Tutorial problems and questions

1. Derive the expression for homogeneous nucleation rate for precipitation, namely,

$$N_{hom} = \omega C_0 \exp\left[\frac{\Delta G_m}{k_B T}\right] \exp\left[\frac{[\Delta G]_c}{k_B T}\right] \quad (47)$$

Answer

The number of clusters (per unit volume) that have reached a critical size C^* in a solid that contains C_0 atoms per unit volume as

$$C^* = C_0 \exp\left\{\frac{\Delta G_{hom}}{k_B T}\right\} \quad (48)$$

An addition of a single atom to these clusters will transform them from embryos to stable nuclei. Let f_0 be the frequency of attachment of an atom to such a cluster; it is a complex function of vibration frequency of atoms, diffusivity of atoms in the undercooled melt, and the surface area of the critical nuclei. Using f_0, one obtains the homogeneous nucleation rate (in units of nuclei per unit volume per second) as

$$N_{hom} = f_0 C_0 \exp\left\{\frac{\Delta G_{hom}}{k_B T}\right\} \quad (49)$$

It is possible to write f_0 as where contains the $\omega \exp -\Delta G_m / kT$ dependence on ω vibration frequency and surface area of the ciritial nucleus while ΔG_m is the activation energy per atom for diffusion. Hence,

$$N_{hom} = \omega C_0 \exp\left[\frac{\Delta G_m}{k_B T}\right] \exp\left[\frac{[\Delta G]_c}{k_B T}\right] \quad (50)$$

2. Comment on the assumptions made in deriving the homogeneous preciptiate nucleation rate and their implications.

Answer

Typically the nucleation rate is assumed to be a constant. However, as time goes by, when the nuclei start growing, the rate for further nucleation drops since the supersaturation in the matrix is reduced.

The nuclei are assumed in our treatment to be spherical; they are also assumed to be of the composition and structure of equilibrium β. However, in the initial stages where interfacial energy is the key parameter, it is possible that the equilibrium phase is not the one that nucleates but a phase with as small an interfacial energy as possible. The formation of GP zones discussed later is an example of the formation of such metastable phases.

3. Comment on heterogeneous nucleation during continuous cooling as opposed to the same during isothermal treatment.

Answer

As discussed in the heterogeneous nucleation section, during heterogeneous nucleation, there are two factors that are to be accounted for: one is the smaller barrier for nucleation; the other is the availability of sites with such small barriers. Thus, during isothermal transformations for example, with increasing driving force for nucleation, the nucleation sites change from grain corners, to grain edges to grain boundaries and so on. However, during continuous cooling, the driving force for nucleation keeps increasing with time; hence, the availability of sufficient number of sites is essential for any heterogenous site to contribute to nucleation.