Solutions to ECE 6450 Homework #1

1.) **A.)** Considering the phase diagram for SiGe, if one wishes to pull a solid crystal with a 85% Si composition, only one temperature can be used, ~1317 degrees C. At this temperature the tie line results in a solid with Si composition of 85% (See point A below). At this temperature, the phase diagram predicts that for compositions greater than 85% atomic Si, the material will be solid only, for compositions less than ~59% atomic Si, the material would be liquid only and for intermediate Si percentages (between points a and B), the material would coexist as both solid and liquid (NOTE: in the 2 phase L+S region, the solid would still contain 85% atomic Si. Thus, the desired crystal composition would be possible). **B.)** From the discussion above, 59%<Si<85%. **C.)** Lower end of the range: At 59% atomic, the weight percent (top "x" scale) would be ~36%, leading to 36 Kgrams of Si and 64% Ge or 64 Kgrams. For the upper end of the range: At 85% atomic, the weight percent (top "x" scale) would be ~69%, leading to 69 Kgrams of Si and 31% Ge or 31 Kgrams.

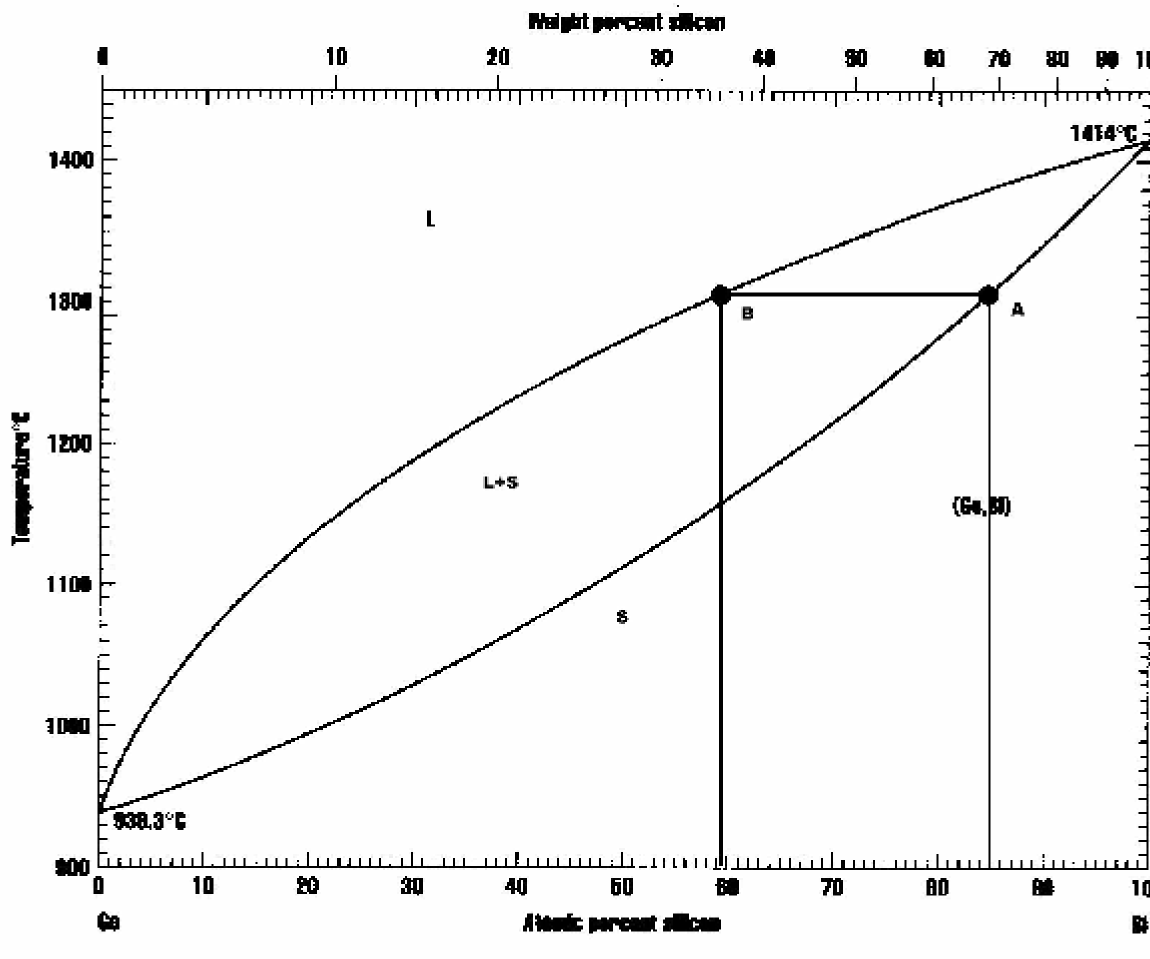

Figure 2-1 Phase diagram of Si-Ge. The dashed lines correspond to a heating process that remains in thermodynamic equilibrium *(courtesy of ASM International)*.

2.) This problem attempts to reinforce 2 concepts: A.) Whatever impurities exceed the solubility limit in the material tends to precipitate out of solid solution and B.) even for small concentrations in the few ppm range, the precipitates can posses a significant volume.

A.) 18 ppm is equivalent to,

$$[O] = \frac{18}{1x10^{6}} 5x10^{22} \ atoms/cm^{3} = 9x10^{17} \ atoms/cm^{3}$$

while the solubility of oxygen at the process temperature is,

$$[O_{Soluable}] = 2x10^{21} e^{-1.032/(8.63e-5(273+1100))} \ atoms/cm^{3} = 3.3x10^{17} \ atoms/cm^{3} = 6.6 \ ppm$$

Thus, the oxygen exceeds the solubility limit by 9e17 - 3.3e17 = **5.7e17 atoms/cm^3.**

B.) There are 2 oxygen atoms per SiO_2 molecule. Thus, there are 0.5 x 5.7e17 = 2.84e17 SiO_2 molecules. Using Avogadro's number, this number of molecules can be converted into the number of moles of SiO_2 present.

$$\text{Number of Moles } SiO_2 = \frac{2.84x10^{17}}{6.02x10^{23}} = 4.7x10^{-7} \ moles$$

Using the molecular weight and density of SiO_2, the volume can be found,

$$Volume = \frac{(4.7x10^{-7} \ moles)(60.085 \ grams/moles)}{2.2 \ grams/cm^{3}} = 1.29x10^{-5} \ cm^{3}$$

C.) Taking the cube root of this volume, we obtain (V=LxWxD= (for a cube) L^3), 0.0234 cm or 234 um! This is thicker than the original wafer!!!!

D.) Applying the equation given in class and in chapter 2 of your book,

$$L_{Denuded \ Zone} = \left(\sqrt{0.091\frac{cm^{2}}{second}\left(6 \text{ hours x } 60\frac{\text{minutes}}{\text{hour}} \text{x}60\frac{\text{seconds}}{\text{minute}}\right)}\right)\left(e^{-1.2/(8.63x10^{-5}(273+1100))}\right)$$

$L_{\text{denuded zone}}$ = 17.8 um

E.) The oxygen concentration in the denuded zone is at the solubility limit, or from A, $[O_{\text{denuded zone}}]$ = 3.3e17 atoms/cm^3.

3.) This problem is meant to reinforce the economic reasons why microelectronic fabrication requires exacting control, can afford expensive process monitoring and failure diagnostics.

The area of the 300 mm diameter wafer is,

$$\text{Area} = \pi(15\ \text{cm})^2 = 706.8\ \text{cm}^2$$

Thus, $706.8\text{cm}^2/2\text{cm}^2 = 353$ computer chips can be produced from one wafer. This results in a company revenue of

$$\text{Revenue} = 353 \times \$700 = \$247{,}100$$

Compare this to the average commercial costs for failure analysis of a few hundred dollars per analysis, or the cost of a process tool that may be a few million dollars (just a few wafers) and one quickly sees why such techniques/equipment are easily justified.