

## ECE 6450 Homework #7 Solutions

1.) Explain why plasma etching trends have been moving toward lower pressures while deposition trends have been moving toward higher pressures.

In many plasma etching applications (but not all) high degrees of anisotropy is desired. Thus, one desires a low pressure process to allow a longer mean free path and a more directional delivery of the etching gases. Again, biases (either plasma induced or added DC biases) can also increase this directionality. For deposition, most processes (but not all, especially III-V technology) require conformal coatings with equal thicknesses on all surfaces including sidewalls and corners. Thus, a shorter mean free path resulting from higher pressures allows more uniform coatings. However, too high of a pressure can result in exterior corners (like the top corners of a trench) being deposited faster than the flat areas (higher incident collection angles as discussed in class).

2.) When dilute amounts of oxygen are introduced into a  $\text{CF}_4$  plasma process, a scavenged byproduct gas like CO (carbon monoxide) is produced. A.) If the gases are introduced to a large chamber (infinite conductance) with an exit tube with a conductance of 100 liters/(sec-torr) to a roots blower pump at 50 millitorr ( $50 \times 10^{-3}$  torr), what is the maximum possible throughput (in sccm) of  $\text{CF}_4$  and CO respectively? (Assume the vapor pressure of  $\text{CF}_4$  is 1 torr and the vapor pressure of CO is 1000 torr at the process temperature). B.) If the chamber has a volume of 10 liters and is maintained at 1 torr pressure, what (approximate) average time is required to purge the two gases (this is effectively the speed for which a process change can be made and is why minimization of the volume of process chambers is important)? C.) How does this difference in the rate of removal of CO and  $\text{CF}_4$  effect the average carbon content in the chamber for the cases where oxygen is not present versus when it is present? D.) What effect does the change in carbon content have on the sidewall polymerization and why (Assume RIE conditions)? E.) What effect does the oxygen have on the anisotropy?

A.) What flow regime are we in? The statements, roots blower, vapor pressures of 1 and 1000 torr, 50 millitorr, and  $C=100$  [liters/(sec-torr)] each indicate the viscous flow regime. Thus,  $Q=K(P_{\text{upstream}}^2 - P_{\text{downstream}}^2)$  where  $C$  is 100 liters/(sec-torr). To a first approximation, assuming independent, non-interacting gases, we can approximate the gases as being independent systems. But we were not given  $K$ : Therefore similar to example 10.2,

$$Q = C(P_{upstream} - P_{downstream})$$

$$P_{average} Q = C(P_{upstream} - P_{downstream})P_{average}$$

$$P_{average} Q = C(P_{upstream} - P_{downstream}) \frac{(P_{upstream} + P_{downstream})}{2}$$

$$P_{average} Q = C(P_{upstream}^2 - P_{upstream}P_{downstream} + P_{upstream}P_{downstream} - P_{downstream}^2) \frac{1}{2}$$

$$Q = \left( \frac{C}{2P_{average}} \right) (P_{upstream}^2 - P_{downstream}^2)$$

$$Q = K(P_{upstream}^2 - P_{downstream}^2)$$

$$\therefore K = \left( \frac{C}{2P_{average}} \right)$$

Therefore:

$$\text{CF}_4: Q = (100 / [2 (\frac{1}{2}(1+0.05))]) (1^2 - 0.05^2) = 95 \text{ torr-liters/sec or } 7500 \text{ sccm.}$$

$$\text{CO: } Q = (100 / [2 (\frac{1}{2}(1000+0.05))]) (1000^2 - 0.05^2) = 9.9\text{e}4 \text{ torr-liters/sec or } 7,894,000 \text{ sccm.}$$

B.) The above values are the maximum achievable throughput. Note that the CO can be pumped faster than the CF<sub>4</sub>. Since the chamber is held at 1 torr, we can calculate the approximate time to empty the chamber of these gases as,

$$\text{CF}_4: \text{Time} = \text{Volume} \times \text{Pressure} / \text{Throughput} = 10 (1) / 99.75 = 0.1 \text{ seconds}$$

$$\text{CO: } \text{Time} = \text{Volume} \times \text{Pressure} / \text{Throughput} = 10 (1) / 1\text{e}6 = 10 \text{ microseconds}$$

Note: in reality the approximation of gases as independent in flow, is a poor approximation because the slower pumped gas can be “pushed along” by the faster pumped gas. Also note that the pressures are not “the real” vapor pressures of these gases and are for illustration only. Thus, real gas systems switch slower than that presented here but the concept is similar.

C.) If the throughput of CF<sub>4</sub> is constant into the chamber, the more rapid removal of CO than CF<sub>4</sub> when oxygen is introduced results in a lower average carbon concentration in the reaction chamber compared to when oxygen is not present.

D.) Since carbon concentrations are lowered with the introduction of oxygen, less carbon is available to deposit and polymerize.

E.) From (D.) above, the sidewalls are less protected and etched more readily, decreasing the anisotropy.

3.) What percentage of gas molecules (assume 3 angstrom molecular diameter) traveling a distance of 50 cm has underwent a randomizing scattering event at 0.5 Pa (sputtering chamber) and at 10<sup>-4</sup> Pa (evaporator chamber)? You may use the expression for scattering probability,

$\frac{n}{n_0} = 1 - e^{-\frac{d}{\lambda}}$  where  $n$  is the number of molecules having been scattered,  $n_0$  is the total number of molecules,  $d$  is the distance traveled and  $\lambda$  is the mean free path between collisions.

Assume room temperature:

$$\lambda = \frac{1}{\sqrt{2}\pi d^2 n} = \frac{kT}{\sqrt{2}\pi d^2 P} = \frac{1.38e-23(300)}{\sqrt{2} 3.14159(3e-10)^2 P}$$

Thus,  $\lambda=2.07\text{cm}$  for  $0.5\text{ Pa}$  while  $\lambda=10,366\text{ cm}$  for  $1e-4\text{ Pa}$ . Plugging these numbers into the above equation using  $d=50\text{ cm}$ ,

$n/n_0=1$  (or 100%) for the sputtering chamber at  $0.5\text{Pa}$

$n/n_0=0.0048$  (or 0.48%) for the evaporator chamber at  $1e-4\text{Pa}$

Note that this is why the evaporator is highly directional in its deposition whereas the sputtering chamber is not.

4.) Look over example 12.1 in your book (no need to turn it in).

Each semester, I get comments that the book answer is incorrect. This is not true. The key to this problem is in the units. Some useful insights and conversion factors are:

Boltzmann's Constant Joules/Kelvin

1 Joule =  $\text{Kg m}^2/\text{sec}^2$

1 atomic mass unit (amu) =  $1.66e-27\text{ Kg}$

Using these conversion factors, the units and numbers work out as described in the problem.