CHE323/384 Chemical Processes for Micro- and Nanofabrication
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Homework #6 Solutions

1. Calculate the mean free path at room temperature for N_2, with a molecular diameter of 0.4 nm, at pressures of 1 atm, 0.01 atm, 0.0001 atm, and 10^{-6} atm. How do these distances compare to the size of typical semiconductor features (< 100 nm, called the feature-scale), the size of a wafer (~100 mm, called the wafer-scale), and the size of the vacuum chamber (~1 m, called the reactor-scale)?

Convenient units for the Boltzmann constant for this problem is $k = 1.3626 \times 10^{-22}$ atm-cm^3/K. Letting T = 295 K represent room temperature, the mean free path becomes

$$\lambda = \frac{kT}{\sqrt{2}\pi P d^2} = \frac{1.3626\times10^{-22}(295\,K)}{\sqrt{2}\pi P(0.4\times10^{-7}\,cm)^2} = \frac{5.655\times10^{-6}\,atm-cm}{P}$$

P (atm)	λ	Comments
1	5.7×10^{-6} cm = 57 nm	At the feature scale
.01	5.7×10^{-4} cm = 5.7 µm	A bit bigger than the feature scale, but smaller than the wafer scale
.0001	5.7×10^{-2} cm = 0.57 mm	Between the feature scale and the wafer scale
1×10^{-6}	5.7 cm = 57 mm	At the wafer scale

2. Calculate the mean free path of a particle in the gas phase of a deposition system and estimate the number of collisions it experiences in traveling from the source to the substrate in each of the cases below. Assume that in each case the molecular collisional diameter is 0.3 nm and that the number of collisions is approximately equal to the source-to-substrate distance divided by the mean free path.
    a. An evaporation system in which the pressure is 10^{-5} torr, the source-to-substrate distance is 70 cm, and the temperature is 25˚C.
    b. A sputter deposition system in which the pressure is 3 mtorr, the source-to-substrate distance is 5 cm, and the temperature is 25˚C.

a) $\lambda = \frac{kT}{\sqrt{2}\pi P d^2} = \frac{1.3626\times10^{-22}(298.15\,K)}{\sqrt{2}\pi(10^{-5}/760)(0.3\times10^{-7}\,cm)^2} = 772\,cm = 7.8\,m$ Thus, the average number of collisions is approximately 70 cm/780 cm = 0.09 collisions. These are pretty typical conditions for an evaporation system, though usually we try to get the pressure lower by about an order of magnitude.

b) The pressure is 300 times larger than in part a), so the mean free path is reduced by a factor of 300, to give $\lambda = 2.57$ cm. The average number of collisions is approximately 5 cm/2.6 cm = 2 collisions. These are pretty typical conditions for a sputter system.

3. Why does the sputter yield have a maximum at some ion energy?

At low enough energies, the ion cannot supply enough energy to knock a target atom out, so the yield goes to zero. At very high energies, the ion implants deep into the target, and does not knock any target atoms out. So again the yield is zero at very high energies. If the yield is zero at very high and very low energies, and greater than zero at moderate energies, then there must be a maximum yield (the extreme value theorem of calculus) at some energy between the extremes.

4. Campbell textbook, Chapter 12, problem 3.

5. Campbell textbook, Chapter 12, problem 7.