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RESEARCH ON INCREASING THE CAPACITY OF THERMAL ELECTRON EMISSION OF METAL SURFACES BY ELECTROEROSIVE METHOD

Program: 242.05 Technologies, processes and processing equipment

Summary of the Doctoral Thesis in Engineering Sciences

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The thesis in Engineering Sciences was developed within the Department of Physical and Engineering Sciences, of *Alecu Russo* Balti State University.

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The doctoral thesis and the abstract can be consulted at the Library of the Technical University of Moldova and on the ANACEC website (www.anacec.md).

The abstract was sent on 17 February 2024.

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CONCEPTUAL FRAMEWORK OF THE RESEARCH

The title of the doctoral thesis contains the keywords: ***thermo-electronic emission*** and ***electro-erosion***. The first keyword leads us to the correct choice of the material necessary for the elaboration of thermo-cathodes intended for thermo-electronic emission, which are used in various fields such as: construction of machines and devices, dimensional processing with the use of the electron beam [1], in various experimental research with the application of microscopes scanning electronics, energy dispersive X-ray spectroscopy [2] and in medical imaging with X-rays produced in Roentgen tubes [3]. The second keyword "electro-erosion", also found in the literature as "electrical erosion" (EE), tells us about the application of an unconventional processing technology [1, 4], used for the dimensional processing of hard and very hard materials or of those that cannot be processed by conventional methods, the formation of deposits from compact materials and powders. In the last period [5-7] it was demonstrated the possibility of this method to synthesize on metal surfaces of oxide and hydro-oxide films under normal conditions, of carbon films [8, 9] containing fullerenes and carbon nanotubes and modification of the micro-geometry of metal surfaces [10-13]. Conical asperities have been observed both in the center of erosion craters and at their peripheries [10, 14-16]. In the works [13, 17] these conical asperities were called *ectons* and it is emphasized that they are important sources of ions and electrons, which could beneficially influence the phenomenon of electronic emission. The process of changing the microgeometry of the surfaces of metal parts consists in the fact that following electric impulse discharges (EID), under certain conditions, the formation of conical asperities called Taylor cones in the specialized literature, with the size of the angle, are formed on the surface of these parts from the peak equal to 90^o, but which can vary by $\pm 1 – 2^o$, according to the results obtained by the authors [14, 18, 19]. The effect of increasing the active surface area of the part processed by EID, under established conditions, contributes to changing the nature of its interaction with the surrounding environment and with other active surfaces with which it is brought into contact. Increasing the active surface area directly influences their ability to emit electrons and ions [20 – 23] and at the same time to absorb different types of radiation [32], moreover, these conical asperities also function as field concentrators electrically, facilitating the electronic emission effect. The specificity of changing the microgeometry of the surfaces is based on the extraction of conical shaped asperities with determined dimensions. The extraction conditions of conical asperities in general and the accompanying phenomena in particular remain poorly elucidated. In the paper, the conditions for extracting asperities in the form of Taylor cones from metallic surfaces under the action of EID are investigated. It is confirmed that due to the presence of strong electric fields (greater than 10^8 V/m) generated by the presence of "anodic" and "cathodic" spots, ("hot" and "cold"), as well as the forces of gravity and surface tension on surface of the liquid metal, disturbances develop and capillary waves propagate [10, 24], which lead to the formation of conical asperities. Directed modification of the microgeometry of metal surfaces in general and of thermo-cathodes in particular with the application of EID under normal conditions, is carried out in order to increase the operating efficiency of simple thermo-cathodes.

The actuality and importance of the topic addressed, the framing of the topic in the international, national, zonal concerns of the research group and in an inter- and transdisciplinary context, the presentation of the results of previous research related to the chosen topic. The research topic is connected to the National Research-Development Program, the priority: "Economic competitiveness and innovative technologies", the strategic direction: "Innovative materials, technologies and products" and to the trends of world science, because the research carried out presents new functional properties of the analyzed materials. The further development of contemporary technique and technologies also contributes to reducing the shortage of materials for the fields of electronic technique, because its requirements and needs are always increasing, and the technical-technological possibilities are limited [25]. Reducing the consumption of materials for the execution of cathodes and the amount of energy needed to ensure their functionality at the necessary technological parameters. The modification of the microgeometry of the surfaces leads to the considerable increase of the active surface area of the thermo-cathodes applied in the construction of electronic tubes, electronic microscopes, industrial facilities for processing materials with the application of the electron beam, etc., and ensures a considerable increase in the intensity of the emission electric current in their operation process, using cathodes with much smaller dimensions and functioning at the same parameters with the reduction of the energy required for their heating. The experimental installation for the research and modification of the microgeometry of metal surfaces by the electro-erosion method presents an electric current impulse generator of the RC type with parallel priming of the interstice as an energy source and the positioning, gripping and fixing device made on the basis of the biological microscope.

The aim of the paper consists in establishing the laws and technological factors for achieving the prescribed geometry of the metal surfaces in order to increase the thermo-emission efficiency of the cathodes based on the updated physical model of the electro-erosion phenomenon.

Research objectives: analysis of specialized literature regarding the research problem; establishing the technological parameters for extracting asperities in the form of a Taylor cone from the surfaces of metal samples and systematizing the results obtained; experimental research of thermo-electronic emission in the absence and presence of Taylor cone asperities on the surfaces of thermo-cathodes; recommending solutions to improve the functional properties of cathodes used in electronics. Samples made of tungsten and its alloys with rhenium served as **the object of the research**, both to establish the conditions for the extraction of Taylor cone asperities, as well as their influence on the thermo-electronic emission capacity, processed by the electro-erosion method.

Research hypothesis: the formation of Taylor cone asperities on metal surfaces occurs under the action of the electric and temperature fields generated by the electrode spots, and their presence on the active surfaces of the parts contributes to increasing the active area and, respectively, to improving the operating performance of the thermo-cathode.

Synthesis of research methodology and justification of chosen research methods. In order to carry out the actual research, the following research methods were justified and applied: the “Razread” (*discharge*) type laboratory facility for researching the phenomena of extraction of conical asperities; oscilloscopy, for determining the duration and energy of electrical impulse discharges; express optical microscopy, for studying surfaces after interaction with EID plasma; electron microscopy (SEM), for precision measurements of the shape and dimensions of asperities; EDX analyses, to determine the chemical composition; XPS analyses, to determine the phases obtained in the processed surfaces; direct electronic thermo-emission tests of cathodes processed in vacuum; mathematical modeling of phenomena and processes; establishing the laws of obtaining asperities and their influence on electronic thermo-emission.

The experimental research carried out here includes the following and was supported by the assistance of several scientific centers:

- the modification of the microgeometry of the surfaces of the metal samples were completely carried out in the Scientific Laboratory of Micro- and Nanotechnologies (LSMNT), from the Department of Physical Sciences and Engineering (CSFI), Faculty of Exact, Economic and Environmental Sciences (FSREM), *Alecu Russo* State University of Balti (USARB);
- SEM and EDX analysis of the metal surfaces of the researched thermo-cathodes was carried out in 1) University research laboratories: Christian-Albrecht University (CAU), Kiel town, Germany and 2) National Center for the Study and Testing of Materials (CNSTM), of the Technical University of Moldova (UTM), building 3, office 324, Chisinau city, Republic of Moldova;
- the thermo-electronic emission of the investigated cathodes was carried out within: 1) USARB laboratories and 2) in *Horia Hulubei* National Research-Development Institute for Physics and Nuclear Engineering (IFIN-HH) in Bucharest-Magurele, Romania.

Scientific novelty and innovation consist in the increase of the electronic emission efficiency of simple thermo-cathodes made of technical purity tungsten or rhenium tungsten alloys based on the modification of the micro geometry of the surfaces, i.e. by extracting Taylor cone-type conical asperities from the cathode surfaces by the EE method. The conical asperities thus obtained increase the active surface area of the cathodes and serve as concentrators of strong electric fields. Tapered asperities are good sources of electrons. A scientific novelty of the thesis is the possibility of obtaining nano asperities on the surface as well as the application of the deoxidation of asperities, by applying EID with an electrode made of pyrolytic graphite.

Important scientific problem solved: directed modification of the microgeometry of the metal surfaces, in order to increase the operating efficiency of simple thermo-cathodes.

The **theoretical significance** is ensured by the establishment of the laws of formation of asperities under the action of EID; the development of the theory regarding the modification of the microgeometry of the surfaces and the multiplication of the electron emission of the cathodes; establishing the operation legalities of the cathodes with the modified microgeometry of the active surface.

The **applicative value** consists in the identification of the basic parameters regarding the extraction of conical menisci on metal surfaces with the application of EID (the energy and duration of the discharge pulse, the size of the interstice and the properties of the execution material of the sample subjected to processing).

The obtained results that contribute to the solution of an important scientific problem: the definition of the physical picture of the phenomena that occur during electric discharges and their influence on the physical and compositional transformations of the electrode surfaces and the determination of the multiplication coefficient of the electronic emission by the cathode surfaces based on physical phenomenology and structural transformations caused by EID.

Implementation of scientific results: laboratory works were carried out in cycle II, within the Department of Physical and Engineering Sciences, Faculty of Exact, Economic and Environmental Sciences, of *Alecu Russo* State University of Balti.

Approval of scientific results. The obtained scientific results were presented at national and international conferences, scientific colloquiums and symposia: Advanced Manufacturing Technologies 2013, 26-30 June, Sozopol, Bulgaria; Bachelor and Master Students' Conference within *Alecu Russo* Balti State University, Balti, 2014; International Scientific Conference Light and Photonics: Science and Technology dedicated to International Year of Light and Light-based Technologies-2015, *Alecu Russo* Balti State University; International Conference of Nonconventional Technologies, UTM 30th of June – 1st of July, Chisinau. 2016; 22nd International Exhibition of Inventics "INVENTICA 2018", Iasi, Romania. 2018; Doctoral School Conference, TUIASI, 23-24 May, Iasi, Romania. 2018; ModTech 2014, 2015, 2016, 2017, 2018, 2020, 2021, International Conference "Modern Technologies in Industrial Engineering"; 11th International Conference of the Balkan Physical Union "BPU11 CONGRESS", 28.08.2022, etc.

Publications on the thesis topic: 62 papers were published on the research side, including: 1 chapter in an international monograph, 2 reports of research projects, 6 articles in journals from the Web of Science and SCOPUS databases, 3 articles in journals with an impact factor, 2 articles in category C journals, 15 articles in the materials of national and international conferences (national and international), 2 articles in non-accredited journals, 34 theses of scientific reports at conferences (national and international). Articles by a single author – 3.

Thesis structure: introduction, four chapters, general conclusions and recommendations, bibliography of 166 titles, 149 pages of core text (up to Bibliography), 81 figures, 19 tables and 9 appendices.

Keywords: erosion, impulse, gap, microgeometry, electrode, cathode, vacuum, emission.

1. BIBLIOGRAPHIC STUDY OF TECHNICAL-SCIENTIFIC ACHIEVEMENTS IN THE FIELD OF THE RESEARCH PROBLEM

Two types of thermo-electrodes are used in the world: simple and compound, the simple ones are characterized by the high degree of stability of the electronic emission, and the compound ones by the increased efficiency. From the point of view of production, simple thermo-cathodes are easier to make, and compound ones require a much more complex technological process. Resulting from the purpose of the work, but also from the real technical possibilities of the laboratory where the experimental research was carried out, it was decided to try to improve the thermo-electronic emission characteristics, namely of simple thermo-cathodes, by applying the procedure of modifying the microgeometry of their metallic surfaces. The paper highlighted the fact that all electrically conductive materials can be processed by the EE method.

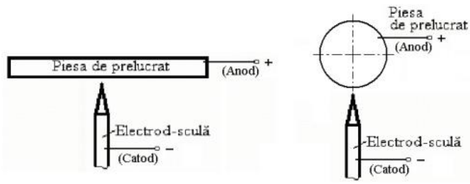
The current stage of research on the electro-erosion process. A retrospective of the electrical erosion phenomenon is made, highlighting the fact that the application of new research equipment has allowed to come up with new findings and developments in the theory and practice of EE. Thus, according to [10, 24] the development of the plasma channel on the electrode spots, generators of high temperature fields and electric fields with intensities reaching or exceeding the value of 10^8 V/m, leads to the melting and disturbance of the surfaces with the development of capillary waves [10, 14, 16, 18, 19, 21, 22], extraction of austerities on electrode surfaces.

Based on the new physical model of the EE phenomenon, the possibility of extracting Taylor-type conical asperities from metal surfaces was demonstrated, but the legitimacy and technological factors for achieving the prescribed geometry were not established.

From the **analysis of the specialized literature on thermo-electronic emission** [13, 15, 26], it is established that the emission power is directly proportional to the area of the active emission surface (i.e., $P_E \sim \Delta A$), and in the construction and operation of thermo-emission cathodes, different constructive forms are applied, but the functionality of cathodes with conical asperities formed is not studied and analyzed by applying the EID, as a simple and easily achievable one.

2. EXPERIMENTAL RESEARCH METHODOLOGY

The strategy of experimental research, regarding the modification of the microgeometry of metallic surfaces. Experimental research, regarding the increase of the active area through the formation of conical menisci, was carried out in air (normal conditions) and inert gas (argon), at room temperature, with single and multiple discharges [27, 28]. As a material for the execution of the working element of thermo-cathodes intended for thermo-electronic emission [13, 15, 29], wires made of tungsten or its alloys were used, e.g.: W (90%) with Re (10%) or W (80%) with Re (20%). For experimental research, regarding the extraction and solidification of asperities in the form of Taylor cones on the cylindrical surface with the application of EID [15, 30], the pair of electrodes was used: the electrode-part and the electrode-tool made of the same material (tungsten wire) of the shape cylindrical bar. The execution of the sample and the tool-electrode of the same material (W–W, W+Re–W+Re) was imposed by two conditions: the exclusion of the change of the chemical and phase composition of the sample surface with a different material due to the phenomena of material sampling and transfer and ensuring the erosion resistance of the tool-electrode [29, 31]. The electrodes were clamped into the positioning elements of the fixation device, then the electrodes were manually brought closer to each other until they came into contact, and then the gap size was selected. In fig. 2.1 are shown the positioning schemes of the electrodes used in the process of experimental research and their connection in the discharge circuit of the pulse generator.



a) **b)**

Fig. 2.1. Schemes of positioning the electrodes used in the process of experimental research and their connection in the discharge circuit of the power pulse generator: a) flat sample case; b) cylindric sample case

For safety, in the process of measurements the electrodes were connected to a current indicator and brought into contact in a short-circuit state. The measurement starts from the moment the circuit is interrupted, i.e., from the “zero” position of the current indicator. The current pulse generator [14] of the RC type with parallel priming is composed of the priming block and the power block. The measurements of the energy parameters of the current pulses were carried out by oscilloscopy according to the scheme and methodology [14]. Electron microscopy (SEM) was applied to study the surface morphology and chemical composition of the elaborated thermo-cathodes. Energy dispersive X-ray spectroscopy (EDX) was applied to determine the composition of the material of the cathodes and the surfaces with conical asperities after processing.

Experimental research methodology regarding thermo-electronic emission. In order to determine the influence of the increase in the active surface area of the cathode on the thermo-electronic emission under express conditions, in the Scientific Laboratory of Micro- and Nanotechnologies, unprocessed thermo-cathodes were used, without the modification of the microgeometry by the application of EID, and processed thermo-electrodes, with the surface modified by the application of EID, with the formation of conical menisci. In order to determine the electric current of the thermos-electronic emission in express conditions, the special installation of the “ВУП-5” type was used. In fig. 2.2, the basic electrical diagram is presented with the help of which the volt-ampere characteristics were determined during the experimental research. In the working room, a depression of approx. 10^{-3}– 10^{-4} mbar was reached. The potential difference at the terminals of the thermo-cathode and the intensity of the electric current passing through it were measured with voltmeter V1 and ammeter A1, respectively. The potential difference between the anode and the cathode was measured with a voltmeter V2, and the intensity of the thermo-emission current was determined with a microammeter. In order to increase the accuracy of measuring the electronic thermo-emission current, an experimental stand was applied consisting of: the thermo-cathode power source, multimeter (model “FLUKE 902”) used to measure the temperature of the cathode, the high voltage source, multimeter (model “FLUKE 289”) used to measure the intensity of the emission current, vacuum meter (model “adixen ACC, 2009”), turbomolecular pump (component of the vacuuming installation, used to obtain a high degree of vacuuming, 10^{-5} – 10^{-6} mbar).

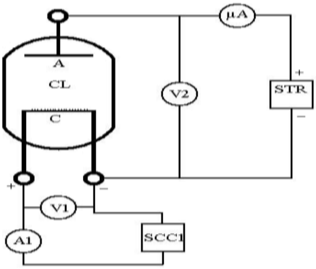


Fig. 2.2. The main electrical diagram for determining the volt-ampere characteristics: CL – working chamber; V1 – voltmeter; A1 – ammeter; SCC1 – direct current source; V2 – voltmeter; μA – microammeter; STR – adjustable voltage source (0 – 1050 V); A – stainless steel anode; C – linear cylindrical thermo-cathode

Determination of the surface area of the menisci, obtained with the EID application. According to the experimental measurements, a database composed of measurements of several conical asperities, namely the base diameter, meniscus heights, crater diameter, apex angle, transversal and longitudinal wavelengths of capillary waves, was formed, being entered into application “Solid Works”.

3. EXPERIMENTAL RESEARCH ON THE MODIFICATION OF THE MICROGEOMETRY OF THE ACTIVE SURFACES OF THE ELECTRODES

Establishing the influence of processing parameters on the geometry of menisci extracted from the surfaces of metal samples. According to the methodology [10, 15], asperities in the form of a Taylor cone (fig. 3.1) were extracted from the metallic surfaces from the cylindrical surfaces of the samples.

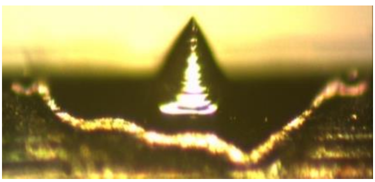


Fig. 3.1. General view of the Taylor cone extracted by the EID method (height ≈ 60 μm and the diameter of the base of this meniscus is of the order of 80 μm)

The workpiece (sample) was connected in the discharge circuit as the anode and the tool electrode as the cathode. Energy parameters of the electrical impulse discharge: Ws = 0.86 J (energy released in the gap), S = 0.3 mm (the size of the gap), n = 1 (the number of electrical impulse discharges per unit area). As a result, a conical asperity shown in fig. 3.1. was extracted from the surface of the sample.

The influence of the energy released in the interstice on the diameter of the base and the height of the menisci. In the process of experimental research, the influence of the energy released in the interstice on the formation of menisci on the surface of the anode, when it was in the upper position in the discharge circuit, was analyzed. The parts were made of tungsten alloy of technical purity and its alloys, such as W + 10% Re and W + 20% Re. To vary the energy released in the gap, the capacity of the capacitor banks is changed in steps starting from the minimum value of 100μF to the maximum value of 600μF. The experiments were repeated several times, with the aim of ensuring more accurate results.

It was observed that for the alloy W + 10% Re, with the increase of the energy on the capacitor bank from 0.072 J to 0.432 J, the height of the menisci varies from 51μm to 123μm, and for parts made of W of a technical purity, their height varies from 29μm to 71μm. Using the oscilloscope method, the values of the current in the pulse and the duration of the pulse were determined for all the values of the capacities of the capacitor batteries (table 3.1 and table 3.2).

Table 3.1. Meniscus base diameter and height as a function of interstitial energy and discharge pulse duration for the alloy W + 10% Re

Nr.	S, mm	C, μF	U_c, V	I_m, A	W_s, J	τ, μs	h_m, μm	$d_{b.m.}$, μm
1.	0,25	100	60	94	0,072	100	51	83
2.		200	60	125	0,144	125	72	89
3.		300	60	151	0,216	160	86	110
4.		400	60	163	0,288	180	97	139
5.		500	60	172	0,36	200	109	170
6.		600	60	177	0,432	220	123	195

Table 3.2. The diameter of the meniscus base and its height as a function of the energy released in the interstice and the duration of the discharge pulse for W

Nr.	S, mm	C, μF	U_c, V	I_m, A	W_s, J	τ, μs	h_m, μm	$d_{b.m.}$, μm
1.	0,2	100	60	100	0,072	100	29	55
2.		200	60	144	0,144	125	34	83
3.		300	60	168	0,216	160	41	110
4.		400	60	180	0,288	180	55	134
5.		500	60	186	0,36	200	64	161
6.		600	60	204	0,432	220	71	179

In the process of electrical impulse discharges, the sampling of material takes place from the surface of the tips of the Taylor cones in the form of separate particles, or in the form of elementary particles due to the electric field, but not only under the action of the depression formed in the gas bubble. To compare the experimental results with the theoretical ones, the dependences of the height of the menisci as a function of the energy released in the interstice were constructed. In fig. 3.2, the dependences of the menisci height depending on the energy accumulated on the capacitor battery (discharge pulse duration) are presented for different values of the charge voltage of the capacitor battery, respectively, for different values of the energy released in the gap.

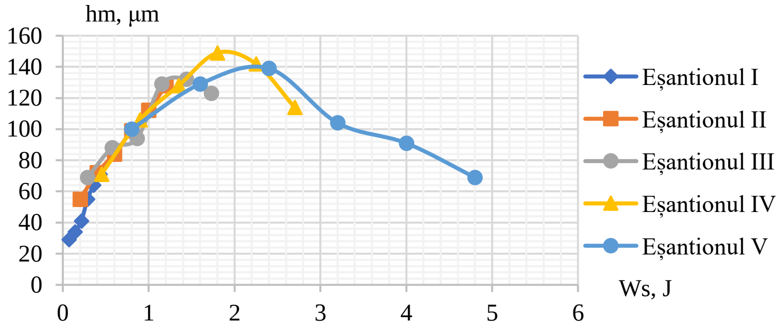


Fig. 3.2. The dependence of the height of the menisci according to the energy released in the interstice.

The influence of the duration of the current pulse on the height of the menisci. It is necessary to mention, that the duration of the discharge pulse influences not only the height of the menisci, but also the dimensions of the diameters of their bases. As the duration of the discharge pulse increases, the diameters of the menisci base increase. In the case when the duration of the discharge pulse is a constant value, and the energy accumulated on the capacitor bank varies increasing, the same phenomenon is observed (fig. 3.3).

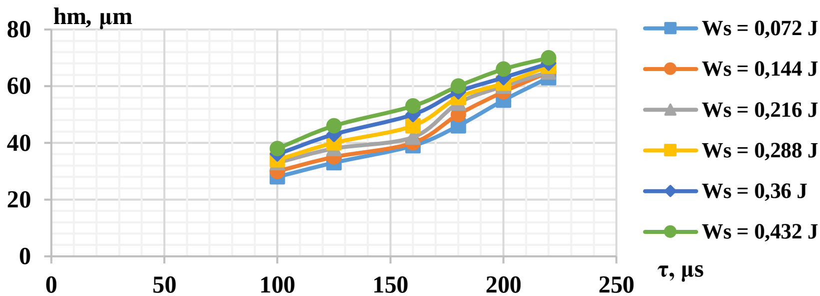


Fig. 3.3. Dependence of the height of the menisci as a function of the duration of the discharge pulse

To obtain the mathematical relationships, regarding the formation of conical asperities, the duration of the discharge pulse, which varied from 100 to 220 µs, the size of the interstice between 0.1 and 0.4 mm and the energy released in the interstice, which varied in limits of 0.072 to 4.8 J. The heights and diameters of the conical asperities obtained on the surfaces of the metal parts made of W or tungsten alloys with rhenium (10 and 20%) were measured.

Analyzing experimental data with reference to the obtaining of conical asperities and the equations obtained through mathematical modeling for the average values of the optimal processing intervals, for the height of the conical asperities, h_m and the diameters of their bases, dm, the following mathematical relations were obtained:

- for samples made of wires with diameters equal to 0.2 and 0.25 mm of tungsten of technical purity:

$$h_m = 0{,}77 \cdot W_S^{0{,}56} \cdot \tau^{0{,}88} \cdot S^{-0{,}34} \quad (3.1)$$

$$d_m = 2{,}08 \cdot W_S^{0{,}46} \cdot \tau^{0{,}85} \cdot S^{-0{,}34} \quad (3.2)$$

- for samples made of wires with diameters equal to 0.2 and 0.25 mm from the alloy of tungsten with rhenium 10%:

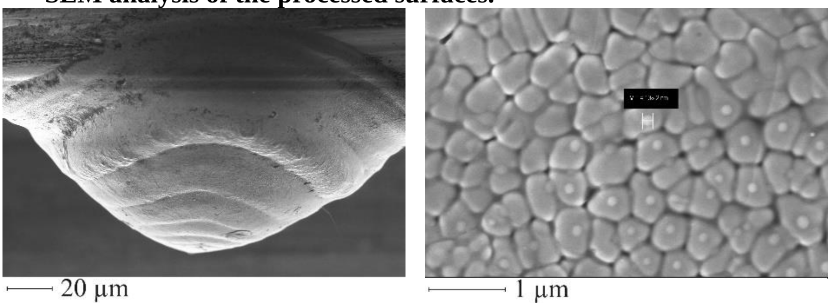
$$h_m = 0{,}66 \cdot W_S^{0{,}51} \cdot \tau^{0{,}88} \cdot S^{-0{,}34} \quad (3.3)$$

$$d_m = 1{,}32 \cdot W_S^{0{,}35} \cdot \tau^{0{,}85} \cdot S^{-0{,}34} \quad (3.4)$$

where: h_m – the height of the conical asperities (µm); d_m - the diameters of the bases of the conical asperities (µm); W_s – the energy released in the interstice (J); τ – the duration of the discharge impulse (µs); S – the size of the interstice (mm).

Relations (3.3) and (3.4) are also valid for parts made of tungsten alloy wires with 20% rhenium, with diameters equal to 0.2 and 0.25 mm. From the last two systems of relations, we can establish that the size of the interstice S and the duration of the impulse influence almost in the same way the height, h_m and the diameter, d_m regardless of the composition of the material of the pieces. If we refer to the energy released in the interstice and the proportionality coefficient from these relations, we will find that they are much higher for the parts made of tungsten than for the alloys of tungsten with rhenium, a fact that can be explained by the high melting temperature of it in relation to the tungsten-rhenium alloy.

SEM analysis of the processed surfaces.



a) b)

Fig. 3.4. The lateral surface of the asperity [15]: a) presence of concentric waves; b) the presence of mosaic blocks on the lateral surface of the conical asperity

More accurate information about the dimensions and morphology of Taylor cone asperities can be obtained by performing SEM analysis. In most cases, the sizes of Taylor cone asperities depend on the energy parameters. The application of contemporary research equipment (SEM) made it possible to establish that the lateral surface of the formed asperities is complicated and presents micro- and nanometric undulations (see fig. 3.4). These undulations are possibly caused by the variation of current in the electrical discharge. In the works published by the authors [16, 32], it was stated that EID is multichannel, some discharge channels “die” and others are “born”, which is why the current of the solitary electrical discharge has a pulsating character. These undulations are possibly caused by the variation of current in the electrical discharge.

Previously, it was already demonstrated that EID is a multichannel one. Some discharge channels die, and others are born, due to which the current of the solitary electric discharge has a pulsating character. This hypothesis is experimentally confirmed by the authors of the works [33-35]. From what it is presented in fig. 3.5, we observe that during a single discharge there are variations of both the voltage pulse and the current impulse.

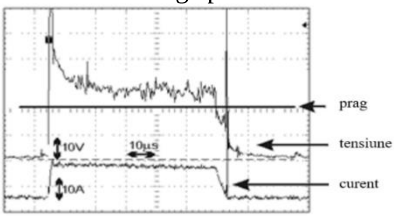


Fig. 3.5. The pulsating character of the solitary electric discharge [36]

The variation of the intensity of the electric current in a single pulse is multiple, which can explain the formation of several channels and the extraction of several conical asperities during it. The development of the menisci, their orientation, as well as their dimensions for the case of a solitary discharge, directly indicate the fact that they cannot appear due to depressions in the plasma channel but are caused by the action of the electric field along the vector ray from the electrode spot to the processed surface of the sample.

The results regarding the chemical composition analysis (EDX) of the processed surfaces. Depending on the working environment in the interstice, phases containing oxygen, nitrogen, hydrogen, and carbon can be synthesized on the surface of the asperities, which in turn modify the functional properties of the cathodes applied to electronic thermo-emission (see fig. 3.6). For EDX analyses, 4 points were chosen to be measured: the tip of the conical asperity, at the base of the asperity, in the area near the asperity and in an area that was not influenced by EID effects. The obtained results will allow us to understand what changes occurred in the base material of the tool-electrode following electrical impulse discharges, namely, to know what chemical composition is in the material from which the sample is formed and already the conical meniscus itself. From the data presented in tables 3.3 – 3.6, we will find that the largest amount of oxygen dissolves in the material of the piece at the base of the meniscus and at the edge of the crater, where the favorable conditions for this are met (plasma action throughout the duration of the impulse, temperature at the periphery of the plasma channel is lower, the diffusion processes take place in the liquid state of the sample material), while at the tip of the conical asperity the amount of dissolved oxygen is lower (intensive vaporization processes take place in it, and the solidification of the molten metal takes place with speeds of the order of 10^6 m/s).

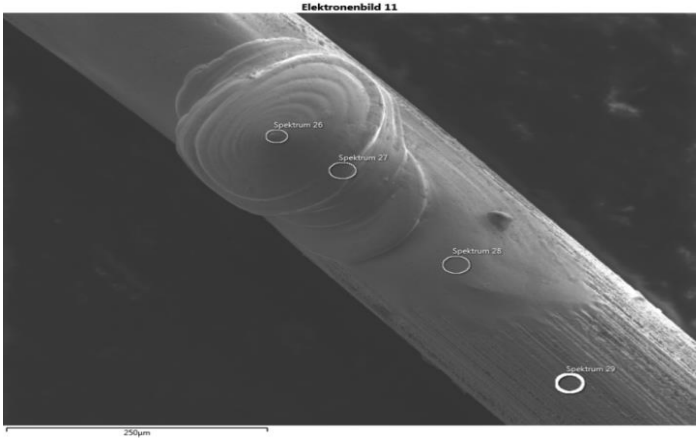


Fig. 3.6. EDX analysis performed in four different areas of the sample- electrode

The chemical content of the different areas of the processed sample determined by EDX analysis is presented in the tables below.

Table 3.3. Chemical content in the center of the conical meniscus (p. 26 of fig. 3.6)

Elements detected	Line type	Apparent concentration	k- ratio	Mass, %	Mass, % (Sigma)	Implicit name
O	Series K	21.73	0.07313	9.33	0.32	SiO2
W	Series M	278.51	2.78511	85.07	0.57	W
Re	Series M	16.00	0.15995	5.59	0.53	Re
Total:				**100**		

Table 3.4. The chemical content at the base of the conical meniscus (p. 27 of fig. 3.6)

Elements detected	Line type	Apparent concentration	k- ratio	Mass, %	Mass, % (Sigma)	Implicit name
O	Series K	9.95	0.03347	12.12	0.38	SiO2
W	Series M	87.02	0.87023	78.02	0.62	W
Re	Series M	9.72	0.09724	9.85	0.59	Re
Total:				**100**		

Table 3.5. The chemical content of the tungsten cathode material in the crater area (p. 28 of Fig. 3.6)

Items detected	Line Type	Apparent concentrat ion	k-ratio	Mass, %	Mass, % (Sigma)	Implicit name
O	Series K	34.68	0.11670	11.66	0.33	SiO2
W	Series M	325.68	3.25685	80.09	0.54	W
Re	Series M	29.56	0.29555	8.24	0.51	Re
Total:				**100**		

Table 3.6. The chemical content of the sample material (p. 29 of Fig. 3.6)

Items detected	Line Type	Apparent concentrat ion	k- ratio	Mass, %	Mass, % (Sigma)	Implicit name
O	Series K	28.05	0.09440	12.41	0.35	SiO2
Ca	Series K	1.78	0.01590	0.59	0.08	Wollastonite
W	Series M	259.02	2.59018	83.94	0.57	W
Re	Series M	8.26	0.08262	3.06	0.53	Re
Total:				**100**		

Additions to the physical model of EE with EID action. If we go back to the physical model presented in Chapter 1, then it could be supplemented with the following: conductivity channels are “born” and “die” and they, in turn, can cause multiple asperities to be extracted in a solitary discharge; under certain conditions in the asperities, thanks to the scintillations of the discharge current, transverse capillary waves are “born” that cause the droplets to break off from the tip of the asperity; the ions from the plasmogenic gas bombard the surfaces of the electrodes causing erosive effects or the formation in their layers of chemical compounds such as oxides, hydro-oxides and nitrides (in air conditions), carbides (in an acetylene, propane, butane or liquid diesel medium , lamp gas, oil, etc.); at the end of the solitary discharge with the reduction of the current intensity, there are processes of division of the electrode spots, up to the cold ones, which cause the extraction of nano asperities from the surface of the new grains formed on the surface by the solidification of the crater; in the case of repeating solitary discharges, the asperities extracted from the surfaces increase in height and decrease in diameter until merging. If we take into account the experimentally attested and the results obtained by the authors of the works [11, 13, 15], in which it is mentioned that on the surface of the crystallization grains of the liquid phase resulting after the interaction of the EID plasma with the surface of the metal asperities of nanometers. I think, that in this case we would be justified to support the hypothesis, that EID is “born” on “cold” electrode spots - which are the support for elementary conductivity channels, which attract according to Lorentz’s law and merge giving rise to “hot” electrode spots, they cause melting, disruption, extraction of conical asperities, breaking of particles, etc., but finally the discharge is completed by splitting the “hot” electrode spots, due to the depletion of energy in the conductivity channel, transforming vice versa into “cold” electrodes spots, which in turn interact with the still hot surface of the periphery of the processed surface on which it causes the extraction of nanometer-sized asperities (see fig. 3.4, b). At the end of the solitary discharge, with the reduction of the current intensity, there are processes of dividing the electrode spots, until the cold ones, which cause the extraction of nano asperities from the surface of the newly formed grains on the surface, by solidifying the crater, so in the case of repeating solitary electric discharges, the asperities drawn from surfaces grow in height and shrink in diameter until merging.

4. ESTABLISHING THE THERMOELECTRONIC EMISSION CHARACTERISTICS OF THE ELABORATE CATHODES

Establishing the factors that determine the amplification of the active surface area of the cathodes, the intensity of the electric field and the current density. The micro irregularities of the surface change the configuration and intensity of the electric fields when these surfaces are part of some electrical or electronic devices. In order to quantitatively characterize the active surface of the cathode by [17], the concept of the electric field amplification coefficient is adopted, which is denoted by β_E. It shows the ratio of the actual value of the electric field created by the upper end of the conical asperities (menisci) to the average macroscopic value of the electric field for a flat surface cathode. If the values βE » 1, then the following relation can be used (4.1) [17]:

$$\beta_E \approx h/r \tag{4.1}$$

where: β_E – electric field amplification coefficient; h – meniscus height (μm); r – radius from the apex of the real cone (μm).

Considering that by applying EID, asperities similar to conical ones are obtained, the current density amplification factor β_i for the specific case will be determined by the *l/r* ratio, but we must be careful to use the length of the conical asperity generator correctly, because according to our own experimental results, the asperities do not present regular cones. If we look at the image presented in fig. 4.1 and we draw attention to the central conical asperity we notice that the asperity itself consists of a conical top, a cone trunk and its base, which is nothing but the edge of the crater, from which this formation was extracted.

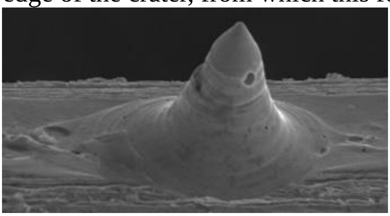


Fig. 4.1. The component parts of the conical asperity: conical tip, truncated cone, and crater area

Next, experimental results are presented that attest that the micro and nano geometry of the side surface of the conical asperity is a complex one.

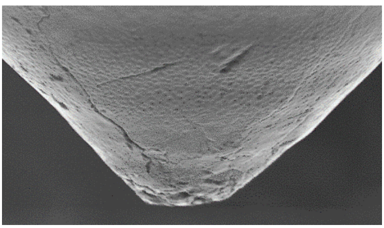


Fig. 4.2. SEM image of the side surface of the tip of the conical asperity with the tip radius

Fig. 4.2 shows the SEM image of the side surface of the tip of the conical asperity. If this surface is analyzed on a larger scale, then the existence of “undulations” of micro and even nanometric dimensions is observed (see the images in fig. 4.3). In the case of the research carried out in the present, a multitude of modifications of the active surface of the cathode subjected to modification by the application of electrical impulse discharges are encountered.

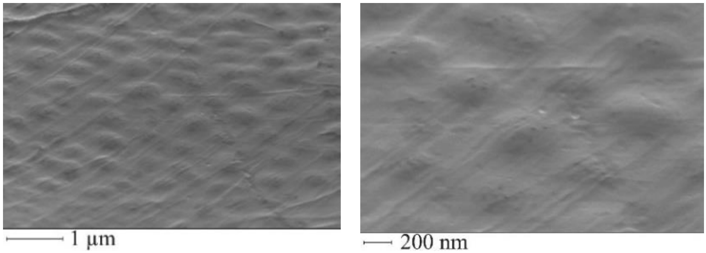


Fig. 4.3. Micro- and nanometer-sized “undulations” are presented on the lateral surface of the conical asperities

Thus, within an asperity there is a radius at its upper tip (fig. 4.1 and fig. 4.2), micro and non-metric undulations on the lateral surface of the cone and small micrometric asperities (compared to the main asperity) which they are found at the base of the cone extracted from the cathode (according to the image shown in fig. 4.1).

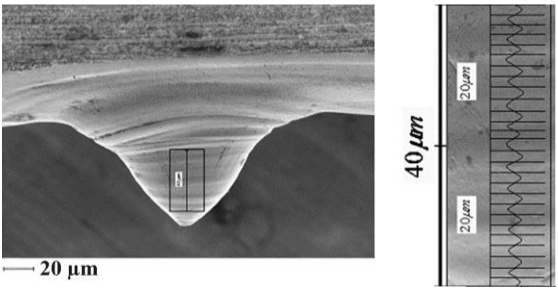


Fig. 4.4. Surface morphology of the Taylor cone asperities: a) image obtained by the SEM method; b) determining the average wavelength for the transverse wave [18]

This sufficiently complicated morphology induces additional difficulties in the scientific interpretation of the obtained results. For our simpler case is to experimentally determine the value of the current density amplification factor and then determine the length of the cone generator, it visually presents on a micrometric scale a sinusoidal curve, but with higher magnifications, it is observed that it is not just a simple sinusoid. On the lateral surface of the menisci, longitudinal waves develop under the action of the plasma. Attempts have been made to find the magnitude of the wavelength of these longitudinal waves. In fig. 4.4 we can see the simulation regarding the determination of the wavelength that is attested on the side of the solidified cone trunk. After modeling, an average value of the longitudinal wavelength was obtained:

$$\lambda_{l\,med} = \frac{40\ \mu m}{13} = 3{,}077\ \mu m \qquad (4.2)$$

where: $\lambda_{l\,med}$ – the average length of the longitudinal mechanical wave (µm).

Based on the SEM images obtained for the conical asperities extracted from the flat surfaces of the 45 steel parts, the value of the longitudinal wavelength was determined, which varies within the limits of 3-5 µm, and for the asperities extracted from the surfaces of tungsten metal wires and its alloys with rhenium, the value of the longitudinal wavelength varies within 3-15 µm (see fig. 3.4 a and 4.4).

The thermo-emission properties of electrons by the processed surfaces in the case of the formation of a layer of oxides on the active surfaces and in the case of their absence. Measurements were performed for thermo-cathodes made of tungsten wire and/or its alloys with the active surface without and in the presence of menisci extracted with the application of electrical impulse discharges.

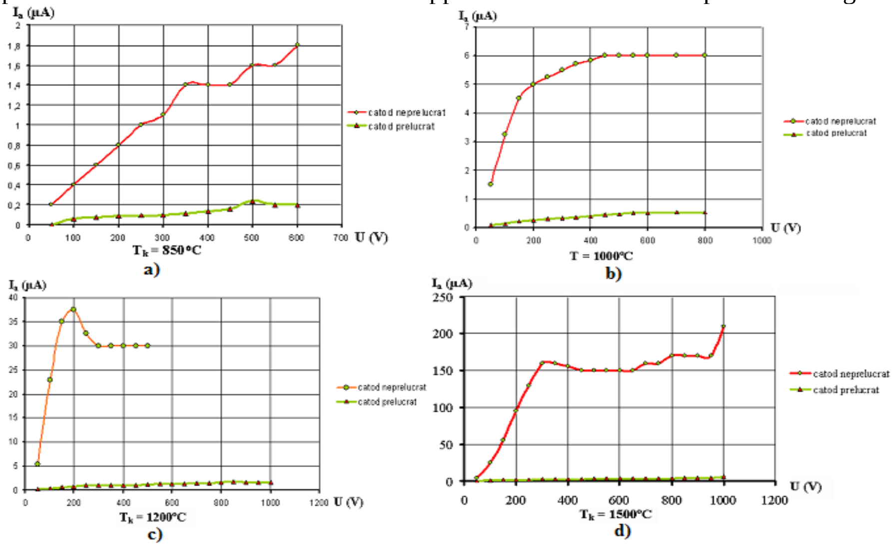


Fig. 4.5. The volt-ampere characteristics obtained in express conditions, of the simple cathodes compared to those that were processed with the application of EID in air environment and that were not subjected to the process of deoxidation of the active surfaces: a) T_k = 850°C; b) T_k = 1000°C; c) T_k = 1200°C; d) T_k = 1500°C

In fig. 4.5, the volt-ampere dependences regarding the thermo-electronic emission cathode test in express conditions are presented. It is observed in all these 4 cases, that when the temperature increases, the value of the intensity of the thermo-emission current increases. If we carefully analyze the data presented in fig. 4.5, we note that for the thermo-cathodes whose surfaces were processed with the application of EID and for which the increase of the active surface was ensured, instead of obtaining higher measured intensity values compared to the intensities obtained for simple thermo-cathodes, not processed by the EID method, obtained vice versa. All the investigated cases demonstrated that the presence of oxides considerably diminishes the electronic emission properties. This result is relatively simple to explain. EID that took place in the air environment, contribute to the formation of oxide layers on the processed surfaces. The oxide layers prevent free electrons from leaving the metal because they have a higher electrical resistance compared to surfaces that are not covered with oxides [6]. Based on these considerations and in order to obtain another result, it is necessary not to modify the microgeometry of the thermo-cathode surfaces made of tungsten wires, with the application of EID in air. In order to avoid the formation of the oxide layer on the surface of the piece in the process of changing the microgeometry, the processing of the piece was carried out in the special chamber where argon was introduced. In the case of using cathodes processed in the argon plasma gas environment, a completely different character of the results regarding the volt-ampere characteristics was obtained for the sample with asperity and for the one without conical asperity on the active surface (see fig. 4.6).

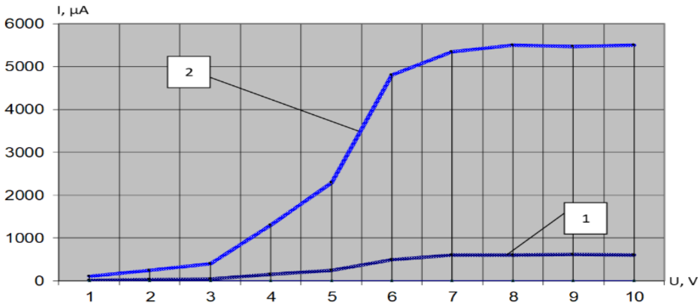


Fig. 4.6. Emission volt-ampere characteristic obtained under express conditions, in which the potential difference between the cathodes remained a constant value [37]

If we analyze the facts presented in fig. 4.6, we note that in the case of thermo-cathodes whose surface contains conical menisci, under the same operating conditions as those of cathodes with smooth surfaces, we observe that the intensity of the emission current (in saturation mode) is approximately 9 times higher.

Measurements, regarding the thermo-electronic emission under real operating conditions. According to the obtained results, the intensity of the thermo-electronic current *I* will increase with the increase of the potential difference *U*, applied between the anode and the cathode, due to the increase of the intensity of the electric field between the two electrodes, favoring the emission through the electric field, only up to a certain value – called the intensity of the saturation current I_s. After studying the specialized literature and according to the own results of the obtained experimental measurements, it is demonstrated that the values of N_{sec} and respectively I_s increase with the increase of the cathode temperature. The emission power is directly proportional to the increase in the variation of the active surface and increases in dependence on the temperature, because the value of the temperature in this relation is to the fourth power.

Determination of the size of the variation of the active surface of the cathodes. Tables 4.1, 4.2 and 4.3 show the experimental values of the diameter of the base and the height of the conical meniscus, depending on the surface processing regime for samples made of tungsten of technical purity and tungsten alloys with rhenium (10% or 20% Re).

Table 4.1. The variation of the size of the active surface for thermo-cathodes made of W of technical purity [38]

Nr.	U_c, V	W_S, J	τ, µs	h_m, µm	$d_{b.m.}$, µm	Δ*A*, µm²
1.	60	0,18	100	28	56	1206,47
2.	60	0,36	125	35	84	1991,94
3.	60	0,54	160	42	112	2945,88
4.	60	0,72	180	56	140	5154,53
5.	60	0,90	200	63	168	6628,23
6.	60	1,08	220	70	182	8133,43

Table 4.2. The variation of the size of the active surface for thermo-cathodes made of tungsten alloy with rhenium (10%) [38]

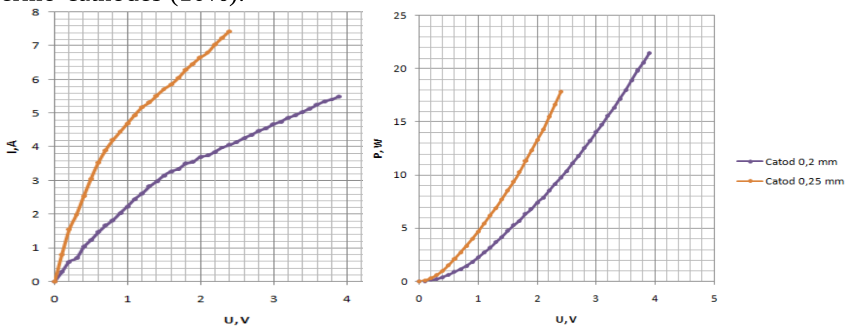
Nr.	U_c, V	W_S, J	τ, µs	h_m, µm	$d_{b.m.}$, µm	Δ*A*, µm²
1.	60	0,18	100	49	84	3493,33
2.	60	0,36	125	70	84	6049,79
3.	60	0,54	160	84	112	9190,21
4.	60	0,72	180	98	140	12925,69
5.	60	0,90	200	112	168	17259,69
6.	60	1,08	220	126	196	22193,96

Table 4.3. The variation of the size of active surface for thermo-cathodes made of wolfram (tungsten) alloy with rhenium (20%)

Nr.	U_c, V	W_S, J	τ, µs	h_m, µm	$d_{b.m.}$, µm	Δ*A*, µm²
1.	60	0,18	100	50	86	3642.12
2.	60	0,36	125	71	88	6329.61
3.	60	0,54	160	83	116	9177.37
4.	60	0,72	180	97	143	12846.26
5.	60	0,90	200	111	169	17064.58
6.	60	1,08	220	124	194	21547.98

Based on these results, the increase in the area of the active surface (ΔA) was also determined, by extracting an asperity in the form of a Taylor cone from it, with the condition of idealizing the shape of these asperities, towards the shape of regular cones, which in practice does not correspond. Analyzing the data presented in Tables 4.2 and 4.3, the increase in active area for the alloy of tungsten with rhenium (10% or 20%) is about the same. For tungsten cathodes of technical purity, with the increase of energy released in the interstice (from 0.18 to 1.08 J), the height of the menisci varies from 28µm to 70µm, and the diameter of asperities varies from 56µm to 182µm, and for cathodes made of tungsten-rhenium alloys, processed under the same conditions, the height of the menisci varies from 49µm to 126µm, and the diameter of the asperities varies from 84µm to 196µm maximum. Obtaining on the surface of tungsten alloys with rhenium, the menisci with a higher height, compared to their height on the surface of tungsten of technical purity, is explained by the "rhenium effect". As we can see, the height of the menisci and the diameter of their base largely depends on the energy released in the interstice. In other words, the amount of energy released in the interstice is an important parameter influencing the formation of menisci on metal surfaces.

Measurement results for electrical resistance, determination of thermo-cathode material resistivity and of the functions I(U), P(U) and a T(P). As mentioned in this thesis, similar thermo-cathodes, which are used to this day, are made of tungsten wires or its alloys with diameters of 0.15 – 0.3 mm. Only wires with a diameter of 0.2 mm and 0.25 mm respectively, made from the alloy of tungsten with rhenium, were subjected to the realization of thermo-cathodes (10%).



a) **b)**

Fig. 4.7. The volt-ampere characteristic (a) and the dependence of the power dissipated on the cathode (b) depending on the voltage applied from the power source for cathodes with diameters of 0.2 mm and 0.25 mm, respectively, made of tungsten alloy with 10%Re [38]

For the wire with a diameter of 0.2 mm and an initial length of 66 cm, the electrical resistance equal to 3.7 Ω was measured, the resistivity equal to about $17{,}6 \cdot 10^{-8}$ Ω·m, the resistance of the cathode with a length of 2 cm, equal to 0.112 Ω, and for the wire with a diameter of 0.25 mm and a length of 134 cm the resistance of 4.2 Ω was determined, the resistivity of about $15{,}38 \cdot 10^{-8}$ Ω·m and for these thermo-cathodes the resistance electrical resistance for 2 cm length was equal to 0.063 Ω [38]. In the case of the volt-ampere characteristic shown in fig. 4.7 (a), can be approximated with the relations:

$$I = 2{,}08 \cdot U^{0{,}77} \quad (4.3)$$

$$I = 4{,}44 \cdot U^{0{,}65} \quad (4.4)$$

where: I – the intensity of the electric current passing through the thermo-cathode (A); U – the electrical voltage applied to the thermo-cathode, from the current source (V).

In relation (4.3) the exponent index is equal to 0.77 for cathodes with diameters of d = 0.2 mm and in relation (4.4) the exponent index is equal to

0.65 for cathodes with diameters of d = 0.25 mm, fact which is easily explained by the fact that the cathode with a smaller diameter heats up more strongly, and with it the intensity of the electric emission current increases faster.

The relations (4.5) and (4.6) shows the dependence of the power dissipated on the cathode and in this case for smaller diameter, the value of the parameter increases faster for the smaller thickness of the cathode wire (see the curves shown in the diagram in fig. 4.7, b).

$$P = 2{,}08 \cdot U^{1{,}77} \quad (4.5)$$

$$P = 4{,}44 \cdot U^{1{,}65} \quad (4.6)$$

where: P – power dissipated on the thermo-cathode (W); U – the electrical voltage applied to the thermo-cathode, from the current source (V).

Experimentally, the values of the electric intensity I and the electric voltage U were directly measured, in order to calculate the power, with the aim of determining the dependence of the temperature (see fig. 4.8) on the input parameters.

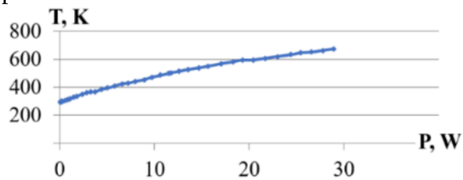


Fig. 4.8. The dependence of the cathode temperature on the power dissipated on it from the current source [38]

Based on the data presented graphically in fig. 4.8, the relationship of the dependence of the thermo-cathode heating temperature on the power of the power source was determined:

$$T = 293 + 25{,}22 \cdot P^{0{,}84} \quad (4.7).$$

where: T – cathode temperature (K); P – power dissipated on the thermo-cathode (W).

The electrical resistivity of the material, respectively the electrical resistance of the thermos-cathodes changes with the change in temperature, which is also confirmed experimentally, and Ohm's law cannot be applied for the high temperature range.

Results, regarding the determination of the intensity of the saturation electric current of thermo-cathodes under real operating conditions. For small values of the potential difference applied in the working chamber, between the anode-electrode and the cathode-electrode U_{a-c}, the intensity of the emission current I_e increases slowly at first. This is explained by the fact that, at low values of the potential difference between the electrodes, not all the electrons emitted by the cathode reach the anode, being rejected by the cloud of electrons (negative space charge), located in the space between the anode and the cathode. With the further increase of the potential difference U_{a-c}, the dispersion of the electron cloud takes place and the intensity of the emission current I_e increases. Experimentally, it was determined that the optimal potential difference between the electrodes must be at least 500 V, for the distance between the electrodes equal to 4 mm. For the potential difference between the electrodes, U_{a-c}, equal to the value of the saturation voltage, U_s, the intensity of the emission current no longer increases, because all the electrons emitted by the cathode, at the temperature to which the cathode has been heated, reach the anode.

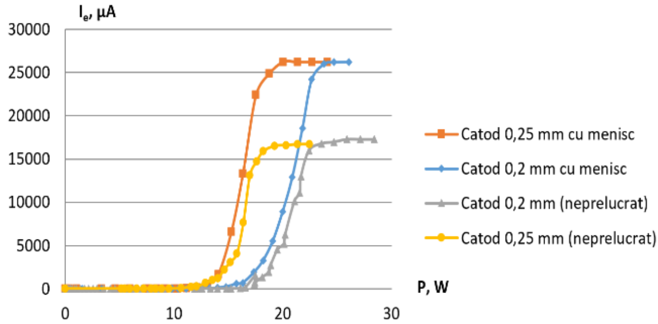


Fig. 4.9. Dependence of the intensity of the thermos-electronic emission current depending on the power of the thermo-cathode power source [38]

Fig. 4.9 shows the dependences of the intensity of the thermo-electronic emission current on the power of the source for the tested cathodes, with the aim of determining the maximum values of the intensity of the saturation current of the thermo-electronic emission. It is observed that for small values of the power *P* dissipated on the cathode, the intensity of the emission current I_e increases slowly at first for all types of cathodes subjected to experimental tests. This is also explained by the fact that at low values of the power dissipated on the cathode, the free electrons do not receive enough energy to be able to leave the material from which the thermo-cathode is made. If we try to present the experimental dependencies of the intensity of the thermo-electronic emission current as a function of the power dissipated on the cathode, according to the data presented in fig. 4.9, by mathematical relations, then they can be written under [38]:

$$I_e = -0{,}007P^6 + 0{,}527P^5 - 12{,}55P^4 + 134{,}2P^3 - 633{,}5P^2 + 1039P - 214{,}0 \quad (4.8)$$

$$I_e = 0{,}019P^6 - 1{,}476P^5 + 41{,}05P^4 - 508{,}0P^3 + 2774{,}P^2 - 5445P + 1326 \quad (4.9)$$

$$I_e = 0{,}000P^6 - 0{,}036P^5 + 2{,}458P^4 - 49{,}18P^3 + 369{,}6P^2 - 910{,}8P + 318{,}2 \quad (4.10)$$

$$I_e = 0{,}021P^6 - 1{,}692P^5 + 49{,}95P^4 - 677{,}9P^3 + 4221P^2 - 9655P + 45{,}19 \quad (4.11)$$

where: I_e – the intensity of the thermo-electronic emission current (μA); *P* – power dissipated on the thermo-cathode (W).

Relations (4.8) and (4.9) respectively express the intensity of the thermo-electronic emission current as a function of the power dissipated on it, for the cathode with the diameter equal to d = 0.2 mm and for the cathode with the base diameter equal to d = 0.25 mm, on the surface of which the presence of conical asperities on the active surface is attested. Relations (4.10) and (4.11) present the same dependencies, but for cathodes with a smooth cylindrical surface, where the micro geometry modification was not achieved by the application of electrical impulse discharges. Comparing the experimental results for all cases, we will conclude that the cathodes that were processed by the method of electrical impulse discharges with the extraction from the active surface of Taylor cone-type asperities and that do not present oxide layers on the surface, presented a current intensity of saturation for higher muted thermo-electronic emission relative to untreated cathodes by this method. At the same time, it is observed that the cathode with a larger diameter ensures a faster increase in the electronic current, a fact that can be explained by the fact that it heats up faster and that it has a larger external surface. At the same time, it is observed that reaching the value of the saturation current is similar, if we refer to the power consumed by the cathode, both for smooth cathodes and for those with asperities.

Increasing the active area of the cathode by approximately only 0.02 mm^2 considerably influences the emission current increase. It would seem that the laws described by the classics of thermo-emission theory are violated, but things are not quite like that. As already mentioned in the works [11, 39], the surface of the conical asperity is complex, showing undulations, and on the surfaces of the crystallization grains, asperities of nanometric order were observed, which in turn can cause the increase in the electron emission efficiency. Therefore, the operating temperature of the thermo-cathodes studied is within the limits of 700 to 2300° C. The lifetime of thermo-cathodes is between hundreds and tens of thousands of hours, if high vacuuming of the room in which they work is ensured. As the operating temperature increases, the efficiency increases and therefore the intensity of the emission current increases, but increasing the operating temperature towards the operating limits will lead to a reduction in cathodes durability. Because the newly developed cathodes are more efficient, it is possible for them to be operated at lower temperatures, not intimidating the emission characteristics compared to conventional cathodes, and their durability to increase. If we carefully analyze these volt-ampere characteristics, we notice that the value of the intensity of the saturation electric current for the cathodes processed with the application of EID is higher by approximately 1.5-1.6 times, in relation to the untreated cathodes. If we compare with how much the area of the active surface is amplified, if a Taylor cone-type asperity is extracted from the surface of the cathode, then we notice that in the medium it increases respectively by 1.5-1.6 times (based on the data presented in tables 4.2 and 4.3). From here, we can state that the amplification coefficient of the electric emission current, in the case of these research, is approximately 1.5-1.6 times, and the value of the saturation intensity of the thermo-electronic emission current is obtained at supply voltages of thermo-cathodes smaller by approximately 2 V, which presents another parameter attesting to the improvement of the thermo-electronic emission characteristics.

Comparing the experimental results, namely the volt-ampere characteristics, regarding the thermo-electronic emission, we will conclude, that the cathodes that were processed by the method of electrical discharges in impulse with the extraction of Taylor cone-type asperities from the active surface, presented an intensity of the saturation current for the thermo-electronic emission mute higher, compared to cathodes not processed by this method. If we analyze the volt-ampere graphs, we notice that for all cathodes an increase in the value of the intensity of the saturation current was detected from approximately 16500 mA to 26500 mA, i.e., by approximately 10 thousand microamperes.

It is important to mention that with the substantial increase in the intensity of the thermo-electronic emission current, a substantial increase of this parameter is witnessed at applied voltages approximately 2 times lower, and the value of the saturation current is also reached for applied voltage values of 2 V smaller. The one that means that for the same heating current of the cathode, it will apply or consume approximately 2 times less energy. In the research previously performed by the authors [15, 18, 37], it was established that the heating temperature of the cathode satisfies the classical dependencies for regular surfaces. The results presented in this chapter differ a little in relation to the classical dependences, because the conical asperities, as mentioned before, serve as concentrators of the electric and thermal fields and on the lateral surface there are cones of nanometric dimensions, which can also serve as sources additional electrons. It has been experimentally demonstrated that the intensity of the saturation electric current is not directly proportional to the number of asperities present on the active surface of the thermo-cathode. However, for the thermo-cathodes that had on the active surfaces more than one conical asperity on the tip, the value of the saturation intensity of the electric emission current was only slightly higher.

Technological recommendations for obtaining cathodes intended for thermo-electronic emission. In order to obtain in practice, the cathodes applicable in the construction of devices operating on the basis of electron beams, the following technological operations will be observed: - Fixing the semi-finished sample (by screwing) in the form of a cylindrical wire with a diameter of 0.2 mm (or 0.25 mm) and 25 mm length in the device, followed by red heating (T ≈ 450-600^{o} C) with current flow and bending to functional shape; - Extraction, by unscrewing the obtained cathode; - Electric resistance welding of the port-cathode cathode. The port-cathode is a ceramic disc (insulator) with an outer diameter of 14 mm, which has 2 holes perpendicular to the disc at a distance from the edge equal to 3 mm and contains 2 cylindrical bars made of stainless steel (conductor) with a diameter of 1.4 mm and the length of 25 mm, which at one end have a flat edge, obtained by pressing, to be easier to weld by the electric resistance method; - Mounting the device created by screwing the fasteners. Clamping and fixing the cathode in the installation device as an anode with the surface to be processed facing down: setting the value of the interstice S = 0.2 mm; connecting the source of current impulses; inserting the electrode holder into the working chamber; reaching the vacuum degree value of at least 10^{-2} mbar; the introduction of inert gas (argon) at atmospheric pressure into the room;

- Ensuring local melting of the sample determined by the relationship: $Q = \frac{4W}{\pi \cdot d_C^2 \cdot S} \geq Q_{top}$ [10], where: Q – the amount of heat released in the plasma channel during EID (J); W_s – the energy released in the plasma channel (J); d_C – the average diameter of the liquid phase crater on the cathode surface (m); S – the size of the interstice between the electrodes (m); Q_{top} – the amount of heat required to melt the sample material (J). The amount of heat required to melt the sample material, Q_{top}, depends on the bulk melt density of the part material, which takes into account the specific heat of fusion, q_{top}, expressed in J/kg and the density of the sample material, ρ, expressed in kg/m^3. An electric field with an intensity of approx. 10^8 V/m [10] will be created, according to the relation: $E_{cr} = \sqrt[4]{64\pi^2 \rho g \gamma \cdot 3 \cdot 10^4}$, where: E_{cr} – the critical intensity of the electric field (V/m); ρ – the density of the metal (kg/m^3); g – the acceleration of free fall (m/s^2); γ – the surface tension of the material in the liquid state (N/m). The direction of action of the electric field will coincide with the direction of action of the force of gravity. The EID realization with conical asperity extraction. Disconnecting the voltage source. Dismantling the device by unscrewing the fasteners; Extraction of the fixing device for the electrodes intended for thermo-electronic emission research.

GENERAL CONCLUSIONS AND RECOMMENDATIONS

Final conclusions

From the analysis of bibliographic sources, the results obtained by other researchers, as well as our own, we conclude that:

Following the research carried out and the results obtained, the following final conclusions can be formulated:

- based on the physical model of the electro-erosion phenomenon and its additions proposed in chapter III, paragraph 3.9, which is based on the development of capillary waves on the surface of the liquid metal under the action of the electric field forces, the surface tension of the molten metal and the force of gravity, it was demonstrated and confirmed the possibility of extracting and freezing Taylor-type conical asperities from metal surfaces of parts made of technical purity tungsten (wolfram), tungsten alloys with rhenium (10 and 20 %), steel 45 etc. [37];
- at the end of the solitary discharge, with the reduction of the current intensity, there are processes of division of the "hot" electrode spots, up to the "cold" ones formed on hot surfaces, which cause the extraction of nano asperities from the surface of newly formed grains on the surface processed by solidification [13 , 15], and in the case of repeating solitary discharges, the asperities extracted from the surfaces increase in height and decrease in diameter until merging (chapter III, paragraph 3.7, subparagraph 3.7.4);
- the size of the interstice (S) and the duration of the discharge pulse (τ) influence in almost the same way on the size of the height (h_m) and the diameter of the base (d_m) of the conical asperities extracted from the metal surfaces, regardless of the composition of the material of the samples, however we will find that they are much higher for the samples made of tungsten of technical purity, than for the alloys of tungsten with rhenium (10 or 20%), a fact that can be explained by the higher melting temperature of tungsten of technical purity in relation to that of the tungsten-rhenium alloy (chapter III, paragraph 3.8);
- in order to extract conical asperities from metal surfaces of parts made of tungsten of technical purity, tungsten alloys with rhenium (10 and 20%), steel 45 etc., it is necessary to respect the basic energy parameters that influence their geometry (chapter III, paragraph 3.8): the energy released in the interstice (W_s), with values within the limits of 0.072 to 4.8 J; duration of the discharge pulse (τ),

from 100 to 220 µs; the size of the interstice (S), from 0.1 to 0.4 mm and taking into account the properties of the material of the sample electrodes (density, specific heat of fusion, etc.);
- the extraction of conical asperities can take place at gap sizes ranging from 0.1 to 0.35 mm, the optimal range being 0.16 – 0.3 mm, and the height of the asperities can reach maximum values of up to 0.15 mm, however, it is not recommended to set the interstice smaller than 0.2 mm, in order to avoid micro-welding of the two electrodes and to avoid short-circuiting the electric circuit (chapter III, paragraph 3.2) [13, 15];
- the intensity of the electron emission current, as well as the power, are functions directly proportional to the size of the active area of the emission surface of the cathode electrode, and that of the saturation electron emission current is a constant quantity [20] and does not depend on the diameter of the cathode, but increases considerably faster for the smaller diameter electrode, given the fact that it heats up faster (chapter IV, paragraph 4.3, subparagraph 4.3.3) [38];
- the increase in the area of the active surface of the thermo-cathode by only 0.01 – 0.02 mm2, compared to its total initial surface equal to approximately 12 – 15 mm^2 (chapter III, paragraph 3.8), considerably influences the increase in the value of the intensity of the thermo-electronic emission current (from 16.5 mA to 26.5 mA), thus the presence of conical asperities, extracted from the metal surfaces of the thermo-cathodes, with the application of EID allow to increase the intensity of the thermo-electronic emission current by about 104 µA, in relation to the thermo-cathodes whose active surfaces were not processed by this method [38].

Technological recommendations

The analysis of the results of the theoretical and experimental research obtained in the doctoral thesis summarizes the following recommendations: - in the surface processing process to ensure the effectiveness of extraction and freezing of conical asperities, the electrodes will be positioned so that the direction of action of the electric field coincides with the direction of the force of gravity; - the sample part subject to processing will be included in the discharge circuit of the current pulse generator as an anode; - when extracting conical menisci from metal surfaces, the energy parameters, interstice (0.2 – 0.3 mm) and the thermo-physical properties of the execution material will be taken into account; - to avoid the formation of oxides in the processed surface, the processing process will take place in an inert plasmogenic gas environment (vacuum, argon, etc.) or the processed surface will be deoxidized with the application of EID; - in order to increase the intensity of the thermo-emission current, high vacuuming of the test chamber ($\leq 10^{-5}$ mbar) and creation of a potential difference between the electrodes of at least 1000 V (at most 1.5 KV) is necessary; - to ensure the most effective thermo-electronic emission, the properties of the cathode material, the area of the active emission surface and its heating temperature will be taken into account.

BIBLIOGRAPHY

1. BOLUNDUŢ, Ioan-Lucian. *Materiale şi tehnologii neconvenţionale.* Chişinău: Tehnica-Info, 2012. 229 p. ISBN 978-9975-63-334-5.

2. MOHAMMED, A., ABDULLAH, A. *Scanning Electron Microscopy (SEM): A Review.* In: Proceedings of 2018 International Conference on Hydraulics and Pneumatics – HERVEX, November 7 – 9, Băile Govora, Romania, 2019, 9 p. ISSN 1454-8003. https://www.researchgate.net/publication/330169176.

3. ROTARU, N., MALÎGA, O., CODREANU, I. *Radiologie şi radioprotecţie.* Poligrafic Medicina, Chişinău, 2020. 242 p. ISBN 978-9975-82-177-3.

4. SLĂTINEANU, L. *Tehnologii neconvenţionale în construcţia de maşini.* Chişinău: Tehnica-Info, 2000. 252 p. ISBN 9975-910-99-8.

5. TOPALA, P., RUSNAC, V., GUZGAN, D., OJEGOV, A., MELNIC, V., BALANDIN, A. *Cercetări experimentale privind obţinerea peliculelor de oxizi pe suprafeţe semiconductoare cu aplicarea plasmei.* Materialele Colloquia Professorum, 10.10.2014. Tradiţie și inovare în cercetare științifică, ed. a V-a, Bălţi, 2015. p. 212 – 217. ISBN 978-9975-50-144-6.

6. OJEGOV, A. *Obţinerea peliculelor subţiri de oxizi pe suprafeţele metalice ale aliajelor de fier, cupru, aluminiu şi titan, cu aplicarea descărcărilor electrice în impuls.* Autoreferatul tezei de doctor în tehnică. Tehnica UTM, Chişinău, 2014. 30 p.

7. TOPALĂ, P., MELNIC, V., **GUZGAN, D.** *Formarea peliculelor de oxizi pe suprafaţa siliciului cu aplicarea plasmei descărcărilor electrice în impuls de acţiune indirectă*. Simpozionul „Realizări şi perspective în inginerie agrară şi transport auto", 12 – 13 noiembrie. Lucrări Ştiinţifice, Vol. 45. Chişinău, 2015, p. 249 – 252. ISBN 978-9975-64-276-7. https://ibn.idsi.md/ro/vizualizare_articol/74501.

8. MARIN, L., TOPALA, P., STOICEV, P., BESLIU, V., OJEGOV, A., PÎNZARU, N, **GUZGAN, D.,** PLATON, A. *Influenta parametrilor tehnologici – tensiune, cantitate de electricitate - la generarea formațiunilor spațiale alcătuite din atomi de carbon de tipul fulerenelor, la aplicarea DEI.* Revista Meridian Ingineresc, nr. 1 (64). Editura Tehnica UTM. 2017. p. 30 – 35. ISSN 1683-853X. https://ibn.idsi.md/ro/vizualizare_articol/53571.

9. MARIN, L. *Cercetări privind omiterea efectelor de priză dintre suprafețele metalice și nemetalice prin intermediul peliculelor de grafit. Rezumatul tezei de doctor în științe inginereşti.* Tehnica UTM. Chișinău, 2022. 34 p.

10. TOPALĂ, P., STOICEV, P. *Tehnologii de prelucrare a materialelor conductibile cu aplicarea descărcărilor electrice în impuls.* Chişinău: Tehnica-Info, 2008. 265 p. ISBN 978-9975-910-61-3.

11. TOPALA, P., BEŞLIU, V., RUSNAC, V., **GUZGAN, D.,** PLEŞCO, I. *Obtaining surfaces with taylor cone shaped asperities of micro- and nano-scale dimensions using the EDI method*. IJMMT, Vol. VI, nr. 2/2014, ModTech Publishing House, Romania, 2014, pp. 91 – 96. ISSN: 2067-3604.

12. СМИРНОВ, А., ХВОЩАН, О., ЖЕКУЛ, В. *Эрозия электрода при высоковольтном электрическом разряде в жидкости*. Электронная обработка материалов, 58 (3), 2022. с. 21 – 33. ISSN 0013-5739. DOI: https://doi.org/10.52577/eom.2022.58.3.21.

13. TOPALĂ, P., **GUZGAN, D.,** PLEȘCO, I. *Conditions of formation of Taylor cone shaped asperities on metal surfaces by the action of pulsed electric discharge machining.* AIP Conference Proceedings 2075, 060013 (2019), DOI: https://doi.org/10.1063/1.5091191. ISBN: 978-0-7354-1803-5. https://ibn.idsi.md/ro/vizualizare_articol/130868. IF: 0.43.

14. RUSNAC, V. *Modificarea microgeometriei suprafeţelor pieselor la formarea straturilor de depunere prin metoda electroeroziunii. Rezumatul tezei de doctor.* Galaţi, România. 2008. 56 p.

15. TOPALĂ, P., **GUZGAN, D.,** PLESCO, I. *Increasing the surface thermo-emission by the formation of asperities of Taylor cone type*. In. NAITO, M., BUCHACZ, A., BAIER, A., TOPALA, P., NEDELCU, D. *Research and Innovation in Advanced Engineering Materials*. ModTech Publishing House. 2019. pp. 159 – 184. ISBN 978-606-93704-5-2.
16. TOPALA, P., HIRBU, A., OJEGOV, A. *Acţiunea plasmei descărcărilor electrice asupra suprafeţelor metalice.* Fizica şi tehnologiile moderne, vol. 10, nr. 1-2, 2012. p. 13 – 21. ISSN 1810-6498. https://ibn.idsi.md/sites/default/files/j_nr_file/vol10_2012.pdf.
17. МЕСЯЦ, Г. *Эктон – лавина электронов из металла.* Обзор актуальных проблем. Успехи физических наук. Том 165, №. 6, 1995. с. 601 – 626. Web of Science A1995RL93800001. DOI: https://doi.org/10.3367/UFNr.0165.199506a.0601.
18. TOPALA, P., **GUZGAN, D.**, RUSNAC, V. *Tehnologii de formare a suprafeţelor pentru emisie electronică.* Lucrări ştiinţifice: Inginerie agrară şi transport auto. Vol. 38. UASM, Chişinău, 2013, p. 196 – 201. ISBN 978-9975-64-251-4.
19. TOPALA, P., RUSNAC, V., GUZGAN, D. *Formation of Taylor conic meniscuses on cyllindrical surfaces by applying electric discharges in pulse.* Advanced Materials Research Vol. 1036, Trans Tech Publications, Switzerland, 2014, pp. 178 – 183. ISSN 1662-8985. DOI: 10.4028/www.scientific.net/AMR.1036.178.
20. **GUZGAN, D.** *Conferirea unei micro-geometriei prescrise a suprafeţelor metalice în scopul sporirii intensităţii curentului de emisie termo-electronică*. Materialele Conferinţei Știinţa și inovarea în nordul R. Moldova: Probleme, realizări, perspective, 25 – 26 septembrie, Filiala Bălţi a AȘM. Indigou Color. 2015. p. 21 – 23. ISBN 978-9975-3054-5-7.
21. БАЛАН, Н., ИВАШОВ, Е., ЛУЧНИКОВ, П., НЕВСКИЙ, А. *Острийные эмиттеры электронов микроприборов и конструктивно-технологические особенности их изготовления*. Вестник науки Сибири: Серия Инженерные науки, № 3 (4). 2012. с. 89 – 98. ISSN 2226-0064.
22. МЕСЯЦ, Г. *Взрывная электронная эмиссия: монография*. Физматлит, Москва, 2011. 280 с. ISBN 978-5-94052-207-2.
23. ZHANG, J., CAI, G., LIU, X., HE, B., WANG, W. *Molecular dynamics simulation of ionic liquid electrospray: Revealing the effects of interaction potential models*. Acta Astronautica, Vol. 179, 2021. pp. 581 – 593. ISSN 0094-5765.
24. TOPALA, P. *Studiul fundamental şi aplicativ al efectelor electroerozive în tehnologiile neconvenţionale. Autoreferat al tezei de doctor habilitat în tehnică.* Tehnica UTM. Chişinău. 2008. 51 p.
25. TOPALA, P., OJEGOV, A., BEȘLIU, V., STOICEV, P. *Tehnologii moderne și inovații în inginerie. Note de curs.* Indigou Color, Bălţi, 2017, 217 p. ISBN 978-9975-9904-4-8.
26. DETLAV, A., IAVORSKI, B. *Curs de fizică.* Chişinău: Lumina, 1991. 606 p. ISBN 5-372-00755-9.
27. TOPALA, P., KANTSER, V., HIRBU, A. *Theoretical and experimental study of mechanisms governing the occurrence of electric discharges in gases*. Moldavian Journal of the Physical Sciences, Vol. 14, No. 3-4, Chisinau, 2015, pp. 221 – 230, ISSN 1810-648X.
28. САУШКИН, Б. *Электрический разряд в жидких и газовых средах – основа нового поколения методов и технологий машиностроительного производства*. Электронная обработка материалов, № 1, 2004. с. 4 – 17. ISSN 0013-5739.
29. TRUCCHI, D., MELOSH, N. *Electron-emission materials: Advances, applications, and models.* Materials Research Society (MRS) Bulletin, Vol. 42, Springer, 10 JULY, 2017. pp. 488 – 492. ISSN: 0883-7694. DOI: https://doi.org/10.1557/mrs.2017.142.
30. RUSNAC, V. *Distribuţia temperaturii in piesa de lucru la aplicarea descărcărilor electrice in impuls*. Fizică şi tehnică: procese, modele, experimente. Nr. 2. 2008. p. 53 – 56. ISSN 1857-0437.

31. PÎNZARU, N. *Cercetări privind conceperea, proiectarea şi elaborarea „electrozilor-scule” pentru formarea straturilor de suprafaţă cu aplicarea descărcărilor electrice în impuls. Autoreferatul tezei de doctor în tehnică.* Tehnica UTM. Chișinău, 2020. 26 p.
32. HÎRBU, A. *Procese de excitare şi relaxare a moleculelor în medii gazoase*. *Autoreferatul tezei de doctor în fizică.* Academia de Ştiinţe a Moldovei. Chișinău, 2016. 34 p.
33. GINZEL, J., BEHRENS, A., WULFSBERG, J. *Technology development for EDM using statistical analysis of arc information.* 14-th International Symposium on Electromachining, 10 Iunie 2004, JMPT, pp. 232 – 237. ISSN 0924-0136. DOI: https://doi.org/10.1016/j.jmatprotec.2003.10.039.
34. КРАСНОВА, Е., МОРГУНОВ, Ю., САУШКИН, Б. *Статистическое исследование шероховатости поверхности изделий из Ti-6Al-4V, построенных методом селективного электронно-лучевого плавления*. Электронная обработка материалов, 58 (6), 2022. с. 1 – 12. ISSN 0013-5739. DOI: https://doi.org/10.52577/eom.2022.58.6.01.
35. САПРОНОВА, Т., УЛЬЯНОВ, К. *Теория высоковольтного тлеющего разряда с учетом термоэмиссии электронов*. Теплофизика Высоких Температур, том 57, № 3, 2019. с. 323–327. ISSN 0040-3644. DOI: 10.1134/S0040364419030153.
36. TOPALA, P., RUSNAC, V., **GUZGAN, D.** *Formation of Taylor conic meniscuses on cyllindrical surfaces by applying electric discharges in pulse.* Advanced Materials Research Vol. 1036, Trans Tech Publications, Switzerland, 2014, pp. 178 – 183. ISSN 1662-8985. DOI: https://doi.org/10.4028/www.scientific.net/AMR.1036.178.
37. **GUZGAN, D.** *The results on metal surface micro geometry modification by applying electric discharges in impulse*. Proceedings of the 1st international conference for doctoral students IPC 2013. ACTA Uiversitatis Cibiniensis – Technical Series. Vol LXV, 2014., “Lucian Blaga” University of Sibiu, pp. 32 – 38. ISSN 2668-6449. DOI: https://doi.org/10.1515/aucts-2015-0006.
38. TOPALA, P., **GUZGAN, D.,** OJEGOV, A. *Increasing the energy efficiency of thermocathodes operation.* GJRA, Vol. 10, India, 2021, pp. 164 – 168. ISSN 2277–8160. DOI: https://www.doi.org/10.36106/gjra/4914740. IF: 5,956.
39. TIGINYANU, I., TOPALA, P., URSAKI, V. *Nanostructures and Thin Films for Multifunctional Applications.* Technology, Properties and Devices. Springer, 2016. 576 p. ISBN 978-3-319-30197-6.
40. TOPALA, P., OJEGOV, A., HIRBU, A., BESLIU, V., **GUZGAN, D.** *Physical and chemical phenomena at the interaction of EDI plasma with electrodes surfaces.* AIP Conference Proceedings 2075, 060012 (2019), DOI: https://doi.org/10.1063/1.5091190. ISBN: 978-0-7354-1803-5. https://ibn.idsi.md/ro/vizualizare_articol/176573. IF: 0.43.
41. TOPALĂ, P., OJEGOV, A., BEȘLIU, V., RUSNAC, V., **GUZGAN, D.,** HIRBU, A., PLESCO, I. *Oxidation of Taylor cone-shaped asperities by application of plasma in normal condition.* Nonconventional Technologies Review. Vol. 19, Nr. 2, Editura Politehnica, Timisoara, Romania, 2015. pp. 56 – 61. ISSN 2359-8646. http://dspace.usarb.md:8080/jspui/bitstream/123456789/3167/1/Topala_oxidation.pdf.
42. TOPALA, P., **GUZGAN, D.**, RUSNAC, V. *Cercetări experimentale privind modificarea geometriei suprafeţelor pieselor metalice.* Colocviul „Tradiţie şi inovare în cercetarea ştiinţifică”, 18 octombrie 2013, Ediția 4, USARB, Bălți, 2014. p. 250 – 255. ISBN 978-9975-50-136-1. https://ibn.idsi.md/ro/vizualizare_articol/99302.
43. TOPALA, P., RUSNAC, V., **GUZGAN, D.** *Analiza morfologiei suprafeţelor pentru emisie electronică obţinute în urma prelucrării cu aplicarea descărcărilor electrice în impuls.* Colocviul „Tradiţie şi inovare în cercetarea ştiinţifică”, 18.10.2013, Ediția 4, USARB, Bălţi, 2014. p. 255 – 259. ISBN 978-9975-50-136-1. https://ibn.idsi.md/ro/vizualizare_articol/99303.

ADNOTARE

Guzgan Dorin, „Cercetări privind sporirea capacității de emisie termoelectronică a suprafețelor metalice prin metoda electroeroziunii”. Teză de doctor în științe inginerești, Bălți, 2023

- **Structura tezei:** introducere, patru capitole, concluzii generale și recomandări, bibliografie din 166 de titluri, 9 anexe, 149 de pagini de text de bază (până la Bibliografie), 81 de figuri, 19 tabele, rezultatele obținute sunt publicate în 62 de lucrări științifice;

- **Cuvinte-cheie:** eroziune, impuls, interstițiu, microgeometrie, electrod, catod, vacuum, emisie;

- **Scopul lucrării** constă în stabilirea legităților și factorilor tehnologici de realizare a geometriei prescrise a suprafețelor metalice în vederea sporirii eficienței de termoemisie a catozilor în baza modelului fizic actualizat al fenomenului electroeroziunii.

- **Obiectivele cercetării:** analiza literaturii de specialitate, privind problema cercetării; stabilirea parametrilor tehnologici de extragere a asperităților sub forma de con Taylor din suprafețele probelor metalice și sistematizarea rezultatelor obținute; cercetarea experimentală a emisiei termoelectronice în lipsa și prezența asperităților de tip con Taylor pe suprafețele termocatozilor; propunerea soluțiilor de îmbunătățire a proprietăților funcționale ale catozilor utilizați în electronică.

- **Noutatea și originalitatea științifică:** sporirea eficienței de emisie electronică a termocatozilor simpli executați din wolfram de puritate tehnică sau aliajele wolframului cu reniu (10 și respectiv 20%) pe baza modificării microgeometriei suprafețelor;

- **Rezultatele obținute care contribuie la soluționarea unei probleme științifice importante:** Perfecționarea tabloului fizic al fenomenelor ce se produc în cadrul descărcărilor electrice și influența acestora asupra transformărilor fizice și de compoziție din suprafețele electrozilor și determinarea coeficientului de multiplicare a emisiei termoelectronice de către suprafețele catozilor, în baza fenomenologiei fizice și transformărilor structurale provocate de DEI.

- **Semnificația teoretică** este asigurată de stabilirea legităților de formare a asperităților sub acțiunea DEI; dezvoltarea teoriei, privind modificarea microgeometriei suprafețele și a multiplicării emisiei termoelectronice a catozilor cercetați;

- **Valoarea aplicativă** constă în identificarea parametrilor de bază privind extragerea meniscurilor conici pe suprafețele metalice cu aplicarea DEI (energiei și duratei impulsului de descărcare, mărimii interstițiului și proprietăților materialului de execuție a piesei supuse prelucrării);

- **Implementarea rezultatelor științifice:** au fost realizate lucrări de laborator la ciclul II, în cadrul Catedrei de științe fizice și inginerești, Facultatea Științe Reale, Economice și ale Mediului, Universitatea de Stat „Alecu Russo” din Bălți.

АННОТАЦИЯ

Гузган Дорин, "Исследования по увеличению способности термоэлектронной эмиссии металлических поверхностей методом электроэрозионной обработки",

Докторская диссертация инженерных наук, Бельцы, 2023 г.

- **Структура диссертации**: введение, четыре главы, общие выводы и рекомендации, библиография из 166 наименований, 9 приложений, 149 страница основного текста (до библиографии), 81 рисунка, 19 таблиц, полученные результаты опубликованы в 62 научных работах;

- **Ключевые слова**: эрозия, импульс, межэлектродный промежуток, микрогеометрия, электрод, катод, вакуум, эмиссия;

- **Цель работы** состоит в установление закономерностей и технологических параметров получения заданной геометрии металлических поверхностей с целью повышения термоэмиссионной эффективности катодов на основе обновленной физической модели электрической эрозии

- **Задачи исследования**: анализ литературы по специальности относительно проблемы исследования; установление технологических параметров получения неровностей в виде конуса Тейлора на поверхности металлических образцов и систематизация полученных результатов; экспериментальное исследование термоэлектронной эмиссии при отсутствии и в наличии конусов Тейлора на поверхности термокатодов; предложение решений по улучшению функциональных свойств катодов, используемых в электронике.

- **Научная новизна и оригинальность**: повышение эффективности электронной эмиссии термокатодов из вольфрама и его сплавов с рением (10 и 20% соответственно) на основе изменения микрогеометрии поверхности;

- **Полученные результаты, способствующие решению основной научной задачи**: Совершенствование физической модели явлений, происходящих при электрических разрядах и их влияния на физические превращения и изменения состава поверхности электродов; определение коэффициента усиления термоэлектронной эмиссии поверхности катода согласно физической модели и структурных превращений, вызванных ЭИР.

- **Теоретическая значимость** обеспечивается установлением закономерностей образования неровностей под действием ЭИР; разработка теории изменения микрогеометрии поверхности и увеличения электронной эмиссии катодов;

- **Прикладное значение** состоит в определении основных параметров получения конических менисков на металлической поверхности с применением ЭИР (энергии и длительности импульса разряда, размера межэлектродного промежутка и свойств материала обрабатываемой детали);

- **Внедрение научных результатов**: проведены лабораторные работы для студентов магистерского цикла кафедры физико-технических наук в составе Бельцкого Государственного Университета им. Алеку Руссо.

ANNOTATION

Guzgan Dorin, “Research on increasing the capacity of thermal electron emission of metal surfaces by electroerosive method”. PhD thesis in Engineering Sciences, Balti, 2023

- **Structure of the thesis**: introduction, four chapters, general conclusions and recommendations, bibliography of 166 titles, 9 appendices, 149 pages of main text (before bibliography), 81 figures, 19 tables, results are published in 62 scientific papers;

- **Key words**: erosion, impulse, gap, microgeometry, electrode, cathode, vacuum, emission;

- **The purpose of the paper** is to establish regularities and technological parameters for obtaining a given geometry of metal surfaces in order to increase the thermo-emission efficiency of cathodes based on an updated physical model of electro-erosion.

- **Research objectives**: analysis of specialty literature regarding the research problem; establishing technological parameters for obtaining Taylor cone shaped irregularities on the surface of metal samples and systematizing the obtained results; experimental study of thermo-electronic emission in the absence and in the presence of Taylor cones on the surface of thermo-emission cathodes; proposal of solutions to improve the functional properties of cathodes used in electronics.

- **Scientific novelty and originality**: increasing the efficiency of electron emission of thermo-cathodes made of tungsten and its alloys with rhenium (10 and 20% respectively) based on changing the surface microgeometry;

- **The obtained results, contributing to the solution of the main scientific problem**: Perfecting the physical model of the phenomena occurring during electrical discharges and their influence on physical transformations and changes in the composition of the electrode surface; determining the amplification factor of the thermo-electronic emission of the cathode surface according to the physical model and structural transformations caused by pulsed electric discharge machining (PEDM).

- **The theoretical significance** is provided by the establishment of patterns of formation of irregularities under the action of PEDM; development of the theory of changing the surface microgeometry and increasing the electron emission of cathodes;

- **Applied value** consists in determining the main parameters for obtaining conical meniscuses on metal surfaces by applying PEDM (the energy and the duration of the discharge pulse, the size of the gap and the properties of the workpiece material);

- **Implementation of scientific results**: laboratory work was carried out for students of the master's cycle at the Department of Technical and Physical Sciences from the ARBSU.

GUZGAN DORIN

RESEARCH ON INCREASING THE CAPACITY OF THERMAL ELECTRON EMISSION OF METAL SURFACES BY ELECTROEROSIVE METHOD

Program: 242.05 Technologies, processes and processing equipment

Summary of the Doctoral Thesis in Engineering Sciences

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