Contact Glow Discharge Formation in the Electrolyte

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1. Introduction

Electric discharges in systems in which one of electrodes is the liquid electrolyte, for a long time attract attention of researchers both as interesting object for physical experiments [1] and as the tool for realization of various technologies: electrolyte-plasma polishing, clearing of liquids from organic pollution [2], cutting of biological tissue [3]. In the English literature this discharge frequently refers to Contact Glow Discharge (CGD), therefore in the present work we shall use this term. Such discharge is realized in the system of two electrodes with different sizes immersed to electrolyte. The CGD occurs around of the electrode with the smaller area. If this electrode is under positive potential, the discharge can exist stably in wide voltage range.

Despite the large number of publications, nature CGD, especially in the field of small voltage, is not fully explained. Among the explanations of this nature offered in last years, in our opinion, the most adequate assumption was proposed in the paper [1] in which CGD with the active cathode was studied, and in the paper [4] in which the anode was active. The "active" electrode here is understood as an electrode with the smaller area around of which CGD is ignited. According to the assumptions made in these works, CGD arises, when the heat flux produced by electrolyte resistive heating in near-electrode area under passing of the electric current, exceeds some critical value. In this case the phenomenon similar to well known in thermal physics as a "boiling crisis" – formation of continuous steam layers around of an active electrode is occurred [5.] In this layer the electric discharge with the characteristics close to glow discharge one is initiated.

The purpose of the present work is to examine this assumption and to investigate the CGD with the active anode formation dynamics.

2. Experiment

Experimental setup for researching of CGD formation process is presented schematically in Fig. 1. Experiments were carried out in cell (*1*) which consisted of glass (*1*), active electrode – the anode and an auxiliary electrode – the cathode. For the electrolyte temperature keeping heater (*2*) was used. Generator (*3*) could operate both in DC and single-pulse regimes. The output voltage could be changed at the range 0–600 V. For registration of a current and a voltage waveforms, four-channel oscillograph АСК-3117 (*4*) was used. For investigation of the steam layer formation near the active electrode, four-channel CCD-camera (*5*) was used. Using the generator of pulses G5–63 (*6*) we synchronized the triggering of the CCD camera with the triggering of an oscillograph. Control of the CCD camera and record of images was made with the use of personal computer (*7*).

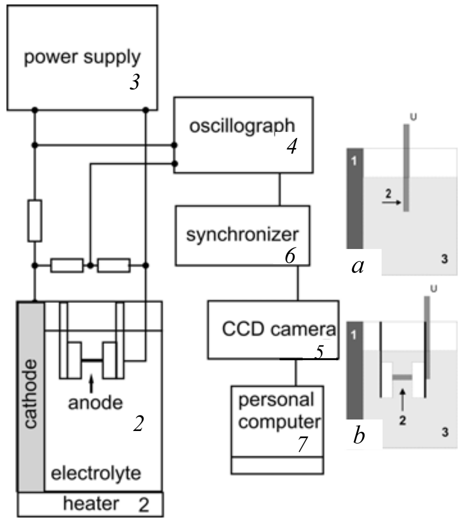

Fig. 1. Scheme of the experimental setup

Experiments were carried out both in DC and pulse modes. Nichrome wire of 0.6 mm in diameter was used as an active electrode. In the experiments on DC-mode, an electrode was immersed to the electrolyte (5% water solution of NaCl) on the depth of 4 mm (Fig. 1, *a*). In pulse mode the active electrode had a length of 8 mm. It was placed between two Teflon plates, and completely immersed to the electrolyte (Fig. 1, *b*). The auxiliary electrode has been made of stainless steel, and had the area much more then active one.

3. Results and discussions

Experiments in DC regime were carried out with the electrode represented in Fig. 1, *b*. Temperature of electrolyte was 25 °C. Photographing of an active electrode and registration of a current and voltage oscillograms at various operating conditions were carried out. Current-voltage characteristic is presented in Fig. 2. The values of a current presented in the graph are received by the averaging for the period of time 300 ms. It can see three parts on the graph: 1) resistive region, from 0 up to 120 V, in which linear dependence of current on voltage is observed; 2) transitive region (100–140 V) in which the average current decreases sharply when the voltage is increased; 3) area of CGD existence (150–500 V) in which the current practically does not depend on voltage.

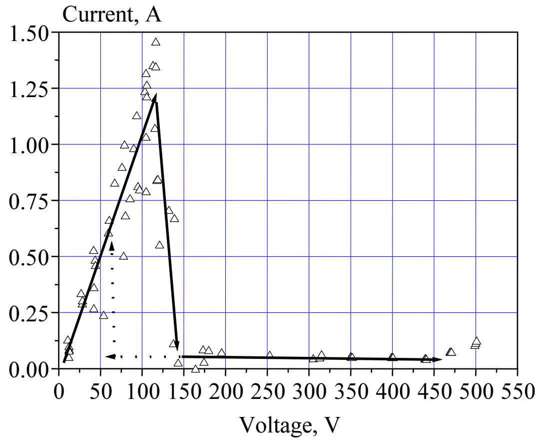

Fig. 2. Current-voltage characteristics of the process at positive polarity on an active electrode

In a range from 0 up to 100 V, on the growing part of current-voltage characteristics, the current is transferred via contact electrode–electrolyte.

This part corresponds to regimes before boiling and bubble boiling. Current and voltage oscillograms for this case are presented in Fig. 3. The current has the irregular form, depth and rate of the current dips sharply grows when the voltage is increased. Fluctuations of current, obviously, are connected with fluctuations of the bubbles volume fraction in near-electrode region. The photo of the electrode and surrounding electrolyte in the bubble boiling regime is presented in Fig. 4. Near the electrode plenty bubbles, moving in various directions in turbulent flows of a liquid is formed.

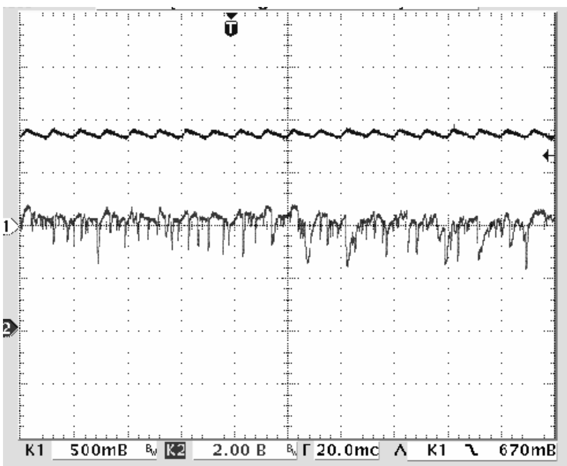

Fig. 3. The voltage (top) and the current (bottom) oscillograms in the regime of bubble boiling: voltage – 50 V/div, current – 0.4 A/div

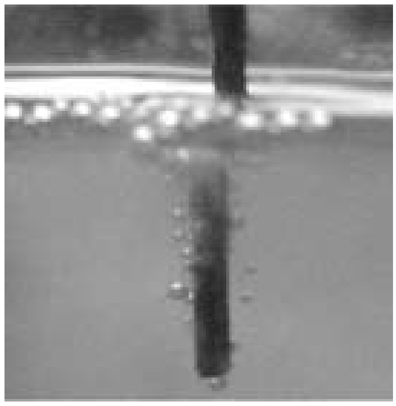

Fig. 4. The photo of the bubble boiling regime. Exposure 1/1000

In a range of voltages 100–140 V the current-voltage characteristic has a falling part. The current is characterized by decreasing of average value and increasing of amplitude of fluctuations (Fig. 5). Obviously, in this regime the area of the electrode covered by the steam is growing, sometimes a steam layer can cover the electrode entirely.

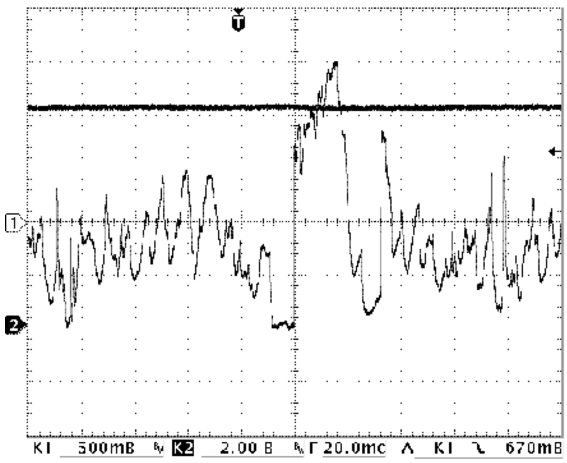

Fig. 5. The voltage (top) and the current (bottom) oscillograms in a transition regime: voltage – 50 V/div, current – 0.4 A/div

When the voltage is higher than 150 V, the regime of stable steam layer around the electrode is realized. The current practically does not depend on the voltage up to 450 V. Corresponding oscillograms are presented in Fig. 6. In Fig. 7, the photo of the electrode and surrounding electrolyte is presented. The voltage was 300 V and exposure time was 1 ms. One can see that the electrode is entirely surrounded with the gas layer.

Note that the luminescence is located on the surface of the electrolyte, but not the electrode. The luminescence of the discharge is observed not on whole surface of electrolyte, but only in the regions with smaller width of steam layer. In Fig. 7, the meniscus connecting steam layer with a surface of a liquid also is seen.

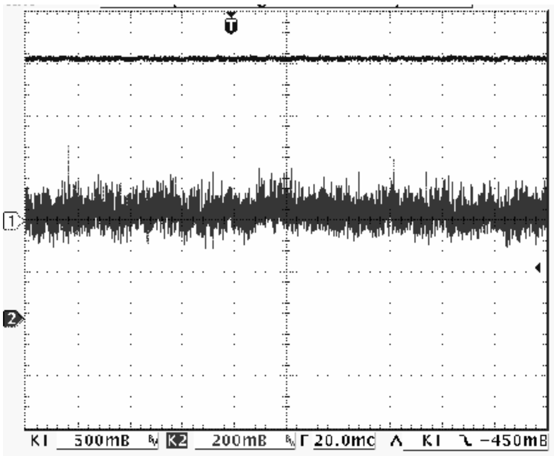

Fig. 6. The voltage (top) and the current (bottom) oscillograms in the regime of continuous steam layer formation: voltage – 50 V/div, current – 0.04 A/div

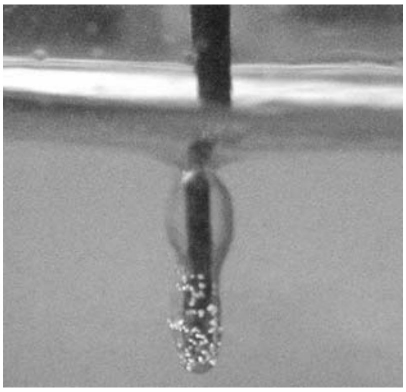

Fig. 7. Film boiling on positive polarity of the electrode. Exposure 1/1000

It is significant, that at increase of the voltage above 450 V, the average current starts to increase (Fig. 2). In the oscillogram (Fig. 8) one can see, that at these voltages irregular changes of the current again begins. The electrode is melted very quickly. It is necessary to assume, that the discharge transforms into the new form.

In the experiments, the effect of a hysteresis was observed also at formation and destruction of the steam layer. If formation of the layer occurs at voltage 100–140 V, the destruction of existed layer is observed at voltage 40–60 V only.

For studying the steam layer formation dynamics, we have carried out the investigation with pulsed supply of the system. Experiments were carried out with the system of electrodes presented in Fig. 1, *b*. This geometry allows sufficiently easy carry out computer modeling and analytical calculations. The voltage pulses, applied to the cell had front no more than 1 μs and amplitude from 250 V to 550 V. Voltage pulse duration was 5 milliseconds. The temperatures of electrolyte were 40 °C, 60 °C, and 80 °C. Oscillograms of the current pulses for various voltages are shown in Fig. 9.

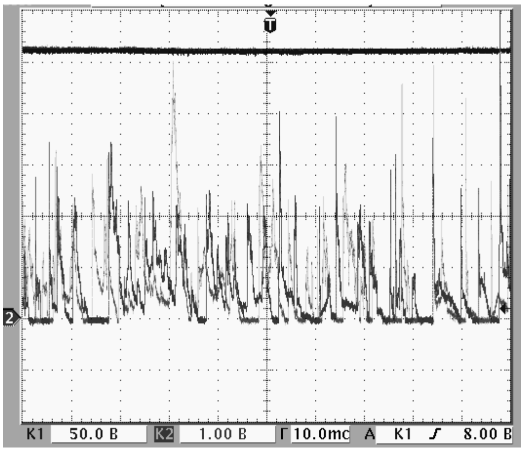

Fig. 8. The voltage (top) and the current (bottom) oscillograms at high positive voltage on an electrode in a film boiling regime: voltage – 520 V (100 V/div), current – 0.2 A/div

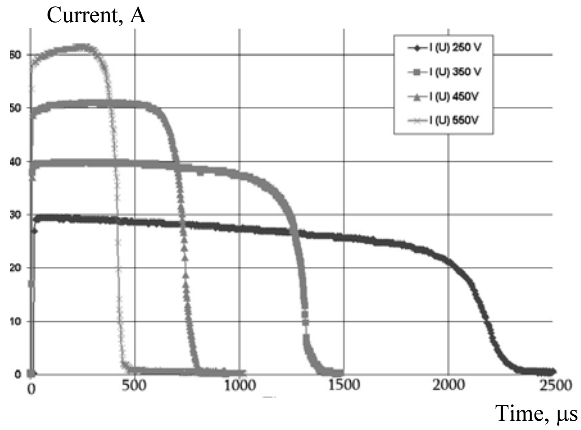

Fig. 9. Oscillograms of the current pulses for various voltages in electrolyte with temperature 40 °C

It is obvious, that directly after the voltage applied to the cell, the current amplitude is determined by conductivity of electrolyte. After heating of the electrolyte near the electrode up to temperature of boiling, its evaporation begins. It leads to formation of a steam layer and the current falls up to the values determined by parameters of the glow discharge in the layer. It is observed natural dependence of layer formation time in dependence of current and power. When the voltage is increased, the current is increased, and the layer formation time is decreased. Moreover, as one can see in Fig. 10, the energy dissipated in the electrolyte before current interruption does not depend on the voltage, practically but changed when temperature of the electrolyte is changed.

For temperature estimation in the field near the anode at the moment of current interruption, we have carried out the calculations with using of COMSOL Multiphysics software. Calculations were carried out for electrolyte temperature 40 °C and two voltages: 250 and 500 V. The results are presented in Fig. 11. Two lines for 250 and 500 V concur completely. From the calculations follows that current interruption through electrolyte is observed at the overheating of electrolyte layer of about 0.1 mm thick to the temperature about 110 °C. The maximal value of the heat flux is reached directly on the electrode – electrolyte boundary, and this value is 180–200 W/cm^2. It is approaches to the critical heat flux in water which is specified in the literature as critical value at which a "boiling crisis" phenomenon occurred [5].

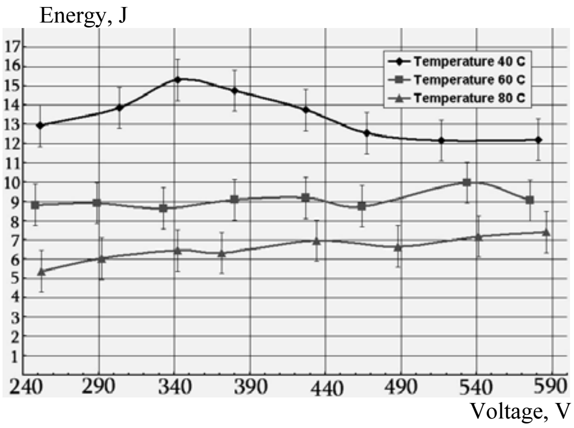

Fig. 10. Dependences of the energy dissipated in electrolyte before current breakdown from a voltage for three values of temperature (40 °C, 60 °C, and 80 °C)

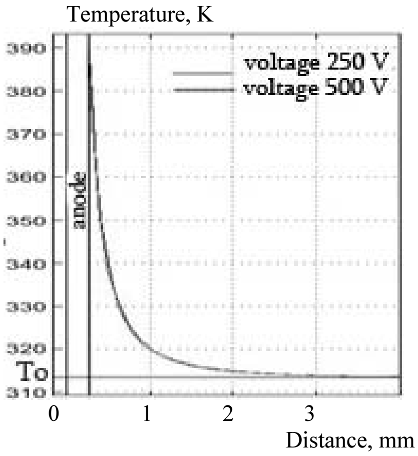

Fig. 11. Electrolyte temperature versus distance from the anode for two voltages applied to the cell

For visualization of the steam layer formation dynamics, the experiments with using of four-channel CCD-camera have been carried out. In Fig. 12, the current oscillogram and photos of the electrode for different moments of the pulse are shown. Voltage amplitude was 550 V. Photo number 1 corresponds to the moment, when the pulse current starts to drop (see Fig. 2.). The moments of other photos are presented in the oscillogram Fig. 12. This oscillogram is a part of whole pulse oscillogram, which is separated out by two dashed lines in Fig. 2. The CCD-camera exposure was 3 μs. It can see that there is no vapor around the electrode up to the moment of the current drop. Layer starts to form at the ends of electrode, and it expands to the center of the electrode. Expansion of the steam layer leads to increasing of the cell resistance, and current decreases. But at the moment corresponds to picture 4, the steam layer becomes continuous, and the CGD is initiated.

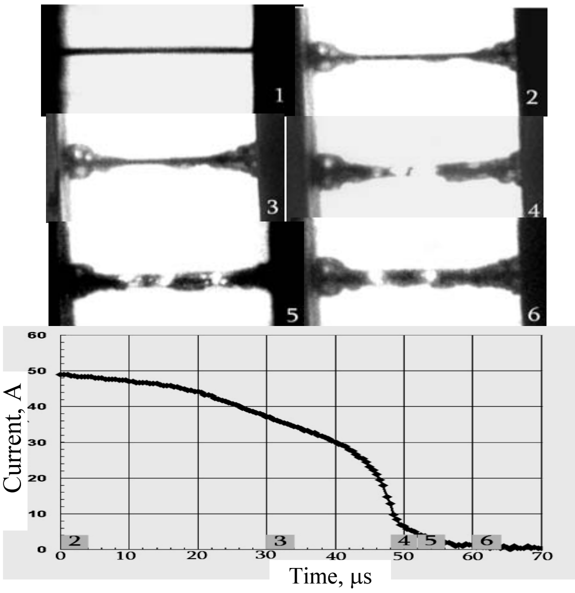

Fig. 12. The current oscillogram and photos of the steam layers around the electrode for different moments

4. Conclusion

Excitation of CGD occurs in completely generated steam layer which, is formed when the heat flux on the electrode – electrolyte boundary reaches critical value 180–200 W/cm^2 that corresponds to the critical heat flux at which appears a boiling "crisis" phenomenon [5]. For a configuration with the active anode, CGD exists in a wide range of voltage, and it is observed a hysteresis phenomenon at disintegration already generated steam layer.

References

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