Problem 1: Vacuum System Terms and Definitions (20 points)

1-1. Define the following terms: adsorption, absorption, chemisorption, and physisorption. How are they different from one another?

1-2. What are the two primary flow regimes encountered in pumping? What is the third flow regime that exists between the two primary flow regimes, but is often not mentioned? How can you tell which flow regime you are in (i.e., is there a figure of merit)?

1-3. Define the following: scc, sccs, and sccm.

1-4. What is the “throughput” of a pump? Is it the same as pumping speed?

1-5. Since a cryo pump operating at 130 K is sufficient to remove all water vapor, why do most cryo pumps operate at a much lower temperature (20 K)?

1-6. How does an ion gauge work? Draw a picture to illustrate your explanation.

1-7. Explain what the following valves do in a typical vacuum system and when they do it: foreline valve, roughing valve, vent valve, and hi-vac valve.

1-8. What typically happens to the pressure inside an evacuated chamber when you close all the valves? Also be sure to explain WHY it happens. Lastly, what would happen if you then heated the walls of the chamber? Again, explain why this would happen?
Problem 2: Vacuum System Calculations (20 points)

2-1. Perform the following unit conversions:
   - 1 psi in terms of Pa
   - 1 mbar in units of mtorr
   - 1 torr in atmospheres
   - 1 Pa in terms of µtorr

2-2. Considering normal air atmospheric pressure and room temperature (not 0 °C), how many H₂ molecules are contained within a vacuum system that has a volume of 1 m³?

2-3. If you pump down that 1-m³-volume of normal air to $1 \times 10^{-6}$ torr, what is the density of N₂ molecules in the chamber per cm³?

2-4. What is the mean-free-path of a molecule of air at 0.1 µtorr?

2-5. What is the impingement rate of O₂ molecules on the surface of a wafer inside a vacuum system pumped down to 1 µtorr?

2-6. As O₂ molecules strike the surface of a wafer, a certain fraction will stick to the surface (and could be incorporated into a film that is being deposited or grown on the surface of the wafer). If one assumes that the molecules migrate on the surface until they find the lowest energy place to stick to (i.e., first clustering together in single-molecule-thick islands and then filling in the gaps between the islands until a full and complete monolayer is formed), then it is possible to calculate the time required to complete a monolayer for a given impingement rate.

For the purposes of this problem, assume that you are working with air in a vacuum system, but that only O₂ molecules will stick to the surface of interest. Furthermore, assume that the O₂ molecules will stick in a rectangular grid arrangement as shown on the right, with a center-to-center separation that can be estimated from the collision cross section of an O₂ molecule.

Use Excel or some other graphing software to plot the time needed to complete a single monolayer of O₂ as a function of pressure. Use a log-log plot and cover the complete range between 1 atm and 1 ntorr. Put pressure on the abscissa (x axis) in units of torr and time on the ordinate (y axis). Draw horizontal lines to indicate the location of the major time units (e.g., 1 ns, 1 µs, 1 ms, 1 s, 1 min, 1 hour, 1 day, etc.).

Plot lines assuming that 1%, 10%, or 100% of O₂ molecules that strike the surface will stick.

Repeat the procedure to obtain results for N₂ and H₂.

2-7. If you take normal air, pump it down to 1 µtorr, then back fill with Argon to a pressure of 100 mtorr, and then pump the system back down to 1 µtorr, what would be the density of oxygen molecules in the vacuum chamber?