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BREAKDOWN IN SATURATED WATER VAPOR

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Abstract. This paper presents the results of breakdown measurements in water vapour at pressures around and higher than vapour pressure for water. Breakdown voltage dependences on *pd* (*p* – pressure and *d* – electrode gap) or Paschen curves are recorded for two electrode gaps: 0.5 mm and 1 mm. Measurements were performed at room temperature of 22ºC (vapour pressure 19.8 Torr) and under conditions when the entire discharge chamber was cooled to the temperature of 8ºC (vapour pressure 8.1 Torr), in order to reach conditions where droplet formation takes place at stable discharge conditions. Paschen curves indicate that at room temperature breakdown voltages obtained at 0.5 and 1 mm agree well with the values at the centimetre electrode distances, while at the temperature of 8ºC, for pressures higher than vapour pressure, deviations occur. These deviations can be consequences of liquid droplet formation.

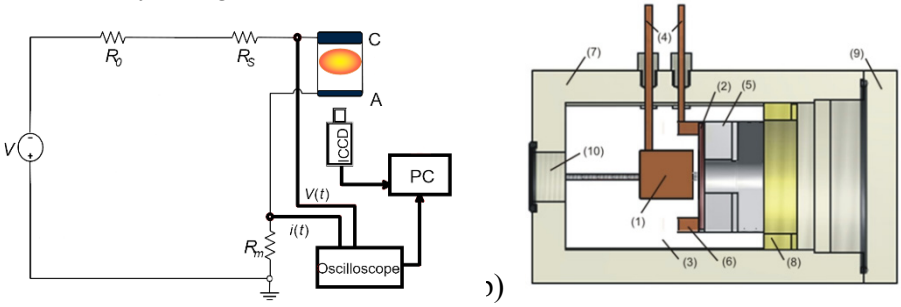
1. INTRODUCTION

Discharges in water and water vapour have a diverse field of application, in food, textile, and aerospace industries, for sterilization and decontamination of different surfaces and instruments in medicine, for the processing, treatment, and functionalization of materials, in biomedicine, etc. (see Stalder et al., 2006; Fumagalli et al., 2012; Rossi et al., 2009). Due to the variety of possible applications, there is a growing need to develop and design different plasma sources that can operate at atmospheric and low pressure, in vapour and in the liquid itself. A common feature of all the above-mentioned applications is the complex working environment – from a mixture of gas and vapour to an environment saturated with water vapour or humid air. In this respect, it is crucial to investigate and understand the breakdown in liquid and at the gas-liquid boundary.

Our previous studies of DC breakdown and discharges in water vapour included measurements of Paschen curves, axial emission profiles, emission spectra and Volt-Ampere characteristics at low pressures (Sivoš et al. 2015). This paper presents an investigation of the breakdown at pressures above the vapour pressure, under the conditions where condensation i.e. liquid droplets formation is expected in the discharge.

2. EXPERIMENTAL SET-UP

The schematic of the experimental setup is shown in Fig.1a) and the discharge chamber in Fig.1b). The discharge is ignited between plane-parallel electrodes that are tightly fitted inside the cylindrical teflon housing that prevents the breakdown around and behind the electrodes, ensures the parallelity of the electrodes, and fixes the electrode system itself. The electrodes are of circular cross-section, separated from each other by a ring-shaped dielectric, which also limits the volume for discharge ignition and operation. The interelectrode distance is adjustable and can be continuously changed.



a) ›)

Figure 1: a) Schematic of the experimental setup and the electrical circuit used in measurements, and b) Cross-section of the chamber for micro-discharges with marked structural parts: (1)–stainless still cathode; (2)– transparent anode with ITO film; (3)–teflon electrodes housing; (4)–high-voltage inlets; (5)–anode mounting ring; (6)–metal contact ring; (7)–plexiglass outer cylinder; (8)–electrodes housing mounting ring; (9)–transparent chamber cover, and (10)–inlet for connection to the vacuum system.

The cathode is made of stainless steel and the anode is made of glass covered by a thin, conductive, and transparent indium-oxide film (Indium Thin Oxide coated glass). The effective diameter of the electrodes exposed to discharge is 2 mm. The electrode system with its housing is fitted inside a plexiglass cylinder, which one side is closed with a transparent lid. This design enables the ICCD recording of radial emission profiles from discharge.

Vapor is obtained from bi-distilled, deionized water in a test tube. The tube is connected to the discharge chamber by a pressure regulating valve. The other side of the discharge chamber is connected to a vacuum pump and a pressure gauge. The chamber is evacuated to low pressure ($<10^{-6}$ Torr), then water vapor is introduced into the system at a slow flow rate while monitoring that the pressure stays below the vapor pressure for water (19.8 Torr at T=22ºC, and 8.1 Torr at

T=8ºC in the case of a cooled chamber). Before measurements, the vapor is left in the system for 1-2 hours to achieve saturation of all surfaces in the chamber.

3. RESULTS AND DISCUSSION

Measurement of breakdown voltages is performed for two electrode gaps 0.5 and 1 mm and compared with Paschen curves obtained for the standard size discharge - 0.5 and 1.1 cm (Fig.2). Paschen curves for micro-discharge are measured at two temperatures 22ºC (vapor pressure is 19.8 Torr) and 8ºC (vapor pressure is 8.1 Torr). In the second case, the entire chamber was cooled to enable measurements at higher pressures than the vapor pressure. Decreasing discharge size and decreasing operating temperatures enabled us measurements at more stable operating conditions, close to a Paschen curve minimum, but above a vapour pressure for water. At room temperature (22ºC), there is good agreement between the Paschen curves recorded in standard size discharge (black and red lines) and micro-discharge (black and red diamonds).

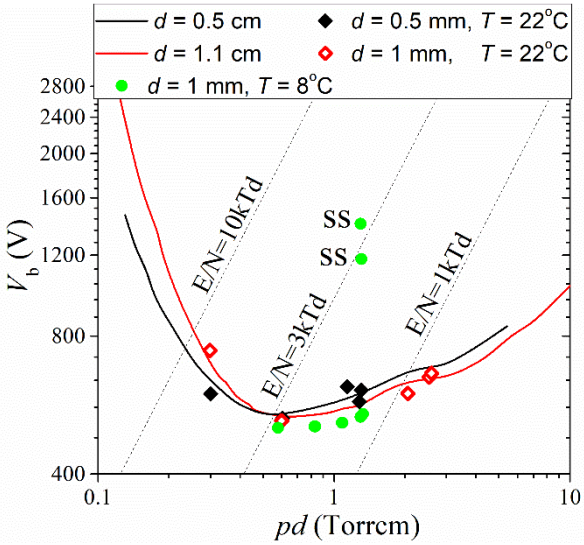


Figure 2: Comparison of the Paschen curves obtained in the chamber for standard size discharge for electrode distances of 0.5 cm (black line) and 1.1 cm (red line) and in the chamber for micro-discharges for electrode distances of 0.5 mm (black diamonds) and 1 mm (red diamonds). These measurements are done at room temperature of 22ºC. Green diamonds show breakdown voltages obtained for electrode distance of 1 mm at a temperature of 8ºC.

At micrometre interelectrode distances, the discharge was unstable, but it was possible to estimate the breakdown voltages from the relaxation oscillations (see Kuschel et al., 2011). In the case when the chamber was cooled (at 8ºC) discharge ignited and operated in the relaxation oscillations mode up to ~1.1 Torr cm. At 1.29 and 1.33 Torr cm, discharge first operated in the steady-state mode (green diamonds marked with SS), and after approximately one minute of stable

operation, it switched to the relaxation oscillations mode. Figure 3 shows the waveforms for current and voltage at pd = 1.29 Torr cm. In Fig.3a discharge operates in steady-state mode at a high voltage of ~1.4 kV while the current is 1 μA, and in Fig.3b discharge is in the oscillatory mode, where the voltage is lower for ~860 V, and the current higher for 18 μA.

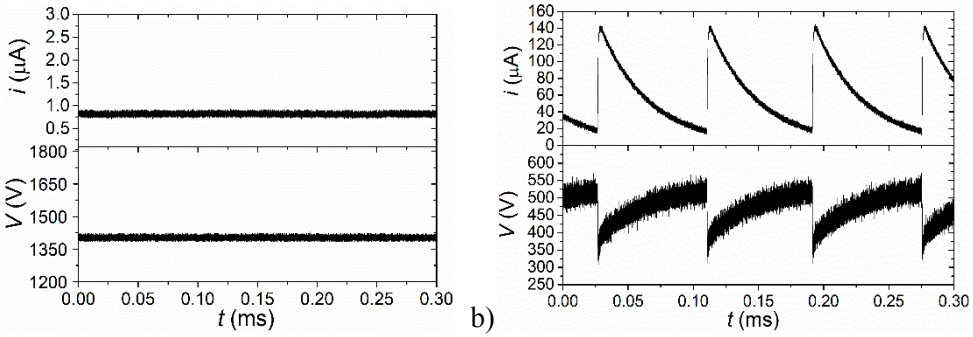


Figure 3: Voltage and current waveforms for micro-discharge in water vapor at pd = 1.29 Torr cm and d = 1 mm: a) when discharge operates in the stationary mode (i =0.8 μA, Vb = 1405 V), and b) when discharge operates in the relaxation oscillations mode (i = 19 μA, V_b = 541 V).

We assume that this behaviour is a consequence of the phase transition in the gas, and the occurrences of condensation or liquid droplets. As the chamber had to be cooled, we could not record the discharge through the transparent anode with an ICCD camera. Therefore, it could not be confirmed whether the discharge was in the Townsend mode upon breakdown. Our further investigation will include recordings of radial emission profiles of discharge, and measurements at shorter electrode gaps, in conditions when the chamber is cooled to lower the limit for the phase transition in water vapor. It must be noted that the ratio of electrode diameter and interelectrode distance should be taken into account, and maintained when reducing the electrode gap. That will limit the radial losses of charged particles to an acceptable level, and allow the application and validity of the one-dimensional Townsend theory.

Acknowledgements

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