BOUNDARY CONDITIONS FOR PLASMA JET FOOTPOINT ON VACUUM ARC CATHODE

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The paper considers the boundary conditions for the plasma jet footpoint on cathode of the vacuum arc. It is presented results of calculations for the concentration, ionic composition and flow of plasma, current density, electron temperature, plasma ideality parameter on the border of the spot plasma core for copper electrode.

1. Introduction

One of the property of the metal vapor arc is a plasma jet originated from the cathode spot [1] as a result of the electrode erosion. In some applications it is a shortcoming due to reduction of the electrode lifetime, while in an others it used for technological purposes as a source of the metal vapor and ions [2, 3]. Closely related to this phenomenon is the explosive electron emission [4], when the high power electron current extracts from the expanding plasma ball with the footpoint on the electrode.

Detail analysis of numerous experimental and theoretical data was presented in [5, 6]. There are a few theories which promises new insight in cathode spot processes including the plasma jet generation. Some of them are stationary and assumes within the spot the surface with the metal “liquid – vapor” phase transition [7, 8, 9]. The other models are substantially non–stationar and based on the ecton theory [10, 11].

2. The problem geometry and physical model

Following to the work [12] the structure of expanding plasma ball and cathode spot schematically illustrated on **FIG. 1,*a*.** The inner Zone 1 are the highly collisional and non–ideal dense plasma core with the subsonic expansion and radial dimensions proportional to the cathode spot radius $r \approx R_c \leq 10$ μm. This Zone 1 includes the pre–sheath and space charge layer on which realize the near cathode potential fall $U_c \approx 15$ V. That sheath thickness is proportional to Debye radius $R_d \leq 10^{-5}$ cm so its processes might be described one–dimensionally. In Zone 2 begins plasma acceleration to supersonic velocity, ionization becomes non–LTE (local thermodynamic equilibrium) and “freezing” of the ionization states occurs. The plasma in an outer Zone 3 is collisionless and on distances $r \geq 10^2$ μm ions accelerates to supersonic velocity with the energy up to ~100 eV which exceeds the total difference of potential on the discharge electrodes.

In our model it was assumed that the origin of the flow of heavy atomic particles (in a kind of atoms or ions) is the evaporation of the metal within the cathode spot. Part β of the

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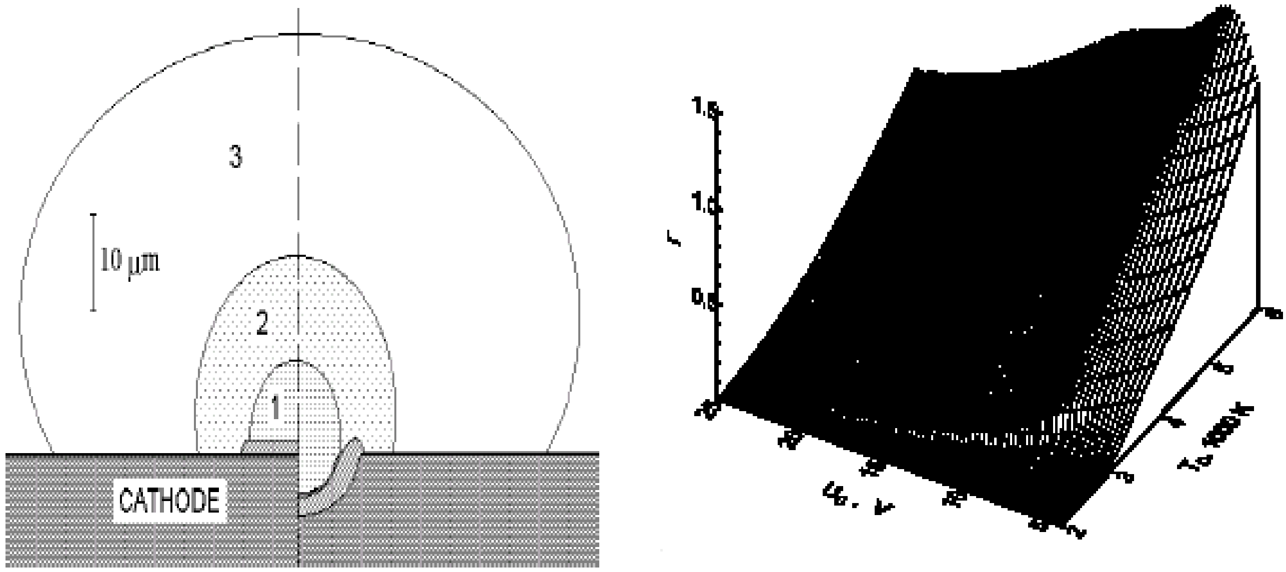
vapor flow I_{v0} returns to cathode after ionization into the pre–sheath of the dense plasma. Formation of the positive space charge layer near the surface leads to increasing the electric field on the surface followed by increasing the electron emission current. Accelerated in cathodic potential fall emitted electrons provides energy for (i) ionization of evaporated atoms and (ii) formation of the charged particles flows. The physical model for the set of coupled processes presented in more details in [13]. The self–consistent description of the near cathode plasma sheath was carried out on the basis of the system of balance equations with the final dependence of all calculated parameters on pair (T_c, U_c) – the local values of the cathode surface temperature T_c and cathode fall U_c.



a) *b*)

FIG. 1. Schematic illustration of the assumed structure of the cathodic plasma ball (*a*) and plasma ideality parameter $\Gamma = e^2/kT_eR_d$ for dense plasma core (Zone 1) in dependence on local surface temperature T_c and cathode potential fall U_c (*b*). Zone 1 – dense plasma core with the moderate non–ideality and subsonic hydrodynamic flow of the heavy particles, 2 – transition to supersonic velocities and ions charge states "freezing" occurs, 3 – zone of the ions final acceleration in collisionless expansion.

The influence on ionization of the non–ideality of the near cathode plasma [14, 15] was taken into account. Presented on Fig.1,*b* plasma parameter approves used approaches.The times of attainments of the ionization equilibrium [16] in plasma core of the cathode spot for the electron temperature $T_e \geq 2.5$ eV, current density $J_c \geq 10^5$ A/cm^2 and concentration of heavy particles $N_p \cong N_i \geq 10^{17}$ cm^{-3} are much smaller compare to times of the heat transition process in cathode bulk. So dependence on time t realizes in cathode processes as dependence on $(T_c(t), U_c(t))$

3. Results and discussion

The calculated parameters on the cathodic side of the dense plasma core (Zone 1) are presented in Table 1 for copper cathode. That is the current density J_c, electron temperature T_e, ion concentration N_i, plasma parameter $\Gamma = e^2/kT_eR_d$ and flow $I_v = I_{v0} \cdot (1-\beta) = \langle N_i \upsilon_i \rangle$, ion mean charge $\langle Z_i \rangle = \Sigma z f_z / \Sigma f_z$, and ionic composition f_z of the plasma.

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Presented parameters differs by dependence on the surface temperature and the near cathode fall. For example, the spot current density are dependent on the T_c, and practically independent from the U_c, at least for $U_c \geq 15$ V. Such dependence are character also for the ion concentration and flow. The plasma parameter decrease, and mean charge increase with increasing U_c or decreasing of T_c.

Table 1. Parameters of dense plasma core on the cathodic side.

U_c	T_c	J_c	T_e	N_i	Γ	I_v	$\langle Z_i \rangle$	Ion fraction f_z (%)			
V	K	A/cm^2	eV	cm^{-3}		cm^{-2}s^{-1}		+1	+2	+3	+4
25	5000	1.3×10^8	5.26	2.08×10^{20}	0.36	2.8×10^{24}	2.36	1.67	61.89	34.79	1.66
	4000	2.6×10^7	5.01	3.85×10^{19}	0.17	3.9×10^{23}	2.56	0.46	45.99	50.37	3.19
	3000	1.2×10^6	4.65	2.19×10^{18}	0.05	1.3×10^{22}	3.03	0.02	12.52	72.26	15.20
20	5000	1.3×10^8	4.31	1.99×10^{20}	0.44	3.6×10^{24}	2.06	5.11	83.67	11.17	0.05
	4000	2.8×10^7	4.09	3.58×10^{19}	0.21	5.1×10^{23}	2.16	1.97	80.37	17.57	0.09
	3000	1.3×10^6	3.79	1.96×10^{18}	0.06	1.8×10^{22}	2.50	0.17	49.89	49.32	0.62
15	5000	1.3×10^8	3.25	1.95×10^{20}	0.62	4.7×10^{24}	1.80	20.94	78.26	0.80	0
	4000	3.0×10^7	3.01	3.54×10^{19}	0.30	6.9×10^{23}	1.87	13.94	85.34	0.72	0
	3000	1.4×10^6	2.79	1.82×10^{18}	0.08	2.6×10^{22}	2.00	2.54	94.92	2.55	0

The other parameters might be derived from the data presented in Table 1. That is a pressure $P_c \approx \langle Z_i \rangle N_i T_e \approx 20 - 7\times10^3$ bar, specific erosion $G_m \approx m_a I_v / J_c \approx (2\div7)\times10^{-6}$ g/(A·s). It is interesting to note, that such a small specific erosion (for copper) is enough to close material sub–cycling on the active surface of the spot.

It seems quite reasonable to suppose some kind of "plateau" for parameter values within the Zone 1 when the temperature T_c and potential fall U_c hasn't pronounced gradients over the spot surface and its geometry remains the semi–spherical.

4. Summary

Boundary conditions for the plasma jet footpoint on cathode has a wide intervals of change in dependence on the surface temperature and cathode potential fall. That is the possible origin of the scattered distribution of the experimental data.

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