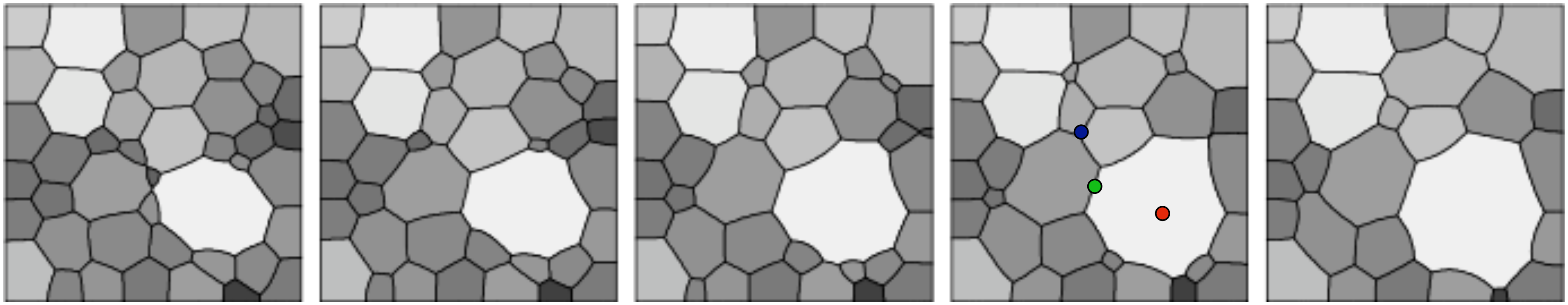
Phase Transformations: Grain Growth; *T-T-T Curves*

Today's topics:

- **Grain growth kinetics in 2- and 3-D**
- **Kinetics of nucleation and growth transformations: time-temperature-transformation behavior**

Grain growth in polycrystalline materials



- **Is capillarity-driven**
- **Simple models for 2-D grain growth based on a linear velocity-driving force relationship give important results that are also valid in 3-D.**
- **Grain structure in 2-D consists of 2-D grains (•), 1-D grain boundaries (•), and 0-D grain corners (•).**

Grain growth in polycrystalline materials

- **2-D growth of an isolated grain contained entirely within a second grain**

See Figure 15.12a in Balluffi, Robert W., Samuel M. Allen, and W. Craig Carter. *Kinetics of Materials*. Hoboken, NJ: J. Wiley & Sons, 2005. ISBN: 0471246891.

- **Velocity** v **proportional to driving force**

$$v = M_B \gamma \left(\kappa_1 + \kappa_2 \right)$$

$$\frac{dA}{dt} = -\int_{GB} v \, ds = -\int_{GB} M_B \gamma \kappa \, ds$$

$$\frac{dA}{dt} = -M_B \gamma \int_{GB} \kappa \, ds = -M_B \gamma \int_{GB} \frac{d\theta}{ds} ds = -2\pi M_B \gamma = -\text{constant!}$$

Grain growth in polycrystalline materials

- **2-D growth of a circular grain contained entirely within a second grain**

$$\frac{dA}{dt} = \frac{d\left(\pi R^2\right)}{dt} = 2\pi R \frac{dR}{dt} = -2\pi M_B \gamma$$

$$R\,dR = -M_B \gamma$$

$$R^2(t) = R^2(0) - 2 M_B \gamma\, t$$

- **Parabolic grain-growth law is predicted, i.e.,**

$$R^2(t) \sim t$$

Grain growth in polycrystalline materials

- **2-D growth of a grain in contact with N neighboring grains**

$$\frac{dA(N)}{dt} = -M_B\gamma\left(\int_{\text{seg }1} d\theta + \int_{\text{seg }2} d\theta + \ldots + \int_{\text{seg }N} d\theta\right)$$

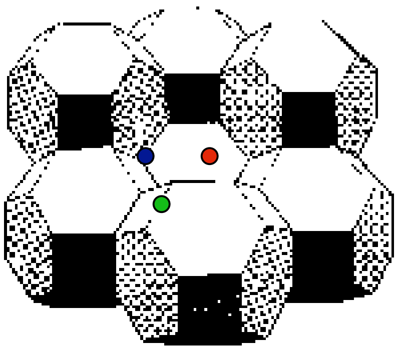
$$= -M_B\gamma(2\pi - N\Delta\theta)$$

$$= M_B\gamma\frac{\pi}{3}(N-6)$$

Fate of a given grain depends on the number of sides it has!

Also, $\langle R(t)\rangle^2 \sim t$

Grain growth in polycrystalline materials



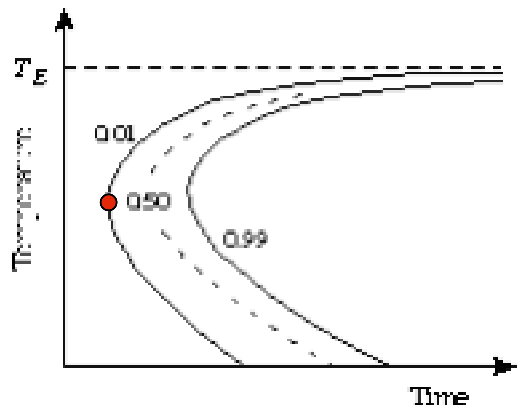
- **3-D grain growth is much more complex and there does not seem to be a 3-D analog of the "N–6" rule in 2-D.**
- **Grain structure in 3-D consists of 3-D grains, 2-D grain boundaries (•), 1-D grain edges (•), and 0-D grain corners (•).**
- **Nevertheless,** $\langle R(t)\rangle^2 \sim t$

Time-Temperature-Transformation Curves

- **"TTT curves" are a way of plotting transformation kinetics on a plot of temperature vs. time. A point on a curve tells the extent of transformation in a sample that is transformed isothermally at that temperature.**
- **A TTT diagram usually shows curves that connect points of equal volume fraction transformed.**

Time-Temperature-Transformation Curves

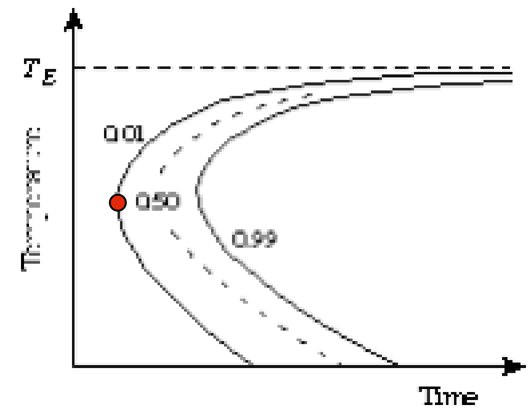
- **Curves on a TTT diagram have a characteristic "C" shape that is easily understood using phase transformations concepts.**



- **It is easy to see the temperature at which the transformation kinetics are fastest; this is called the "nose" (•) of the TTT diagram**

Time-Temperature-Transformation Curves

- **Consider the case of precipitation of a phase β from a supersaturated α solution of composition c_0. Let T_E be the "solvus" temperature below which the solution becomes supersaturated.**



- **Close to T_E , the driving force Δg_B is very small so nucleation is very slow.**
- **The nucleation rate increases at lower T but because nucleation and growth processes involve diffusion, they slow when the temperature gets very low. The "nose" of the TTT curve is at an intermediate temperature.**