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SEMICONDUCTORS

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Abstract. In this article, we have explained about semiconductors, their types and their properties with scientifically based results.

Semiconductors are materials that have properties in between normal conductors (materials that allow electric current to pass, e.g. aluminium) and insulators (which block electric current, e.g. sulphur).

Semiconductors fall into two broad categories. First, there are intrinsic semiconductors. These are composed of only one kind of material. Silicon and germanium are two examples. They are also called "undoped semiconductors" or "i-type semiconductors".

Extrinsic semiconductors are made of intrinsic semiconductors that have had other substances added to them to alter their properties.

Intrinsic Semiconductors. Every atom consists of a nucleus surrounded by a number of electrons. Only the electrons are involved in electronic processes. The electrons can exist only in certain electron shells around the atom. There are many shells in each atom.

It requires energy to get an electron from a shell close to the nucleus to one further away, and if an atom's electrons are in a position which is not the position with least energy (i.e. they are in a higher (further from nucleus) shell and there is space in a lower shell), energy is given up so the electrons "fall" into the inner shells. Thereby, the shells closest to the nucleus are filled first, and then the next closest and so on. It requires more energy for an electron in a shell that is close to its nucleus to fill an outer shell than it is for an electron on an outer shell to fill an inner shell, so the inner shell is filled first.

We will consider our material to be arranged in a lattice, which is a regular arrangement, like a crystal. This helps to describe and explain the principles. In the lattice, each electron can "see" every atom in the entire lattice, and therefore is not just affected by the presence of electrons in its own atom, but by all the other atoms in the material. The huge number of atoms (usually greater than one thousand billion billion in a cube 1mm on a side) means that the number of electrons in each shell of each atom is not important - the shells "merge" into bands. All that matters is that if that band is filled, partially filled or empty. The size of bands and the gaps between them is determined by the nature of the material.

In a lattice, there will be a set of filled bands, with a full complement of electrons and unfilled bands which have no electrons (because they are in the lower-energy filled bands). The highest energy band with electrons in it is called the valence band, from the chemists' term "valence electrons" which are the electrons on the outermost shell of the atom which are responsible for chemical reactions. The conduction band is the band above the valence band. Electrons in the conduction band are free to move about in the lattice, and can therefore conduct current. The energy gap between the valence and conduction band is called the band gap. Every material has associated with it a Fermi energy. Imagine the bands "filling up" from the bottom up, like water poured into a container. The continuous nature of the filling arises from the fact that there is such a large number of electrons they are essentially infinite in number. This behavior does not happen in a single atom, as the small number of electrons means that the amount of energy is heavily quantized. The Fermi energy is the level of the top of the "sea" that is formed. This is defined at absolute zero, when there is no thermal energy to allow the electronics to form "ripples" on the sea.

In insulators, the Fermi level lies between the valence and conduction bands, in one of the "forbidden zones" where electrons cannot exist. Thus all electrons in the lattice are in the valence band or a band under that. To get to the conduction band, the electron has to gain enough energy to jump the band gap. Once this is done, it can conduct. However ,the band gap for insulators is large (over 3 eV) so very few electrons can jump the gap. Therefore, current does not flow easily in insulators.

In metals, the conduction band and the valence band overlap or the valence band is only partially full, both with the Fermi energy somewhere inside. This means that the metal always has electrons that can move freely and so can always carry current.

In semiconductors, the Fermi energy is between the valence and conduction band, but the band gap is smaller, allowing electrons to jump the gap fairly easily, given the energy to do it. At absolute zero, semiconductors are perfect insulators, but at room temperature, there is enough thermal energy to allow occasional electron jumps, given the semiconductor limited conductivity, even though, by rights, it should be an insulator.

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If there are no electrons in the conduction band of a semi-conductor it won't conduct. To move electrons out of the valence band and into the conduction band, one needs to give them energy. This may be through heat, incident light or high electric field. As most semiconductors operate at non-zero temperature, there are generally some electrons in the conduction band. This also means that if the semi-conductor gets too hot (125°C for silicon), excess electrons will exist in the conduction band, hence the semi-conductor will act more like a conductor.

Because intrinsic semiconductors contain no "extra" electrons from impurities like extrinsic semiconductors do, every time an electron jumps the band gap, it leaves a hole behind. This hole represents a positive charge as it is the lack of an electron. Intrinsic semiconductors have exactly equal numbers of holes and electrons, so, where n is the number of electrons and p is the number of holes.

Direct and Indirect Semiconductors. The total energy of an electron is given by its momentum and its potential energy. To move an electron from the conduction band to the valence band, it may need to undergo a change in potential energy and a change in momentum. There are two basic material types, in-direct and direct band gap materials. In an indirect band gap material, such as silicon, shown in figure 4, to move into the valence band, the electron must undergo a change in momentum and energy[1]. The chance of this event is small. Typically this process is achieved in several steps. The electron will first move to a trap site in the forbidden band before moving into the valence band. A change in potential energy will result in the release of a photon, while a change in momentum will produce a phonon (a phonon being a mechanical vibration which heats the crystal lattice).

In a direct band-gap material such as GaAs, only a change in energy is required, as seen in figure 5. As such GaAs is very efficient at producing light, although in the infrared spectrum.

Extrinsic Semiconductors. One may also dope the semiconductor material. Semi-conductor materials are doped with impurities chosen to give the material special characteristics. One may want to add extra electrons or remove electrons.

Doping atoms are chosen from elements in group III or V of the periodic table which are similar in size to silicon atoms. Thus individual intrinsic semiconductor atoms may be replaced with dopant atoms to form an extrinsic semi-conductor. The binding energy of the outer electron added by the impurity is weak. This is represented by placing the excess electrons just below the conduction band. Thus very little energy is required to move these electrons into the conduction band. Thus an extrinsic semi-conductor operating at room temperature will have most of these "extra" electrons existing in the conduction band. Thus at normal operating temperature,

$n_c \approx N_d$

Where n_c is the number of conduction electrons and N_d is the number of dopant atoms.

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