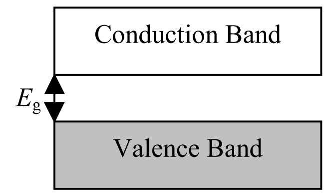
PHYS 210
Spring 2006
Semiconductors

Semi-conductors probably had a larger impact on our society than any other materials discovery in the 20th century. The wide utility of semiconductors lies in the ability to tailor their electrical properties.

1. Undoped Semiconductors



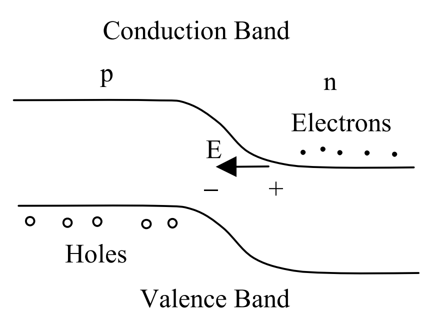
The energy levels of an un-doped semiconductor or an insulator are shown on the right. As in any solid, electron energy levels are merged into continuous bands. The valence band contains as many electrons as allowed by the Fermi exclusion principle while the conduction band is empty. Electrical conductivity results from electrons moving from occupied to unoccupied energy states, so in this state the material in insulating. The difference between semi-conductors and insulators is that in semi-conductors the energy gap E_g between the two bands is relatively small, about 1 eV. A small fraction of the electrons (about $\exp(-kT/E_g)$) are thermally excited to the conduction band where they can participate in current flow. As a result, semi-conductors have an intermediate resistively that depends exponentially on temperature. The thermistors we used in the temperature measurement lab use that type of material.

2. Doped semiconductors

Semiconductor materials, such as Si, are often doped with elements that have either one more or one less electron in the outer shell. For example, Ga has 3 valence electrons, one less than Si. When added to a Si crystal it produces "holes" – unoccupied electron states in the valence band. Similarly, As has 5 valence electrons and the extra electrons have to go into the conduction band. As a result, doped materials have much higher electrical conductivity than pure Si. The electric current can be carried either by electrons (n-type semiconductor) or holes (p-type semi-conductor).

3. p-n-Junction

A p-n junction is formed by bringing two doped semi-conductors together. Initially, electrons and holes diffuse into the other material due to the gradient in their concentration. However that sets up a charge imbalance that creates an electric field and eventually stops diffusion of the charge carriers. An applied voltage can either increase or decrease this electric field. When the external voltage reduces the electric field, the p-n junction can conduct electric current. Thus, the p-n junction works as a diode, i.e. conducts current only in one direction. p-n junctions can also convert light to electricity and vise versa. If the electrons and holes recombine they release energy equal to the band gap. This energy can be emitted as a photon. Conversely, an electron-hole pair can be created by a photon.



4. Schottky Diode

A diode can also be formed on an interface of a semi-conductor and a metal. The properties of the interface depend on the work-function of the metal. If the top energy level of the electrons filling the conduction band in the metal falls in between the two bands of the semiconductor the junction acts as a diode. Schottky junctions are easy to fabricate and they can often be used in place of p-n junctions. We will fabricate a solar cell using a Au-Si junction.

5. Diode lasers

As mentioned above, electron-hole recombination can result in emission of photons. Light-emitting diodes let the photons simply escape the semi-conductor. It is also possible to construct a diode laser by recycling the photons in a cavity. The basic layout of a laser is shown in the figure on the right. The photons bounce between the mirrors and stimulate additional photon emissions in the same direction. This is a consequence of Bose-Einstein condensation, photons prefer to occupy the same state. The light forms a standing wave in the cavity and some fraction of it escapes through the mirror, forming the output laser beam. For laser diodes the entire cavity is about 100 μm long.