

The electrical breakdown characteristics of the water vapor in micrometer gap sizes

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ABSTRACT

The liquid water-metal interface and the liquid water-gas interface, both play an important role in the initiation and the development of the electrical discharge in the gas bubbles. Evidence from the environmental application studies supports the strong dependence of the discharge properties on the applied voltage, the pressure and the electrode distance. This paper contains results of the experimental studies on the electrical breakdown characteristics in water in micrometers gap sizes. The minimum electrical breakdown voltage for water vapor was found to be around 618 V and 626 V at a pd (the pressure times the gap distance) value of around 0.7 Torr x cm (the pressure of 14.55 Torr) and 0.84 Torr x cm (for the pressure of 20.9 Torr), respectively.

Keywords: Liquid-gas interface, electrical breakdown, discharge, microgaps

1. INTRODUCTION

Plasmas in and in contact with liquids recently have received a lot of attention in view of their considerable environmental and (bio-)medical applications [1]. In particular, electrical discharges in water have been studied for various purposes such as water treatment [1,2], microorganism destruction [3] and construction of compact pulse power generators for bioelectric applications [4].

The influence of water vapor on the breakdown voltage has been subjects of numerous studies. Allen and Phillips [6] studied the effect of humidity on the spark breakdown voltage. Measurements of the Paschen curve for water vapor performed by Craggs [7] cover a very limited range of conditions, at high pd (pressure times the electrode gap) and fail to identify the conditions for a minimum breakdown potential. Recently, more precise measurements in a large range of the experimental conditions have been performed for low-pressure breakdown in water vapor [8] and in microgaps [9].

In this paper we present experimental results of the breakdown voltage curves for direct current (dc) breakdown of water vapor performed for two values of the gas pressure by varying the micrometer gap sizes. The volt-ampere characteristic are also discussed. The problems in recording accurate breakdown voltages are addressed by careful vapor and electrode preparation and simultaneous measurements of the current-voltage characteristics. Establishment of the connection between V-I characteristics and the structure of the discharge allows us to identify main processes that participate in breakdown and the discharge operation.

2. EXPERIMENTAL-SET UP

The discharge chamber consists of two parallel plate tungsten electrodes 5mm in placed in the vacuum chamber (see Figure 1). The vacuum chamber itself consists of three parts: positioner for centering the electrode in three directions (with accuracy about $1\mu\text{m}$) and tilting the upper electrode is located in the upper part. In the middle part there is a glass crux with four fused silica window. In the bottom part there is also positioning system for tilting electrode as well as improved system for very ultra fine tilting. The apparatus includes new positioning systems which allow movement of electrodes in different directions during the lower pressure in the vacuum chamber.

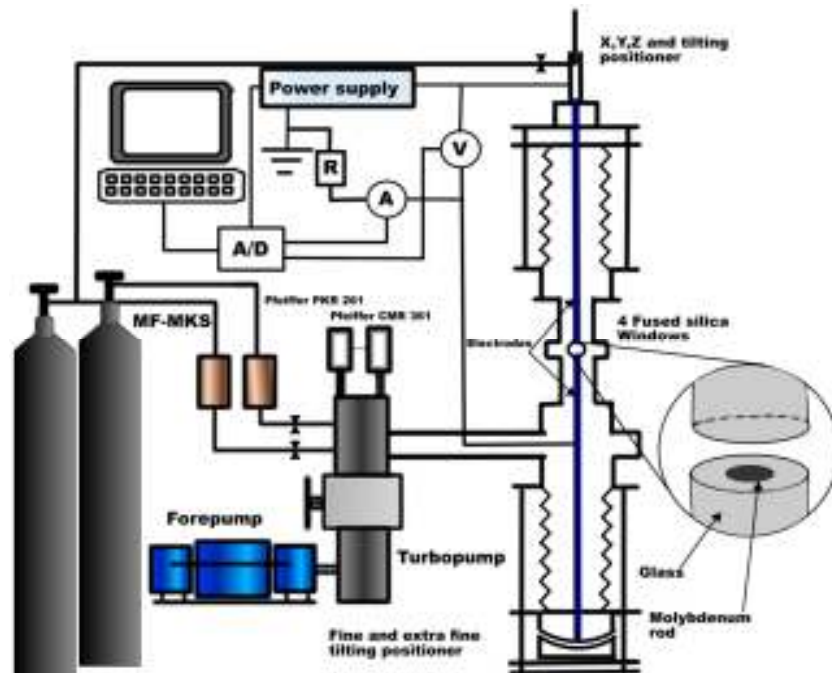


Fig.1. The general layout of the experimental arrangement used for the measurements of the breakdown voltage and volt-ampere characteristics in water vapor.

The distance between the electrodes is adjustable and measurements have been performed for electrode separations (d) of between $40\mu\text{m}$ and $800\mu\text{m}$ (for the pressure of 14.55 Torr) and $100\mu\text{m}$ and $900\mu\text{m}$ (for the pressure of 20.9 Torr). Both electrodes were equipped with dielectric cap (immune to vacuum, dielectric breakdown strength $\approx 13, 8\text{ kV/mm}$) to prevent the ignition of the discharge at longer path at low pressures. The the electrode surface has been polished by the finest diamond paste ($0.25\mu\text{m}$ grain size) in order to achieve the average roughness of the electrode better then $0.25\mu\text{m}$ and measured by using SEM.

The DC breakdown voltage was determined by observing the time dependence of the potential difference across the discharge tube measured using a digital oscilloscope. After applying a very slowly increasing potential to one of the electrodes (ramp speed 0,05 V/s), the potential across the discharge tube was increasing until the breakdown was reached. Due to discharge breakdown the potential across the discharge tube decreases rapidly and the breakdown voltage was determined from the maximum potential achieved across the discharge gap.

There are several key issues in the experimental measurements of electrical breakdown potentials in liquids. The first one is ensuring that the lowest voltage limit associated with Townsend discharge formation is observed, rather than the higher voltage associated with streamer, is detected. Here this is overcome by observing the light emission from the gap region and more specifically the axial emission profile. The second is related with the water vapor stems from gases dissolved in the liquid water, condensation on surfaces and hydration of charged particles in the gas phase. It is thus necessary to ensure that the water vapor is devoid of any dissolved oxygen [8] and other volatile constituents.

3. RESULTS AND DISCUSSION

In Figure 2 the measured breakdown voltage curves as a function of the pd product are shown. Red and blue symbols present results of measurements performed at the pressure of 20.9 Torr and 14.55 Torr, respectively. All the curves agree well within the experimental uncertainties on the left hand side and around the minimum. At larger electrode gaps, the water impurities do not affect the value of the dc breakdown potential. This can be explained by the fact that some of the dissolved impurities are not volatile and also the breakdown is dominated by ionisation through the high energy electrons. Presented results satisfactorily agree with the experimental data taken from ref. [8] (open symbols). Difference between them can be attributed to the different experimental conditions.

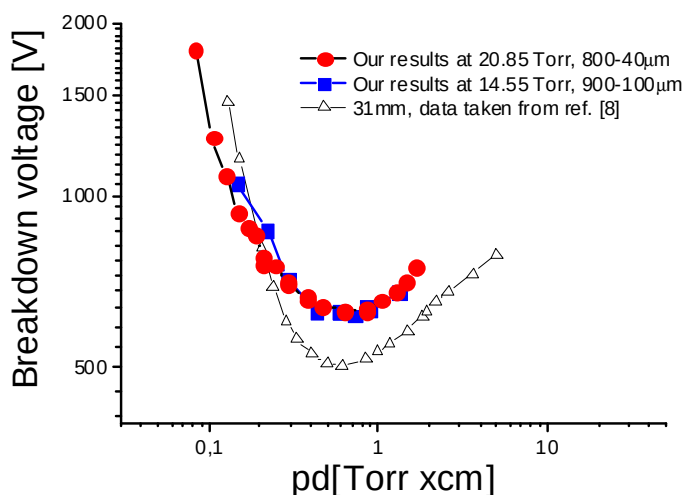
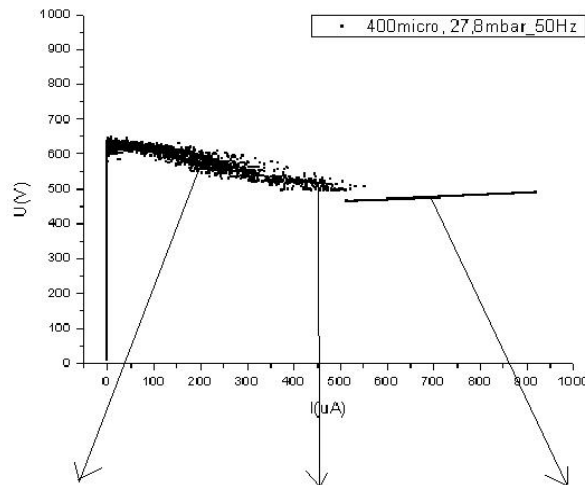


Fig. 2. Breakdown voltage vs. pd product in water vapour. Blue and red symbols represent measurements performed at the pressure of 14.55 Torr (the gap size in the

105 range 900 μm - 100 μm) and 20.9 Torr (the gap size in the range 800 μm - 40 μm),
106 respectively. Experimental data taken from ref. [8] are shown by open symbols.
107

108 Figure 3 demonstrates an interesting behavior observed on the right side of the Paschen
109 curve at the pressure of 20.9 Torr and the gap of 400 μm . As can be seen from Figure 3,
110 up to current of 500 μA an oscillating regime exists. The discharge became stable as the
111 current went above 500 μA , which was observed optically like contraction of the discharge
112 and electrically like a small voltage drop.
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116

117 **Fig. 3. Volt-ampere characteristics and images of the contraction of discharges at 20.9**
118 **Torr and 400 μm .**

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120 The current-voltage characteristics for the pressure of 20.9 Torr and various gap sizes are
121 depicted in Figure 4. As can be observed, the voltage unnoticeable changes with
122 increasing the current.
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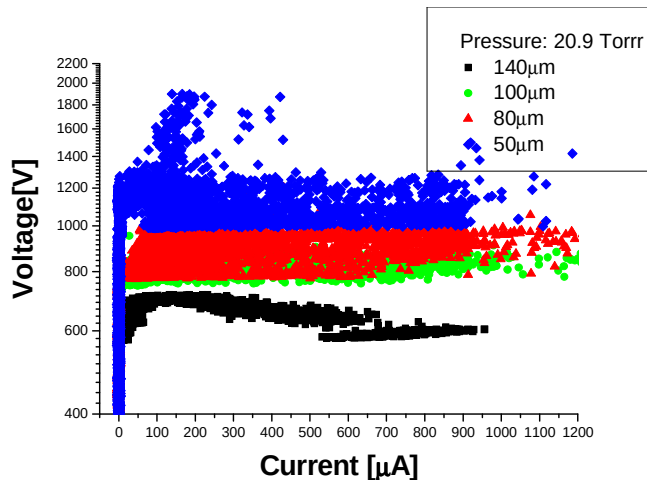


Fig.4. Volt-ampere characteristics of discharges at the pressure of 20.9 Torr by varying the gap size from 50 μm to 140 μm .

4. CONCLUSION

Measurements of the breakdown voltage curves in water vapour at the pressure of have been made. There is a good agreement between the curves measured for the pressure of 14.55 Torr and the electrode gaps ranging from 100 μm to 900 μm and the pressure of 20.9 Torr and the electrode gaps ranging from 40 μm to 800 μm . The agreement with the experimental data taken from ref. [8] is also satisfactorily. For the pressure of 14.55 Torr and 20.9 Torr, the electrical breakdown minimum voltages for the water vapour were found to be 618 V and 626 V at a pd value of around 0.7 Torr x cm and 0.84 Torr x cm, respectively.

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COMPETING INTERESTS

"Authors have declared that no competing interests exist."

AUTHORS' CONTRIBUTIONS

Š. Matejčik and M. Klas performed the measurements and plot the figures. M. Radmilović-Radenović, B. Radjenović and P. Beličev plot the figures, performed the analysis of the results, wrote the protocol and wrote the first draft of the manuscript. All authors read and approved the final manuscript.

REFERENCES

- 162 1. Park GY, Park SJ, Choi MY, Koo IG, Byun JH, Hong JW, Sim JY, Collins GJ, Lee JK.
163 Atmospheric-pressure plasma sources for biomedical applications. Plasma Sources Sci.
164 Technol. 2012;21(4):043001.
- 165 2. Yatsu S, Takahashi H, Sasaki H, Sakaguchi N, Ohkubo k, Muramoto T, Watanabe S.
166 Fabrication of Nanoparticles by Electric Discharge Plasma in Liqui. Archives of Metallurgy
167 and Mater. 2013;58(2):425-29.
- 168 3. Akishev Y, Grushin M, Karalnik V, Trushkin N, Kholodenko V, Chugunov V,
169 Kobzev E, Zhirkova N, Irkhina I, Kireev G. Atmospheric-pressure, nonthermal plasma
170 sterilization of microorganisms in liquids and on surfaces. Pure Appl. Chem. 2008; 80(9):
171 1953–69.
- 172 4. Schoenbach K, Kolb J, Xiao S, Katsuki S, Minamitani Y, Joshi R. Electrical breakdown
173 of water in microgaps. Plasma Sources Sci. Technol. 2008;17(2):024010.
- 174 5. Druyvesteyn MJ, Penning FM. The Mechanism of Electrical Discharges in Gases of Low
175 Pressure. Rev. Mod. Phys. 1940;12(2): 87-174.
- 176 6. Allen KR, Phillips K. Effect of Humidity on the Spark Breakdown Voltage. Nature. 1959;
177 183(2): 174-75.
- 178 7. Prasad AN, Craggs JD. Measurement of Ionization and Attachment Coefficients in
179 Humid Air in Uniform Fields and the Mechanism of Breakdown. Proc. Phys. Soc. 1960; 76:
180 223-32.
- 181 8. Škoro N, Marić D, Malović G, Graham WG, Petrović ZLJ. Electrical Breakdown in Water
182 Vapor. Phys. Rev. E. 2011;84(5): 055401(R).
- 183 9. Klas M, Matejčík Š, Radmilovic-Radjenov M, Radjenovic B. Electrical breakdown and
184 volt-ampere characteristics in water vapor in microgaps. Europhysics Lett.
185 2012;99(5):57001.