

Lecture 2 Dry Etching I

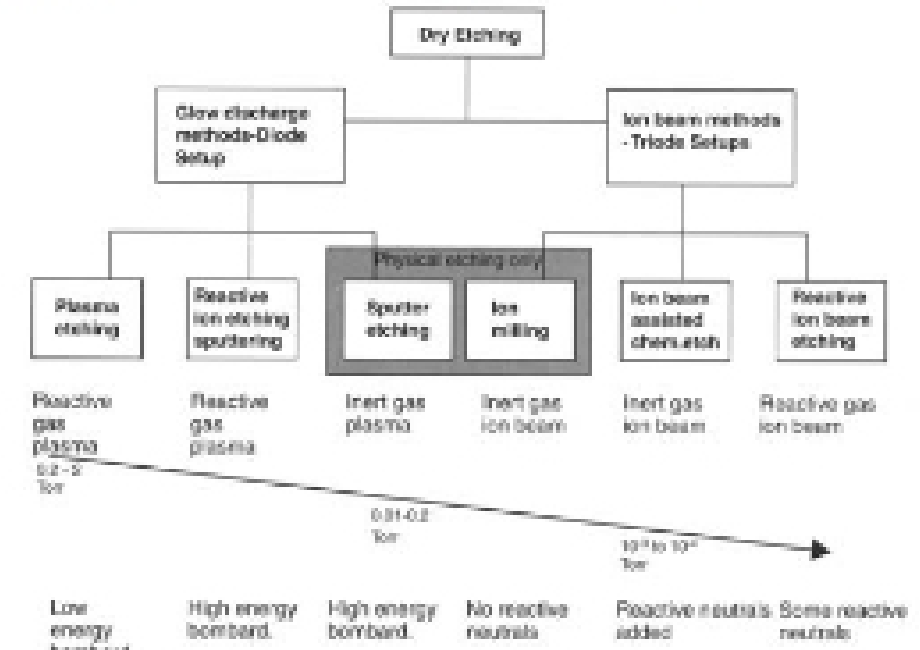
Agenda:

- DC Plasma
 - Plasma discharge zones
 - Paschen's Law
- RF Plasma
- High-density Plasmas
- DRIE
 - Microloading
 - Silicon grass

Reading: M. Madou, Chapter 2, pp. 77-107

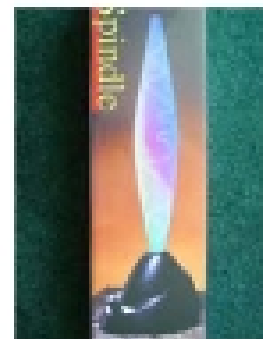
Most figures in this presentation are adapted from M. Madou, Chapter 2

Dry Etching



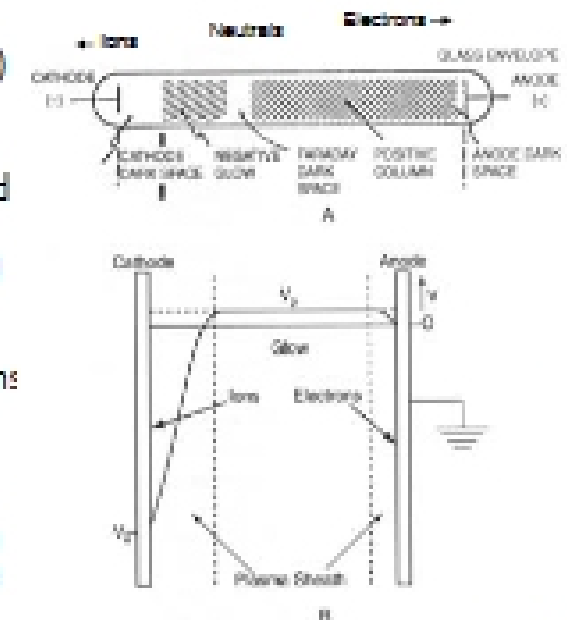
1.1 Various dry etching techniques. (Adapted from H. W. Lehmann in: Thin Film Processes II, J. L. Moxley, ed. W. Kern, Ed. series, 1991, 1)

Plasmas



Glow Discharge Plasma

- Glow occurs when a DC voltage is applied between two electrodes in a gas
 - Low pressure (0.001~10 Torr)
 - High voltage (~1kV)
 - Electrons from cathode accelerated in the electric field ionize gas molecules and provide the plasma-sustaining current
 - Energetic collisions create avalanche of ions and electrons
 - Electrons move much faster than ions
 - Neutral species greatly outnumber electrons and ions by 4 to 6 orders of magnitude



Glow Discharge Plasma

➤ Average particle energy is given by

$$\langle E_e \rangle = k_B T_e \text{ for electrons}$$

$$\langle E_i \rangle = k_B T_i \text{ for ions}$$

➤ Typical values

$$\langle E_e \rangle: 1 \sim 10 \text{ eV (hot)}$$

$$\langle E_i \rangle: 0.02 \sim 0.1 \text{ eV (cold)}$$

Thus, $T_e \gg T_i$

e.g., $E_e \sim 2 \text{ eV}$; $E_i \sim 0.4 \text{ eV}$

Then, $T_e = 23,000 \text{ K}$

But $T_i = 490 \text{ K}$

➤ Effective current density

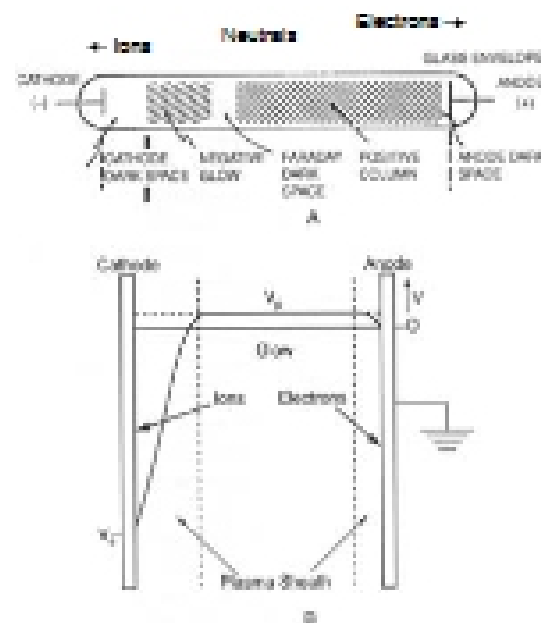
$$J_e = n_e e \langle v_e \rangle / 4$$

$$J_i = n_i e \langle v_i \rangle / 4$$

→ $\langle v_e \rangle$ is much greater than $\langle v_i \rangle$, so $J_e \gg J_i$

⇒ Permanent positive charge

⇒ electrons lost to the walls



Glow Discharge Plasma

Electron-Molecule Collisions

➤ Dissociation



Highly reactive radicals

➤ Ionization

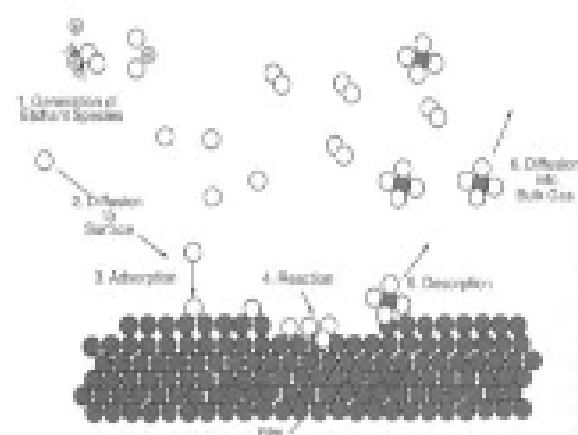
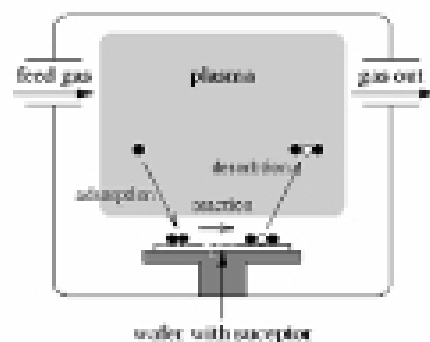


➤ Excitation



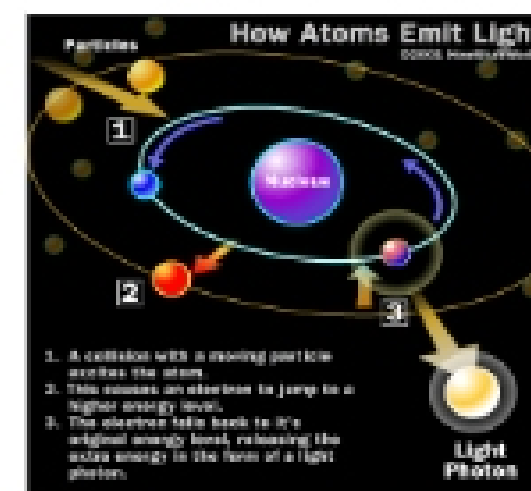
Photons

Reactive Plasma Etching



- Chemical etching
- Isotropic

Glow Discharge Plasma

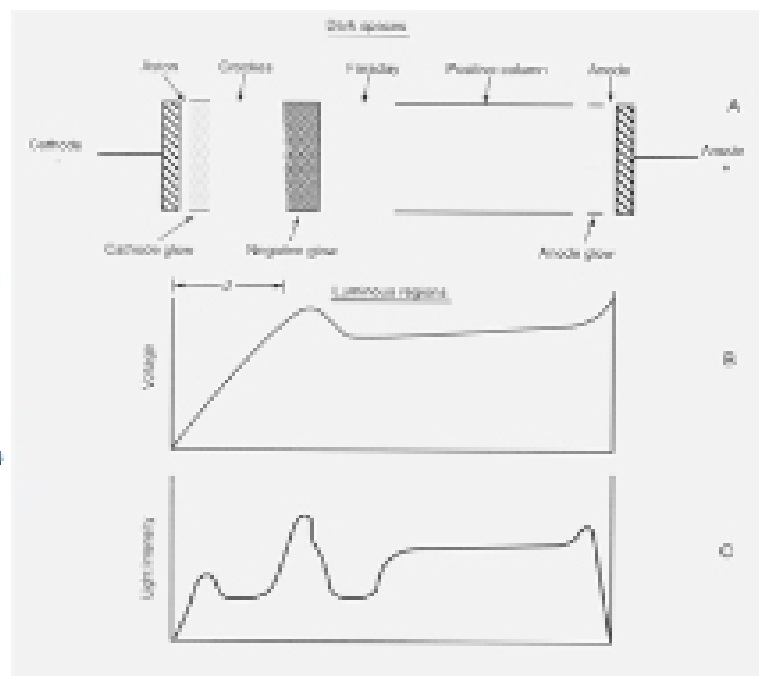


➤ Color of light emission depends on gas, ionization energy, pressure and electric field

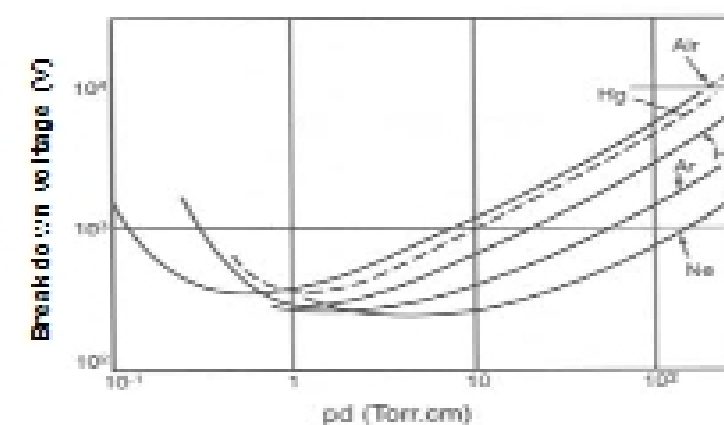
Glow Discharge Plasma

Special zones

- Anon dark space: low energy electrons
- Cathode glow: electrons gain sufficient energy to excite gas atoms
- Crookes dark space: electrons gain too much energy and luminescence is weak due to inefficient excitation
- Negative glow (brightest region): low electric field
- Faraday dark space: electrons slows down due to collisions and low electric field
- Positive column: quasi-neutral, low electric field, uniform; not important for etching or deposition

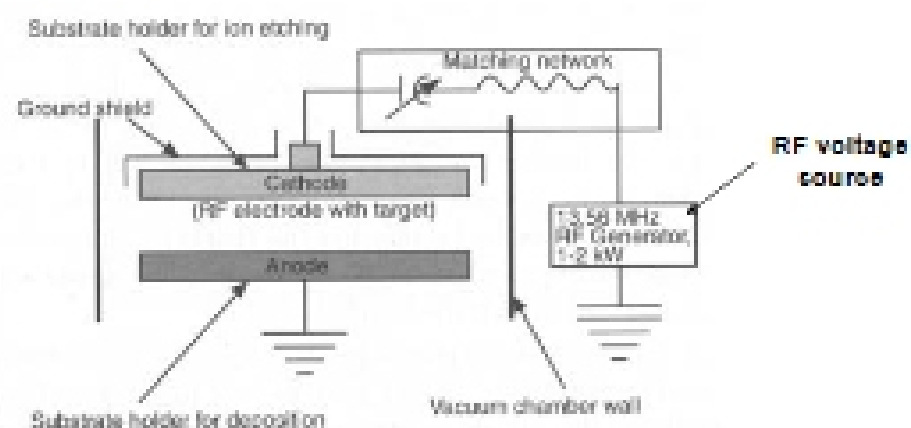


Paschen's Law



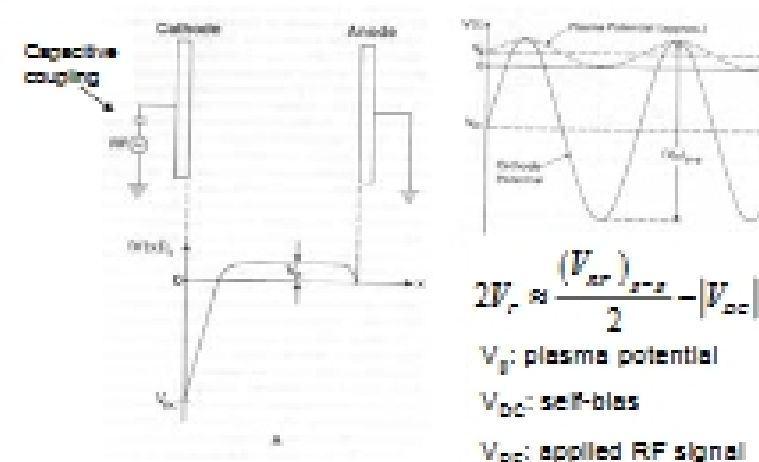
- The breakdown voltage is a function of the product of the gas pressure and the gap distance, i.e., $V = f(p \cdot d)$
- The curves have minima. For large $p \cdot d$, increasing $p \cdot d$ results in larger breakdown voltages.
- For small $p \cdot d$, breakdown voltages increase with $p \cdot d$ decreasing. This is because when the pressure is too low or the distance is too small, most electrons reach the anode without any collisions.
- In air, the minimum breakdown voltage is 327 V.

RF Plasmas



- Electrons oscillates between the electrodes with the AC voltage. No need for electron emission from cathode.
- Can sustain RF plasma at lower pressures than DC plasma.
- RF plasma allows etching of dielectrics as well as metals.

RF Plasmas



- Self-bias V_{DC} : electrons move faster than ions and charge up the cathode (electrons cannot cross over the capacitor) to build up a negative potential.
- The maximum energy of positive ions striking the cathode is $e(V_{DC} + V_p) \sim 300\text{eV}$
- The maximum energy of positive ions striking the anode is $eV_p \sim 20\text{eV}$