Kinetics Lecture 11: Particle Coarsening

Lecture References

1. Porter and Easterling, *Phase Transformations in Metals and Alloys*, Van Nostrand Reinhold (International), Wokingham, 1988. Section 5.5.6, pp. 314–317.

2. Balluffi, Allen, and Carter, *Kinetics of Materials*, Section 15.1, "Coarsening of a Distribution of Particles," pp. 363–373.

Key Concepts

- Capillarity (effects of excess surface free energy) provides the driving force for many important processes that lead to microstructural changes. The *capillarity driving force* is the change of free energy when an interface sweeps through a unit volume of material. It is equal to $\gamma(\kappa_1 + \kappa_2)$, where γ is the excess surface free energy per unit area and κ_1 and κ_2 are the *principal curvatures* of the surface. The sum $(\kappa_1 + \kappa_2)$ is called the *mean curvature* of the surface and it varies from point to point on a surface of arbitrary shape. For a sphere, the mean curvature is $2/R$; for a cylinder, it is $1/R$; for a plane, it is zero.

- *Particle coarsening* occurs spontaneously in two-phase systems comprised of a distribution of particle sizes, and it is driven by a reduction in the total interphase boundary energy, as small particles continually dissolve and feed the growth of larger particles. A kinetic model for particle coarsening starts with the *Gibbs–Thomson* equation which relates chemical potentials to particle size and results in the following expression for the matrix solubility as a function of particle size for a dilute solution (see *KoM* Fig. 15.1, p. 364):

$$c^{\text{eq}}(R) = c^{\text{eq}}(\infty) \exp\left(\frac{2\gamma\Omega}{kTR}\right) \approx c^{\text{eq}}(\infty)\left[1 + \frac{2\gamma\Omega}{kTR}\right] \tag{1}$$

  A two-phase solution of very small particles in a matrix will have a higher solute content in the matrix phase than a similar two-phase solution of larger particles. When a distribution of particle sizes exists in a two-phase solution, and there is local equilibrium at the particle/matrix interfaces, the concentration gradients that result in the matrix lead to solute diffusion from small particles to larger ones.

- The kinetics of volume-diffusion controlled coarsening can be derived by considering the solute diffusion field in the matrix, and follow a "t-to-the-one-third" law for the mean particle size having the form

$$\langle R(t)\rangle^3 - \langle R(0)\rangle^3 = \frac{8\widetilde{D}\gamma\Omega^2 c^{\text{eq}}(\infty)}{9kT}\, t = \kappa\, t \tag{2}$$