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EMISSION AND EROSION PROCESSES, TERMOELASTIC AND TERMOPLASTIC DEFORMATION IN CATHODE SPOTS OF GAS DISCHARGE

INTRODUCTION

Theoretical model

The change of electrode surface geometry due to erosive processes and thermoelastic deformation, in particular of thermoelastic fraction will influence on emission processes. The mass deposition defines the process generation of space charge in the near cathode zone, and consequently influence on emission processes. This work is devoted to the analysis of interconnection of thermoelastic deformation, emission and erosive processes.

Both moving and stationary cathode spots are considered in whose elementary volumes the heat exchange is effected due to the spot motion, heat conductivity, evaporation front displacement, Joule heating, melting heat and thermoplastic deformation. The heat balance in the elementary volume can be expressed as:

$$\frac{dT(x,y,z,t)}{dt}+\tau_2\frac{d^2T(x,y,z,t)}{dt^2}\ldots-V_n\frac{\partial T(x,y,z,t)}{\partial y}=\frac{1}{C_v[T]}\nabla\lambda[T]\nabla T(x,y,z,t)+$$

$$+V_\phi\frac{\partial T(x,y,z,t)}{\partial x}+\frac{A\rho[T]}{C_v[T]}j^2(x,y,z,t)+\frac{Lev}{C_v[T]}\frac{dVev}{dt}+\frac{1}{C_v[T]}\frac{\partial W(x,y,z,t)}{\partial t}$$

The dynamics of the spot and cathode region parameters variation was studied using the technique `[1, 2]. The current density was determined on the assumption of thermo-autoelectronic mechanism taking into account the emission rate increase because of thermal stresses [1] and explosive emission [3]. The current density at each point of electrode is determined by solving the Laplace equation for elementary volume. The boundary conditions account for the surface heat source due to bombardment with charged particles with regard for Nottingham heat and emission cooling, heat removal as a result of evaporation, Heat exchange due to mutual irradiation of plasma and electrode is also taken into account:

$$-\lambda[T]\frac{\partial T(x,y,z,t)}{\partial x}=F_i-F_e+F_{eo}+F_{not}+\sigma\left[\varepsilon pT_p{}^4-\varepsilon T^4(x,y,z,t)\right]$$

For surface temperatures below the melting point the rate of evaporation is calculated on the assumption of Langmuir's mechanism, at higher temperatures Frenkel's mechanism is employed. The increase of summary pressure of the electrostatic, electromagnetic. electrodynamic, gasokinetic and thermoelastic forces in excess of surface tension forces was the condition of metal liberation from liquid phase. The condition of electrode material destruction in solid phase was taken as the increase of thermal stresses in excess of ultimate strength. The problem made use of linear approximation of the material and physical characteristics and specific electrical resistance vs. temperature. The thermoelastic potential of unit volume W was determined through the values of displacements and shifts which, in their turn, were calculated by solving the equation of thermoelastic potential of displacement. The joint problem of heat conductivity and thermal elasticity was solved numerically by a computer.

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RESULTS AND DISCUSSION

The examination of the dynamic processes in the stationary cathode sport for plane and pointed cold cathodes was made.

In the result of the solution of near electrode, erosive, thermoelastic and emissive problem [1, 2] were determined the temperature field, temperature stresses, speed of erosion, the area of cathode spot, the current in spot and transferring charge in it.

The starting parameters of cathode spot which we use in calculations, are $T_н = 300K$, $U_к = 20V$, $n_п = 10^{22}$ m^{-3}, $T_п = 1eV$.

The change of temperature (Fig.1) in time for plain molybdenum cathode is shown on fig.1. From this diagram [Fig. 2] it follows that to $t = 4{,}3 \cdot 10^{-7}$ s the metal removal in vapour phase due to Langmuir's mechanism is appeared, and to $t = 1{,}4 \cdot 10^{-6}$ s the evaporation is realized due to Frenkel's mechanism. In the next moment of time the conditions for liquid phase of metal ejection is appeared ($t = 1{,}2 \cdot 10^{-7}$ s – the time of blow-out), when the erosion velocity have grown in order. The temperature of surface descends to the fusing temperature, and then the growth of temperature and erosion speed is observed. In the conditions of repeated ejection of liquid phase are made and the process is repeated.

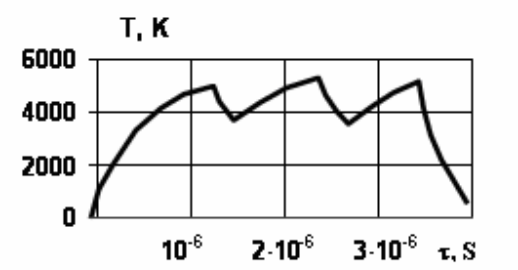


Figure 1 – The change of maximal temperature in time on the plain molybdenum cathode

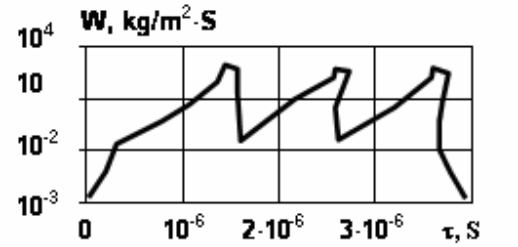


Figure 2 – The change of maximal speed of erosion in time on the plain molybdenum cathode

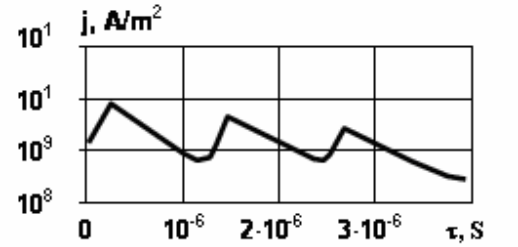


Figure 3 – Dynamic of current density change on the plain molybdenum cathode

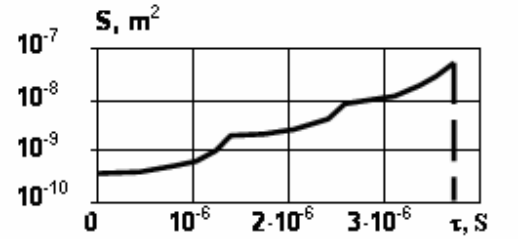


Figure 4 – Dynamic of spot area change on the plain molybdenum cathode

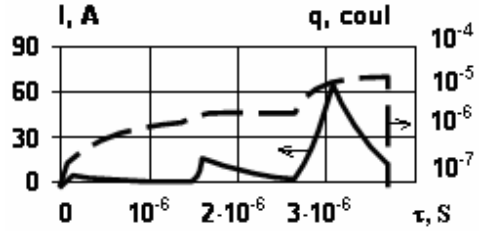
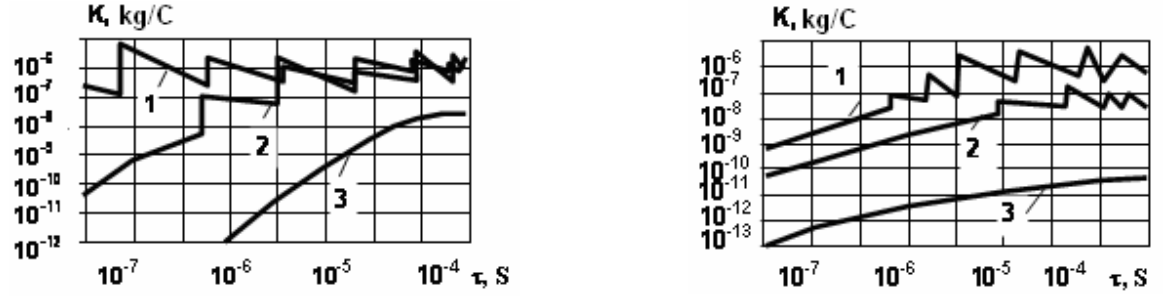


Figure 5 – The relation of transferred change in spot and current in spot from time

In the moment of spot birth some growths of current density have taken place due to growth of emission under action of non-stationary temperature tensions [Fig. 3]. Then the mechanism of emission from autoemissive displace to thermoemissive, and after ejection of liquid metal the process is repeated.

The character of change the area of cathode spot in time is (shown on Fig. 4). In the moment of birth the size of spot is small, to the first delete of material in liquid faze there is a smooth increase of spot area and after ejection of metal in liquid phase the increase of spot size repeats.

The current in a spot (Fig. 5) in initial moment increases from the increase of emission as a result of thermoelastic deformation, and then diminishes because of passing to thermoemission mechanism after the ejection of metal in a liquid phase ($t = 1{,}2 \cdot 10^{-6}$ s) there is an increase of current density as a result of action of autoemissive mechanism, and the further passing to thermoemissive mechanism results to the descent of current density. At the same time the substantial growth of current have taken place due to the considerable increase of emission surface (Fig. 4, 5) and passing to the autoemissive mechanism: subsequent descent of current density is related to passing to thermoemissive mechanism.



a b

Figure 6 – The relation of erosion coefficient from the lifetime of the cathode spot on aluminum (a), and moving cathode spot on molybdenum (b) under different current density 1-10^{11} A/m^2, 2 -10^{10} A/m^2, 3 -10^3 A/m^2

The dependence of transferring charge in a spot on time (Fig. 5) has its own feature at the realization of ejection of metal in a liquid phase.

In erosive and thermoelastic problems on the acute cathode the dynamic of near by electrode zone, particularity of thermoelastic problem on the acute cathode, the increase of emission because of geometry change and temperature tensions action, and also the mechanism of explosive emission taken into account. The emission equation of Mallin and Gass is utilized.

Also the mechanism of explosive emission ($t = 10^{-10} \ldots 10^{-9}$ s). On the transfer of current these factors do not render the substantial influence, and a charge is mainly curried by thermoautoelectronic mechanism with predominating of current transfer by thermoautoelastions (Fig. 6).

As a result of decision of this task we get the fields of temperatures and temperature tensions, and also the speed of removal of material from unit of spot surface on a tungsten electrode at the following initial conditions in a spot: $T_к$ = 1000K, $n_p = 10^{22}$ 1/m^{-3}, U_k = 1,2 eV. And on the Fig. 7 - 9 is shown the change of temperature in an electrode spot, the change of current density and maximal speeds of erosion.

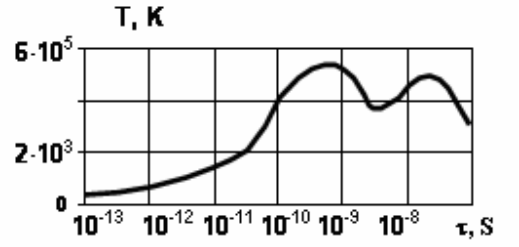


Figure 7 – The change of maximal temperature on the surface of the acute tungsten cathode in time

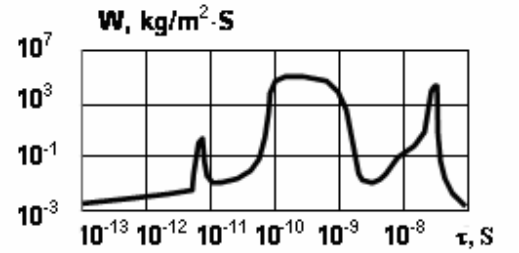


Figure 8 – The change of erosion speed on the surface of acute tungsten cathode in time

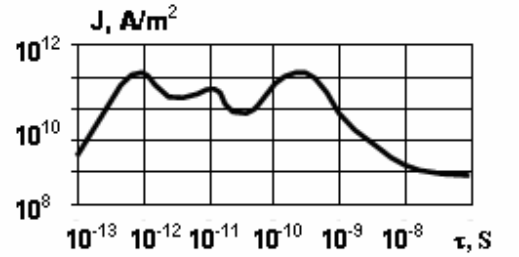


Figure 9 – Dynamic of current density change on the surface of acute tungsten cathode

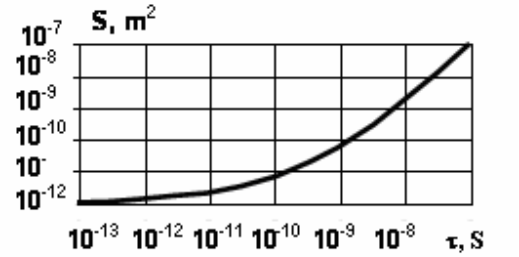


Figure 10 – The change of spot area on acute cathode in time

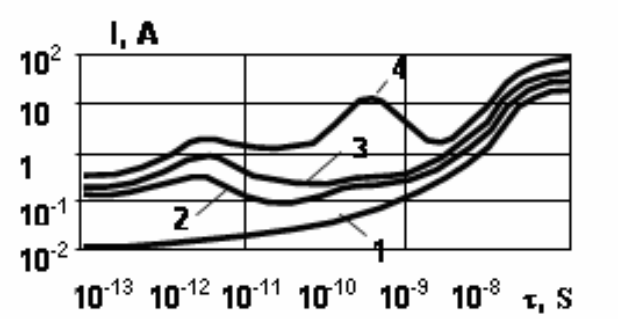


Figure 11 – The change of current in spot in time under the accounting only thermoemission – curve 1, thermoemission and its heighten for account of thermal stress – curve 2, with an additional influence of geometry – curve 3, and as well as additionally with explosive emission – curve 4

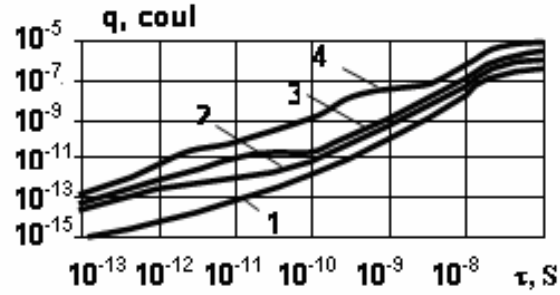


Figure 12 – The change of transferred charge in spot in time under the accounting only thermoemission – curve 1, thermoemission and its heighten for account of thermal stress – curve 2, with an additional influence of geometry – curve 3, and as well as additionally with explosive emission – curve 4

The analysis of the got decisions shows that for the characteristic time about 10^{-12} s the substantial increase of emission is possible as a result of temperature tensions, thus their action in this moment can actual to the thermoplastic destruction of cathode material, and consequently, to the output of mass due to thermoplastic shear (Fig. 7-9).

Simultaneously the emission current is increased in the area of destruction (characteristic time t = 10^{-11}…10^{-10} s), which, by-turn, raises the intensity of volume source of heat, promotes the growth of conditions of Frenkel, and then explosive evaporation and in the total results in realization of explosive autoelectronic emission (characteristic time t = 10^{-10}…10^{-9} s, Fig. 9). Thus the substantial ejection of mass takes place because of explosive evaporation and in the range of time t = 10^{-9}…10^{-8} s there is a considerable decrease of current density (on two-three orders) and erosion speed (on three-four orders), that is explained by the transition of emission to thermoautoelectronic mechanism, and evaporation – to Frenkel (Fit. 8). Later on the emission is descended and the erosion speed is raised some (in correspondence with Frenkel evaporation) fit

with the Frenkel evaporation. Then there is a jumping growth of erosion speed, associated with the metal ejection in liquid phase, and current density continue descend herewith.

On fig. 10-12 the dependence of spot area S (Fig. 10), current I (Fig. 11) and charge (Fig. 12) from time is shown. From the picture evidently, that the area of spot grows in course of time, thus especially quickly from 10^{-8} to 10^{-7} s (Fig. 10).

Current and charge transferring by a spot depending on time, were examined taking into account a thermoelastic mechanism (curves 1), increase of emission as a result of temperature tensions (curves 2), influence of change geometry on emission (curves 3), and also to explosive emission (curves 4). On the size of current the substantial influence is rendered the increase of emission because of thermoelastic deformation of electrode material (characteristic time t = 10^{-12} s) (Fig. 11, 12), the change of geometry as a result of thermoelastic shear of the cathode material (t = 10^{-11}…10^{-10} s) and also the mechanism of explosive emission (t = 10^{-11}…10^{-10} s). On the transfer of current these factors do not render the substantial influence, and a charge is mainly curried by thermoautoelectronic mechanism with predominating of current transfer by thermoautoelectrons.

SUMMARY

All of the considered additional mechanisms of emission increase insignificant change the transfer of current, but they intensify the thermoemission, that testifies to the necessity of account of given effects at the research of processes in the cathode spots.

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