Discharge Ignition in the Diaphragm Configuration Supplied by DC Non-pulsing Voltage

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1 Introduction

Electrical discharges generated directly in liquids or direct plasma interaction with liquid phase is one of the hot topics of the contemporary plasma research. These systems can be applied for example in water treatment[1, 2], sterilization[3], and surface treatment of various temperature sensitive materials[4] as well as for the nanoparticles generation[5]. The plasma in water solutions can be generated by various electrode configurations, and it can be supplied by many kinds of the applied voltage from DC up to RF frequencies using pulsed as well as non-pulsed regimes. In general, there are two theories describing the discharge ignition in liquids.

The electron theory is based on the fact that water molecules are ionized and dissociated by the applied strong electric field, and the plasma creation is very similar to the classical Townsend's theory of electron avalanches in gases[6].

The thermal (bubble) theory supposes that liquid is strongly heated by passing current and thus it is evaporated and micro bubbles are created. The discharge is consequently ignited due to the strong potential gradient inside these bubbles[6].

The presented contribution deals with the direct observation of the breakdown of diaphragm and capillary discharges in water solutions. In this case, both electrodes are immersed inside the liquid phase, and the electrodes are separated by a dielectric barrier with a small orifice. In the case when the aspect ratio (thickness/diameter) is about 1 (thin barrier with a relatively big orifice), the discharge is called the diaphragm discharge; if the aspect ratio is much higher than 1, the discharge is called the capillary discharge. The non-pulsing DC voltage was used for the discharge generation. The time resolved current-voltage characteristics and ICCD imaging were applied for the discharge breakdown determination.

2 Experimental

One batch discharge reactor was used for the presented study. Its volume was about 110 ml of water solution. Its simplified scheme is shown in Fig. 1.

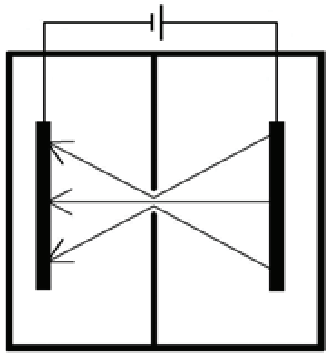

Fig. 1: Simplified scheme of the diaphragm/capillary discharge configuration. Arrows represent the electric intensity vector.

The electrodes were made of stainless steel; the diaphragm was made of Shapal-M™ ceramics. A set of diaphragms with one central orifice with the diameter of 0.3 and 0.6 mm and thickness of 0.3–1.5 mm was used for the contemporary experiments. NaCl solutions with conductivity of 250 μS were prepared.

Diagnostics of the system were performed by a four channels LeCroy LT374L oscilloscope and the ICCD camera (Andor iStar with Cosmicar/Pentax TV Lens 50 mm, 1:2.8 objective). The ICCD camera was synchronized with the discharge by a current value.

3 Results

The current-voltage characteristics of the diaphragm discharge breakdown were measured for the ceramic diaphragm (orifice diameter of 0.3 and 0.6 mm) with the thickness of 0.3–1.5 mm. NaCl solutions of 250 μS cm^{-1} were used. The current-voltage characteristics for diaphragm discharge with barrier with orifice diameter 0.3 mm and different thickness are shown in Fig. 2 – left, and with the barrier with orifice diameter 0.6 mm and different thickness are shown in Fig. 2 – right.

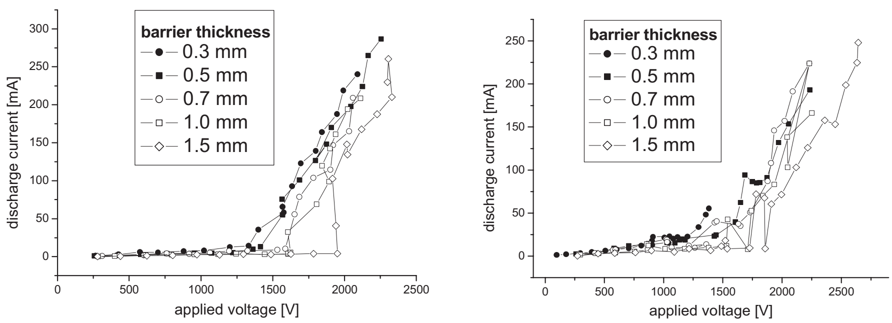

Fig. 2: Current-voltage characteristic of the diaphragm discharge breakdown in NaCl solution (250 μS cm^{-1}). Ceramic diaphragm (orifice of 0.3 mm – left, orifice of 0.6 mm – right), thickness of 0.3–1.5 mm.

On these current-voltage characteristics it can be observed that in the first part (up to about 700 V), very low current is determined which corresponds to regular electrolysis. Due to the high current density in the orifice, the solution is overheated in the diaphragm, and microbubbles are generated. Resistance between the electrodes increases and thus current passing through the system decreases[7]. When the applied voltage reaches values of about 1 200 V, the discharge is ignited inside small bubbles. The discharge lifetime is very short because the bubble rapidly expands, and applied voltage is not sufficient for the discharge maintenance. If the applied voltage is around 1 400 V, the discharge becomes more regular, and the current rapidly increases.

Comparing Figs. 2 left and right, it can be visible that in the case of the bigger orifice (Fig. 2–right), discharge current reaches lower values with smaller voltage. Increasing the orifice diameter, the shift of curves to higher values of voltage can be observed. Discharges created in the barriers with the bigger thickness require higher voltage at the same current.

In Figs. 3–6 discharge ignition and the camera closing in the dependence on current is demonstrated. When discharge current increases it is a signal for the camera closing because the discharge is ignited. For smaller diaphragm orifices, higher current is needed for the ignition. On photographs assigned to the graphs, discharges under the barriers are visible. This light emission corresponds to the grey curves in the graphs which are demonstrating the camera closing.

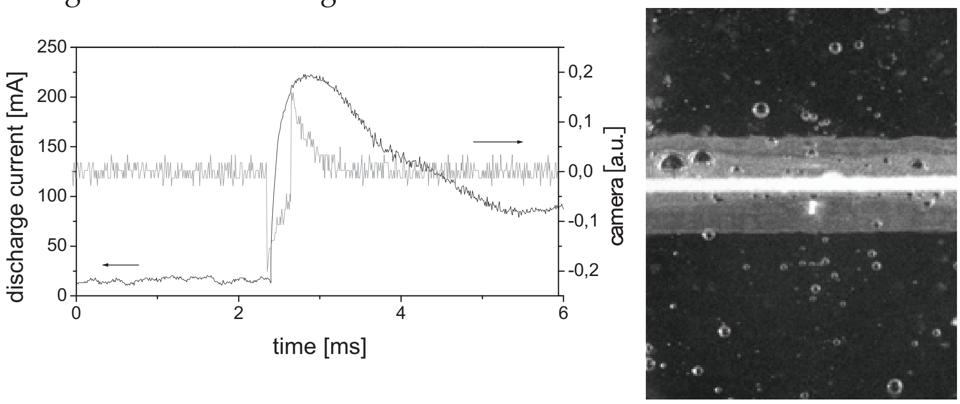

Fig. 3: Experiment with the diaphragm with the smaller orifice (diameter of 0.3 mm) and thickness of 0.3 mm. Camera closing by a current impuls (left). Photography exposure time of 0.5 ms (right).

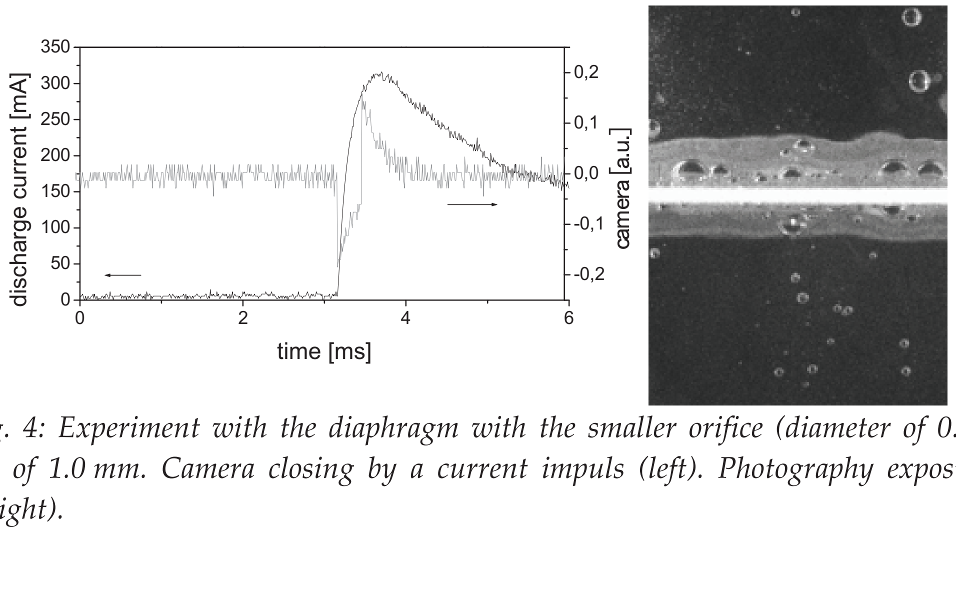

Fig. 4: Experiment with the diaphragm with the smaller orifice (diameter of 0.3 mm) and thickness of 1.0 mm. Camera closing by a current impuls (left). Photography exposure time of 0.5 ms (right).

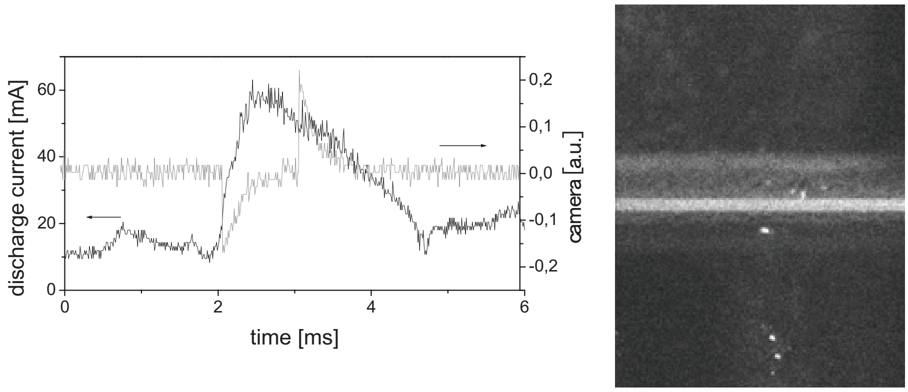

Fig. 5: Experiment with the diaphragm with the bigger orifice (diameter of 0.6 mm) and thickness of 0.3 mm. Camera closing by a current impuls (left). Photography exposure time of 1.0 ms (right).

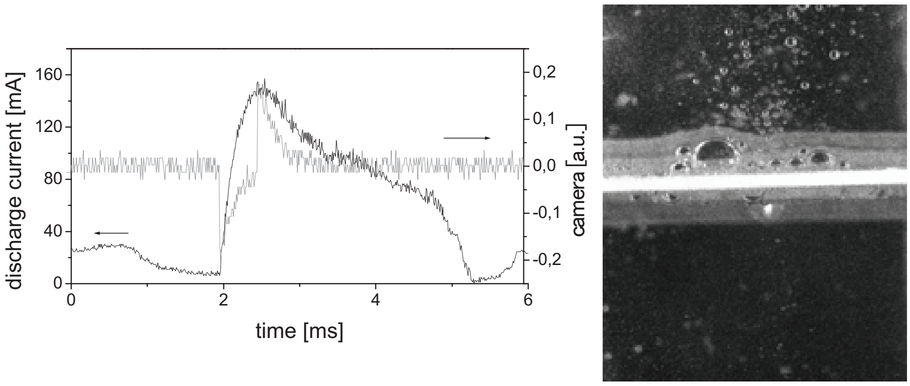

Fig. 6: Experiment with the diaphragm with the bigger orifice (diameter of 0.6 mm) and thickness of 1.0 mm. Camera closing by a current impuls (left). Photography exposure time of 0.5 ms (right).

4 Conclusion

The discharge breakdown was observed in the diaphragm and capillary configurations. It was compared in the dependence on the aspect ratio of the diaphragm (thickness and orifice diameter). For smaller orifice diameter, higher current and voltage are needed for the discharge ignition. Increasing the dielectric barrier thickness, discharge current and applied voltage reach higher values

5 References

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