University of Anbar/ Faculty of Engineering

Department of Mechanical Engineering

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Lecture # 9

CHAPTER FOUR/IMPERFECTIONS IN SOLIDS

Diffusion the phenomenon of material transport by atomic motion, **or** diffusion is just the stepwise migration of atoms from lattice site to lattice site.

In fact, the atoms motion in solid materials are restricted due to presence of the bonding. For an atom to make such a move (diffuse), two conditions must be met:

1) there must be an empty adjacent site, and
2) the atom must have sufficient energy to break bonds with its neighbor atoms and then cause some lattice distortion during the displacement.

There are two diffusion mechanisms in crystalline materials:

1) **Mechanism of vacancies and substitutional diffusion**: involves the interchange of an atom from a normal lattice position to an adjacent vacant lattice site or vacancy, as represented in **Fig 2**.

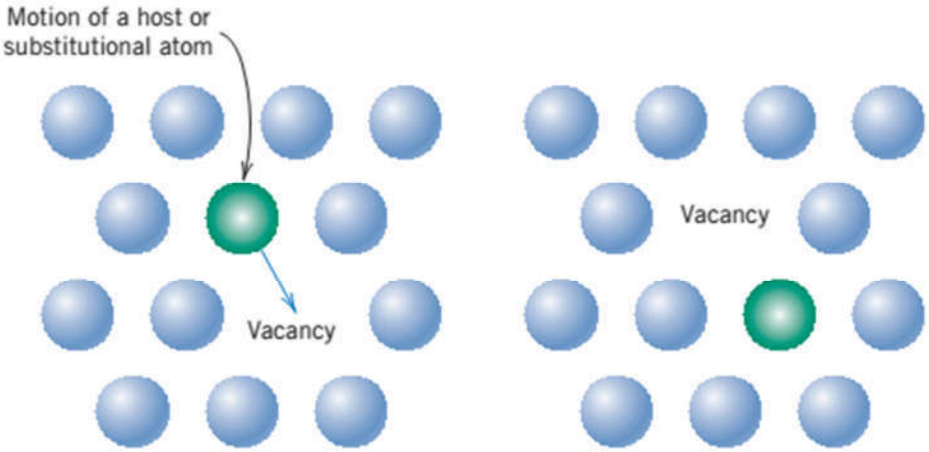

Figure 2. **Mechanism of vacancies and substitutional diffusion**

2) **Mechanism of interstitial diffusion**: involves atoms that move from an interstitial position to a neighboring one, as represented in **Fig. 3**.

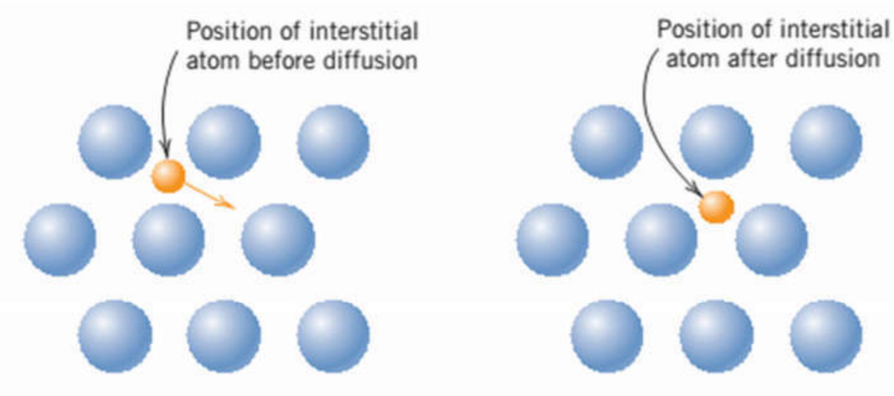

Figure 3. **Mechanism of interstitial diffusion**

- Diffusion mechanisms depend on the point defects. <u>Diffusion is affected by the following factors</u>:
  1) **Temperature**: at a specific temperature some small fraction of the total number of atoms is capable of diffusive motion,

2) **Concentration**: atoms move from higher concentration to lower one, if the difference of concentration is larger, lead to increase the diffusion rate.

3) **Time**: diffusion rate increase with time.

Application example on Diffusion

Application example on diffusion is surface heat treatment (**Gas Carburizing**)

- **Gas Carburizing** is the process of saturating the surface layer of steel with carbon.
- **This treatment is applied** to low carbon steel parts after machining, as well as high alloy steel bearings, gears, and other components.
- **Carburizing include** put steel parts in furnace at temperature > 920°C, containing hydrocarbon gas in a closed furnace, it makes hardened thin layer by carbon atoms from the surrounding atmosphere diffused into the surface, finally, it produces a surface which is resistant to friction and wear, while maintaining toughness and strength of the core.

B. Line defects: one or single dimensional defects in lattice.

Dislocations are linear defects, around which the atoms of the crystal lattice are misaligned. There are two basic types of dislocations, the ***edge dislocation*** and the ***screw dislocation***.

1) **Edge dislocation:** Extra line of atoms normal to paper. Burgers vector (b) is perpendicular to dislocation line. Its term is a $\perp$, as shown in **Figure 4.**

2) **Screw dislocation:** a linear crystalline defect related with lattice distortion when normally parallel planes are joined together to form helical path or ramp, as shown in **Figure 5.**

Burgers vector (b): a vector denotes to the magnitude and direction of the lattice distortion resulting from a dislocation in a crystal lattice.

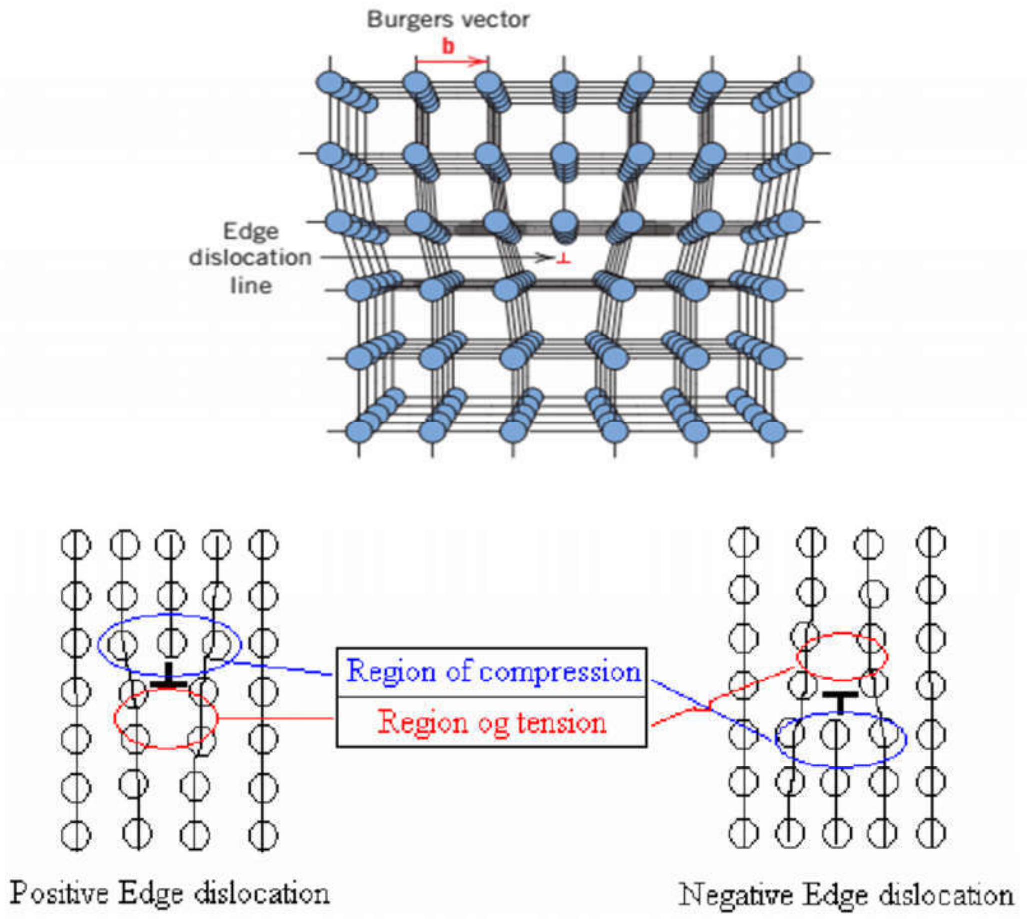

Figure 4. Edge dislocation

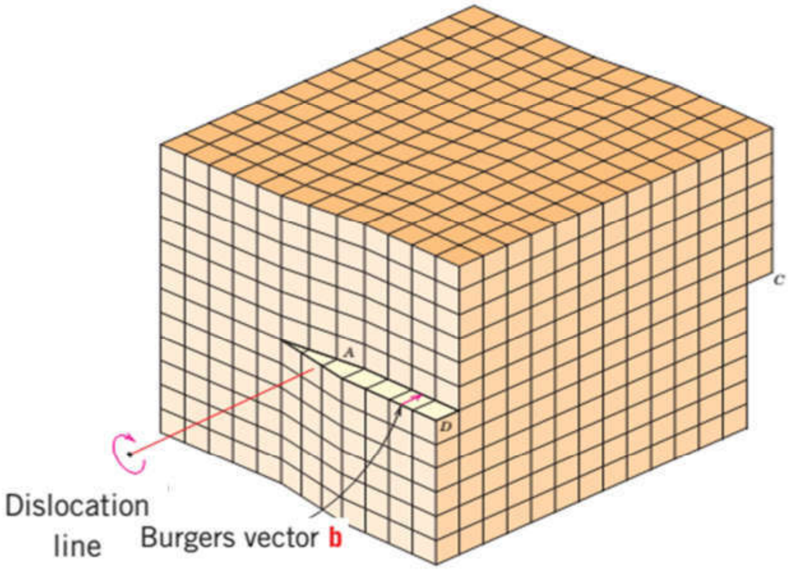

Figure 5. Screw dislocation

C. ***Surface defects***: two dimensional defects in crystal lattice. These are boundaries that have two dimensions and normally separate regions of the materials that have different crystal structures and/or crystallographic orientations. Surface defects include:

1) **External Surfaces:** Surface atoms are not bonded to the maximum number of nearest neighbors, and are therefore in a higher energy state than the atoms at interior positions. The bonds of these surface atoms that are not satisfied give rise to a surface energy, expressed in units of energy per unit area (J/m^2). To reduce this energy liquids will have minimum surface area.
2) **Grain Boundaries:** Boundaries between two grains. These useful in etching process during the preparation of sample for microscopic examination, where grain boundaries are chemically more reactive (more corrosive) because of grain boundary energy, this help to detect the distinct phases. A small and high-angle grain boundaries are represented schematically from an atomic perspective in **Figure 6.**

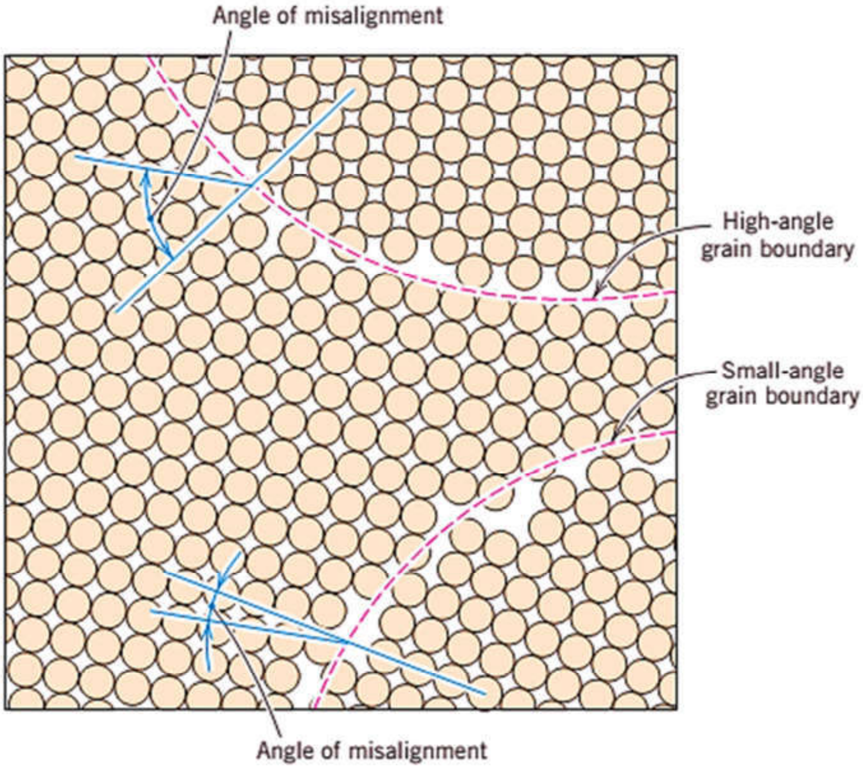

Figure 6 Schematic diagram showing small and high-angle grain boundaries

D. ***Volume* defects**: three dimensional defects in crystal lattice. They are resulted during processing and fabrication steps. These include: **pores**, **cracks**, and **inclusions**.

Plastic Deformation and Elastic Deformation

Plastic deformation: a permanent deformation caused by a sufficient load, it produces a permanent change in shape and size of a solid body without fracture under the action of a sustained force

Elastic Deformation: a temporary deformation; the recovery of the original dimensions of a deformed body when the load is removed.

Ductility: amount of plastic deformation that occurs before fracture, ***if ductility is high***, the material can be deformed by applying stresses. Ex.: gold - ***if ductility is low***, material breaks first, without significant deformation (material is brittle) - depend on Temp.: at low T many metals become brittle and can break as a glass

Plastic Deformation and Dislocations

- Mechanism of Plastic deformation by motion of dislocations: plastic deformation occur by plastic shear or slip where one plane of atoms slides over adjacent plane by defect motion (dislocations). In the metal slip mechanism, dislocations move through the metal crystals like wave fronts, allowing metallic atoms to slide over each other under low shear stress ⇒ deformation without fracture. If dislocations don't move, deformation doesn't occur.
- Plastic deformation corresponds to the motion of large numbers of dislocations. An edge dislocation moves in response to a shear stress applied in a direction perpendicular to its line; the mechanics of dislocation motion are represented in **Figure 7.**

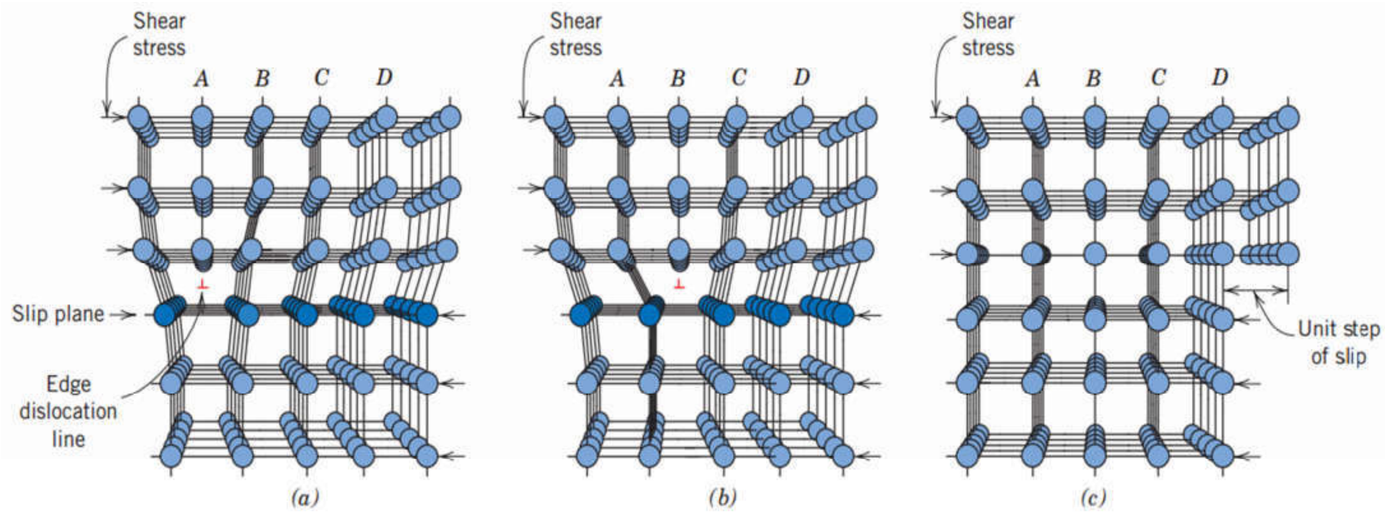

Figure 7 The motion of an edge dislocation as it moves in response to an applied shear stress

Theory of dislocation motion which is caused plastic deformation may be explained as follow:

1) Plastic deformation corresponds to the motion of dislocations. If dislocations don't move, deformation doesn't occur.

   Dislocation motion is similar to the mode of motion employed by a caterpillar (**Figure 8**).

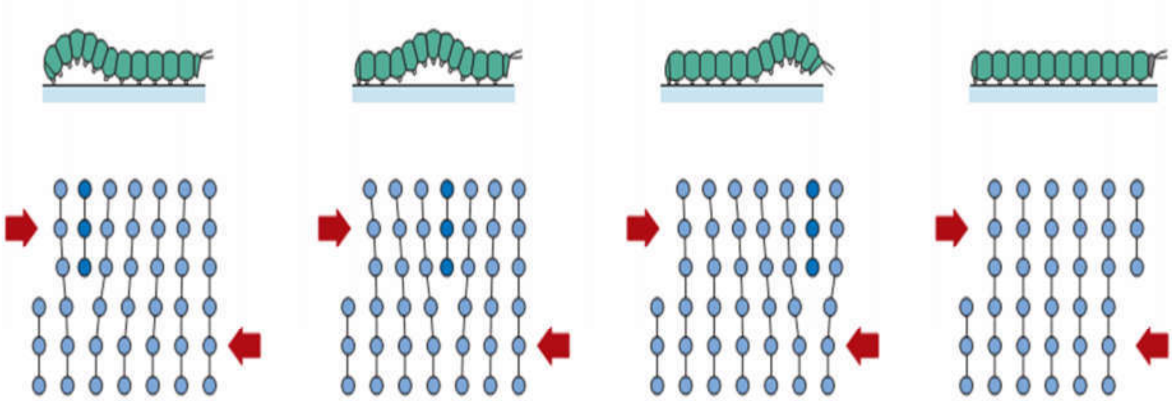

Figure 8 Dislocation motion

2) Under low shear stress metallic atoms slide over each other, and dislocation be stable on the sides. (**Fig. 8**)
3) Dislocation motion increases with temperature.

4) Dislocation motion becomes more difficult after cold working.
5) Dislocations density leads to barriers (obstacles) for dislocation motion.
6) Dislocation annihilation (**Figure 9**); Edge dislocations of opposite sign and lying on the same slip plane exert an attractive force on each other. Upon meeting, they annihilate each other and leave a region of perfect crystal.

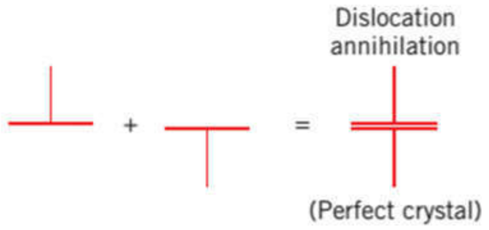

Figure 9. Dislocation annihilation

Factors that obstacle or prevent (barriers) for dislocation motion;

1) **Grain size**: Smaller grain size, more barriers to slip because of increase the grain boundaries which act as barriers for dislocation motion.
2) **Cold work**: after cold working, dislocation motion becomes more difficult because of increase of dislocations density which act as barriers.
3) **Solute atoms**: small impurities tend to concentrate at dislocations and reduce motion of dislocations (decrease of plastic deformation and increase strength).
4) **Annealing**: Heat treatment (heating) of metal after cold working, can reduce dislocation density and increase grain size. This increases plasticity of metal and decreases its strength. **Note**: at high temperature, probability of dislocation annihilation increases as result from increasing of dislocation motion.

Pure metals easily deform in comparison with alloys, why?

- Small impurities tend to concentrate at dislocations and reduce motion of dislocations this decrease of plastic deformation and increase strength in alloys. In pure metals have no impurities, this make them easy to deform.

Alloys have high strength (hardness) in comparison with pure metals, why?

- Strength (hardness) is increased by making dislocation motion difficult. Solute atoms in alloys tend to concentrate at dislocations and reduce motion of dislocations.

Hardness: a measure of the resistance of a material to plastic (permanent) deformation