Final Exam

December 20, 2013

Instructions: Answer all questions on the examination sheets. (use backs if needed). If there is a fact or equation you cannot recall, ask and I will write it on the board for everyone.

There are five (5) essay questions, as well as 10 T/F and 10 fill-in-the-blank comprising a 6th question. You have 3 hours (180 minutes). Exam is over at 7:00 PM = 4:00PM +3 hours

Calculators Allowed but No Books & No Reference Sheet. Time: 180 minutes.
1. (20 pts) Write an essay describing how to count the atoms in a unit cell with two sketches (showing portions of each atom inside a cell) that shows why there are two atoms per unit cell in a body centered cubic lattice and 4 atoms per unit cell in a face centered cubic unit cell. If the lattice parameter of the BCC cell is 3 Ångstroms (0.3 nm) what is the lattice parameter of the FCC cell so that the weight density of an element of atomic weight $W$ will be the same in either allotropic form.

Proper counting requires that we enclose the cell boundary and show fractions of atoms so that only portions of the atom actually in the cell are shown. For BCC we see 8 corners, atoms cut off by each corner and one corner atom, fully enclosed. Thus $8 \times \frac{1}{8} + 1 \times 1 = 2$ atoms per cell for BCC.

For FCC, we have $8 \times \frac{1}{8} + 6 \times \frac{1}{2} = 4$ atoms per unit cell where the atoms at the faces are cut off with six faces. The $\frac{1}{2}$ atoms at the corners are counted the same way as in BCC.

The density is \[ \frac{\text{Total Weight}}{\text{Total Volume}} \] \[ = \frac{\text{Weight grams of 1 atom at atomic weight W}}{\text{23 atoms/mole}} \] \[ \approx \frac{6.023 \times 10^{23}}{\text{atoms/mole}} \] \[ \times W \text{ grams/atom} \]

Same density means \[ \frac{2W}{a_{\text{BCC}}^3} = \frac{4W}{a_{\text{FCC}}^3} \]
\[ a_{\text{FCC}}^3 = \frac{4W}{2W} \times a_{\text{BCC}}^3 \]
\[ a_{\text{FCC}} = \sqrt[3]{2} a_{\text{BCC}} = (1.2599) 3 \text{Å} = 3.78 \text{Å} \]
2. (20 pts) Write an essay that describes the operation of a p-n-p field effect transistor. Include a sketch of the cross section of such a device including reference to the types of semiconductors used and to the connections known as the Source, Gate, and Drain.

\[ \text{N type have P added to produce excess negative charge carriers while P type have Al added (valence 3) to create holes in Si lattice, making them extrinsic p type semiconductors} \]

**Operation**

The power of the battery drives a current as shown through the load which might be a speaker coil for example. The current is controlled by the voltage at the gate which produces an electric field which repels the electrons (n carriers) in the n-type semiconductor so that the p-type holes can cross the n-type region without being combined (filled with) electrons. Thus, a time-varying signal \( V \) acts the control to current driven by the battery producing an amplified signal. This is the way Field-effect works — no current is driven — only enough charge is needed to produce the field so new devices have very small loading of the input voltage.
3 (20 pts) Your company has found a way to terminate both ends of 50 mer long polystyrene chains with a carbon to which is attached a double bond oxygen and a single bond O with H. This is a styrene-chain-based dicarboxylic acid. Your company also owns the technology to create diamines with 200 mers of ethylene between them. Since these functional groups are similar to the end groups used to make nylon 6 6, write a first paragraph to describe the process of making nylon 6 6.

Then write a second paragraph about how to react the more complicated styrenic di acid and di amine species to form a chain that has the styrene chain segments alternating with the polyethylene segments. Close your essay with a discussion of the mechanical properties you might expect if this material shows phase separation on cooling with the shorter styrene sections forming zones that exclude the polyethylene segments. Be sure to include mention of anything that can go wrong.

\[
\text{ny}l/m 6 6 \text{ means using condensation polymerization of a diacid + diamine to contain 6 carbons.}
\]

\[
\text{The circled O H and H combine to leave radicals which combine as:}
\]

\[
\left[ \begin{array}{c}
\text{H} \\
\text{H}
\end{array} \right] + \text{ZnH}_2\text{O} \rightarrow \text{HN} + \text{H}_{2}\text{O}
\]

\[
\text{to make chains of length n where n is the degree of polymerization.}
\]

We use the same condensation process to combine the styrenic diacid and the nylon hard diamine. They will actually alternate. Naturally we want to heat the system above the melting point of the resulting polymer so we get good mixing, or we can realize the density difference allowing us to float one liquid on the other at an intermediate temperature and pull the polymer-form at the liquid interface out. We could have some chains that bad in a circle but that should not happen often. Nevertheless, we expect the polystyrene to form a region that insoluble in water so it is best to keep the nylon at a flat interface.
4 (20 pts) Draw a typical eutectic phase diagram with the eutectic point at 60 w% B and 400 °C, a peak solid solubility of B in α of 30 w%, and a maximum solubility of A in β of 20 w%. The melting point of pure A is 600 °C and the melting point of pure B is 500 °C. Certain compositions of this material are known to produce a lamellar eutectic. Write two paragraphs and do a calculation:

First, describe what happens when an alloy of A and B with 20 w% B is heated to the eutectic temperature and, after reaching an equilibrium microstructure, is quenched into cold water.

Second, describe what you would expect if this quenched sample is held at 250 °C for increasingly longer times that allow its microstructure to evolve. Be sure to mention any changes in mechanical properties and why these properties would develop.

Third, determine quantitatively a specific composition of the alloy x in weight percent that would produce a desired fraction of the alloy y as α phase, once the entire system has solidified during a slow cool. Remember you need to include all the α, both the preeutectoid alpha AND the alpha that forms during the eutectic decomposition. The correct answer will be in the form of an equation in x and y. Be sure to verify the limiting behaviors for 0 ≤ y ≤ 1.
\( x = 50 - 50y \)

For \( y = 0 \), \( x = 50 \text{ wt\%} \) (No autochthon deposit)

\( y = 1 \), \( x = 0 \text{ wt\%} \) with presence of \( x \) with no liquid.

For other values of \( y \) such as \( y = \frac{1}{2} \) for example:

\[
x = 50 - 50\left(\frac{1}{2}\right) = 50 - 25 = 25 \text{ wt\%}
\]
5 (20 pts) We know that the eutectoid transformation of steel occurs as a diffusion controlled process involving nucleation of the ferrite and the carbide phases and their cooperative growth into the austenite. We also know it takes different times for the austenite to transform at different temperatures. During isothermal transformation at 500 °C corresponding to the nose of the eutectoid TTT curve, we can conduct an experiment where we quench the sample from austenite temperatures into molten lead at 500 °C and then, after 10 seconds, pull the sample out and plunge it into ice water. If 10 seconds corresponds to the 50% line in the TTT diagram at 500 °C, then 50% has transformed to pearlite and 50% is still austenite when you pull it out of the lead bath.

You also know from your labs that martensite looks very different than pearlite, having an acicular structure so in a micrograph of a polished and etched cross section, we can see which areas are martensite and which areas are pearlite. This question is about what you will see if you could actually observe the microstructure as it is developing. Such interrupted transformations let us observe the transformation process and are the means to produce the TTT curves that have been obtained.

**Make relatively detailed schematic sketches of the microstructure evolution** you would expect as a time series showing the phases present at 500 °C at 0 seconds, 1 second, 2 seconds, 5 seconds, 10 seconds and 10.2 seconds (after the quench—so 0 °C). Assume you are illustrating exactly the same microstructural spot in your schematic so you can used the prior austenite grain boundaries that should be visible at 0 seconds as a template in all 6 of the micrograph sketches you make to show where the new phases nucleate and how they grow. Assume ferrite nucleates first and that carbides nucleates once the transformation starts and has disturbed the carbon concentration. Label the phases.

**Write an essay to go with these micrograph schematics** that starts as follows: “Schematic micrographs illustrating the time series of microstructures during the transformation of eutectoid (1080) steel.... Describe all the physics of the transformation process. Talk about the motion of the carbon in the austenite during the cooperative growth and why there is a gradient in the carbon content of the austenite that enables this diffusion. Talk about why the quench creates a shear transformation that produces a different looking microstructure, enabling us to see what must have been happening.
In (c), we have approximately 50% of the austenite remaining at 50% in the form of pearlite. When this is quenched, the untransformed austenite goes to martensite. This unique structure shows needles of lattices and is acicular as shown in (f) where different phases are labeled. The quench causes a large amount of transformation energy because the large undercooling causes the shift to trap carbon in the body centered lattice and in more distortion to BCT. The shearing provides by forming zones of shear producing the circular appearance.
Answer the following short answer questions with T or F.

a. T. Thermoplastic elastomers have phase separated regions that serve the role of cross links.

b. F. Once a ceramic is fired, it is fully waterproof.

c. T. The color changes in steel allow technical people to estimate the temperature when using a torch to temper a piece of tool steel.

d. T. Piano wire is typically a 1080 steel which has been deformed to reduce the lamellar spacings.

f. F. When elements form a stoichiometric compound in their phase diagram, the generic name for such a compound is a metalloid.

g. T. The adage “Likes dissolve likes” is quantified by the solubility parameter.

h. F. Stress is the critical variable in fatigue, not strain which relates to dislocation motion.

i. F. Brittle materials fracture when too many dislocations have moved.

j. T. Fick’s third law is that large atoms diffuse slower than small atoms.

Fill in the blank or complete the phrase with one or more words to make a true statement.

a. Resistivity has units of ohm-cm while conductivity changed from the nho/cm to ____________ S/cm.

b. Coarsening of a microstructure is driven by ____________ energy.

c. NbC and VC particles in HSLA steels double the strength by reducing the ____________.

d. The two methods to reduce the likelihood that steel will cracking during hardening are known as ____________ and ____________.

e. The isothermal TTT curve emphasizes the fact that the spacing of the lamellae comprising pearlite is controlled by ____________ and ____________. The observation that the spacings look different from place to place in the same sample is just a result of the ____________ of the lamellae.

f. The names of the two lines in a phase diagram for a fully miscible pair of elements are the ____________ and the ____________.

g. Fracture mechanics refers to understanding the growth of ____________.

h. Shore A Durometer refers to the ____________ of polymers and elastomers.

i. The Hirth-Pound model relates to the fact that when a surface is slightly inclined to a low index direction, we will observe ____________ and ____________ on the surface.

j. Slip via dislocations occurs in the direction of the ____________ vector, which is the vector that ____________ a circuit enclosing the dislocation if this circuit would have closed without the dislocation inside.