CHAPTER 4: IMPERFECTIONS IN SOLIDS

ISSUES TO ADDRESS...

- What types of defects arise in solids?
- Can the number and type of defects be varied and controlled?

- How do defects affect material properties?
- Are defects undesirable?

TYPES OF IMPERFECTIONS

- Vacancy atoms
- Interstitial atoms
- Substitutional atoms

Point defects

- **Dislocations**

Line defects

- Grain Boundaries

Planar Defects

Deformation

- Deformation of materials occurs when a line defect (dislocation) moves (slip) through the material

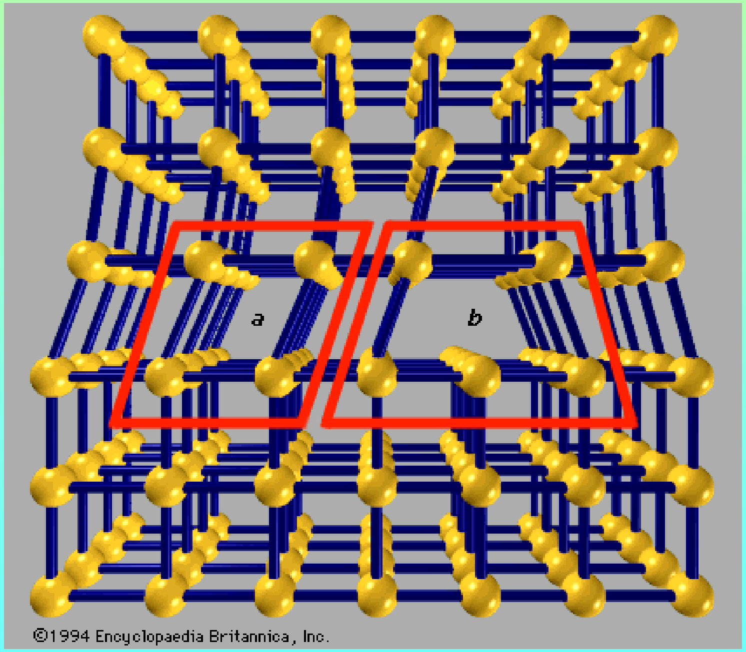
Strength of a Material

- Based on the bond strength most materials should be much stronger than they are
- From Chapter two we know that the strength for an ionic bond should be about 10^6 psi
- More typical strength is $40*10^3$ psi
- Why?
- Materials must not usually fail by breaking bonds!!

LINE DEFECTS

Dislocations:

- are linear defects, lead to the atom misalignment
- cause slip between crystal plane when they move
- produce permanent (plastic) deformation.



- **<u>Dislocation Types:</u>**

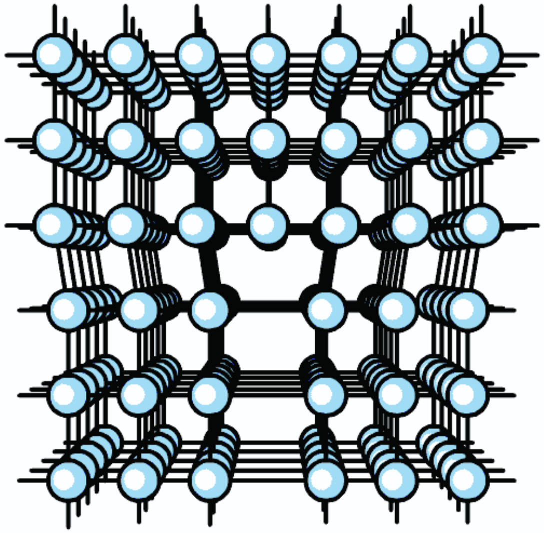
  - Edge dislocation

  - Crew dislocation

  - Mixed dislocation

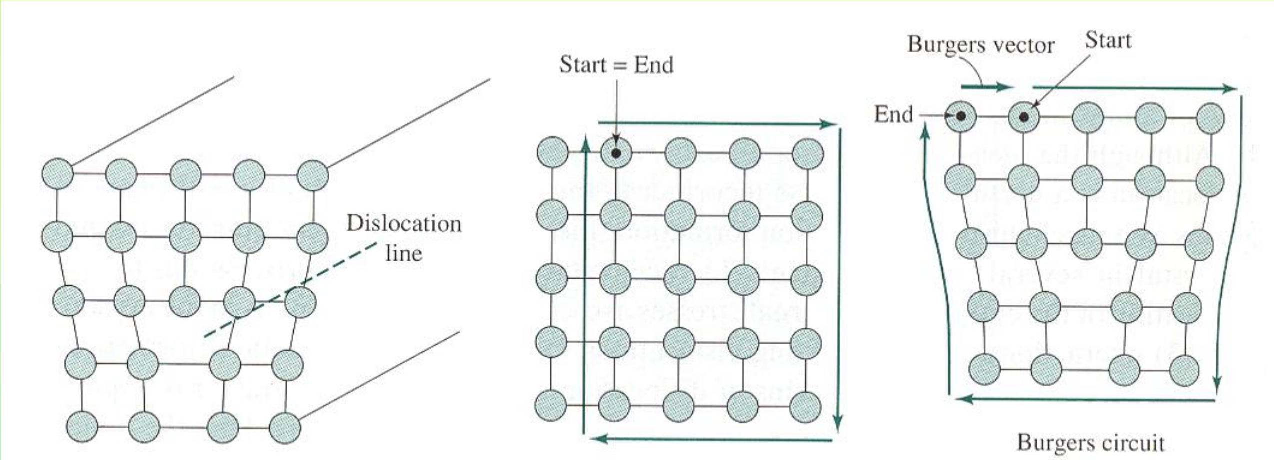
EDGE DISLOCATION

centers around the ***edge dislocation line*** that is defined along the end of the extra half-plane of atoms



- ***Distortion*** to the lattice decreases with distance away from dislocation line;
- ***Burgers*** vector, **b**, defines the magnitude and direction of the deformation;
- For edge dislocation **b** and ***dislocation line*** are ***perpendicular***

Burger Vector



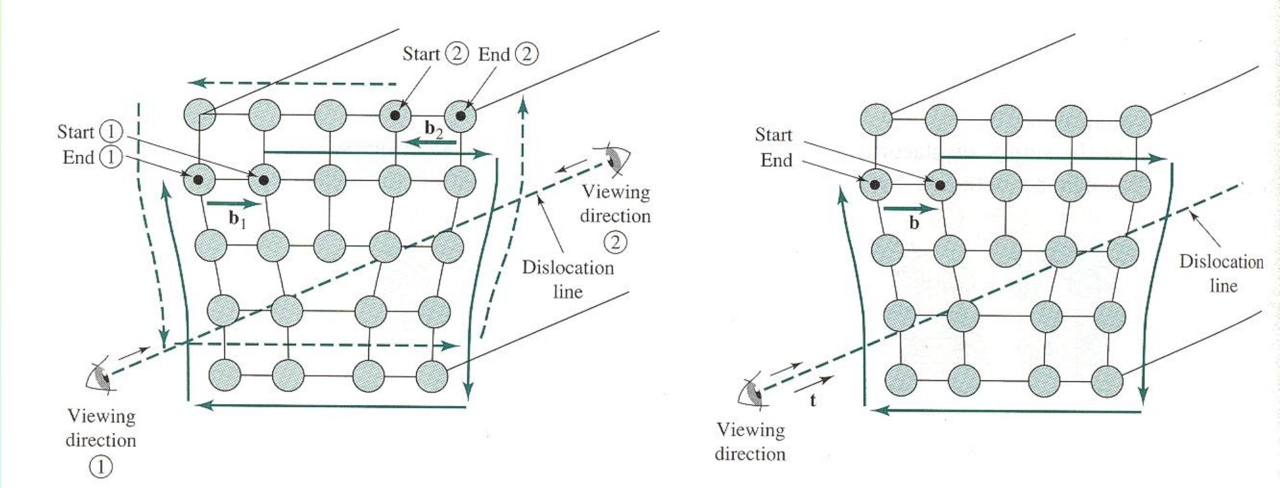
A 3-D view of the edge dislocation

A Burger circuit closes upon itself

The vector pointing from the end point to the start point is A Burger vector of dislocation

- This parameter is simple <u>**the displacement vector**</u> necessary to close a stepwise loop (so-called a burger circuit) around the defect.
- This vector represents the ***magnitude of the structural defect***.
- This magnitude for the common metal structure (bcc, fcc and hcp) is simply the <u>repeat distance along</u> the highest atomic density direction (where atoms touching each other)

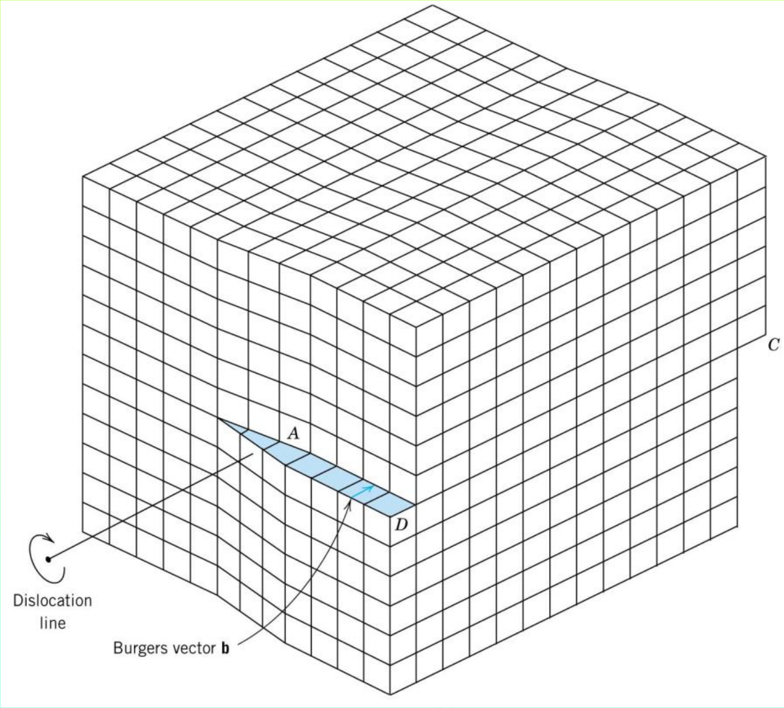
Burger Vector



A Burger depends
on the viewing direction

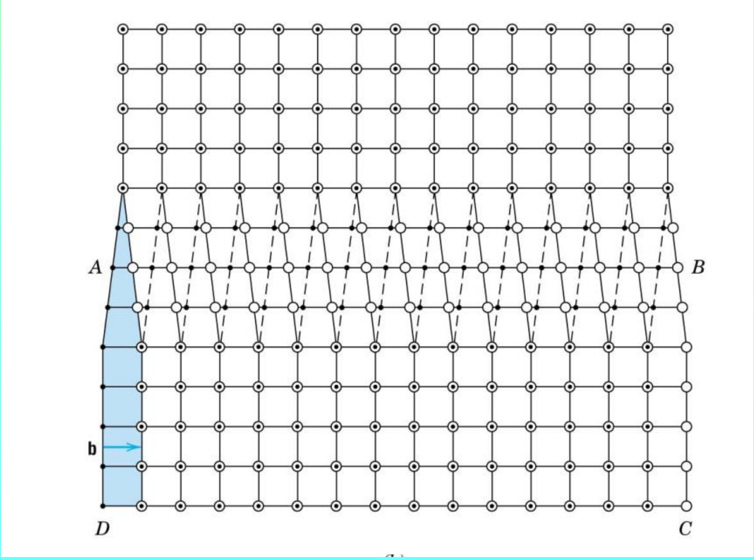
The choice of positive
viewing direction:
“clockwise” Burgers circuit

SCREW DISLOCATION



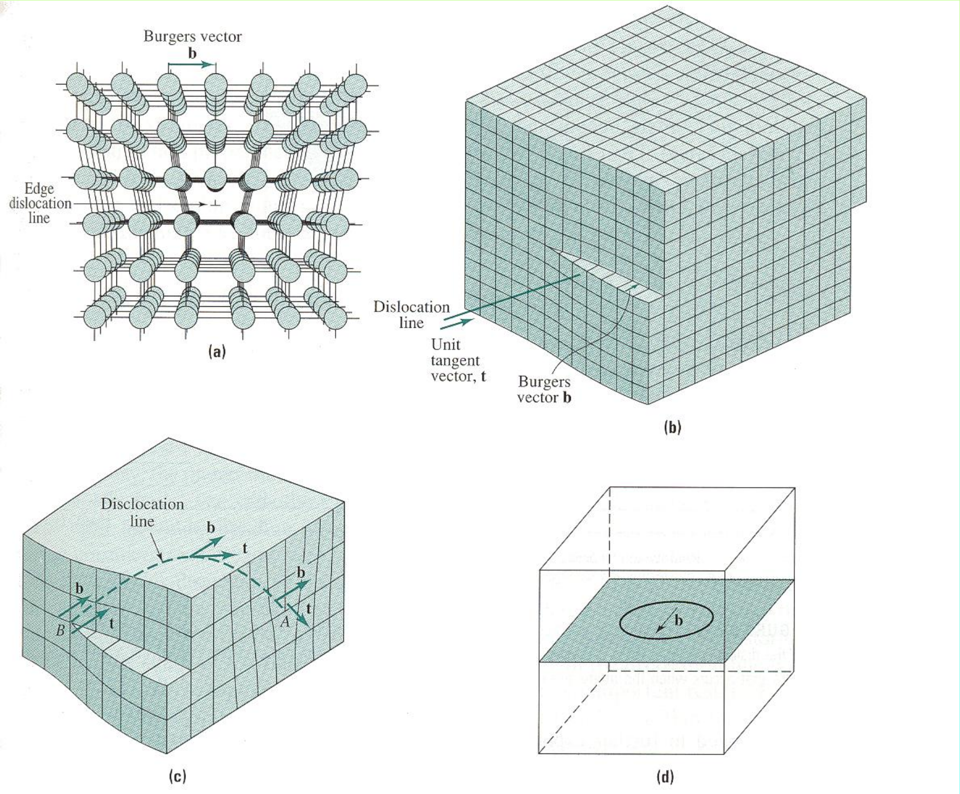
Open circles upper half atoms
Solid circles lower half atoms

Connecting "looks like a screw"



- A ramped step
- Burgers vector:
  direction of the atoms displacement for a screw dislocation is parallel to the line of the dislocation
- Harder to visualize than edge dislocations

Key Features of Dislocations



- The character of a dislocation is defined by the relation between its Burgers vector (**b**) and unit tangent vector (**t**)

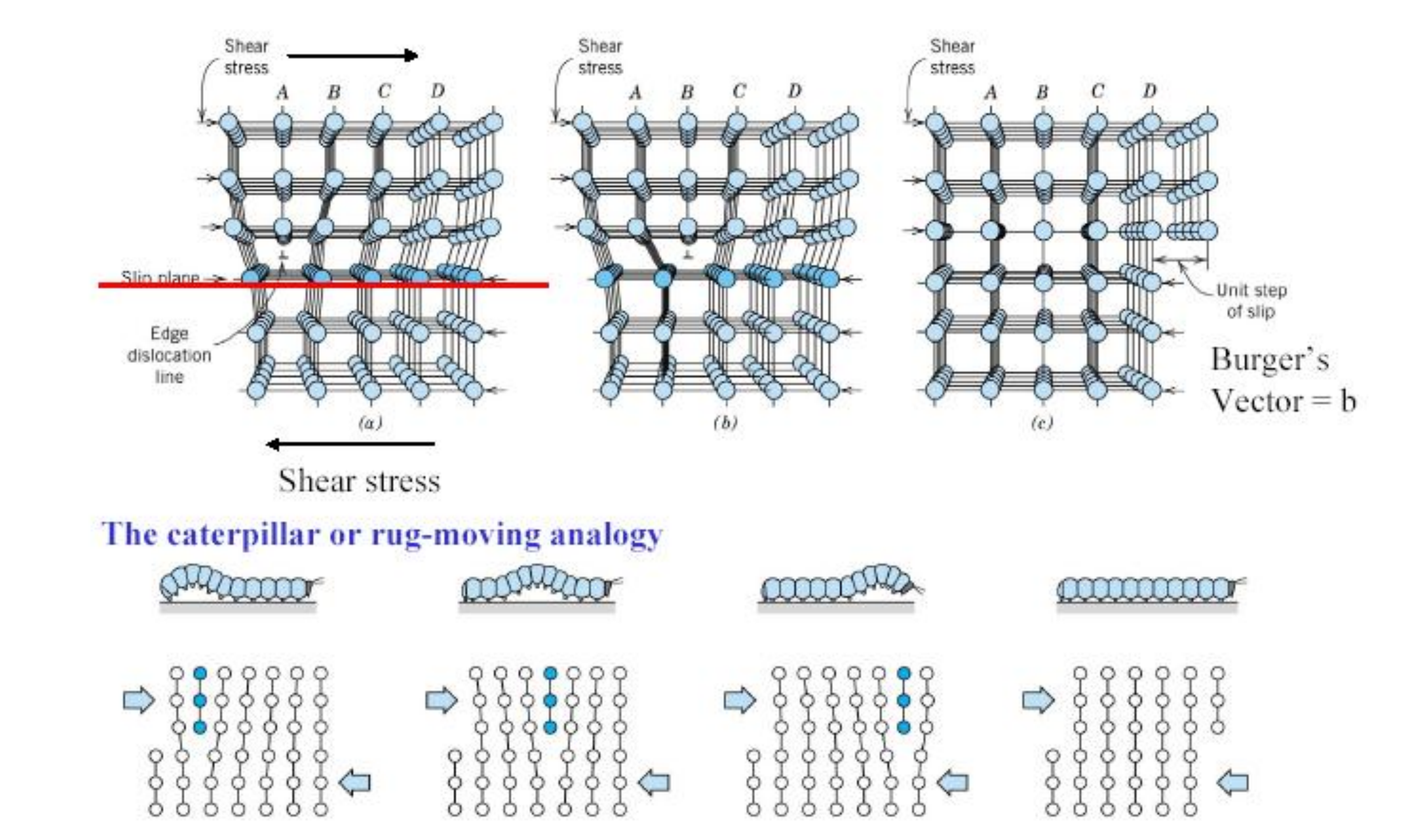
- The plane on which a dislocation may slip contains both **b** and **t** vectors

•A dislocation cannot end in the middle of a defect- free region of a crystal. It can end at the crystal surface, on itself, or on other dislocation

Deformation

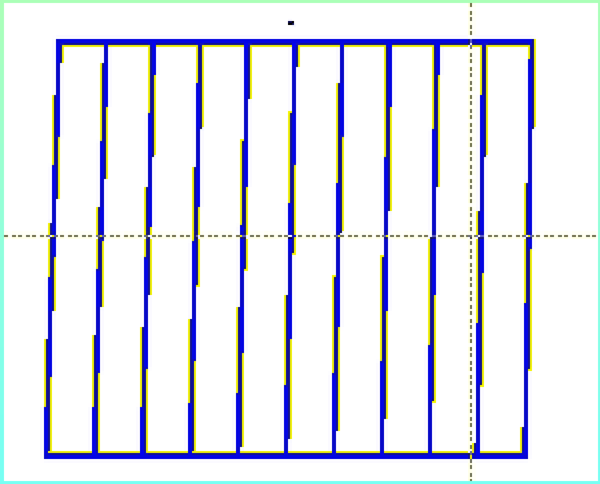
- When a shear force is applied to a material, the dislocations move
- Real materials have lots of dislocations, therefore the strength of the material depends on the force required to make the dislocation move, not the bonding energy

Edge Dislocation Exiting Crystal Form Steps



INCREMENTAL SLIP

- Dislocations slip planes *incrementally*...
- The dislocation line (the moving red dot)...
  ...separates slipped material on the left
  from unslipped material on the right.



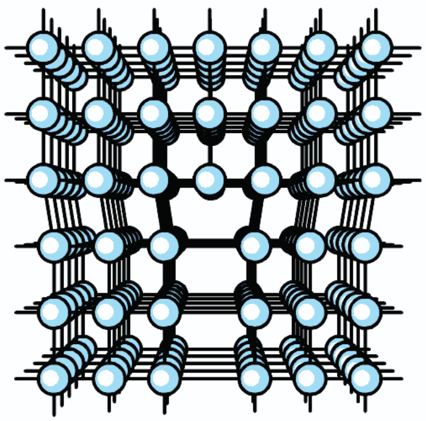
Simulation of dislocation motion from left to right as a crystal is sheared.

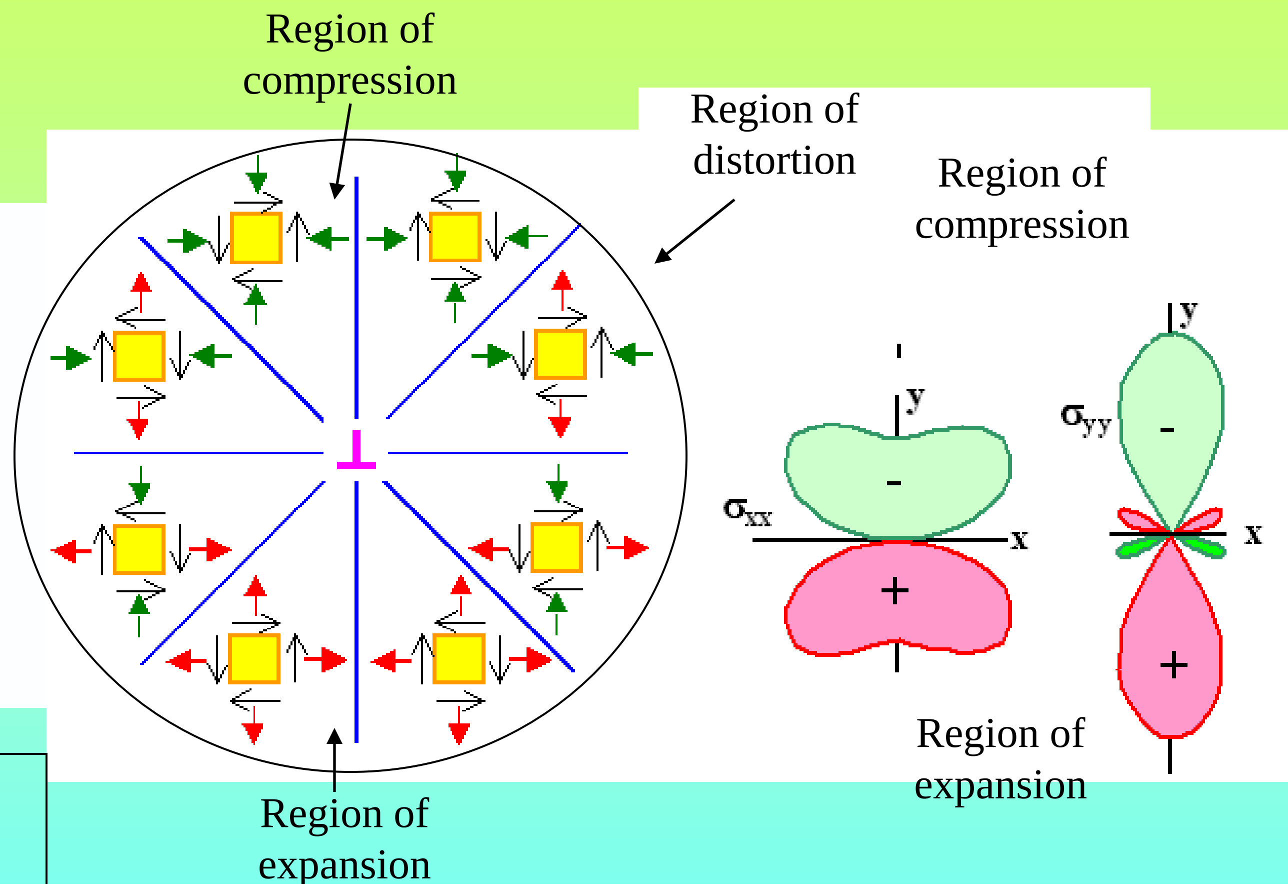
(Courtesy P.M. Anderson)

Slip

- When dislocations move slip occurs
  - Direction of movement – same as the Burgers vector
- Slip is easiest on ***close packed*** **planes**
- Slip is easiest in the ***close packed*** **direction**

Slip: Energetic Considerations

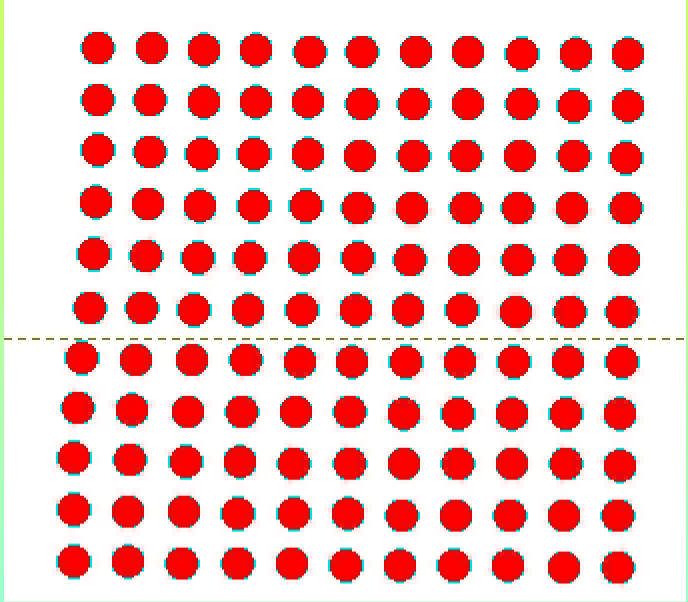




$E_{dist} \sim |\mathbf{b}|^2$

Thus energy associated with dislocation is a minimum for the ***shortest*** Burger Vectors

Slip: Crystallographic Requirements



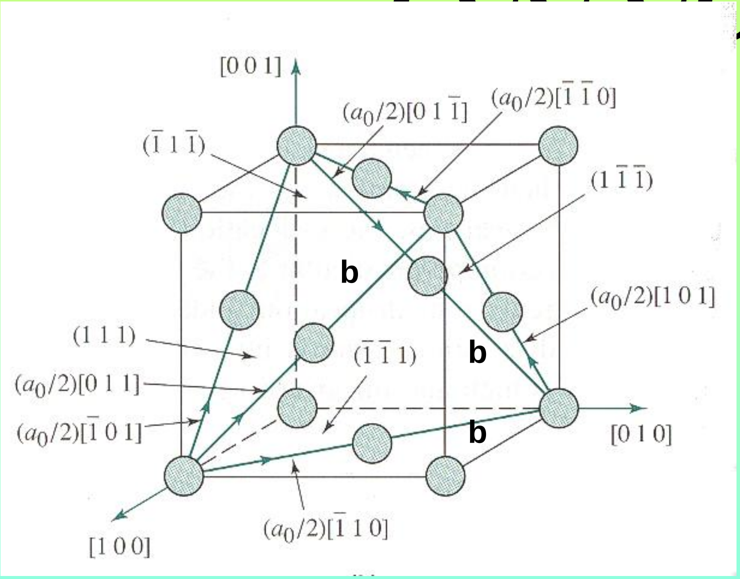
- Burger vector for unit dislocations **MUST** joint crystallographically equivalent positions in the lattice

- The motion of the dislocation **MUST transport** atoms from one equilibrium position to another

Thus the most favorable Burgers vectors is the shortest vectors that connect equivalent lattice positions

In the simple crystal structures the Burgers Vectors are in the ***closed –packed directions***!!!

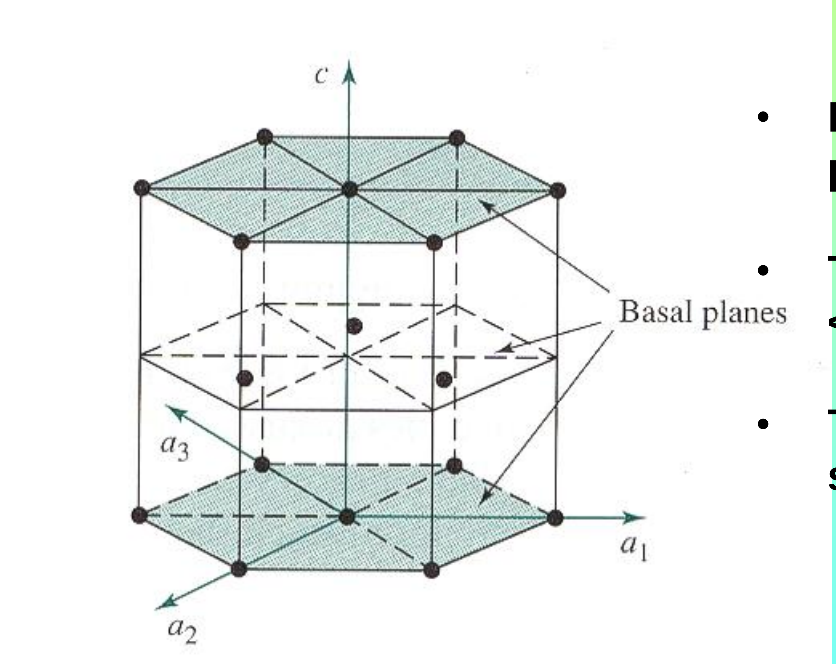
Burgers Vectors and Slip Systems: FCC Crystal Structure



- **{111} planes are the closed-packed and hence the slip planes;**
- **The shortest vector joining equivalent lattice positions – one half of any face diagonal**
- **These vectors belong to <110> family of directions**

•The combination of a slip direction and slip plane = slip system
• There are four nonparallel {111} planes
• Each contains three nonparallel directions <110>
• Thus 12 slip systems in FCC are collectively represented as {111}<110>

Burgers Vectors and Slip Systems HCP Crystal Structure

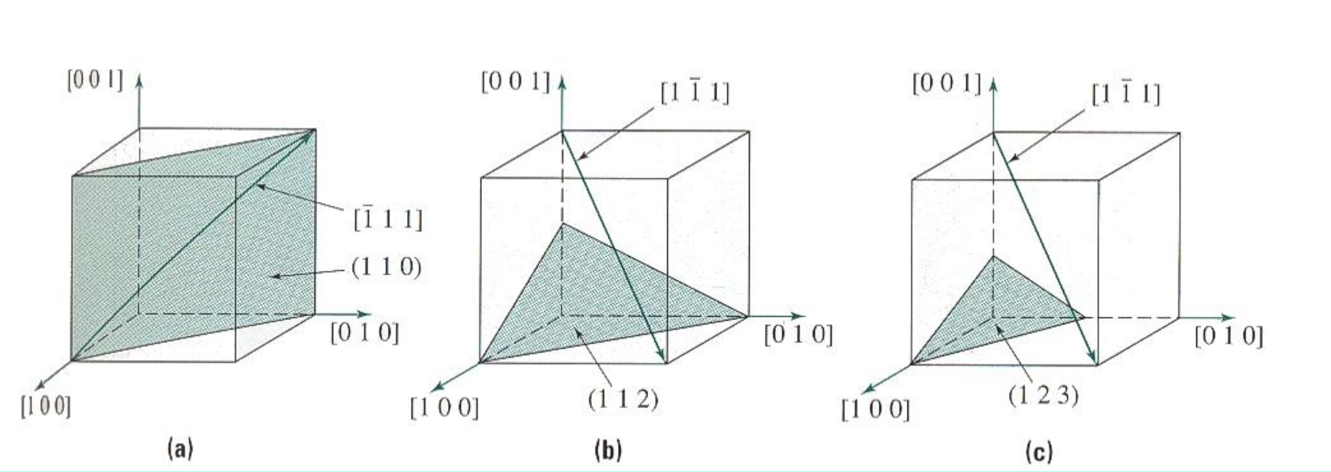


- **Basal or (0001) planes represent one set of parallel closed-packed slip planes**
- **This one set contains three slip directions <11$\bar{2}$0> family in the "a" directions – *basal slip***
- **Thus there are three not intersected slip systems in the HCP structure**

Burgers Vectors and Slip Systems
BCC Crystal Structure

There are no closed-packed planes in BCC structure!!

The planes of highest atomic density frequently observed to be a *slip planes*

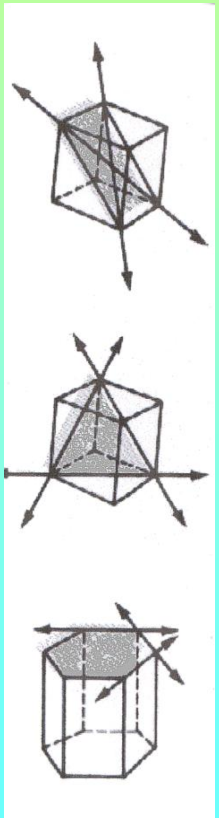


A member of the {110}<111> system

A member of the {112}<111> system

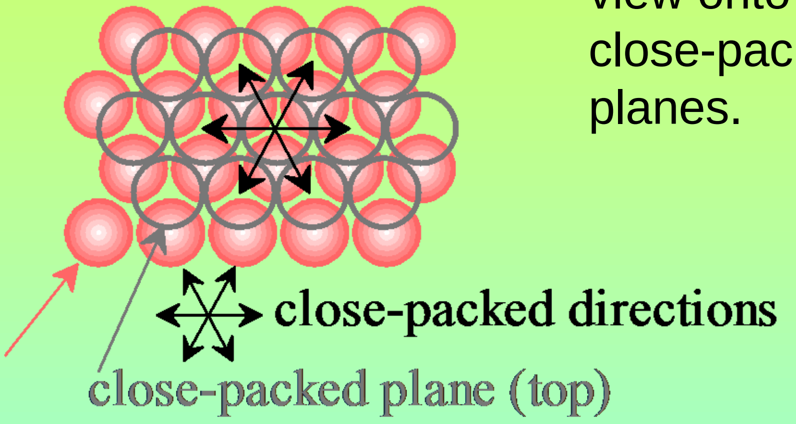
A member of the {123}<111> system

Major Slip Systems in the Common Metal Structures

Crystal Structure	Slip Plane	Slip Directions	Number Of Slip Systems	Unit Cell Geometry	Examples
BCC	{110} {211} {321}	<111> <111> <111>	6 x 2=12 6 x 2=12 6 x 4=24		α-Fe, Mo, W
FCC	{111}	<110>	3 x 4=12		Al, Cu, γ–Fe, Ni
HCP	Basal	a	1 x3=3		α-Ti, Mg, Zn, Cd

DISLOCATIONS & CRYSTAL STRUCTURE

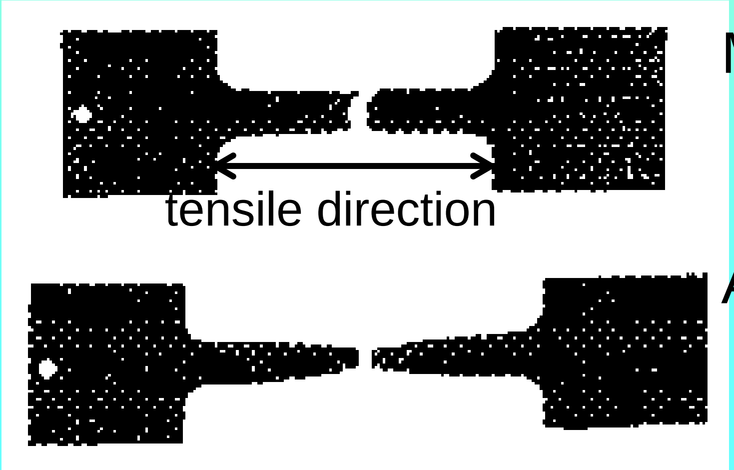
- Structure: close-packed planes & directions are preferred.



view onto two close-packed planes.

- Comparison among crystal structures:
  FCC: many close-packed planes/directions;
  HCP: only one plane, 3 directions;
  BCC: none

- Results of tensile testing.



TYPES OF IMPERFECTIONS

- Vacancy atoms
- Interstitial atoms
- Substitutional atoms

Point defects

- Dislocations

Line defects

- **Free Surfaces in Crystal**
- **Grain Boundaries**
- **Stacking Faults**
- **Low-Angle Tilt Boundary**
- **A Twin**

Planar Defects

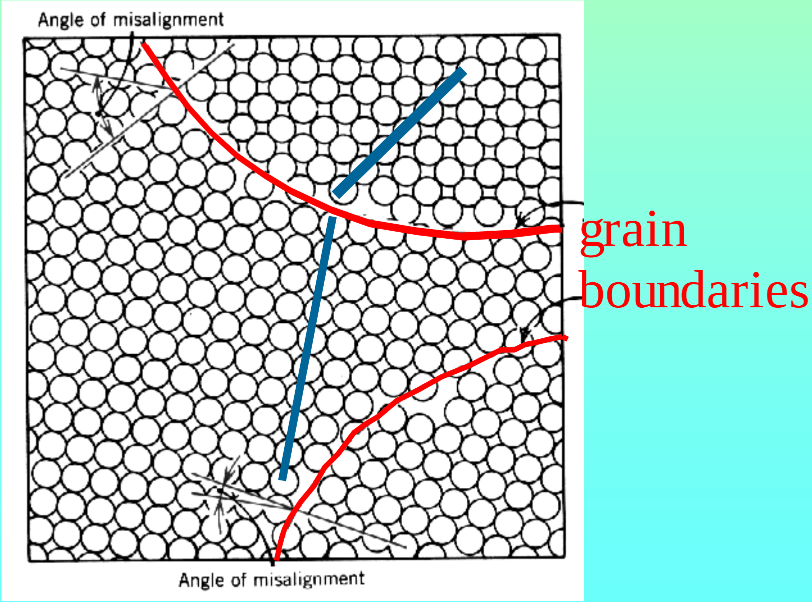
Bulk Defects

- **Pores *(esp. ceramics)*** - can greatly affect optical, thermal,mechanical properties
- **Cracks -** can greatly affect mechanical properties
- **Foreign inclusions** - can greatly affect electrical, mechanical,optical properties

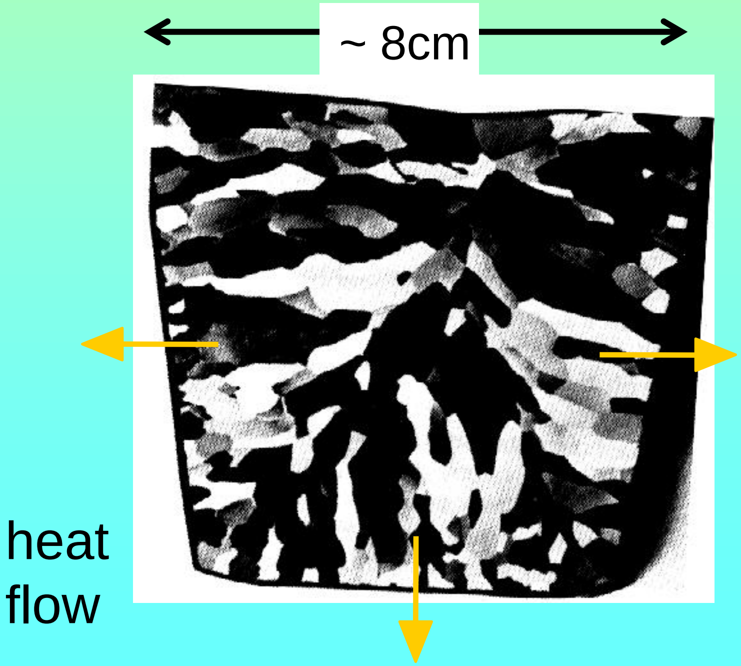
Grain Boundaries

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

Schematic



Metal Ingot



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.)