Study of the discharge with an electrolytic electrode (Gatchina's discharge)

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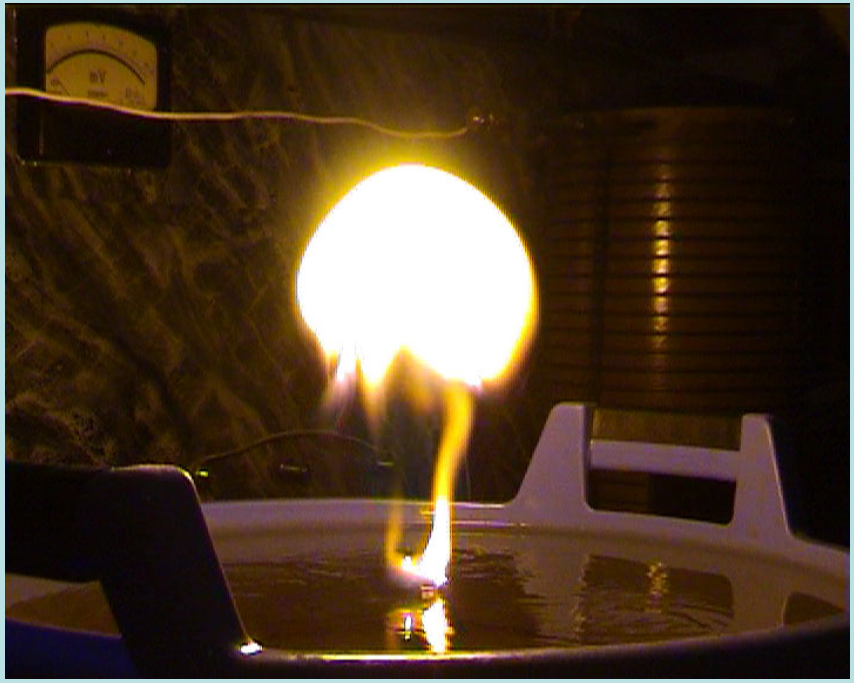
1. Introduction

Gatchina's discharge [1, 2, 3] is one of the most interesting experiments that gives a possibility to model some properties of the balllightning on the base of non-ideal dust chemical plasma. It is a discharge between the surface of a low conductive solution and a metal or carbon central electrode isolated from the water via a fused silica tube. Previously [4], we showed that under initial voltage of a storage capacitor ~ 5 kV and a current attaining at maximum of a magnitude about tens ampere a characteristic feature of the discharge is a setting in of a uniform current distribution with a low density (~ 10-1 A/cm^2) over the electrolytic anode surface, while at a sufficient decrease of the current a transition to a non-uniform distribution with a three order of magnitude greater current density occurs. In the present paper we point out differences between the discharge regimes of opposite polarity and indicate nature of the current distribution peculiarity with the help of an additional experiment.

2. Gatchina's discharge at different polarities

Experiments were carried out using installation described in [4]. A carbon rod was used as the central electrode, and the vessel was filled either by mains water with addition of NaCl or by distillated water with addition of nitric acid. In the latter case this implies the absence in the solution of components capable to form dust particles in the discharge and to cause an intensive visible radiation at relatively low electron temperatures characteristic for the afterglow.



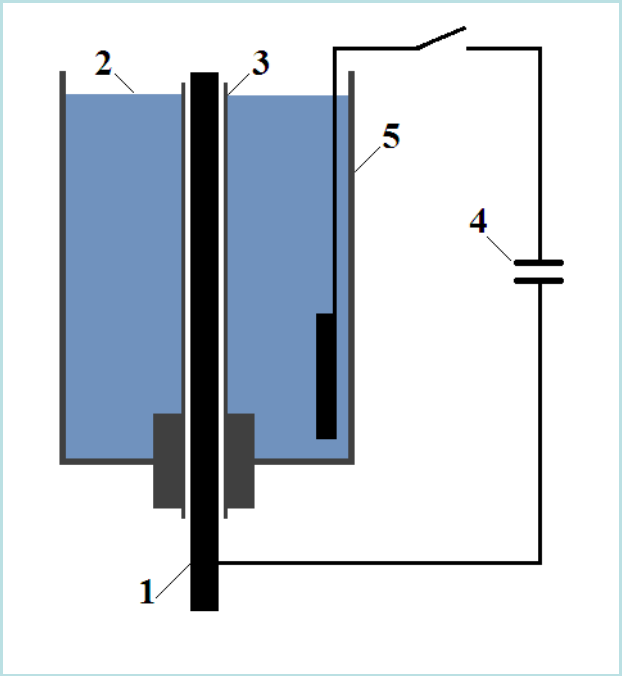


Fig. 1 shows time dependencies of the current and of relative optic radiation intensity of the discharge under different polarities of low conductive NaCl solution. As may be seen from the figure, in the case of electrolyte anode the radiation intensity reaches a maximum sufficiently later than in the case of electrolytic cathode.

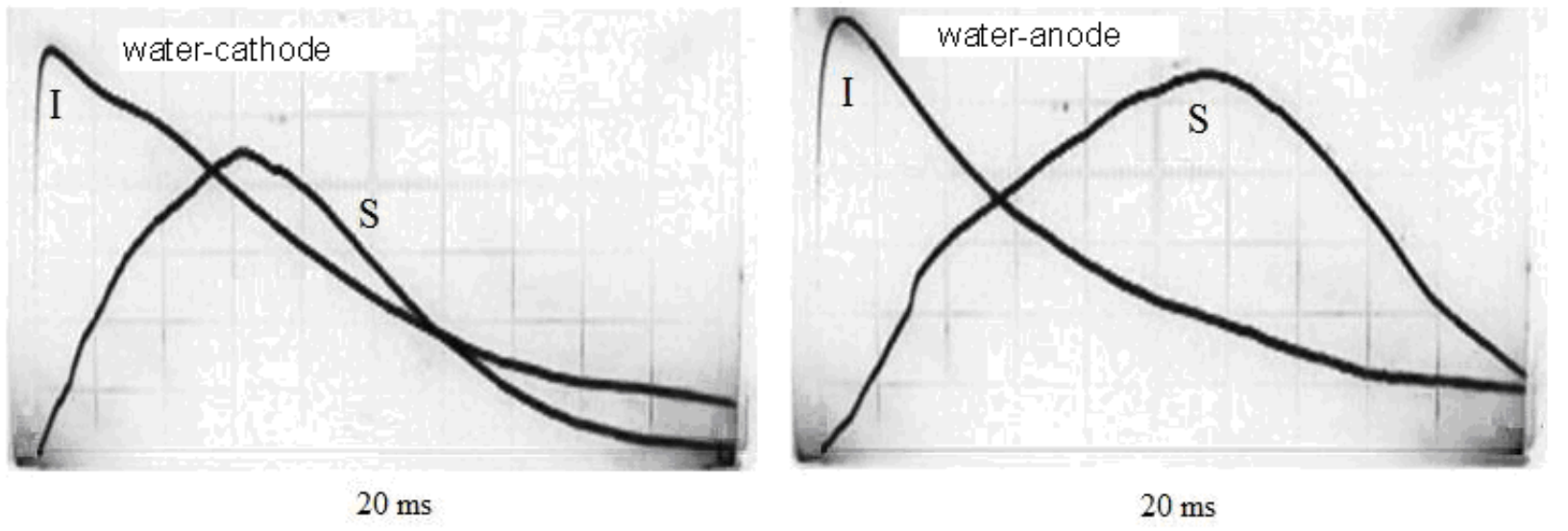


Fig. 1 The current (I) and relative optic radiation intensity (S) of the discharge in the cases of the electrolytic cathode and electrolytic anode (NaCl).

From videorecording data (Fig. 2) it has been found that the discharge current distribution over the surface of the electrolytic cathode is rather different than that in the case of the electrolytic anode described in [4]. A conjunction of the volume discharge to the solution-cathode occurs via a great number of spots, the current density in them being several orders of magnitude greater than in the case of the uniform discharge distribution over the anode. Measured spectral characteristics showed that due to a high current density at the conjunction spots to the solution surface an ejection of the dissolved substance into the discharge occurs just after the discharge beginning that results in more rapid catalytic decomposition of the chemically active mixture and in a shorter duration of the afterglow.

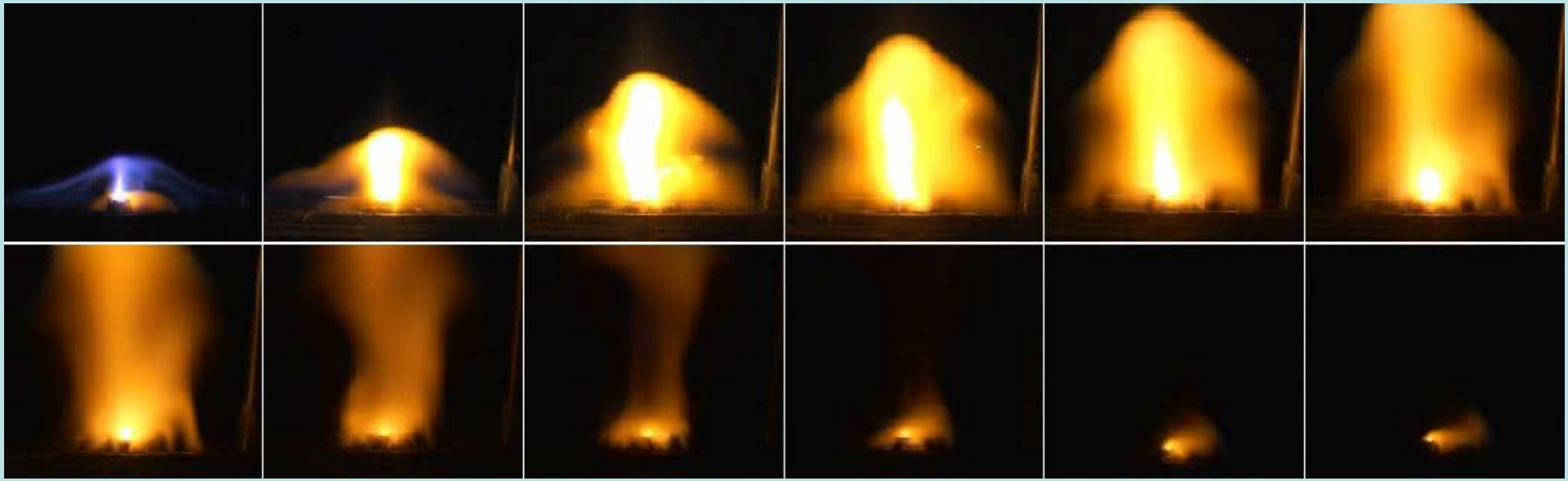


Fig. 2. Discharge images of low luminosity taken 20 ms with intervals in the case of the electrolytic cathode (NaCl).

A significant difference of the discharge at different polarities manifests itself in the erosional ejections dynamics which can be easily traced via a videogram of spectral images. Fig. 3 shows the spectral images of the discharge visible radiation at the short-wave area of the visible range, where spectral images corresponding to Ca II (393,367 nm and 396,847 nm) and Ca I (422,673 nm) are more prominent.

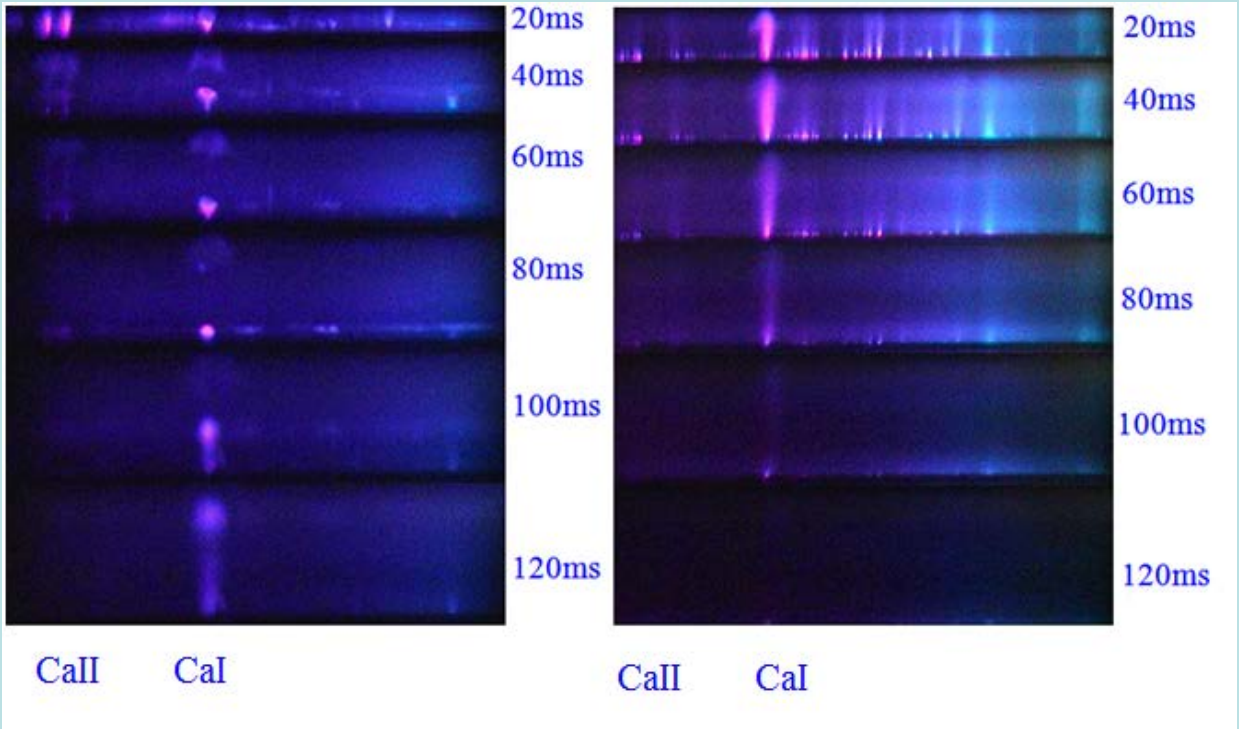


Fig. 3. Spectral images at bands Ca I and Ca II for the NaCl solution and the carbon electrode.
On the left – for the case of the electrolyte anode, on the right – for the electrolyte cathode.

In the case of the electrolytic cathode more lines are excited but all they decay rapidly with the current decrease. This indirectly points to (integrally) a lower density of the cathode current at the case of the normal polarity (i.e. at positive potential of the solution). On the Fig. 3 an erosional ejection radiation arising approximately at the moment of the transition to a non-uniform current distribution on the 80-th millisecond can be apparently seen, which forms a flying up object and is absent at the reverse polarity. We think that this intensification of the radiation can be explained, on the one hand, by the appearance of a droplet phase in the solution inflow to the plasma at increasing of the current density by three orders of magnitude, and, on the other hand, by explosion processes at the central electrode related with accumulation of hydrogen due to the ionic current. In the case of a positive temperature dependence of cathode material saturation by hydrogen, a cathode cooling occurring with the current decreasing should lead to a local over-saturation by hydrogen, to an explosion and to appearance of hydrogen saturated dust particles in the plasma that gives qualitatively different properties to the generated autonomous plasma formation.

Figures 4 and 5 represent a videorecording of the discharge at different polarities. The discharge with the electrolytic cathode on the base of HNO3 similarly to the case when a NaCl solution was used has a shorter lifetime of the afterglow relative to the case of the electrolytic anode.

Fig. 4. Images of the discharge taken with an interval 20ms in the case of electrolytic anode at the initial storage capacitor voltage 5 kV (HNO_3).

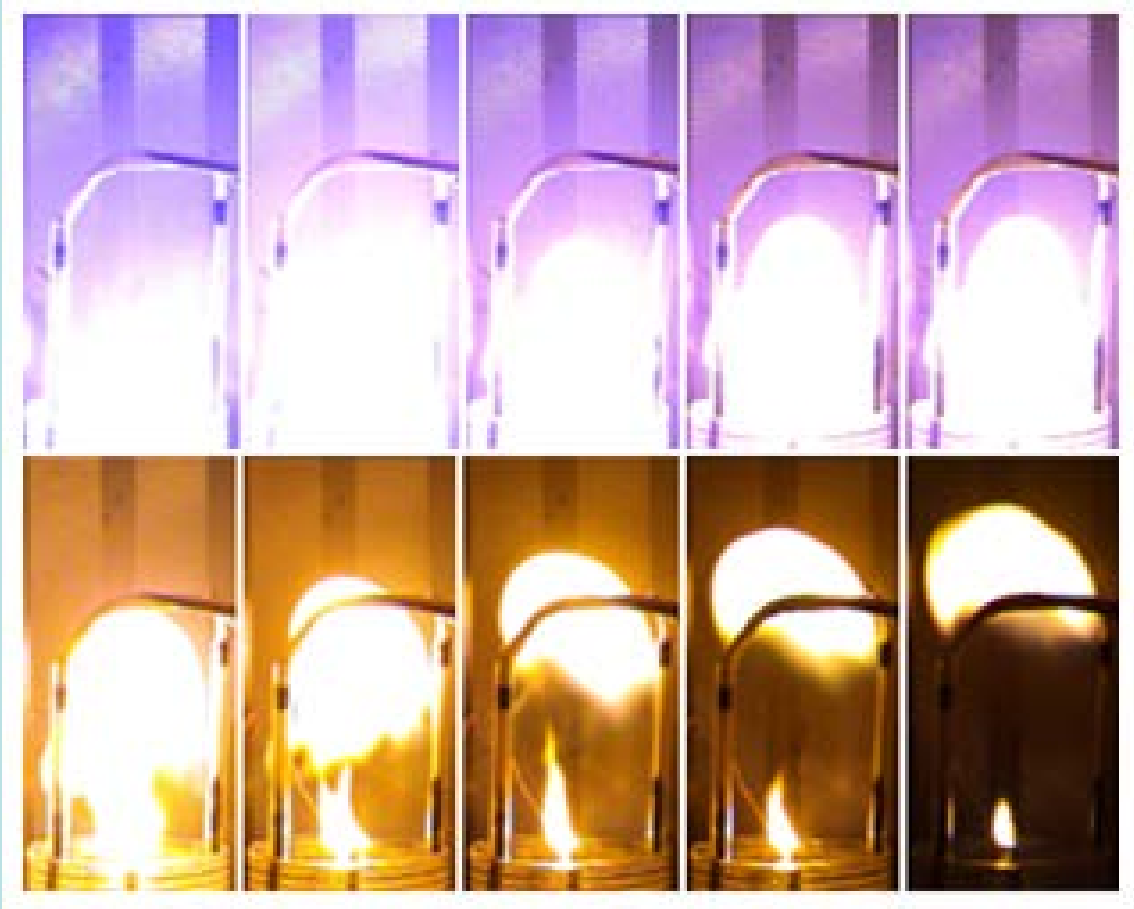


Fig. 5. Images of the discharge taken with an interval 20ms in the case of electrolytic cathode at the initial storage capacitor voltage 5 kV (HNO_3).

With increasing of the initial storage capacitor voltage this difference intensifies, the radiation maximum at reverse polarity disappears (Fig. 6), and the object practically is not forming.

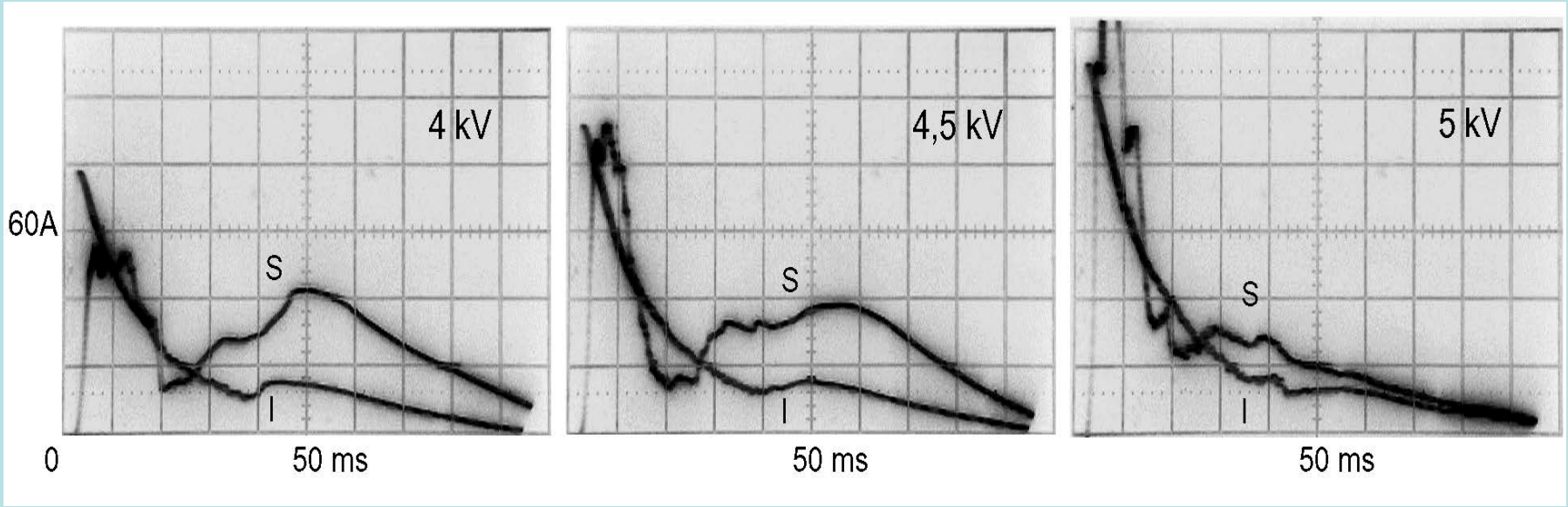


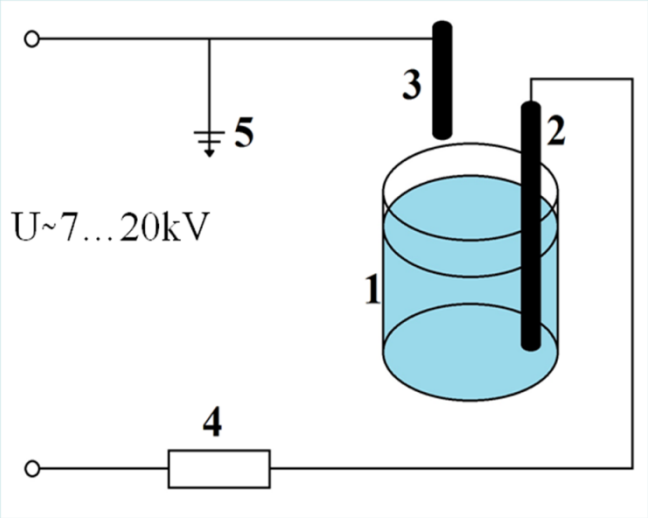
Fig. 6. Current (I) and intensity of optical radiation (S) of the discharge in the case of electrolytic cathode on the base of HNO_3 at different initial capacitor torage voltages.

On the base of the videorecording data the following differences in behavior of the erosional jet from the central electrode depending on the discharge polarity can be noted. At the normal polarity of the water electrode the erosional particles which have a positive charge form a relatively thin upward directed jet. On the stage of a vortex formation under influence of the aerodynamic deceleration the substance of the cathode jet flows around the chemically active substance volume and forms an "envelope". At opposite polarity, the dust particles under influence of the electric field get into interior of the chemical plasma volume which results in a more rapid decay of the plasma.

So, the comparison of Gatchina's discharge characteristics at different polarity revealed some of its features, the common nature of them, by our opinion, consists, firstly, in low mobility of hydrated charge carriers, and secondly, in a short deactivation time of the chemically active substance, created from water by the discharge. The former determines the existence of a special form of the glow erosional discharge characterized by a significantly (about three orders of magnitude) lower current density at the anode [5-7]. The later necessitates some techniques for a compulsory formation of the autonomous object complicating related physical conditions because the self-structuring processes is longer than self-decay of the water-based chemically active plasma.

3. Discharge of a small current

To study of a contact area of the discharge with water electrode the experiment with high-voltage discharge within a range of currents characteristic for a glow discharge has been carried out. Distilled, tap water or water with addition of baking soda poured in a glass jar of 19 cm in diameter and 17 cm in depth served as high-voltage electrode. The carbon rod 0.8 cm in diameter fixed on a dielectric rod with possibility of moving relative to the water surface was the grounded electrode. The source of DC voltage up to 25 kV with possibility of the polarity switch and the maximum current up to 200 mA has been connected through the limiting resistor 40 – 540 kOhm to the coal anode which has been isolated by a glass tube and lowered in water. Images were taken by means of videocamera SONY HDR-HC9 operating at DV-mode with a speed of 50 or 200 fields per second and resolution of 720x576 pixel.



The experimental setup.

Approach of a carbon electrode to a water surface up to characteristic distance [7] led at first to occurrence of a corona discharge with a depression on the water caused the action of an ionic wind and then to a streamer breakdown similar to [1] and to setting up of the discharge. On Fig. 7 images of discharges including the area of contact with water at different conductivities are presented. It is clearly visible that various ordered structures in the form of circles, rings, wheel spokes and their combination have been formed at the water. At the greatest concentration of a solution-cathode the yellow torch at its surface was present when the anode was both carbon and aluminium. At a current 150 mA the diameter of the anode spot at the surface of distilled water was more than 3 cm and it corresponds to average density of a current ~ 20 mA/cm^2. However the luminescence of the spot had a bright external border. Depression on a water surface at the spot was greatest for the anode on the basis of the distilled water, also as well as in the case of a corona dischage it point out to presence of a stream of gas.

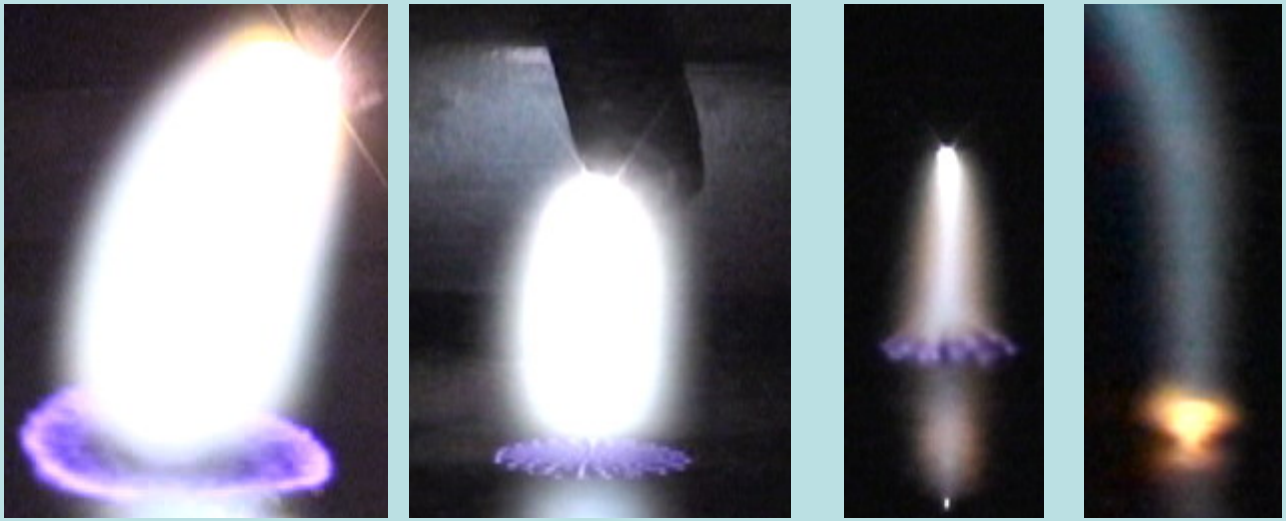


Fig. 7. Discharge images (from left to right):
- the anode – distilled water, coal cathode;
- the anode – tap water, coal cathode;
- the cathode – tap water, coal anode;
- the cathode – water with baking soda addition, aluminium anode.

Intensity of the luminescence of a plasma column above the water anode rose sharply at some distance from the water surface which increased with moving off of the carbon cathode up to some limit (Fig. 8). When magnitude of the current was of order of tens milliampers and more, further increase in the interelectrode distance led to formation of the plasma column. For the chosen voltage there was the optimum value of a current corresponding to the greatest height of area in which the luminescence is very weak despite the current value being two order of magnitude greater than the maximum current of a corona discharge at the same voltage (Fig. 8 on the left).

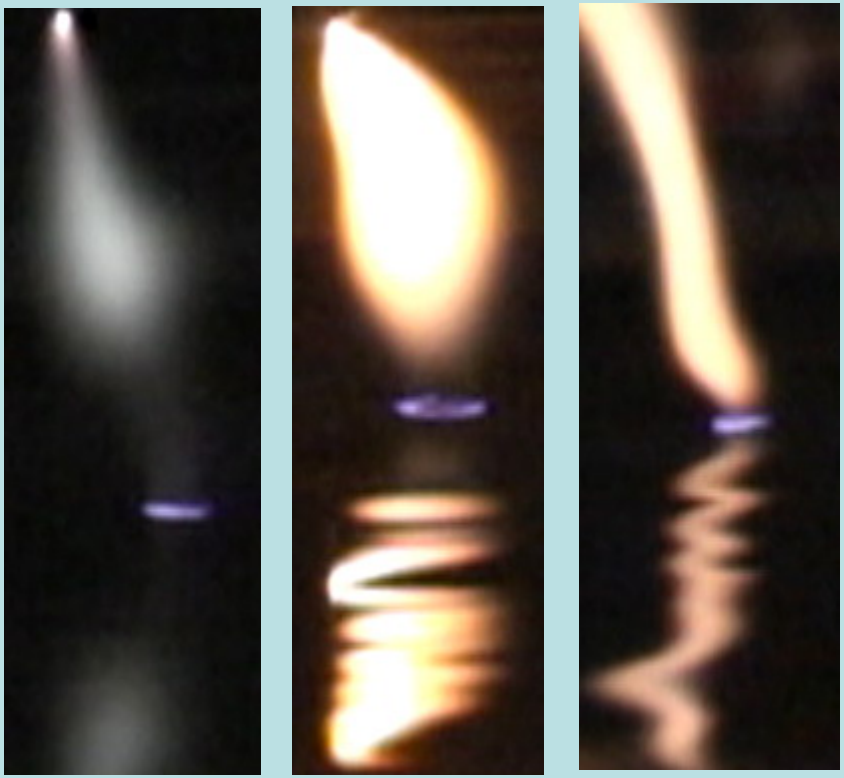


Fig. 8. Limiting height of dark area at a current of 15 mA and voltage of 12,5 kV (at the left) and at more voltage and current (the rest).

For comparison of strength of electric field in a regular part of the discharge and in thin near-surface area the dependence of voltage at the anode having been at the jar's bottom on the height of the carbon cathode above the water surface was measured in a range from 0,5cm to 3 cm for two values of a current: 140 mA and 44 mA (Fig. 9). The voltage drop on water was defined when the cathode had been dipped in water and proved to be 227.3 V for the big current and 57 V for the small one. Then the anode drop ΔU_A extrapolated to a zero gap, was 515 V and 610 V accordingly. If to consider a thickness of dark area at the big current equal to ~ 2mm the voltage drop on it will 571 V that coincides with the minimum magnitude of interelectrode voltage drop in Gatchina's discharge [4]. The field strength in it is about ~ 2.85 kV/cm that is 10 times more than in a regular part of a plasma column.

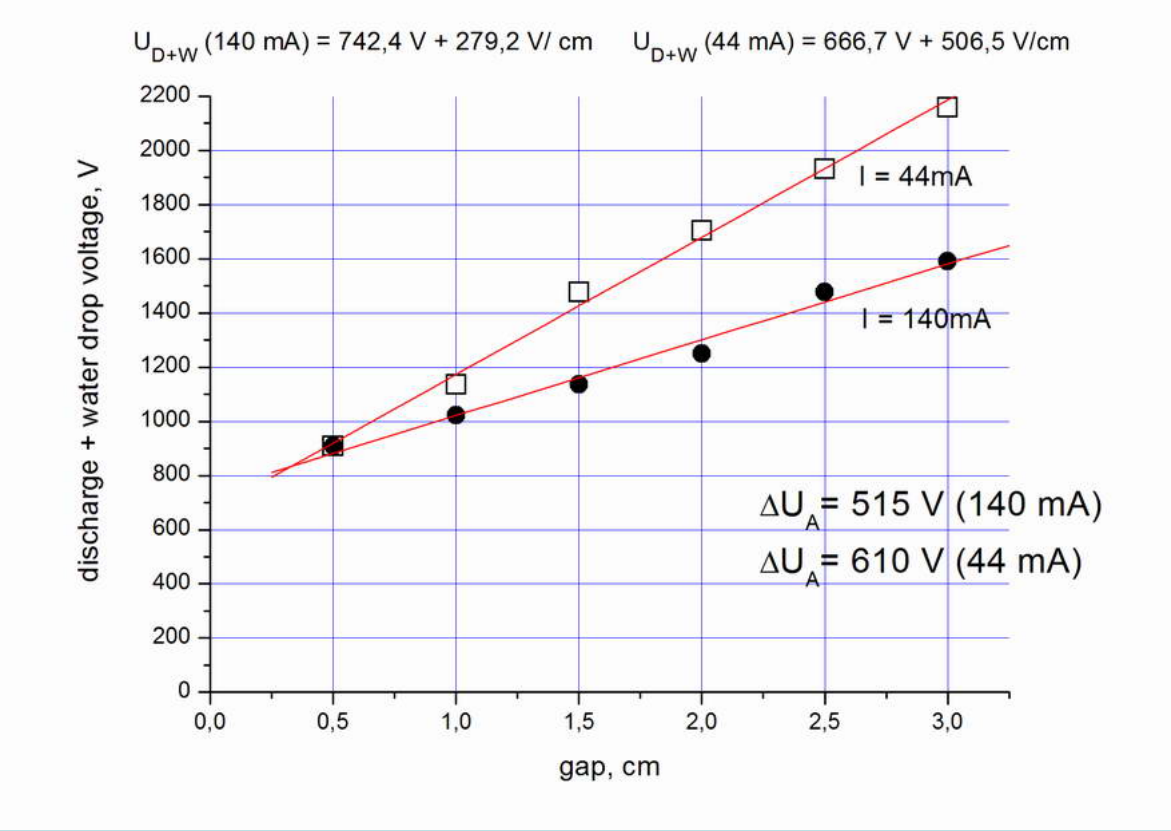


Fig. 9. Dependence of the total voltage drop at the water and the discharge on the gap distance for two values of the current: 44 mA and 140 mA. ΔU_A – the anode drop extrapolated to a zero gap.

Further increase in the interelectrode distance led to occurrence of instability of a picture of the discharge, character of which depended on current and voltage values. In the optimum mode the anode spot started moving under the influence of a steam jet and new spots could arise on smaller distance from the bright cathode part of a plasma column. At such secondary breakdown the field strength is many times lower than at primary breakdown, nevertheless the torches which were not crossing completely a dark area could develop from the centers of spots. Different spots with torches co-existed some time (Fig. 10 on the left). At higher currents the torches appearing from new anode spots created a flashover of the gap and formed shorter plasma column (Fig. 10 on the right). The coexistence of anode spots was limited by time of development of the new plasma column and degradation of the old one. At further growth of the current the time of such secondary breakdown decreased but remained two orders of magnitude more than time of primary breakdown [3], the electric strength being lowered 10 times.

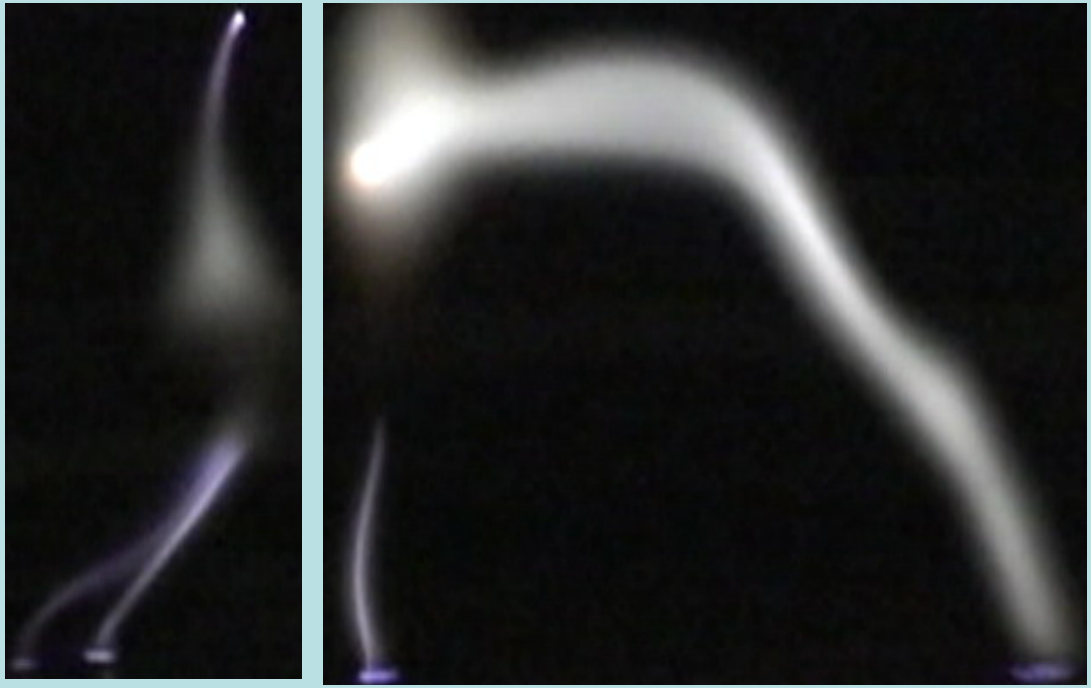


Fig. 10. Torches not resulting (at the left) and resulting in flashover (on the right).

On Fig. 11 an example of the oscillogram of a discharge current break-off at lengthening of a plasma column (under the rectifier voltage of 15 kV and 290 kOhm limiting resistor) is represented. The first stage — a relaxation of the self-maintained discharge was characterised by growth of excess of its voltage drop above the voltage drop at the limiting resistor and by smooth reduction of a current. At the second stage the magnitude of the current (less than 1 mA) was determined by a relaxation of plasma as source of electrons and the electric field strength. The characteristic form of the current impulses (Fig. 11 on the right) corresponds to the avalanche nature of the semi-self-maintained discharge. The voltage increase at a part of the relaxing plasma close to a cathode can prove to be sufficient for increase of a current of the semi-self-maintained discharge by shorter way and an avalanche formation (Fig. 10 on the right). In case of the breakdown beginning actually after the end of the stage of the self-maintained discharge, as it takes place at the oscillogram (Fig. 10 at the left), it is possible to find breakdown parameters. The current at the initial stage is ~ 1 mA, its duration – about 0.4 ms, a total time up to a current setting up – about 1 ms, so speed of a streamer movement is ~ 100 m/s.

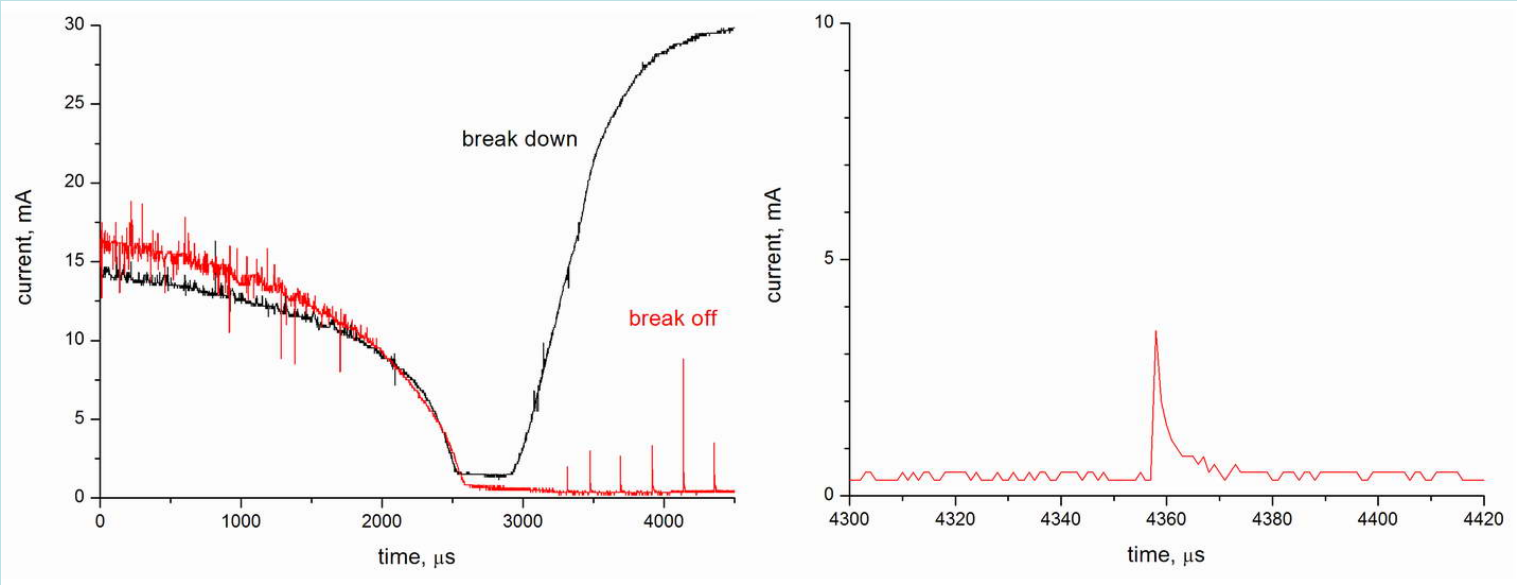


Fig. 11. At the left – examples of oscillograms of the current for two possible variants of a non-stationary phase of the discharge: resulting in transition to the semi-self-maintained discharge and resulting in breakdown by shorter way. On the right — the characteristic form of current impulses.

Besides breakdowns from the water surface, the breakdowns between different parts of the curved plasma column were observed also (Fig. 12). They developed so slowly that change of a column configuration often leaved them not finished. "Slow" streamers extended exclusively in the electric field direction.

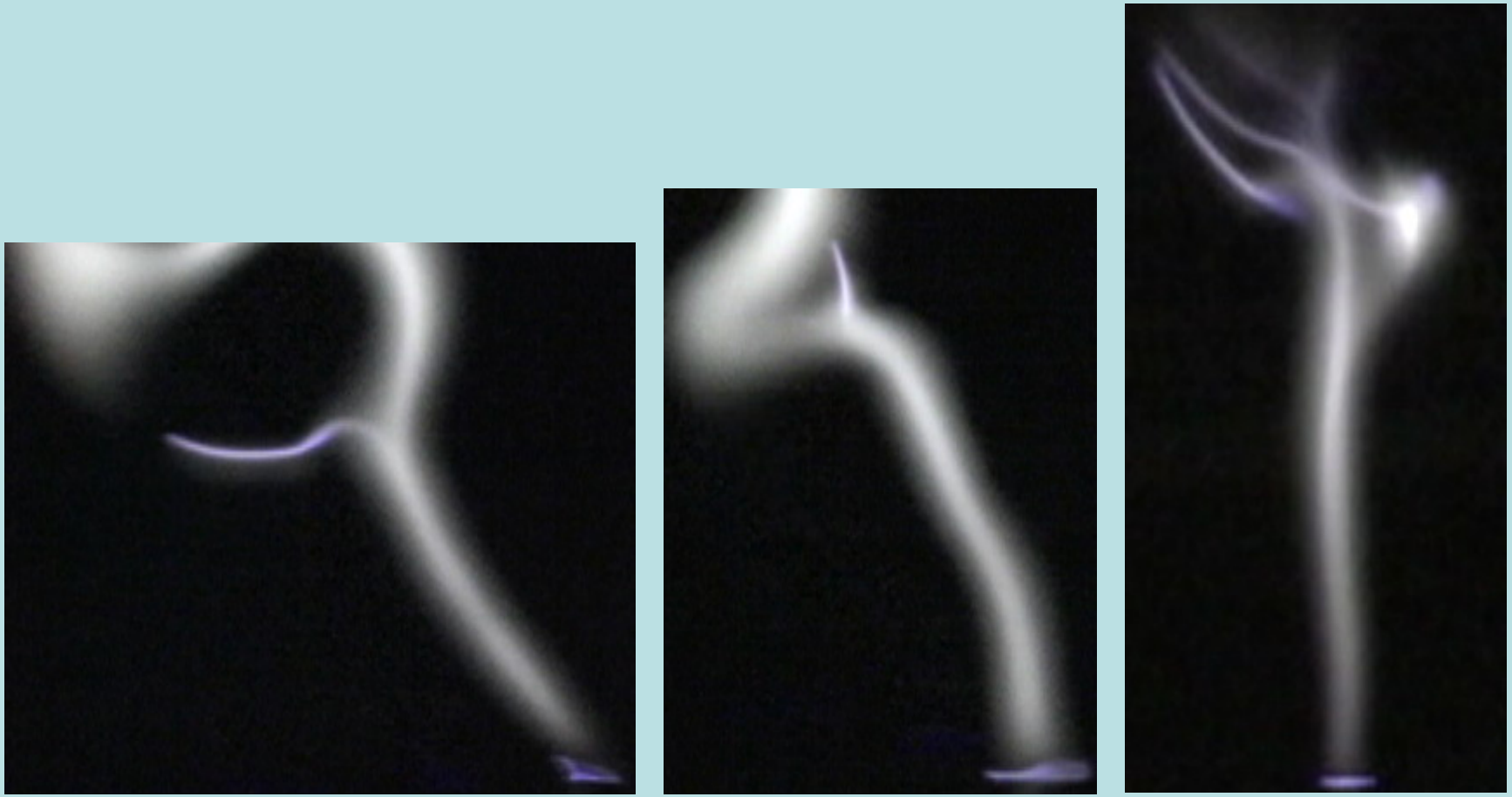


Fig. 12. Development of breakdowns at the arched parts of a plasma column and a group of the not completed streamers (on the right).

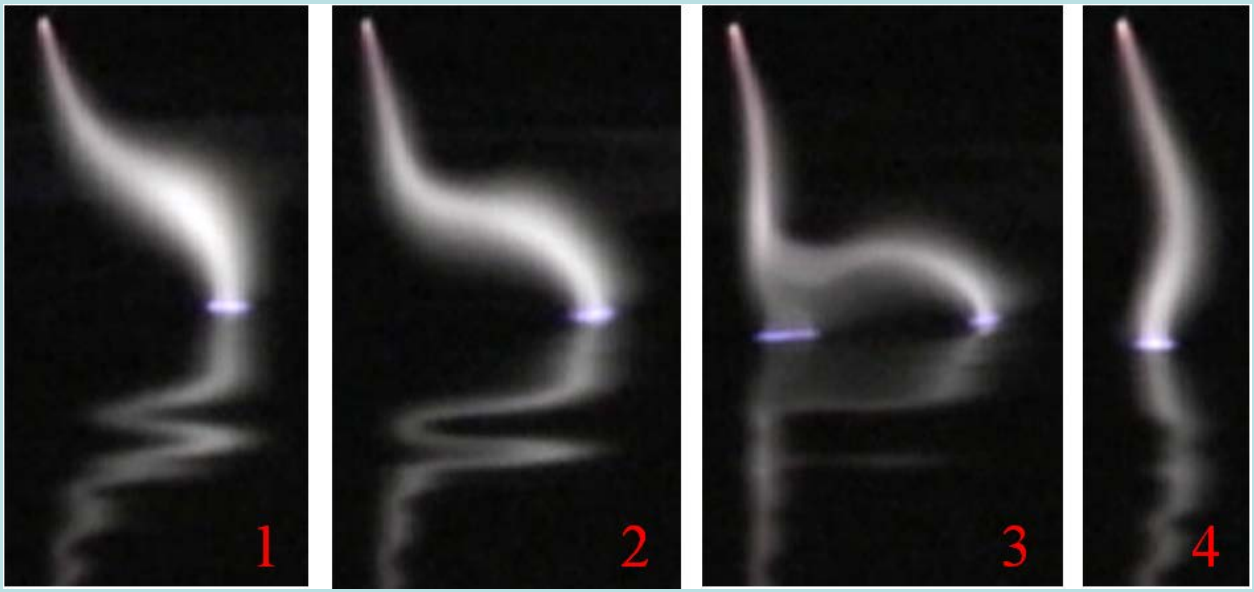


Fig. 13 Instability of the discharge with electrolytic cathode.

4. Conclusions

From the obtained experimental results it is possible to conclude that in the Gatchina's discharge at the water surface the dark plasma layer exists limited from above by chemically active plasma. It represents not self-sustained zone of the discharge which arises under the influence of evaporated water and receives electrons from the top plasma layer. The low temperature of steam in it leads to a steady hydrating of charges, decrease of their mobility and suppression of radiation. The discharge expansion on the water surface after streamer stages is connected with formation of a layer of chemically active plasma and points out that not self-sustained zone of the discharge is in a saturation mode. In case of opposite polarity on the water surface the glow discharge is set up, the normal current density of which repeatedly exceeds average one in a cathode spot. It leads to parting of a cathode layer into group of separate cathode spots and to entering of the dissolved substance into the plasma due to a droplet phase at the erosional stream.

References

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