TYPES OF IMPERFECTIONS

- Vacancy atoms
-Interstitial atoms
-Substitutional atoms

- Dislocations

- Grain Boundaries
-Stacking faults

Point defects
Line defects
Area defects
No longer perfect: Thermal Energy

- Lattice points
- Atom positions

Chapter 17 on CD
DEFECTS IN CERAMIC STRUCTURES

- **Frenkel Defect**
  --a cation is out of place.

- **Shottky Defect**
  --a paired set of cation and anion vacancies.

- Equilibrium concentration of defects \( \sim e^{-Q_D/kT} \)

Adapted from Fig. 13.20, *Callister 5e*. (Fig. 13.20 is from W.G. Moffatt, G.W. Pearsall, and J. Wulff, *The Structure and Properties of Materials*, Vol. 1, *Structure*, John Wiley and Sons, Inc., p. 78.) See Fig. 12.21, *Callister 6e*. 
EQUIL. CONCENTRATION: POINT DEFECTS

- Equilibrium concentration varies with temperature!

\[
N_D = \frac{1}{N} \exp \left( -\frac{Q_D}{kT} \right)
\]

No. of defects

Activation energy

No. of potential defect sites.

Boltzmann's constant

(1.38 \times 10^{-23} \text{ J/atom K})

(8.62 \times 10^{-5} \text{ eV/atom K})

Each lattice site is a potential vacancy site.
MEASURING ACTIVATION ENERGY

- We can get $Q$ from an experiment.

\[
\frac{N_D}{N} = \exp\left(\frac{-Q_D}{kT}\right)
\]

- Measure this...

- Replot it...

\[\ln\frac{N_D}{N} = \text{slope} \cdot \frac{1}{T} - \frac{Q_D}{k}
\]

exponential dependence!

defect concentration
POINT DEFECTS

• **Vacancies:**
  - vacant atomic sites in a structure.

![Vacancy distortion of planes]

• **Self-Interstitials:**
  - "extra" atoms positioned between atomic sites.

![Self-interstitial distortion of planes]
Two outcomes if impurity (B) added to host (A):

- **Solid solution** of B in A (i.e., random dist. of point defects)

- Solid solution of B in A plus particles of a new phase (usually for a larger amount of B)

- **Substitutional** alloy (e.g., Cu in Ni)

- **Interstitial** alloy (e.g., C in Fe)

- Second phase particle
  - --different **composition**
  - --often different structure.
• Impurities must also satisfy charge balance

• Ex: NaCl $\text{Na}^+ \bullet \text{Cl}^-$

• Substitutional cation impurity

• Substitutional anion impurity
LINE DEFECTS

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
Edge dislocation
BOND BREAKING AND REMAKING

• Dislocations slip planes *incrementally*...
• The dislocation line separates slipped material on the left from unslipped material on the right.
Dislocation motion requires the successive bumping of a half plane of atoms (from left to right here).
• Bonds across the slipping planes are broken and remade in succession.

Atomic view of edge dislocation motion from left to right as a crystal is sheared.

(Courtesy P.M. Anderson)
Screw dislocation
Area Defects

- Surface
- Grain boundary
AREA DEFECTS: GRAIN BOUNDARIES

Grain boundaries:
- are boundaries between crystals.
- are produced by the solidification process, for example.
- have a change in crystal orientation across them.
- impede dislocation motion.

Schematic

Adapted from Fig. 4.10, *Callister 6e*. (Fig. 4.10 is from *Metals Handbook*, Vol. 9, 9th edition, *Metallography and Microstructures*, Am. Society for Metals, Metals Park, OH, 1985.)
Twin boundary
**OPTICAL MICROSCOPY (1)**

- Useful up to 2000X magnification.
- Polishing removes surface features (e.g., scratches)
- Etching changes reflectance, depending on crystal orientation.

Adapted from Fig. 4.11(b) and (c), *Callister 6e*. (Fig. 4.11(c) is courtesy of J.E. Burke, General Electric Co.)

**micrograph of Brass (Cu and Zn)**

Close-packed planes

0.75mm
Grain boundaries...

- are imperfections,
- are more susceptible to etching,
- may be revealed as dark lines,
- change direction in a polycrystal.

\[
N = 2^n - 1
\]

no. grains/in² at 100x magnification

Adapted from Fig. 4.12(a) and (b), *Callister 6e*. (Fig. 4.12(b) is courtesy of L.C. Smith and C. Brady, the National Bureau of Standards, Washington, DC [now the National Institute of Standards and Technology, Gaithersburg, MD].)
SUMMARY

• **Point**, **Line**, and **Area** defects arise in solids.

• The number and type of defects can be varied and controlled (e.g., T controls vacancy conc.)

• Defects affect material properties (e.g., grain boundaries control crystal slip).

• Defects may be desirable or undesirable (e.g., dislocations may be good or bad, depending on whether plastic deformation is desirable or not.)