# ECE 418/518 Semiconductor Device Processing

## Thin Film Deposition

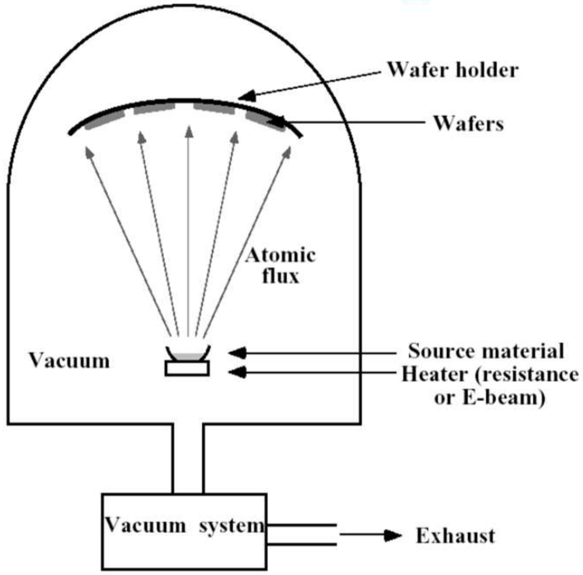
# Outline

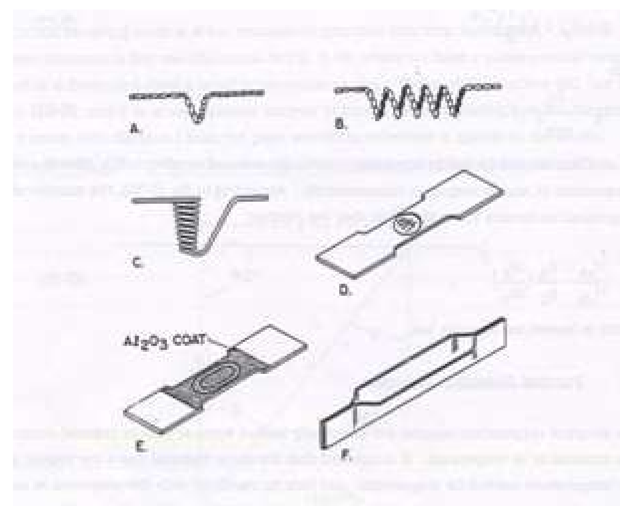
- Different types of materials deposited as thin films during semiconductor processing.
  - Metals and metallic silicides - Al, Au, $CoSi_2$ , $NiSi_2$, etc. Used for contacts, interconnects and schottky barriers.
  - Insulators - $SiO_2$, $Si_3N_4$, silicon oxy-nitride, etc. Used as dielectrics, passivation layer, diffusion barriers, etc.
  - Semiconductors - poly-silicon and silicon epitaxy.

# Thin Film Deposition Techniques

- Physical vapor deposition (PVD)
  - Vacuum evaporation
  - Sputtering
- Chemical vapor deposition (CVD)
  - Atmospheric pressure CVD (APCVD)
  - Low pressure CVD (LPCVD)
  - Plasma enhanced CVD (PECVD)
  - Atomic layer deposition (ALD)
- Epitaxy
  - Vapor phase epitaxy (VPE)
  - Molecular beam epitaxy (MBE)
  - Liquid phase epitaxy (LPE)

# Vacuum Evaporation



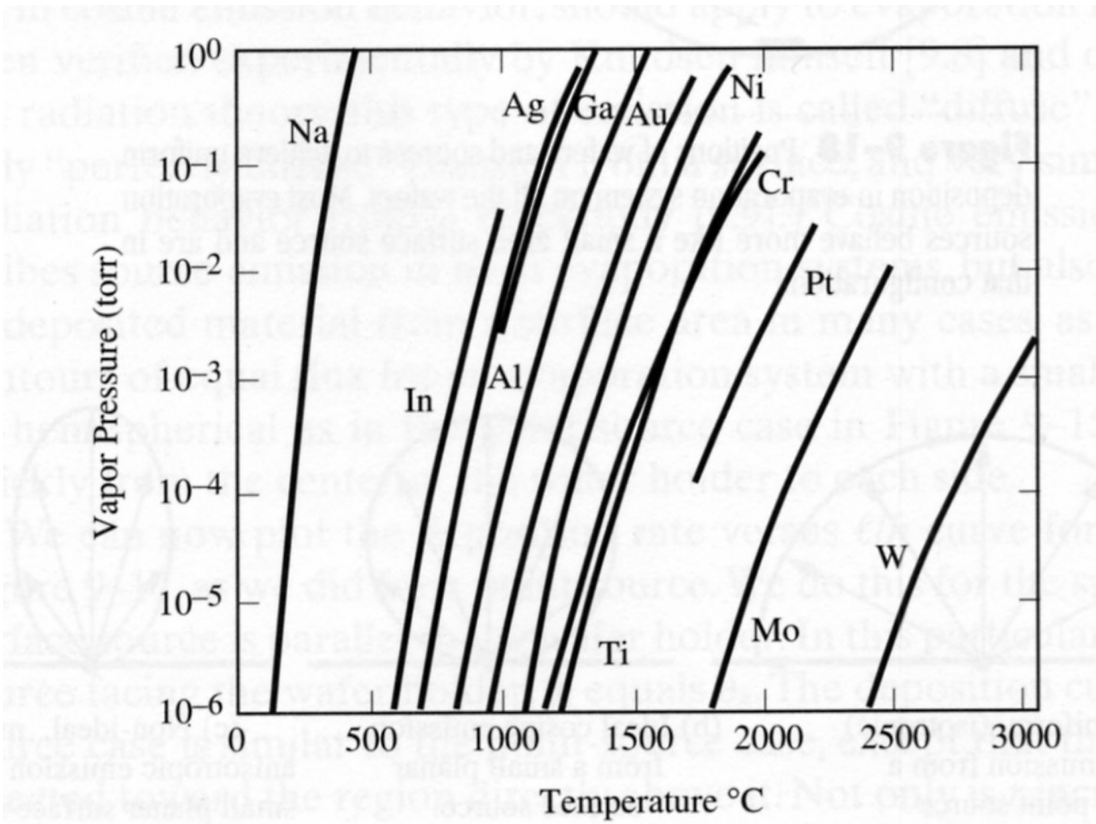
# Evaporation

- The wafers and a piece of the material to be evaporated (called charge) are loaded in a chamber. Sometimes, a shadow mask is used in contact with the samples for large area devices. The chamber is then evacuated to a high degree of vacuum (~ $10^{-6}$ Torr).
- Thermal evaporation:

  The evaporation charge is held in a spiral basket or a flat bottomed boat made of tungsten or molybdenum or tantalum. The evaporation is done by heating the charge first to its melting point and drive any surface scum. At this point the liquid charge typically wets the heating element. Then the melt it raised to its boiling point to evaporate the material. The heating it done by passing a current through the tungsten filament basket/boat (resistive heating).
- E-beam evaporation:

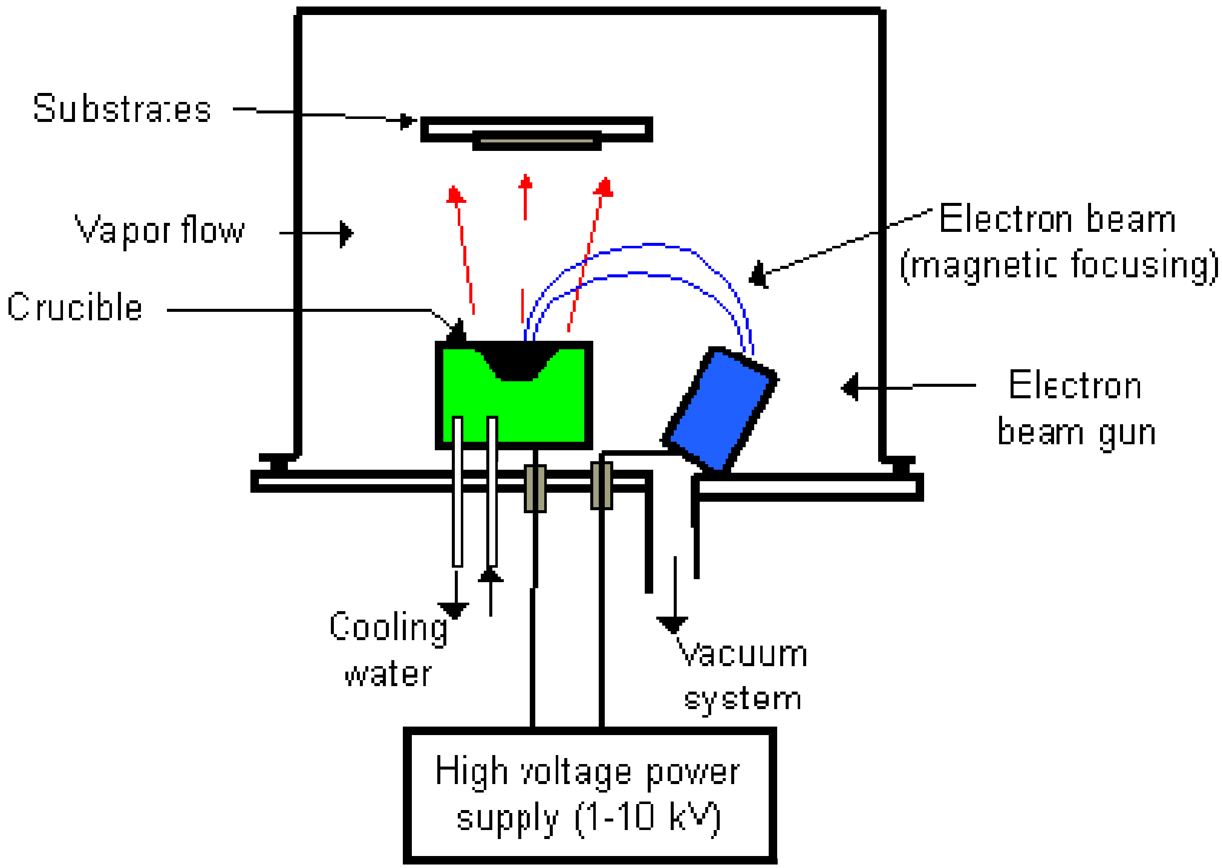
  The charge is held in a graphite crucible. Heating is done by directing a focused electron beam on to the charge.

# Vapor Pressure of Metals



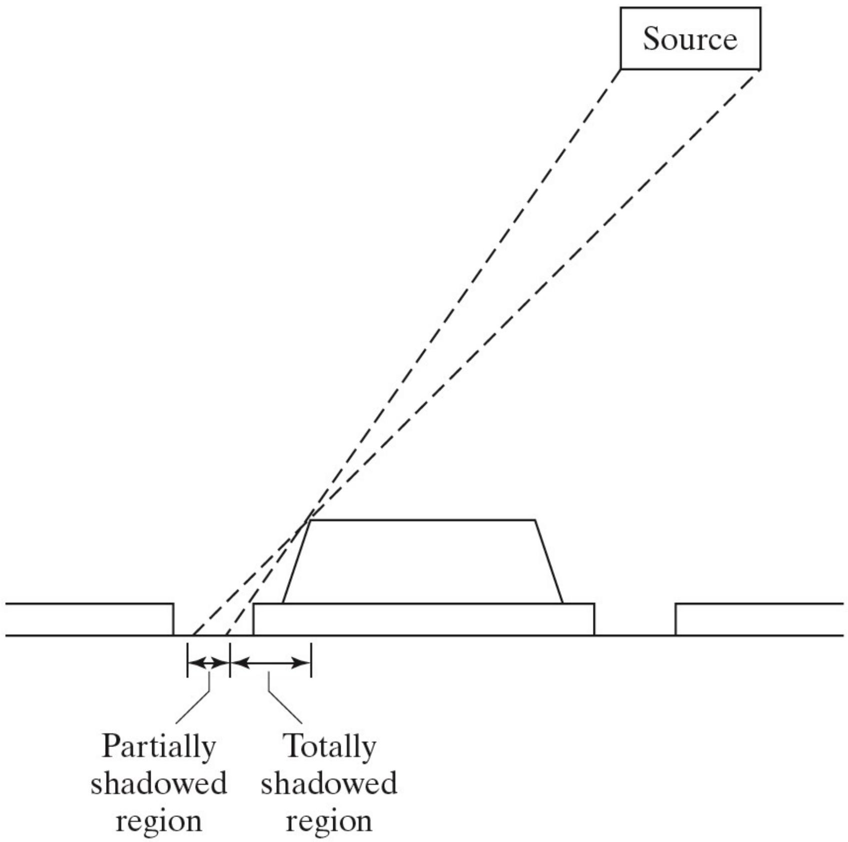

Vapor pressure as a function of temperature of commonly evaporated metals

# E-beam Evaporator



# Evaporation

## Shadowing and Step Coverage




- Shadowing and Step Coverage Problems Can Occur in Low Pressure Vacuum Deposition in which the Mean Free Path is large (~60 m at $10^{-6}$ Torr)

$$\lambda = \frac{kT}{\sqrt{2}\,\pi p d^2}$$

P = pressure
d = diameter of the gas molecule

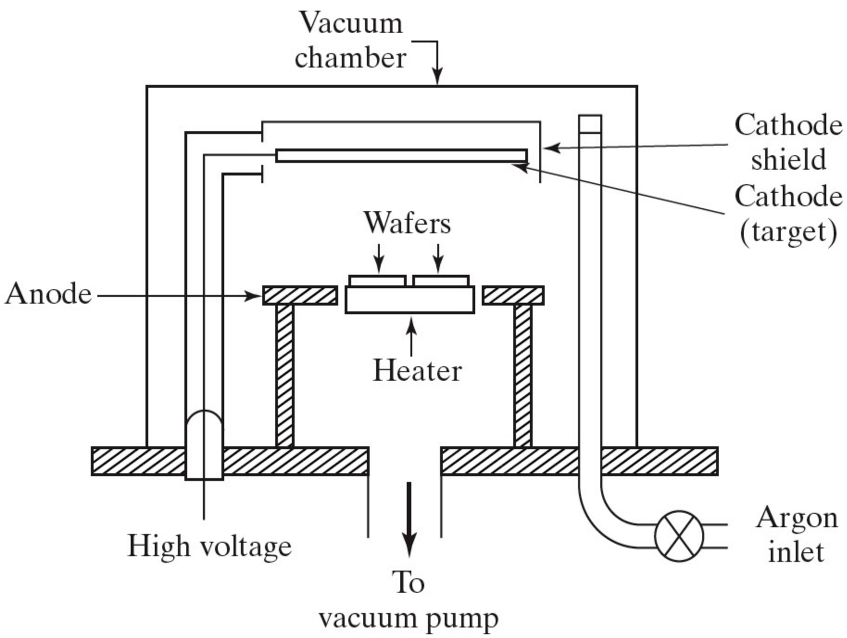
# Sputtering

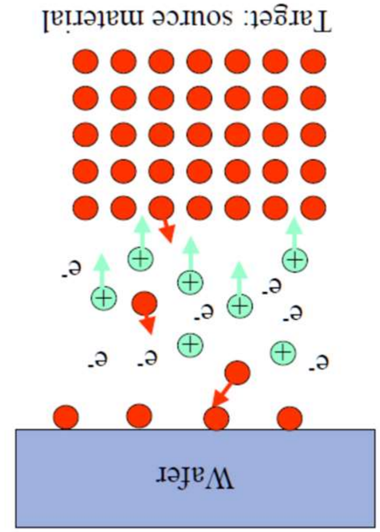
- The material to be deposited is prepared in the form of a target. Metals can be easily made into a thin sheet or foil to act as targets. Even multi-component materials (e.g. ceramics) can be prepared into targets by powdering the individual components, mixing and pressing together. The targets are usually left in the vacuum chamber. Multi-target commercial systems are also available. After loading the wafers, the chamber is first evacuated to a high vacuum ($10^{-6}$ Torr). Then an inert gas such as Argon is passed through the system and a steady state pressure of ~ 100-500 mTorr is maintained by using a throttle valve between the chamber and the pump. A plasma is created by applying either a high DC voltage (1 ~ 2 KV) or RF power between the target and the wafers. The atoms/molecules of the target material released by the bombardment of $Ar^+$ ions on the target surface deposit on the wafers.

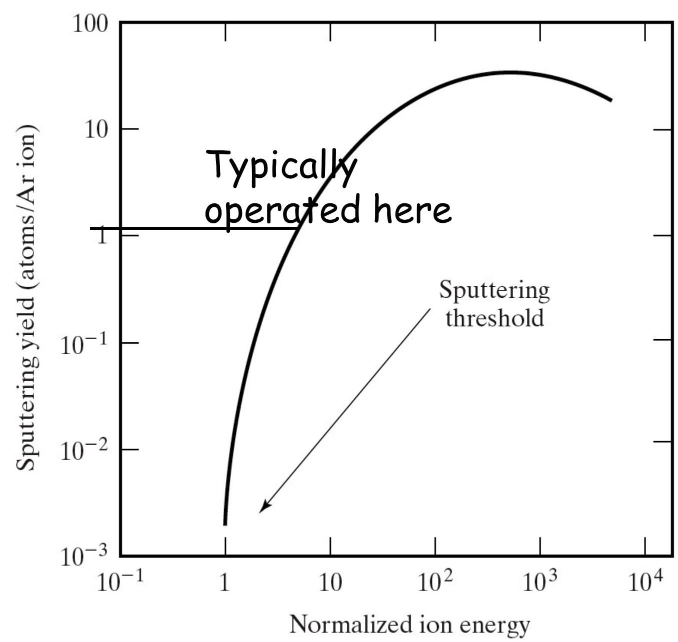
# Different forms of sputtering systems

- DC Sputtering
  - A high DC voltage between the target (cathode) and the wafer (anode) creates the plasma discharge. This type of systems is also called diode sputtering systems.
- RF sputtering
  - RF power (usually 13.5 MHz) is applied between the target (RF electrode) and the wafer (ground electrode). This type of systems is called capacitor geometry systems.
- Magnetron sputtering systems
  - This type can be either DC or RF. The main difference is in the use of a magnetic field to increase the path length of the ions between the anode and the cathode to increase the plasma density.

# Film Deposition
## Sputtering




Mean free path is small (~ 60 um)
Plenty of collisions. Better step coverage.

# DC Glow Discharge

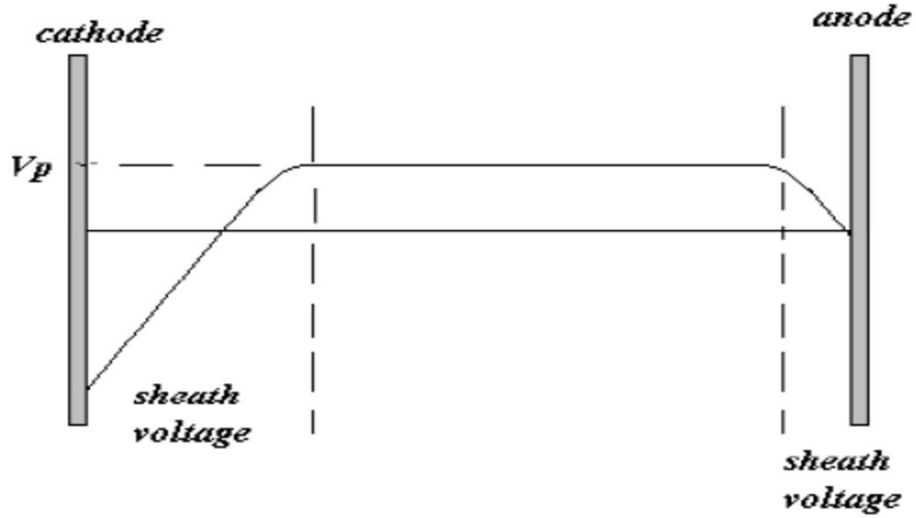
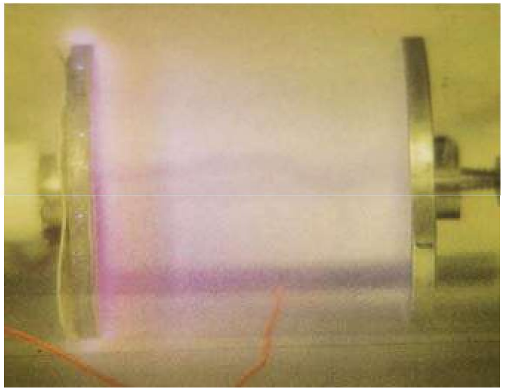
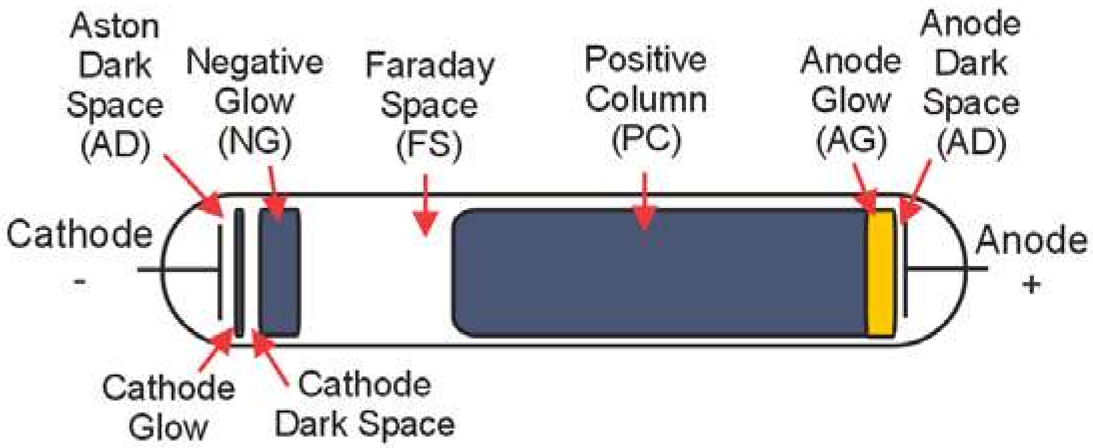
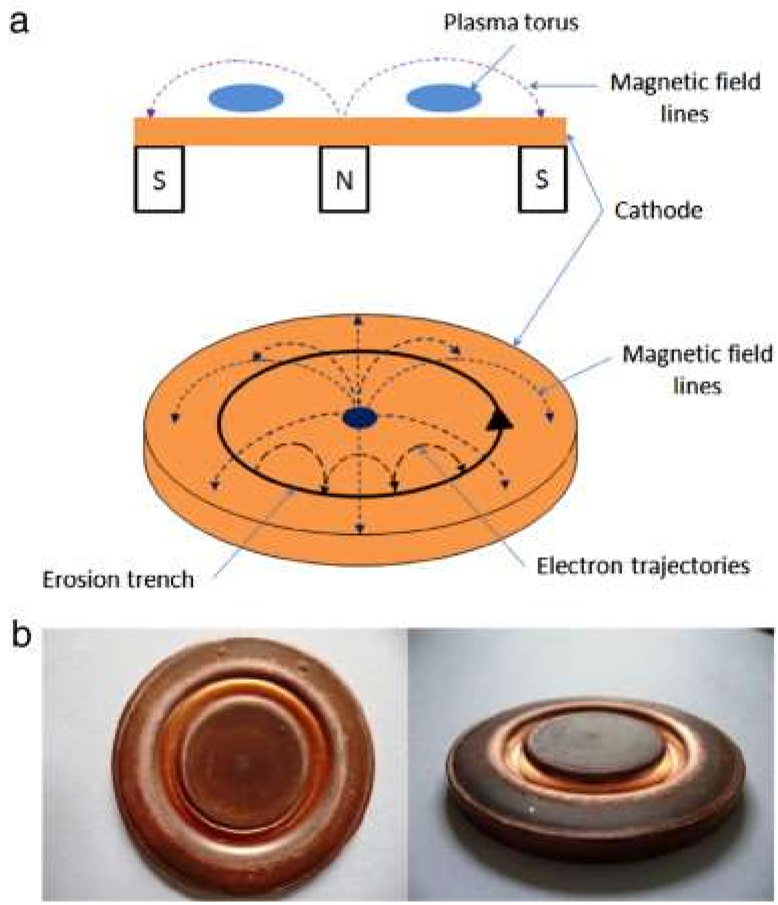



Fig. 1 Voltage distribution in a dc glow discharge process.



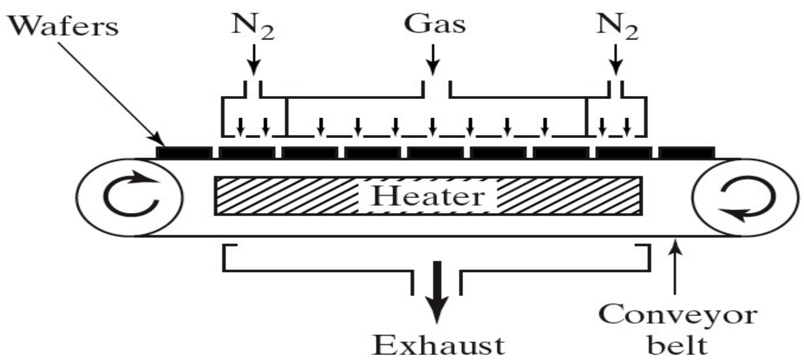


# Magnetron Sputtering (DC or RF)



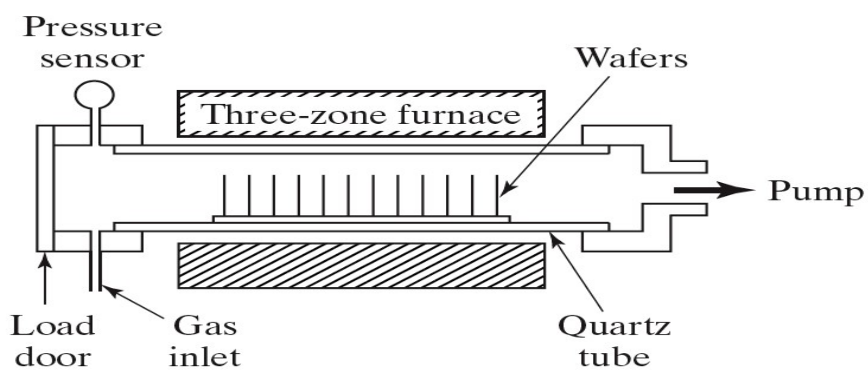
# CVD

## Chemical Vapor Deposition




(a)

Atmospheric Pressure CVD (APCVD)
Consumes large gas flow



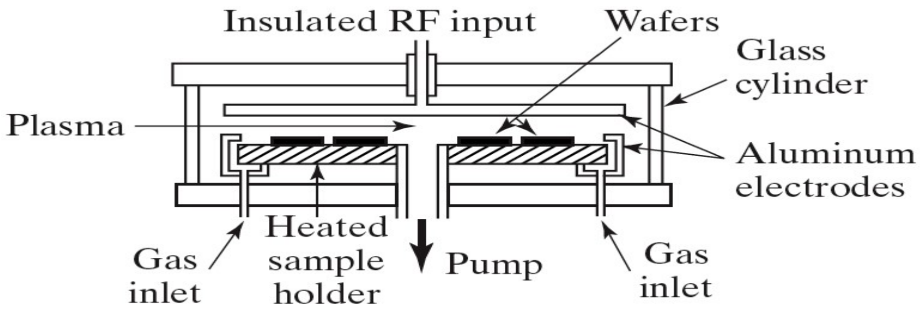

(b)

Hot wall, Low Pressure CVD (LPCVD)
100 mTorr ~ 3 Torr

Four types of CVD systems. (a) Atmospheric-pressure reactor (b) hot-wall low-pressure (LPCVD) system in a three-zone furnace (c) parallel-plate plasma-enhanced system (d) photo-enhanced (PECVD) system using a three-zone furnace. Copyright 1983 Bell Telephone Laboratories, Inc. Reprinted with permission from Ref. [2].

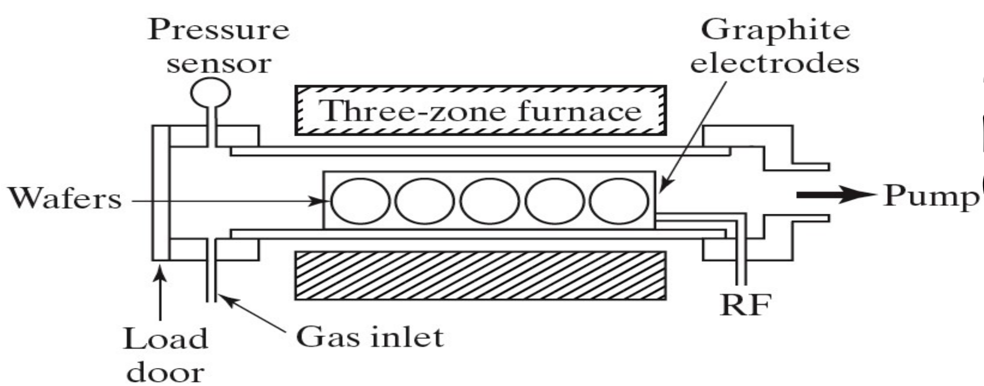
# CVD

## Chemical Vapor Deposition




(c)

Plasma enhanced CVD (PECVD)




(d)

Hot wall, Plasma or photo enhanced CVD (PECVD)

# CVD
## Polysilicon Deposition

- Low Pressure Chemical Vapor Deposition (LPCVD)
  - 25-150 Pa
- Thermal Decomposition of Silane
  - 100% Silane
  - 20-30% Silane in Nitrogen

$$SiH_4 \xrightarrow{600^o C} Si + 2H_2$$

  - 100-200 Å/min at 600-650$^o$ C

# CVD

## Silicon Dioxide Deposition

Deposition of Silicon Dioxide over Aluminum $(300 - 500\ C)$

$$SiH_4 + O_2 \rightarrow SiO_2 + 2H_2 \qquad \mathrm{T} \leq 577^{\circ} C$$

Phosphous Doped $\mathrm{SiO_2}$ - Atmospheric Pressure or LPCVD

$$4PH_3 + 5O_2 \rightarrow 2P_2O_5 + 6H_2$$

P-glass reflow at 1000 ~ 1100 C used to improve step coverage

LPCVD Decomposition of TEOS $650 - 750^{\circ}\mathrm{C}$

$$\mathrm{Si}\left(\mathrm{OC}_2 H_5\right)_4 \rightarrow \mathrm{SiO_2} + \mathrm{byproducts}$$

(better uniformity and step coverage)

Before metallization or on bare Si wafers:

$SiCl_2H_2 + 2N_2O$ ------> $SiO_2 + 2N_2 + 2HCl$ ~ 900 $^{o}C$

# CVD
## Silicon Nitride

Silicon Nitride

- Oxidation Mask for Recessed Oxidation
- Final Passivation Layer Over Die Surface

Also as a gate metal (EEPROM)

Silane Reaction with Ammonia- $700-900^{o}C$ at Atmospheric Pressur

$$3SiH_4 + 4NH_3 \rightarrow Si_3N_4 + 12H_2$$

Hydrogen-rich ~ 8%
High tensile stress.
Thicker films (>0.2 um) may crack

Dichlorosilane Reaction- LPCVD at $700\text{-}800^{o}C$

$$3SiCl_2H_2 + 4NH_3 \rightarrow Si_3N_4 + 6HCl + 6H_2$$

Plasma Reaction of Silane with Nitrogen

$$2SiH_4 + N_2 \rightarrow 2SiNH + 3H_2$$

Plasma nitride is not stoichiometric contains 20~ 25% hydrogen

Plasma Reaction of Silane with Ammonia (Argon Plasma)

$$SiH_4 + NH_3 \rightarrow SiNH + 3H_2$$

# CVD

## Metal Deposition (Mo, Ta, Ti, W)

Tungsten - Thermal, Plasma or Optical Assisted Decomposition of $WF_6$

$$WF_6 \rightarrow W + 3F_2$$

Tungsten - Reduction of $WF_6$ with Hydrogen

$$WF_6 + 3H_2 \rightarrow W + 6HF$$

Mo, Ta and Ti - LPCVD Reaction with Hydrogen

$$2MCl_5 + 5H_2 \rightarrow 2M + 10HCl$$

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Copper is Deposited by "Standard" Plating Techniques

# Si Epitaxy

- Gas phase or Vapor Phase Epitaxy (VPE)
- $SiCl_4$ , $SiH_2Cl_2$ , $SiHCl_3$ and $SiH_4$ have all been used.
- At low temperatures reaction controlled – follows Arrhenius relationship (exp-Ea/kT)
  - Growth rate is very sensitive to temperature
- At high temperatures mass-transfer (or diffusion) limited
  - Growth rate is less sensitive to temperature.
  - Generally operated in this regime

# Back etching of Si during epitaxy

- $SiCl_4(g) + 2H_2\ (g) <\rightarrow Si\ (s) = 4Hcl\ (g)$
- Competing etching reaction
- $SiCl_4(g) + Si\ (s) <\rightarrow 2SiCl_2(g)$
- If the concentration of $SiCl_4$ is too high etching will occur.
- Pyrolytic decomposition of silane
- $SiH_4 \rightarrow Si + 2H_2$ (600 C)

# Atomic Layer Deposition (ALD)