SOLUTION

3.40J/22.71J Physical Metallurgy
Mid-Term Examination
1.5 hours

Closed Book, Closed Notes, except one, 8.5"x11" Spike sheet.
R = 8.3 J/mole K = 1.98 cal/mole K. k = 1.38×10^{-23} J/K

Do all four problems, which are weighted equally. Show all your work and justify all assumptions and approximations. This exam is to be written in your choice of ink, except disappearing ink

1. Three α grains meet along a line at 120 degree angles. A quantity of a second phase, λ is located at the line along which these grains met. Describe quantitatively the equilibrium morphology of the second phase for each of the following cases.

a. $\gamma_{\alpha\alpha} = \gamma_{\alpha\lambda}$
b. $\gamma_{\alpha\alpha} = 2\gamma_{\alpha\lambda}$
c. $5\gamma_{\alpha\alpha} = \gamma_{\alpha\lambda}$

Solution:
Most people got this one pretty well.
a. Simple triangle of forces gives a triangular prism of material lying along grain boundary. Some remarked the phase may ball up. Could well be.
b. Zero free energy change for replacement of two α:a grain boundaries with two $\alpha\lambda$. Thus, λ phase penetrates the GB.
c. Solution of triangle of forces gave me 168 degrees. λ phase will be almost a circular cylinder. It will probably ball up, but you did not need to know that.

2. The Johnson-Mehl-Avrami-Kolmogorov equation was derived in class.
a. Outline the derivation of the equation. Pay particular attention to assumptions and approximations.
b. How are the assumptions of the J-M-A-K equation violated in the real world of annealing? Give at least three violations.

Solution:
a. Assume constant nucleation rate at random sites and constant isotropic growth rate so that particles grow as spheres. Subtract out the phantom grains so that nucleation and growth only occur in non-transformed material. Derivation does not assume pure material.
b. All assumptions are violated. Nucleation is certainly not at random and is not at a constant rate, even in the non-transformed material. Growth is not isotropic and

certainly varies with size of the recrystallized grain, due to solute drag, for one reason. Over counting of phantom grains is not done, hence is not a violation of the assumptions.

3. Consider interactions between interstitial solutes and dislocations.

a. Explain clearly why interstitial solutes interact with screw dislocations in BCC crystals but not in FCC. Use sketches and/or equations to illustrate your argument.

b. Name one metallurgical phenomenon which is due to dislocation: solute interactions. Describe clearly what the phenomenon is and how it arises. (The phenomenon need not be one which I (or for that matter the text) discussed.)

Solution:

a. The interstitial in the FCC lattice has a cubic displacement field, hence creates no shear stresses or strains. The screw dislocation creates only shear, so does not interact with the FCC interstitial. The interstitial in the BCC lattice creates a tetragonal strain, which gives shear stresses as well as normal stresses. This defect thus interacts with screw dislocations.

b. I will accept upper and lower yield point, Luders bands, Portevin-Lechatlier effect, or any of a bunch of solute:dislocation induced phenomena.

4. Second phase particles which neither coarsen nor are dragged may be very effective in limiting grain size.

a. Give a physical basis for the preceding statement. Be as quantitative as possible.

b. It was stated that at least one particle per grain face was needed for the particles to be effective in limiting grain size.

   1. Give a rationale for this statement.
   2. APPROXIMATELY what is the smallest grain size which would probably have one particle per face if the particles are of radius r and volume fraction f_v. You may assume cubic grains for simplicity.

Solution:

a. I wanted a discussion of pulling a grain boundary away from particles and having to fill in "holes" in the grain boundary with new grain boundary area.

b. Any face without a particle on it is free to migrate. Pinning five faces of a cube will only result in an elongated rectangular parallelepiped.

The average area/area on a face has to be at least the area of a cross section of a particle, or a bit less than the particle area at the equator. Also, area per unit area equals volume per unit volume. I thus have $\pi D^2/a^2 = f_v$ ***or*** $a > D/f_v^{0.5}$

I gave nearly full credit for an answer which gave $f_v^{0.33}$