3.155J/6.152J
Microelectronic Processing
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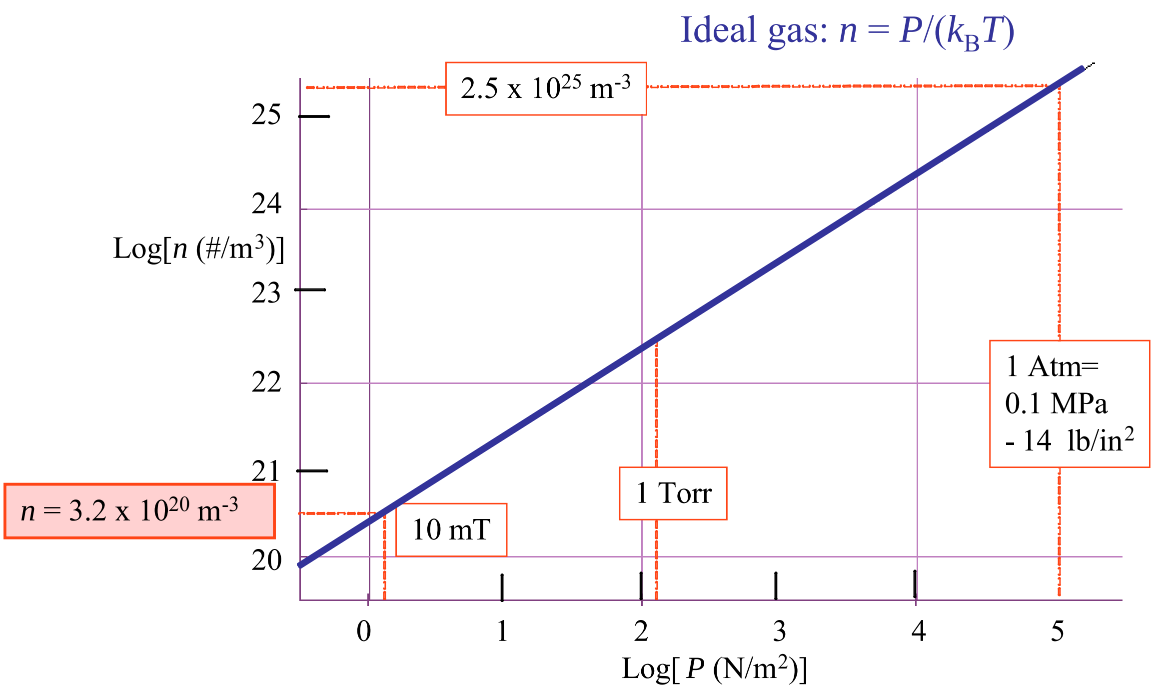
Tayo Akinwande

Bob O'Handley

PS 7 **Sputtering, Evaporation** **April 20, 2005**



1. Refer to the figure above.
   a. What is the average distance between molecules at 3 mT and room temperature?
   b. What is the mean free path at 3 mT. Here, make a reasonable assumption for the molecular diameter, *d*, and state what it is.

$$\lambda = \frac{k_B T}{\sqrt{2} \times \pi d^2 P}$$

Solution: a) By scaling, $n \approx 9.6 \times 10^{19}$ m^3. Inter-molecular distance $\approx n^{-1/3} = 0.22$ µm.
b) P = (0.003 Torr/760 Torr/atm) x 10^5 Pa/atm assume $d = 1.5 \times 10^{-10}$ m and this gives for the mean free path 2.09 x 10^{-5} m = 0.1 m.

2. Enter "Sputtering", Evaporation", or "Both" below to best match the statement at left
   a. Viscous transport. ___________________
   b. Ballistic transport ___________________
   c. Film deposition rate depends on source vapor pressure. ___________________
   d. Film deposition rate depends on substrate bias & input power _________________
   e. Film deposition rate depends on ratio of substrate area to source area. ___________________

   Solutions: Sputter, evap, evap, sputter, both.

3. When Ar+ ions strike the cathode, one of the results is the ejection of several electrons from the cathode.
   a. Explain what it is about the electrons that causes a "dark space" near the cathode?

   Answers: a) In order to cause the emission of a visible glow, the electrons have to accelerate to have a high-enough kinetic energy to cause an electronic transition greater than about 1.4 eV (red). They start out with nearly zero kinetic energy.

4. Mary's lab partner, Bill, wants to grow an Al_2O_3 insulator film. Bill says he will us an Al target in a DC sputtering system and bleed in a continuous flow of O_2 (at a rate he saw in the literature) into a pressure of 10 mT Ar. What should Mary tell him?

   Answer: Bill, you idiot, using a DC sputtering system will result in a buildup of charge on the Al anode. At some point the charge will reduce the voltage and quench the plasma. End of experiment.

5. It is very difficult to *evaporate* stoichiometric SiO_2; you often get SiO_x with $1 < x < 2$, which implies a mixture of SiO and SiO_2. But you still need to get as close as possible to SiO_2.
   a) What partial pressure of O_2 must you have in your vacuum chamber so that the flux of O_2 on the substrate is the same as that of Si? Your evaporation source has a surface area of 1 cm^2, the substrate is at a planetary radius of 20 cm, and your crucible is heated to 1500°C.
   b) What is the mean free path of O_2 in this partial pressure (assume the diameter of an O2 molecule is 0.3 nm).
   c) What does your measurement in b) mean for your process?

Solution

. a) $A_{crucible} = 1\ cm^2$, $r = 20$ cm, T_{Si} =1500°C (1773K)

$$\frac{J_{O_2}}{J_{Si}} = 1 = \frac{P_{O_2}}{P^{Si}_{eq.vap}} \times \frac{\sqrt{2\pi k T_{Si} m_{Si}}}{\sqrt{2\pi k T_{H_2O} m_{O_2}} \frac{A_{cru}}{4\pi r^2}}$$, m_{Si} = 28 amu. m_{O_2} = 32 amu

from table, $P^{1500°C}_{Si} \cong 2 \times 10^{-3}$ Torr

$$P_{O_2} = \frac{2 \times 10^{-3} \times [133(\mathrm{Pa}/\mathrm{Torr})] 1\mathrm{cm}^2 \sqrt{293 \times 32}}{4\pi \times 20^2 \mathrm{cm}^2 \sqrt{1773 \times 28}} = 2.3 \times 10^{-5} \mathrm{Pa} = 1.7 \times 10^{-7} \mathrm{Torr}$$

b) $\lambda = \frac{kT}{\sqrt{2}\pi d^2 P_{Tot}}$ = 23 cm (using T, P of Si)

c) There are virtually no collisions between O_2 molecules in the chamber, for that matter between O_2 and Si vapor molecules. Both species do collide with walls of chamber. Without collisions, the two gases (Si, O_2) are not in equilibrium.

Also Si vapor follows a straight line path to substrate. It is only on the substrate that Si has a chance to interact with O_2.