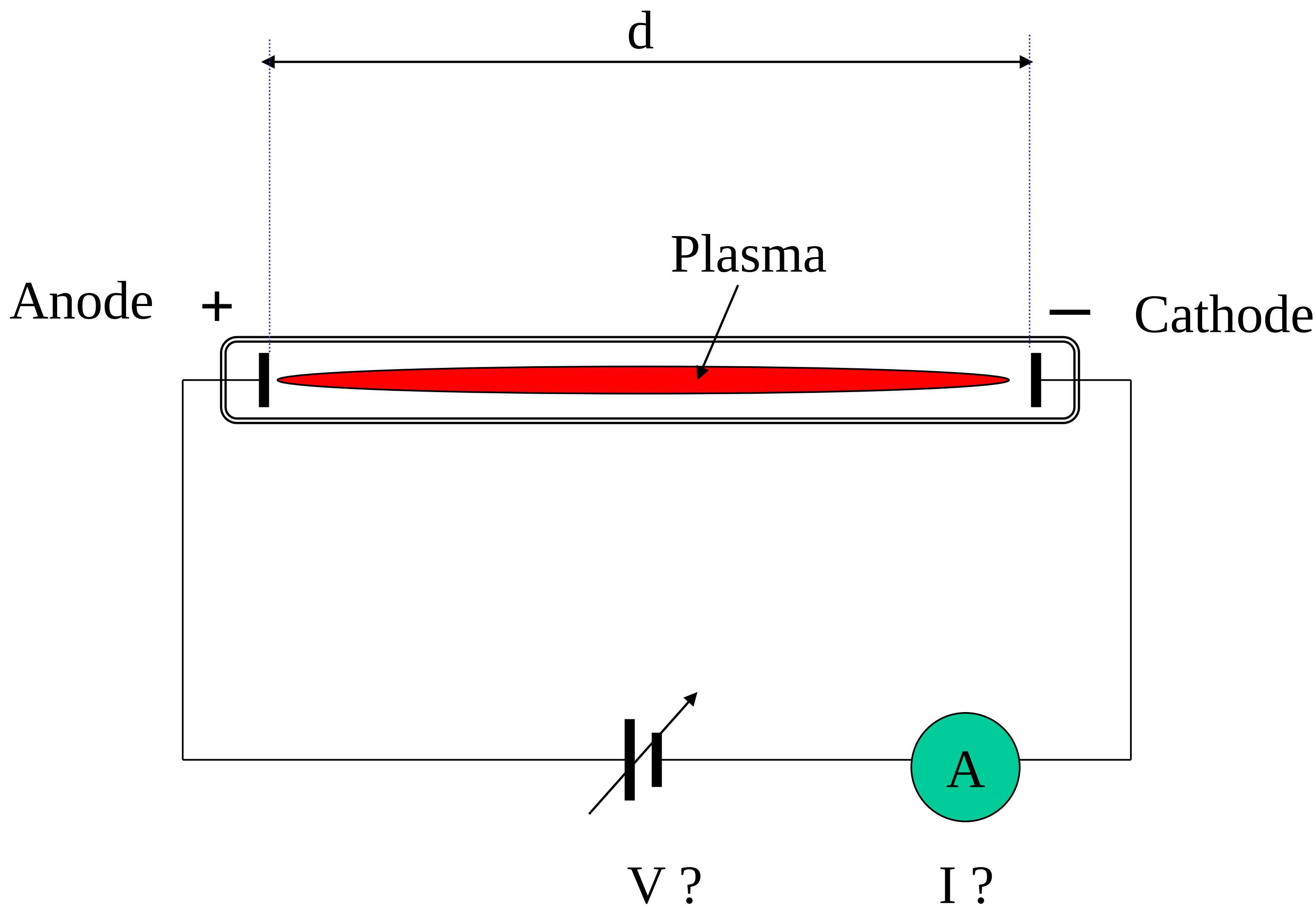
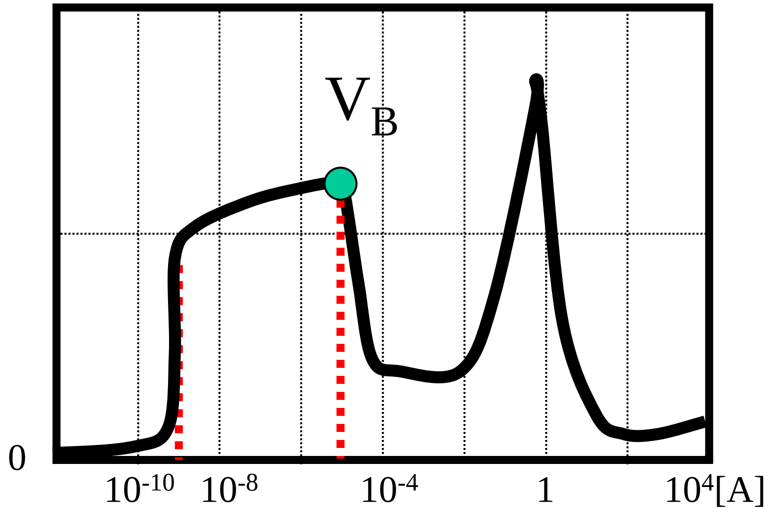
EE 403/503
Introduction to Plasma Processing

DC Discharge II

October 26, 2011


d
Plasma
Anode
+
−
Cathode
A
V ?
I ?

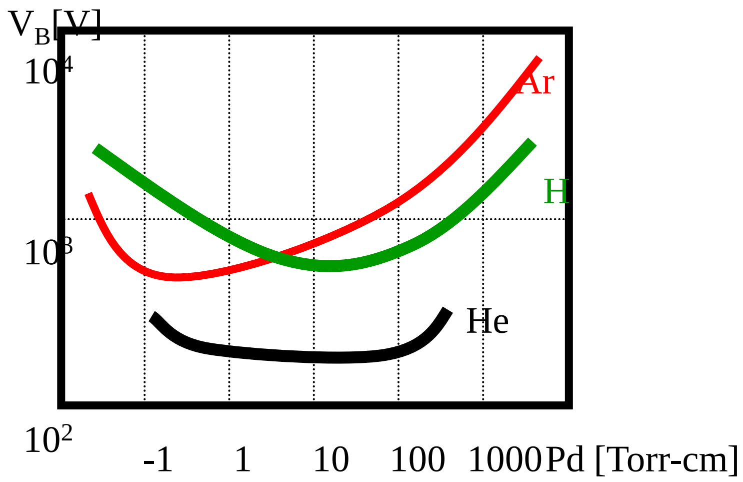


First Townsend Coefficient

$$j_e = \frac{j_o e^{\alpha d}}{1 - \gamma (e^{\alpha d} - 1)}$$

Secondary Emission Coefficient

Breakdown Voltage

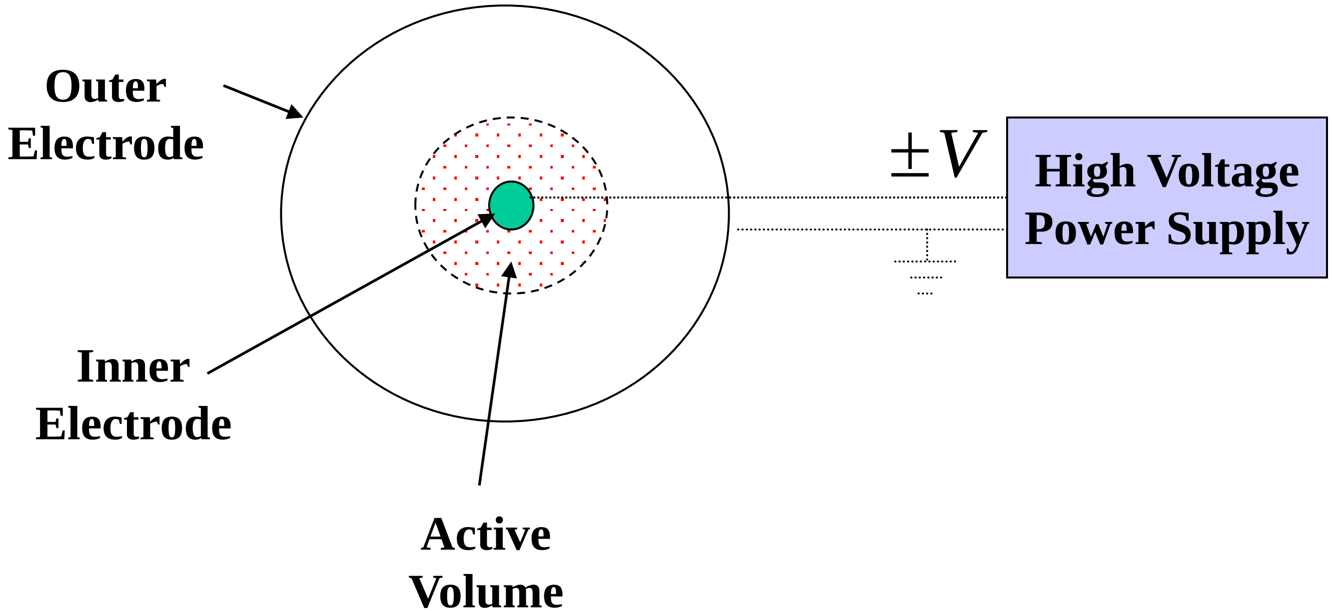


$$
\begin{cases}
n_e = \dfrac{n_o e^{\alpha d}}{1-\gamma(e^{\alpha d}-1)} \\[2ex]
\gamma(e^{\alpha d}-1)=1 \quad \text{Townsend breakdown criterion} \\[2ex]
\alpha = C_1 \times p \times \exp\left(\dfrac{-C_2 \times p}{E}\right) \\[2ex]
V = E \times d
\end{cases}
$$

$$
\Rightarrow \quad V_B = \frac{C_2(pd)}{\ln(pd) + \ln C_1 - \underbrace{\ln\left(\ln\left(\frac{1}{\gamma}+1\right)\right)}_{\text{Almost Constant}}}
$$

Almost Constant

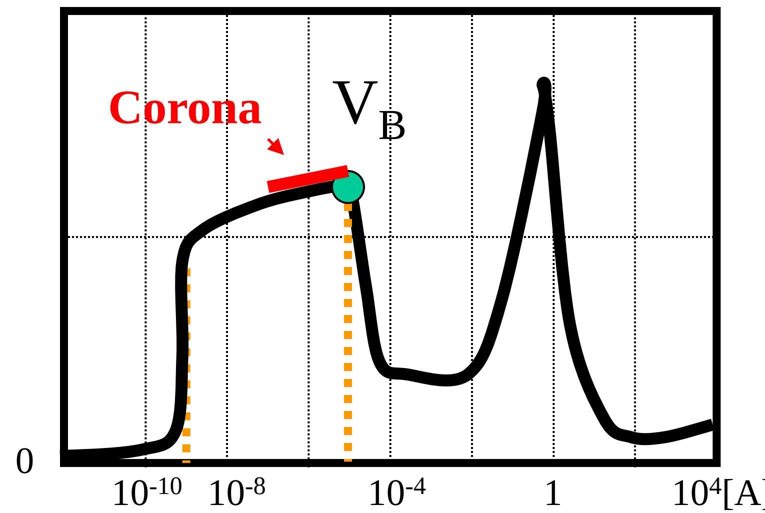
Corona Discharge



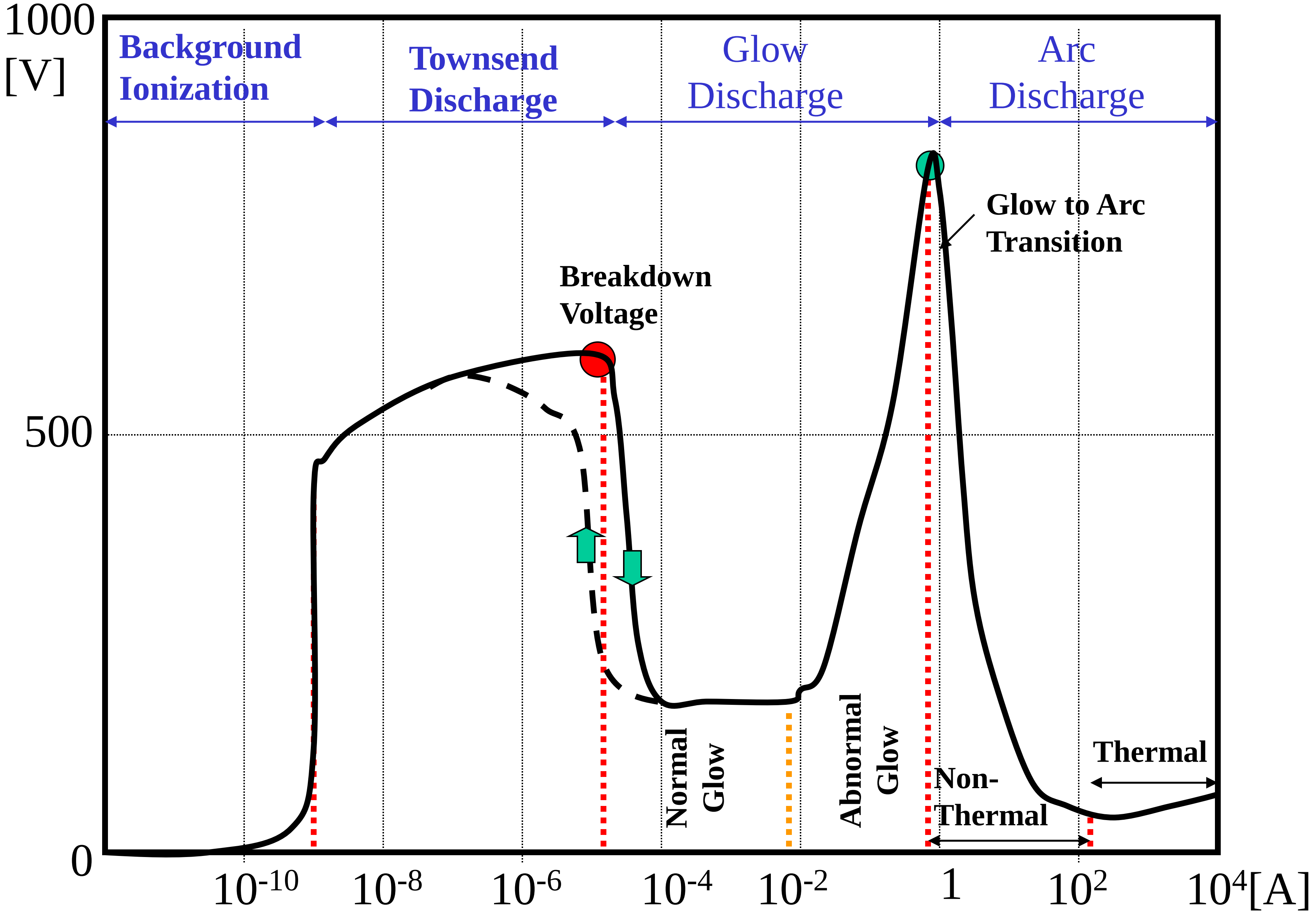
For dry Air for parallel electrodes:

$$V_B = 3000d + 1.35 \qquad [\mathrm{kV}]$$

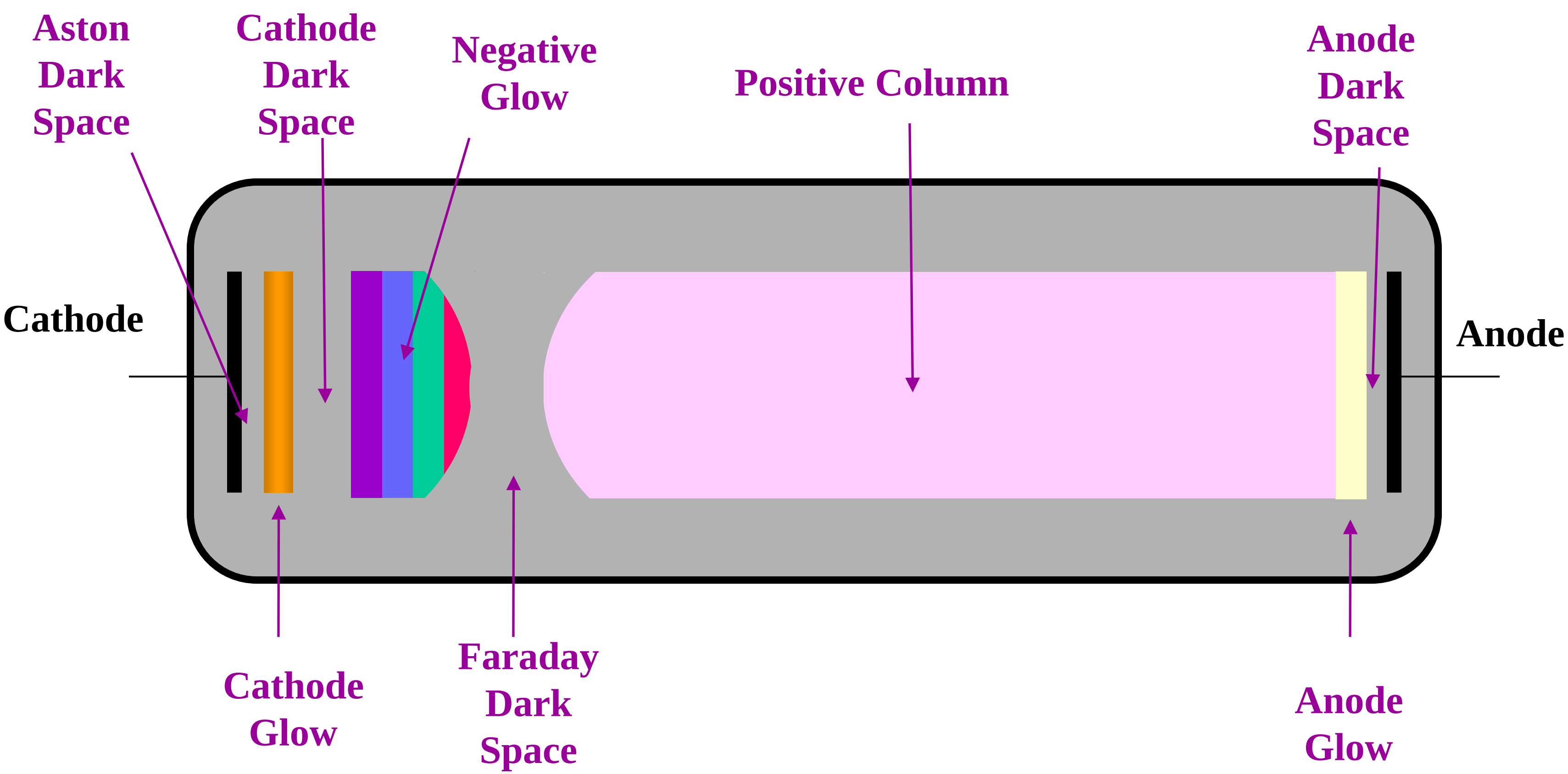
$$E_B = \frac{V_B}{d} = 3000 + \frac{1.35}{d} \qquad [\mathrm{kV/m}]$$

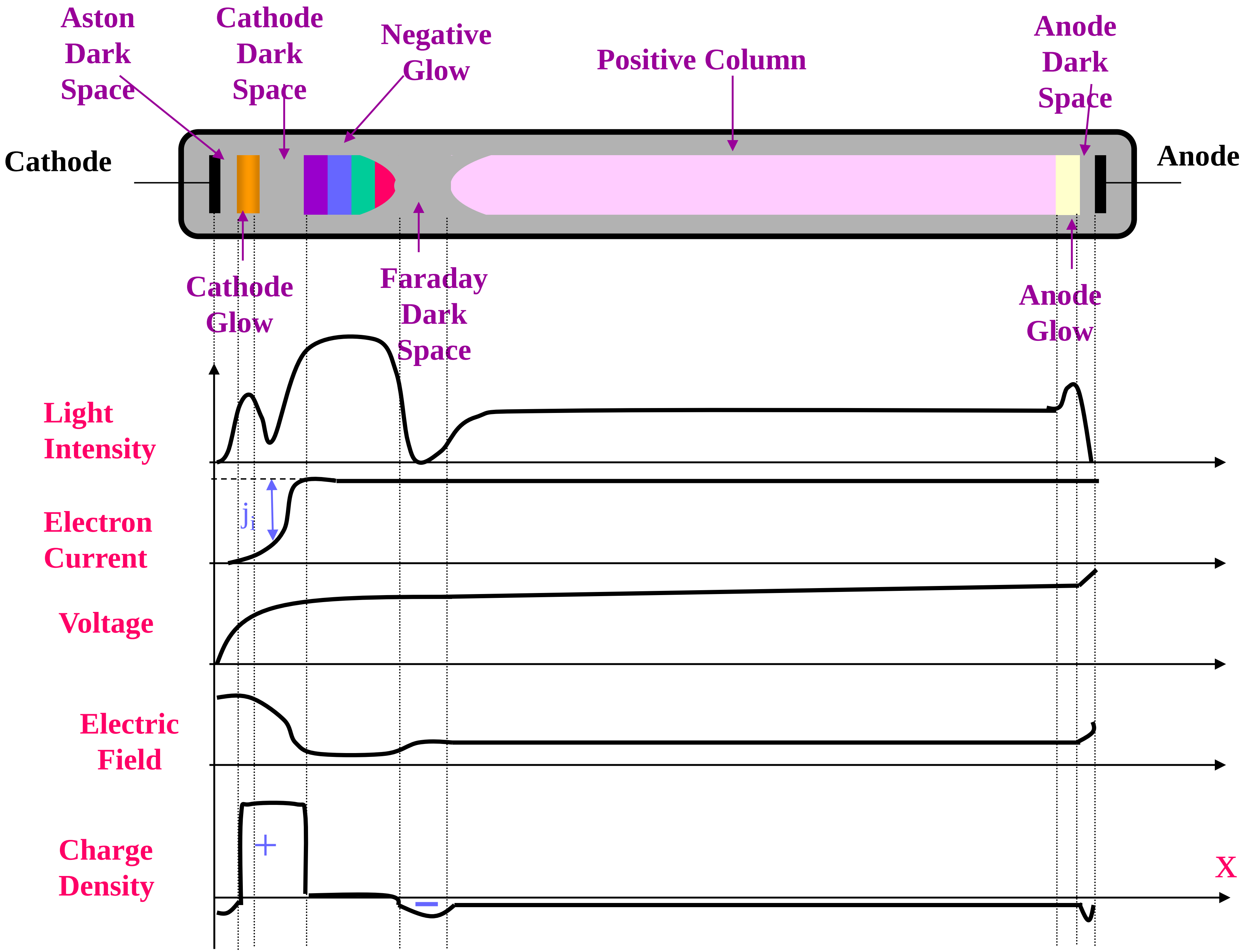


V-I Characteristic of DC Discharges



Glow Discharge

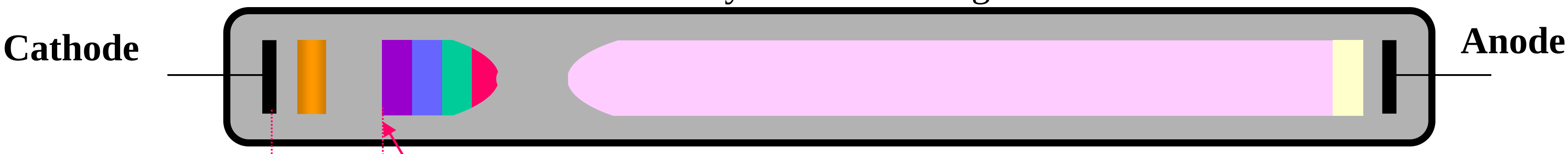



Aston Dark Space
Cathode Dark Space
Negative Glow
Positive Column
Anode Dark Space
Cathode
Anode
Cathode Glow
Faraday Dark Space
Anode Glow
Light Intensity
Electron Current
j_i
Voltage
Electric Field
Charge Density
+
−
X

Characteristic parameter range of DC glow Discharge

Parameter	Unit	Range	Typical value
Pressure	Torr	10^{-6}-760	0.5
Voltage	V	100-50000	1000
Current	A	10^{-4}-20	0.5
$\mathbf{n_e}$	$1/m^3$	10^{14}-$6x10^{18}$	$5x10^{15}$
$\mathbf{T_e}$	eV	1-5	2
Power	W	0.01-250000	200
Volume	liter	10^{-6}-100	0.1

Townsend Theory of Cathode Region



d_c

$V_c = V_{b,min}$

Cathode Fall Region

(Townsend theory approximately applies to cathode fall region)

Paschen Minimum

d_c adjust itself so that $d_c p = (dp)_{min}$

Typical values at 1 Torr: $d_c \sim 0.5$ cm

$$E = C(d_c - x)$$

$$V(x) = \int_0^{d_c} E\,dx$$

$$\frac{d^2V}{dx^2} = -\frac{e\,\delta n}{\varepsilon_0}$$

Poisson's Equation

$$\delta n = \frac{2\varepsilon_0 V_C}{e d_c^2}$$

Net Charge Density in the Cathode Fall Region

Energy Transfer

Unmagnetized Plasmas

$$m_e \frac{dv}{dt} = -\nu_c m_e v + eE \rightarrow v(t) = \frac{eE_0}{\nu_c m_e} + \left(v_0 - \frac{eE_0}{\nu_c m_e} \right) e^{-\nu_c t}$$

b.c. : v(t)=v_0 at t=0

t→∞

Power absorbed

$$P = n_e p_e = n_e \frac{dW}{dt} = n_e \frac{F.dx}{dt} = n_e (eE_0) v(t) = \frac{n_e e^2 E_0^2}{\nu_c m_e}$$

Energy density of the electrostatic field

$$U_{\max} = \frac{1}{2} \varepsilon_0 E_0^2$$

Energy Transfer frequency

$$\nu^* = \frac{2\omega_p}{\nu_c}$$

$$\omega_p = \frac{n_e e^2}{\varepsilon_0 m_e}$$

$$\boxed{P = U_{\max} \times \nu^*}$$

Energy Transfer in Magnetized Plasmas

$$m_e \frac{dv}{dt} = -\nu_c m_e v + e\left[E + (v \times B)\right]$$

Plasma Frequency

$$\omega_p = \frac{n_e e^2}{\varepsilon_0 m_e}$$

Collision Frequency

Power absorbed

$$P = U_{\max} \times \nu^*$$

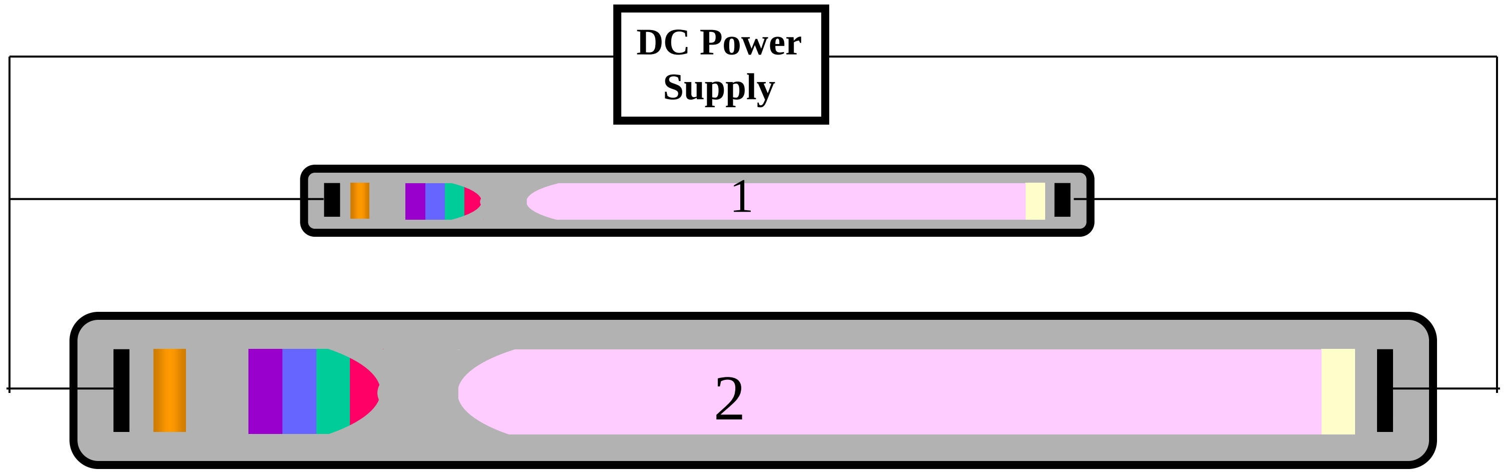
Energy Transfer frequency

Energy density of the electrostatic field

$$\nu^* \equiv \frac{2\omega_p^2}{\nu_c} \frac{\nu_c^2}{(\omega_c^2 + \nu_c^2)}$$

Gyrofrequency $\frac{qB}{m}$

Similarity Relations



$V_1=V_2$

$I_1=I_2$

length $d_1=ad_2$

Diameter $D_1=aD_2$

$p_2=ap_1$

$\lambda_1=a\lambda_2$

$E_2=aE_1$

$J_2=a^2J_1$

$n_{e2}=a^2n_{e1}$

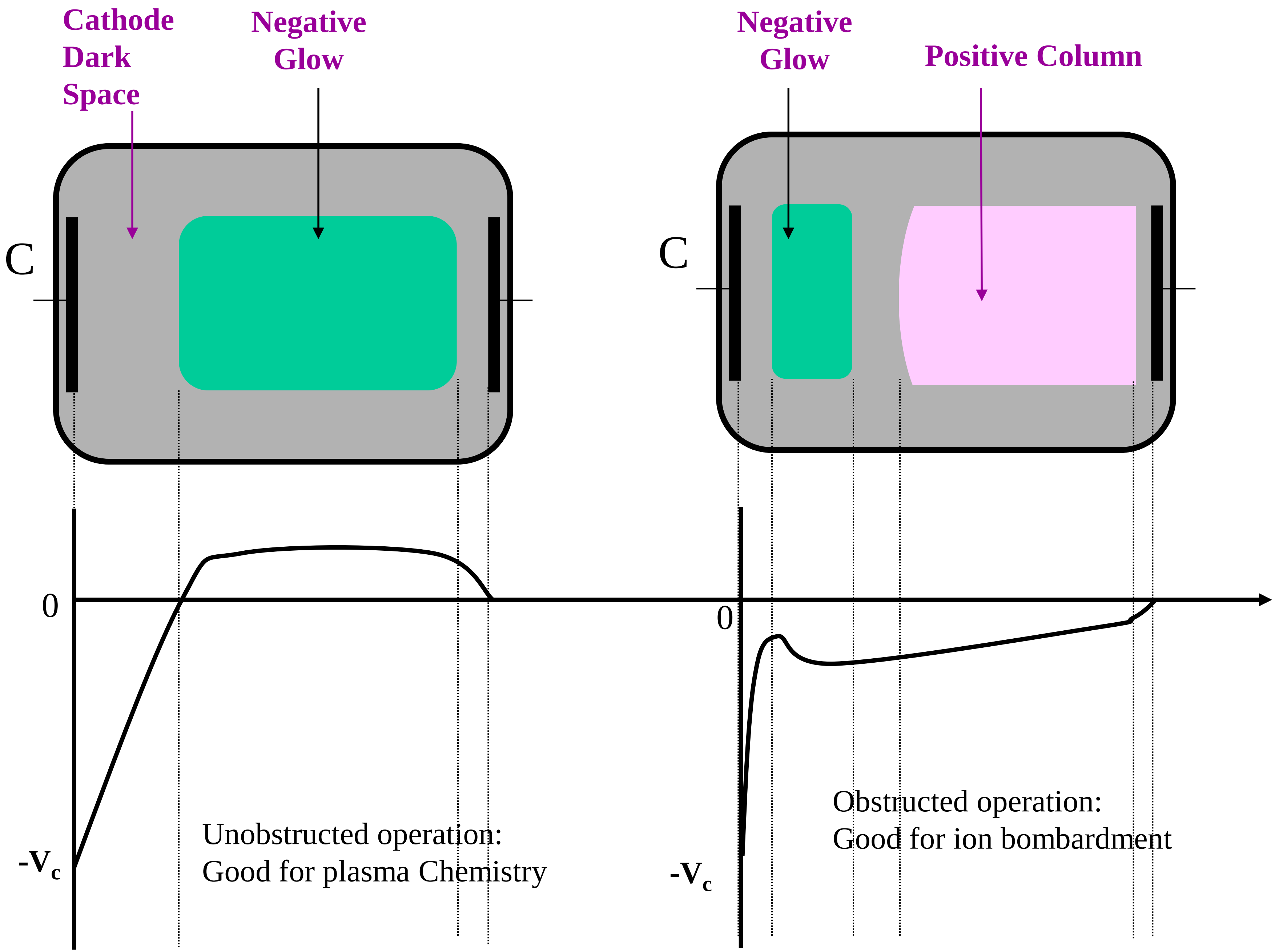
$d_1p_1=d_2p_2$

$\alpha_1=a\,\alpha_2$

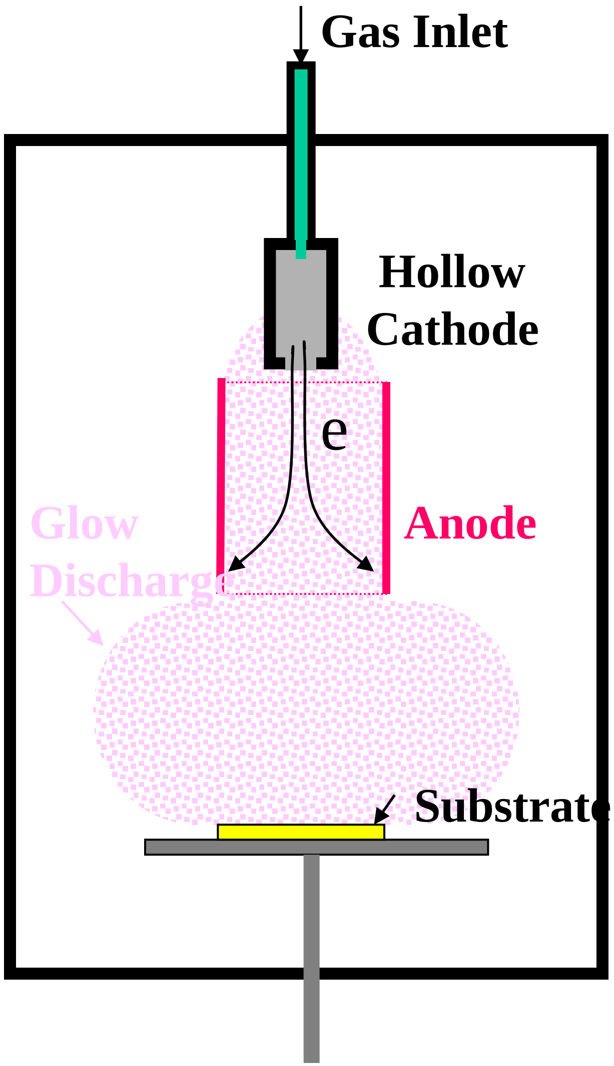
$$\frac{\alpha_1}{p_1}=\frac{\alpha_2}{p_2}=const$$

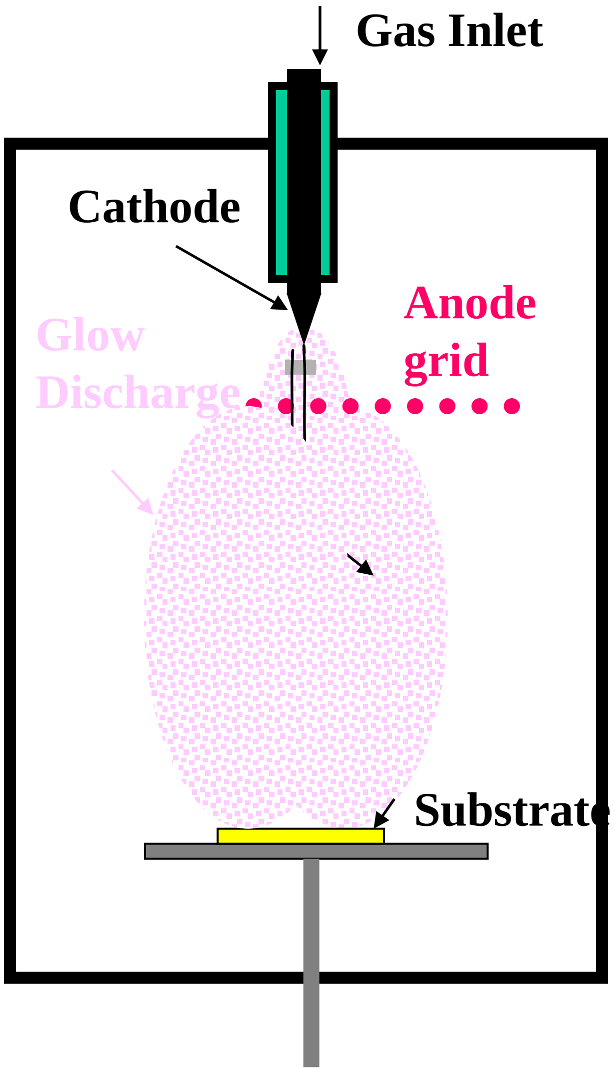
$$\frac{E_1}{p_1}=\frac{E_2}{p_2}=const$$

DC Parallel Plate Normal Glow Discharge



Electron beam Plasma Source





Magnetron Plasma Source