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IONSATION AVERAGE FREQUENCY IN ANODE SHEATH OF PENNING-TYPE HIGH-VOLTAGE DISCHARGE

N.A. Kervalishvili, V.P. Kortkhonjia.
Institute of Physics, Academy of Sciences of the Georgian SSR, Tbilissi, U.S.S.R.

Theoretical and experimental investigations of physical processes and anode sheath structure in high voltage discharge in crossed \(E\times B\) fields often require knowledge of ionization frequency dependence on anode sheath parameters. Recently, there is a lack of such data. The aim of this work was to measure the dependence of ionization average frequency on electric field strength in anode sheath.

In the "vacuum regime" in anode sheath a condition \(n_i \ll n_e\) is fulfilled. The total ion current when the anode sheath thickness \(d < \tau_a\) is determined by the expression

\[
J_i = 2\pi e \alpha_a \int \tau_a n_i d \tau = \frac{\rho_{\alpha a}}{2} \frac{\nu_a}{E_a}
\]

Hence, ionization average frequency

\[
\nu_a = \frac{\int \tau_a E_a}{\rho_{\alpha a} E_a} = \frac{2 J_i}{\rho_{\alpha a} E_a}
\]

Electric field strength at the anode can be determined by frequency of rotational oscillations \(\nu_0\)

\[
E_a = \frac{2\pi}{c} \tau_a H \nu_0
\]

where \(H\) is an external magnetic field strength.

As it is shown in [1], a fundamental mode of rotational oscillations always exists in magnetron geometry and in Penning cell in anode sheath at the anode surface.

On Fig. 1 \(\nu_a\) versus discharge voltage and magnetic field dependence in magnetron geometry \((\tau_a = 3.2 \text{ cm}, \ L_a = 7 \text{ cm}, \ r_a = 0.75 \text{ cm}, \ p = 2.10^{-4} \text{ Torr})\), the working gas is \(Ar\). The conditions of anode adjustment [2] are maintained. The measurement scheme is given in [1].

Ion current \(J_i\) is about 1.5 times greater than discharge current \([2]\) and has been measured directly during the experiment.

\(\nu_i\) versus \(\nu_a\) is shown on the Fig. 2. As it is seen, \(\nu_i\) changes approximately as square root of discharge voltage. Since values \(\nu_i\) for different \(H\) and \(\nu_a\) are plotted on the figure, it is possible to assume, that \(\nu_i\) is proportional to the square root of potential in anode sheath.

Fig. 3 illustrates \(\nu_i\) versus \(\frac{E_a}{H}\) dependence. For high magnetic fields, when \(d < \tau_a\)

\[
\nu_i \approx \frac{\int \frac{E_a}{H}(E) \ dE}{E_a}
\]

It is always possible to select such dependence \(\nu_i = f(E)\), at which \(\nu_i\) calculated by (3), coincides with a measured one. E.G. in [3] an expression...
has been used for electron energy.

If we assume, that $T_e << W_e$, then

\[ W_e \approx \frac{m_e^2}{e} \frac{E_e^2}{H^2} \]

and we'll get

\[ \gamma_i = \gamma_{im} \frac{2 \sqrt{\frac{W_e}{W_{eo}}} \frac{E_e^2}{W_{eo}}}{1 + \frac{E_e^2}{W_{eo}}} \]  

(4)

Here $E_o = \sqrt{\frac{2W_{eo}}{m_e}} H$

Substituting (4) into (3), we'll find

\[ \frac{\bar{\gamma}_i}{\gamma_{im}} = \frac{E_e}{E_o} \ln \left( 1 + \frac{E_e^2}{W_{eo}} \right) \]

This dependence for $\gamma_{im} = 1.5 \times 10^{-7} \text{m}^{-1}$ and

$W_{eo} = 300 \text{ eV}$ is plotted on the Fig. 3 with solid line and it coincides satisfactorily with the experimental results.

Fig. 1

\[ \gamma_i = \gamma_{im} \frac{2 \sqrt{\frac{W_e}{W_{eo}}} \frac{E_e^2}{W_{eo}}}{1 + \frac{E_e^2}{W_{eo}}} \]

Fig. 3

References

1. B.A. Kervalishvili, V.P. Kortkhonjia, XII ICPIG, part I, Lindhoven, the Netherlands, August 18-22, 1975, p. 112.