Nonequilibrium Liquid Plasma Generation

Yong Yang, Andrey Starikovskiy, Young I. Cho, Alexander Fridman

Department of Mechanical Engineering and Mechanics, Drexel University, Philadelphia PA 19104, USA

Abstract: In most cases, the electric breakdown of liquids is initiated by the application of high electric field on the electrode, followed by rapid propagation and branching of plasma channels. Typically plasmas are only considered to exist through the ionization of gases and typical production of plasmas in liquids has generated bubbles through heating or via cavitations and sustains the plasmas within those bubbles. The question appears: Is it possible to ionize the liquid without cracking and voids formation? We have demonstrated possibility of formation of nonequilibrium plasma in liquid phase and investigated the dynamics of excitation and quenching of nonequilibrium plasma in liquid water.

Keywords: list 3-5 relevant keywords

1. Introduction

Development of discharges in liquids were performed for a long time [1]. The difference of the current approach is using picoseconds high-voltage pulsed power systems [2], which guarantee absence of voids. First power supply generates pulses with +16 kV pulse amplitude in 50Ohm coaxial cable (up to 32 kV on the high-voltage electrode tip because of pulse reflection), 10 ns pulse duration (90% amplitude), 0.3 ns rise time and 3 ns fall time. The second system generates +112 kV pulses (224 kV on the gap) with 150 ps rise time and duration on the half-height about 400 ps. In all experiments we used the pulse frequency $f = 1$ Hz.

2. Experiment

Discharge cell had point-to-plate geometry with a high-voltage electrode diameter of 100 μm. The high voltage electrode was a cut-off platinum rod. Inter-electrode distance was 4 mm, low-voltage electrode diameter was 18 mm (Figure 1). Discharge cell has a couple of quartz windows (thickness was 1 mm). The water layer between center of the discharge gap and window was 50 mm. We used double-distilled water for these experiments without de-ionization or pH adjustment (pH ~ 6.4, conductivity ~ 5 μS/cm).

The measurements were performed with the help of 4Picos ICCD camera by Stanford Computer Optics. The camera has 18-mm diameter multi-alkaline photocathode with a spectral response from 180 to 750 nm. Quartz lens with a focal distance of 70 mm and diameter of 50 mm was used to focus the discharge gap to the photocathode with four-times magnification. Typical camera’s field of view was 2.6×1.7 mm (Figure 2, 3), spectral response 250-750 nm taking into account UV-emission absorption in water layer.

3. Results and Discussions

It was found that discharge in distilled, degassed liquid water develops in picosecond time scale. Size of excited region near the tip of the high-voltage electrode was ~ 1 mm. The discharge has a complex multi-channel structure and this structure has slightly changed from pulse to pulse, but discharge had almost the same dynamics (Figure 2). To analyze the spatial structure of the discharge we used longer camera gate (1 ns) without signal accumulation. Typical emitting channel’s diameter was ~ 50 μm and propagation length was 0.5-0.6 mm for $U = 27$ kV. In the case of short rise time we observed discharge propagation with the velocity up to 2000 km/s (2 mm/ns) during very initial stage of the discharge corresponded to the voltage rise time (Figure 2). The propagation velocity was estimated as an integral speed of the plasma channel head. When voltage reaches the maximum, the discharge propagation stops and the “dark phase” appears. During this phase discharge cannot propagate because of space charge formation and electric field decrease. Voltage decrease leads to the return stroke formation and second emission phase. This means that the channels lost the conductivity and the trailing edge of the nanosecond pulse generates significant electric field and excitation of the media which is comparable to the excitation corresponded to the leading edge of the pulse. The experiments at elevated voltage prove the discharge propagation in
the liquid phase and the dark phase of the discharge did not appear (Figure 3). As in the case with 10-ns pulses no bubble formation was observed. Figure 3 shows the dynamics of the discharge: 100-200 ps plasma channels reach the length of 0.5-0.8 mm, formation for \( U = 224 \) kV. The \( \Lambda \)-shaped pulse has no plateau and the dark phase of the discharge did not appear (Figure 3). Discharge development takes an extremely short time (in 100-200 ps plasma channels reach the length of 0.5-0.8 mm, diameter \( \sim 100 \) \( \mu \)m).

References numbered [1] following American Institute of Physics Style Manual or another clear format of your preference.

References


Figure 2. Dynamics of discharge emission and high-voltage potential on electrode. Distilled water, $U = 27$ kV. Camera gate is 1 ns. Spectral response 250-750 nm. Each row is shifted with respect to previous on 100 ps. Lower right image is a picture of 100-µm electrode.

Figure 3. Dynamics of discharge emission. Distilled water, $U = 220$ kV. $dU/dt = 1.46$ MV/ns. Camera gate is 500 ps. Time shift between frames is 50 ps. Second row is shifted with respect to first on 50 ps.