INFLUENCE OF ELECTRODE EROSION ON FORMATION OF LONG-LIVING LUMINOUS OBJECTS, FORMED BY ELECTRICAL DISCHARGE IN WATER

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This paper presents the results of experimental studies of the influence of electrode erosion, which occurs during the electrical discharge in liquid on formation of long-living luminous objects. On the basis of these results the authors conclude that the electrode material is not only involved in the formation of long-living luminous objects, but also hinders this formation.

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1. INTRODUCTION

Long-living luminous objects (LLO) are formed during the expansion of low-temperature plasma initiated by high-voltage discharge in water [1,2]. They are formed from an amorphous glowing clouds, composed of unusual metastable compounds of oxygen and (or) hydrogen, which appear in the process of disintegration of the expanding plasma [3]. These compounds have a certain reserve of energy, which, in particular, manifests itself in the long afterglow.

In order to observe LLO formation it is necessary to satisfy certain conditions. In addition to restrictions on current and temporal characteristics of the discharge, it is necessary that the energy release occurs in pure (distilled) water with refractory electrodes. The most convenient material used for these purposes is tungsten. When all the necessary conditions for the formation of LLO are satisfied the duration of post-discharge glow exceeds the characteristic time of glow of the discharge plasma, initiated in the liquid, by more than four orders of magnitude. Experiments showed that the duration of the afterglow is inversely proportional to the melting temperature of the electrode material. Thus, the available experimental data indicate that the best conditions for LLO formation are implemented during the disintegration of pure water plasma. One further confirmation of this is that the emission spectrum of long-living luminous objects does not depend on the electrode material (graphite, tungsten, molybdenum) used in the discharge [1,2]. However, the effect of erosion of the electrodes during the discharge processes leading to LLO formation is not fully understood.

2. AN OUTLINE OF PLASMA FORMATION IN WATER AND OF RECORDING OF LLO FORMATION DYNAMICS

This paper presents the results of experiments in which an attempt was made to get rid of the penetration of the electrode material in plasma, initiated by an electric discharge in water. The scheme of the discharge gap used for this purpose is shown in Fig.1. The discharge was produced by the electrodes – 1, the sharpened ends of which are located in the air. Between the electrodes a flat water jet – 2 is passed through, its thickness d = 0.2…0.3 mm. The velocity of the liquid in it is ≈ 10 m/sec. The distance from the edge of one electrode to the flat surface of the jet is D = 3…5 mm. The width of the jet (the size perpendicular to the plane of the figure) is 60…70 mm.

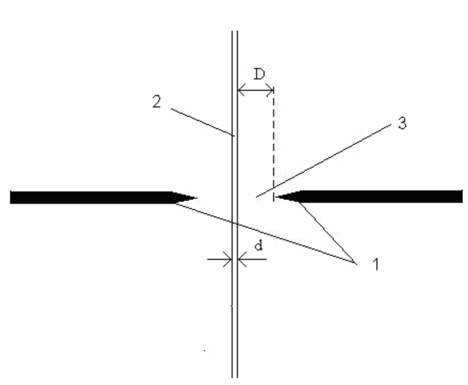

Fig.1. The scheme of the discharge gap with a plane water jet

The figure shows that the discharge channel is divided into three parts. Two of them are airborne and adjacent to the electrodes. In the middle there is plasma, which is formed when the current flows through the flat water jet. The penetration of the electrode material into plasma is difficult due to the presence of air zone between itself and the electrodes. In addition, the erosion of the electrodes during the discharge in the air is by some orders of magnitude less than erosion in the water discharge, ceteris paribus. Thus, in plasma, initiated in a planar jet of water through the air gaps, the amount of substance of the electrodes will be much less than at a discharge in a continuous aqueous medium. This makes it possible to compare the dynamics of post-discharge processes accompanying the disintegration of water plasma with different concentrations of impurities of chemical composition.

The device, which was used for discharge in a continuous volume of water, is shown on Fig.2. The figure shows that the discharge occurs in the jet of water with round section. The electrodes are arranged so that the water flow completely covers them during their motion. Such a scheme of the discharge was chosen to approximate conditions for the occurrence of LLO with both methods of initiation. The diameter of water jet, shown in Fig.2 was 7…8 mm. The velocity of the jet is ≈ 2 m/sec. When reducing the diameter of the jet the discharge channel can take place not only through the volume of water, but also through the air.

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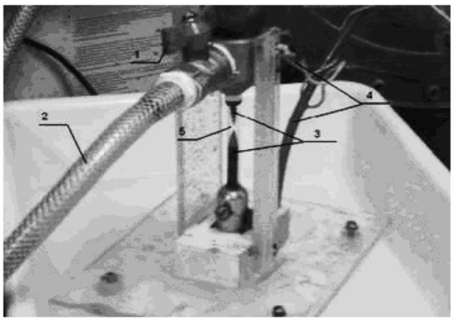


Fig.2. Photography equipment for the implementation of the discharge in a jet of distilled water: 1 – valve; 2 – flexible hose for water supply; 3 – electrodes; 4 – cable for supplying high-voltage pulse; 5 – water jet

Schematic diagram of the setup for recording the dynamics of post-discharge processes is shown in Fig.3.

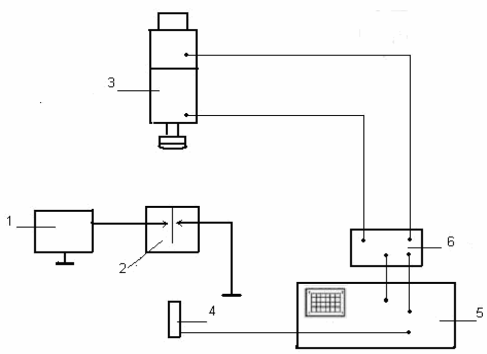


Fig.3. Schematic diagram of the installation for registering post-discharge processes

The discharge was carried out using a generator of high voltage pulses – 1 in the chamber – 2. The integrated light flux is recorded with photomultiplier (FEU-84) – 4. The dynamics of post-discharge processes is recorded by an electron-optical camera (EOC) – 3 collected on the basis of time-analyzing electron-optical converter PIM-103 and brightness amplifier PMU-2V. Changing the integral light flux is fixed by a dual-beam storage oscilloscope – 5, type C 8-14. The control of the EOC is made using the unit of synchronization – 6. The signals from the control unit and the synchronization are fed to an oscilloscope, which allows to control the start time of the shooting and the capture rate of the EOC. Breakdown voltage – 20 kV, time of energy release ~ 5 μs.

The device operates as follows. The signal from the photomultiplier, which records the light flash from the discharge, enters the input of the synchronization of the oscilloscope. As a result, in its electron sweep a pulse is generated which after amplification enters the input of the control unit and the synchronization of the EOC. The start of shooting begins after a time interval whose value can be set between 30 ns to 10 ms depending on the task. The minimum time delay in the commencement of the camera's work relative to the time of arrival of the pulse from the photomultiplier ≤ 60 ns.

During the recording of post-discharge processes EOC operates in frame-by-frame mode. The maximum number of frames – 9. Exposure of any of the frames can be set in the range from 30 ns to 100 μs. The time interval between each of them, going consistently, can be set in the range of 50 ns – 200 μs.

3. THE RESULTS OF THE EXPERIMENTS

During the experiments, we used electrodes of spectrally pure graphite ES 22, the graphite rods from Panasonic batteries, tungsten, steel (nails), and copper wire. Filming was carried out, without any external illumination, that is, the EOC recorded only radiation from the decay products of the discharge plasma.

Figure 4 shows typical results of frame-by-frame photography of LLO resulting from high-voltage discharge in a cylindrical jet (see Fig.2). The first photo (Fig.4,a) shows the evolution of LLO formed as a result of the discharge using the electrode of spectrally pure graphite. Fig.4,b shows the evolution of long-living luminous objects formed in the experiments with tungsten electrodes.

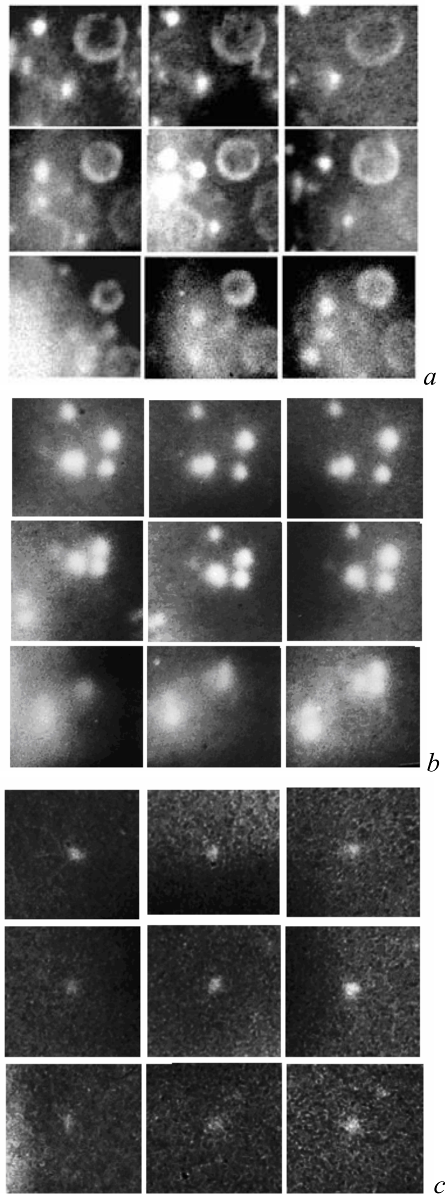
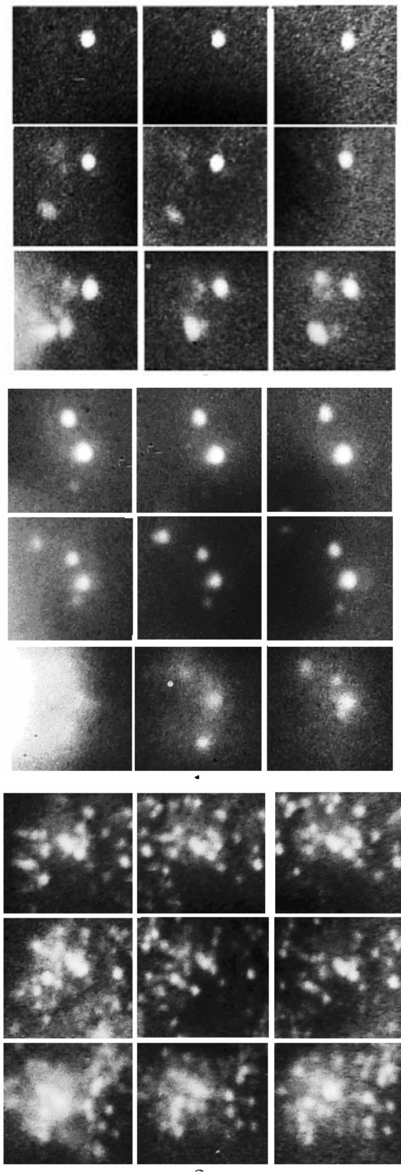


Fig.4. The evolution of LLO, which appear after using electrodes of spectrally pure graphite (a), tungsten (b), steel (a). The discharge in a cylindrical vertical jet of water. The sequence of frames from left to right, bottom to top. The delay in the start of shooting in relation to the end of the energy release – 400 μs. The exposure of each frame – 5 μs. The time interval between frames – 200 μs

Fig.4 shows the LLO, which were obtained in 20% of cases when using steel electrodes. In the remaining 80% of experiments with steel electrodes luminous objects are not registered. The results of registration of LLO formed at discharges with electrodes of graphite rods batteries are similar to that shown in Fig.4,c. Differences in the size, brightness, number and form of long-living luminous objects in the Figs.4,a and 4,c can be explained by the presence of approximately 10% of impurities in the graphite rods from the batteries. Above all, in the composition of these impurities are included low-melting metals such as aluminum and calcium. In cases where the discharge was carried out with copper electrodes LLO was not recorded.



a

b

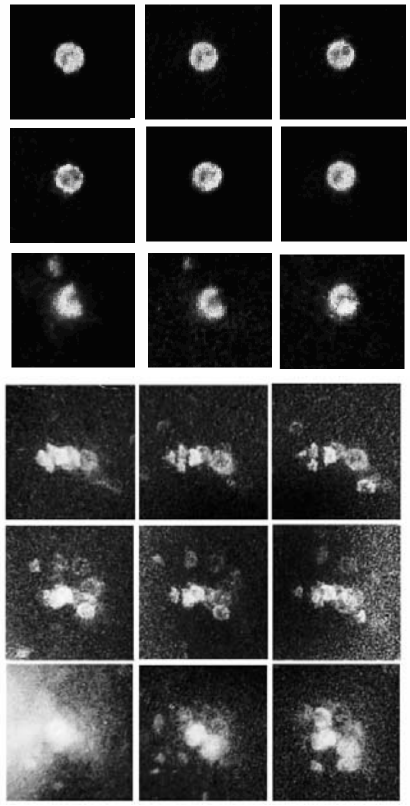
c

Fig.5. The evolution of LLO, which appear after using electrodes of spectrally pure graphite (a), tungsten (b) and steel (c). The discharge through a flat jet of water. The sequence of frames from left to right, bottom to top. The delay in the start of shooting in relation to the end of energy release - 400 μs. The exposure of each frame - 5 μs. The time interval between frames - 200 μs

It should be noted that in addition to common long-living luminous objects in Fig.4,a luminous objects were registered that resemble a certain expanding shells. Their presence can not be explained by conventional LLO illumination, as the similar "shells" are recorded even without any other luminous objects. The glowing and expanding shells are registered also as a result of discharges with tungsten electrodes in a cylindrical water jets. Fig.5 shows the results of frame-by-frame shooting mode of long-living luminous objects typical for discharge through a flat jet of water (see Fig.1). The sequence of photos on it is the same as in Fig.4.

It should be noted that at discharges through a flat stream of water with electrodes made of copper and graphite rods of batteries LLO are not recorded. At discharges with electrodes of spectrally pure graphite, structures resembling the expanding shells are not recorded (Fig.5,a). The discharge through a flat jet of water produced by means of a steel electrodes in the main leads to the formation of a large number of small, luminous objects, as illustrated in Fig.5,c.

In about 10% of the events in which the discharge occurs through a planar jet of water using tungsten and stainless steel electrodes, a different kind of luminous objects are observed. The photos of these events are shown on Fig.6.



a

b

Fig.6. The evolution of LLO, which appear when using electrodes made from tungsten (a) and steel (b). The discharge is through a flat jet of water. The sequence of frames from left to right, bottom to top. The delay of the start of shooting in respect to the end of the energy release - 400 μs. The exposure of each frame - 5 μs. The time interval between frames - 200 μs

From Fig.6,a its clearly seen that in some cases the discharge through a flat jet of water using tungsten electrodes causes the LLO formation which have a dark core. The size of such luminous objects during their registration changed slightly. The semicircular shape of these formations in the first two frames of Fig.6,a is due to the shading of the jet of water through which a discharge had been made. The slope of the shadow is due to rotation of the EOC in respect to the horizontal axis. The luminous objects that are formed during the discharge through a plane jet with steel electrodes sometimes have the form, which is shown on Fig.6,b. On this picture, starting with the third frame, there are structures similar to those shown on Fig.4,a.

CONCLUSIONS

Comparing the results of experiments on the initiation of electric discharge in cylindrical and flat jet of distilled water one can draw the following conclusions:

1. In case of using refractory electrodes (spectrally pure graphite and tungsten) LLO are formed in both the events.

2. The use of copper electrodes does not lead to formation of long-living luminous objects.

3. For discharges in a cylindrical jet of distilled water, made with steel electrodes, in some cases one observes objects similar to LLO. However, their brightness and size are much smaller than similar characteristics of long-living luminous objects formed as a result of a discharge with the use of refractory electrodes.

4. Discharges through a flat stream of water using steel electrodes lead to a sustainable formation of a multitude of small LLO.

5. The use of graphite electrodes with impurities (rods from batteries), leads to a noticeable decrease in the effect of LLO formation in comparison to discharges in a cylindrical jet of distilled water and to its complete suppression in the case of discharges through the planar jets.

6. In these experiments, we've found new types of luminous objects. We've registered LLO with a dark (not glowing) core (Fig.6,a) and objects similar to the widening luminous shells (Fig.4,a and 6,b).

These data suggest that the electrode material that gets caught in water plasma during the discharge does not only participate in the formation of long-living luminous objects, but even hinders this formation.

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ВЛИЯНИЕ ЭРОЗИИ ЭЛЕКТРОДОВ НА ФОРМИРОВАНИЕ ДОЛГОЖИВУЩИХ СВЕТЯЩИХСЯ ОБЪЕКТОВ, КОТОРЫЕ ОБРАЗУЮТСЯ В РЕЗУЛЬТАТЕ ЭЛЕКТРИЧЕСКОГО РАЗРЯДА В ВОДЕ

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Представлены результаты экспериментальных исследований влияния эрозии электродов, которая происходит во время электрического разряда в жидкости, на процесс формирования долгоживущих светящихся объектов. На основе полученных данных авторы делают вывод о том, что материал электродов не только не участвует в процессе формирования долгоживущих светящихся объектов, но и препятствует их образованию.

ВПЛИВ ЕРОЗІЇ ЕЛЕКТРОДІВ НА ФОРМУВАННЯ ДОВГОІСНУЮЧИХ СВІТНИХ ОБ'ЄКТІВ, ЩО УТВОРЮЮТЬСЯ В РЕЗУЛЬТАТІ ЕЛЕКТРИЧНОГО РОЗРЯДУ У ВОДІ

П.І. Голубничий, Ю.М. Крутов, Є.В. Нікітін

Представлені результати експериментальних досліджень впливу ерозії електродів, яка відбувається під час електричного розряду у рідині, на процес формування довгоіснуючих світних об'єктів. На основі отриманих даних автори роблять висновок про те, що матеріал електродів не тільки не бере участі у процесі формування довгоіснуючих світних об'єктів, але і перешкоджає їх утворенню.