Axial emission profiles of Townsend discharge in water vapour

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In this paper we report studies of the basic properties of breakdown and low current Townsend discharge in water vapour in the range of *pd* (pressure x electrode gaps) from 0.1 to 10 Torrcm. Experimental results for Paschen curves at several electrode gaps (from 0.5 cm to 3 cm) and corresponding distributions of emission intensity are analyzed based on elementary processes that are relevant for breakdown and maintenance of low-pressure non-equilibrium discharges.

Increasing interest in application of plasmas in medicine, nanotechnologies and environmental remediation [1,2] has drawn attention to studies of discharges in water and in contact with water [3]. Current studies show that in such systems, discharge is formed in water vapour either from evaporating liquid electrode or in bubbles created by induced phase transition within the liquid. More generally, all atmospheric discharges contain some degree of water vapour. Our aim was to study basic parameters of breakdown in water vapour, which are scarce in literature, and this paper is an extension of our previously published results on Paschen curves for the same gas [4].

In our experiment, the discharge is established in parallel-plate system of electrodes, placed in a tightly fitting quartz tube. The diameter of the electrodes is 5.4 cm. The distance between electrodes is adjustable. In this study, measurements are performed for electrode separations from 0.5 to 3.1 cm. Cathode is made of copper, while anode is a transparent film of platinum deposited on a quartz window. Such construction of the discharge chamber allows us recording of axial and radial profiles of emission. Vapour is introduced into the vacuum system at a slow flow rate. Following the initial period of boiling, water in the tube becomes still and devoid of dissolved oxygen and other volatile constituents. Saturation of all surfaces in the chamber is achieved by containing the vapour in the system for several hours before measurements. Pressure is kept below 20 Torr in order to avoid creation of droplets of water in the discharge chamber.

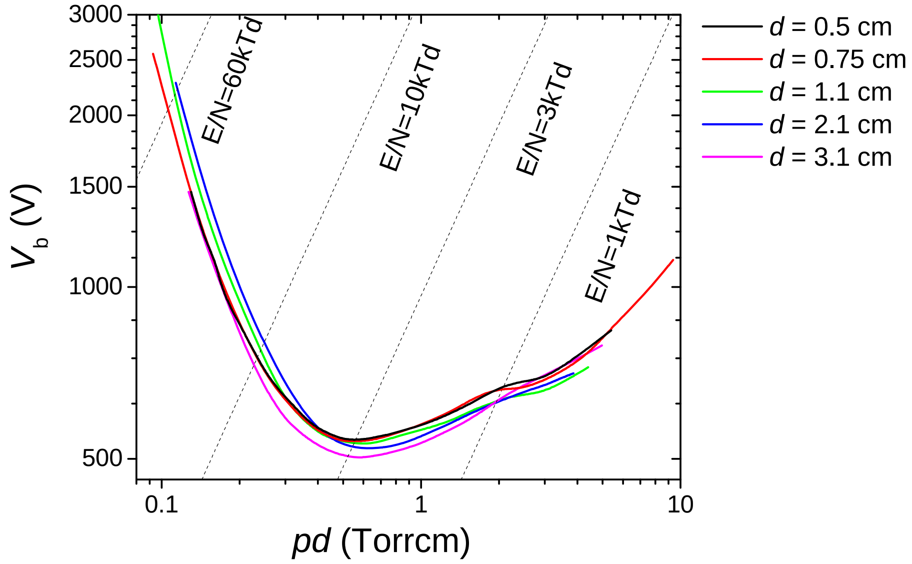

Figure 1 Paschen curves measured for different electrode gaps.

Paschen curve for water vapour is presented in Fig. 1. Breakdown voltage is shown in the *pd* range from 0.1-10 Torrcm for five different electrode gaps. *pd* is standard scaling parameter, proportional to the number of collisions of a particle over distance. Testing of the validity of scaling gives us an insight in processes that participate in breakdown. Reduced electric field (*E/N*) is indicated in Paschen curve at several points, as another important scaling parameter, which is proportional to mean energy gained between collisions.

In order to obtain breakdown voltages in our experiment, we ignite the discharge in the low-current regime and than by continuously changing the operating voltage we reach the lowest stable, recordable current. Breakdown voltage is then determined by extrapolation of the discharge voltage to zero current. In addition, at the lowest possible current, axial profile of emission is recorded by ICCD camera, to confirm that the discharge is operating in Townsend regime of discharge. Several emission profiles are presented in Fig. 2. We selected profiles at 0.65 Torrcm (Fig. 2a) and 0.11 Torrcm (Fig. 2b) to illustrate how structure of the discharge changes depending on working conditions and reveals basic processes in discharge. As additional test of the validity of scaling, profiles are scaled by *px* (*x*- distance from the cathode), so we may compare emission intensity distribution for different electrode gaps.

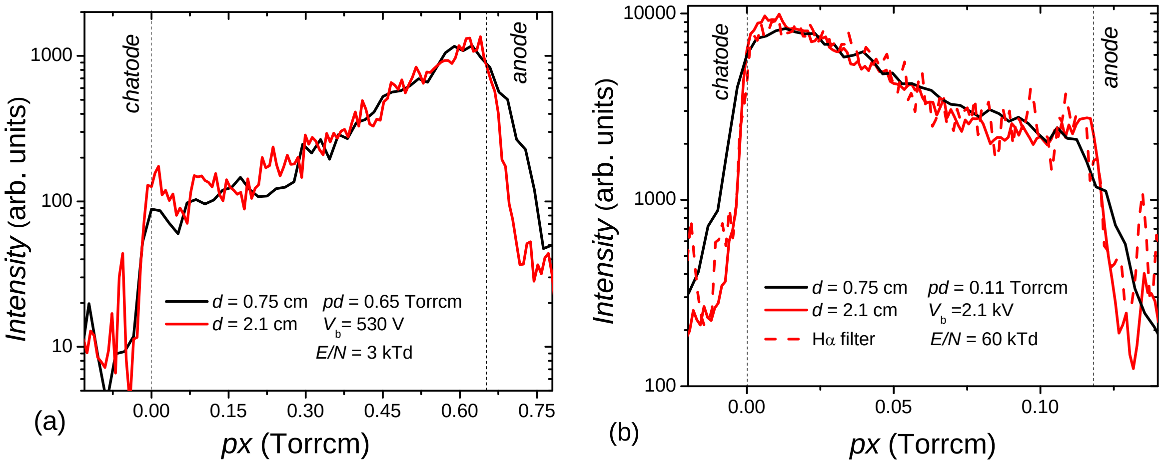

Figure 2 Axial profiles of emission from Townsend discharge in water. Distance from the cathode *x* is multiplied by *p* to enable comparisons of profiles recorded at the same *pd* for different electrode gaps.

In the region of the minimum of the Paschen curve (*E/N* = 3 kTd), we observe typical exponential increase of emission intensity from the cathode to the anode (Fig. 2a). This indicates excitation mainly induced by electrons. Slope of the profile in semi-log scale determines the ionization coefficient of water vapour. From ionization coefficients and Paschen curve we may calculate the secondary electron yield. Thus, measurements presented here give us a set of the key parameters that determine the breakdown [5]. On the other hand, at low *pd*-s (high *E/N*), heavy ions and atoms gain enough energy to perform excitation and ionization and even dominate over electron excitation, which is revealed through emission close to the cathode (Fig. 2b). Fast hydrogen atoms are the most probable candidates for high emission in cathode region [6]. Excellent agreement with the profiles recorded by using H_α filter supports this assumption.

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