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THE MODEL AND CALCULATION OF HOLLOW CATHODE EROSION

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Absract

The numerical method of the hollow cathode life-time calculationand observing of its working characteristics changing are offered. The inad-missible increasing of cathode orifice is accepted as the main cause of its failure damage. The mechanism of thermo-stimulated cathode erosion is considered as the main one of the cathode material removing. The physical and mathematical model of the plasma processes inside the hollow cathode is used for the determination of the erosion factors values. The comparison with the experimental data is made. The given model can be used for the formulation of the recomedations for hollow cathode design achiving larger life-time values.

Investigated problem

The hollow cathode used as electron source for electric propulsion rocket thruster has the restriction of its life-time because of arc discharge parameters are changing during the work time and then have obtained the inadmissible values down to the cathode failure. One of the main causes of the discharge parameters changing is the increasing of the orifice diameter that results into the decrease of gas pressure inside the cathode and the increase of discharge voltage and the erosion rate.

The hollow cathodes low-voltage arc discharge that is experimentally observed is charecterized by the voltage and cahtode potential drop close and less then plasma-making gas atoms ionization potential and is the most acceptable having into consideration the cathode lifetime. The bombing particles energy is near 8 - 15 eV in that regime.

Cathode erosion model

The erosion model is offered that considers the orifice diameter increase as a result of cumulative influence of ion bombardment and thermal vibrations of solid surface crystal grid atoms. Such approach is known as the thermo-stimulated cathode erosion (TSCE) [1]. We may notice that the classical cathode erosion theory declares the zero of erosion rate in that range of the bombing ions energy - less than the erosion treshold. The surface atoms and the bombing ions are described as the solid balls and the connections between adjacent surface crystal grid atoms - as linear ones.

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The probability of the surface atom separation per unit of time as a result of its thermal vibrations as well as the bombing atom pushes is determined by the next ratio:

$$W = W_T + I\pi R_a^2 W_k \quad . \qquad (1)$$

where I - the bombing particles flow density;

R_a - the maximal impact parameter value, i.e. the half of the effective distance between the atoms in surface shield.

The parameters W_T and W_k are the probabilities of surface atom evaporation and breaking-out per unit of time. The evaporation probability is determined as:

$$W_T = \frac{1}{\tau} \cdot \exp\left(\frac{k\delta^2}{2T}\right) , \qquad (2)$$

where τ - the period of the crystal grid thermal vibrations;

δ - the minimal for the breaking-out atom's displacement from the equilibrium state;

k - an effective elasticity constant;

T - surface temperature (in eV).

The breaking-out koefficiency W_k is calculated by the routine:

$$W_k = \int_{C_m}^{\infty} f(C) \cdot W_1(C) dC \quad , \qquad (3)$$

where f(c) - the post-impact displacement distribution function;

$W_1(c)$ - the breaking-out probability of atoms with the initial post-impact displacement C:

$$W_1 = \int_0^{\infty} f(a) \cdot W_0(a,C) da \quad , \qquad (4)$$

where $W_0(a,c)$ - the breaking-out probability of atoms with the pre-impact thermal displacement a and post-impact one C:

$$W_0 = \begin{cases} 0 \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_}, (C+a) < \delta_-; \\ \frac{1}{\pi} \cdot \arccos\left(\frac{\delta^2 - C^2 - a^2}{2aC}\right) \text{\_\_}, (C+a) > \delta > |C-a|_-; \\ 1 \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_}, |C-a| > \delta_-; \end{cases} \qquad (5)$$

f(a) - thermal displacement distribution function:

$$f(a) = \frac{ka}{T} \cdot \exp\left(-\frac{ka^2}{2T}\right) . \qquad (6)$$

The function f(c) can be written as:

$$f(C) = \frac{1}{\alpha} \cdot \sqrt{\frac{k}{2E_1}} \cdot \left(\frac{R_1+R_2}{R_a}\right)^2 , \qquad (7)$$

where R_1 , R_2 - bombing and bombed particles' effective radiuses;

α - proportional factor between maximal normal component of displacement inside the surface on initial stage of first cycle of initiated atom's motion and the same one outside the surface in the second part of first cycle of displacement; the value $\alpha<1$ can be determined as a result of solving of the initiated surface atom's dynamic problem;

E_1 - maximal energy that can be transmitted to initiated surface atom:

$$E_1 = E_i \cdot \frac{4m_1m_2}{(m_1+m_2)^2} , \qquad (8)$$

where m_1 and m_2 - bombing and bombed particles' masses;

E_i - bombing ion energy.

The greatest C and the smallest C possible post-impact displacements can be obtained from:

$$C_0 = \alpha \cdot \sqrt{\frac{2E_1}{k}} , \qquad (9)$$

$$C_m = C_0\left(1 - \left(\frac{R_a}{R_1+R_2}\right)^2\right) . \qquad (10)$$

<u>Complex using of erosion and cathode models</u>

The computer analysis of the erosion using this model had demonstrated the considerable sesitivity of the cathode material removalrate to the erosion factors: bombing energy E_i and surface temperature T with the direct proportionality to the ion flow density I. Due to the change of these parameters with the increase of the orifice diameter there would be non-linear charecter of that diameter dependence on time.

To take this fact into consideration the hollow cathode plasma processes model was used discribed in [2].

Theotetical and experimental results comparement

Below the Fig.1 submits the experimental orifice erosion dependence and the theoretical one calculated by presented model for cathode KE-50D operated on 50 A . The abcence of theoretical line on the first stage of cathode operation is caused by so-called start period of cathode operation, which is characterized by another erosion mechanismes. So, the presented model is able to calculate cathode erosion in statinary cathode regimes.

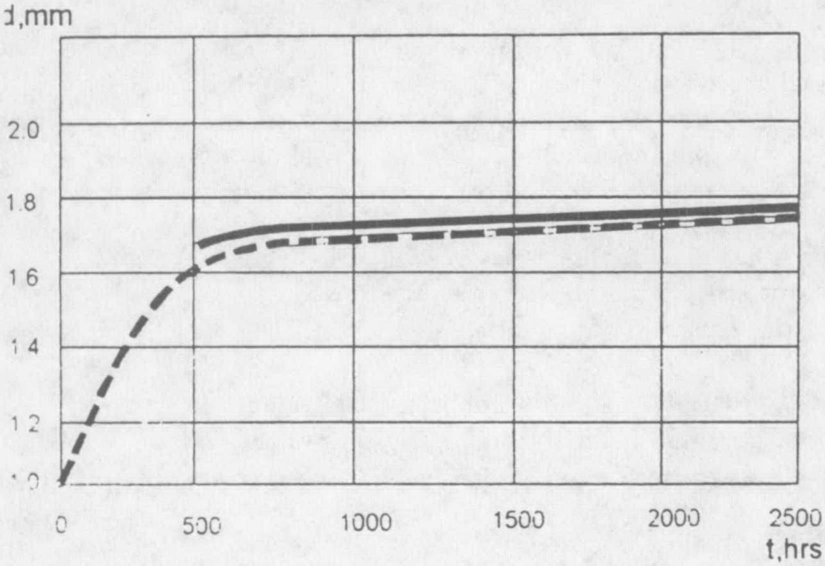

Fig.1. Orifice diameter versus time for experiment and calculations.

Summary

Using both the hollow cathode erosion and plasma processes models there is possible to investigate the hollow cathode work in time down to its parameters expand from the critical borders. The last meens the finishing of the hollow cathode life-time. So the life-time forecast can be made. The model can be used for making the recomendations on the hollow cathode designing to obtain greater life-time. Some constants used by model were taken in an accordance to experimental data.

References

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