Greer

**Point, interfacial & line defects in crystals**

- Any region where order of crystal is broken
- Control structure-sensitive properties

**Point defects**

- Defects limited to isolated lattice sites

**Vacancies:** Missing atoms from crystal lattice (regions of tension)

**Interstitials:** Extra atoms squeezed into crystal lattice (compression)

- Lattice may locally distort around defect, resulting in a displacement of atoms from equilibrium position ⇒ local regions of stress
  - Vacancies ⇒ tensile stresses
  - Interstitials ⇒ compressive stresses

**Interfacial defects**

- Defects in a plane

**Grain boundaries:** Disordered region between grains
**Twin boundaries:** Portions of lattice related to each other by simple rotation

- Net result of twinning is shear deformation

- Note that plastic deformation is a permanent shear deformation
  
  (occurs in response to shear stresses ⇒ change of shape not volume)

  ∴ Twinning is a possible mechanism of plastic deformation

Twinning can occur in h.c.p. metals (Zn, Sn and Mg), not in f.c.c. metals

- However, a much more important mechanism of plastic deformation is **slip**

  *Slip occurs by motion of dislocations*

**Line defects**

**Dislocations:** Two types of dislocation: **Edge** and **Screw**

Can be visualized in terms of atoms or as a continuum model
• Motion of top portion, relative to bottom portion, corresponds to motion of dislocation through crystal.

**Terminology:**

*Dislocation line*  
Line of defect

*Burgers vector*  
Strength (and direction) of defect \( \mathbf{b} \)

Edge dislocation \( \Rightarrow \) \( \mathbf{b} \) is perpendicular to dislocation line

Screw dislocation \( \Rightarrow \) \( \mathbf{b} \) is parallel to dislocation line

Mixed dislocations \( \Rightarrow \) edge and screw components

**Dislocation density:**  
Length of dislocation lines / unit volume of material

**Glide plane:**  
Plane on which dislocation moves (slip plane)
Role of dislocations in plastic deformation

- Most important mechanism of plastic deformation is slip

\[ U \approx -U_o \cos \left( \frac{\pi x}{r_o} \right) \]

- Shear force required to cause all atoms to slip at once is huge

\[ \gamma = \frac{1}{\sqrt{3}} \frac{x}{r_o} \]

- Move top plane relative to bottom \( \Rightarrow \gamma = \frac{1}{\sqrt{3}} \frac{x}{r_o} \) across slip plane

- Can show that shear modulus is given by

\[ G = \frac{\pi^2 U_o}{r_o} \left( \frac{\partial^2 U}{\partial \gamma^2} \right) \bigg|_{\gamma = 0} \]

\[ \therefore \quad G \approx \frac{3\pi^2 U_o}{r_o^3} \] (1)

- Force per atom:

\[ F_{atom} = \frac{\partial U}{\partial x} = \frac{\pi U_o}{r_o} \sin \left( \frac{\pi x}{r_o} \right) \]

- Number of atoms / unit area = \( \frac{1}{r_o^2} \)

\[ \therefore \quad \text{Maximum shear stress to slide planes is given by} \quad \tau_{max} = \frac{F_{max}}{r_o^2} = \frac{\pi U_o}{r_o^3} \]

\[ \therefore \quad \text{From Eqn. (1):} \quad \tau_{max} = \frac{G}{3\pi} \approx \frac{G}{10} \]

- \( \tau < \tau_{max} \): Atoms fall back to original position - elastic strain
• $\tau > \tau_{\text{max}}$ Slip occurs and atoms fall into new position
  
  (Permanent shear deformation = plasticity)

• Experimentally, shear strength of crystals orders of magnitude lower.
• Slip occurs incrementally (breaking one bond at a time) by motion of dislocations

Key points to learn about dislocations

• Plastic deformation caused by shear stresses
• Dominant mechanism is slip between atomic planes
• Slip occurs by the motion of dislocations on glide plane
• One dislocation results in slip by an amount $\mathbf{b}$ (Burgers vector) parallel to $\tau$
• Edge dislocation moves parallel to $\tau$
• Screw dislocation moves perpendicular to $\tau$

In later classes you will learn that:
(i) Motion of dislocations impeded by microstructural features
(ii) These microstructural features are controlled by processing and composition
(iii) If motion of dislocations is impeded, the yield stress increases