

LIGHT EMITTING DIODES

Solids are classified as metals, semi-metals, or non-metals by their ability to conduct heat and electricity. "Band theory" is a bonding model for solids that explains conductivity by assuming a higher energy level exists above the valence electron level called the "conduction band". The theory assumes electrons in the conduction band are not attached to individual atoms (localized) but move freely throughout the entire solid (delocalized). In a metal the delocalized electrons in the conduction band behave like a "sea of electrons" which "surges" throughout the solid, forming an electrical current.

The **band gap** is the energy needed to promote an electron from the lower energy **valence band** into the higher energy **conduction band** (Figure 1). The band gap in metals is very small. Ordinary thermal energy (present at room temperature) promotes the valence electrons to the conduction band where they move freely about the metal. Therefore, metals are called "conductors" because they easily carry current. In non-metals the band gap is very large and electrons seldom have enough energy to cross from the valence level to the conduction band. Therefore, non-metals are called "insulators" because they carry no electrical current. In semi-metals, the band gap is moderately wide, so under certain conditions, electrons are promoted into the conduction band resulting in a current. This is why semi-metals are often referred to as "semi-conductors".

A factor affecting band gap size in semi-metals is interatomic distance (and the related strength holding electrons in the valence level). Assuming that atoms in a solid are so densely packed that they are touching, the distance between two atoms is proportional to the sum of their atomic radii. So if the relative size of atoms is known, we should be able to discover whether band gap energy will increase or decrease with interatomic distance.

Gallium phosphorus arsenide ($\text{GaP}_x\text{As}_{1-x}$, where $0 \leq x \leq 1$), a semi-conducting material in the form of light emitting diodes (LEDs), are an example of a "solid solution" – a homogeneous mixture of elements crystallized into a solid. The stoichiometry of a solid

solution varies just like solution concentration, hence the unusual formula, $\text{GaP}_x\text{As}_{1-x}$. The fractional formula represents the probability of finding P or As atoms around the central Ga atoms. For example, in $\text{GaP}_{0.40}\text{As}_{0.60}$, there is a 40% chance of finding phosphorus atoms and a 60% chance of finding arsenic atoms at tetrahedral sites around gallium. As the phosphorous – arsenic ratio changes, so do the properties of the semiconductor.

The light color emitted by the $\text{GaP}_x\text{As}_{1-x}$ diodes is indicative of the magnitude of energy needed for an electron to cross the band gap. After an electron is excited (by heat or electricity) into the conduction band, its return to the lower energy valence band causes a release of a photon of light (Figure 1).

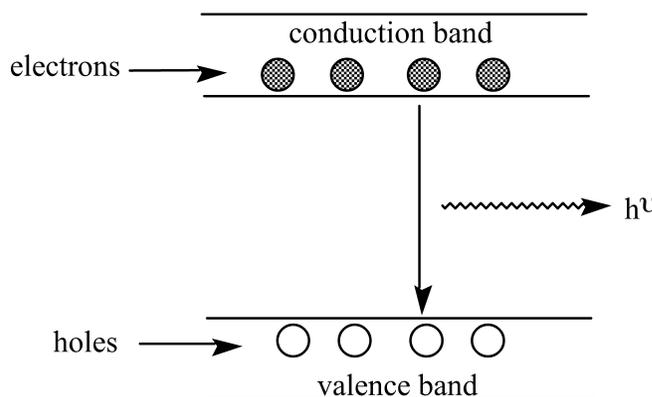


Figure 1: Electron passing from conduction band to the valence band releases energy. If the photon of light has a wavelength in the visible range, "colored" light is observed.

The energy of the photon ($E = h\nu = hc/\lambda$; where E = energy, h = Planck's constant, ν = frequency of light, c = speed of light, and λ = wavelength of light) is directly related to the band gap size. The relationship between light color (energy) and band gap of an LED is demonstrated in Table 1 below.

Table 1: Relationship between LED Color, Wavelength and Energy of Light.

Color of Light	Wavelength (nm)	Energy (eV & kJ/mol)
Violet	410	3.0 (290)
Blue	480	2.6 (250)
Green	530	2.3 (225)
Yellow	580	2.1 (205)
Orange	610	2.0 (195)
Red	680	1.8 (175)

The voltage change (drop) through the LED can also be used to measure band gap size. Voltage is a product of current and resistance ($V = iR$). The electrons in the current entering the LED must overcome the band gap (cross from the valence band to the conduction band) to be part of the current leaving the LED. Therefore, a voltage change ($\Delta V = V_f - V_i = (i_f - i_i)R$) occurs as current passes through the LED.