Sustaining Voltage for DC Diode Discharges

H.Mase

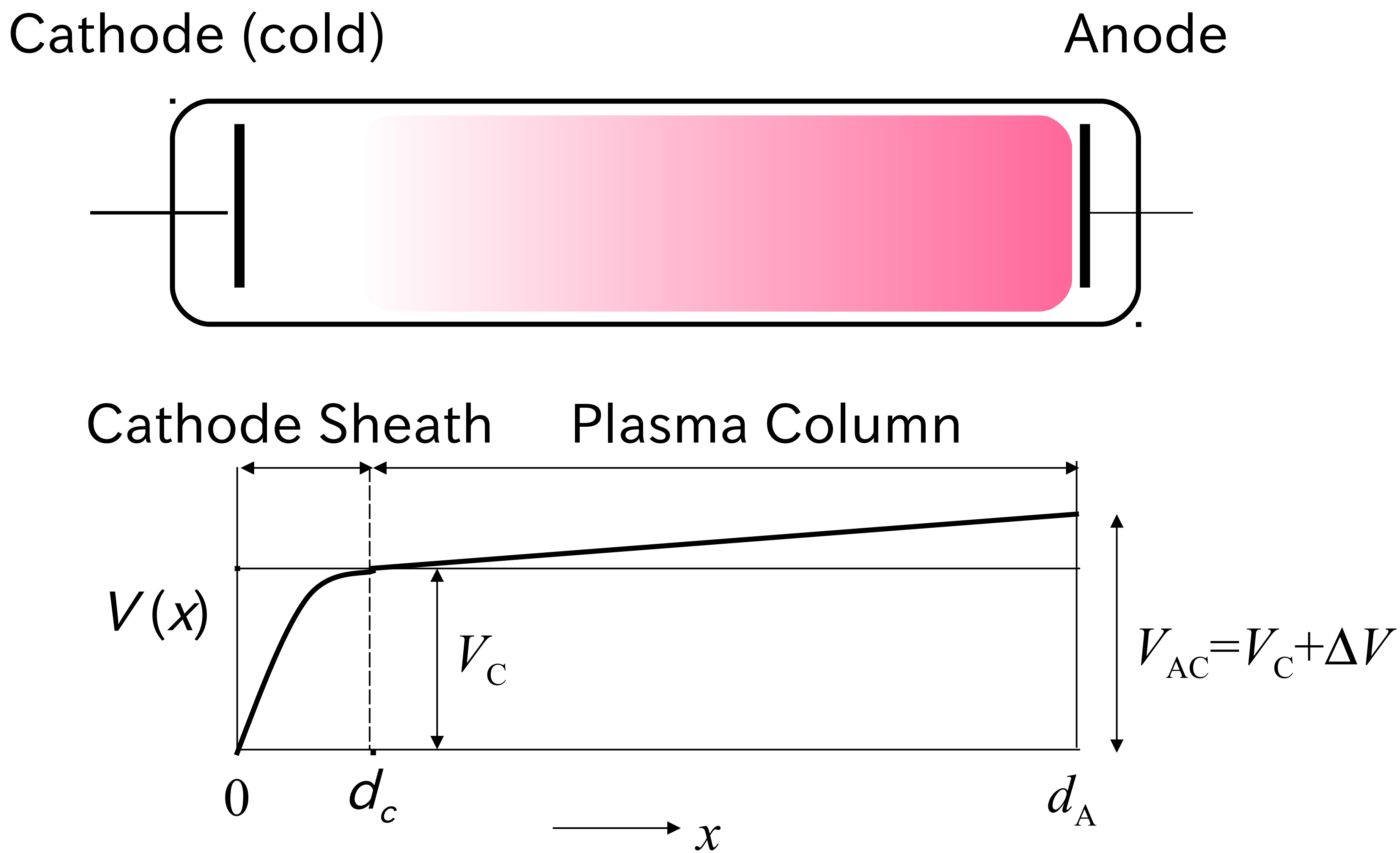
Comprehensive discussion of the sustaining voltage for dc diode discharges with both ***cold***- and ***hot***- cathodes using the same conceptual model, which is based on the collisionless cathode sheath model and the plasma balance equations.

Table of symbols 1/2

V_C	cathode fall potential
ΔV	potential drop across plasma column
V_{AC}	voltage across electrodes
d_C	cathode sheath thickness
d_A	electrode separation
R_{gen}, R_{loss}	generation and loss rates of plasma particles
φ_i	ionization potential
η	efficiency of ionization by 1ry electron beam
J_{eb}	1ry electron beam current density
J_i	ion current density
J	discharge current density $= J_{eb} + J_i$
γ	coefficient of γ process $= \left(J_{eb} / J_i \right)$

Table of symbols 2/2

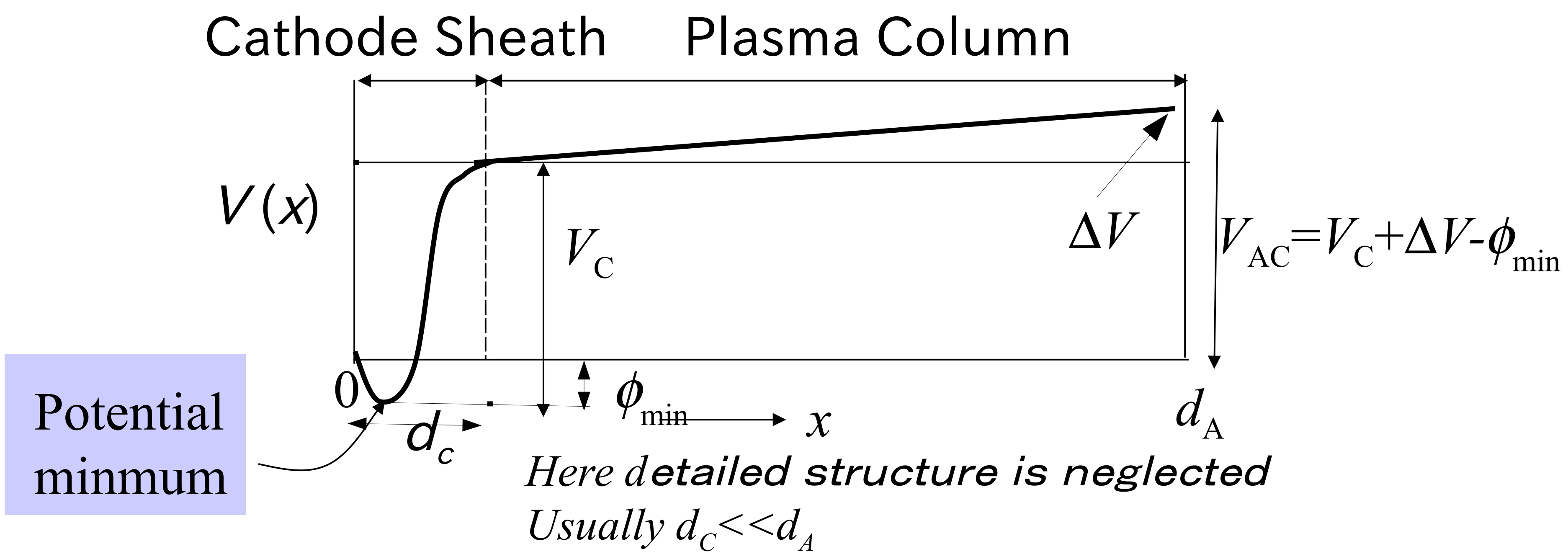
$\lambda^{¿}$	mean ionizaion length
J_{th}	thermoionic emision current density
m	electron mass
M	ion mass
n_i	ion density
n	plasma density $=n_i=n_e$
c_S	sound speed
σ	plasma conductivity
E	electric field in plasma column
r_p	radius of plasma column
α_r	coeffient of volume reconbination
Ω	volume of plasma column



Here detailed structure is neglected

Usually $d_C \ll d_A$

Outline of Potential Structure in DC Diode Discharges with Hot-Cathode



Derivation of Sustaining Voltage

Plasma Balance Equations;
Continuity of number density and energy

$$\frac{dn_i}{dt} d_{AC} = R_{gen} - R_{loss} = 0$$

$$\frac{d\varepsilon}{dt} d_{AC} = \eta V_C J_{eb} + \sigma E^2 \left(d_{AC} - d_C \right) - R_{gen} e \varphi_i = 0$$

ϕ_i is ionization potential
J_{eb} is 1ry electron beam current density
$\eta \leq 1$ is ionization efficiency of 1ry electron beam

Derivation of Sustaining Voltage

Glow Discharge

In the case of relatively short discharge tubes

Potential drop along the plasma column is neglected

$R_{\text{loss}} = n_i v_i$,   surface and volume losses are neglected

$$R_{gen} - R_{loss} = R_{gen} - n_i v_i = 0$$

$$\eta V_C J_{eb} - R_{gen} e\varphi_i = \eta V_C J_{eb} - e\varphi_i n_i v_i = 0$$

$$V_C = \frac{e\varphi_i n_i v_i}{\eta J_{eb}} = \frac{\varphi_i J_i}{\eta J_{eb}} = \left(\frac{1}{\eta}\right)\frac{\varphi_i}{\gamma},$$

Self-sustaining condition

$$\frac{J_{eb}}{J_i} = \gamma < 1$$

$\eta = 1$, ie $\frac{\lambda^{¿}}{\gamma} < d_{AC}$

$\lambda^{¿}$ is mean ionization length

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most low impedance glow discarge

$$V_C = \frac{\varphi_i}{\gamma}$$

Derivation of Sustaining Voltage

Externally Heating Arc Discharge

In the case of relatively short discharge tubes

Potential drop along the plasma colimn is neglected

$R_{loss} = n_i v_i$, surface and volume losses are neglected

$$V_C = \frac{e\varphi_i n_i v_i}{\eta J_{eb}} = \frac{\varphi_i J_i}{\eta J_{eb}}, \qquad \frac{J_i}{\eta J_{eb}} \geq 1$$

$J \approx J_{eb} < J_{th}$, $\frac{J_i}{J_{eb}} = \sqrt{\frac{m}{M}} << 1$, double layaer: Lamgmuir mode

$J \approx J_{eb} = J_{th}$, $\frac{J_i}{J_{eb}} \leq 1$, temperature limited mode

$\eta \frac{J_{eb}}{J_i} = 1$, $V_C = \varphi_i$ most low impedance arc discharge

Derivation of Sustainig Voltage

Potential Drop along Plasma Column

$$\frac{dn_i}{dt}\Omega = R_{gen} - R_{loss} = 0$$

$$\frac{d\varepsilon}{dt}\Omega = \sigma E^2 \Omega - R_{gen} e\varphi_i = 0$$

$$R_{gen} = R_{loss} \approx nc_s \left(2\pi r_p d_{AC}\right)\left(1 + \frac{\alpha_r n}{nc_s}\cdot\frac{r_p}{2}\right)$$

$$\Delta V = Ed_{AC} = \frac{R_{loss} e\varphi_i}{\sigma E\left(\pi r_p\right)}$$

$$\approx \left(\frac{enc_s}{J}\right)\left(1 + \frac{\alpha_r n^2}{nc_s}\cdot\frac{r_p}{2}\right)\cdot\left(\frac{2d_{AC}}{r_p}\right)\cdot\varphi_t,$$

r_p is the radius of plasma column,

ΔV depends on the ratio (d_{AC}/r_p)

R_{loss} is surface and volume losses of plasma particles

$$E = \frac{\Delta V}{d_{AC}} \propto \left(\frac{enc_S}{J}\right)\cdot\left(\frac{\varphi_i}{r_p}\right),$$

same as Schottky's diffusion theory

Sustaining Voltage for DC Diode Discharges

$$V_{AC} = V_C + \Delta V - \varphi_{\min},$$

$\varphi_{\min} = 0$ for glow mode

$$V_C = \left(\frac{1}{\eta}\right) \cdot \frac{\varphi_i}{\gamma} \geq \frac{\varphi_i}{\gamma},$$ for glow mode

$$V_C = \left(\frac{1}{\eta} \cdot \frac{J_i}{J_{eb}}\right) \cdot \varphi_i \geq \varphi_i,$$ for arc mode

$$\Delta V = \frac{R_{loss} e \varphi_i}{\sigma E} \approx \left(\frac{enc_s}{J}\right)\left(1 + \frac{\alpha_r n^2}{nc_s} \cdot \frac{r_p}{2}\right)\left(\frac{2 d_{AC}}{r_p}\right) \cdot \varphi_i,$$

Sustaining Voltage as a function of J_{eb} / J_I