

## LOW-PRESSURE DC DISCHARGE IN WATER VAPOUR

NIKOLA ŠKORO<sup>1</sup>, DRAGANA MARIĆ<sup>1</sup>, GORDANA MALOVIĆ<sup>1</sup>,  
WILLIAM G. GRAHAM<sup>2</sup> and ZORAN Lj. PETROVIĆ<sup>1</sup>

<sup>1</sup>*Institute of Physics, University of Belgrade,  
Pregevica 118., 11080 Belgrade, Serbia*

*E-mail: nskoro@ipb.ac.rs*

<sup>2</sup>*Centre for Plasma Physics, Queens' University Belfast, BT7 INN, UK*

**Abstract.** We present investigations of low-pressure breakdown and different regimes of dc discharges in water vapour. Results of measurements include Paschen curves and Volt-Ampere characteristics of the discharge for various  $pd$  conditions and with water samples of different purity.

### 1. INTRODUCTION

Over the past several years a wide range of possible applications drew attention to studies of properties of non-equilibrium discharges in water vapour (Bruggeman and Leys 2009). It is expected that development of sources of atmospheric pressure non-equilibrium (low temperature) plasmas provide cheaper technologies in treatment of materials (Mohan Sankaran and Giapis 2003, Makabe and Petrović 2006), lighting (Eden and Park 2005) and biomedical applications of plasmas (Stalder et al. 2006). Atmospheric pressure sources operate in ambient air which inevitably contains water vapour so it is of great importance to study basic processes that determine properties of discharges in water vapour. Furthermore, recent development and studies of discharges with liquid electrodes (water or some electrolyte) (Bruggeman and Leys 2009) and discharges in heterogeneous water air bubble systems (Bruggeman et al. 2008) are closely connected to water vapour discharges since in both cases the gas would be expected to contain a significant percentage of water vapour that would determine most of its transport properties (Juarez et al. 2008). In spite of increase demand for water vapour data, existing data on breakdown and discharge properties are scarce and often not well documented. We aim to investigate low-pressure dc discharges in water vapour: gas breakdown conditions and the electrical characteristics of the discharge as well as variations of these characteristics in different discharge regimes, from the low-current (Townsend) regime to high current glow discharges.

## 2. EXPERIMENTAL SET-UP

The discharge chamber consists of two parallel plate electrodes 5.4 cm in diameter, with adjustable electrode separation. The electrodes are placed inside a tightly fitting quartz cylinder, which prevents long-path breakdown. The cathode is made of copper and the anode is made of quartz with transparent conductive platinum film deposited on its surface.

The electrical circuit in the experiment allows a current pulse of desired length and amplitude to be superimposed on a dc discharge running at very low-current, thus avoiding breakdown delays (Marić *et al.* 2003). The pulse duration is long enough to develop a steady state discharge, minimize gas heating and cathode heating and conditioning effects (Petrović and Phelps 1993, Marić *et al.* 2002) and so produce stable and reproducible voltage-current ( $VI$ ) characteristic measurements. In addition before each set of new measurements, the surface of the cathode is treated by a moderately high-current, (30  $\mu A$ ) hydrogen discharge until a stable breakdown voltage is achieved and so ensuring the same surface conditions each time

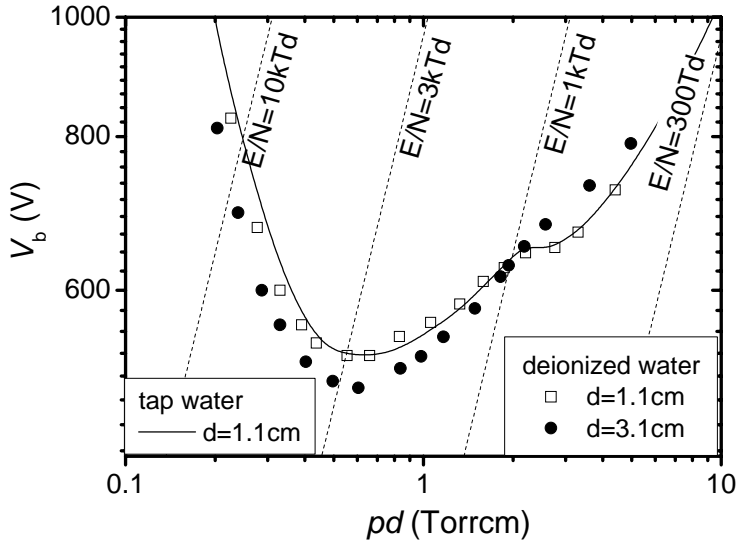
The construction of the chamber allows the axial discharge profiles to be observed and recorded using a sensitive ICCD camera whose gate is synchronized with current pulses so capturing the quasi-steady state part of the pulse.

The discharge chamber is connected to a vacuum pump unit on one side and to a water vapour supply on the other. The water in the supply is pumped on, the subsequent boiling removes dissolved oxygen (and other volatile constituents). The water vapour is introduced in the chamber at a slow flow rate, to prevent freezing of the water, to achieve the desired pressure. During measurements, the ambient temperature in the vicinity of the discharge chamber was measured and remained constant at around 300K.

## 3. RESULTS AND DISCUSSION

We present results for breakdown voltage against  $pd$  (pressure  $\times$  electrode gap), Paschen curves, for water vapour obtained from different water samples. In Fig. 1 Paschen curves are shown for  $d=1.1$  cm and 3.1 cm obtained from deionized water (symbols) and for  $d=1.1$  cm using tap water (line). In the left-hand branch and around the minimum, three Paschen curves agree well. Results show no significant discrepancies and breakdown voltages agree well within the experimental errors, even for curves obtained with different water samples. This indicates that “impurities” contained in tap water do not influence properties of the discharge.

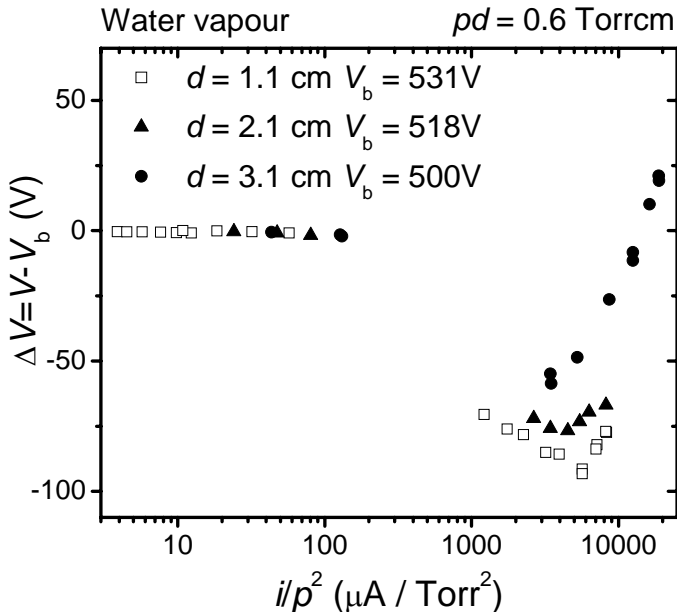
Both the curves for 1.1 cm manifest an inflection point around 2 Torr cm, which is not present at larger gaps. The origin of the inflection point is not yet clear, but it may indicate the presence of a process that occurs at higher water vapour pressures (close to the critical point).



**Figure 1:** Paschen curves of water vapour.

We have also performed measurements of voltage-current ( $VI$ ) characteristics for  $d=1.1$  cm, 2.1 cm and 3.1 cm. Results shown in Fig. 2 are scaled by the scaling parameter  $i/p^2$ . We used  $i/p^2$  instead of standard parameter  $j/p^2$  (where  $j$  is the current density) since the effective discharge area is not measured here. Strictly speaking, the proportionality  $i \sim j$  is fulfilled only for the ‘one-dimensional’ diffuse abnormal mode of the discharge that occupies the entire area of the cathode (Škoro et al. 2008). However, we may use it as a close approximation when constriction of discharge is not pronounced, which is the case for conditions covered in Fig. 2.

Discharges at different gaps scale well in the range of Townsend discharge (low currents  $\leq 100 \mu\text{A}/\text{Torr}^2$ ). This indicates that no processes, which would lead to breakdown of scaling, participate in our discharge (gas or electrode heating, stepwise processes of excitation and ionization, three-body collisions etc.) (Marić et al. 2003). Small differences in breakdown voltages can be contributed to variations in cathode surface conditions. While generally  $j/p^2$  scaling should be valid in low-current discharges, it’s worthwhile to comment on scaling in high current glow discharge ( $\geq 1000 \mu\text{A}/\text{Torr}^2$ ). Voltages are slightly elevated at the 3.1 cm gap, i.e. the lowest pressure. Based on our previous studies of the scaling (Marić et al. 2003), this kind of behaviour could be attributed to additional diffusion losses. When the electrode separation becomes comparable to the diameter of the discharge, radial losses of charged particles become gradually more important. The discharge tries to enhance the ionization rate with the help of an increased voltage in order to compensate for the radial losses and to sustain a given current.



**Figure 2:** VI characteristics at  $pd=0.6 \text{ Torr cm}$  for three electrode gaps. Voltage is shown as a difference between discharge ( $V$ ) and breakdown ( $V_b$ ) voltage.

### Acknowledgements

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