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CHE323/CHE384
Chemical Processes for Micro- and Nanofabrication

Formulas
Lectures 20-37

Chris A. Mack
Adjunct Associate Professor

http://www.lithoguru.com/scientist/CHE323/

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Mean Free Path

- Mean free path (λ) = average distance a molecule travels between collisions

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

Boltzmann Constant (k)
Absolute Temperature of Chamber (not vapor) (T)
Pressure (P)
Gas molecule diameter (2-5Å) (d)

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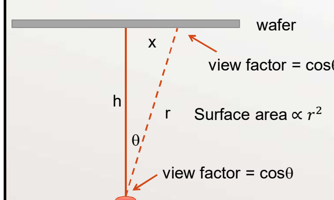
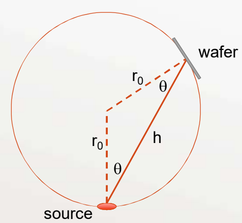
Evaporation

Single Wafer Geometry



$$rate \propto \frac{cos^2\theta}{r^2} = \frac{h^2}{(h^2+x^2)^2}$$

Multiple Wafer Geometry



$$rate \propto \frac{cos^2\theta}{h^2} \qquad cos\theta = \frac{h/2}{r_0}$$

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CVD Deposition Rate

$$v = \frac{k_T}{N}C_g = \frac{k_T}{N}\left(\frac{1}{kT}\right)P_g \qquad k_T = \frac{h_g k_s}{h_g + k_s}$$

$$D_g \propto T^{\frac{3}{2}}\frac{P_g}{P_T}, \qquad \delta \text{ varies slowly with T}$$

D_g = diffusivity of reactant in gas
C_g = bulk reactant concentration
δ = boundary layer thickness
$h_g = D_g/\delta$ = mass transfer coefficient
k_s = reaction rate constant
N = # atoms/cm³ in deposited film

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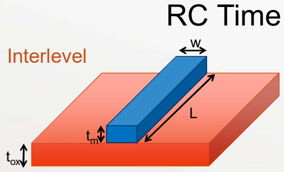
RC Time Constant

Interlevel



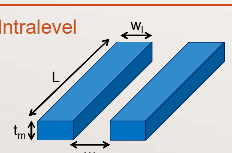
$$\varepsilon_{ox} = K_{ox}\varepsilon_o$$

$$R = \rho_m \frac{L}{wt_m} \qquad C = \varepsilon_{ox}\frac{wL}{t_{ox}}$$

$$\tau = RC = \rho_m \varepsilon_{ox}\frac{L^2}{t_m t_{ox}}$$

ρ_{AL} = 2.8 X 10^{-6} Ω cm, ρ_{Cu} = 1.7 X 10^{-6} Ω cm, for SiO_2 K_{ox} = 3.9

Intralevel



$$R = \rho_m \frac{L}{w_l t_m} \qquad C = \varepsilon_{ox}\frac{t_m L}{w_s}$$

$$\tau = RC = \rho_m \varepsilon_{ox}\frac{L^2}{w_l w_s}$$

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Defect Model

- Independent defects: $Y = (1-G)e^{-A_c D_o}$

G = fraction of die that always fail (edge die)
A_c = critical area (area of die where a defect matters)
D_o = defect density (# killer defects/area)

Main Western Electric Rules

- Any single point falls outside of the +/- 3σ limits
- Eight successive points are above the mean, or eight successive points are below the mean
- Two out of three successive points are between 2σ and 3σ, or between -2σ and -3σ
- Four out of five successive points are between 1σ and 3σ, or between -1σ and -3σ

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Process Capability Index: C_p and C_{pk}

$$C_p = \frac{USL - LSL}{6\sigma}$$

USL = upper spec limit
LSL = lower spec limit

$$C_{pk} = (1-k)C_p \qquad k = \frac{2|Target - mea\ |}{USL - LSL}$$

- $C_{pk} > 1$ is minimum requirement
- $C_{pk} > 1.5$ is good
- $C_{pk} > 2$ is great (called "six-sigma" quality)

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Etch and CMP

- Etch Selectivity
  - Selectivity versus mask material ($s = r_{SiO2}/r_{resist}$)
  - Selectivity versus etch stop layer ($s = r_{SiO2}/r_{Si}$)

$$Anisotropy \quad 1 - \frac{r_H}{r_V}$$

$$CMP\ Polish\ Rate \propto vP$$

v = relative speed
P = pressure

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Useful Constants

• Avogadro Constant	6.02204×10^{23} mole^{-1}
• Boltzmann Constant (*k*)	1.38066×10^{-23} J/K 8.617×10^{-5} eV/K 1.3626×10^{-22} atm-cm^3/K
• Gas Constant (*R*)	1.987 cal/mole/K
• Electric Charge (*q*)	1.60218×10^{-19} C
• Permittivity in vacuum (e_o)	8.854×10^{-14} F/cm
• Thermal voltage at 300 K (*kT/q*)	0.0259 V

- **Pressure**: 1 atm = 1.01325×10^5 Pa = 1.01325 bar = 760 torr = 14.696 psi (1 Pa = 1 kg/(m·s^2) = 1 N/m^2)
- **Energy**: 1 J = 1 kg m^2/s^2 = 9.4782×10^{-4} Btu = 6.2415×10^{16} eV = 0.23901 cal = 1 A V s
- **Capacitance**: 1 F = 1 A s/V = 1 C/V = 1 s/W