Lecture 12: Low energy defect surfaces

March 30, 2004
Review: Grain size & Mechanical effects

- GBs are obstacles for dislocation movement
- Plastic deformation proceeds by dislocation motion and multiplication
- If dislocations form or move inside grains, GB obstacles impede movement
- Dislocations will pile up at GB until generating sufficient stress to move through GB
- The larger the grain, the more dislocations pile up, and the lower the applied stress to move dislocations

\[ \tau = \text{applied stress} \]

Thus, metals with large \(d\) yield under lower stress than metals with small \(d\).
Review: Grain size & Mechanical effects

- Hall-Petch relation: \( \sigma_y = \sigma_0 + kd^{-1/2} \)  
  
  (EO Hall, 1951; NJ Petch, 1953)

![Graph showing the Hall-Petch relation with yield stress and grain size.]

\[ \text{Yield stress/10 [MPa]} \]

\[ \text{Increasing flow stress} \rightarrow \]

\[ \text{Increasing grain size} \leftarrow \]

Experimental data
G.W. Brandie, 2003; Chemical Engineering, Queens College
Samples = steel
Review: Grain size & Mechanical effects

Reducing grain size strengthens material to a point, but...

the density of defects at the GB ultimately weakens the metal when the grain size approaches the GB thickness.

(Image removed due to copyright considerations.)
Low energy defect surfaces

Examples

Importance
LEDS: Low Energy Dislocation Structure

**Examples:**
- Real ones:
  - Tilt boundary
  - Kink band array
LEDS: Low Energy Dislocation Structure

Examples:
- Imagined ones:
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Dislocation Cell Structures

LEDS:
Dislocation cell structures:

g \propto \frac{1}{\rho^{1/2}}

cell

dislocation tangles

relatively dislocation-free
“On the basis of a study on the microstructures of ballmilled Ru and AlRu, the formation of [a nanocrystalline] structure is thought to evolve from the development of dislocation cell structures within shear bands;[15] then, the dislocation cells transform into low-angle grain boundaries and finally form nc grains surrounded by high-angle boundaries via grain rotation.[16]

More recently, Fecht[13] has proposed that the grain size refinement includes three stages: (1) localized deformation in shear bands consisting of high density dislocation array; (2) dislocation annihilation and recombination that lead to small-angle grain boundaries separating the individual grains; and (3) development of completely random misorientations between neighboring grains.”
Dislocation Cell Structures: Dynamic recovery and work softening

Dislocation cells form under applied stress/plastic deformation

1. Stress

2. Strain

3. Stress-strain curve
Coincident Site Lattices

Coincident sites of lattices

Lattice 1

Lattice 2

1y, 2x

-1y, 2x

γ
Coincident Site Lattices

bubble raft \{111\}: white = coincident site
Coincident Site Lattices: Applications

CSLs of large $\Sigma$ have special properties. Why?

T. Watanabe (1980s)

Examples:
1. Pb electrodes:
   Lifetime in batteries limited by corrosion and cracking.

   Improved via GBE of 67% CSLs

   Images: After 40 +/- cycles

   CSL: $3 < \Sigma < 29$
Coincident Site Lattices: Applications

Examples:
2. Ni alloy creep:
Inconel deforms under constant stress, temp

By adding large fraction of CSLs, creep resistance dramatically enhanced

Mechanism: Dislocations trapped at CSLs, and cannot move to facilitate creep.

**CSLs are efficient dislocation obstacles, even at elevated temp (tangles).**

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Coincident Site Lattices: Curiosities

1. $\Sigma$ only odd integers, never even
2. $\Sigma < 29$
3. Low $\Sigma$ boundaries have lower energy than random boundaries BUT energy does not scale with $\Sigma$: 