

CHAPTER 1

Atoms and bonding

- The periodic table
- Ionic bonding
- Covalent bonding
- Metallic bonding
- van der Waals bonding

Atoms and bonding

- In order to understand the **physics of semiconductor (s/c) devices**, we should first learn **how atoms bond together to form the solids**.
- Atom is composed of a nucleus which contains protons and neutrons; **surrounding the nucleus are the electrons**.
- Atoms can combine with themselves or other atoms. The valence electrons, i.e. the **outermost shell electrons govern** the chemistry of atoms.
- Atoms come together and form gases, liquids or solids depending on the strength of the attractive forces between them.
- The atomic bonding can be classified as **ionic, covalent, metallic, van der Waals, etc.**
- In all types of bonding the **electrostatic force acts between charged particles.**

The periodic table

1A	2A							8A
Li	Be							He
Na	Mg		3A	4A	5A	6A	7A	Ne
K	Ca		B	C	N	O	F	Ar
Rb	Sr	2B	Al	Si	P	S	Cl	Kr
Cs	Ba	Zn	Ga	Ge	As	Se	Br	Xe
Fr	Rd	Cd	In	Sn	Sb	Te	I	Rn
		Hg	Ti	Pb	Bi	Po	At	

Groups 3B,4B,5B,6B
7B,8B,1B lie in here

A section of the periodic table

The periodic table

- Ionic solids

Group 1A (alkali metals) contains lithium (Li), sodium (Na), potassium (K),...and these combine easily with group **7A** (halogens) of fluorine (F), chlorine (Cl), bromine (Br),.. and produce ionic solids of NaCl, KCl, KBr, etc.

- Rare (noble) gases

Group 8A elements of noble gases of helium(He), neon (Ne), argon (Ar),... have a full complement of valence electrons and so do not combine easily with other elements.

- Elemental semiconductors

Silicon(Si) and germanium (Ge) belong to **group 4A**.

- Compound semiconductors

1) **III-V** compound s/c's; GaP, InAs, AlGaAs (**group 3A-5A**)

2) **II-VI** compound s/c's; ZnS, CdS, etc. (**group 2B-6A**)

Covalent bonding

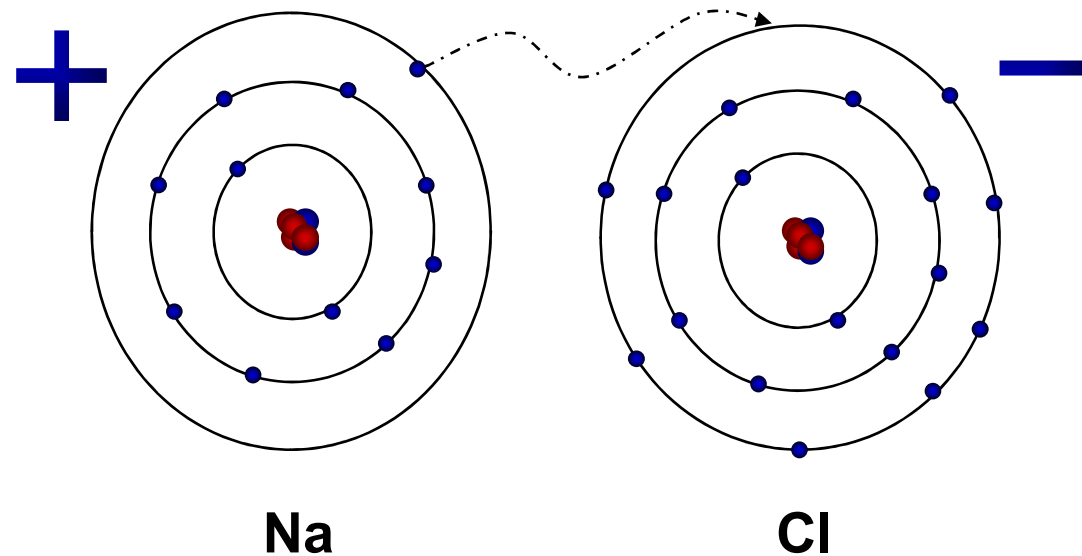
- Elemental semiconductors of Si, Ge and diamond are bonded by this mechanism and these are purely covalent.
- The bonding is due to the sharing of electrons.
- Covalently bonded solids are hard, high melting points, and insoluble in all ordinary solids.
- Compound s/c's exhibit a mixture of both ionic and covalent bonding.

Ionic bonding

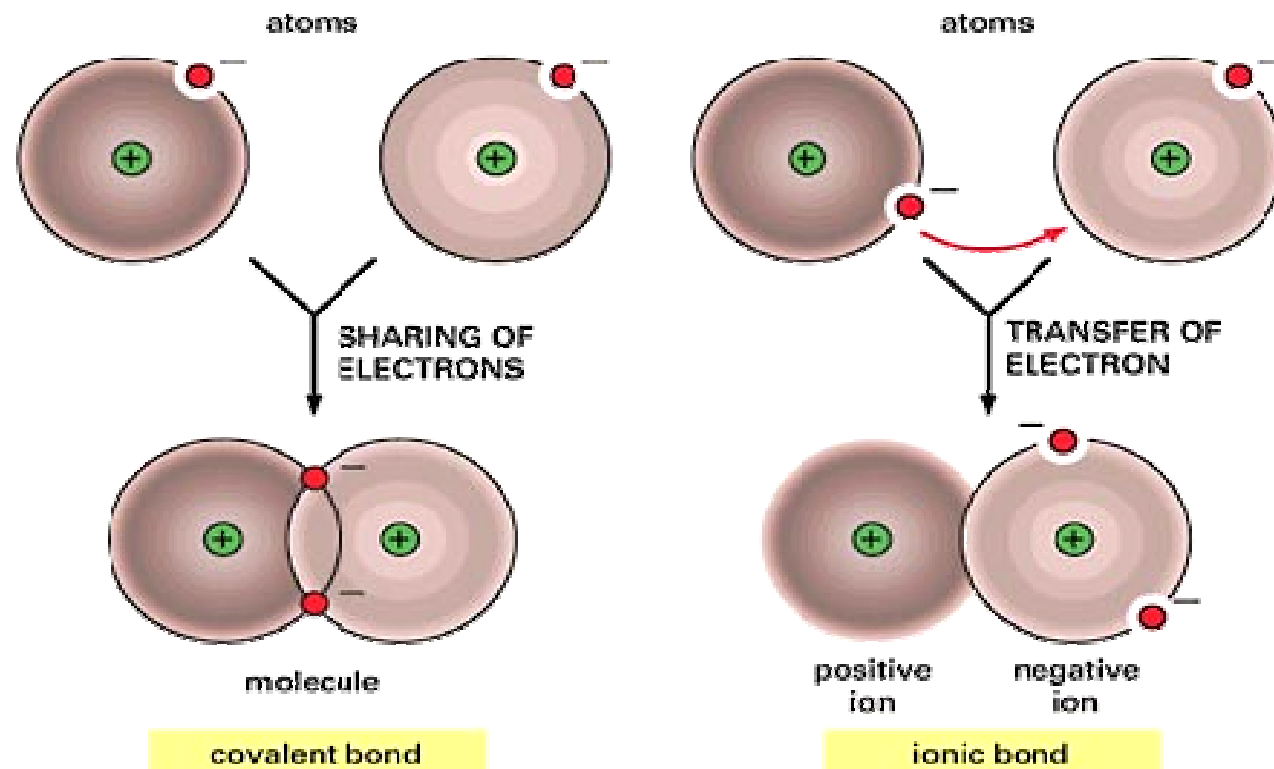
- Ionic bonding is due to the **electrostatic force of attraction between positively and negatively charged ions** (between 1A and 7A).
- This process leads to electron **transfer and formation of charged ions**; a **positively** charged ion for the atom that has **lost the electron** and a **negatively** charged ion for the atom that has **gained an electron**.
- All ionic compounds are **crystalline solids** at room temperature.
- **NaCl and CsCl** are typical examples of ionic bonding.
- Ionic crystals are hard, high melting point, brittle and can be dissolved in ordinary liquids.

Ionic bonding

The metallic elements have only up to the valence electrons in their outer shell will lose their electrons and become positive ions, whereas electronegative elements tend to acquire additional electrons to complete their octet and become negative ions, or anions.

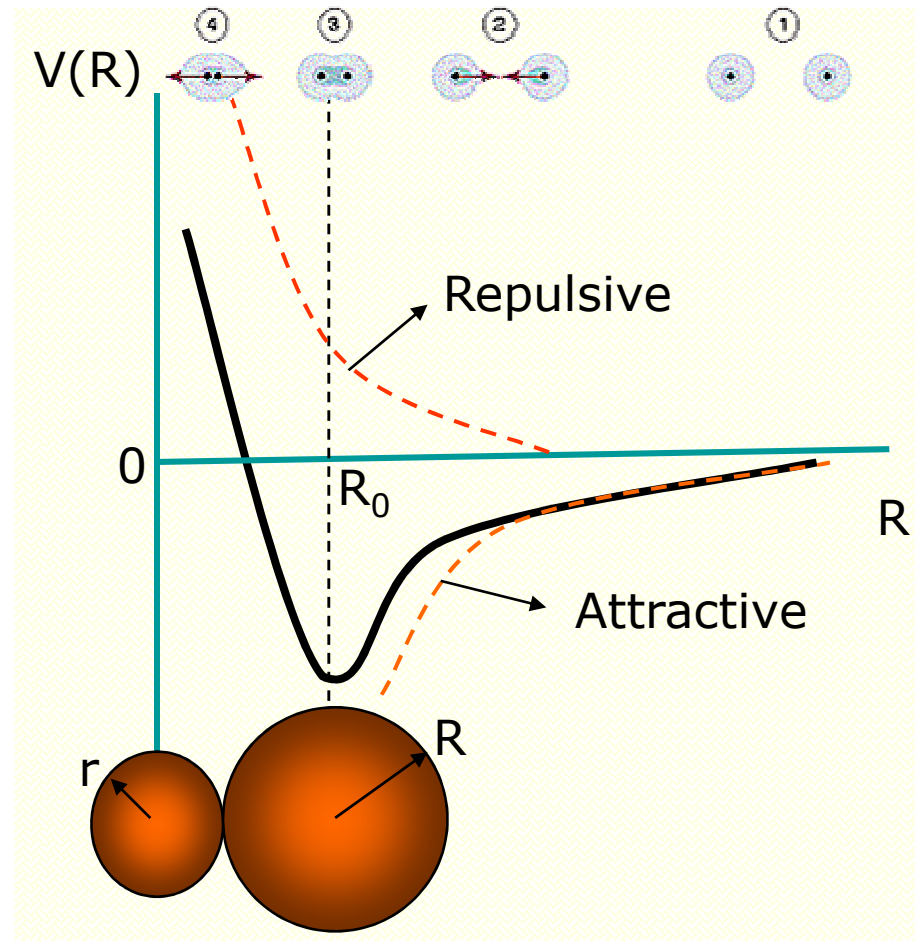


Comparison of Ionic and Covalent Bonding



Potential energy diagram for molecules

- This typical curve has a minimum at equilibrium distance R_0
- $R > R_0$;
 - the potential increases gradually, approaching 0 as $R \rightarrow \infty$
 - the force is attractive
- $R < R_0$;
 - the potential increases very rapidly, approaching ∞ at small radius.
 - the force is repulsive

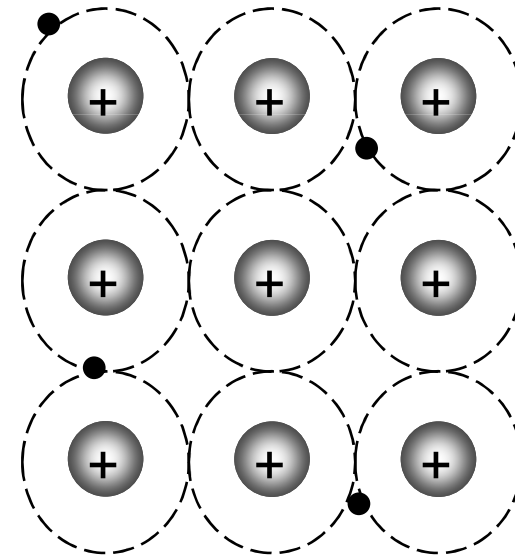


Metallic bonding

❖ Valance electrons are relatively bound to the nucleus and therefore they move freely through the metal and they are spread out among the atoms in the form of a low-density electron cloud.

❖ A metallic bond result from the sharing of a variable number of electrons by a variable number of atoms. A metal may be described as a **cloud of free electrons**.

❖ Therefore, metals have high electrical and thermal conductivity.



Metallic bonding

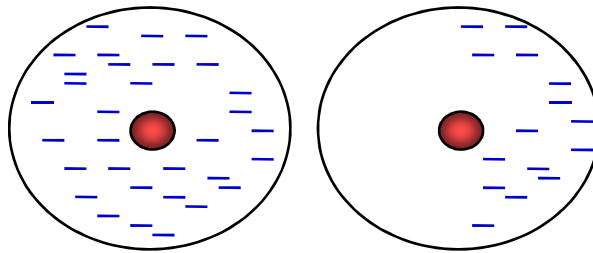
- All valence electrons in a metal combine to form a “sea” of electrons that *move freely between the atom cores*. The more electrons, the stronger the attraction. This means the melting and boiling points are higher, and the metal is stronger and harder.
- The *positively charged cores* are held together by these *negatively charged electrons*.
- The free electrons act as the bond (or as a “glue”) between the positively charged ions.
- This type of bonding is nondirectional and is rather insensitive to structure.
- As a result we have a high ductility of metals - the “bonds” do not “break” when atoms are rearranged – metals can experience a significant degree of plastic deformation.

van der Waals bonding

- It is the **weakest bonding** mechanism.
- It occurs between neutral atoms and molecules.
- The explanation of these weak forces of attraction is that there are **natural fluctuation in the electron density** of all molecules and these cause small temporary dipoles within the molecules. It is these **temporary dipoles that attract one molecule to another**. They are as called van der Waals' forces.
- Such a weak bonding results low melting and boiling points and little mechanical strength.

van der Waals bonding

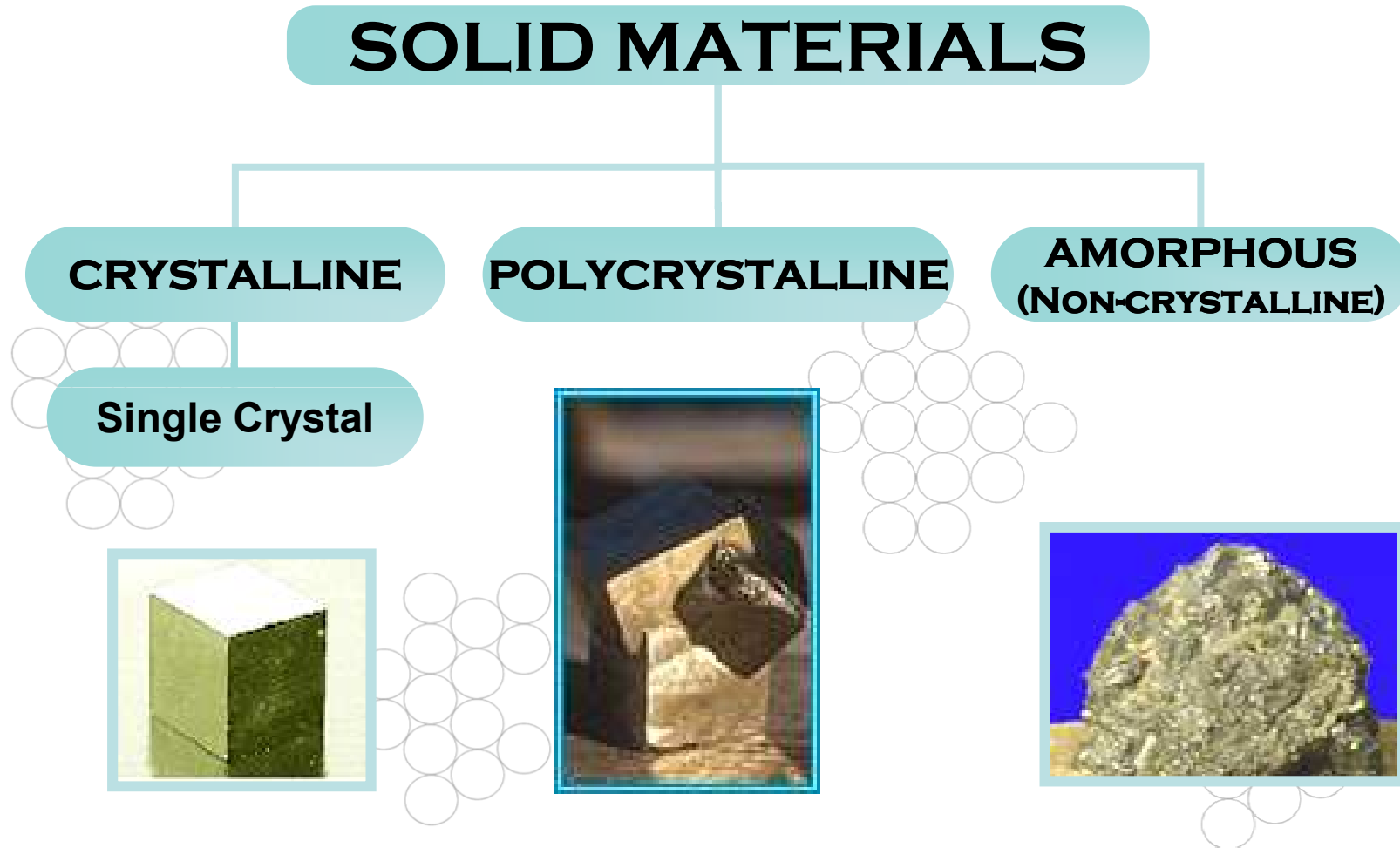
The dipoles can be formed as a result of **unbalanced distribution of electrons in asymmetrical molecules.** This is caused by the instantaneous location of a few more electrons on one side of the nucleus than on the other.



symmetric asymmetric

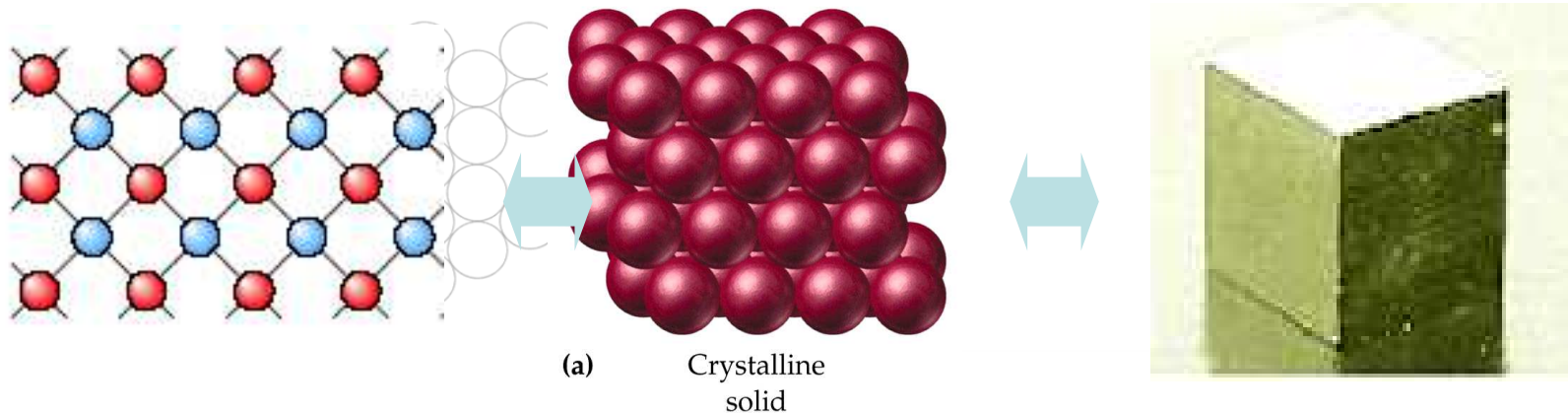
Therefore atoms or molecules containing **dipoles are attracted to each other by electrostatic forces.**

Classification of solids



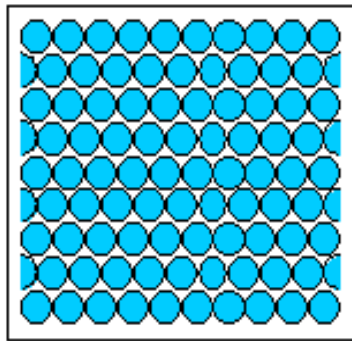
Crystalline Solid

- Crystalline Solid is the solid form of a substance in which the atoms or molecules are arranged in a definite, repeating pattern in three dimension.

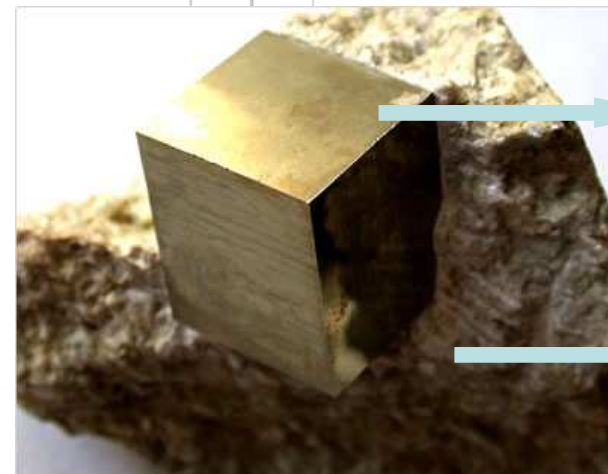
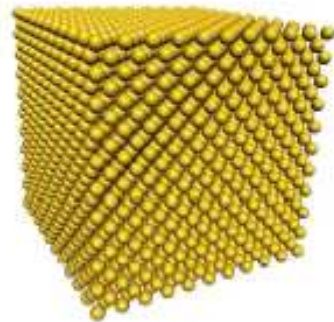


Crystalline Solid

- Single crystal has an atomic structure that repeats periodically across its whole volume. Even at infinite length scales, each atom is related to every other equivalent atom in the structure by translational symmetry



Single Crystal

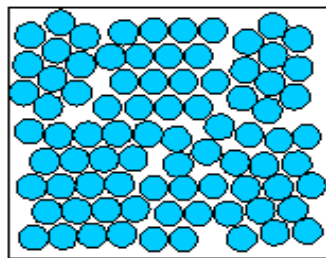


Single Pyrite
Crystal

Amorphous
Solid

Polycrystalline Solid

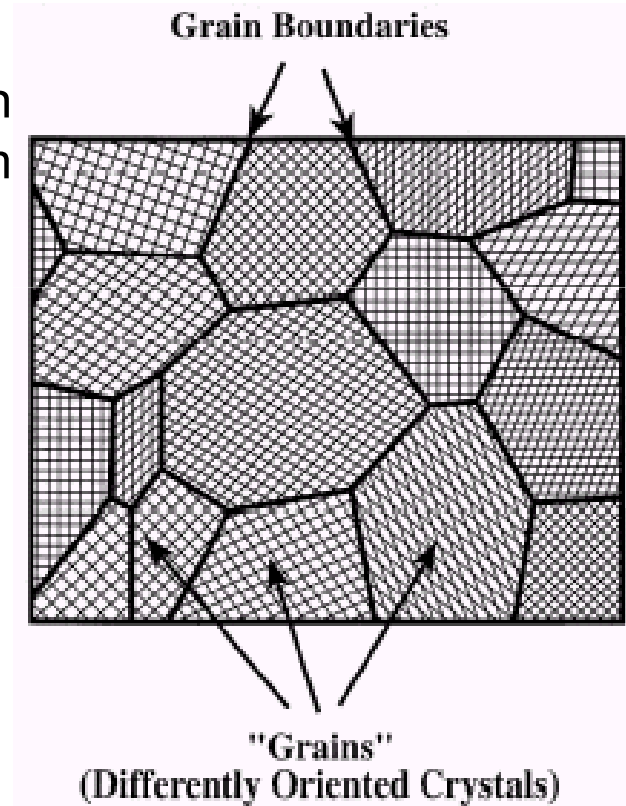
- Polycrystal is a material made up of an aggregate of many small single crystals (also called crystallites or grains).
- The grains are usually 100 nm - 100 microns in diameter. Polycrystals with grains that are <10 nm in diameter are called *nanocrystalline*



Polycrystal



Polycrystalline
Pyrite form
(Grain)



Amorphous Solid

- Amorphous (non-crystalline) Solid is composed of randomly orientated atoms, ions, or molecules that do not form defined patterns or lattice structures.

