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The high-frequency current pulsations in the gas discharge with liquid electrode

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Abstract. The electrical discharges are experimentally investigated in the air between the liquid electrolyte and metal electrodes. Spectra of the current signals are registered and analyzed in the megahertz frequency range. It is established that one of the main causes of the high-frequency current pulsations is the flow of products and the erosion of the sputtering electrodes in the discharge region.

1. Introduction

Electrical discharges which contacted with the liquid are not uncommon. It is known the gas discharges which are burning between the solid electrodes in water or in a specially prepared electrolyte [1-3]. They are used in industry for the underwater stamping large-size thin-walled of sheet metal material, and also a plasma electrolytic modification of metal surfaces. Often there are some variations of a solid electrode placed above the liquid electrolyte [4-8]. They are perspective for initiating chemical processes in the electrolytes which are used in the textile industry [4-5]. These electrical discharges can be used in plasma-chemical reactors intended for the production of the syngas [7]. Low-current discharges can be applied in medicine [8]. However, in despite of the fairly widespread practice, electrical discharges contacted with the liquid poor investigated nowadays, especially in the low spatial and temporal intervals. One of the properties which are shown in small intervals of time is the presence of high-frequency current pulsations. They are fixed in various variants of electrical discharge with liquid electrolytes [9-12]. In the closed volume inside of the electrolyte can occur magnetosonic waves with frequencies in the megahertz range are assumed by authors of works [11]. This assumption is clearly inadequate to explain the reasons for the emergence of high frequency current pulsations in various embodiments, electrical discharges in contact with liquid electrolytes. The aim of this work was the experimental investigation of high frequency current pulsations in gas discharges which generated in the air gap between the liquid electrolyte and solid electrode.

2. Experiment

The power supply was a three-phase full-wave rectifier which was connected to the secondary windings of step-up transformer. The output voltage was smoothed by C-L-C filter. At idle, it is amounted to 1760 V. The current limit was made with by wire resistors.

Oscillograms of current were recorded with an oscilloscope AKIP-15/1, 25 MHz bandwidth. The analysis of the current oscillations mode was performed with using fast Fourier transform of the same oscilloscope.

Solid electrodes are made of copper most often in the research practice. The solutions of sodium chloride in distilled water as a liquid electrolyte are used as the liquid electrolyte. Experimental results for such a combination of electrodes are provided on the figure 1*a*. The cathode is a liquid electrolyte, and an anode - a pointed cone at the copper rod with a diameter of 4.5 mm. On the figure outlines of the copper rod are marked with white lines. Specific electrical conductivity of the electrolyte was 10 mS/cm. It was poured into a porcelain vessel. Inside of the vessel was mounted graphite plate which was connected to the output terminal of the power source. A distance between the liquid electrolyte and a copper rod was set to 5 mm. The same interelectrode gap was maintained in all subsequent experiments with other electrodes.

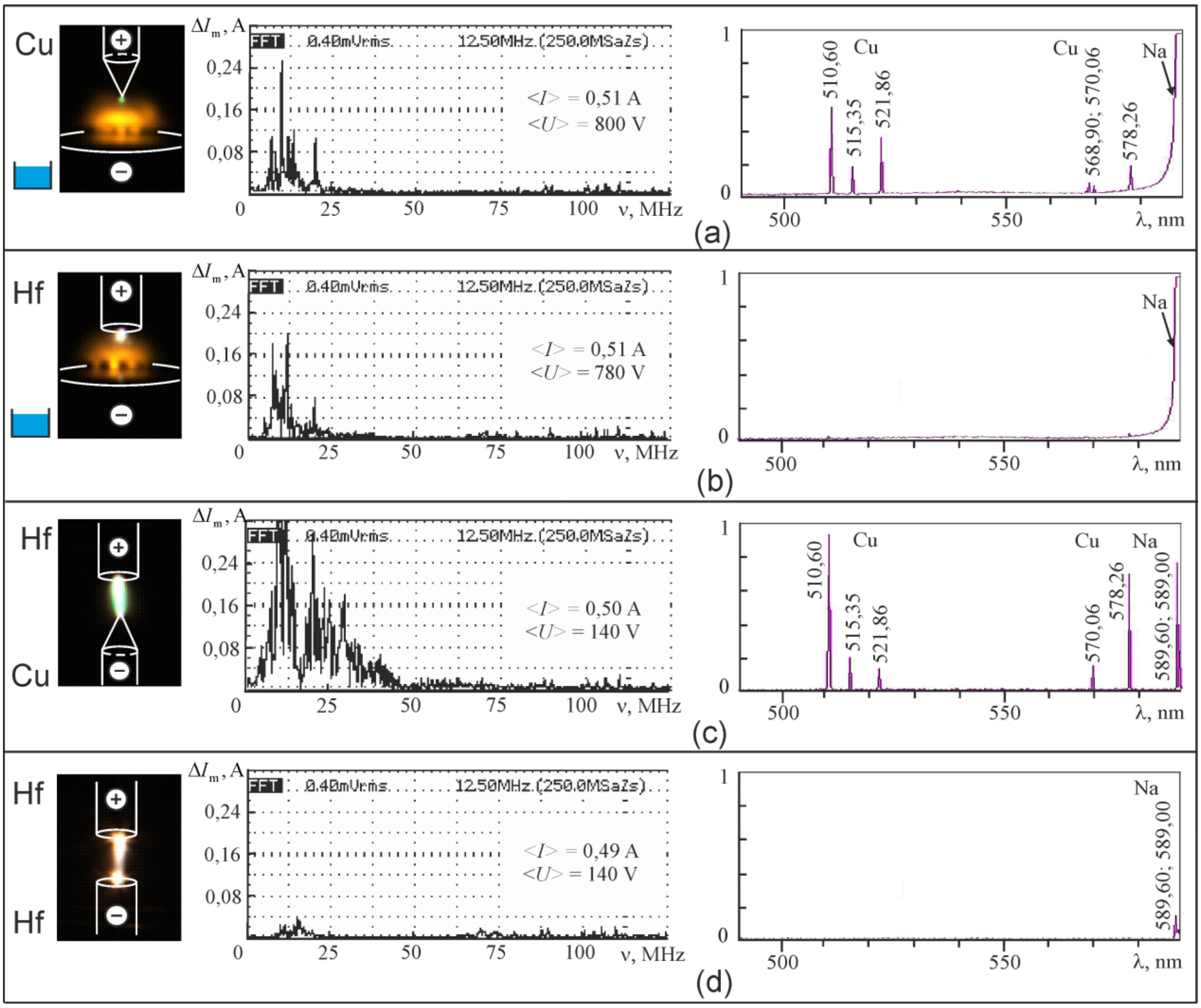

Figure 1. The variants of electrodes combinations. From left to right: instant photo of the electric discharge, the spectrum of pulsations and the emission spectrum.

Instant photos of discharge were obtained by using high-speed video camera Videoscan-401 which can record up to 25 frames per second with a minimum exposure of 1 μs. For all shown in figure 1 photos the diaphragm disclosed the same and selected the same exposure equal to 1 ms. As seen photos witch placed on the figure 1*a*, the discharge of liquid electrolyte cathode is a volumetric and zone of its binding to the electrolyte has a fairly large area. Plasma column discharge is colored in yellow, which indicates the flow of sodium from the electrolyte in the discharge area. The most likely mechanism for the portage of sodium is the spraying of the electrolyte. In fact, the spraying of the electrolyte was observed visually with the naked eye. The copper tip of the cone has a green color. This color indicates about the arrival of the copper atoms in the anode area of discharge.

Next to the pictures typical spectra of signals are located which they received by the oscilloscope. At the same place were got testimony switch devices M2016 and M2015, which was used as an ammeter and voltmeter for measure the discharge current $<I>$ and voltage $<U>$ between the cathode and the anode. The oscillograms were recorded at the same current in order to ensure a level playing field in the experiments. The signal for the registration of the discharge current was served as the voltage drop across the shunt with a resistance of 0.01 Ω. The spectral signals are submitted on the figure 1. As seen in the gas discharge which stimulated between the liquid electrolyte cathode and the copper anode are present the pulsations of high frequency current in the megahertz range. At that the effective amplitudes of pulsations ΔI_m are significant and their maximum values approaching 50% of the average discharge current $<I>$.

The fragment of the emission spectrum of the electric discharge in the visible wavelength range is shown on the figure 1*a*. There contains the spectral lines of copper, which also confirms the receipt of the copper atoms in the discharge area. The curve line on the right edge is the result of saturation of the CDD-detector spectrometer. This picture confirms the intense flow of sodium in the plasma column with droplets of electrolyte. The recording of the emission spectrum was carried out with fiber-optic spectrometer AvaSpec-3648 with a resolution of 0.15 nm (diffraction grating 1200 lines/mm, the input optical gap of 10 microns). The spectra were recorded without averaging. The integration time of one record was 400 ms. The all subsequent entries (for all combinations of the electrodes and their relative position) was carried out in such a mode that allowed you to compare the intensity of spectral lines in spectra obtained.

Thus, the experiments showed that in the embodiment, "liquid electrolytic cathode - copper anode" high-frequency current pulsations with significant amplitude occur on the background of receipt of electrode materials (electrolyte, and copper) in the discharge area.

Repetition of the experiments in the embodiment of "liquid electrolytic cathode - anode hafnium" are showed that high frequency current pulsations remain, in spite of the elimination of one of the receipt of the electrodes, specifically, anode metal (copper). The results of these experiments are shown in figure 1*b*. In the emission spectrum (on the right edge of the second row) were recorded saturated radiation sodium atoms of CDD-signal detector, which indicates the intensity of receipt droplets of electrolyte in the discharge area.

The results which obtained in an embodiment "copper cathode - hafnium anode" are shown on the figure 1*c*. On the photo a greenish color in the discharge column, is visible. It indicates the arrival of copper atoms. The presence of the spectral lines in the emission spectrum of copper confirms this fact. Comparing the spectra of the current which signals obtained in this with the previous ones, we can see that the pulsations of current increased. This result can be explained by a more intensive introduction of the copper atoms in the discharge area. This assumption is confirmed by increasing the copper spectral lines of the emission spectrum.

The results which obtained in an embodiment "hafnium cathode - hafnium anode" are shown on the figure 1*d*. In this embodiment, the oscilloscope was fixed very weak pulsation, hardly distinguishable from the noise signal. In the spectrum of the radiation in the selected wavelength range was registered only the spectral lines of the "footprints" of sodium. In the experiments, a noticeable erosion of hafnium electrodes was not observed. Consequently, the flow of the material of the electrodes in the discharge area was practically absent. Thus, summarizing, we can conclude that the high-frequency current pulsations is occured when intensive inflow of materials of the electrodes in the discharge area.

In a gas discharge with contact to liquid electrolytes the cause of high-frequency current pulsations reason is the flow of droplets of the electrolyte in the interelectrode space.

The spraying of liquid electrolyte is increased with increasing current. However, in such combustion modes the electrolyte is heated and it requires forced cooling. The one method of heat removal from the electrolyte technically is implemented in this research [13]. In figure 2 is showed a photograph of the discharge between the flowing electrolytic cathode and cooled copper anode which produced by using the technical system [13]. The staffs are filmed with a Canon PowerShot S70. It was exhibited exposure equal to 1/2000 s. White lines are indicated the contours of the cathode and anode. Electrolyte was flowed (aqueous salt solution) from a vertical cylindrical passage with an external diameter of 75 mm. Its specific electric conductivity was 2.5 mS/cm. Discharge current $<I>$ = 5.5 A. The interelectrode distance is 5 cm. The voltage between the cathode and anode $<U>$ = 2320 V. In the photo clearly distinguished yellow "bubbles", which is likely to constitute a spherical formations formed as a result of falling droplets of electrolyte in the discharge gap. The green coloring on the photos is indicating on flow of products of erosion of the copper anode to the discharge gap interval.

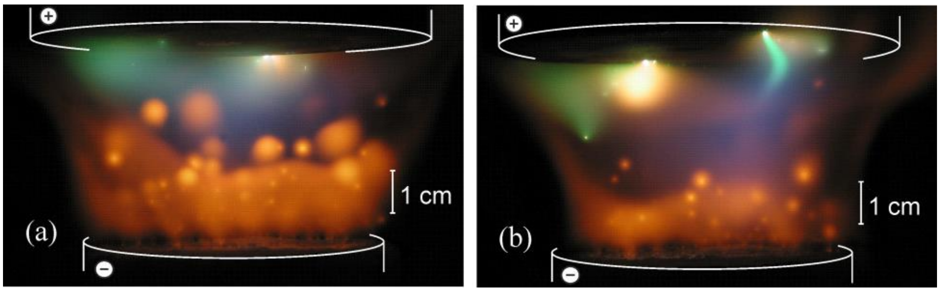

Figure 2. The droplets of electrolyte (yellow "bubbles") in the discharge area: *a* – more; *b* - less.

3. Conclusions

The main cause of high- frequency current pulsations in the electric discharge contacted with the liquid electrolytes is a spray of the electrolyte and flowing droplets to the discharge area. In the result of the rapid thermal decomposition of liquid droplets of electrolyte significant number of ions release which leads to local bursts of carrier concentration of current.

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