3.40J/22.71J Physical Metallurgy

Problem set 8 Solution

Problem 1. Consider homogeneous nucleation in a solid solution with the physical properties of copper. Assume spherical nuclei which are nearly pure solute. The solubility of some solute is 0.1 a/a at 1000K. Assume a pre-exponent in the solubility equation of unity. From this you can get the solubility at any temperature.
Below plot the natural logarithm of $\Delta G^*/kT$ for the temperature range $200K<T<800K$. Indicate the temperature range for which my ROT nucleation criterion that $\Delta G^*/kT <60$ holds.

Consider the following three cases.
a. Incoherent nucleation with no strain energy. Assume that the particle:matrix interfacial energy is 0.5 J/m^2 (typical of an incoherent grain boundary). COMMENT on your answer.

HOMOGENEOUS NUCLEATION WILL NOT OCCUR, NOR WILL HOMOGENEOUS NUCLEATION EVER OCCUR WITH AN INCOHERENT INTERFACE.

b. Repeat a for homogeneous coherent nucleation with a particle:matrix interfacial energy is 0.1 J/m^2 Typical of a coherent interface). Assume that there is no strain energy. COMMENT on your answer.

THERE IS A WIDE MINIMUM WITH HUNDRREDS OF DEGREES WHERE THE CRITERION IS SATISFIED.

c. Repeat b, except that there is a strain energy corresponding to $\Delta a/a$ = 0.04. COMMENT on your answer. Compare the results of the three calculations.

THIS FAIRLY SMALL AMOUNT OF STRAIN SLOWS NUCLEATION ONLY A LITTLE.

Problem 2. Martensitic steels gain their strength from a dispersion of fine carbides. In plain carbon steel, these are (approximately) cementite. In a hot working steel they might be (approximately) WC. Assume that in both steels the initial particles are spheres of 1 nm radius. The temperature is 923K (red heat) and the coarsening time is 1 hour. You may assume a surface energy of $0.5 J/m^2$, a molar volume of $10^{-5}\ m^3$/mole.

The equilibrium solubility of cementite in ferrite is (at least at this temperature) given by eq. 9.14 in the text. The diffusivity of C in ferrite may be calculated from $D_o = 10^{-4}$ m^2/s and Q = 100,000J/mole.

The solubility of WC is given by $X_c X_w = \exp.(-90{,}000/RT)$, in SI units. Enough excess tungsten is added so that the tungsten concentration is fixed at nearly 0.01 a/a, at all temperatures. The diffusion coefficient of tungsten is calculated from $D_o = 10^{-4}$ m^2/s and Q = 280,000J/mole.

The material in the posting "Particles GG" around Eqs. 61, 62 may be useful.

a. What is the final particle size in each case? Be sure to determine which element is rate controlling in the case of WC.

THE CEMENTITE REACHES NEAR-MICRON SIZES AND THE TUNGSTEN CARBIDE BARELY COARSENS.

b. Suppose that carbides above 0.1 μm in radius are ineffective in strengthening. Estimate the useful lifetimes of the two steels at 923 K. Comment on your answer.

THE CEMENTITE IS OVERTEMPERED IN SECONDS WHILE THE TUNGSTEN CARBIDE IS GOOD FOR CENTURIES.

INSTRUCTOR NOTE: SETING THIS PROBLEM UP WAS A PAIN. I HOPE THAT YOU LEARNED FROM IT.