The complex mathematical model and the calculation method are presented, which permit to calculate main local and operation descriptions of high emission gas-discharge hollow cathodes, including the forecast of life-time in steady state operation mode. The mathematical model uses the kinetics description of electrons and electric gas dynamics description of atoms and ions inside the cathode. The state of activator film and surface temperature field are also calculated. Semi-empirc erosion model is based on the thermally stimulated cathode sputtering theory, which is developed by authors.

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This condition can be realized either in the most thin flow section (exit orifice) or because of quasi neutrality break-up (inside Langmuir layer).

Fig. 1. Complex model structure

The emission current depends on the state of activator film. The equations describing the activator dynamics in the volume and on the surface were also considered like mutual boundary conditions. Also activator dynamics and emission currents depend on temperature surface distribution, which in turn is determined on heat flow from the volume. The rate of ionization and excitation as well as electron back current density depends on the peculiarities of electron energy distribution in high energy area.

According to these ideas the complex model includes the following sub-models:
- the processes inside hollow main volume;
- the processes near the orifice;
- Langmuir cathode layer;
- electrons energy distribution;
- heat stimulated cathode sputtering;
- film thermal emitter work and activator dynamics;
- cathode surface temperature distribution;
- external column.
The complex models unite the continuum methods (in the tasks of electric field and plasma components space behavior) and kinetics approach (in the task of electron energy distribution).

It is shown that the main collision factors, which must be considered in plasma components space dynamics, are ion mass flow velocity decrease and velocity dispersion (temperature) increase due to appearance of new ions inside already accelerated ones because of ionizations. We have named these factors like “ionization deceleration” and “ionization heating”.

Electron energy distribution plays the most important role in these models. The kinetics equation in diffusion approximation (Landau mode for collision integral) is formed: 
\[ v \cdot \nabla f(v) + \frac{e}{m_e} \nabla \varphi \cdot \nabla f(v) = \frac{\delta f(v)}{\delta t} \]
and
\[ \left( \frac{\delta f(v)}{\delta t} \right)_e = -\frac{1}{v^2} \frac{\partial}{\partial v} (v^2 \Gamma(v)) , \]
where initial form of electron flow density in velocity space is:
\[ \Gamma(v) = \int_0^\infty \int_0^{2\pi} \int_0^{2\pi} \int_0^{2\pi} \int_0^{2\pi} f(v') f(v') f(v' - \delta v) f(v' + \delta v) \delta v f(v') f(v') f(v' - \delta v) f(v' + \delta v) \delta v f(v') f(v') f(v' - \delta v) f(v' + \delta v) \delta v \times \ldots \]

Other main part of complex model is erosion sub-model based on HSCS theory. Surface atoms flow in this theory is considered as a result of both ion bombardment and surface atoms thermal oscillations with sputter coefficient, which is the function of ion energy and surface temperature:
\[ \Gamma_p = P(e_i, T) \Gamma_i . \]

The sputter coefficient is calculated using the atoms oscillation faze distribution, velocity direction and value distributions:
\[ P(e_i, T) = \frac{\pi}{2} \varepsilon_m \int_0^{\pi} \int_0^{2\pi} f(\varphi) f(v) \sin \vartheta d\vartheta d\varphi . \]

The calculation results for voltage and orifice radius evolution are shown in Fig. 2 and Fig. 3.

Test and forecast results (Fig. 4) for orifice radius evolution had demonstrated good coincidence.

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Thus, the models and software developed permit:
- to make life-time design of HEGHC via optimization by the necessary life-time criterion;
- to make the calculation of evolution of cathode main work descriptions;
- to create calculation-experiment methods of HEGHC life-time tests.

REFERENCES


