Diffusional Transformation I

Homogeneous Nucleation

\[ \Delta G = V \Delta G_v + A \gamma + V \Delta G_s \]

\[ \Delta G = \frac{4 \pi r^3}{3} (\Delta G_v + \Delta G_s) + 4 \pi r^2 \gamma \]

\[ r^* = -\frac{2 \gamma}{\Delta G_v + \Delta G_s} \]

\[ \Delta G^* = \frac{16 \pi \gamma^3}{3 (\Delta G_v + \Delta G_s)^2} \]

Strain energy

Fig. 5.2

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Homogeneous nucleation rate vs $\Delta T$

\[ C^* = fC_0e^{-\frac{\Delta G^*}{kT}} \]

\[ N_{\text{hom}} = fC^* = fC_0e^{-\frac{\Delta G^*}{kT}} \]

\[ f = \omega e^{-\frac{\Delta G_m}{kT}} \]

\[ N_{\text{hom}} = C_0\omega e^{-\frac{\Delta G_m}{kT}}e^{-\frac{\Delta G^*}{kT}} \]

\[ \Delta G^* \propto \frac{1}{\Delta T^2} \quad \Delta G_m = \text{constant} \]
Heterogeneous Nucleation

\[ \Delta G_{\text{het}} = \left[ \frac{4\pi r^3}{3} (\Delta G_v + \Delta G_s) + 4\pi r^2 \gamma \right] S(\theta) + \Delta G_d \]

\[ \Delta G_d = -\pi r^2 \sin^2 \theta \gamma_{gb} \]

Nucleation on grain boundaries

\[ r^* = -\frac{2\gamma}{\Delta G_v + \Delta G_s} + \frac{\gamma_{gb} \sin^2 \theta}{2(\Delta G_v + \Delta G_s) S(\theta)} \]

\[ \Delta G_{\text{het}}^* = \Delta G_{\text{hom}}^* S(\theta) - \Delta G_{\text{GB}}^* \]

\[ S(\theta) = \frac{(2 + \cos \theta)(1 - \cos \theta)^2}{2} \]
Nucleation on dislocations:
- Reduced energy
- Faster diffusion
- Stacking faults between partials facilitate nucleation fcc->hcp nucleus

Excess vacancies:
- Increase the diffusion rate
- Form clusters

The easiness of nucleation (hard to easy, decreasing $\Delta G^*$):
- Homogeneous Nucleation ➔ Vacancies ➔ Dislocations ➔ stacking faults ➔ Grain boundaries ➔ Free surface
Heterogeneous nucleation rate

\[ N_{het} = C_1 \omega e^{\frac{\Delta G_{m}}{kT}} e^{\frac{\Delta G_{het}^*}{kT}} \]

\[ \frac{N_{het}}{N_{hom}} = \frac{C_1}{C_0} \exp \left( - \frac{\Delta G_{het}^* - \Delta G_{hom}^*}{kT} \right) \]

For grain boundaries:

\[ \frac{C_1}{C_0} = \frac{\delta}{D} \]

\( C_1 = \# \text{ of atoms on the defects, e.g. GB} \)
Precipitate growth

Growth of Planar Incoherent Interfaces (e.g. GB precipitates, rough interface)

\[ x = K \sqrt{Dt} \quad v = \frac{\Delta X_0}{2(X_\beta - X_e)^2} \sqrt{\frac{D}{t}} \]

Grain boundary layer does not form continuous layer

Diffusion controlled growth

Fig. 5.16

Fig. 5.18

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Diffusion controlled lengthening of plates/needles

\[ v = \frac{D\Delta X_0}{k(X_\beta - X_r)} \frac{1}{r}(1 - \frac{r^*}{r}) \]

\[ x = k t \]

Constant growth speed

Non-diffusion controlled
(short diffusion distance)

Fig. 5.19

Fig. 5.20
Thickening of plate-like precipitates

\[ v = \frac{D\Delta X_0}{k(X_\beta - X_e)\lambda} \]

Constant growth speed

Non-diffusion controlled
Home Work

• Reading assignment : Ch. 5.4-5.5.4
• HW: 5.5, 5.6, 5.9