3.40 LECTURE SUMMARY – Nov 9th

11/ 16/ 2009

INTRODUCTION

- Precipitation Hardening
  - It relies on changes in solid solubility with temperature to produce a second phase
- Hardening Mechanisms
  - Modulus Mismatch
    - Changes the dislocation energy
  - Ordered Precipitates
  - Size Effect
    - Cutting to Bowing Transition
    - Coherent and Incoherent Precipitates

2 COMPONENT PHASE DIAGRAMS

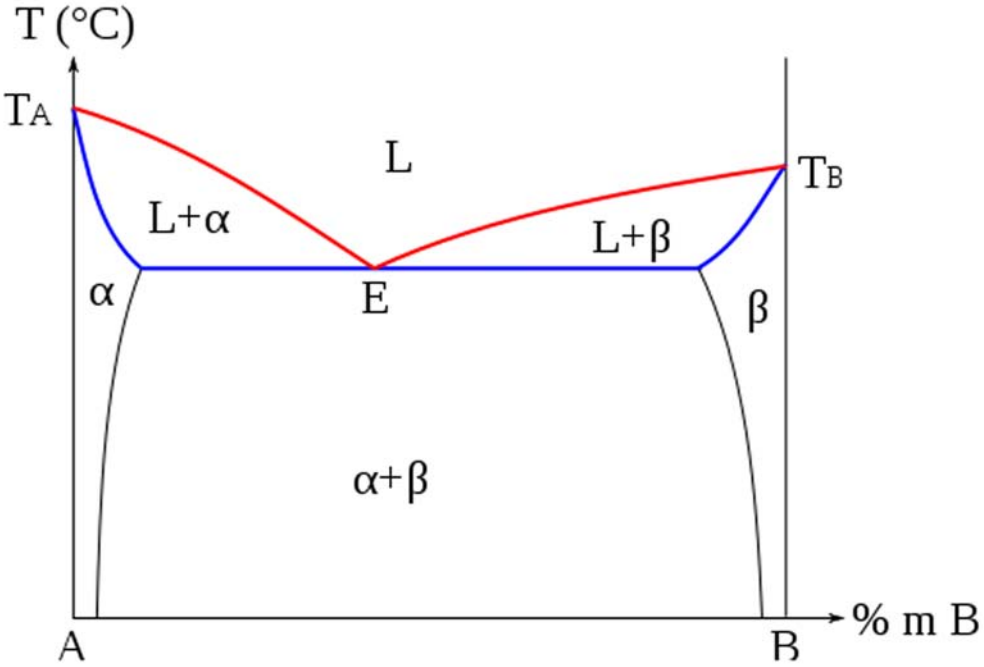
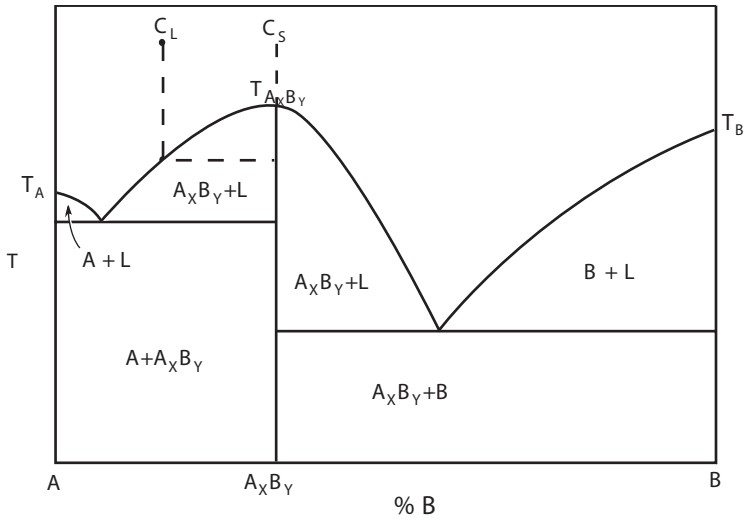


Fig. 1: System forming 2 Solid Solutions
[http://en.wikipedia.org/wiki/Phase_diagram]



Courtesy of Lionel C. Kimerling. Used with permission.

Fig. 2: System forming an Intermetallic
[http://www.substech.com/]

ANTI-PHASE BOUNDARIES

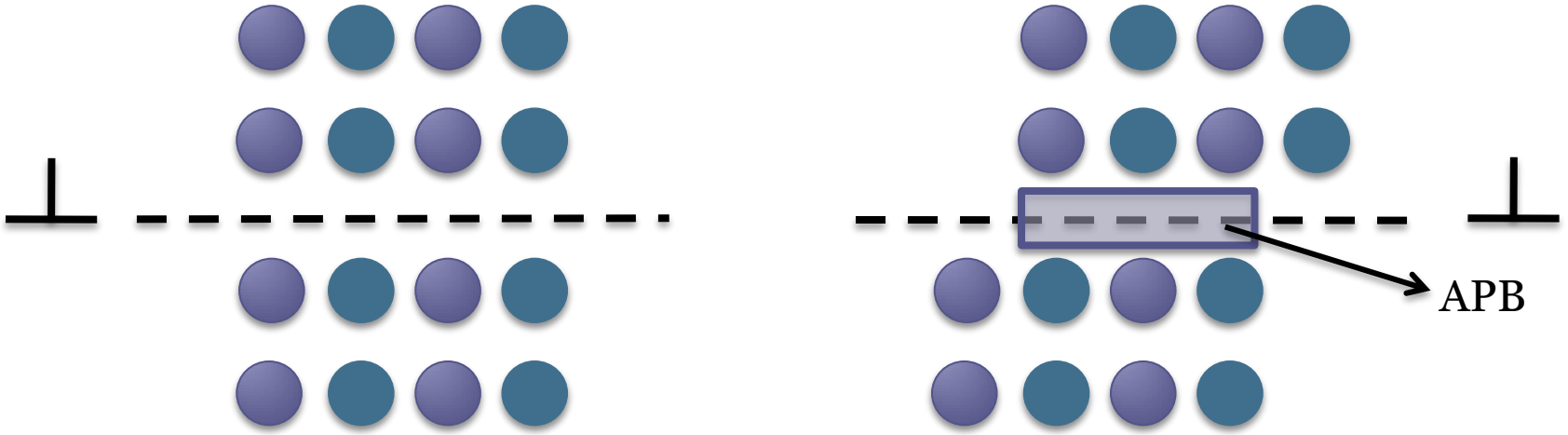


Fig. 3: Dislocation cutting through an ordered precipitate forming an APB

- Additional energy is required to create an APB

$$\Delta\tau_{APB} = \frac{\pi}{2b}\gamma_{APB}\frac{r}{L} = \frac{\pi}{2b}\gamma_{APB}V_f$$

PRECIPITATION HARDENING

- Contributions to Precipitation Hardening
  - Anti-Phase Boundaries
  - Interfaces
  - Coherency Strains
  - Modulus Effect

Decreasing effect on Strength

$$\Delta\tau_{tot} = \Delta\tau_{APB} + \Delta\tau_{\text{int}} + \Delta\tau_{coh} + \Delta\tau_{\text{mod}}$$

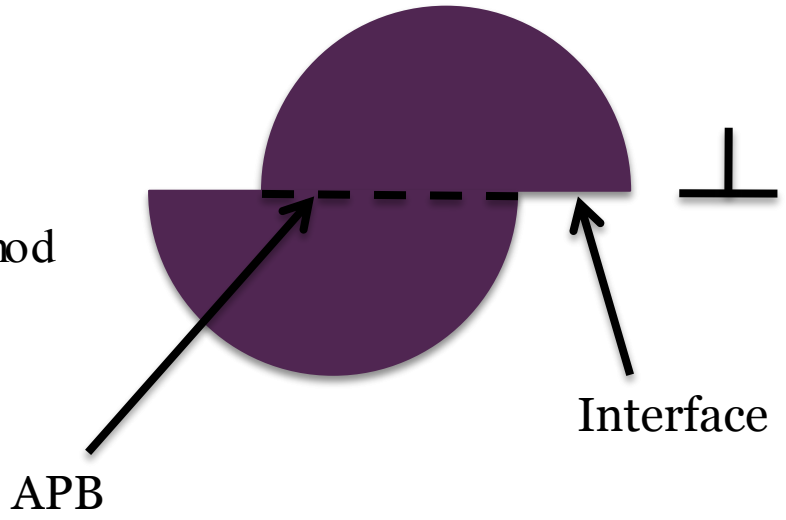


Fig. 4: Schematic of a sheared precipitate

SIZE EFFECTS

- As the size of the second phase particle increases
  - Cutting through it becomes more difficult

$$\Delta\tau_{cutting} \propto r$$

  - Dislocations tend to bow around the particle by Orowan Looping

$$\Delta\tau_{bowing} \propto \frac{1}{r}$$

  - Critical radius ~ 5 – 30 nm

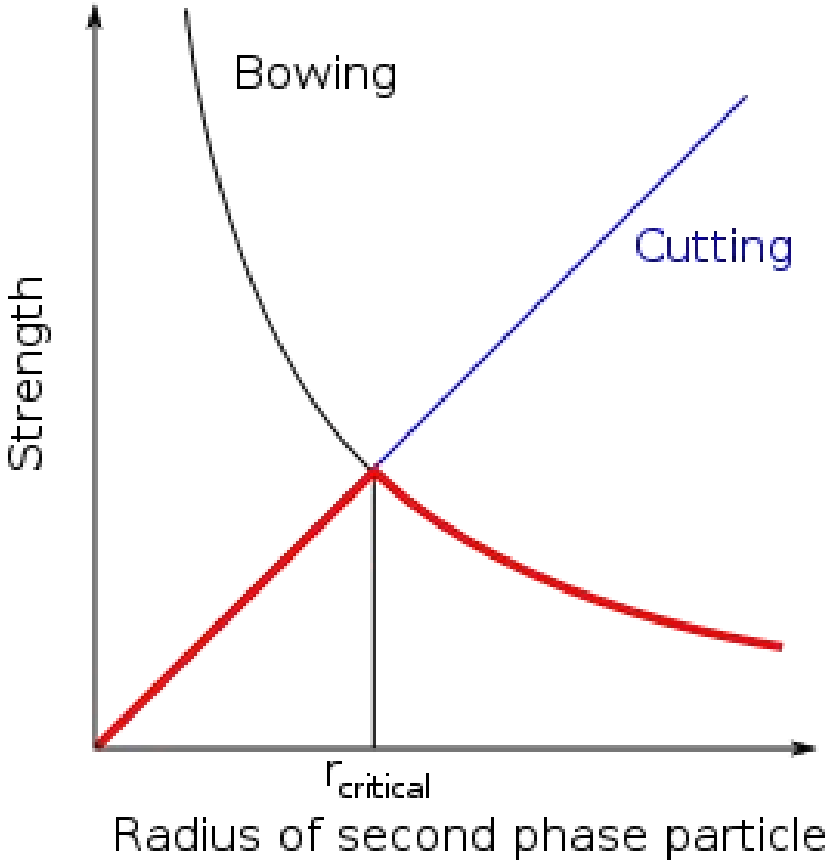
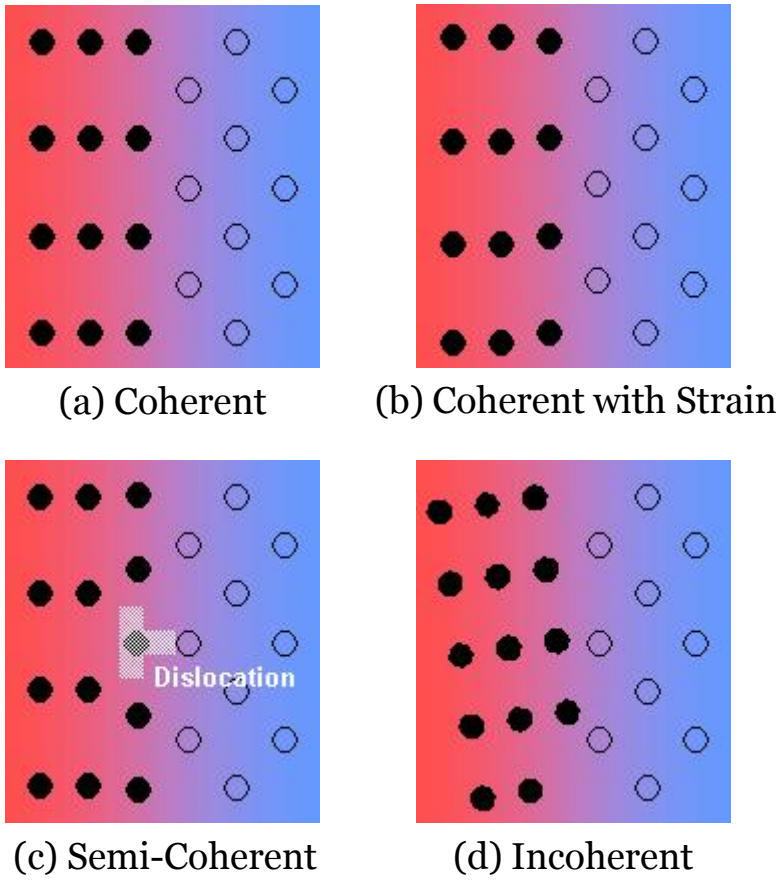


Fig. 5: Shear Strength vs. Particle Radius
[http://en.wikipedia.org/wiki/Precipitation_strengthening]

SIZE EFFECTS

- As the size increases, coherent particles transform to incoherent precipitates
- The strain energy is reduced and the strengthening effect is weakened
- The critical radius for this transition ~ 10 nm – 1 μm



(a) Coherent (b) Coherent with Strain

(c) Semi-Coherent (d) Incoherent

Fig. 6: Different types of interfaces
[http://www.doitpoms.ac.uk/tlplib/solid-solutions/]

PRECIPITATE FREE ZONES

- Heterogeneous nucleation at grain boundaries, dislocations
- Particles nucleate at grain boundaries
- Regions surrounding the grain boundary are depleted of solutes, forming PFZs

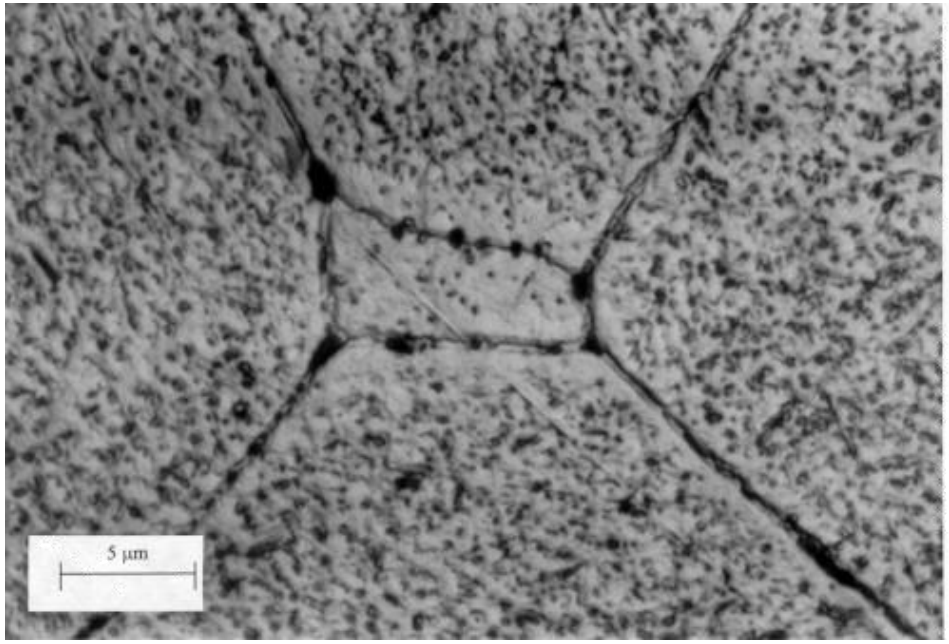


Fig. 7: PFZ near grain boundaries in Al -4 wt% Cu [http://www.msm.cam.ac.uk/phasetrans/abstracts/pfz.html]

SUMMARY

- Precipitation Hardening provides a greater increase in strength than solid solution strengthening
- Intermetallics are better obstacles to dislocation motion due to the creation of Anti-Phase Boundaries
- 2 critical radii exist:
  - Cutting to bowing: $r_c \sim 10$ nm
  - Coherent to Incoherent: $r_{c/i} \sim 10$ nm – 1 μm

QUESTIONS?

3.40J / 22.71J / 3.14 Physical Metallurgy

Fall 2009