Topic number: 6

Independent influence of the inter-electrode distance in Paschen curves

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Paschen law predicts the value of the breakdown voltage as a function of the product of the pressure and the inter-electrode distance, $V_b = \mathrm{f}(pd)$ in a given gas for a given reactor configuration [1]. Later developments proposed the replacement of the pressure, by the gas density ρ [2] and the gas particle density n [3]. However, an additional and independent influence of the inter-electrode distance on the breakdown voltage has been observed by Penning et al. [4], Miller [5], Auday et al. [6], Jacques et al. [7], Lisovskiy et al. [8] and Mariotti et al. [9] for different reactor setups (from cylindrical reactor to micro cavities), inert gases (neon, argon, xenon, krypton), electrode materials (copper, nickel, gold-plated stainless steel, silver, tin, tin oxide, magnesium…), electrode sizes (2.5 to 8 cm in diameter or grid electrodes in case of micro cavities), inter-electrode distances (from about 2 mm to 2 cm or lower in case of micro cavities) and measurement setups. We recognized similar independent influence of the electrode distance on the breakdown voltage in the course of our optimization efforts for plasma processing and investigated the phenomenon in a simplified reactor configuration (under DC conditions). Figures 1 and 2 are taken from the literature, while Figure 3 is the results of own measurements.

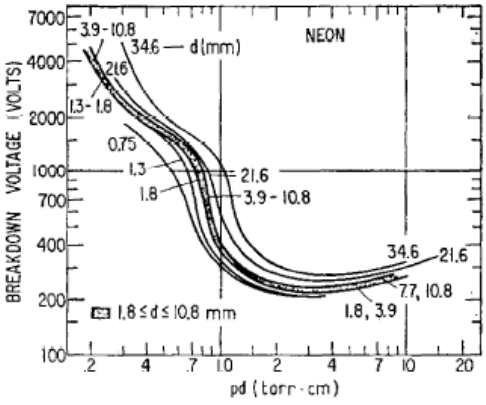

Fig. 1: Paschen curves in neon with round 24.7 mm diameter copper electrodes. The inter-electrode distance is varied from 1.8 cm to 10.8 mm [5].

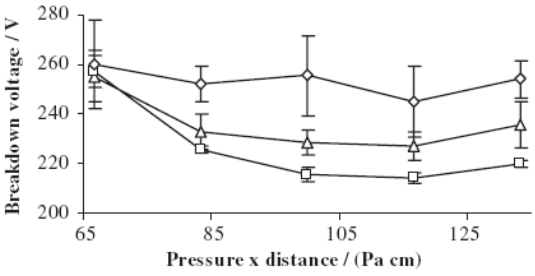

Fig. 2: Paschen curves in argon micro-plasma device with tin oxide electrodes. The inter-electrode distance takes the values 0.1, 0.25 and 0.5 mm [9].

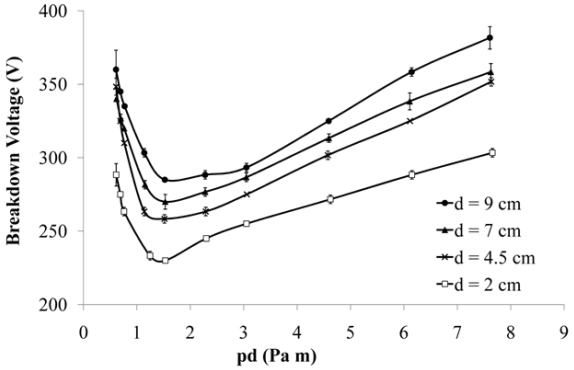

Fig. 3: Paschen curves in argon between round 50 mm diameter aluminum electrodes. The inter-electrode distance is varied from 20 mm to 90 mm.

Various reasons were put forward to explain this departure from the strict course of the Paschen curve, including the gas purity, the cathode surface state, the influence of *d* on the second ionization coefficient, the loss of electrons to the wall (influenced by the ratio of the electrode diameter to the inter-electrode distance), the electron escape fraction and back diffusion of electrons (including the reflection of electrons), the role of other particles in the breakdown (heavy particles and fast neutrals, metastables, photons), the explosive electron emission (so-called ecton). However, most of those explanations are refuted by the spectrum of experimental conditions under which the discrepancy has been observed. In other words, the influence of the inter-electrode distance alone on the breakdown voltage is not well understood. We will describe our observations under our applied experimental conditions, relate them to the results given in the mentioned literature.

Reference

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