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Letters to the Editor

CORPUSCULAR DIAGNOSTICS OF A HOLLOW CATHODE DISCHARGE IN THE PROCESS OF THE THIN METAL LAYER GROWTH*

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КОРПУСКУЛЯРНАЯ ДИАГНОСТИКА РАЗРЯДА В ПОЛОМ КАТОДЕ ПРИ ПРОЦЕССЕ ОБРАЗОВАНИЯ ТОНКИХ МЕТАЛЛИЧЕСКИХ ПЛЁНОК

In investigating the mass spectrum of the ion beam emerging from the extraction capillary hole in one of the discharge chamber cathodes of the double cathode discharge, we have found that with the pressure $P_d \approx 100$ Pa and the discharge voltage $U_a \in (500, 1000)$ V the density of the cathode metal ions becomes comparable to that of the argon ions. The mass spectrum reproduces the cathode material composition to a great accuracy [1]. At the optimum values of the discharge parameters

$$U_{a\,\mathrm{stab}} = 750\ \mathrm{V},\ I_a = 5\ \mathrm{mA},\ p_d = 130\ \mathrm{Pa},\ h = 10\ \mathrm{mm},$$

where h is the separation distance of the cathodes, a sufficient temporal stability of the energy of the ions measured is ensured.

For the stainless steel alloy composition Cr — 19.86 %, Fe — 70.59 %, Ni — 9.55 % the numerical evalution of a great number of measurements yields the following values: Cr — (20.63 ± 0.16) %, Fe — (68.89 ± 0.21) %, Ni — (10.47 ± 0.13) %. The systematic error obscuring the resluts is, apparently, the consequence of different physical and chemical properties of atoms of each of the alloy components and can be excluded by a calibration procedure. At a discharge voltage exceeding 1000 V and a discharge current density of about 20 mA/cm^2, the metal to non-metal ion flux ration M reaches the value equal to or even exceeding 1.

The application of this method to the measurement of mass spectra in the course of the thin metal layer growth in the apparatus described in [2] has not yielded the expected results. Although the thin layer growth rate measurements give evidence of the high ion density in the discharge [2], the metal ion current to the non-metal ion current ratio does not exceed the value $M = 10^{-2}$. The measurements have been performed within the pressure range $p_d \in (5, 20)$ Pa, with the discharge current $I_a \in (50, 500)$ mA, and with the voltage between the anode and the cathode $U_a \in (500, 1000)$ V.

Making a groove of the form of the metric M 14 thread on the cathode inner wall with the aim to enhance the metal atom emission and the electron secondary emission and, therefore, the volume ionization rate, does not influence the M-value significantly. The outstanding phenomenon of the splitting of the initially smooth distribution function occurs, however, in the beam energy spectrum [3]. This phenomenon resembles strikingly the energy losses of an almost monoenergetic ion beam in the course of the ionization on the atoms and ions of Ar and Fe [4]. To verify the dependence of the energy spectrum shape on the angle at which the measured particles leave the extraction aperture the horizontal shift of the discharge chamber has been ensured. The angle dependence of the energy spectrum shape has been confirmed.

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To test the influence of the groove on the inner cathode surface on the phenomenon mentioned above and on the width of the peaks, the cathode with the thread groove of the apex angle of 30° has been introduced into the discharge. A marked narrowing of the peaks occurs. In further experiments the discharge chamber has been mounted on a tilting mechanism enabling us to tilt the discharge chamber axis in two mutually perpendicular planes.

It can be deduced from the features of the energy spectra that, in the investigated range of the ion energies, there exists the limit angle of inelastic scattering of the order of several tens of angle minutes [5]. The particle of the mass m scattered inelastically on the particle of the mass M and loosing the energy quantum Q cannot be scattered at angles lower than the limiting angle. For various values of m, M and Q, empty cones must exist, in which no particles with the energy loss Q can be found.

The concept of the limit angle of inelastic scattering is based on the following assumption: the internal energy state of one of the two colliding particles can be changed by a value Q only if the total potential energy of the particles (in the case of purely repulsive force) is greater than or at least equal to Q. In the given range of energies of impacting particles $T_i \in (500, 750)$ eV and for scattering angles $\vartheta \in (0°, 2°)$, the process being covered by the term "smooth collision" [6], the model described above may be considered as suitable. The solution of the potential scattering of two particles m and M may be reduced to the solution of equations of motion of a single fictitious particle with a reduced mass M_r in the potential field $U(r)$. As soon as the potential energy of the particle with the reduced mass M_r reaches the value Q, the potential energy turns into the internal energy of one of the particles. The change of the internal energy is described in terms of the change of the potential. The limit angle can be determined analytically for the potential of the form $U(r) = r^{-n}$, $n = 1, 2$. For the parameters $T_i = 750$ eV, $Q = 15$ eV, $m = M$ we obtain: $n = 1 - \vartheta_{\mathrm{lim}} = 35'$, $n = 2 - \vartheta_{\mathrm{lim}} = 53'$.

The inelastic collision of two particles, the projectile m and the target M is described by the equations expressing the energy and momentum conservation laws [7]. Denoting $q = Q/T_i$, $\mu = 1 + m/M$, the following relation between scattering angles can be derived

$$\mathrm{tg}\,\vartheta_{1,2} = \frac{-(1-q)\,\mathrm{tg}\,\Theta \pm \sqrt{(1-q)^2\,\mathrm{tg}^2\,\Theta + q\,\mathrm{tg}^2\,\Theta(2-q-\mu-\mu\,\mathrm{tg}^2\,\Theta)}}{2-q-\mu-\mu\,\mathrm{tg}^2\,\Theta} \tag{1}$$

Let us denote by ϑ_{lim} the single solution obtained for a zero discriminator of (1)

$$\mathrm{tg}\,\vartheta_{\mathrm{lim}} = \frac{q}{1-q}\sqrt{\frac{1-\mu q}{\mu q}}\,.$$

The existence of two different values of the angle ϑ for a single value of the angle Θ may be explained as the case of the interaction at the infinite slope of the potential decrease. Calculating the limit angle in the case of conservation laws equations we obtain for $T_i = 750$ eV, $Q = 15$ eV, $m = M - \vartheta_{\mathrm{lim}} = 5°43'$.

Using the fact that the energy and momentum conservation equations describe well the interaction of two particles with the interaction potential of the infinite slope, the problem of the inelastic collision of two absolutely rigid (undeformable) spheres can be formulated.

If we denote by Θ the scattering angle in the centre-of-mass system, $R = R_1 + R_2$, where R_1, R_2 are the radii of projectile and target particles, T_{CM} — energy of the centre of mass, then the differential cross section $\sigma(\Theta, Q)$ is

$$\sigma(\Theta, Q) = R^2\left(1 - \frac{Q}{T_{CM}}\right)\frac{\sqrt{1-\frac{Q}{T_{CM}}\cos^2\Theta - \left(2-\frac{Q}{T_{CM}}\right)\cos\Theta + \sqrt{1-\frac{Q}{T_{CM}}}}}{\left(2-\frac{Q}{T_{CM}} - 2\sqrt{1-\frac{Q}{T_{CM}}}\cos\Theta\right)^2}\,.$$

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The model of collision of two absolutely rigid spheres represents another step in the formulation of a numerical experiment in the output of which energy spectra directly comparable with the experimental ones would appear. The complex numerical analysis will show the influence of the limit angle on the form of mass spectra and thus, it will clear up the problem of ion extraction from a hollow cathode in the course of the thin metal layer growth.

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