УДК 621.373.43:537.523

A.K. SHUAIBOV
Uzhgorod National University, Ukraine
VASYL CHYHIN
National LF Academy named after hetman Petro Sahaydachny, Lviv, Ukraine

PARAMETERS OF HIGH CURRENT NANOSECOND DISCHARGE IN AIR WITH ELECTROLYTIC ELECTRODE

Annotation – *In this work the conditions of the ignition for sustainable nanosecond discharge in atmospheric air pressure with liquid electrode based on zinc chloride solutions and its spatial and electrical characteristics were studied. In the plasma effectively form hydroxyl radicals (OH) that falling in solution and interact with zinc, lead to the synthesis of nanostructures in solution based on zinc oxide. Last are finding now widely used in various nanotechnology.*
Keywords: nanosecond discharge, liquid electrode, spatial and electrical characteristics.

ОЛЕКСАНДР ШУАЇБОВ
Ужгородський національний університет
ВАСИЛЬ ЧИГІНЬ
Національна академія сухопутних військ України ім. гетьмана Петра Сагайдачного, Львів

ПАРАМЕТРИ ВИСОКОСТРУМОВОГО НАНОСЕКУНДНОГО РОЗРЯДУ У ПОВІТРІ З ЕЛЕКТРОЛІТИЧНИМ ЕЛЕКТРОДОМ

В роботі досліджено умови запалювання стійкого наносекундного розряду в повітрі атмосферного тиску з рідинним електродом на основі розчинів хлориду цинку та його просторові та електричні характеристики. При цьому в плазмі ефективно утворюються радикали гідроксилу (ОН), які потрапляючи в розчин і взаємодіючи з цинком, приводять до синтезу в розчині наноструктур на основі оксиду цинку. Останні знаходять тепер широке застосуання в різних нанотехнологіях.
Ключові слова: корона, давач вакууму, числове моделювання, іонізація, прилипання електронів.

1. Introduction

The unique properties of nanomaterials and wide possibilities of their application encourage researchers to seek new methods of synthesis. Among the latter an important place occupies the method based on the ignition of powerful nanosecond discharge in air above the surface of metal salts solution. The advantages of this method include the ability to adjust the parameters of the synthesized particles by variations in discharge mode, very high performance scalable synthesis process, relatively simple design of the reactor and the simple process of preparation of raw materials.

The aim of this work is to study the conditions of the ignition for sustainable nanosecond discharge in atmospheric air pressure with liquid electrode based on zinc chloride solutions and its spatial and electrical characteristics. In the plasma effectively form hydroxyl radicals (OH) [1,2] that falling in solution and interact with zinc, lead to the synthesis of nanostructures in solution based on zinc oxide. Last are finding now widely used in various nanotechnology.

2. Technics and experimental conditions

The discharge in air of atmospheric pressure was investigated in the system of the “blade-surface” electrolyte (Figure 1.) and the system with blades that can be rotated around an axis above the zinc chloride solution in distilled water (Figure 2). The form of the second discharge electrode system is shown in Figure 2. For

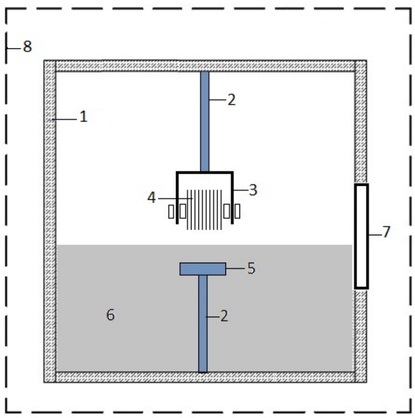

Fig.1 - The structure of discharge cell: 1 – cuvette, 2 - screws for installation of interelectrode distance, 3 - mounting of electrode, 4 - blade system, 5 - metal electrode dipped in water, 6 - distilled water, 7 - quartz window, 8 - metal screen

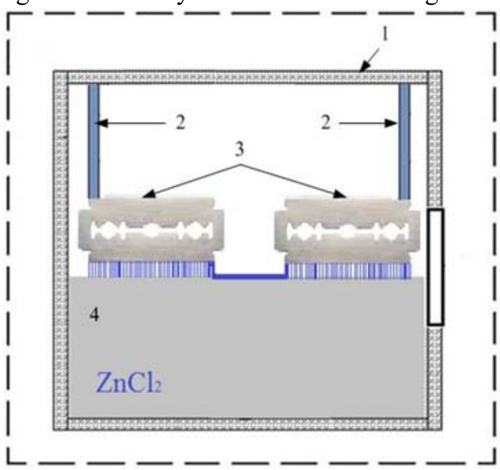

Fig.2 - The structure of discharge cell with rotary electrodes: 1 - cuvette made of organic glass, 2 - regulating electrode screws, 3 – blades, 4 - distilled water or control salt solution of zinc chloride ($ZnCl_2$) in water.

excitation of discharge in this case been used the nanosecond power supply with repetition rate of bipolar voltage pulses 35-1000 Hz and amplitude of positive and negative component voltage pulses of 15-40 kV.

Due to the turning of blades around the mounting axis the distance between them was changed within 5-80 mm. The distance between the blade and the surface of the electrolyte was 5 mm. The level of the working fluid in the cell was maintained constant using drip system.

For registration of the spatial and electrical characteristics of discharge (pictures of plasma pulses of voltage and current) there were used the digital camera, the high frequency capacitive voltage divider or the Rogowski belt and the low inductive shunt and the wideband oscilloscope of 6 LOR type.

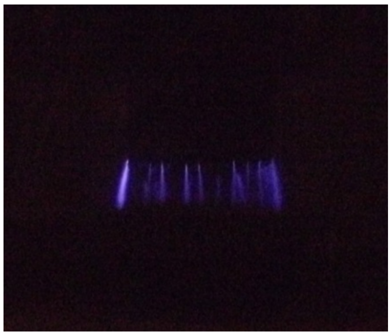

Figure 3 - Photos of the nanosecond discharge with the electrode based on distilled water (view from the end of electrode) at the voltage repetition frequency 40 Hz at the distance between edges of blades and water surface of 7,5 mm and the thickness of water over the solid metal electrode of 4 mm

3. Discharge features

For the system of electrodes of the first electrode type and liquid-based distilled water and solutions with low salt concentration (1.5%) discharge existed in the form of plasma sheet between the edge of each blade and fluid (Figure 3). [3] The optimal interelectrode distance was 7 mm. Uniformity and intensity discharge increased strongly with increasing frequency from 35 to 1000 Hz (Figure 4).

Results of the research of spatial characteristics of nanosecond discharge (with different placement of electrodes, namely interelectrode distance of 3, 10 and 80 mm) above the surface of distilled water and zinc chloride salt solution are shown in Figure 5. At the interelectrode distance of 3 mm the nanosecond discharge between blades in the air gap was realized.

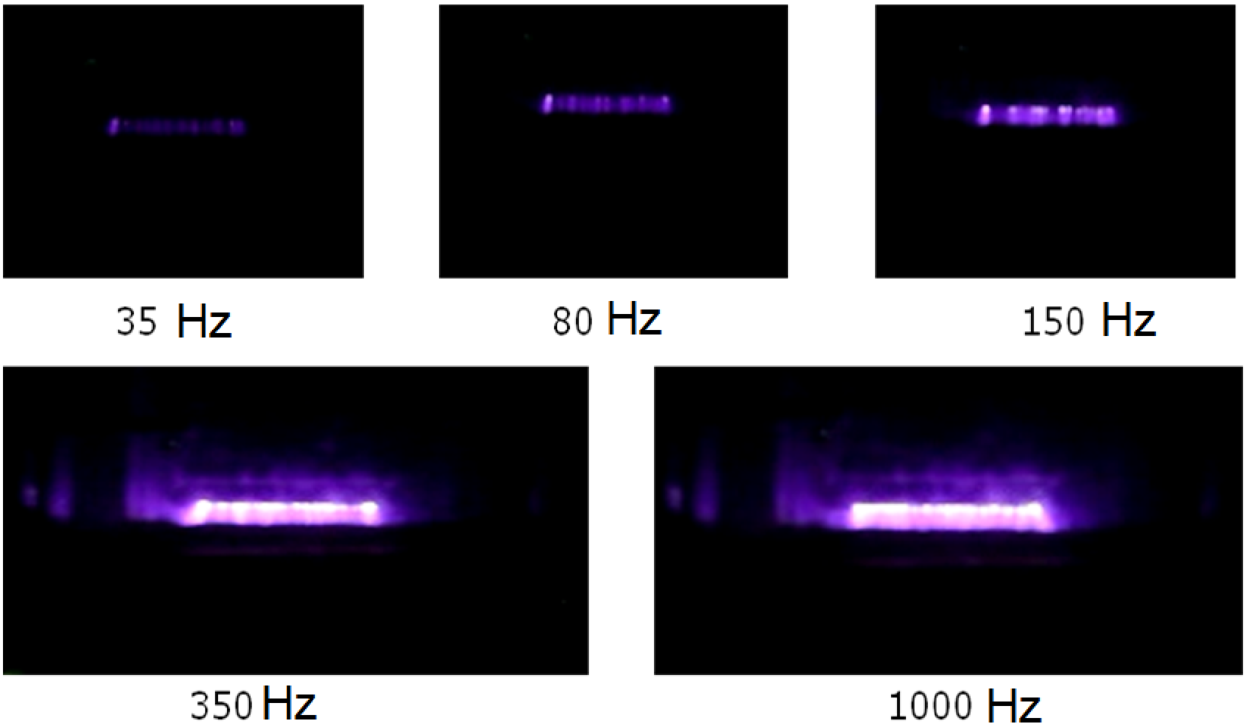

Figure 4 - Photos of the nanosecond discharge with the electrode based on distilled water (view from the side of electrode) at the various voltage repetition frequencies at the distance between edges of blades and water surface of 7,5 mm and the thickness of water over the solid metal electrode of 4 mm

The form of discharges above the distilled water and the salt water solution practically did not differ. At the interelectrode distance of 10 mm the discharge above the distilled water was distributed in the form of sparks on the water, while over the salt solution the sparks did not observed, and the thin streamers have been between the blades and the surface of the solution throughout their length. A similar view has the discharge at the interelectrode distance of 80 mm above the surface as distilled water and above the salt solution.

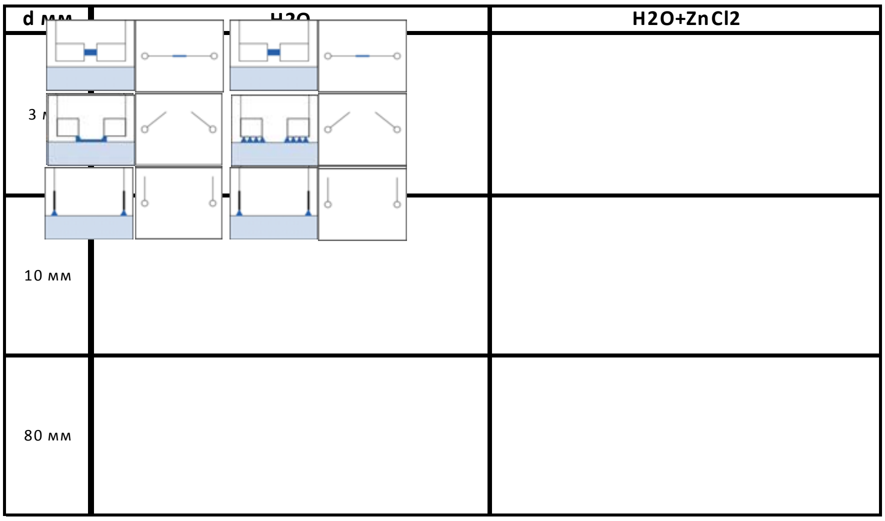

Figure 5 - View of the nanosecond discharge in the "blade-blade" electrode system which is set above the distilled water and control salt solution of zinc chloride in water

The glow of discharge has blue-violet hue and it fills almost the entire gap between the blades and the surface of the liquid. In this case, the passage of electric current was followed by: from blades to the liquid through the subsurface air layer (5 mm), then in the liquid and again in the subsurface layer of air on the blade.

Figure 6 shows oscillograms of the voltage pulses on the discharge gap, the discharge current and the electric power paid in the plasma. The latest graphics obtained through multiplication oscillograms of the voltage and the current. The time integration of the discharge pulse power allowed to determine the energy of one pulse (for conditions of Figure 6 it is 0.102 J). Conditions of Figure 6 were close to optimal for the realization of the maximum plasma power input to achieve maximum speed white sedimentation on the bottom of cuvette electrolyte.

Under optimal conditions of the discharge ignition in the system of electrodes of the second type of the first voltage pulse amplitude was determined by the initial resistance of discharge gap that consists of a layer of air and liquid. Increase of the air layer caused the decrease of the amplitude of current. The beginning of the current pulse began with the decline of first voltage pulse. The presence of the sharp decline in the voltage pulse can be explained by presence of streamers in the discharge.

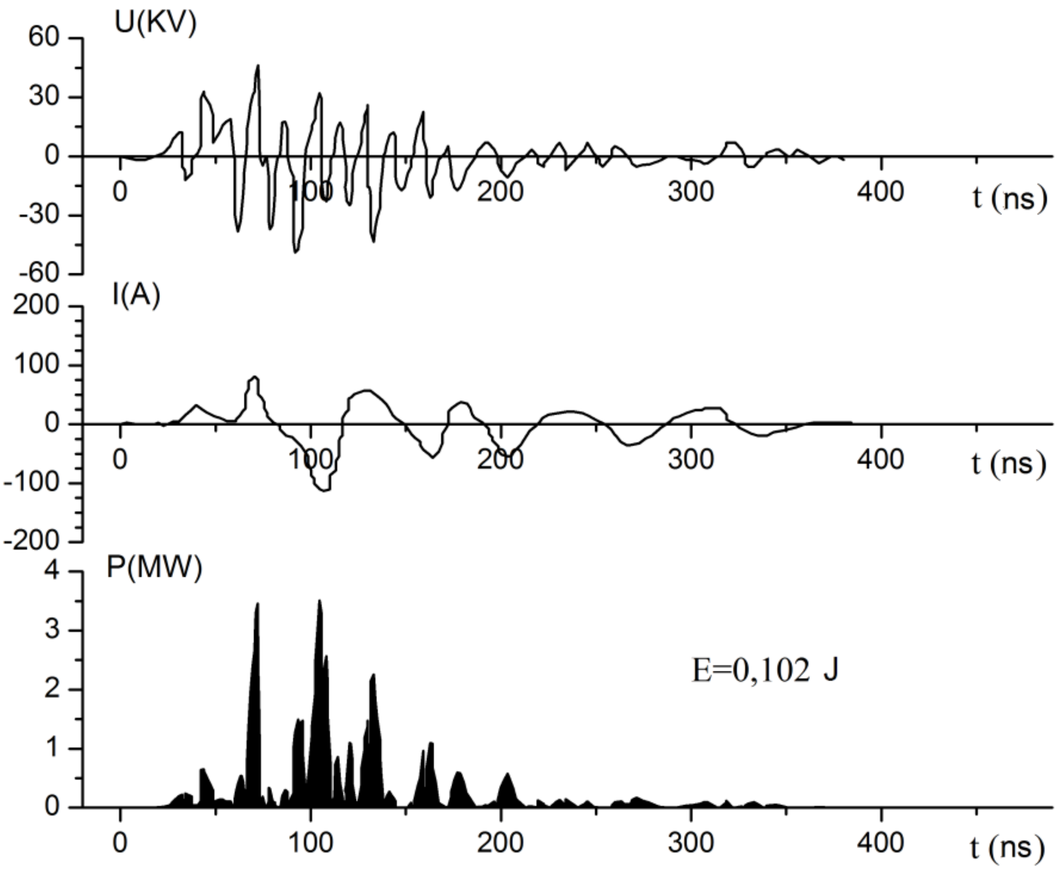

Figure 6 - Temporal dependences of the voltage, current and power of the nanosecond discharge (discharge over the surface of distilled water) at the distance between electrodes of 25 mm.

Analysis of the current and voltage for discharge over the surface of water solution of zinc chloride at the interelectrode distance of 80 mm found that the amplitude current of 170 A, the duration of the first half pulse of about 40 ns and the total duration of about 60 ns formed by the voltage pulse amplitude of 30 kV and provided the peak power of main voltage and current pulses of 4 MW and the energy fee for one pulse reached of 0.13 J.

Analysis of the current oscillograms in the distilled water and the water solution of zinc chloride showed that the current in the discharge above surface of the latter increases, that related to the formation of additional carriers in the electrolyte.

5. Numerical simulation

Information about the parameters of the discharge plasma is usually derived by solving the Boltzmann kinetic equation for the electron energy distribution function (EEDF). Then, from the calculated EEDF, the electron kinetic coefficients (EKC) are determined, which are the transport parameters of plasma electrons, discharge power specific losses due to basic electron processes, and the rate constants of the electron processes as a function of reduced electric field *E*/*P* (*E* is the electric field strength, and *P* is the pressure in the mixture).

Since most widely available programs for solving the Boltzmann kinetic equation and calculating the EEDF and EKCs in the discharge plasma impose limitations on the number of gases in the mixtures, we devised an original program for solving the Boltzmann kinetic equation. Note also that the available databases for the electron process effective cross sections are often incomplete and outdated.

EEDF $f0(\varepsilon)$ in the gas discharge plasma was found by numerically solving the Boltzmann equation in a binomial approximation. For the steady state case, this equation has the form

$$-\frac{1}{3}\left(\frac{E}{N}\right)^2\frac{\partial}{\partial\varepsilon}\left(\frac{\varepsilon}{\sum_i \frac{N_i}{N}Q_{Ti}}\frac{\partial f_0}{\partial\varepsilon}\right)-\frac{\partial}{\partial\varepsilon}\left[2\sum_i\frac{N_i}{N}\frac{m}{M_i}Q_{Ti}\varepsilon^2\left(f_0+T\frac{\partial f_0}{\partial\varepsilon}\right)\right]=S_{eN} \qquad (1)$$

where $S_{eN}=\sum_i\frac{N_i}{N}\left[(\varepsilon+\varepsilon_{thr\,i})Q_i(\varepsilon+\varepsilon_{thr\,i})f_0(\varepsilon+\varepsilon_{thr\,i})-\varepsilon Q_i(\varepsilon)f_0(\varepsilon)\right]-\sum_i\frac{N_{at}}{N}\varepsilon Q_{at\,i}(\varepsilon)f_0(\varepsilon)$ is the collision integral describing electron–atom and electron–molecule inelastic interactions; ε is the electron energy; *T* is the gas temperature; *Ni*, *Mi*, and Q_{ti} are, respectively, the concentrations of atoms and molecules, their masses, and transport scattering effective cross sections; *m* and *e* are, respectively, the mass and charge of an electron; *E* is the electric field strength in the discharge; *N* is the total concentration of particles in the working mixtures under a given pressure of the mixture; *Qi* and $\varepsilon_{thr,i}$ are, respectively, the cross sections and threshold energies of the excitation and ionization of atoms and molecules; Q_{at} is the cross section of attachment of electrons to electronegative molecules; and N_{at} is the concentration of electronegative molecules.

Equation (1) was solved by replacing derivatives by finite differences and using the sweep method for complicated systems [4]. The calculations were carried out with our original dedicated program. Checking calculations were conducted using the BOLSIG program package [5]. The range of reduced electric field *E*/*P* covered all values used in the experimental system. When solving the Boltzmann kinetic equation, we took into consideration such processes as elastic scattering of electrons, dissociative attachment, excitation and ionization of molecule.

The EEDF calculated by us are in good agreement with those obtained using the BOLSIG program package, which is commonly used in the physics of gas discharge. With an increase in *E*/*P*, the fast electrons of the discharge gained more energy and the density of slow electrons decreased considerably. The energy of most plasma electrons ranged from 1 to 10 eV. BOLSIG program package, our database included the effective cross sections of electron impact step ionization of gases.

Conclusions

Thus both systems of the electrodes allow to get above the surface of the distilled water and the solutions of zinc chloride spatially homogeneous discharges into the air of atmospheric pressure without preliminary ionization that is important for the development of simple and effective plasma-chemical reactor for the synthesis of colloidal solutions of nanostructures of zinc oxide in macroscopic quantities.

References

1. Pokryvailo A., Wolf M., Jankelevich J. High–power pulsed corona for treatment of pollutans in heterogenous melia // IEEE transactions plasma science. – 2006. – V.34. – № 5. – Pp. 1731–1743.
2. Bozhko I.V., Falkovsky N.I. Corona discharge on surface of conductive liquids and its use for water treatment // Tehnichna elektrodinamika. 2007. № 2. p. 9-14.
3. Shuaibov A.K. Shevera I.V., Kozak Ya.,Yu., Kentesh G.V. Features of nanosecond discharge in air at atmospheric pressure with a liquid electrolytic electrode // ZhTF. 2014. V.84/6. p.143-146.
4. Samarskiy, E. Nikolaev. Methods for solving of grid equations. M . Nauka, 1978. 592 c.
5. http://www.siglo-kinema.com.

Рецензія/Peer review : 6.9.2016 р. Надрукована/Printed : 8.11.2016 р.
Стаття рецензована редакційною колегією