Lecture 8 – Dislocations
(Defects and Properties)

Heung Nam Han
Professor
Department of Materials Science & Engineering
College of Engineering
Seoul National University
Seoul 151-744, Korea
Tel : +82-2-880-9240
Fax : +82-2-885-9647
email : hnhan@snu.ac.kr
Office hours : Tuesday, Thursday 16:45~17:30
Homepage : http://mmmpdl.snu.ac.kr
Why study defects in materials?

- Defects are present in all materials.
- It is defects that make materials much more interesting!
- Defects affect microstructures and properties of materials.
- Processing controls the presence and concentration of defects.

Microstructure

Materials Optimization Loop
Point defects – the other properties

- Impurity doping in semiconductors
- Colors of ionic crystals
  - Fe & Ti in Sapphire
  - Cr $^{3+}$ in red Ruby

= Semiconductor atoms
= Impurity atom with three valence electrons
= Extra electron from impurity atom
Line defects (one dimension)

- Edge Dislocation

Edge dislocation line moves parallel to applied stress
Line defects (one dimension)

- Screw Dislocation

Screw dislocation line moves perpendicular to applied stress
Dislocation

Dislocations are visible in electron micrographs

Adapted from Fig. 4.6, Callister 7e.
Planar defects (two dimension)

- Grain boundaries
- Twin boundaries
- Stacking faults
- Phase boundaries

MKE Gold Bonding Wire

Stacking Fault
Grain Boundary

Angle of misalignment

High-angle grain boundary

Small-angle grain boundary

Angle of misalignment
Bulk defects (three dimension)

- Voids
- Cracks
- Inclusions
Theoretical strength of a perfect crystal

\[ \tau = \tau_{\text{max}} \sin \left( \frac{2\pi x}{b} \right), \gamma = \frac{x}{a} \]

\[ \tau_{\text{max}} = \frac{Gb}{2\pi a} \approx \frac{G}{2\pi} \]

\[ \tau_{\text{max}} \approx \frac{G}{30} \]
Theoretical Strength & Experimental Strength

<table>
<thead>
<tr>
<th>Material</th>
<th>$\tau_{th} (= G/30) \times 10^9$ N/m²</th>
<th>$\tau_{exp} \times 10^6$ N/m²</th>
<th>$\tau_{exp}/\tau_{th}$</th>
<th>$\tau_f \times 10^6$ N/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag</td>
<td>1.0</td>
<td>0.37</td>
<td>0.00037</td>
<td>20</td>
</tr>
<tr>
<td>Al</td>
<td>0.9</td>
<td>0.78</td>
<td>0.00087</td>
<td>30</td>
</tr>
<tr>
<td>Cu</td>
<td>1.4</td>
<td>0.49</td>
<td>0.00035</td>
<td>51</td>
</tr>
<tr>
<td>Ni</td>
<td>2.6</td>
<td>3.2</td>
<td>0.0070</td>
<td>121</td>
</tr>
<tr>
<td>α-Fe</td>
<td>2.6</td>
<td>27.5</td>
<td>0.011</td>
<td>150</td>
</tr>
</tbody>
</table>

There is much difference between theoretical and experimental strength.

The reasons are:

1. **Defects are present** in all perfect crystals.
2. One type of defects, called **dislocation**, moves during plastic deformation and makes plastic deformation easier than predicted by the Frenkel calculation.

* Whisker is close to the theoretical strength.
Dislocations:
- are line defects,
- cause slip between crystal plane when they move,
- produce permanent (plastic) deformation.

Schematic of a Zinc (HCP):
- before deformation
- after tensile elongation

slip steps
Burgers circuit & Burgers vector

- Burgers circuit: any close loop contains dislocations by an atom to atom path

- Burgers vectors: the vector required to complete the circuit in a perfect crystal; the direction of atom displacement

(a) Burgers circuit round an edge dislocation
(b) the same circuit in a perfect crystal

The Burgers vectors for given dislocations never change!

Edge Dislocation
Burgers circuit & Burgers vector

Burgers vector: closure failure of Burgers circuit. drawn from Start(S) to Finish(F) RH / SF convention. (circuit must be drawn around dislocation line.)

Character of Dislocation based on vector Description

Edge Dislocation
Geometry of dislocation: edge dislocation

- Slip plane: where slip occurs.
- Dislocation line: boundary between the slipped and unslipped part of a crystal.
- Slip plane contains both Burgers vectors and dislocation line.
- Edge dislocation: dislocation line is perpendicular to Burgers vector.
Model of an edge dislocation

Symbols:

\( \perp \): Positive edge dislocation
\( \top \): Negative edge dislocation
Geometry of dislocation: screw dislocation

- Screw dislocation: the dislocation line is parallel to Burgers vector

Screw dislocation

Dislocation line and core

Atoms below slip plane
Atoms above slip plane
Burgers circuit & Burgers vector

Screw Dislocation

\[ \vec{\xi} \cdot \vec{b} = \text{positive for RHS.} \]

Neither \( \vec{\xi} \) nor \( \vec{b} \) unique.

\[ \vec{\xi} \cdot \vec{b} = \text{negative for LHS.} \]
Characteristics of dislocations

<table>
<thead>
<tr>
<th>Dislocation Characteristic</th>
<th>Type of Dislocation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Edge</strong></td>
</tr>
<tr>
<td>Slip direction</td>
<td>// to b</td>
</tr>
<tr>
<td>Relation between dislocation line and b</td>
<td>⊥</td>
</tr>
<tr>
<td>Direction of line movement relative to b</td>
<td>//</td>
</tr>
</tbody>
</table>

Mixed dislocation

Dislocations imaged in NiAl-0.5Zr single crystals deformed at elevated temperatures.

Most dislocations are curved.
Motion of Mixed Dislocations
Dislocations move via slip

Schematic representation of a *dislocation loop*
Movement of Dislocations

- Glide--conservative motion: dislocation moves in the surface which contains both its line and Burgers vector.
Movement of Dislocations (glide)

Edge \( \perp \) moves this way

Screw \( \perp \) moves this way
Movement of Dislocations (glide)

- Edge, screw, and mixed segments move.
- Final shear of crystal is produced by edge and screw dislocations.

Process of slip by expansion of a dislocation loop in a slip plane.
Movement of Dislocations

- Climb-- non-conservative motion: dislocation moves out of the glide surface normal to the Burgers vector
Movement of Dislocations (climb)

Vacancies or Atoms diffuse to bottom of dislocation line.
Acting slip system in FCC

- A \{111\}<110> slip system in Fcc unit cell
Jogs

- Jogs on edge dislocations do not impede glide
- Jogs on screw dislocations have edge character and impede glide

The jogs in (c) edge and (d) screw dislocations
Kink

- Kinks: steps on the dislocation which displace it on the same slip plane
- Kinks in edge and screw dislocations do not impede glide of the dislocation

The kinks in edge (a) and screw (b) dislocations
Cross slip
Cross slip

Slip

Cross-Slip

Screw dislocations can cross-slip
Edge dislocations cannot
Twinning unassisted by dislocation motion requires cooperative and simultaneous motion of a number of atoms:

- Theoretical twinning stress is high.
- Believed associated with dislocation motion.
- Requires cooperative dislocation displacements.
- Recall that slip can take place by the uncoordinated and independent glide of numerous dislocations.