CHE323/CHE384
Chemical Processes for Micro- and Nanofabrication
www.lithoguru.com/scientist/CHE323

Lecture 21
Evaporation, part 2

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Reading:
Chapter 12, *Fabrication Engineering at the Micro- and Nanoscale*, 4th edition, Campbell

Vacuum

- To get high deposition rates and low contamination (hot vapor is very reactive!), low chamber pressure is required
  - Typically ~10^{-9} atm ≈ 10^{-6} torr
- Roughing pump (mechanical), down to 10^{-3} torr
- High Vacuum pump
  - Diffusion, turbomolecular, or cryopump

Mean Free Path

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

Boltzmann Constant → k; Absolute Temperature of Chamber (not vapor) → T

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

Pressure → P; Gas molecule diameter (2-5Å) → d

Mean Free Path

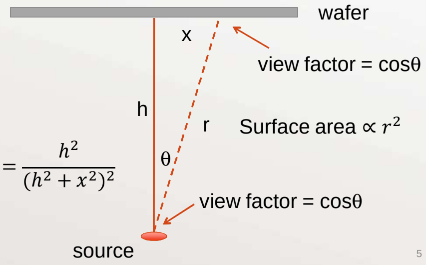
- Example: d = 3 Å, T = 300 K

$$\lambda(cm) = \frac{0.00777}{P(torr)}$$

- P = 10^{-6} torr, λ = 78 m
  - This is long enough to assume no collisions as the vapor travels in a straight line to the wafer

Evaporation Geometry

- Single wafer geometry



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

Across-Wafer Uniformity

$$\frac{rate(x)}{rate(x=0)} = \frac{h^4}{(h^2+x^2)^2}$$

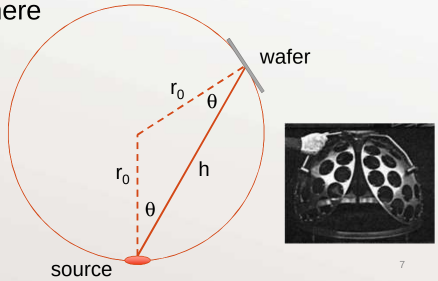
$$\frac{rate(x)}{rate(0)} = \frac{1}{\left(1+\left(\frac{x}{h}\right)^2\right)^2} \approx 1 - 2\left(\frac{x}{h}\right)^2 \quad (x \ll h)$$

Multiple Wafer Geometry

- Put source and wafer on the surface of a large sphere

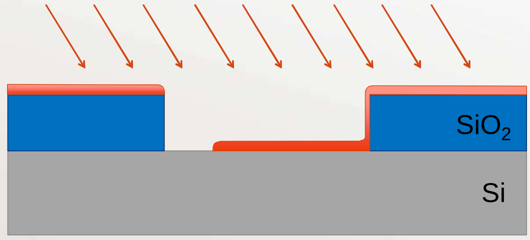
$$rate \propto \frac{cos^2\theta}{h^2}$$

$$cos\theta = \frac{h/2}{r_0}$$



Step Coverage/Shadowing

- Vapor arrives at the wafer at angle θ



Step Coverage/Shadowing

- Improvement: rotate the wafer/planetarium
  - Makes step coverage symmetrical, but still poor in shadowed region
  - The greater the aspect ratio, the worse the problem

- Other option:
  - Heat the wafer (causes diffusion of material after it hits the wafer)
  - Limited by possibility of chemical reactions

Evaporation Overview

- Cheap, easy, high-throughput process for some metals and dielectrics
- Not good for high melting point materials
- Vapor is hot, and thus reactive
- Hard to deposit alloys controllably
- E-beam evaporation causes X-rays
- Trade-off between throughput and uniformity
- Step coverage is a problem

Lecture 21: What have we learned?

- How can we control the mean free path of the vapor?
- Explain the view factor, $1/r^2$ deposition rate dependence, and their impact on across-wafer uniformity
- Why is shadowing/step coverage a problem, and what can we do about it?
- Explain the advantages and disadvantages of evaporation

