

LINEAR AND PLANAR DENSITIES

Subject: Material Science - Lecture #8

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LINEAR AND PLANAR DENSITIES

Linear density (LD) is defined as the number of atoms per unit length whose centers lie on the direction vector for a specific crystallographic direction; that is,

$$LD = \frac{\text{number of atoms centered on direction vector}}{\text{length of direction vector}} \dots \dots \dots (3.16)$$

The units of linear density are reciprocal length (e.g., $\text{nm}^{-1}, \text{m}^{-1}$).

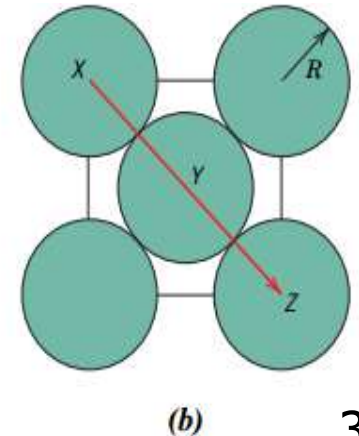
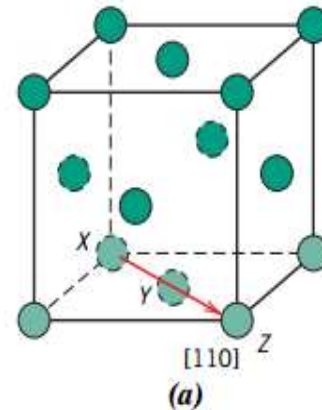
- For example, let us determine the linear density of the $[110]$ direction for the FCC crystal structure.

it is necessary to take into account the sharing of atoms with adjacent unit cells

$$LD = \frac{\text{number of atoms centered on direction vector}}{\text{length of direction vector}}$$

$$LD_{[110]} = \frac{\frac{1}{2} \text{ atom} + 1 \text{ atom} + \frac{1}{2} \text{ atom}}{R + R + R + R}$$

$$LD_{[110]} = \frac{2 \text{ atoms}}{4R} = \frac{1}{2R}$$



planar density (PD) is taken as the number of atoms per unit area that are centered on a particular crystallographic plane, or

$$PD = \frac{\text{number of atoms centered on plane}}{\text{area of plane}} \quad \dots \dots \dots (3.18)$$

The units for planar density are reciprocal area (e.g., nm^{-2} , m^{-2}).

- For example, consider the section of a (110) plane within an FCC unit cell as represented in Figures

$$PD = \frac{\text{number of atoms centered on plane}}{\text{area of plane}}$$

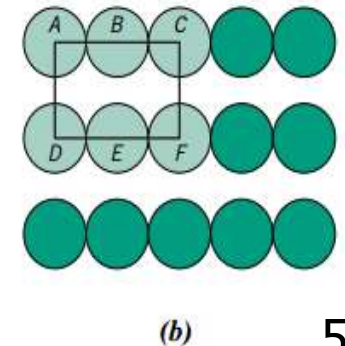
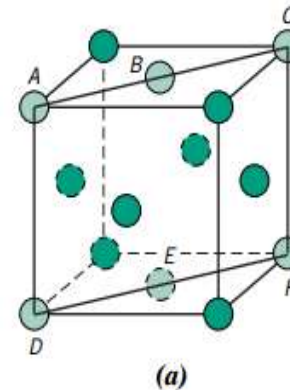
$$\text{area of plane}(110) = a \times fd = a \times (a^2 + a^2) = a \times \sqrt{2}a = \sqrt{2}a^2$$

$$a = 2R\sqrt{2} \rightarrow a^2 = 4R^2 \times 2 = 8R^2$$

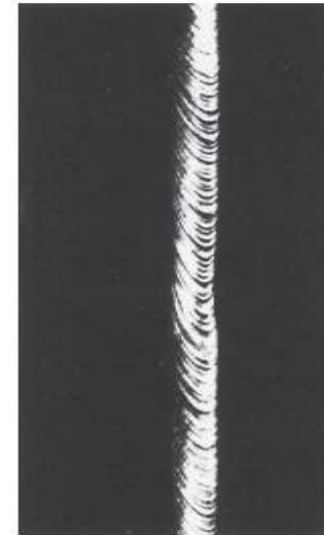
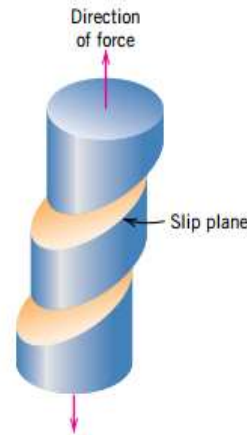
$$\text{area of plane}(110) = 8R^2\sqrt{2}$$

$$PD_{(110)} = \frac{\frac{1}{4} + \frac{1}{2} + \frac{1}{4} + \frac{1}{4} + \frac{1}{2} + \frac{1}{4}}{8R^2\sqrt{2}} = \frac{2}{8R^2\sqrt{2}}$$

$$PD_{(110)} = \frac{1}{4R^2\sqrt{2}}$$



- Linear and planar densities are important considerations relative to the process of *slip*—that is, the mechanism by which metals plastically deform. Slip occurs on the most densely packed crystallographic planes and, in those planes, along directions having the greatest atomic packing.

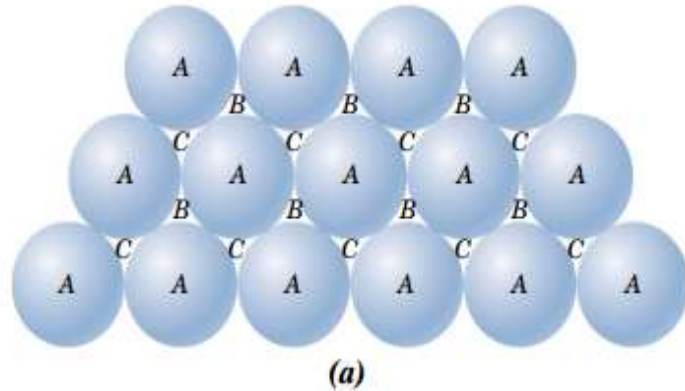


CLOSE-PACKED CRYSTAL STRUCTURES

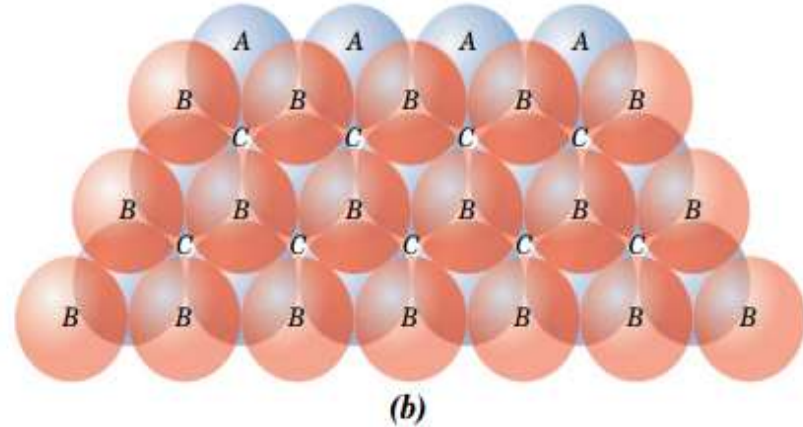
- Previously discussion on metallic crystal structures that both FCC and HCP crystal structures have atomic packing factors of 0.74.
- these two crystal structures may be described in terms of close-packed planes of atoms (i.e., planes having a maximum atom or sphere-packing density).



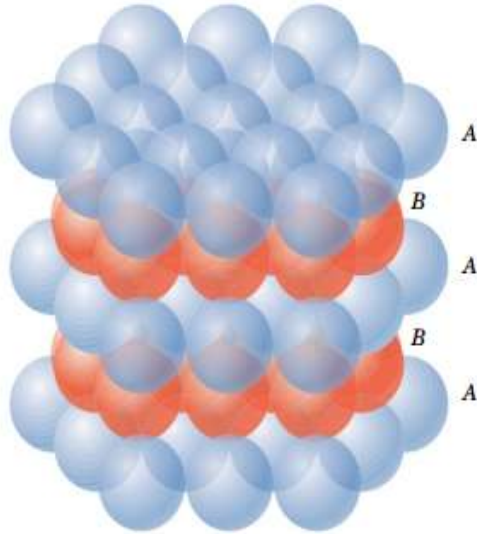
- Both crystal structures may be generated by the stacking of these close-packed planes on top of one another.
- the difference between the two structures lies in the stacking sequence.



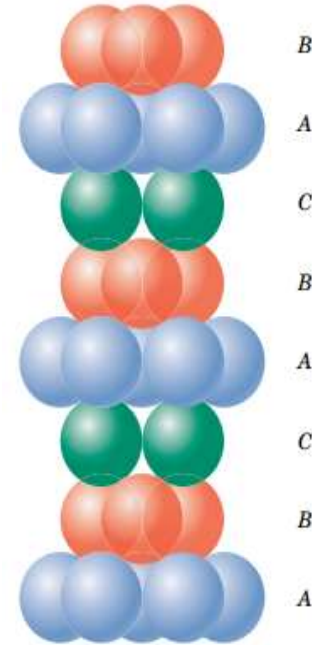
A portion of a close-packed plane of atoms; A, B, and C positions are indicated.



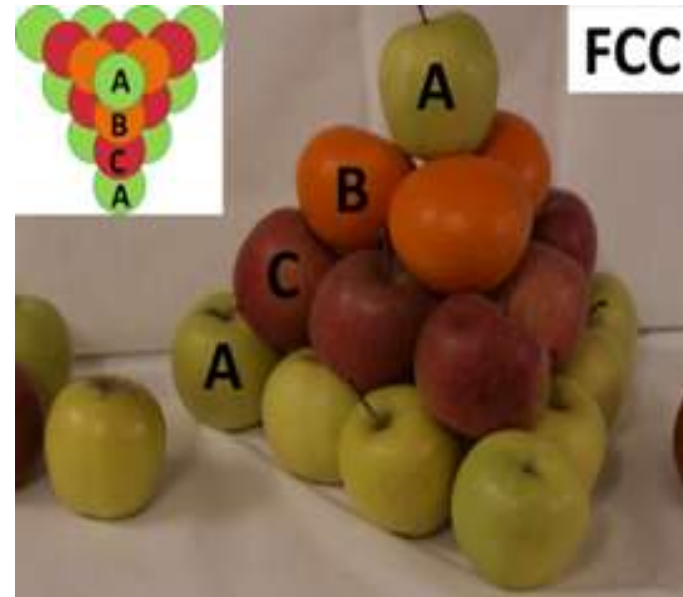
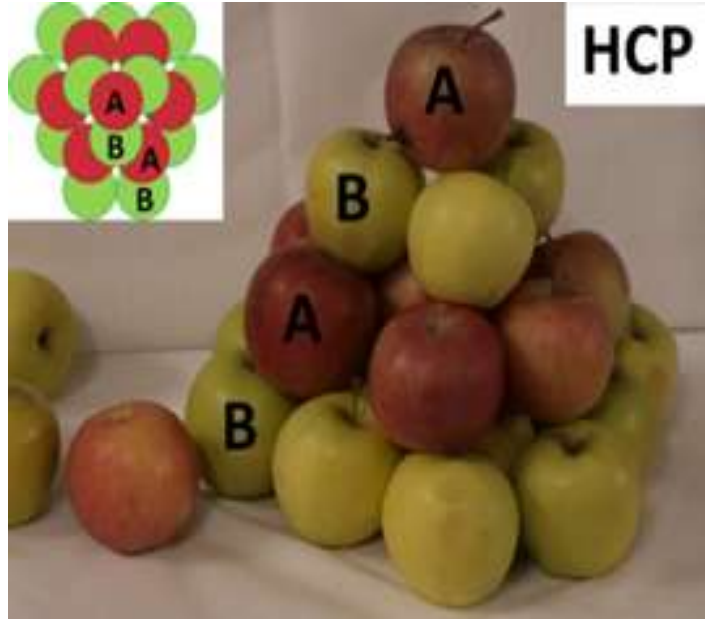
The *AB* stacking sequence for close-packed atomic planes.



Close-packed plane stacking sequence for the hexagonal close-packed structure.



Close-packed stacking sequence for the face-centered cubic structure.



Crystalline and Noncrystalline Materials

SINGLE CRYSTALS

- For a crystalline solid, when the periodic and repeated arrangement of atoms is perfect or extends throughout the entirety of the specimen without interruption, the result is a **single crystal**.
- All unit cells interlock in the same way and have the same orientation.
- Single crystals exist in nature, but they can also be produced artificially. They are ordinarily difficult to grow because the environment must be carefully controlled.
- single crystals are important in many modern technologies, in particular electronic microcircuits, which employ single crystals of silicon and other semiconductors.



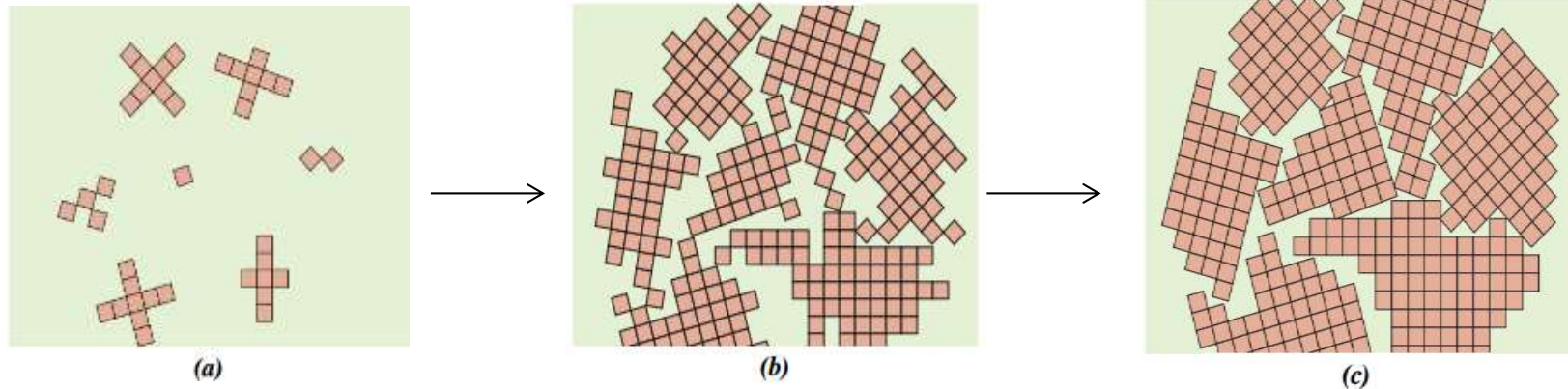
A garnet single crystal that was found China.

POLYCRYSTALLINE MATERIALS

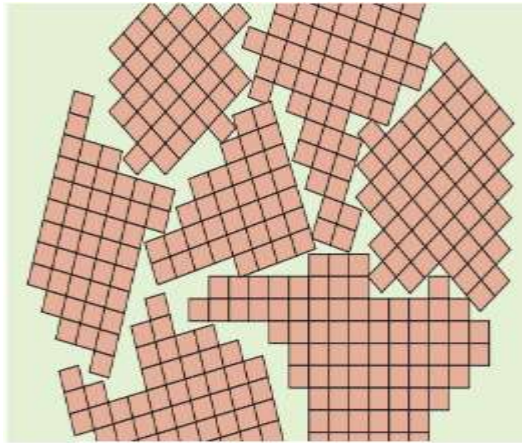
Most crystalline solids are composed of a collection of many small crystals or **grains**; such materials are termed **polycrystalline**.

Various stages in the solidification of a polycrystalline specimen are represented schematically in next slide :

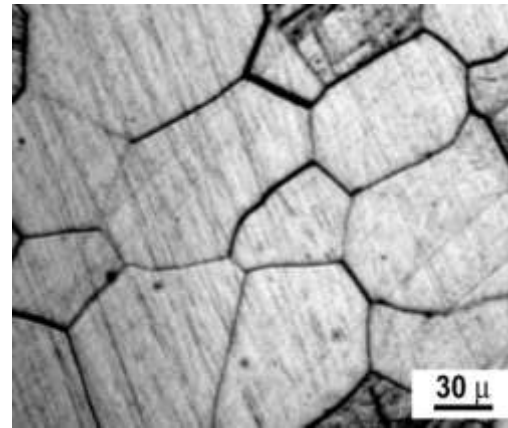
1. Initially, small crystals or nuclei form at various positions. These have random crystallographic orientations, as indicated by the square grids.
2. The small grains grow by the successive addition from the surrounding liquid of atoms to the structure.
3. The edges of adjacent grains touch on one another as the solidification process approaches completion.



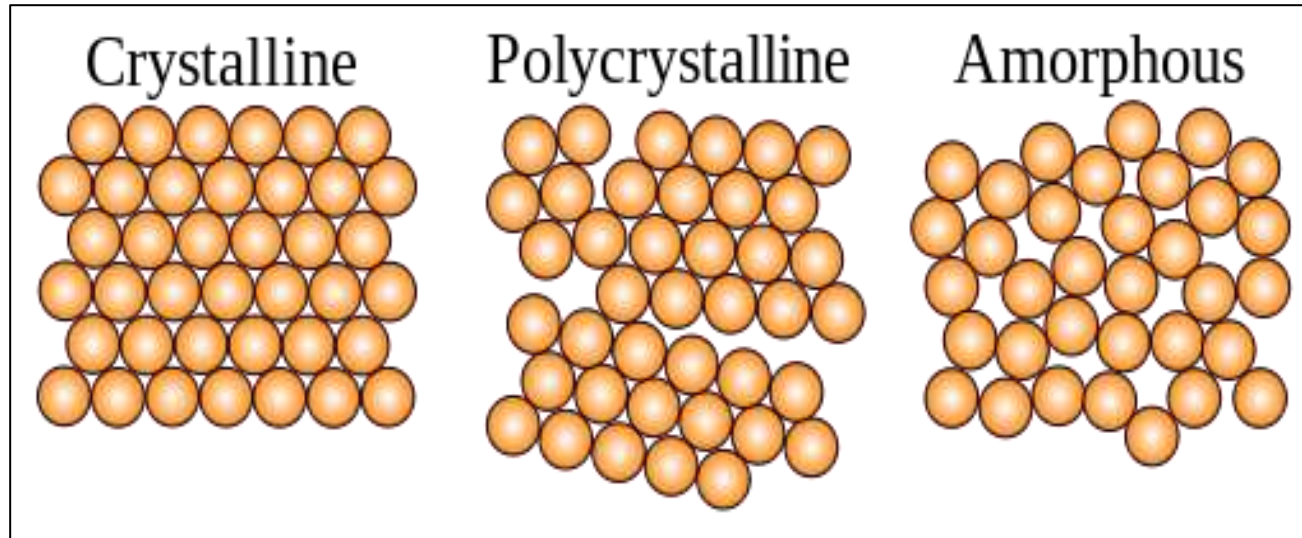
- the crystallographic orientation varies from grain to grain.
- Also, there exists some atomic mismatch within the region where two grains meet; this area, called a **grain boundary**.
- Figure (d) shows the grain structure as it would appear under the microscope; dark lines are the grain boundaries.

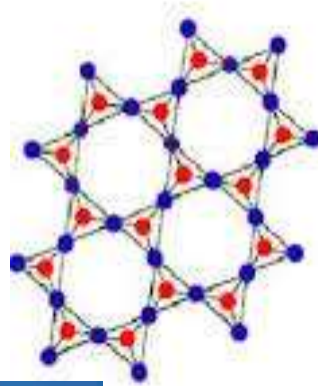
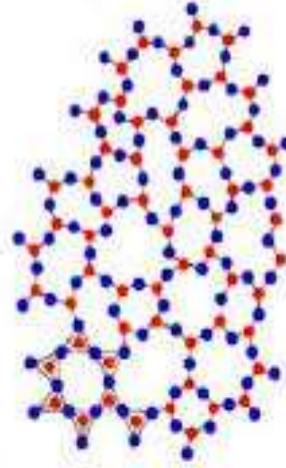


(c)



(d)



Crystalline SiO_2
(Quartz)Amorphous SiO_2
(Glass)

● Si ● O



ANISOTROPY

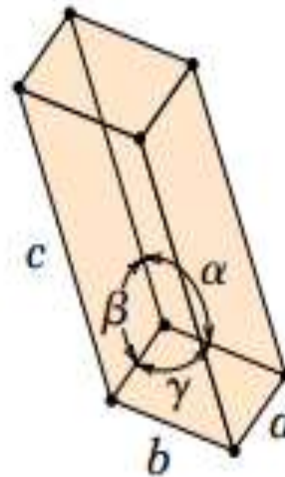
- The physical properties of single crystals of some substances depend on the crystallographic direction in which measurements are taken.

For example, the elastic modulus, the electrical conductivity, and the index of refraction may have different values in the [100] and [111] directions. This directionality of properties is termed **anisotropy**.

- Substances in which measured properties are independent of the direction of measurement are **isotropic**.

- The extent and magnitude of anisotropic effects in crystalline materials are functions of the symmetry of the crystal structure; the degree of anisotropy increases with decreasing structural symmetry

For example triclinic structures normally are highly anisotropic because triclinic structure are least symmetry where $a \neq b \neq c$ and $\alpha \neq \beta \neq \gamma$.

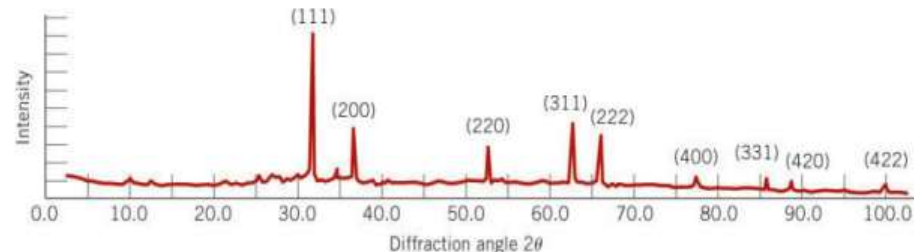
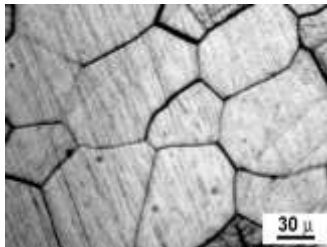


The modulus of elasticity values at [100], [110], and [111] orientations for several metals are presented in Table below.

<i>Metal</i>	<i>Modulus of Elasticity (GPa)</i>		
	<i>[100]</i>	<i>[110]</i>	<i>[111]</i>
Aluminum	63.7	72.6	76.1
Copper	66.7	130.3	191.1
Iron	125.0	210.5	272.7
Tungsten	384.6	384.6	384.6

Q) Explain why the properties of polycrystalline materials are most often isotropic.

For many polycrystalline materials, the crystallographic orientations of the individual grains are totally random. Under these circumstances, even though each grain may be anisotropic, a specimen composed of the grain aggregate behaves isotropically. Also, the magnitude of a measured property represents some average of the directional values. Sometimes the grains in polycrystalline materials have a preferential crystallographic orientation, in which case the material is said to have a “texture.”



Thank you for your attention

