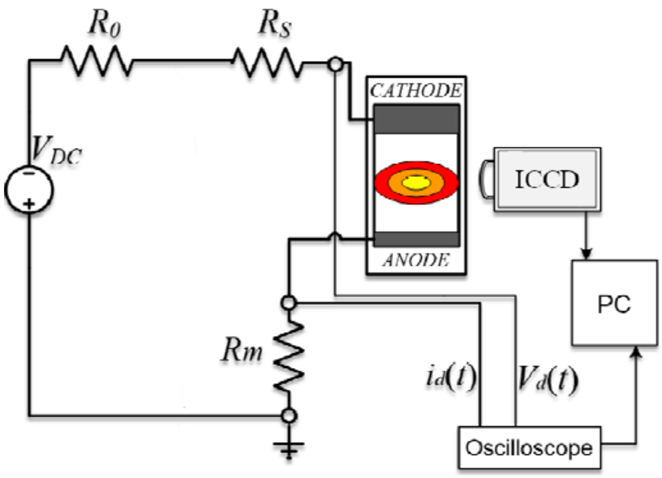

Figure 1. Schematics of the experimental setup and the electrical circuit used in measurements. The series resistors R_0 and R_s are used to limit current and keep it as low as possible for measurements in the Townsend discharge. R_m is the 'monitoring' resistor used to measure discharge current.

3. Results and discussion

During the measurements of breakdown voltage at higher pressures (in a right-hand branch of the Paschen curve), discharge may ignite in the oscillation mode. We will demonstrate that it is possible to determine the breakdown voltage, in the case that discharge ignites in relaxation oscillations. The main feature of such oscillations is that the current briefly passes through the high-current mode and then slowly relaxes to the Townsend low-current mode [4-6]. The breakdown voltage can be estimated from the part of the period corresponding to the lowest current values (fig.2a).

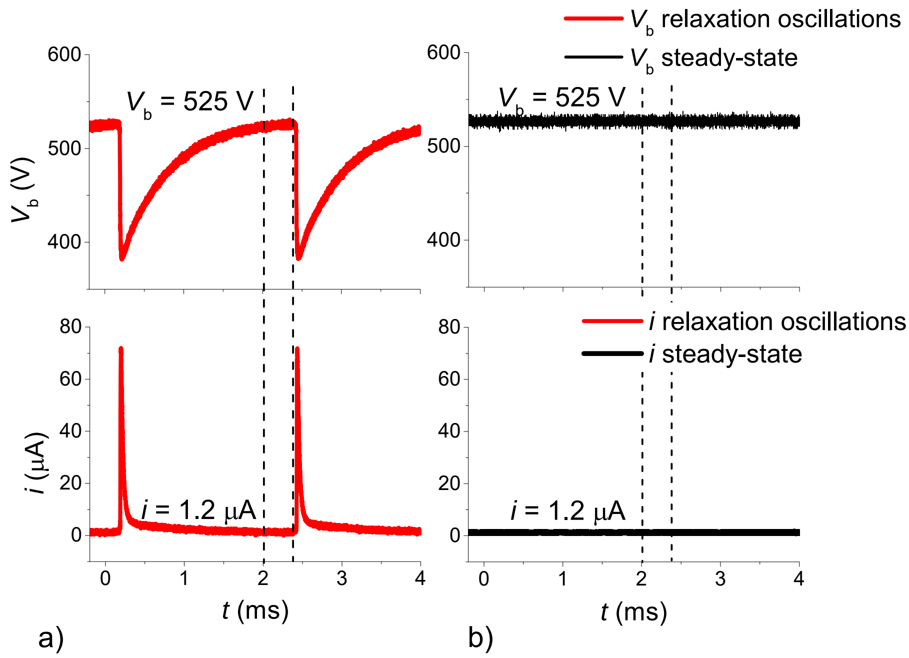

Figure 2. Estimation of breakdown voltage from: a) the relaxation oscillations (red line) and comparison with b) breakdown voltage in the steady-state mode (black line). Presented results are obtained for *pd* = 1.1 Torr cm, by varying the elements of the electrical circuit.

The reproducibility and reliability of results were tested in conditions under which it was possible to obtain a breakdown, both in the steady-state mode (fig.2b) and in the relaxation oscillations (fig.2a) for similar discharge parameters, by varying the elements of the electrical circuit.

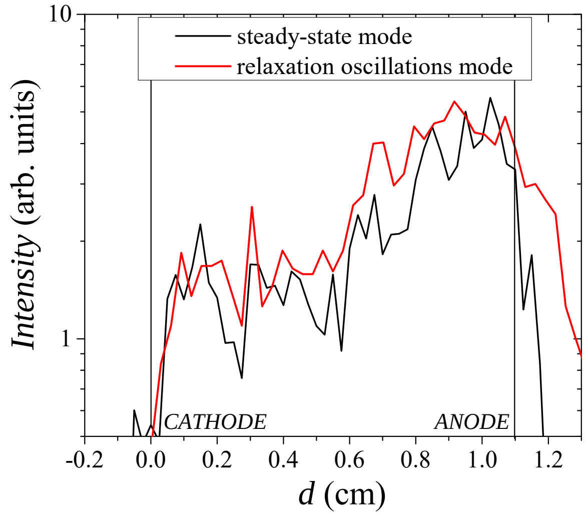

Figure 3. Axial emission profiles obtained by ICCD imaging for breakdown in the steady-state and the relaxation oscillations mode of discharge operation.

Results were also verified by time-resolved ICCD imaging of the discharge emission. These images are used for obtaining axial emission profiles (fig.3). Noise to signal ratio is high because images are taken in a single shot at a very low current, but it is clear that discharge emission in the low current limit of relaxation oscillations corresponds to steady-state conditions. In both cases, the discharge operates in the Townsend regime, with an exponential increase of emission intensity towards the anode. The slope of emission profiles in the log-lin scale is the same, indicating the same ionization coefficient for given conditions.

The presented technique enables breakdown measurements in a considerably wider range of gas pressures and electrode gaps. We have tested and validated the method on a number of gases. Water vapor is chosen as an illustrative example because it has a range of operating conditions where both, steady-state and relaxation-oscillation modes can be easily reached by slight adjustments of elements of electric circuits.

Acknowledgements

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