# Propagation Speed of Streamer in Diode Discharges

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When the breakdown is just starting in gaseous diodes, the front of plasma column generated near tha anode is quickly moving toward the cathode. We discuss the moving velocity of the plasma front (that is propagation speed of streamer). This text is partially revised previous document “ An Estimation of Critical Electron Density at Just Starting Breakdown in Gases”

# Scenario of Starting Electric Breakdown in Gases

1. $E > E^*$ is applied field across the electrodes. $n_{e0}$ occurs at any time and any way.

2. $dn_e/dt > 0$ in front of electron avalanche. $E$ is extremely distorted by the space charge.

3. $n_e = n^* = n_i$ $n^*$ is the critical electron density at just starting breakdown.

   >> appearance of micro-plasma in front of electron avalanche or near the anode.

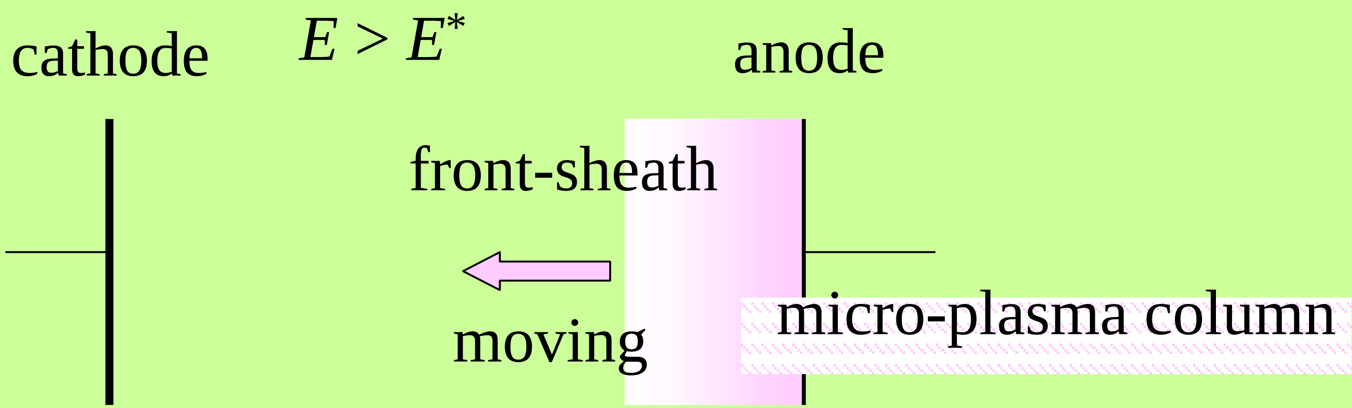
4. $E$ is increasing in the space between the cathode and front of the plasma column >> enhanced ionization >> expansion of plasma column.

5. Front of the plasma column (that is **virtual anode**) is moving toward the cathode (**Streamer**)

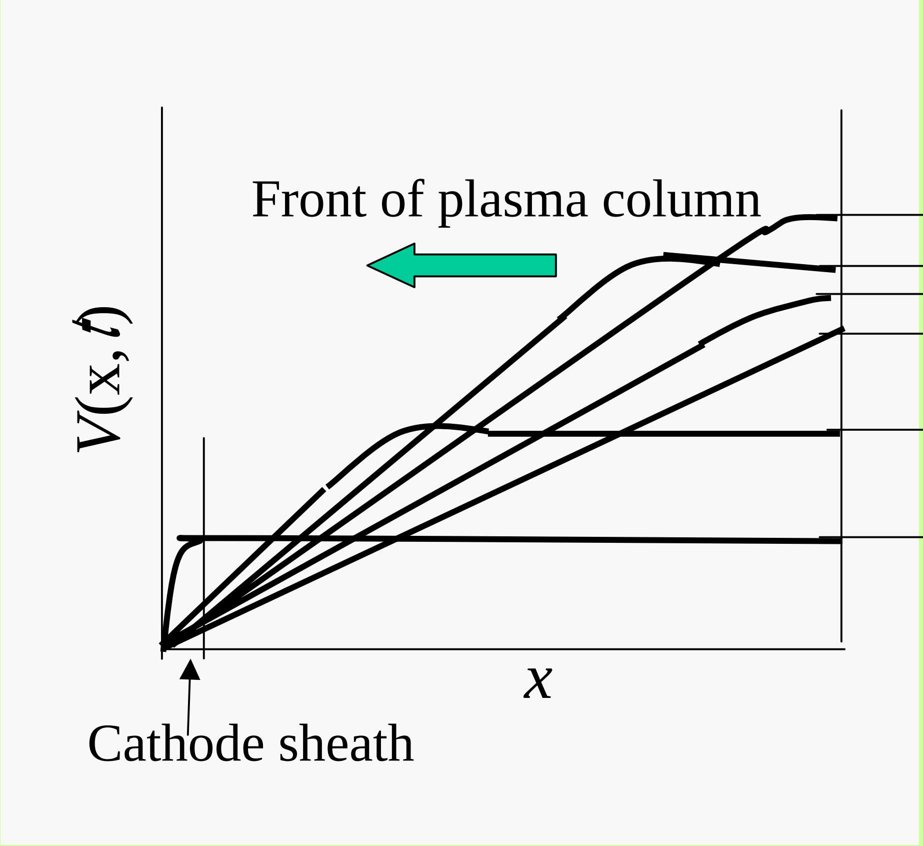
. go back # 4. < positive feedback process > (* More detailed discussion is required to introduce the energy minimum principle.)

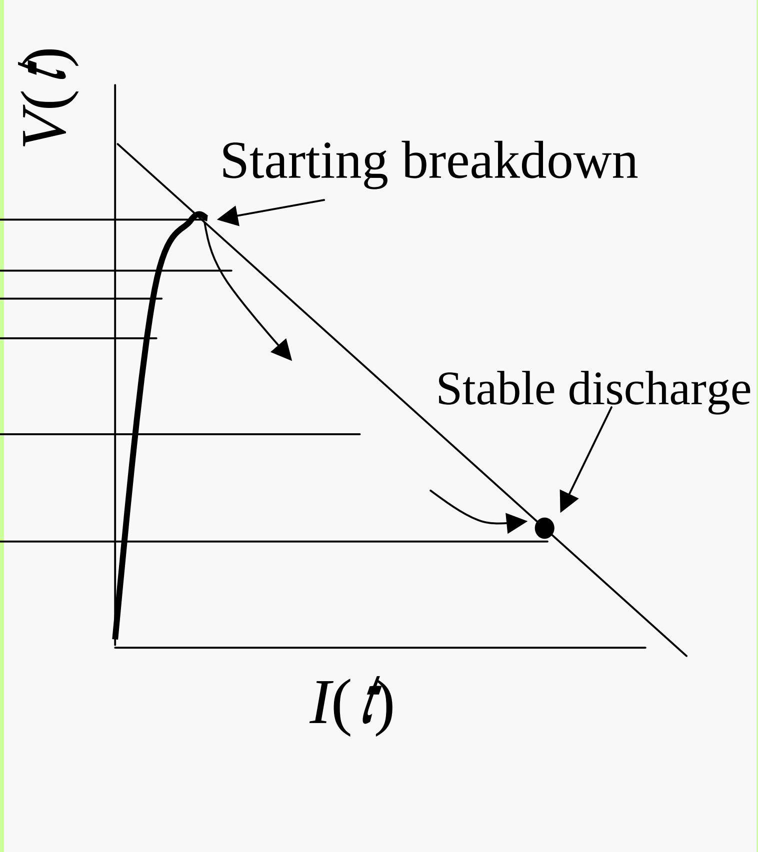
6. When the front-sheath comes at the cathode, the discharge gap makes it to flashover .

7. If the front–sheath satisfies the self-sustaining condition of discharge , the glow discharge or the arc discharge occurs. In the case, the front-sheath means so-coaled "**cathode sheath**". ( *Appendix II* )



# Evolution of Potential Structure before and after Starting Breakdown



# A Hypothesis for the Appearance of Micro-Plasma at Anode Near Region

$$E^* = \frac{\phi_i}{\lambda_i} = \frac{T_{eV}/e}{\lambda_D}$$

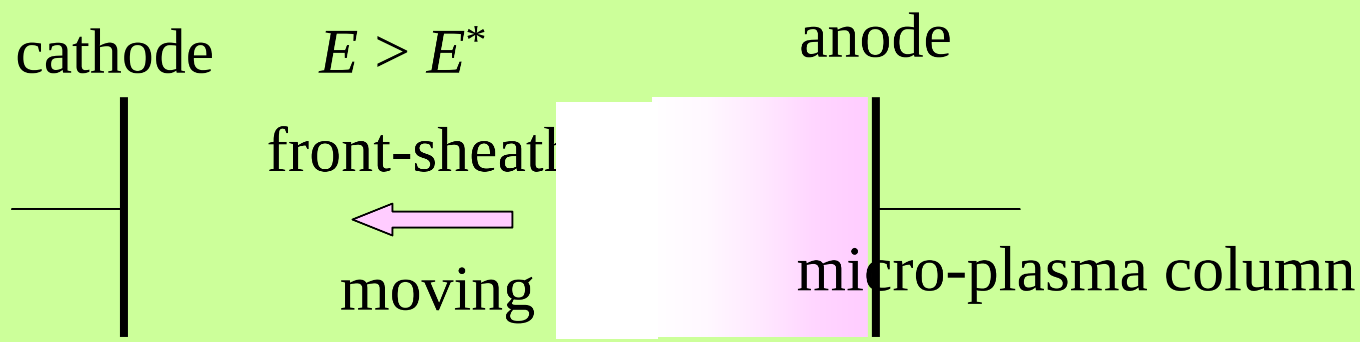
$\boldsymbol{T}_{\mathbf{eV}}$ electron temperature in eV

$\lambda_{\mathbf{D}}$ Debye shielding length

$E \approx 0$ in the plasma column

$E^*$ would be shielded electrically by the polarization of plasma particles. It is best that $T_{ev}$ should be confirmed theoretically by the plasma balance equation. Usually $T_{eV}$ is in the range of several eV.

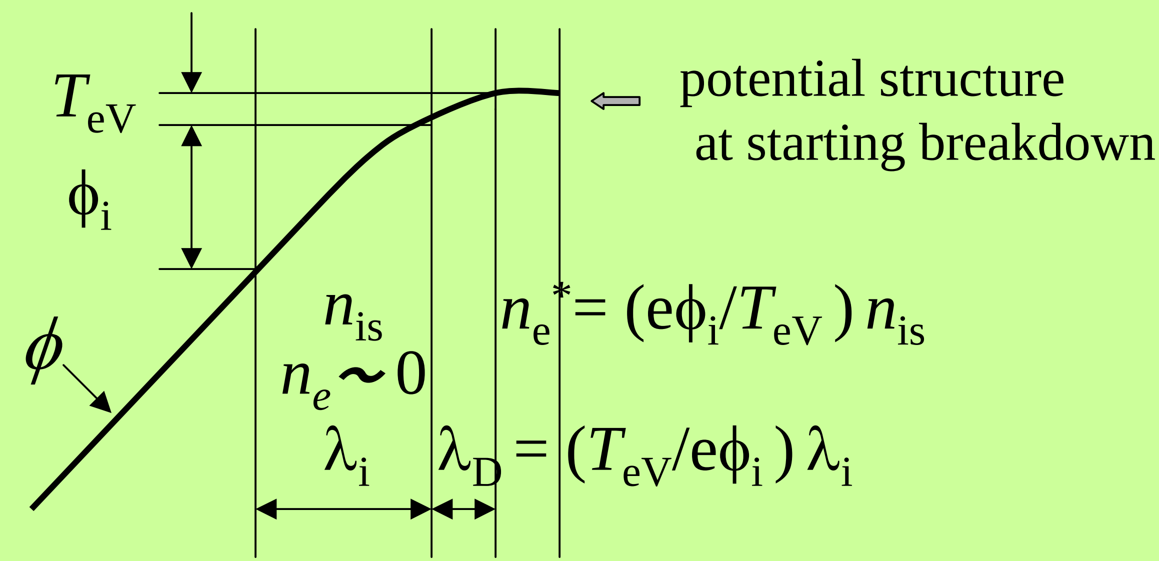
# Relationship between Micro-Plasma Column and its Front-Sheath at Starting Breakdown




space charge density
in front-sheath

$$n_{is} = \frac{\varepsilon_0}{e}\nabla^2\phi$$

$$\approx \frac{\varepsilon_0}{e}\cdot\frac{\phi_i}{\lambda_i^2} = \left(\frac{T_{eV}}{e\phi_i}\right)n_e^*$$



# Critical current density at starting breakdown

Velocity and density of fast electrons which are passing through the front-sheath

$$v_{se} \geq \sqrt{2e\phi_i / m}$$

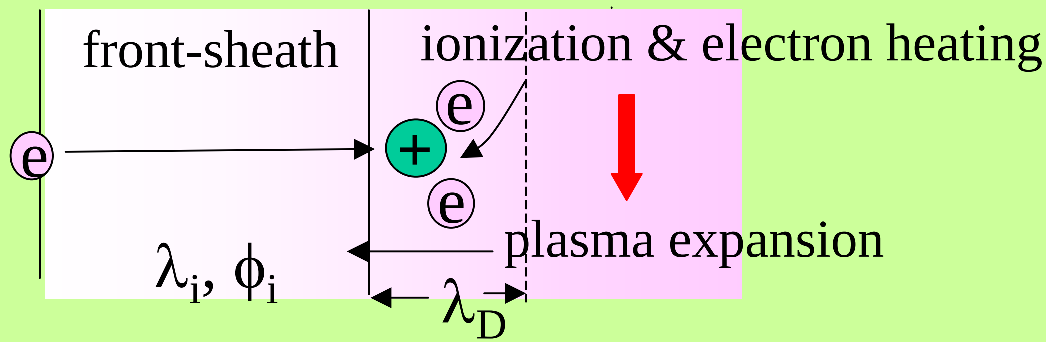
$$n_{se} \approx n_i = \left(\frac{T_{eV}}{e\phi_i}\right) n_e^*$$

Critical current density

$$j^* = en_{se}v_{se} \approx e\left(\frac{T_{eV}}{e\phi_i}\right) n_e^* \sqrt{\frac{2e\phi_i}{m}} = en_e^* \sqrt{\frac{2T_{eV}}{m}} \sqrt{\frac{T_{eV}}{e\phi_i}}$$

# Velocity $v_{fs}$ of Moving Front-Sheath (Streamer).

The growth of plasma volume is caused by the ionization due to fast electrons having their energy of $(1/2)mv^2 > e\phi_i$.




$$\frac{n_e^* L_p}{t} = \frac{n_{se} v_e \phi}{\phi_i} \approx \left(\frac{\phi}{\phi_i}\right)\left(\frac{T_{eV}}{e\phi_i}\right) n_e^* \sqrt{\frac{2e\phi_i}{m}} x \qquad \text{for } L_p > \lambda_i$$

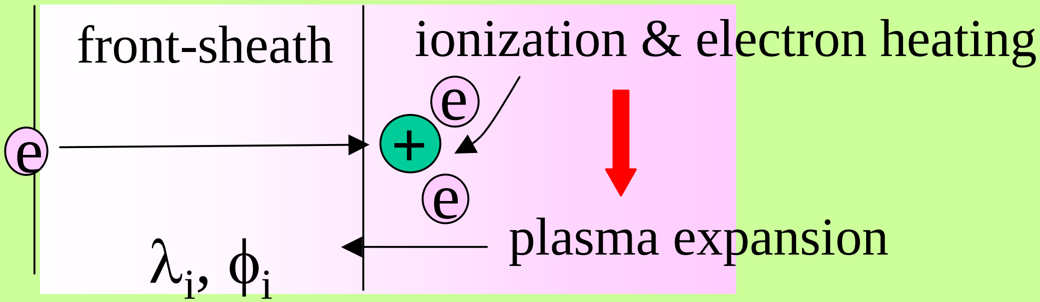
$$v_{fs} = \frac{L_p}{t} \approx \left(\frac{\phi}{\phi_i}\right)\left(\frac{T_{eV}}{e\phi_i}\right)\sqrt{\frac{2e\phi_i}{m}} \approx 5.9\times 10^7 \sqrt{\phi_i} \cdot \left(\frac{T_{eV}}{e\phi_i}\right)\left(\frac{V}{V_{BD}}\right) \ \text{cm/S}$$

***cf*** : expansion due to electron heating is neglected here
$v_{sf}$ depends on the ionization potetial, the plasma electron temperature and the over voltage for the breakdown threshold.($V_{BD}$ ∼ $E^* d_{AC}$)

# Velocity $v_{fs}$ of Moving Front-Sheath (Streamer).

$$v_{fs} \le v_e = \sqrt{2e\phi_i / m} = 5.9 \times 10^7 \sqrt{\phi_i} \quad \text{cm/S}$$

Expansion of micro-plasma is caused by the ionization due to fast electrons having their energy of $(1/2)mv^2 > e\phi_i$. Velocity of moving front-sheath may be mainly determined by the motion of fast electrons which are passing through the front-sheath without any ionization collision. So, $v_{fs}$ could be estimated to be the same velocity of electrons accelerated up to $e\phi_i$ eV (* More detailed discussion is required to introduce the energy minimum principle.)




***cf*** : recent observation of $v_{fs}$ $\sim 10^8$ cm/s

# Propagation Speed of Streamer in Various Gases

$$\left(\frac{T_{eV}}{e\phi_i}\right)\left(\frac{V}{V_{BD}}\right) = 1,\ 0.5,\ 0.2 \text{ and } 0.1$$