PHYSICS OF MATERIALS

Physics School Autumn 2025

Series 12 **05 December 2025**

Exercise 1: Precipitation sequence in Al-Cu

a) We generally observe that coherent precipitates are small (nanometric). Why?

b) Suppose:

1) The elastic energy per unit volume of a flat precipitate (penny-shape) is given by $\Delta G_{el} = \frac{3}{2}E\eta^2$. E is the Young modulus, and η is the relative expansion of the precipitate versus the matrix.

2) The alloy Al-4%Cu has a precipitation sequence: $GP \rightarrow \theta'' \rightarrow \theta' \rightarrow \theta$. The most stable precipitates increasingly lose their coherence with the matrix.

3) Data: E = 70 GPa, $\gamma = 0.5 J/m^2$, the aspect ratio A = radius/thickness is a constant equal to 5. The crystalline structure of the precipitates is represented in the following figure.

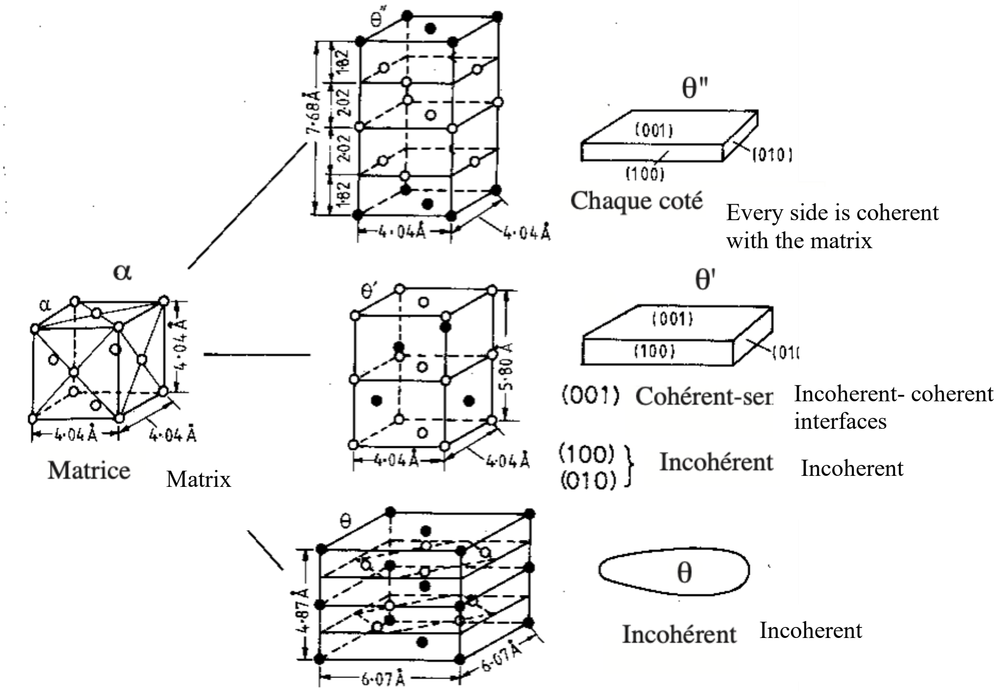

Figure 1 Representation of primitive cells of θ phases in Al-Cu

What is the critical thickness to pass from the formation of GP zones to the formation of θ'' precipitates?

Exercise 2: Localized nucleation

In the case of localized nucleation on a flat surface, show that:

$R_c^{loc} = -\frac{2\gamma_{SL}}{\Delta g_V}$ and $\Delta G_c^{loc} = \frac{4\pi}{3}\frac{\gamma_{SL}^3}{\Delta g_V^2}\left(2 - 3\cos\theta + (\cos\theta)^3\right)$

where $\Delta g_V = g_S - g_L$ is the free energy per volume unit variation during the solidification, and γ_{SL} is the "solid-liquid" interface energy per surface unit.