Announcements

- Starting Wednesday, 24Jan, ALL lectures will be in Wong 1020
- Ch. 3 solutions are on WebCT
- Faculty standard calculator will be required for tutorial quizzes, the mid-term and the final exam.

Faculty Standard Calculator

in the bookstore

- All students must have one of the following two calculators, exceptions will not be permitted: CASIO fx-991 with any extensions, or a SHARP EL-546L or R or V (VB) or G ONLY.
- The Faculty Standard Calculators CASIO fx-991 or SHARP EL-546L/R/V/(VB)/G will be required for some examinations. Under these circumstances, no other calculators will be permitted, regardless of their level of sophistication. **NON-REGULATION CALCULATORS WILL BE REMOVED AND NO REPLACEMENT CALCULATOR WILL BE PROVIDED.**

Announcements

- Lots of anxiety on the quizzes?
  - A WebCT quiz covers concepts
    - Best study aids are the lectures and the book
    - Covers previous week of lectures (Wed – Wed)
  - A tutorial quiz covers problem solving
    - Best study aid is the homework
    - Covers previous week of lectures (Mon – Mon)
    - May be similar to problems worked on in tutorial

Summary of 1D Defects

pictures

- Line (edge) dislocation involves extra ½-plane of atoms. BV ⊥ to dislocation line.

previous lectures

- Screw dislocation involves shearing of lattice, helical arrangement of atoms. BV || to dislocation line.
- Mixed dislocation involves both previous types, complex arrangment of atoms. BV neither || or ⊥ to dislocation line.

Imperfections in Solids

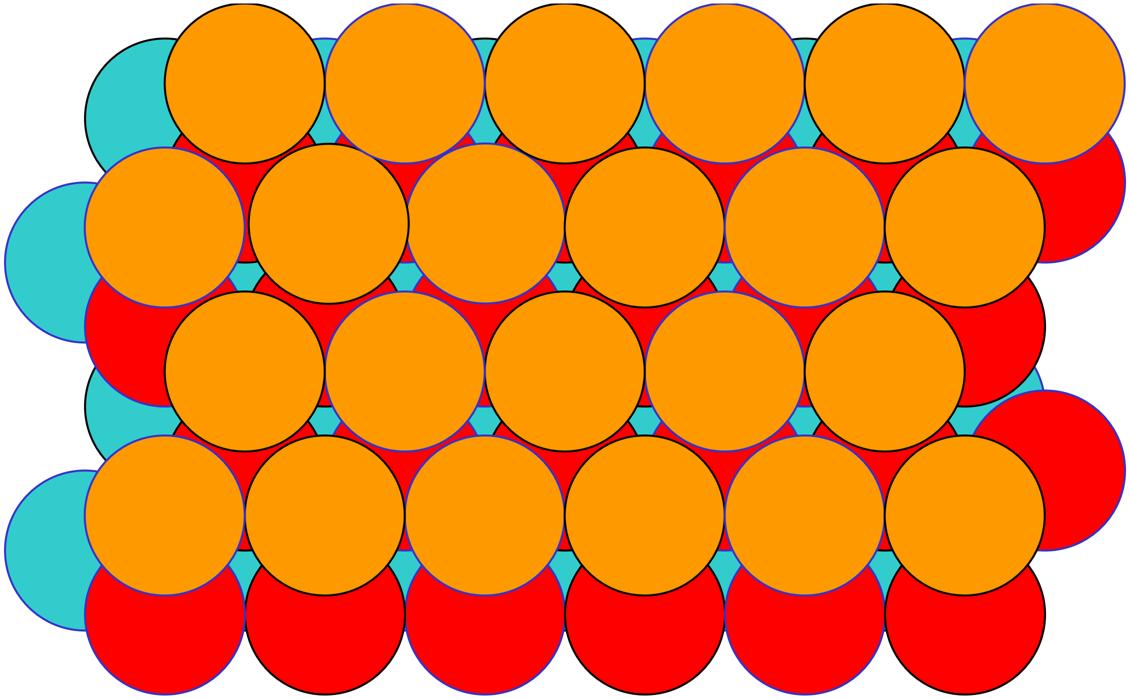
Dislocations are visible in electron micrographs

Adapted from Fig. 4.6, *Callister 7e.*

Summary of 1D Defects

- Properties?
  - Mechanical: dislocation formation and motion are the microscopic mechanisms for plasticity.
  - Mechanical: whenever we shape or form metals dislocations and defects are created
  - Electrical: a highly defective “work hardened” metal would have about 3% greater resistivity than a metal that is not defective.
  - Thermal: similar effect on thermal conductivity as for electrical properties.

Planar (2-D) Defects



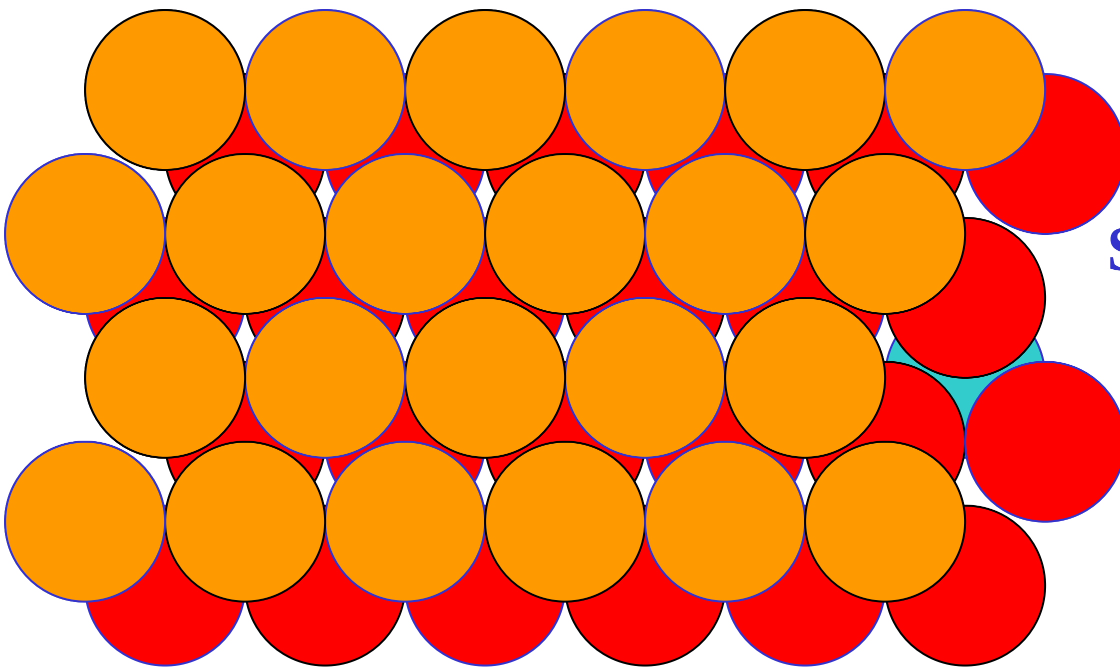
STACKING FAULT

FCC stacking is:

abcabcabc ….

HCP is:

abababab….



STACKING FAULT?

ababcabab….

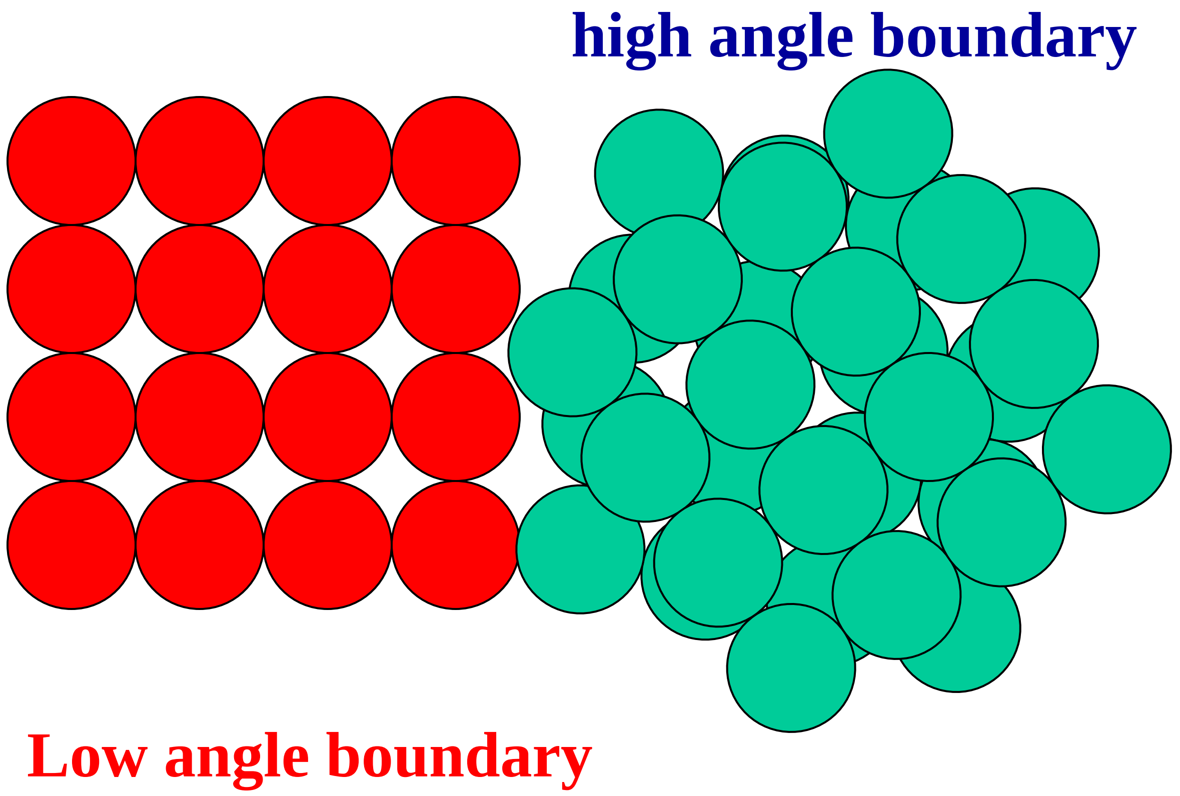
abcabcababc….

Planar (2-D) Defects (cont.)

Grain Boundaries (GBs)

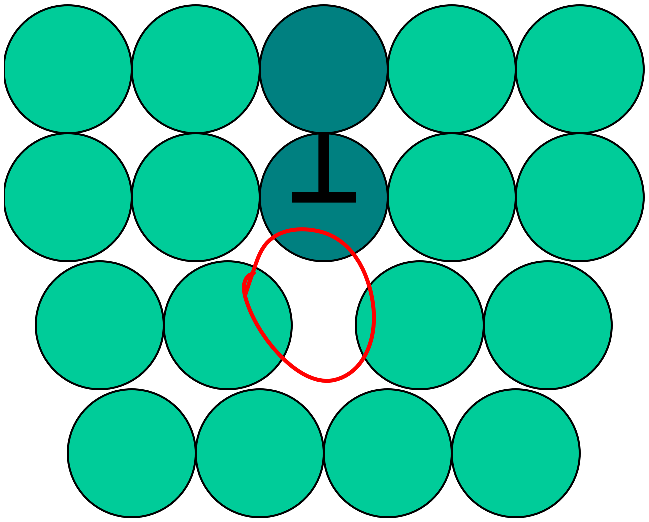
Interfaces between crystals

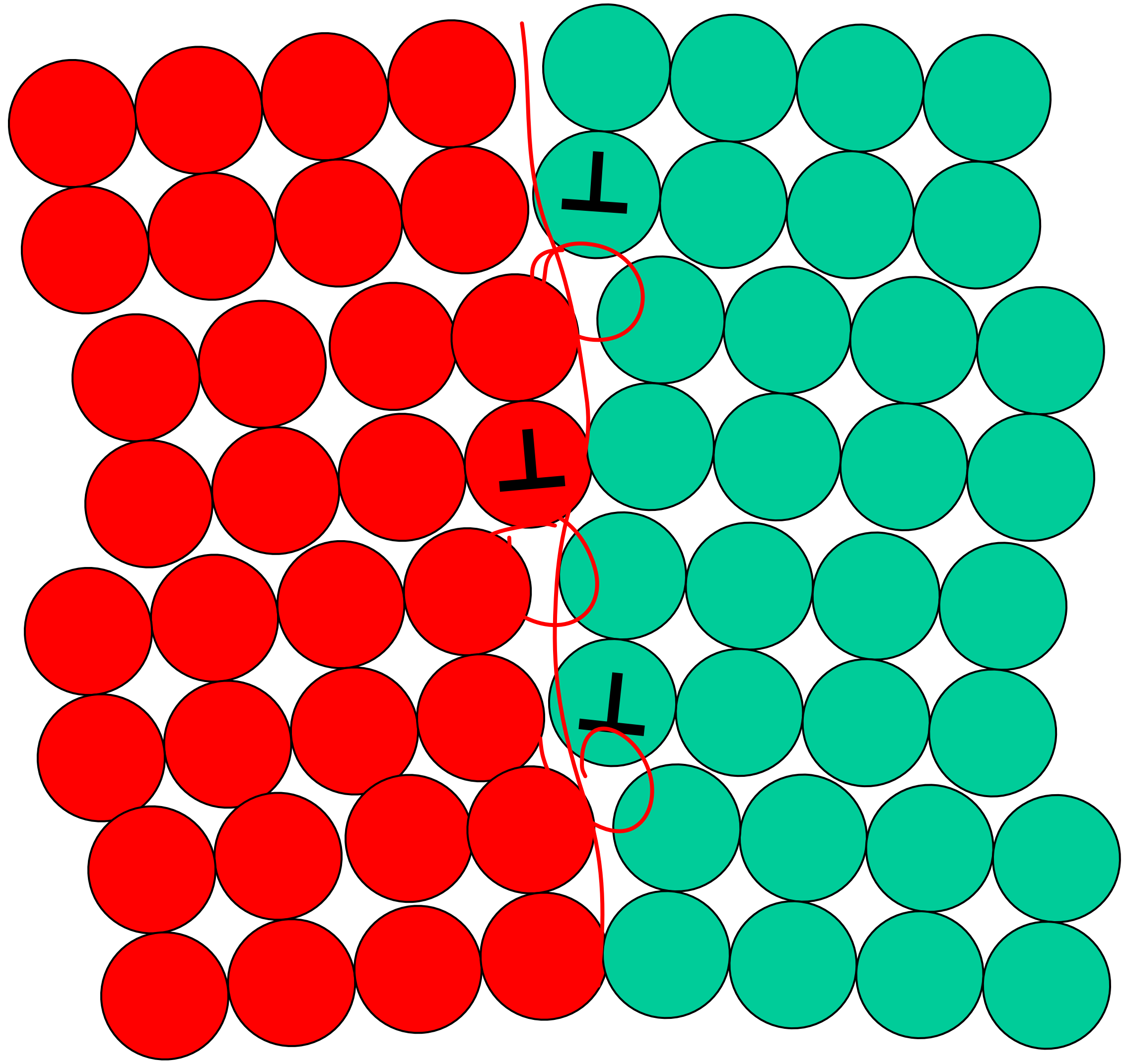
characterized by relative differences in crystal orientation



Planar (2-D) Defects (cont.)

LOW ANGLE BOUNDARIES (CONT.)

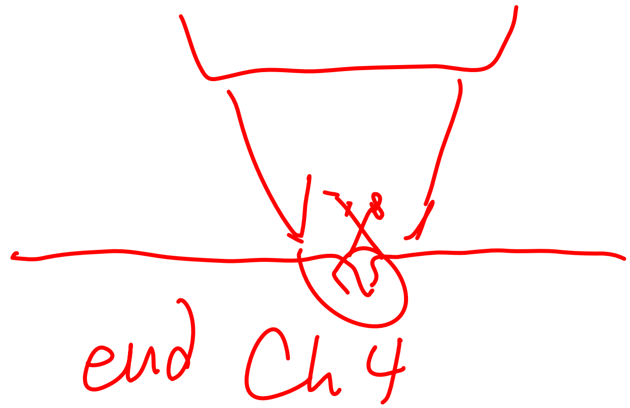




Low angle boundary is an array of dislocations

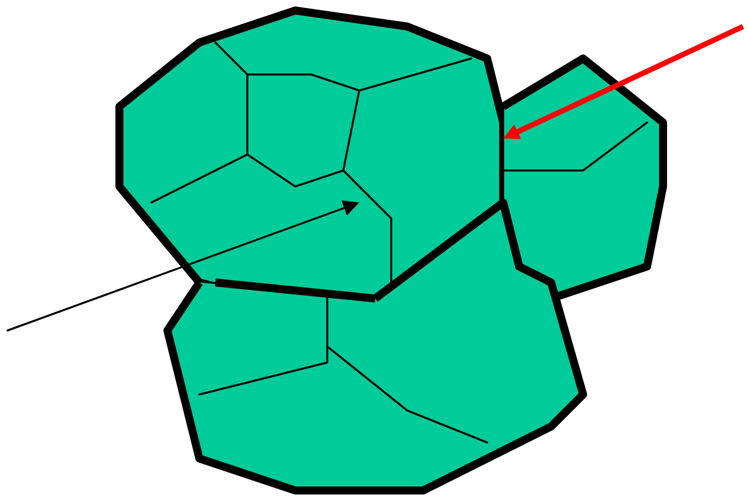
Planar (2-D) Defects (cont.)

Sub-grain boundaries



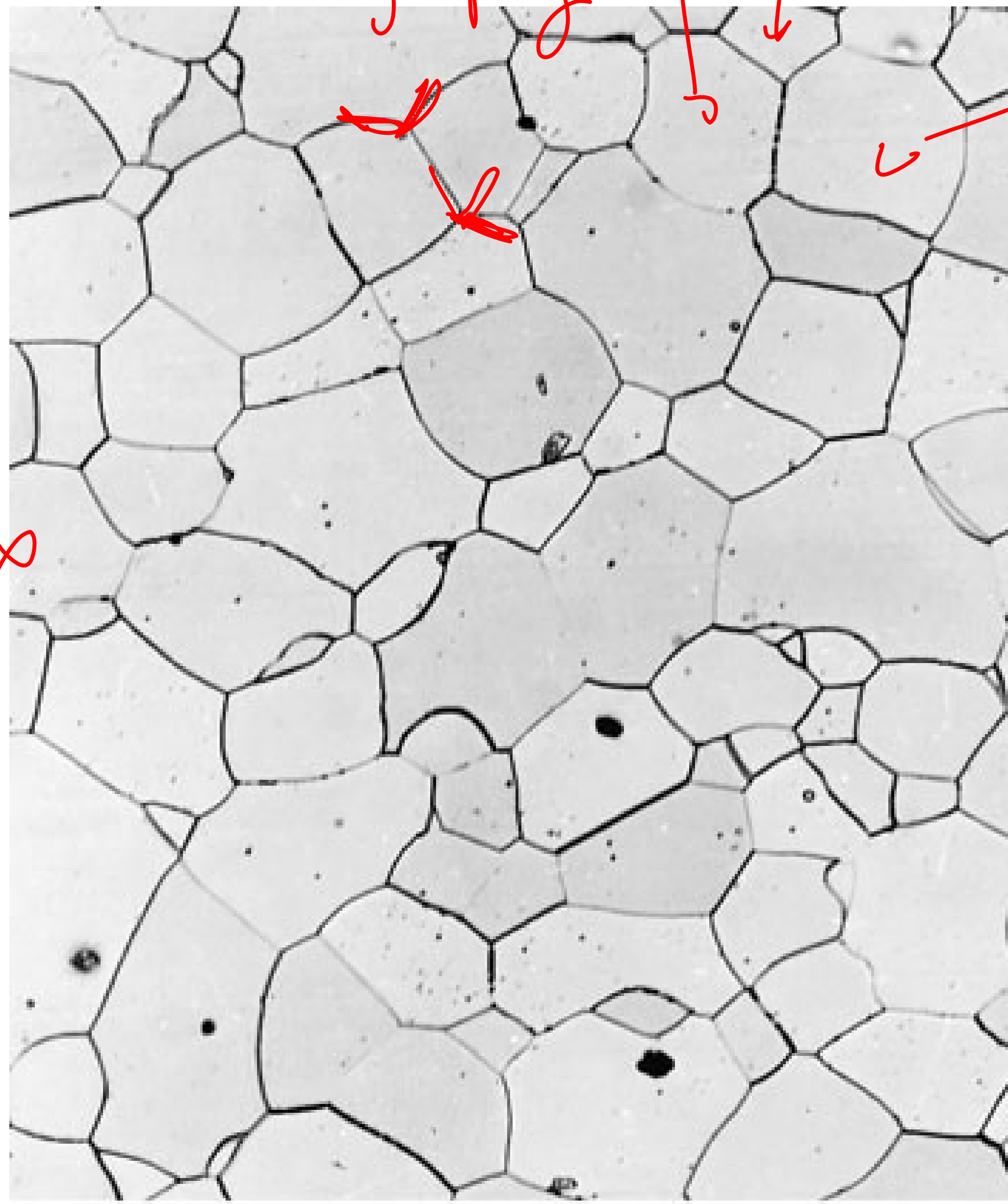
are low angle boundaries

Often occur within grains with high angle boundaries



Metallography

Cu



(b)

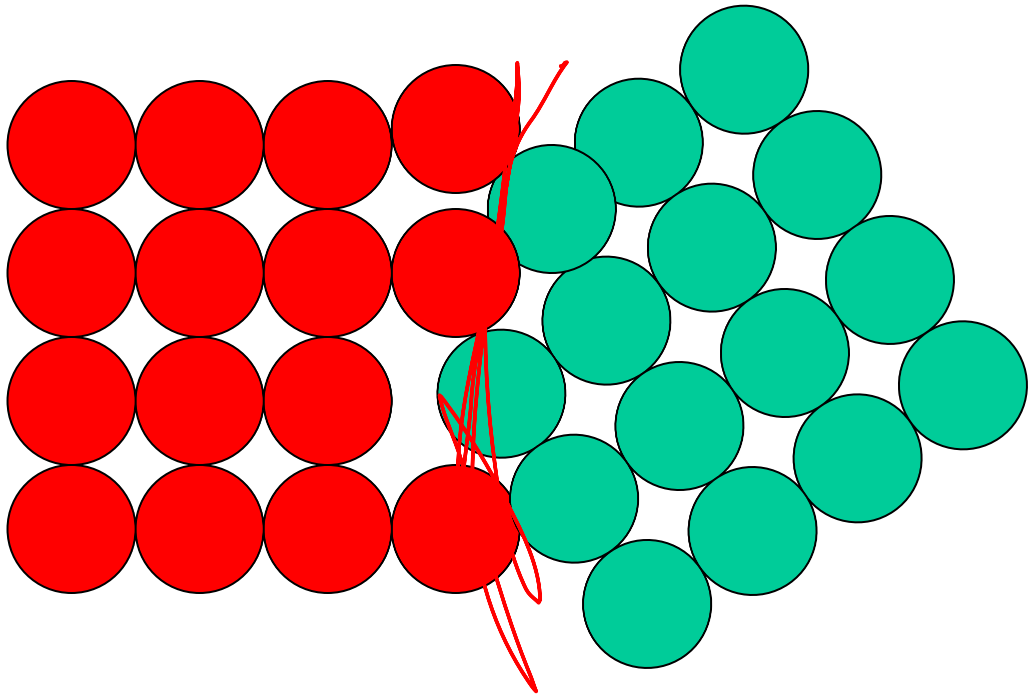
EBSD

electron beam backscatter diffraction

Planar (2-D) Defects (cont.)

Grain boundary energy

Lack of complete bonding means GBs increase energy of material

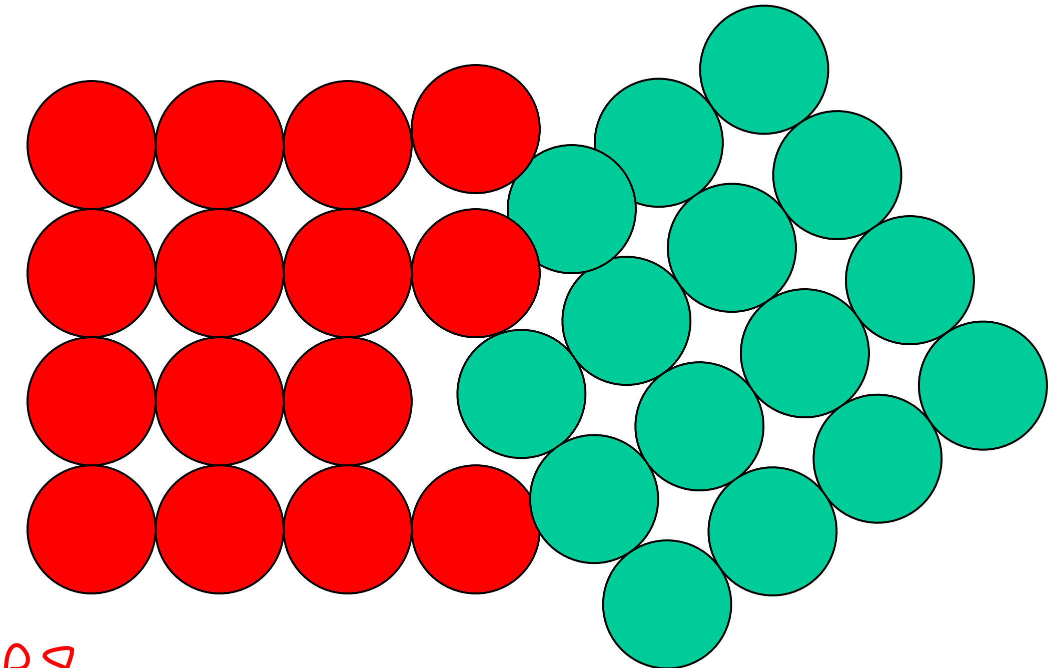


-still pretty close packed, so grains strongly bonded
(density largely unaffected, for example).

i.e. 'no' space between grains

Grain boundary energy

Lack of complete bonding means GBs increase energy of material



vapor dep → nanometer grain sizes

grain size

-still pretty close packed, so grains strongly bonded
(density largely unaffected, for example).

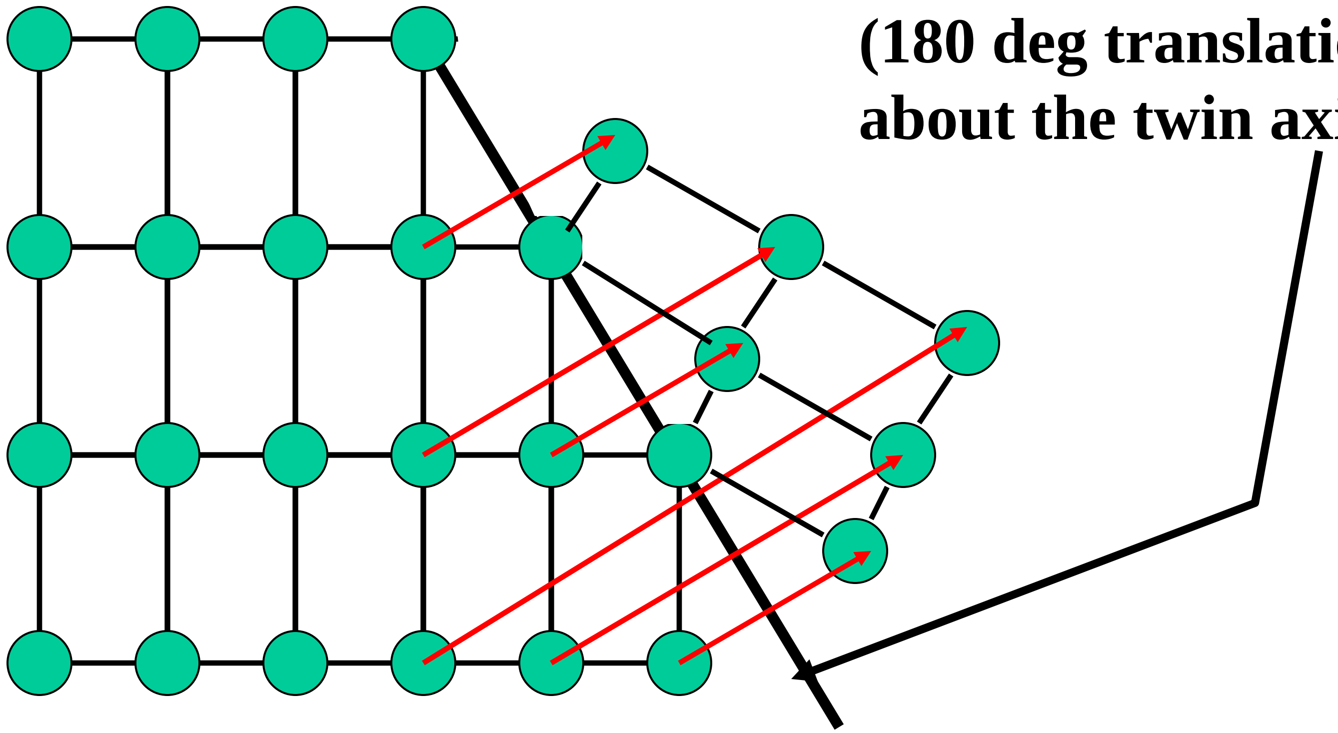
i.e. 'no' space between grains

-small grains will coarsen *(if given the chance)*
-this lowers total energy of system.
(BUT fine grained material is often better)

Planar (2-D) Defects (cont.)

Twin Boundary

Boundary separating mirror images of crystals



(180 deg translation about the twin axis)

Planar (2-D) Defects (cont.)

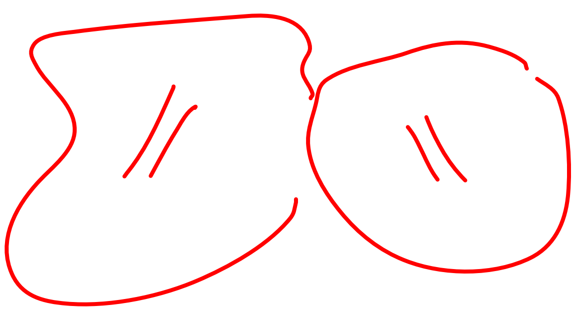
Annealing twins in FCC,

heat an FCC

mechanical twins in BCC and HCP

Occur on definite planes in definite directions (depending on crystal structure)

Revealed as parallel lines in micrographs



Planar (2-D) Defects (cont.)

Other interfacial defects

Phase boundaries: boundary between different phases S.S.

External surface

Considered an imperfection because it's where the crystal terminates.

NOTE:

All interfaces increase energy of material …..

because atoms at interfaces aren't stabilized by electron sharing/exchange strategies.

(incomplete bonding)

BULK OR VOLUME DEFECTS (MACRO DEFECTS?)

Pores, foreign inclusions, cracks.

Very influential and detrimental category of defect.

Processing of materials can avoid these, but sometimes cannot be avoided.

If present, will ‘override’ props of materials.

General Summary

- Point, Line, and Area defects exist 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.)

EE Summary

- Defects, dislocations and impurities can affect conduction of electrons

$$\rho_{total} = \rho_{thermal} + \rho_{impurities} + \rho_{defects}$$

- Grain size, defect structure and orientation of materials in electrical engineering largely depend on **HOW THEY WERE MADE**
- The affect of structure on the properties can be detrimental or we can take advantage of it.

Chapter 5: Diffusion in Solids

ISSUES TO ADDRESS...

- How does diffusion occur?
- Why is it an important part of processing?
- How can the rate of diffusion be predicted for some simple cases?
- How does diffusion depend on structure and temperature?

Diffusion

Diffusion - **Mass transport by atomic motion**

Concentration

Flux ∝ change in conc.

Example

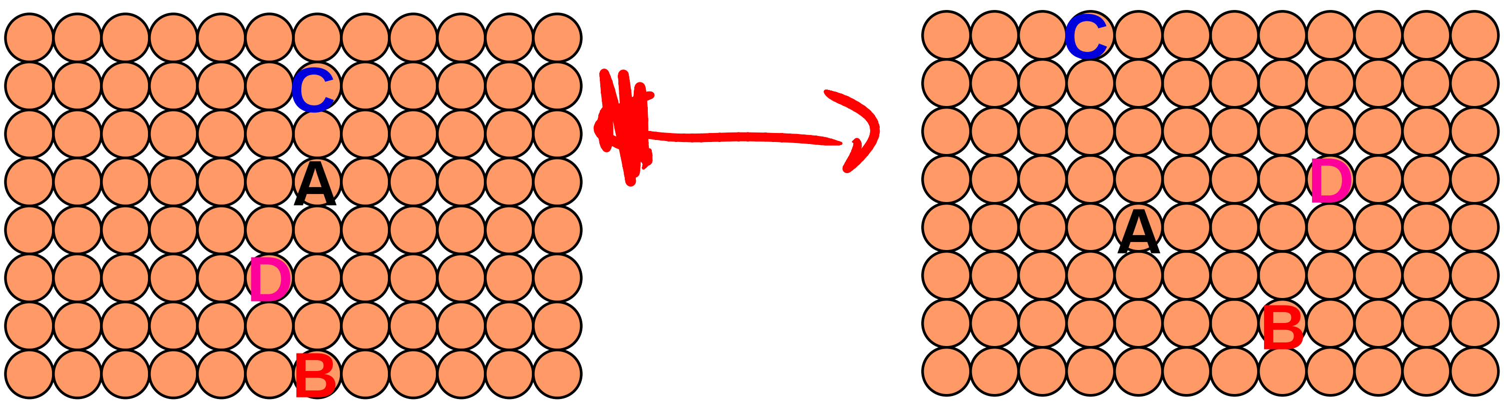
- Diffusion of gas

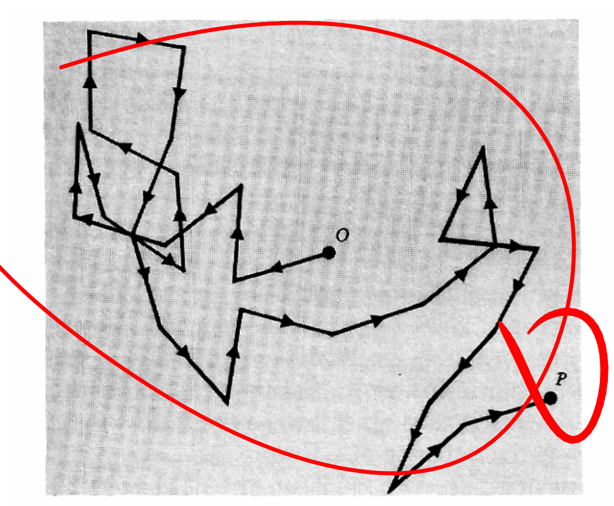
- http://www.purchon.com/chemistry/flash/diffusion.swf

Diffusion

- Self-diffusion: In an elemental solid, atoms also migrate.

Label some atoms | After some time



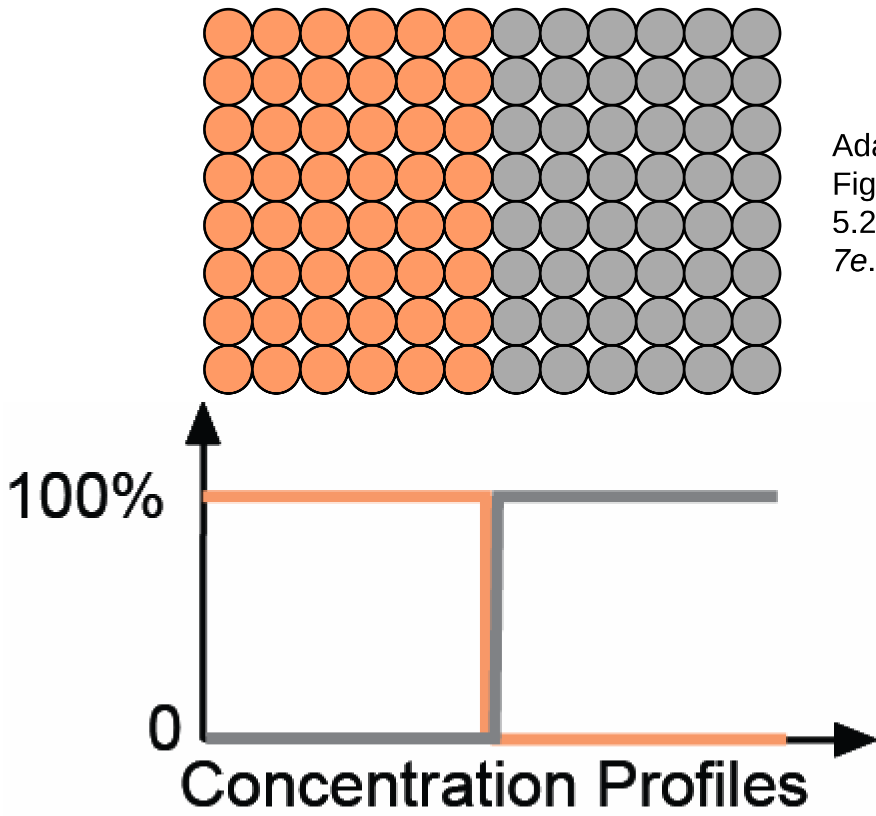


Brownian motion
Random walk
"Drunk by a lamppost"

Diffusion

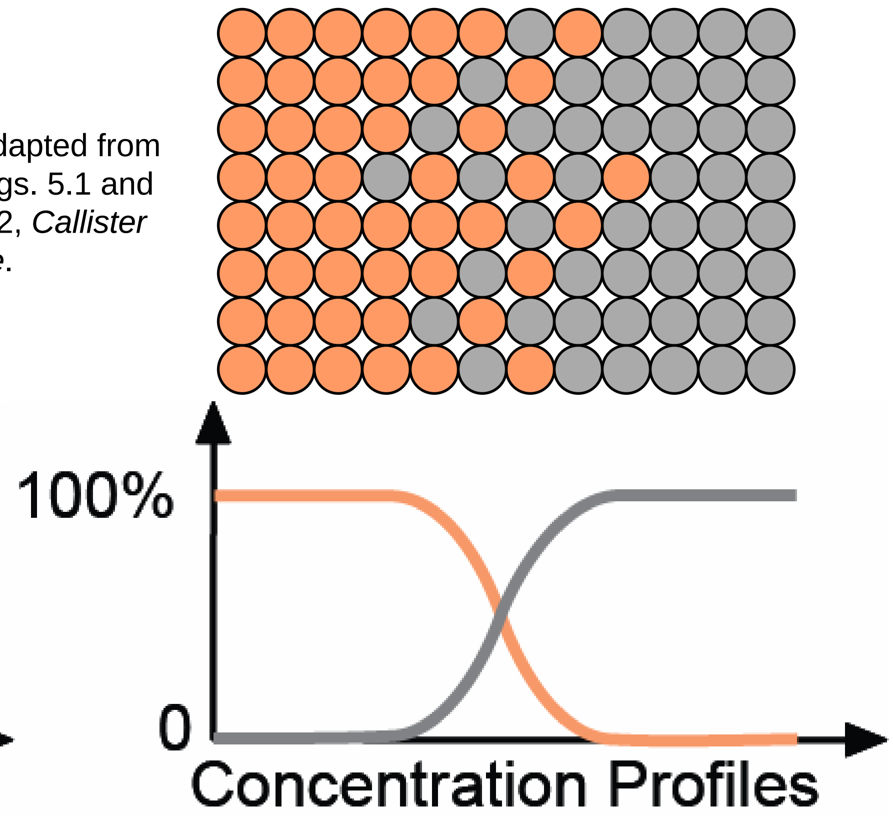
- Interdiffusion: In an alloy, atoms tend to migrate from regions of high conc. to regions of low conc.

Initially

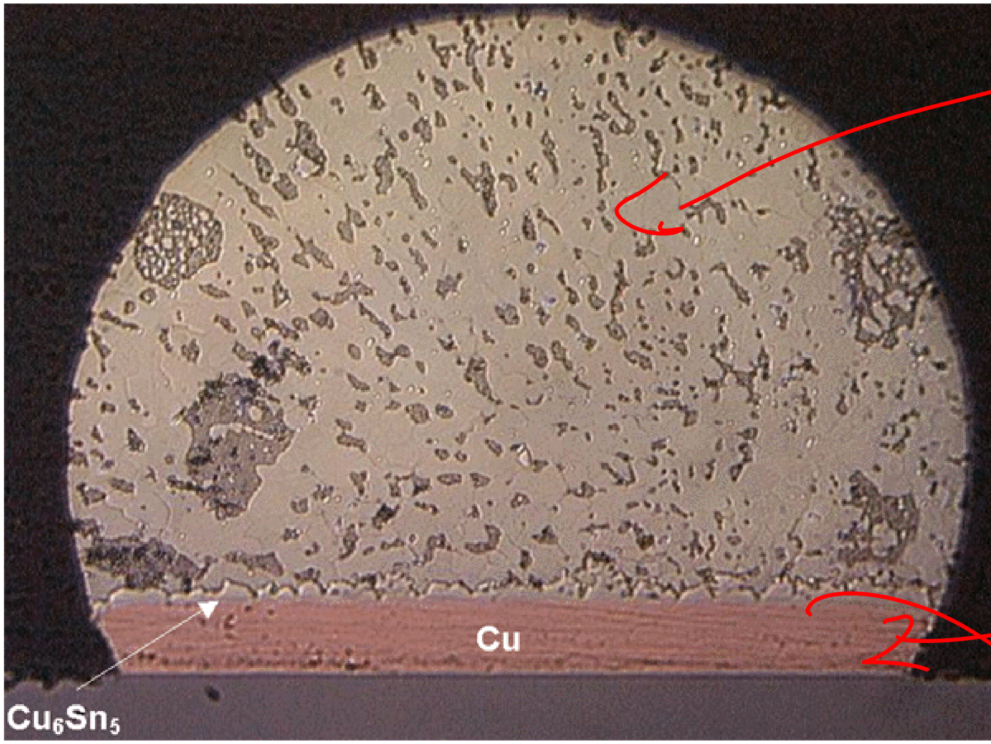


Adapted from Figs. 5.1 and 5.2, *Callister 7e*.

After some time



Example – Soldering in Electronics Packaging

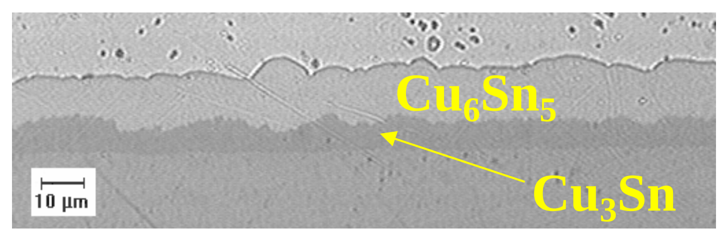


PbSn

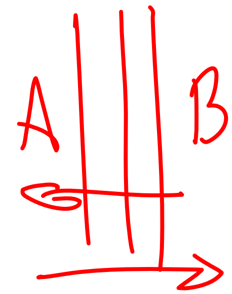
metallurgical
mechanical
electrical

Cu

150°C elevated



Diffusion



Diffusion - Mass transport by atomic motion

Mechanisms

- **Gases & Liquids – random (Brownian) motion**
- **Solids – vacancy diffusion or interstitial diffusion**

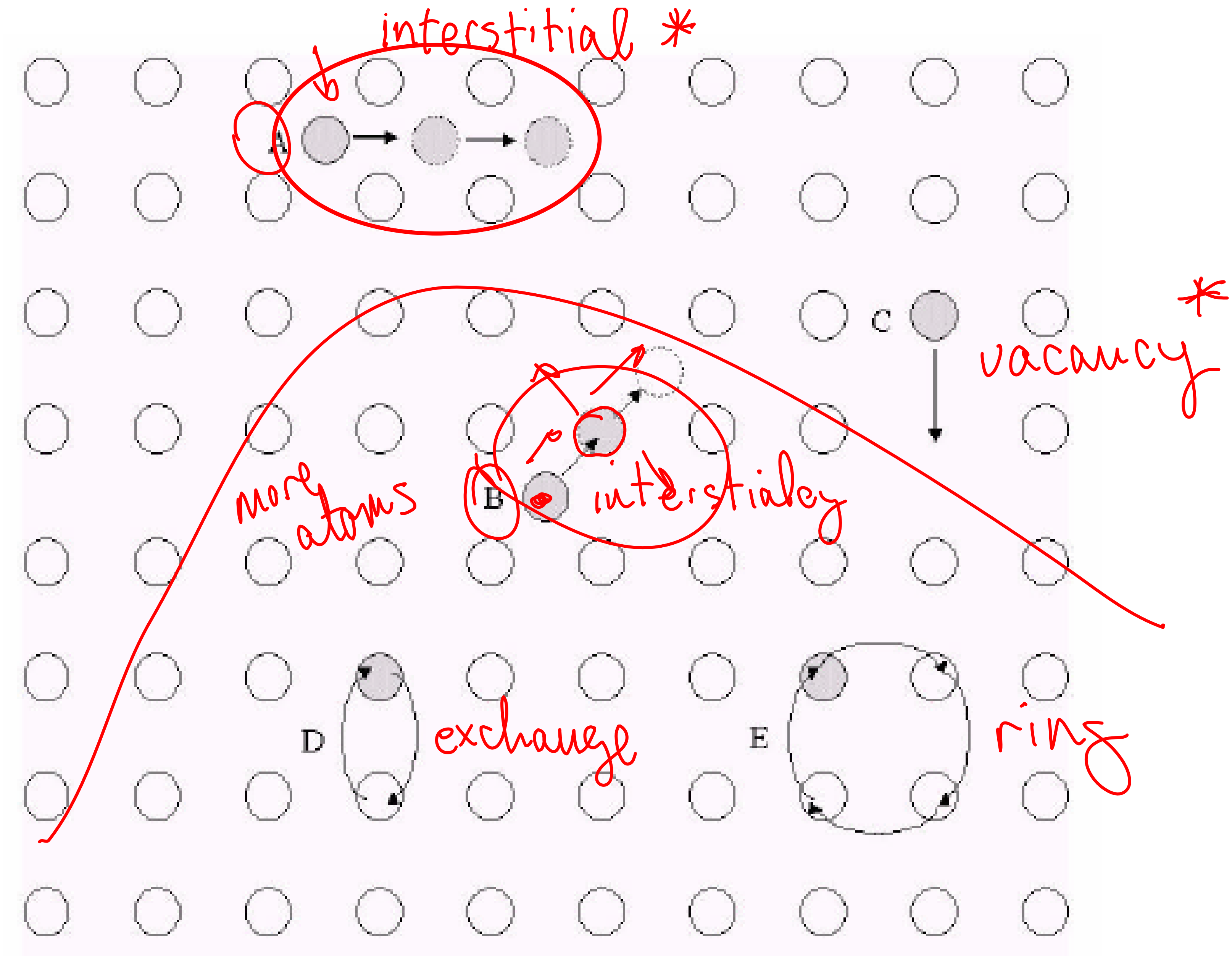
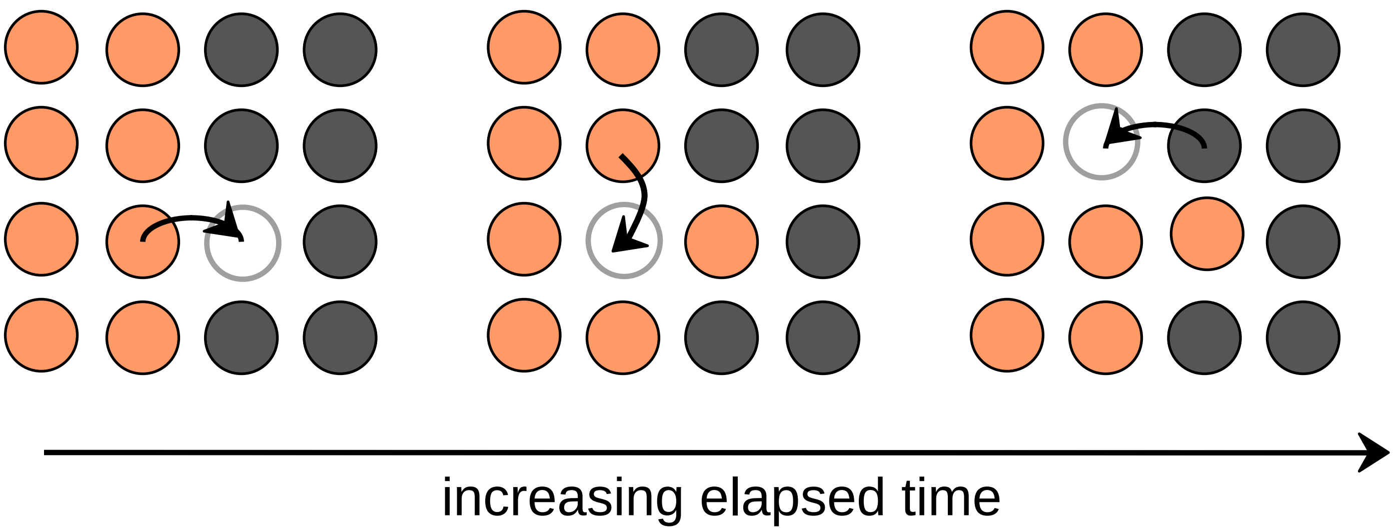


Figure 1.10- An illustration of five basic diffusion mechanisms that have been attributed to the motion of atoms within a solid: *interstitial* (A), *intersticialcy* (B), *vacancy* (C), *exchange* (D), and *ring* (E).

Diffusion Mechanisms

Vacancy Diffusion:

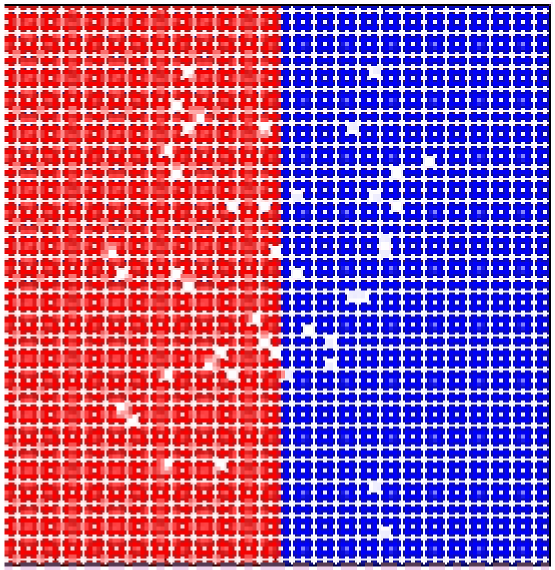
- atoms exchange with vacancies
- applies to substitutional impurities atoms
- rate depends on:
  - --number of vacancies
  - --activation energy to exchange.



Diffusion Simulation

- Simulation of interdiffusion across an interface:

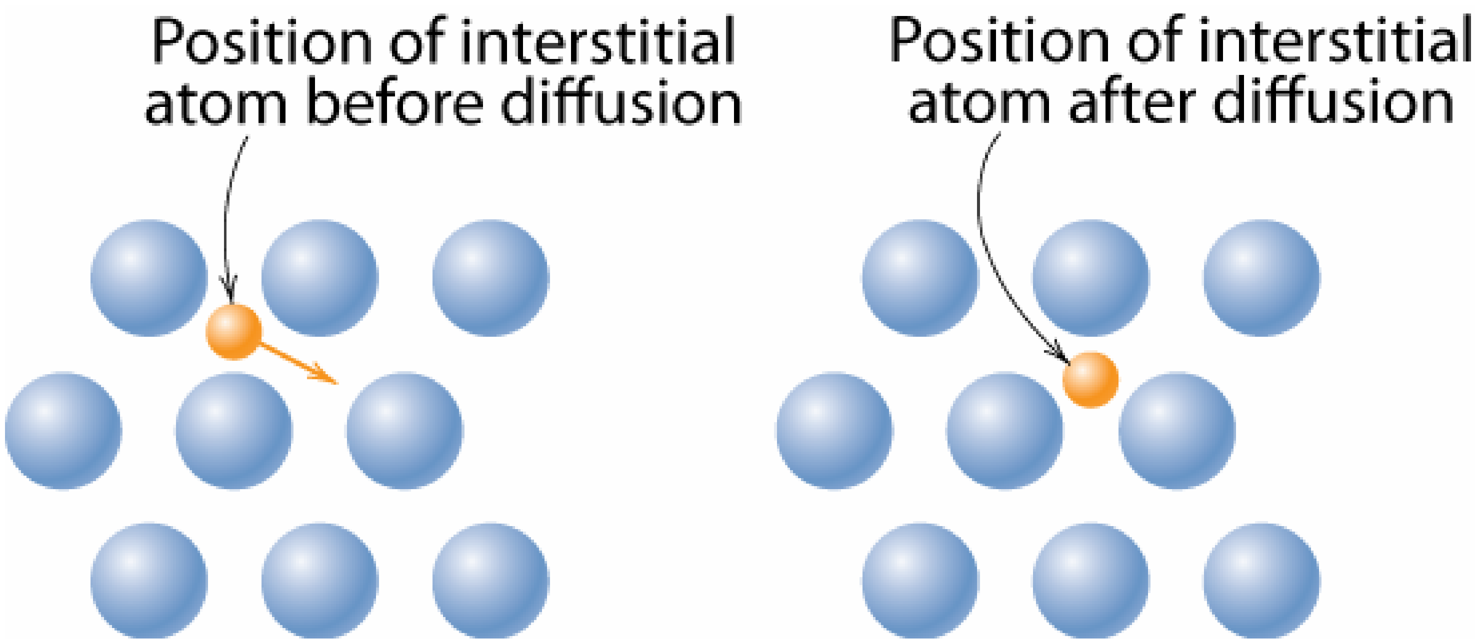
- Rate of substitutional diffusion depends on:
  --vacancy concentration
  --frequency of jumping.



(Courtesy P.M. Anderson)

Diffusion Mechanisms

- **Interstitial diffusion – smaller atoms can diffuse between atoms.**



Adapted from Fig. 5.3 (b), *Callister 7e*.

More rapid than vacancy diffusion

Processing Using Diffusion

- Case Hardening:
  - --Diffuse carbon atoms into the host iron atoms at the surface.
  - --Example of interstitial diffusion is a case hardened gear.

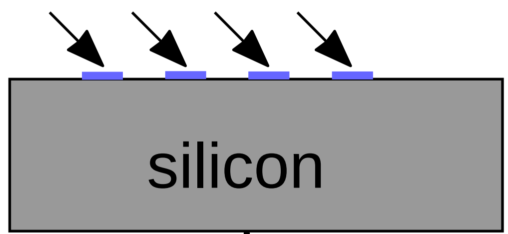
Adapted from chapter-opening photograph, Chapter 5, *Callister 7e.* (Courtesy of Surface Division, Midland-Ross.)

- Result: The presence of C atoms makes iron (steel) harder.

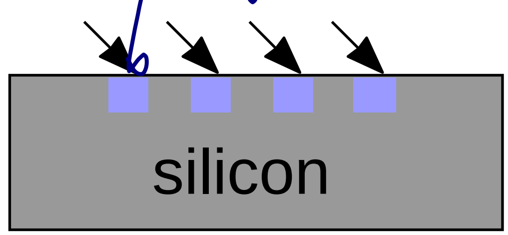
Processing Using Diffusion

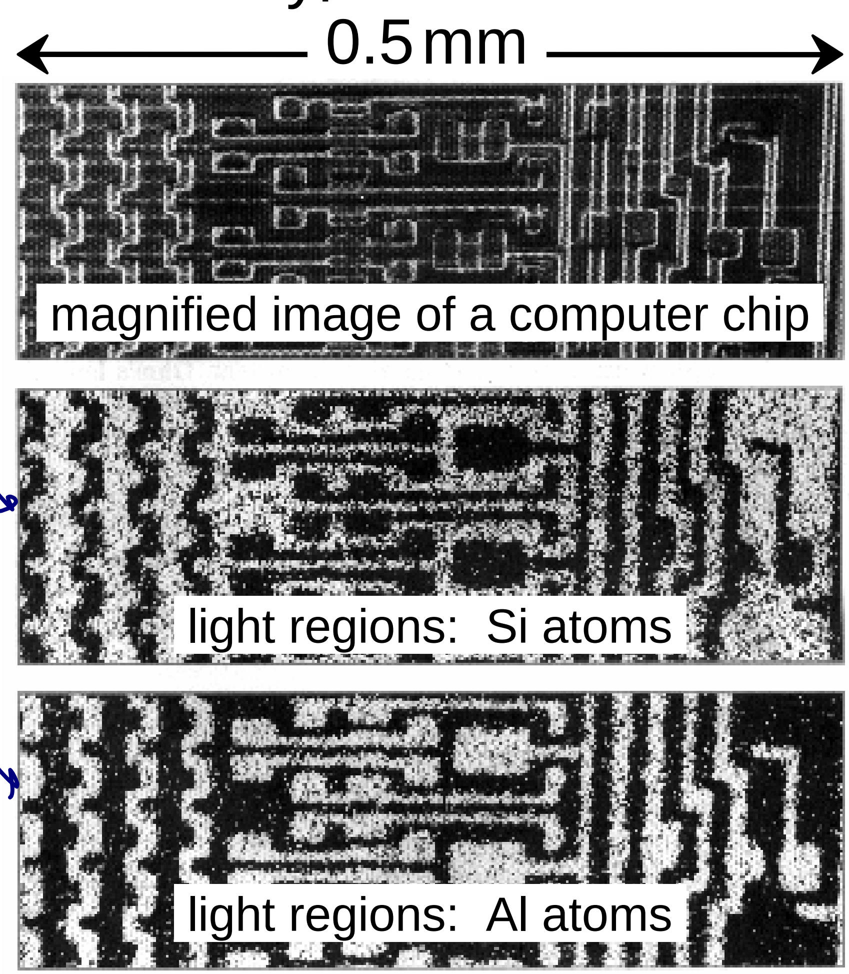
- Doping silicon with phosphorus for *n*-type semiconductors:
- Process:

1. Deposit P rich layers on surface.



2. Heat it.
3. Result: Doped semiconductor regions.





Adapted from chapter-opening photograph, Chapter 18, *Callister 7e.*

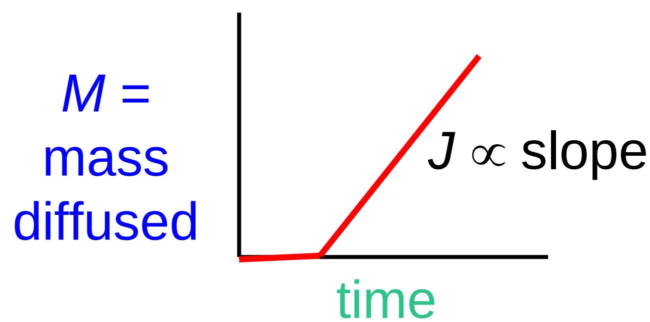
Diffusion

- **How do we quantify the amount or rate of diffusion?**

$$J \equiv \text{Flux} \equiv \frac{\text{moles (or mass) diffusing}}{(\text{surface area})(\text{time})} = \frac{\text{mol}}{\text{cm}^2\text{s}} \text{ or } \frac{\text{kg}}{\text{m}^2\text{s}}$$

- **Measured empirically**
  - **Make thin film (membrane) of known surface area**
  - **Impose concentration gradient**
  - **Measure how fast atoms or molecules diffuse through the membrane**

$$J = \frac{M}{At} = \frac{l}{A}\frac{dM}{dt}$$

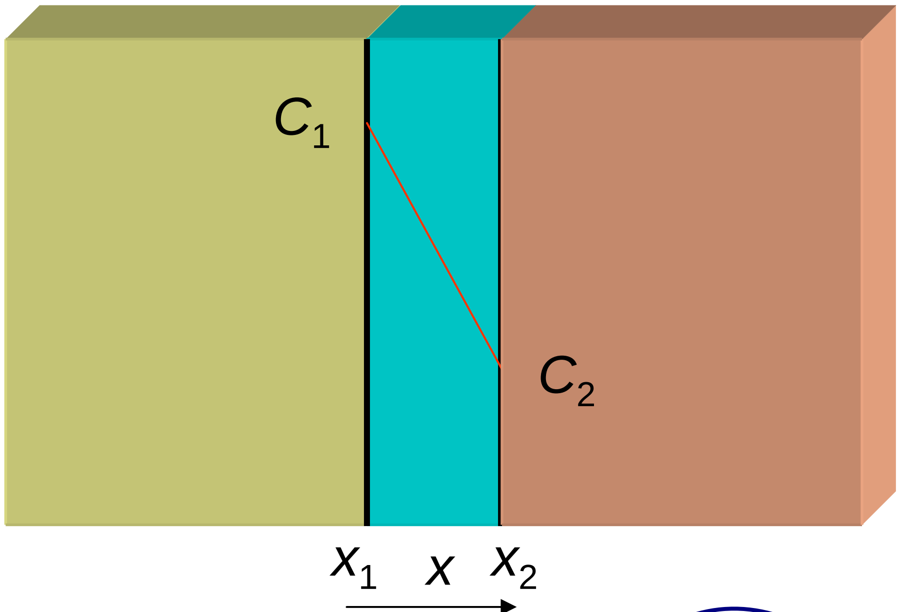


Steady-State Diffusion

Rate of diffusion independent of time

Flux proportional to concentration gradient = $\dfrac{dC}{dx}$

$\dfrac{mol}{m^2 s}$



Fick's first law of diffusion

$$J = -D\frac{dC}{dx}$$

if linear $\dfrac{dC}{dx} \cong \dfrac{\Delta C}{\Delta x} = \dfrac{C_2 - C_1}{x_2 - x_1}$

$D \equiv$ diffusion coefficient

- Analyze the units of Fick’s first law for next time.