Question Sheet 3, Solid–State Transformations

1. A metal yields at a stress of 0.1 GPa and the subsequent work hardening during continued plastic deformation is negligible. If 5% of the plastic work is stored in the metal then estimate the increase in stored energy per unit volume for a true strain of 0.4.

   The grain boundary energy in this metal is $0.5\,\mathrm{J\,m^{-2}}$. Estimate the size of a critical nucleus for the homogeneous formation of a strain–free grain, and the activation energy for nucleation. For a reminder of homogeneous nucleation theory see, for example, Part IA Materials and Mineral Sciences handout DH23.

   Comment on both your answers by imagining the chance of a random fluctuation of the critical size, and by comparing the activation energy versus the energy available from thermal vibrations.

   How does recrystallisation actually "nucleate" in deformed metals?

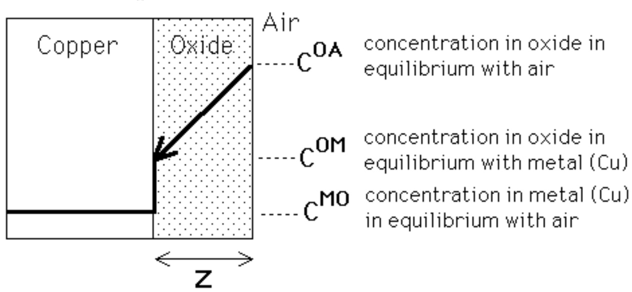
2. Estimate the stored energy due to a dislocation density of $10^{15}\,\mathrm{m^{-2}}$ in a deformed aluminium alloy which has a lattice parameter of 0.4242 nm and a shear modulus of $G \simeq 30\,\mathrm{GPa}$.

   Given that the alloy contains a fraction $f = 0.012$ of spherical oxide particles, each of radius $r = 50\,\mathrm{nm}$, decide whether the particles can hinder the motion of grain boundaries if the force driving the boundaries comes entirely from the elimination of dislocations. The grain boundary energy is $0.3\,\mathrm{J\,m^{-2}}$.

3. Specimen $M24$ is Al–4Cu wt% aged at $220\,^\circ\mathrm{C}$ for 10 days. Comment on the distribution of precipitates in the matrix and in the vicinity of grain boundaries. How can such non–uniform distributions be prevented in practice?

4. Why, in diffusion–controlled growth does the precipitate growth rate decrease with time even though the far–field concentration does not change?

   Copper is oxidised to form a layer of CuO, the rate of formation of which is controlled by the diffusion of oxygen from the atmosphere to the Cu/CuO interface. Show that the thickness z of the oxide increases with the square root of time.



Numerical answers (full answers with BQ1):
1. $r^* = 2\gamma/E = 5 \times 10^{-7}\,\mathrm{m}$, $G^* = \frac{16\pi\gamma^3}{3E^2} = 0.52 \times 10^{-12}\,\mathrm{J}$.
2. The stored energy per unit volume is 1.35 MPa, the pinning stress 0.108 MPa.

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