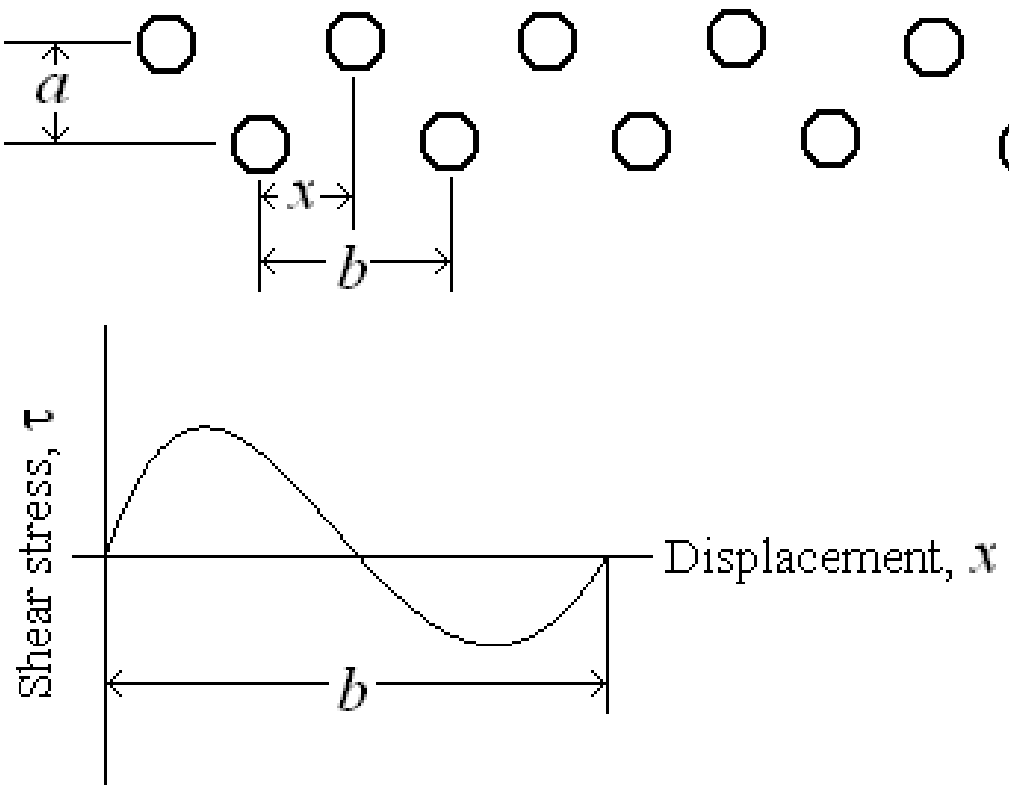
Module-3

Imperfections in Solids

Contents

Theoretical yield strength

- Ideal solids are made of atoms arranged in orderly way.



Theoretical yield strength (contd…)

- Using a *sin* function to represent the variation in shear stress

$$\tau = \tau_m \sin \frac{2\Pi x}{b} \qquad \tau \approx \tau_m \frac{2\Pi x}{b}$$

+

$$\tau = G\gamma = \frac{Gx}{a}$$

(Hooke's law)

⇓

$$\tau_m = \frac{G}{2\Pi}\frac{b}{a}$$

If b≈a

$$\tau_m = \frac{G}{2\Pi}$$

G ≈ 20-150 GPa

⇒ Shear strength ≈ 3-30 GPa

(ideal)

Real strength values ≈ 0.5-10 MPa

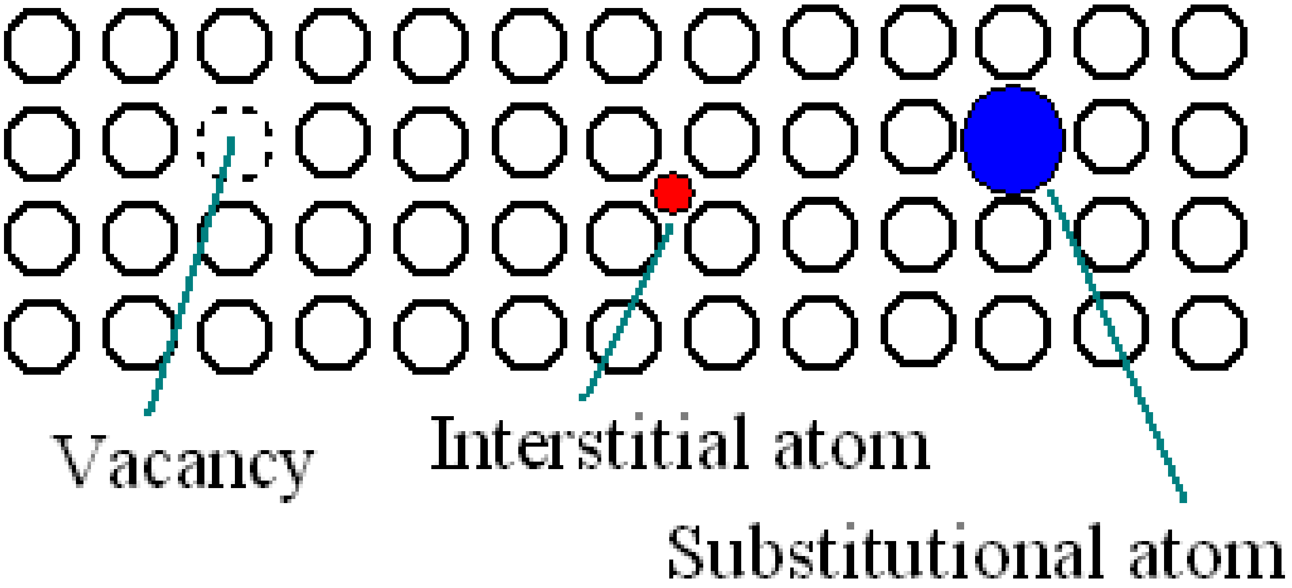
Theoretical yield strength (contd…)

- Theoretical strength of solids shall possess an ideal value in the range of 3-30 GPa.
- Real values observed in practice are 0.5-10 MPa.
- The assumption of perfectly arranged atoms in a solid may not valid…..i.e. atomic order must have been disturbed.
- Disordered atomic region is called *defect* or *imperfection*.
- Based on geometry, defects are: Point defects (zero-D), Line defects (1-D) *or* Dislocations, Interfacial defects (2-D) and Bulk *or* Volume defects (3-D).

Point defects

- Point defects are of zero-dimensional i.e. atomic disorder is restricted to point-like regions.

- Thermodynamically stable compared with other kind of defects.

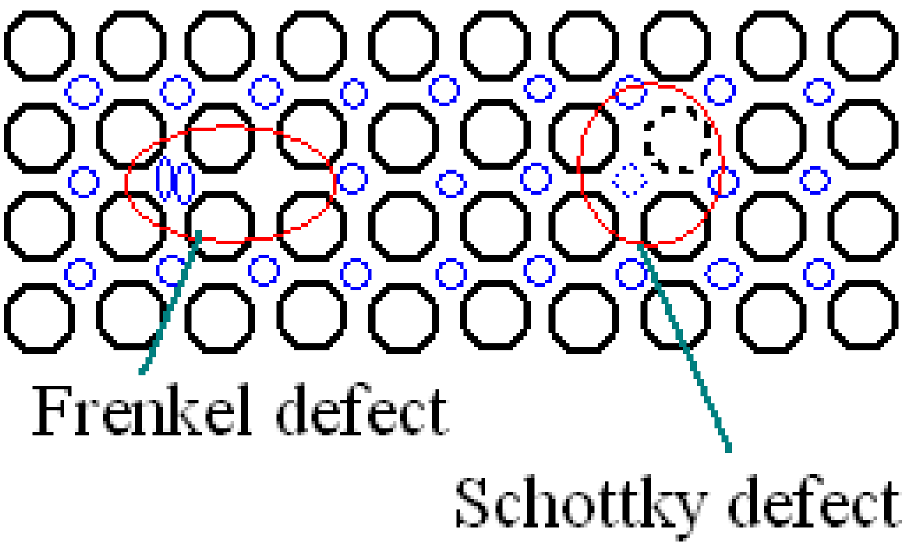


Point defects (contd…)

- Fraction of vacancy sites can be given as follows:

$$\frac{n}{N} = e^{-Q/kT}$$

- In ionic crystals, defects can form on the condition of charge neutrality. Two possibilities are:



Line defects

- *Line defects* or *Dislocations* are abrupt change in atomic order along a line.

- They occur if an incomplete plane inserted between perfect planes of atoms *or* when vacancies are aligned in a line.

- *A dislocation is the defect responsible for the phenomenon of slip, by which most metals deform plastically*.

- Dislocations occur in high densities (10^8-10^{10} m^{-2}), and are intimately connected to almost all mechanical properties which are in fact structure-sensitive.

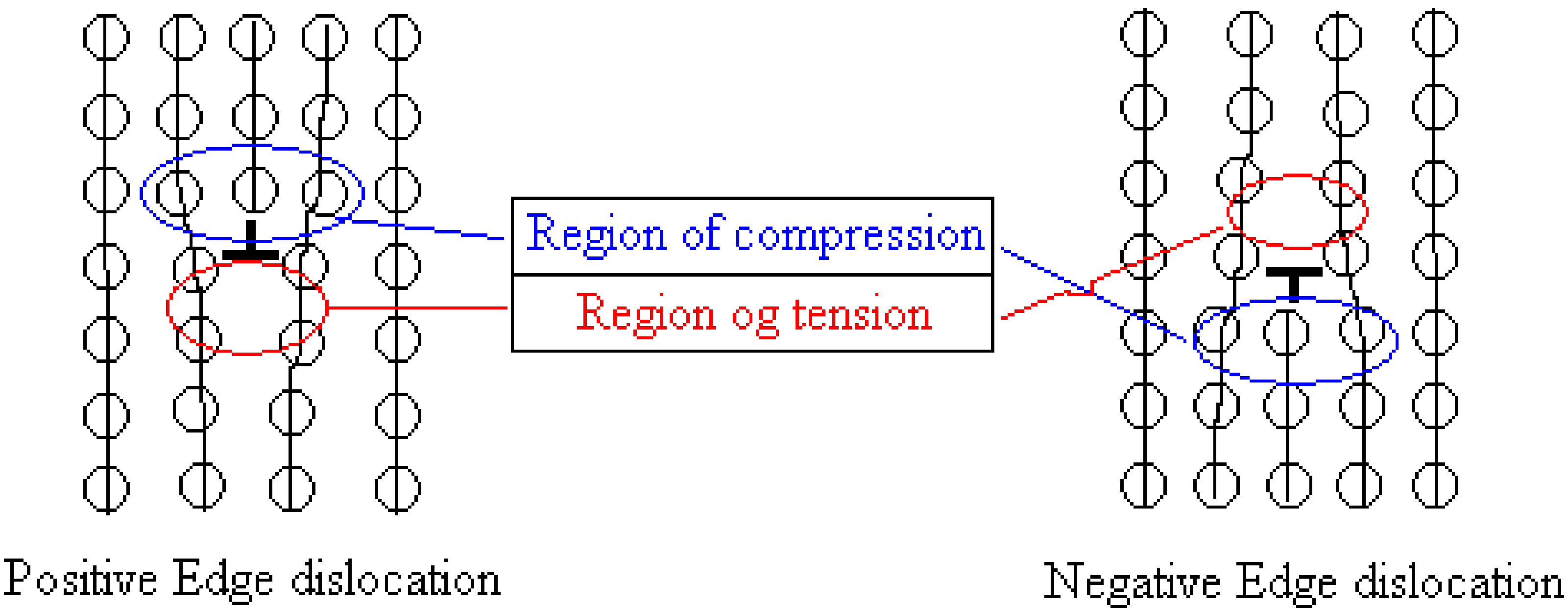
- Dislocation form during plastic deformation, solidification or due to thermal stresses arising from rapid cooling.

Line defects – Burger’s vector

- A dislocation in characterized by Burger’s vector, ***b***.
- It is unique to a dislocation, and usually have the direction of close packed lattice direction. It is also the slip direction of a dislocation.
- *It represents the magnitude and direction of distortion associated with that particular dislocation*.
- Two limiting cases of dislocations, edge and screw, are characterized by Burger’s vector perpendicular to the dislocation line (***t***) and Burger’s vector parallel to the dislocation line respectively. Ordinary dislocation is of mixed character of edge and screw type.

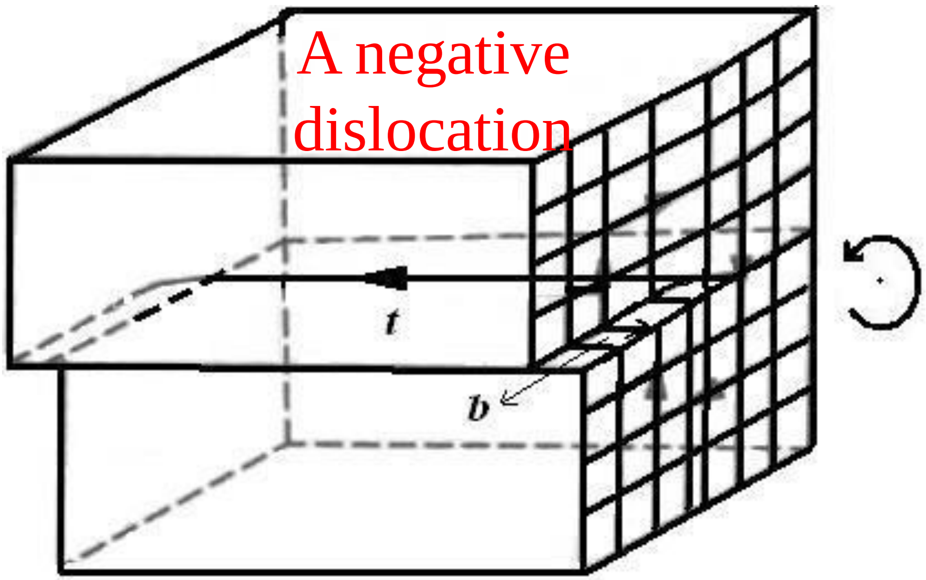
Line defects – Edge dislocation

- It is also called as *Taylor-Orowan dislocation*.
- It will have regions of compressive and tensile stresses on either side of the plane containing dislocation.



Line defects – Screw dislocation

- It is also called as *Burger's dislocation*.
- It will have regions of shear stress around the dislocation line
- For positive screw dislocation, dislocation line direction is parallel to Burger's vector, and vice versa.



Line defects – Dislocation motion

- Dislocations move under applied stresses, and thus causes plastic deformation in solids.

- Dislocations can move in three ways – glide/slip, cross-slip and climb – depending on their character. Slip is conservative in nature, while the climb is non-conservative, and is diffusion-controlled.

- *Any dislocation can slip, but in the direction of its burger's vector*.

- *Edge dislocation moves by slip and climb*.

- *Screw dislocation moves by slip / cross-slip*. Possibility for cross-slip arises as screw dislocation does not have a preferred slip plane as edge dislocation have.

Line defects – Dislocation characteristics

- A dislocation line cannot end at abruptly inside a crystal. It can close-on itself as a loop, either end at a node or surface.
- *Burger's vector for a dislocation line is invariant* i.e. it will have same magnitude and direction all along the dislocation line.
- Energy associated with a dislocation because of presence of stresses is proportional to square of Burger's vector length. Thus dislocations, at least of same nature, tend to stay away from each other.
- Dislocations are, thus, two types – full and partial dislocations. For *full dislocation*, Burger's vector is integral multiple of inter-atomic distance while for *partial dislocation*, it is fraction of lattice translation.

Interfacial defects

- An interfacial defect is a 2-D imperfection in crystalline solids, and have different crystallographic orientations on either side of it.

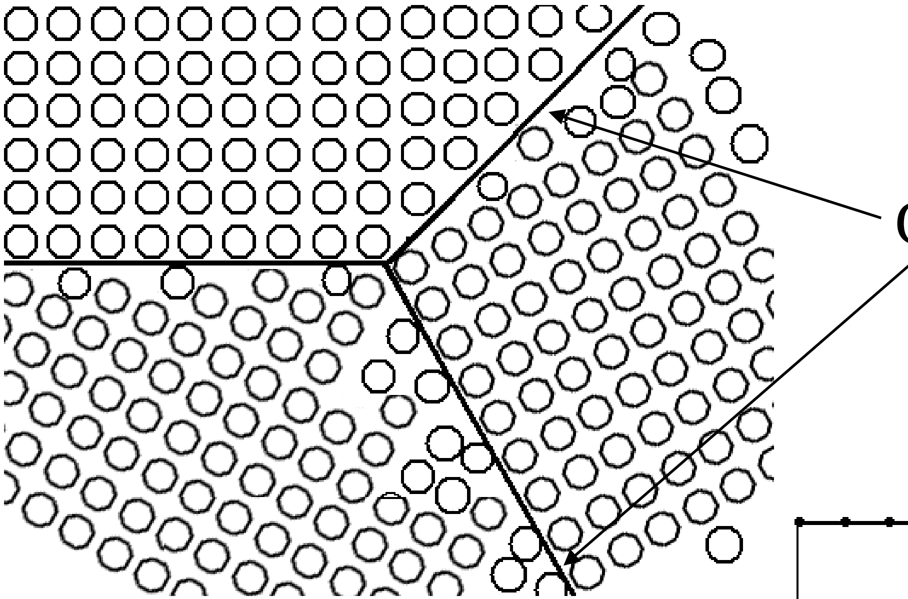
- Region of distortion is about few atomic distances.

- They usually arise from clustering of line defects into a plane.

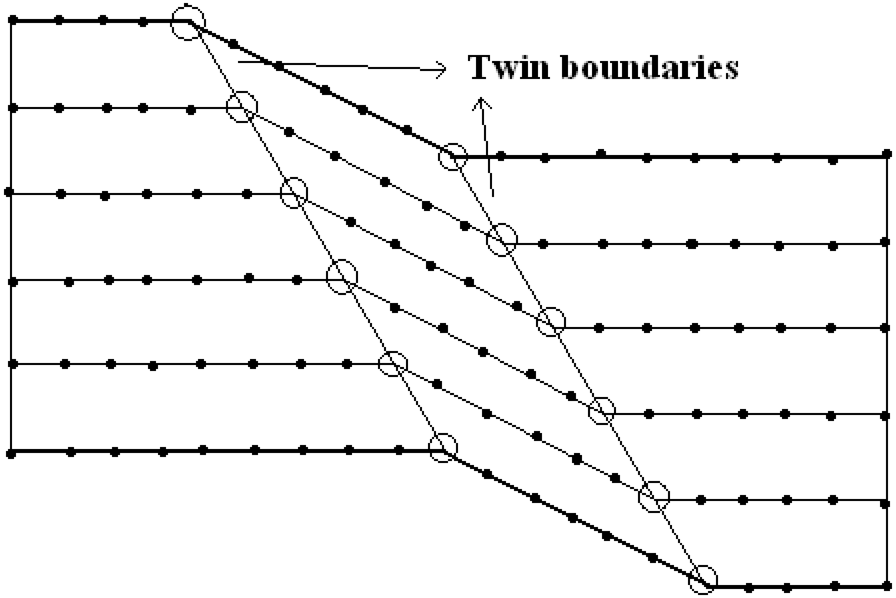
- These imperfections are not thermodynamically stable, but meta-stable in nature.

  E.g.: External surface, Grain boundaries, Stacking faults, Twin boundaries, Phase boundaries.

Interfacial defects (contd…)



Grain boundaries



Bulk *or* Volume defects

- Volume defects are three-dimensional in nature.

- These defects are introduced, usually, during processing and fabrication operations like casting, forming etc.

  E.g.: Pores, Cracks, Foreign particles

- These defects act like stress raisers, thus deleterious to mechanical properties of parent solids.

- In some instances, foreign particles are added to strengthen the solid – dispersion hardening. Particles added are hindrances to movement of dislocations which have to cut through or bypass the particles thus increasing the strength.

Atomic vibrations

- Atoms are orderly arranged, but they are expected to vibrate about their positions where the amplitude of vibration increases with the temperature.

- After reaching certain temperature, vibrations are vigorous enough to rupture the inter-atomic forces casing melting of solids.

- Average amplitude of vibration at room temperature is about 10^{-12}m i.e. thousandth of a nanometer.

- Frequency of vibrations is the range of 10^{13} Hz.

- Temperature of a solid body is actually a measure of vibrational activity of atoms and/or molecules.