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Short Communication

Opportunities of AFM in the Description of Charge Formation from the Nanostructured Electrode at Electroconvection

S.G. Emelyanov, A.E. Kuz'ko, A.V. Kuz'ko, A.P. Kuzmenko, D.I. Timakov

Southwest State University, 94, 50 Let Oktyabrya Str., 305040 Kursk Russia

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The results of research of opportunities of the description of a charge formation from surfaces of the nanostructured electrodes on their ASM-topology are given. The estimation of influence of the sizes of a cantilever on the calculated currents is made.

Keywords: Local enhancement, The form factor, Nanostructure, Fowler-Nordheim equation.

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1. INTRODUCTION

Ensembles of nanoparticles exhibit new dimensional properties that allows to use them as working elements of new effective devices therefore studying of processes occurring at the interface with nanostructures has great practical interest. The using of electric fields as an active method of an intensification of various physical and chemical processes in modern manufacturing is one of the perspective directions effective management electroconvective heat and mass exchange in chemical productions, space technology, non-mechanical switches, automation devices, etc. Local amplification of external electric field on nano- and microstructures represents the greatest practical interest from this point of view [1]. The matter of creation of a controlled charge formation at interfaces, in particular on border dielectric liquid-metal, for management of electroconvection in electrohydrodynamic heat exchangers and pumps is still unresolved. Now approach to management of a charge formation can be found in creation of periodic nanostructures of known geometry on surfaces of electrodes. The creation of such electrodes is technologically very difficult and expensive.

2. THE USING OF SURFACE TOPOLOGY

2.1 Surface Local Fields

However structures self-organized on a surface of the copper and tungsten electrodes polished and etched acid by quality to 20 nm can be an example. The topology of a electrodes surface and profiles of their typical nanostructures are presented in Fig. 1.

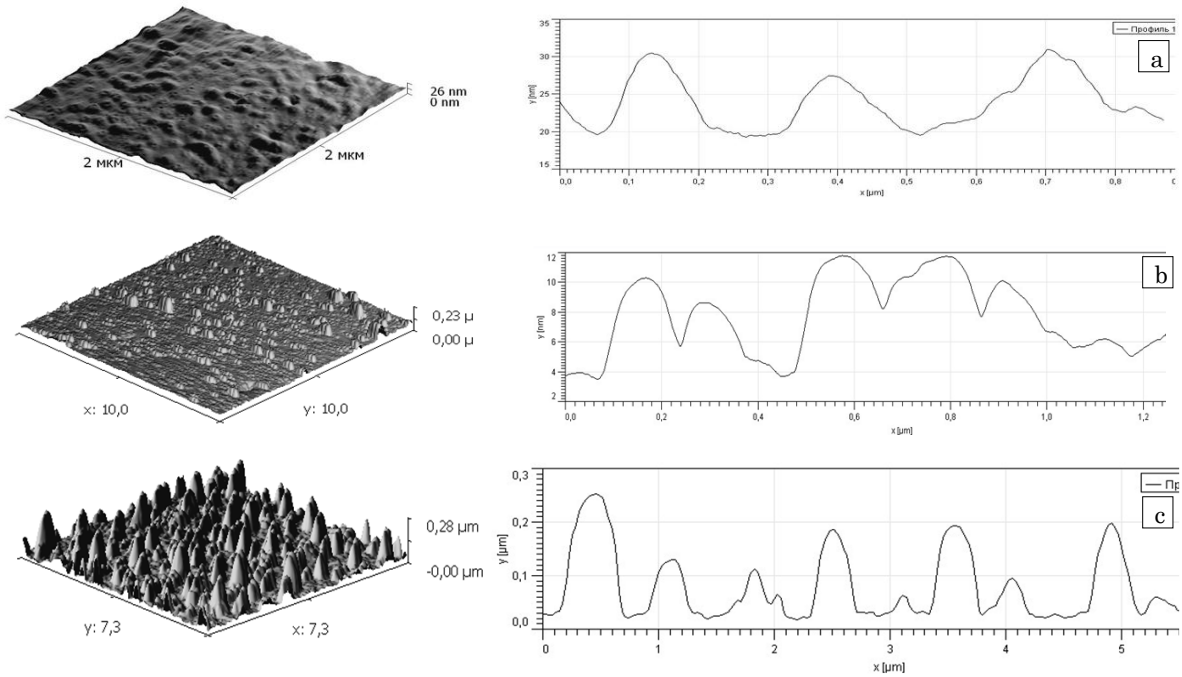

Fig. 1 – AFM image of the surface topology of copper electrode (a), of tungsten electrode (b), of copper electrode etched HCl (c)

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Research AFM images of such structures by the software [2] have shown that the geometry of tops of such structures approximated with high reliability by parabolic profiles that is consistent with [3] allows us to describe the charge formation in their local electric fields on the Fowler-Nordheim equation.)) We will receive values of a form factor $\beta = E/U = 2/(r \cdot ln(2H/r))$ and local tension at the top $E = \beta U$ for distance between tops of structure of the cathode and the plane anode $H = 25$ microns, voltage of anode-cathode system $U = 500$ V and the calculated radiuses of surface curvature r of tops of these metals. The calculation results listed in Table 1 for the local electric field amplification is shown on the possibility of occurrence of a autoemission currents on the tops of these nanostructures. Calculations by the Fowler-Nordheim equation [4] give the value of the current density on the tops of the structures of copper to $6.7 \cdot 10^4$ A/sm^2, and tungsten $1.1 \cdot 10^6$ A/sm^2.

Table 1 – Field enhancement on nanostructures

Electrodes	r, nm	β, sm^{-1}	E, $\times 10^7$ V/sm
Copper	289	13400	0.70
Acid-etched copper	163.5	21370	1.11
Tungsten	14.8	171100	8.55

2.2 Accounting the Cantilever Size

The ability to control charge formation (practically important property of nanostructured surfaces) in the high electric fields by analyzing the geometry of the nanostructures (created artificially, or by self-organization) on the application software on the AFM images proved in [4, 5]. The effect of broadening the profile and the effect of reducing the heights (deficiencies AFM) adversely affect the determination of the charge formation by radius of curvature of tops and profiles of nanostructures. It is explained by ineradicable influence of geometry of cantilever probe on the created image. Especially it concerns objects of nanometer range. Therefore the technique of restoration of real profiles of structures has to be used. The volume image of of a scanned area of tungsten with densely located nanostructures (it is received in the Gwyddion 2.9) and the restored movement of a cantilever on a real surface in one of vertical cross section of this area is submitted in Fig. 2. More exact calculation of density of emission currents can be obtained due to probe having a curvature radius $R = 10$ nm. The results of these calculations are shown in Table 2. Values are specified in brackets excluding R. The analysis of the obtained values shows that the accounting of curvature radius of a probe renders (because of exponential dependence of autoemission current) considerable influence on density of injection current at structure top. $j / j^* \sim 15$-17 for structures on the copper surface. Local resolution is received ~ 0.9 nm taking into account the usual vertical resolution ~ 0.1 Å for typical industrial cantilever probe with a curvature radius $R = 10$ nm. If the curvature radius of structures tops is comparable with a curvature radius of a cantilever calculation of currents leads to the greatest errors therefore AFM-microscopy for such structures is not applicable.

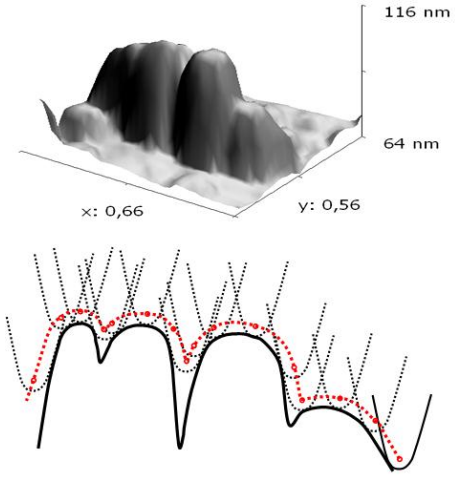

Fig. 2 – Dimensional image area of tungsten and recovery profile

Table 2 – The emission current density at the tops of nanostructures

Samples	r, nm	β, sm^{-1}	E, $\times 10^7$ V/sm	j, A/sm^2 (j^*, A/sm^2)	j / j^*
Copper	279 (289)	13800 (13400)	0.72 (0.70)	$15 \cdot 10^{-9}$ ($1 \cdot 10^{-9}$)	15
Acid-etched copper	153.5 (163.5)	22520 (21370)	1.17 (1.11)	$30.30 \cdot 10^5$ ($1.75 \cdot 10^5$)	17

2.3 Interference of Local Fields

The accounting of distribution in an arrangement of nanostructures with parabolic profiles by means of numerical calculation allows to consider interference of local electric fields of adjacent structures and to define and supervise injection functions of the nanostructured electrodes. The result of numerical calculation of dependence of strengthening coefficient β_{loc} at top of characteristic structure with height h on a acid-etched copper surface

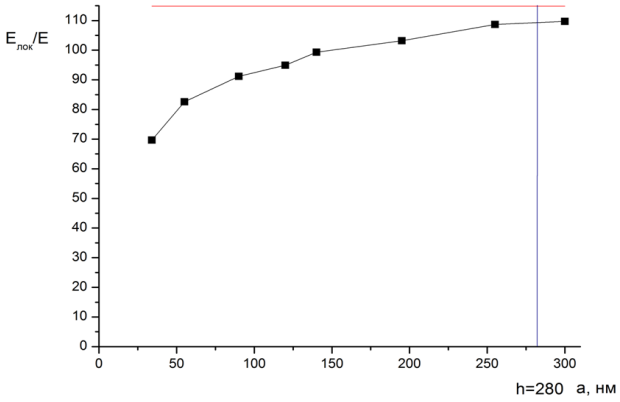

Fig. 3 – Dependence $\beta_{lok} = E_{lok} / E$ on top of the central structure from distance a (average diameter structure $d = 35$ nm, height $h = 280$ nm, the radius of curvature of the $r = 163.5$ nm (etched copper)). Horizontal red lines marked β_{lok} for single peaks, blue vertical line indicates the height of the top of h

(taking into account interference of electric fields of the adjacent regularly located structures) from distance of a (nm)) between lines connecting tops of structures is shown in Fig. 3. Calculations showed that the greatest possible density of structures at which interference of their local

electric fields has little effect on the injection of charges from each separate structure and respectively answering to the most intensive charge formation from a predetermined surface area of an electrode can be realized at distance 1.4 h between tops of nanostructures.

2.4 Problems of the Exact Description

The description of injection of charges from tops of such structures of a surface of at the interface between the dielectric liquid metal in case of electro-convections (EC) is complicated a number of factors.

They include lowering the height of the potential barrier of an exit of ions of a crystal lattice of metal in liquid due to the polarization of the molecules of the electric double layer (EDL), reduction or increase in work of an exit of electrons from a metal surface the adsorptive layers [6], dimensional effects in EDL and for nanostructures [3], a discharge and charging of impurity and molecular ions of liquid, self-organization processes, etc. Accounting for these processes together extraordinarily complex.

So Raman scattering (RS) spectra of the polished copper sample having contact with air and being in the closed container shows eventually the presence of the adsorption processes and oxidation of a blanket of copper (Fig. 4).

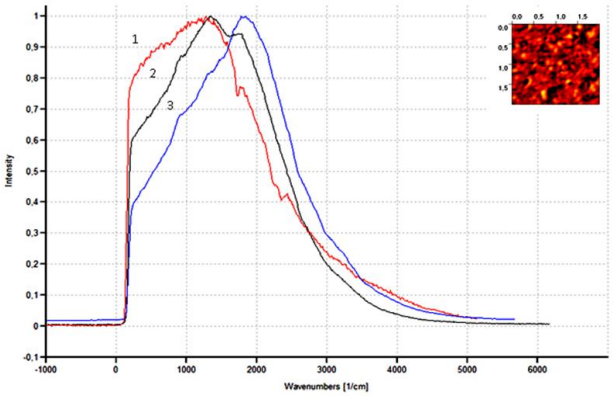

Fig. 4 – The Raman spectrum (532 nm) nanocrystalline copper electrode: the last polish (1), after 2 days (2), one month later (3)

It is visible that in the beginning (schedule 1) the copper sample gives a range of oscillating character as metals aren't active for RS but after a long period the maximum of intensity moves from 1250 to 1750 cm^{-1}.

These dependences show inevitability of influence on characteristics of injection processes of adsorption and oxide films.

3. CONCLUSIONS

Creation of periodic nanostructures on surfaces of known geometry on electrodes surfaces allows to control charge formation by electric fields.

AFM topology surface structures of the copper and the tungsten electrodes polished and etched acid by quality to 20 nm showed that the tops of such structures are approximated with great certainty parabolic profiles.

Calculations of local fields shown on the possibility of autoemission currents on the tops of these nanostructures on the Fowler-Nordheim equation.

It is supported by experimental current-voltage characteristics [7] for electroconvection with using macroscale peaks electrodes.

The exact accounting of the sizes of a cantilever is necessary at charge formation calculation from the tops of nanodimensional structures according to ASM-images.

The account of the sizes of a cantilever leads to increase of values of currents density in tens times at curvature radiuses of structures tops about 200 nm and and the cantilever tip radius of 10 nm

This method for calculation of charge formation isn't applicable due to a large error if curvature radiuses of structures and of a cantilever are comparable.

Numerical calculation shows that the most intensive charge formation from a predetermined surface area of an electrode taking into account interference of local fields of the considered structures can be realized at distance 1.4 h between tops of nanostructures.

One of difficulties of the description of charges injection from nanostructures at electroconvection is existence of a electric double layer and also processes of adsorption and oxidation of the electrode surface.

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