Outline

• Movement of Dislocations - Review
• Screw Dislocation
• Screw vs. Edge Dislocations
• Mixed Dislocations
• Observation of Dislocations
• Dislocations’ Multiplication
• Stress and Dislocation Motion
• Slip in Single Crystals
• Twining

Movement Dislocations: Review

• Bonds across slip plane break consecutively not simultaneously
  – less energy is required but with same end result.
• Dislocations allow deformation at much lower stress than in a perfect crystal.
• The movement of the dislocation requires the breaking and formation of only ONE set of bonds per step.
• Dislocations move in the close-packed directions within the close packed planes.

SCREW Dislocation:

• Crystal is "cut halfway through and then slide sideways" helical path through structure hence "screw".
• The motion of a screw dislocation can be thought of in terms of tearing a sheet of paper.

SCREW Dislocation: Movement

Because \( b \) and disl are parallel there is no set SLIP plane. Instead, screw disl move on planes with low resistance to disl movement.

Can change planes if need to:

Note that \( AB \) is parallel to \( b \).

Cross-slip of a screw dislocation xy from (a) plane A to (b) plane B to (c) plane A. Slip always occurs in direction of Burgers vector \( b \).

Generally, screw dislocations are more .......... than edge dislocations.
**SCREW Dislocation: Movement**

- The motion of a screw dislocation is also a result of shear stress.
- Motion is **perpendicular** to direction of stress, rather than **parallel** (edge).
- However, the net plastic deformation of both edge and screw dislocations is the same.

**Dislocations**

Usually, dislocations have both an edge and a screw character; i.e., they are **mixed** dislocations:

- Slip plane
- Mixed mode here
- Pure edge here
- Pure screw here

makes up most of the dislocations encountered in real life
- **very difficult to have pure edge or pure screw dislocations**

**Screw Disln vs. Edge Disln**

Screw dislocations provide pure shear lattice strain only

**TABLE 2.4 Characteristics of Dislocations**

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<th>Dislocation Characteristic</th>
<th>Type of Dislocation</th>
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<td>Slip direction</td>
<td>Edge: Parallel to $\mathbf{b}$, Screw: Parallel to $\mathbf{b}$</td>
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<td>Relation between dislocation line and $\mathbf{b}$</td>
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<td>Direction of dislocation line movement relative to $\mathbf{b}$</td>
<td>Edge: Parallel, Screw: Perpendicular</td>
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<td>Process by which dislocations may leave the glide plane</td>
<td>Edge: Nonconservative climb, Screw: Cross-slip</td>
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**Mixed Dislocation and Disln LOOPS**

For a dislocation loop:
- Front + back are (+ve) and (-ve) edge
- Sides are LH + RH screw

*Shear stress expands loop radially (grows outwards)*
Observation of Dislocations

- Dislocations have been observed by the Transition Electron Microscope (TEM)

Observation of individual dislocations in thin foil. (a) Planar arrays of dislocations in 18Cr-8Ni stainless steels (b) diagram showing position of dislocations on the guide plane in the foil.

Each disl\(^\circ\) lies along a particular plane and extends from the top to the bottom of the foil

Due to dislocations interaction similar dislocations will pile-up at barriers on SLIP planes (grain boundaries, precipitates) and cause stress concentrations.

Can we observe the SLIP step in a light optical microscope (LOM)?

Dislocation Multiplication

In order to see slip step under a LOM, it requires ~ 10\(^4\) dislocations in order to 1\(\mu\)m size.

➔ Requires many disl\(^\circ\)!

Do we have All originally present in crystal? ……..!

new dislocations are created during deformation

Disl\(^\circ\) density (cm of disl\(^\circ\)/cm\(^2\)) increases from

10\(^4\) - 10\(^5\) → 10\(^{11}\)-10\(^{12}\)

annealed cold-worked (heavily deformed)

A widely accepted mechanism for disl\(^\circ\) multiplication is

FRANK-READ Source

- Segment of disl\(^\circ\) is pinned (by other disl\(^\circ\) or ppts/foreign atoms) Shear stress causes bowing out of segment.
- Curves round on itself; eventually meets itself form Dislocation LOOP and Segment.
- LOOP moves out radially.
- Segment can produce another loop if maintained.

Frank-Read source for dislocation multiplication

A-B is pinned segment

Shear stress causes bowing out of disl\(^\circ\) line between A and B

Instability reached when:

\[ \tau = \frac{Gb}{R} \]

At C-C' there are screw disl\(^\circ\) of opposite sign. Annihilate each other.

- LOOP moves out radially.
- Segment can produce another loop

A-B segment can produce another disl\(^\circ\) loop if shear stress is maintained. First loop moves out causing slip
Frank-Read source for dislocation multiplication

![Silicon crystal](image)

**FIGURE 2.30** Frank-Read source. (a) Photomicrograph in silicon crystal. (From Dush; reprinted with permission of General Electric Co.) Dislocation multiplication by double cross-slip mechanism. (From Low and Guirard; reprinted with permission from Low, Acta Met. 7 (1959), Pergamon Press, Elmsford, NY.)

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**STRESS AND DISLOCATION MOTION**

- Crystals slip due to a resolved shear stress, $\tau_R$.
- Applied tension can produce such a stress.

**Applied tensile stress:**

$$\sigma = \frac{F}{A}$$

**Resolved shear stress:**

$$\tau_R = \frac{F_s}{A_S}$$

**Relation between $\sigma$ and $\tau_R$**

$$\tau_R = \sigma \cos \lambda \cos \phi$$

Magnitude depends on applied stress, as well as its orientation with respect to both the slip plane and slip direction.

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**SLIP IN SINGLE CRYSTAL**

- So, even if an applied stress is purely tensile, there are shear components to it in directions at all but the parallel and perpendicular directions

$$\tau_R = \sigma \cos \lambda \cos \phi$$

(often $\lambda$ and $\phi \neq 90^\circ$ i.e. slip direction, slip plane normal and tensile axis are not usually in same plane).

Several slip systems exist in a crystal.

$\tau_R$ varies depending on $\phi$ and $\lambda$. System with maximum value of $\tau_R$ is one on which slip is 

$$\tau_R(\text{Max}) = \sigma (\cos \lambda \cos \phi)_{\text{Max}}$$

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**SLIP IN SINGLE CRYSTAL**

When $\sigma$ sufficiently high, $\tau_R$ reaches $\tau_{\text{CRSS}}$ (critical resolved shear stress – this is the minimum stress that will cause slip to start) and then slip starts; i.e. yielding begins in that crystal.

$$\sigma_y = \frac{\tau_{\text{CRSS}}}{(\cos \lambda \cos \phi)_{\text{Max}}}$$

Maximum value of $(\cos \lambda \times \cos \phi)$ is 0.5 so therefore:

$$\sigma_y = 2\tau_{\text{CRSS}}$$

Other slip systems may then start to operate (especially as the crystal rotates towards tensile axis).
**CRITICAL RESOLVED SHEAR STRESS**

- Condition for dislocation motion:
  - \( \tau_R > \tau_{CRSS} \)

- Crystal orientation can make it easy or hard to move disl.
  - Typically, \( 10^{-4} \text{ G} \) to \( 10^{-2} \text{ G} \)

- \( \tau_R = \sigma \cos \lambda \cos \phi \)

- Slip planes & directions change from one crystal to another.
  - \( \tau_R \) will vary from one crystal to another.
  - The crystal with the largest \( \tau_R \) yields first.
  - Other (less favorably oriented) crystals yield later.

- As grains do not split from each other during deformation, they must deform together. Accommodate each other’s shape change.
  - Puts CONSTRAINT onto deformation.

- Higher stress is required.

**DISL. MOTION IN POLYCRYSTALS**

- During deformation, coherency is maintained at grain boundaries
  - As mentioned before, grain boundaries do not rip apart, rather they remain together during deformation.

- This causes a level of constraint in the grains, as each grain’s shape is formed by the shape of its adjacent neighbors.
  - Most prevalent is the fact that grains will elongate along the direction of deformation

- Twinning, involving the formation of an atomic mirror image (i.e., a "twin") on the opposite side of the twinning plane: (a) before, and (b) after twinning

- Copper 173X
Twinning

- Displacement magnitude in the twin region is proportional to the atom’s distance from the twin plane
- takes place along defined planes and directions depending upon the system.
  - *Ex: BCC twinning occurs on the (112)[111] system

Twinning

- All parts have the same crystal orientation
- Atomic displacement is less than interatomic spacing
  - displacements take place in exact atomic spacings

Properties of Twinning

- occurs in metals with BCC or HCP crystal structure
  - occurs at low temperatures and high rates of shear loading (shock loading)
  - conditions in which there are few present slip systems (restricting the possibility of slip)
- ........ amount of deformation when compared with slip.

Next time:
Strengthening Mechanisms