PROGRAMA DE PÓS-GRADUAÇÃO EM
ENGENHARIA ELÉTRICA

Thin Film Deposition

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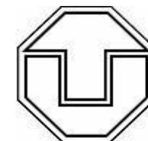

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Thin Film Deposition

- General Caracteristics
- Evaporation
- Langmuire–Knudsen Relations
- Uniform Coating
- Uniformity on a Flat Surface
- Thckness Deposition

II. Thin Film Deposition

Physical Vapor Deposition (PVD)

- Film is formed by atoms directly transported from source to the substrate through gas phase

- Evaporation
  - Thermal evaporation ↩
  - E-beam evaporation ↩
- Sputtering
  - DC sputtering ↩
  - DC Magnetron sputtering ↩
  - RF sputtering ↩
- Reactive PVD

Chemical Vapor Deposition (CVD)

- Film is formed by chemical reaction on the surface of substrate

- Low-Pressure CVD (LPCVD) ↩
- Plasma-Enhanced CVD (PECVD) ↩
- Atmosphere-Pressure CVD (APCVD)
- Metal-Organic CVD (MOCVD)

Oxidation

Spin Coating

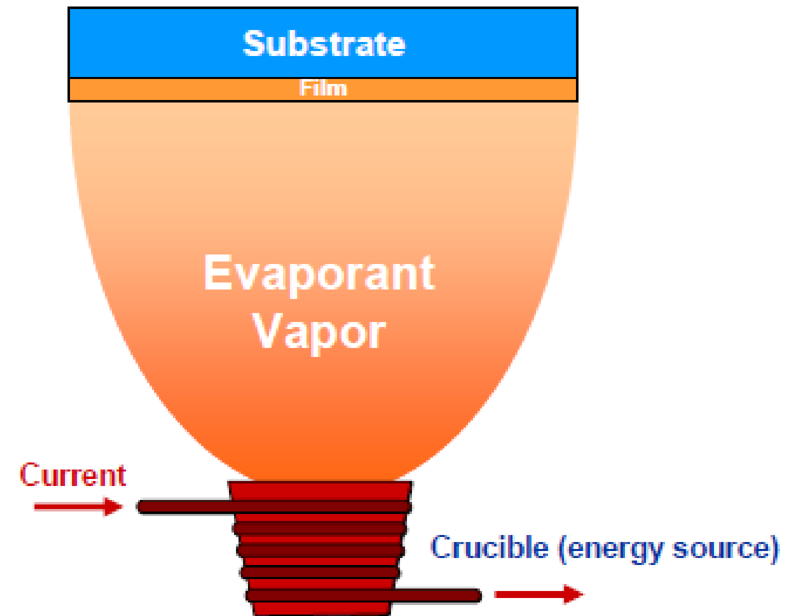
Platting

General Characteristics of Thin Film Deposition

- **Deposition Rate**
- **Film Uniformity**
  - Across wafer uniformity
  - Run-to-run uniformity
- **Materials that can be deposited**
  - Metal
  - Dielectric
  - Polymer
- **Quality of Film – Physical and Chemical Properties**
  - Stress
  - Adhesion
  - Stoichiometry
  - Film density, pinhole density
  - Grain size, boundary property, and orientation
  - Breakdown voltage
  - Impurity level
- **Deposition Directionality**
  - Directional: good for lift-off, trench filling
  - Non-directional: good for step coverage
- **Cost of ownership and operation**

Evaporation

- Load the source material-to-be-deposited (evaporant) into the container (crucible)
- Heat the source to high temperature
- Source material evaporates
- Evaporant vapor transports to and Impinges on the surface of the substrate
- Evaporant condenses on and is adsorbed by the surface



Langmuire-Knudsen Relation

Mass Deposition Rate per unit area of source surface:

$$R_m = C_m \left(\frac{M}{T} \right)^{\frac{1}{2}} \cos\theta \cos\varphi \frac{1}{r^2} \left(P_e(T) - P \right)$$

C_m = 1.85x10^{-2}

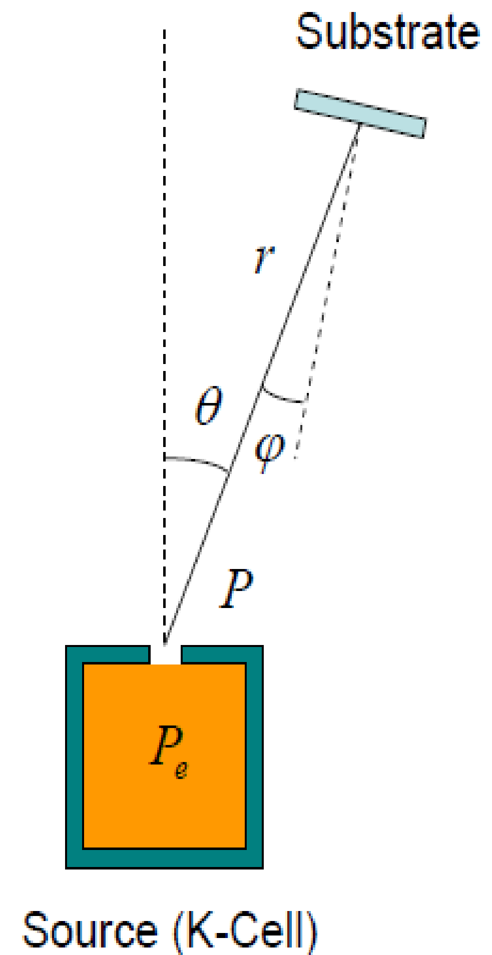
r: source-substrate distance (cm)

T: source temperature (K)

P_e: evaporant vapor pressure (torr), function of T

P: chamber pressure (torr)

M: evaporant gram-molecular mass (g)



- **Maximum deposition rate reaches at high chamber vacuum (P ~ 0)**

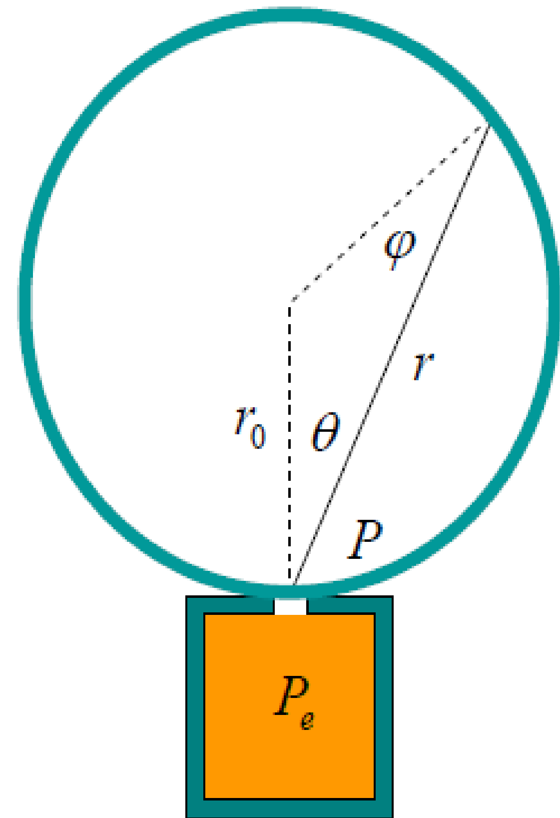
Uniform Coating

Spherical surface with source on its edge:

$$\cos\theta = \cos\varphi = \frac{r}{2r_0}$$

$$R_m = C_m \left(\frac{M}{T}\right)^{\frac{1}{2}} \frac{P_e}{4r_0^{\,2}}$$

- Angle Independent – uniform coating!



- Used to coat instruments with spherical surfaces

Uniformity on a Flat Surface

Consider the deposition rate difference between wafer center and edge:

$$R_1 \propto \frac{1}{r_1^2}$$

$$R_2 \propto \frac{1}{r_2^2}\cos^2\theta = \frac{r_1^2}{r_2^4}$$

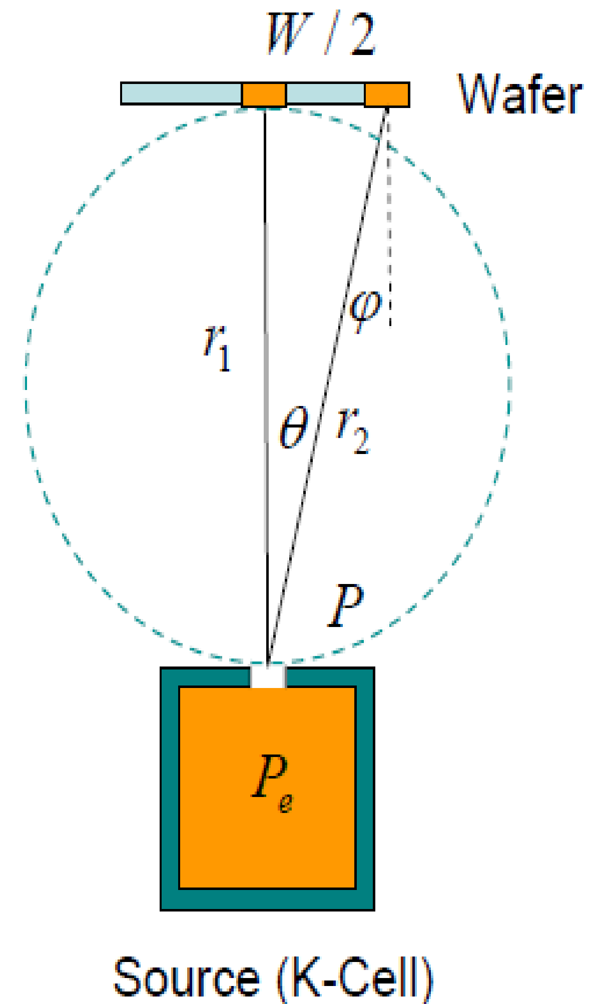
Define Uniformity:

$$\sigma(\%) = \frac{R_1 - R_2}{R_1}(\%)$$

$$\sigma = 1 - \left(1 + \left(\frac{W}{2r_1}\right)^2\right)^{-2} \approx \frac{W^2}{2r_1^2}$$

or

$$\frac{W}{r_1} = \sqrt{2\sigma}$$



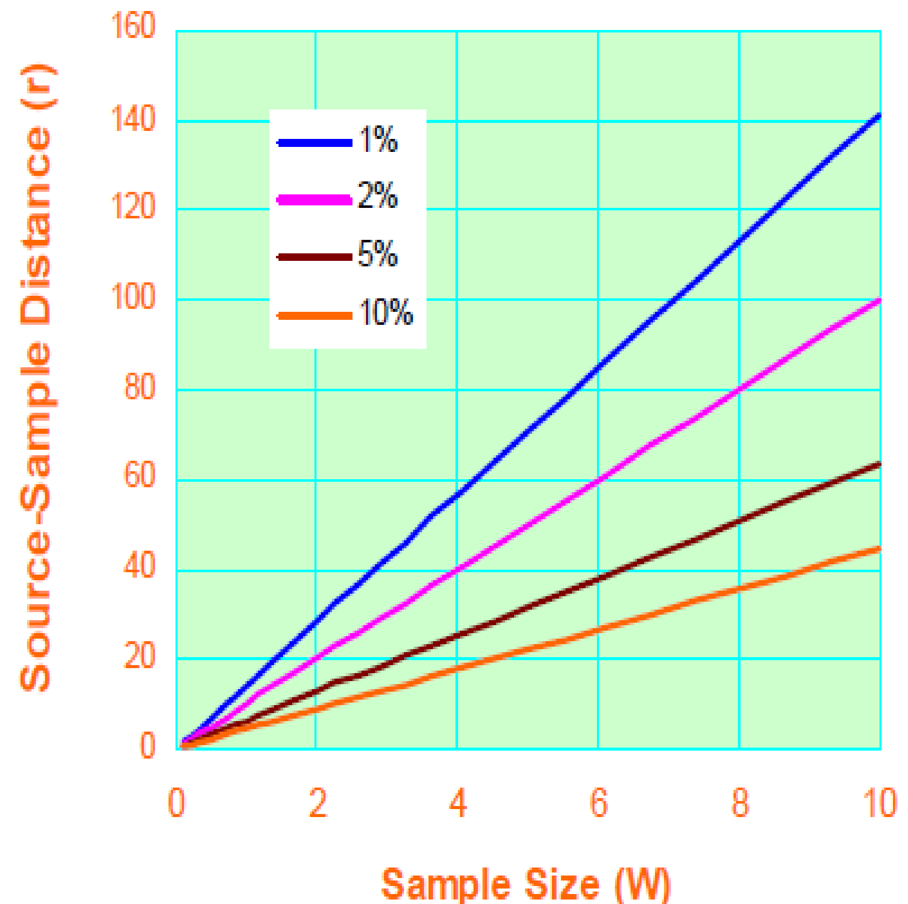
Uniformity Requirement on a Flat Surface

Source-substrate distance requirement:

$$r > \frac{W}{\sqrt{2\sigma}}$$

In practice, it is typical to double this number to give some process margin:

$$r > W\sqrt{\frac{2}{\sigma}}$$



Larger r Means:

- bigger chamber
- higher capacity vacuum pump
- lower deposition rate
- higher evaporant waste

Another Common Solution:
off-axis rotation of the sample

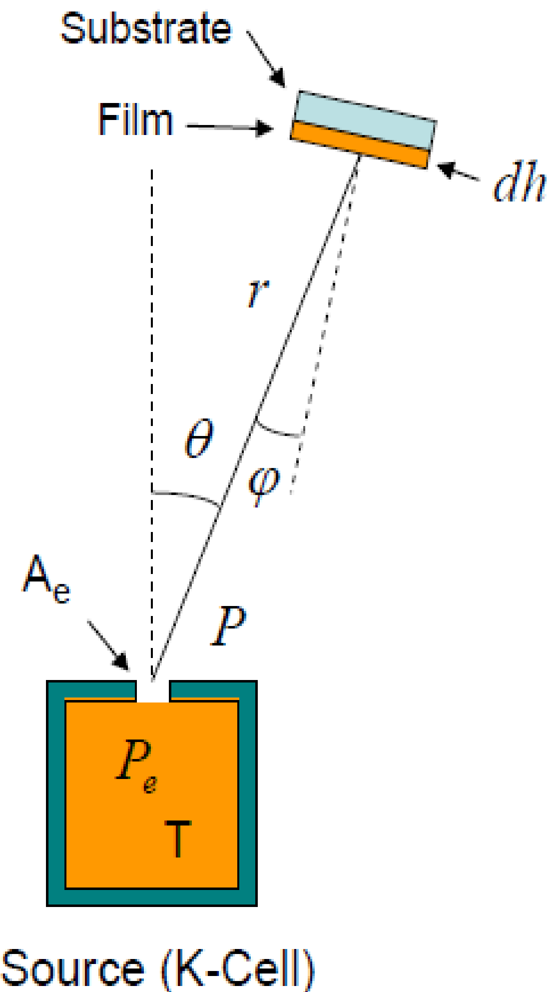
Thickness Deposition Rate vs. Source Vapor Pressure

Thickness deposition rate
$$\frac{dh}{dt} = \frac{R_m}{\rho} A_e$$

$$\frac{dh}{dt} = \frac{A_e}{\rho} C_m \left(\frac{M}{T}\right)^{\frac{1}{2}} \cos\theta \cos\varphi \frac{1}{r^2} P_e(T)$$

T: *source temperature (K)*
A_e: *source surface area (cm^2)*
ρ: *evaporant density (g/cm^3)*

P_e is function of source Temperature!



Example: Al
M ~ 27, ρ ~ 2.7, A_e ~ 10^{-2} cm^2, T ~ 900 K
R ~ 50 cm (uniformity requirement)

$$\frac{dh}{dt} = 50 P_e \quad \text{(A/s)}$$

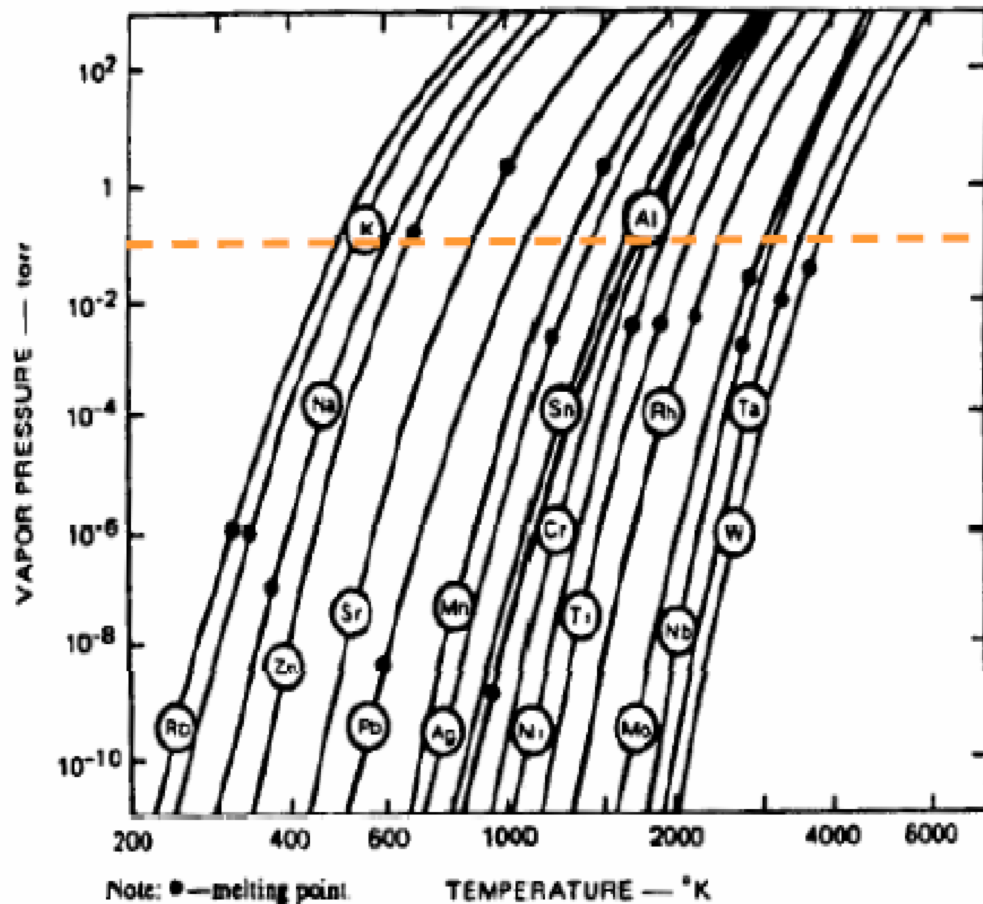
➥ The higher the vapor pressure, the higher the material's deposition rate

Deposition Rate vs. Source Temperature

Typically for different material:

$$\frac{dh}{dt} = (10 \sim 100) P_e(T) \quad (A/s)$$

- For deposition rate > 1 A/s:
  $P_e >\ \sim 100$ mtorr
- P_e depends on: 1) materila and 2) temperature
- Deposition rates are significantly different for different materials
- Hard to deposit multi-component (alloy) film without losing stoichiometry



Example: for Pe > 100 mtoor

T(Al) > 1400K, T(Ta) > 2500K