



Semiconductors: An Investigational Study

Muna Farhan Abed Aladwan
The Ministry of Education, Amman, Jordan

Abstract

Semiconductors are defined as insulating materials at low temperatures but have a certain degree of electrical conductivity at high temperatures. Solids can be divided into three insulating, semiconducting and conductive classes. The conductivity of the semiconductor is influenced by heat, light and magnetic field, and is influenced by the presence of small quantities of impurity atoms. The conductivity of a substance depends on the number of electrons present per unit volume of matter and increases the conductivity by increasing that number.

Keywords: Semiconductors, Connectivity, Education, Teaching.

Introduction

Matter usually consists of the binding of millions of atoms to each other. When these atoms are bound, the energy levels of the electrons turn into an energy band (the electrons are allowed to exist and are separated by energy energies) called the blocked energy nerve, which contains energy levels that electrons can never occupy.

The excitement of an atom, which means adding energy to it, enables electrons to climb this energy gap and move toward a nerve that is farther away from the nucleus.

The most distant energy band in an excited atom is called the valence band. If a certain amount of energy is added to this atom, the electrons in the valence band can jump into the Conduction Band. They appear relatively free to move within matter without belonging to any particular atom. Figure 1 illustrates the nerve of equivalence, conductivity and the energy gap that separates them from each other.

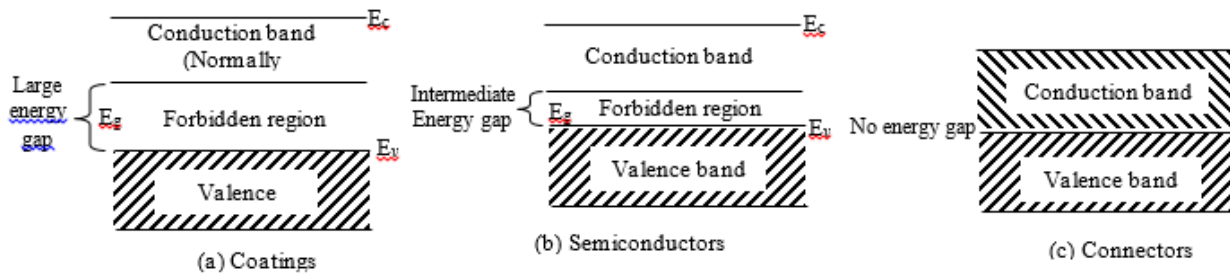


Figure (1)

The distance or energy gap separating the valence from the conductivity is the main measure of the electrical behavior of these materials. Some materials are characterized by a wide energy gap, which means that it is impossible to transfer electrons from the valence to the conductivity, unless a relatively large amount of energy is applied. These materials are known as electrically insulating materials (Fig. 1, a). On the other hand, there are some materials in which the valence band interferes with the conductivity band, which we call electrical conductors (Fig. 1, c) where there are large numbers of electrons in the conductivity band. Between these two types there is a type of material in which the energy gap is the middle between insulators and conductors, and such elements we call semiconductors (Fig. 1, b).

Note: The energy gap is the difference between the energy of the bottom of the conductivity band (E_c) and the top of the valence league (E_v): $[E_g = E_c - E_v]$.

We discussed previously the classification of materials in a simplified way and now we will do some necessary details to complete the understanding that electrons move within the crystals of elements in a movement associated with the crystal structure of the materials. If the conductivity band at absolute zero ($T = 0$) was completely empty of electrons and the valence band was full, the crystal was dielectric. This characteristic of insulating materials persists even when the temperature is raised, because the thermal energy ($K_B T$) [where: K_B Boltzmann constant] is insufficient to transfer the electron from the valence band to the conduction band and make it free, due to the large prohibited field (E_g). However, due to the relative smallness of the prohibited field in the semiconductor (1 to 3) electron volts, some electrons are thermally irritated and are transmitted from the valence band to the conduction band with a probability proportional to $(e^{-E_g/2K_B T})$. Conductivity electrons in the conductivity band and free holes in the valence league and the probability of transition increases with the temperature increase unlike in metals.

Semiconductors represent simple chemical elements such that there are twelve elements in the periodic table: (B, C, Si, P, S, Ge, As, Se, Sn, Sb, Te, I and binary or triple chemical compounds such as...). GaP, AlSb, CuCl, AgCl) There are some organic materials that have semiconductor properties such as (benzol, naphthalene ...).

Element	B	C	Si	P	S	Ge	As	Se	Sn	Sb	Te	I
Atomic number	5	6	14	15	16	32	33	34	50	51	52	53
Display the blocked field (E_g) eV	1	5.6	1.16	1.5	2.4	0.74	1.15	1.8	0.08	0.1	0.35	1.35

Materials can also be classified according to electrical resistivity (specific resistance):

Subject	Connectors (metal)	Semiconductors	Insulators
Resistivity ($\Omega \cdot m$)	10-8 to 10-6	From 10-5 to 810	Greater than 810

Pure Semiconductor Intrinsic Semiconductor

Semiconductors that have no impurities in them are called pure semiconductors and any electrical conductivity in which pure, actual or subjective conductivity can occur.

At room temperature, some parabolic bonds are shattered by thermal energy. When this happens, the electrons caused by breaking these bonds will move toward the conductivity band, where they can move randomly within the crystalline structure. If they are subjected to the influence of an external electric field, these electrons create a problem known as electric current.

When an atom loses a valence electron, it produces an incomplete parity bond. The location of this missing valence electron is called a hole. This hole represents the positive charge carrier because the reason for its formation is the loss of a negative electrical charge is the charge of the electron. However, we must emphasize that the hole is not an object like an electron, but its positive electrical charge can move, resulting in an electric current.

Now let's assume that a valence electron has been able to move to fill this hole, and there is no longer a hole. The electron that filled this hole left behind a vacuum in the parity bond that it left, meaning a new hole in it. Thus, the valence electron has moved to fill the hole or to say that the hole has moved to the place where the valence electron is located.

The question now is why we have taken into account the concept of piercing when we can only talk about the movement of electrons. To answer this question we must distinguish between the movement of the electron and the movement of the hole. The electrons that connect their movement to the movement of the hole are equivalent electrons, while the movement of electrons in the League of conductivity of any movement of the holes. Take, for example, the movement of an electron in the conduction band when it is subjected to the influence of an external voltage, that this electron is not under the influence of any atom and therefore it moves freely responsive to the impact of this external voltage. The situation for a valence electron is quite different, as it is at a level of energy that cannot move to the conduction band but can move towards a nearby hole, so its movement is more restrictive than that of the conduction electrons. In fact, the valence electron will move less than the displacement of the conductivity electron when the same external voltage is applied to them as shown in Figure 2, allowing us to say that the electron conductivity is more dynamic than the holes.

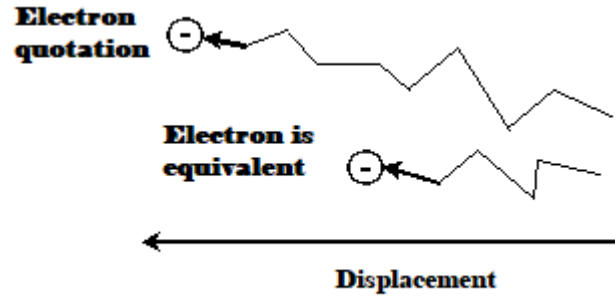


Figure (2)

Many parabolic bonds break down at room temperature and each time this happens a pair of electron-hole will be generated. The hole and the electron are both carriers of charge. If applied to them an electric field, they move the problem of electric current. Thus, this actual conductivity occurs as a characteristic of pure matter and is not due to any additions to external impurities.

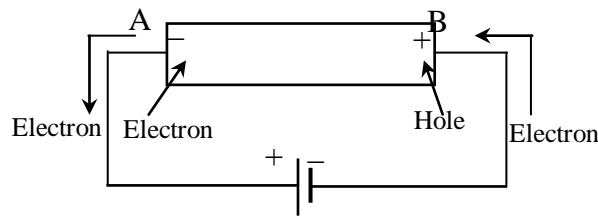


Figure (3)

As an example of the actual conductivity, let's take a column of semiconducting material as shown in Figure 3, showing only the movement of an electron and a hole, even though it contains millions of them for simplification. The following process is performed:

1. The conductor electrons inside the column are pulled towards point (A), where the conduction wire is connected to the positive terminal of the battery. Additional electrons leave the negative terminal of the battery and enter the rod from terminal (B). The clock.
- 2 - The holes inside the column are attracted towards point (B) and as soon as it is modified by the electrons entering from the wire near this point, which is known as recombination (at the same moment that many of the valence electrons near point (A) break their bond Parabolic and plug-in wire are oriented towards the positive end of the battery. Breaking the parity bond enriches the process of generating electric charges (Generation), resulting in electrons and holes, so many holes appear at point (A) and move towards point (B) where they disappear. As a result, there is a stream of holes running in the circuit clockwise.
3. There is a continuous process of reproduction and recombination of electrons and holes, but in reality there are no holes running in the circuit outside the conductor. The holes that disappear at point (B)

represent the electrons that enter this point, while the holes that appear at point (A) represent the electrons that leave and as long as our focus is on the outer circuit, the total current is due to the flow of electrons clockwise, as if the semiconductor rod represents a simple resistance. Within this rod, the total current can be attributed to two basic components: the flow of both electrons and holes.

The presence of impurities and defects affects the potential energy in the crystalline network and thus lead to the emergence of additional energy levels allowed and present within the restricted field (E_g). These levels can be triggered by electrons excited by the valence league, and the electrons of defects and impurities levels can be transmitted by heat excitation to the conduction gang and contribute to the conductivity. Therefore the presence of impurities and defects changes the overall picture of the conductivity of semiconductors.

Actual conductivity (pure) occurs at temperatures high enough to transport electrons from the valence band to the conductivity band (these electrons are called pure carriers). The concentration of pure carriers at elevated temperatures is much greater than that of impurities. The probability of subjective excitation across the restricted field (E_g) is proportional to the limit ($e^{-E_g/2K_B T}$).

Example (1): If ($E_g = 4 \text{ e.V}$) at room temperature \rightarrow ($K_B T = 0.025 \text{ eV}$), the probability of excited electrons is proportional to ($e^{-80} \approx 10^{-35}$). In fact, there are excited electrons in the conduction gang.

Example (2): If $E_g = 0.2 \text{ eV}$ at room temperature \rightarrow ($K_B T = 0.025 \text{ eV}$), the probability of excited electrons is proportional to ($e^{-5} \approx 10^{-2}$) and therefore We observe the electrical conductivity even at room temperature and the number of pure carriers (electrons in the conductivity ring and holes in the valence league), which is proportional to ($-\frac{1}{T}$) increases with increasing (T), that is, the conductivity increases with temperature and this is contrary to what it is in metals.

Impurities are always present in the sample studied, which in turn inevitably affects the nature of conductivity. In order for conductivity to be pure in semiconductors, the concentration of pure carriers must be much higher than that of impurities. This happens when the sample is almost free of impurities. The semiconductor in this case is called a pure semiconductor (Intrinsic Semiconductor). However, the lowest concentration of impurities practically possible is about 10^{10} atoms per (cm^3). Conductivity is then pure only at high temperatures, where a high concentration of pure carriers occurs.

The heat excitation process of electrons from the valence-to-conduction gang is accompanied by a reverse process called recombination, in which electrons return from the conduction-to-valence gang to cancel or combine with free holes. This in turn leads to reduced conductivity. The probability of union is proportional to the number of free electrons in the conductivity band and to the number of free holes in the equivalence band in the case of pure conductivity. But in the temperatures between the excitation and the union equilibrium you get a certain concentration for the charging carriers.

The excitation process can also be done by photosynthesis, where the absorbed photon generates a pair of pregnant women: an electron in the conduction band and a hole in the valence band. These excitation is used to measure the prohibited field (E_g).

Carrier concentration in intrinsic semiconductor

When the temperature of the pure semiconductor is raised, electrons are raised from the top of the valence band to the bottom of the conduction band. The probability that the energy level (E) is occupied by electrons at temperature (T) is determined by the Fermi-Dirac distribution function:

$$f_e(E) = \frac{1}{1 + e^{\frac{E - E_F}{K_B T}}} \dots\dots (1)$$

Where: E_F : Fermi level energy, K_B : Boltzmann constant.

From the previous relationship when (T = 0) the distribution is a step function:

$$f_e(E) = \begin{cases} 1 & \text{if } 0 < E < E_F \\ 0 & \text{if } E_F < E \end{cases}$$

Fermi - Dirac count

It is a distribution function that controls the probability of an electron having a certain energy in a quantum state. The distribution is not limited to electrons but all other fermions subject to the Pauli principle of exclusion or spindle hemispheres.) Does not mean that it will acquire the corresponding energy level (quantum state), but we must also consider the vacancy of this level by taking into account the density of the levels at this energy level.

By generalizing this principle, it is concluded that the concentration of fermions in an energy level depends primarily on two main pillars:

1. Density levels: the number of vacant places in this level.
2. Fermi Dirac count: The number of fermions that have the energy reached by this level.

This means that energy levels that are lower than the Fermi level are completely occupied by electrons, whereas the levels above the Fermi level are completely vacant than electrons. That is, the Fermi level represents the highest energy level that electrons can occupy at absolute zero, where these levels are either completely or partially occupied.

When (T > 0) and (E = E_F), ($F_e(E) = 1/2$) means that the probability of busy Fermi level is equal to (1/2) and then a number of electrons can move to higher levels From the Fermi level (E > E_F) due to the thermal motion of the electrons. A number of vacant energy levels appear below the Fermi level and the number of electrons expected above the Fermi level is equal to the number of holes placed below that level.

In summary:

The probability of an electron at a power level below Fermi's energy is 100%

The probability of an electron at an energy level equal to Fermi's energy is 50%

The probability of an electron at a higher energy level than Fermi is 0%

From the study of the Fermi-Dirac distribution, the probability that the level of occupancy is different from only one and zero in the field \pm (from 2 KBT to 3KBT), while the probability that the level (E) in the valence band is not occupied by electrons, ie the probability of being occupied by holes, is equal:

$$f_h(E) = 1 - f_e(E) = \left(1 + e^{\frac{-(E-E_F)}{K_B T}}\right)^{-1} \dots\dots (2)$$

When $(E-E_F) \gg K_B T$ can be neglected one in the denominator of the relationship (1) and the distribution (Fermi - Dirac) Figure:

$$f_e(E) = e^{\frac{E_F-E}{K_B T}}$$

This is a distribution (Maxwell - Boltzmann).

We can now calculate the concentration of electrons in the conductivity band (in pure semiconductor) using the relationship:

$$n_i = \frac{1}{V} \int_{E_g}^{+\infty} g_e(E) f_e(E) dE \dots\dots (3)$$

Where: $g_e(E)$: density of electronic states, V: volume.

The Conductor League starts from energy (E_g) (the top of the restricted field). It is clear that the beginning of the energy calculation lies at the top of the valence league. We set the upper limit of integration ($\infty +$) instead of a certain value because the probability of electrons occupying the higher levels in the conductivity band is virtually zero. The excited electrons occupy the lower levels at the bottom of the conductivity band. The value $\left(\frac{g_e(E)}{V}\right)$ represents the density of electronic states in a unit of volume near the bottom of the conduction band, which is equal to:

$$\frac{g_e(E)}{V} = \frac{1}{2\pi^2} \left(\frac{2m_e^*}{\hbar^2}\right)^{\frac{3}{2}} (E - E_g)^{\frac{1}{2}}$$

Where m_e^* : the actual mass of the electron. From the previous integration (3) we find:

$$n_i = N_c e^{\frac{-(E_g-E_F)}{K_B T}} \dots\dots (4)$$

Where: $N_c = 2 \left(\frac{2\pi m_e^* K_B T}{h^2} \right)^{\frac{3}{2}}$ The actual density of cases in the conductivity band.

The actual mass of electrons and holes (m_h^* , m_e^*)

The electrons that move independently in the vacuum are called free electrons, and the electrons of minerals act like free but they are not. The reason is that the molecules in metals and other solids called electrons are actually semi-electrons or semi-particles, they are like real electrons: The same electric charge, winding and magnetic torque, but differ in mass.

The movement of electrons within a crystal can be described with the help of the wave beam accompanying the movement of these electrons, consisting of the Bloch functions of the average velocity of the electron in the crystal, is the group velocity of the beams representing the electron waves: ($\vec{V} = \frac{d\omega}{dk}$) Where: ($\omega = \frac{E}{\hbar}$)

The angular frequency of the wave band representing an electron. We calculate the acceleration of the group and subject it to Newton's second law: $a = -\frac{eE}{m_e^*}$

Where E: the electric field and e: the charge of the electron and m_e^* the actual mass of the electron
 $m_e^* = -\frac{eE}{a}$

The actual mass of the electron, reflecting the effect of the periodic grid potential on the movement of the electron within the crystal induces the influence of external force.

Note: The electron acceleration within a crystal under the influence of eE is given by: $a = -\frac{eE}{\hbar^2} \frac{d^2 E}{dk^2}$

From the solution of this equation, it turns out that there are actually negative masses of electrons, that the properties of these electrons differ significantly from the properties of ordinary electrons, and that the dynamics of those particles with negative masses is unusual. Therefore, it is better to express these negative masses using semiconductor particles, each with a charge (e^+) but having a positive mass. These semiconductors are called holes with a positive charge (e^+) and an actual mass (m_e^*).

Bloch function

$$\Psi_K(\vec{r}) = U_K(\vec{r}) e^{i\vec{K}\vec{r}}$$

Where: $U_K(\vec{r})$ The total potential energy function of an electron in a crystal.

\vec{K} : Waveform (determining the direction of the electron wave function in the crystalline field).

The Bloch function checks the Schrödinger equation.

In order to calculate n_i you must know the unknown Fermi (E_F) energy. However, it can be calculated by concentrating the holes (p) in the valence band, distributing the holes at the top of the valence band and considering $\{(E_F - E) \gg K_B T\}$ at normal temperatures. The relationship will be subject to:

$$f_h(E) = e^{\frac{E-E_F}{K_B T}}$$

Since the holes exhibit the behavior of their actual mass particles (m_h^*), we find that the case density of the holes (P) at the top of the valence league in the volume unit is equal to:

$$\frac{g_h(E)}{V} = \frac{1}{2\pi^2} \left(\frac{2m_h^*}{\hbar^2} \right)^{\frac{3}{2}} (E_g - E)^{\frac{1}{2}}$$

We considered the energy of the holes negative (lower than the zero level at the top of the valence league). Thus the concentration of holes is:

$$p_i = \frac{1}{V} \int_{-\infty}^0 g_h(E) f_h(E) dE \dots\dots (5)$$

From integration (5) we find:

$$p_i = N_v e^{\frac{-E_F}{K_B T}} \dots\dots (6)$$

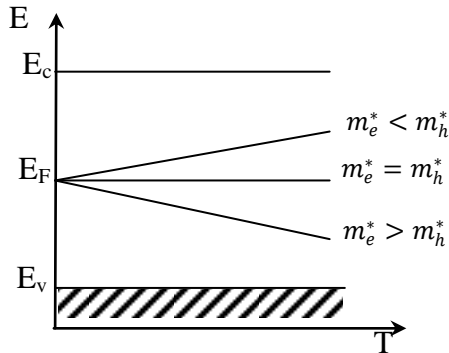
Where: $\{ N_v = 2 \left(\frac{2\pi m_h^* K_B T}{\hbar^2} \right)^{\frac{3}{2}} \}$ Actual density of cases in the valence league

So far, we have treated it as if the concentration of electrons and holes are independent, but in fact they are equal because the electrons in the conduction gang are caused by their irritation from the valence gang and their transmission through the energy separator (E_g) so that each electron that moves to the conduction gang is left behind. The concentration of electrons in the conductivity band is equal to the concentration of the holes in the valence band. Therefore, ($n_i = p_i$), with equal relations (4) and (6), we find:

$$E_F = \frac{1}{2} E_g + \frac{3}{4} K_B T \ln\left(\frac{m_h^*}{m_e^*}\right) \dots\dots (7)$$

And when it is ($m_h^* = m_e^*$) Is: $\ln\left(\frac{m_h^*}{m_e^*}\right) = 0$

The second term of equation (7) is then neglected, making the Fermi level located in the middle of the E_g . When (T = 0K) the Fermi level is also in the energy separator (the prohibited field), and as the temperature increases, the Fermi level deviates from the middle of the energy separator either down or up, depending on the ratio value between the two actual masses (m_h^* & m_e^*). Figure 4 shows the Fermi (E_F) level changes with temperature and the ratio between the two masses.



The concentration of actual charge carriers (concentration of electrons or holes) can be found by substituting relationship (7) in relationship (4).

$$n_i = 2 \left(\frac{2\pi K_B}{h^2} \right)^{\frac{3}{2}} T^{\frac{3}{2}} (m_e^* m_h^*)^{\frac{3}{4}} e^{\frac{-E_g}{2K_B T}} \dots \dots (8)$$

Relationship (8) shows that the concentration of electrons excited through the pure semiconductor energy separator increases exponentially with increasing (T)

Example of silicon: If we consider that (m_0) is the mass of free electron

$$(m_h^* = 1.08m_0 \& m_e^* = 0.56m_0) \text{ At a temperature } (T = 300K) \& (E_g = 1.11eV)$$

We conclude that the concentration of electrons for silicon is about ($n_i \approx 1.9 \times 10^{10} cm^{-3}$)

Example of Germanium: If we consider that (m_0) is the mass of free electron

$$(m_h^* = 0.53m_0 \& m_e^* = 0.56m_0) \text{ At a temperature } (T = 300K) (E_g = 0.67eV)$$

We conclude that the concentration of electrons for germanium is about ($n_i \approx 2 \times 10^{13} cm^{-3}$) When ionized.

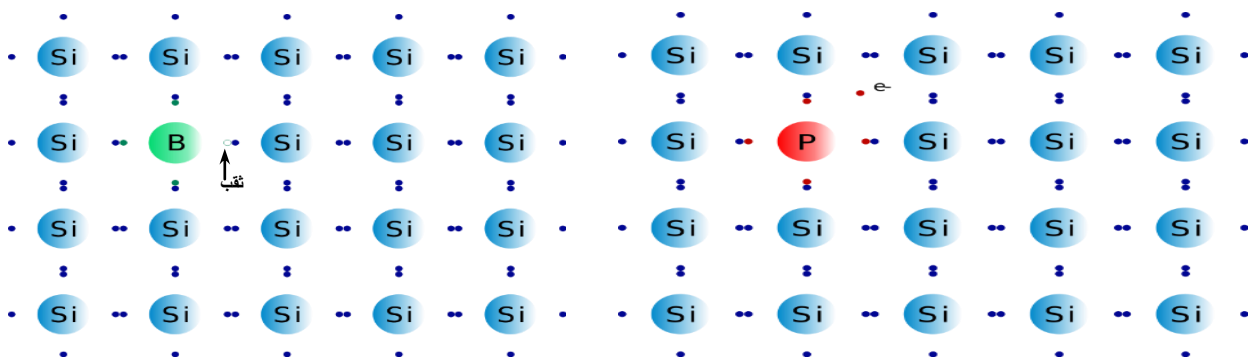
These values are familiar values of concentration in pure semiconductors. To observe the self-behavior of silicon (i.e., pure consideration), the contribution of impurities inevitably present in the sample, when ionized, must be significantly less than ($1.9 \times 10^{10} cm^{-3}$), or that the allowable concentration of impurities in order to keep the silicon pure and behave at room temperature (10^{13} و 10^{12}) Part of the atoms of the original substance, but this purity is very large (the best possible resistance is practically limited (10^{10}) Atom in poison 3). Pure silicon therefore does not exhibit self-behavior at room temperature, but at higher temperatures. Pure germanium exhibits subjective behavior at room temperature.

Doped Semiconductors

We have already talked about the actual (pure) conductivity of semiconductors, that this conductivity due to the presence of pairs (electron - hole) generated by heat or by any other energy source is not useful because it cannot be controlled in practice. Because of this, a finely limited amount of impurities can be

added to the semiconductor material in order to alter its electrical properties in a very specific way. This process of adding impurities is called doping.

Flawed semiconductors can be in the form of (p-type) or (n-type). The semiconductor (type-p) is obtained when the impurity atoms have valence electrons less than the silicon or germanium atoms of the original crystal. The semiconductor (type-n) results from the addition or replacement of impurity atoms that have more valence electrons than silicon or germanium atoms. Silicon and germanium are covalent bonds and their crystal structure follows the diamond composition. When an atom of a trivalent element such as boron, aluminum, gallium, indium and thallium enters the place of the silicon atom, the composition becomes deficient locally and the impurity atom takes an additional electron from an adjacent bond in the network to complete the four-faceted distribution cloud of the network. This exchange results in a positive hole located on the side of the impurity atom, and moves through the crystalline network of the valence league, causing electrical conductivity. The impurity atom is called the acceptor, and since the electrical conductivity results from the movement of the positive holes in the valence band, this type of semiconductor is called (type -p).



Silicon alloys with trivalent B-atoms:
produces P (p-type)

Figure 5

Silicon alloy with p-pentavalent atoms: N (n-type)

Figure 6

If we take elements such as phosphorus or arsine, antimony and barmut we have five equal electrons. If one of these elements replaces a silicon atom, only four valence electrons enter the inter-atomic bonds, and the fifth electron is slightly attracted by the overload of the nucleus. If heat irritation occurs even at room temperature, this electron moves to the conduction strip. This type of semiconductor is called type-n and is called donor atom as shown in Figure 6.

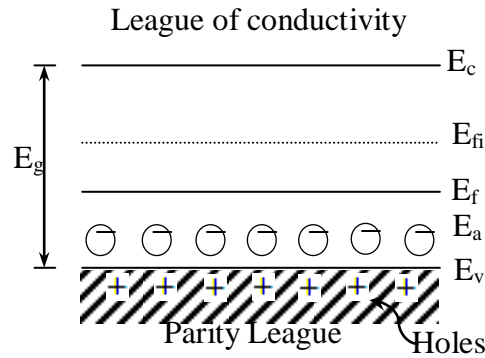
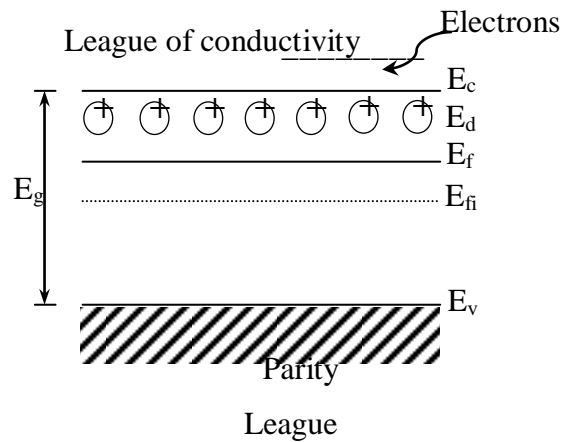


Figure 7



Figures 7 and 8 illustrate the energy nerve of a similar semiconductor at specified temperatures. (7) Semiconductor (Type -p). (8) Semiconductor (Type-N). + And - represent moving charges, holes and electrons, respectively \oplus and \ominus represent non-moving charges resulting from ionization of receiving and donor atoms, respectively. (E_g) Energy gap, (E_{fi}) Fermi level of a semiconductor. (E_d and E_a) are the energy levels of a given atom and a receiving atom respectively. When the ionization continues, the Fermi energy level moves towards the energy level of the impurities until a specified temperature occupies an energy level between the E_{fi} level and the energy level, either E_a or E_d .

If both types of impurities (donor and receptor) are found, there is a tendency for one of the two types to cancel the effect of the other type. This is called the Compensation Equation and the semiconductor type depends on the type of greater concentration of the impurities. Determines the semiconductor type of the Hall-fixed signal.

Hall Effect: The tendency of charge carriers, whether positive or negative, to shift towards the ends of the semiconductor due to the applied or exposed magnetic field. This results in a voltage difference called a Hall voltage between opposite poles in an electrical conductor whose polarity depends on the signal of these carriers.

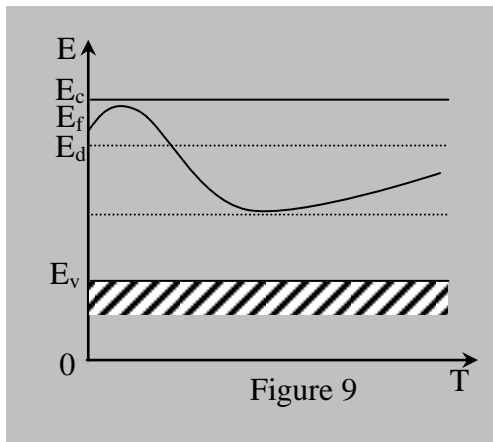
Hall constant: depends on both the temperature and the type of conductor and does not depend on the dimensions of the chip.

In the case of a quantitative increase in impurity concentration, the corresponding energy levels increase in width and overlap with the bands of the bands. Shallow states are sometimes shallow and receptor impurity levels. Ionized impurity atoms generate deep levels within the energy separation.

Carrier concentration in doped semiconductor

To study this topic, we first look at the following two topics:

(A) The location of the Fermi-semiconductor-level: The location of the Fermi-semiconductor-level is very different from that of the pure state. If we take the semiconductor (type - n), we find that all cases in the valence league and the levels of impurities donor is occupied at ($T = 0$ K), while the league of conductivity is completely vacant. . That is why the Fermi level is in a central position between the donating level and the bottom of the conductivity band, as shown in Figure 9, and by increasing the temperature. This is why the Fermi level is in a central position between the donating level and the bottom of the conduction gang, as shown in Figure 9, and by increasing the temperature (as long as $N_c < N_d$) The Fermi level rises and then passes through a super end and then descends towards the donating level as the number of atoms of the ionized blemishes increases. At elevated temperatures, when the subjective excitement is large, the number of electrons in the conduction band is approximately equal to the holes in the valence band, and E_F is then in the middle of the restricted field. The same is said of the p-type semiconductor, where the Fermi level is near the level of the impurities received. The difference in the location of the level (E_F) is essential to understand the communication mechanism (p - n) frequently used in electronic devices.



(A)(B) Semiconductors usually contain both types of impurities, the donor and the receiver, and the electrons in the conduction band (or holes in the valence band) can be generated by the following transitions that generate pregnant women:

1. Electronic transmission by thermal irritation from the valence league to the conductivity league (self-transition).

2. Electronic transitions by thermal ionization of the donating atoms to the League of conductivity, which generate free electrons in the League of conductivity contribute to electrical conductivity.
3. Electronic thermal transfer from the valence league to the level of receptor atoms that generate free holes in the valence league contribute to electrical conductivity.
4. Electronic transitions resulting from the compensation process between the levels of donated and received impurities. These transfers do not generate free carriers; on the contrary, they reduce the number of free carriers that can result from transfers (2) and (3).

Finding the concentration of free swatches (electrons and holes) in the general state that takes all these processes into account is a complex issue. So we distinguish between two areas of transition: self and self:

A - Subjective domain: In this area pregnant women are mainly produced by the transitions (1) this occurs at high temperatures sufficient to meet the condition: $(n_i = p_i)$ where (n_i) : self-concentration. In this case, the impact of the presence of impurities is neglected because of the small number of charge carriers resulting in comparison with (n_i) . This condition is best achieved by increasing (n_i) (ie the higher the temperature) as well as the lower the concentration of impurities. Often for the typical deformation, of the 1510 cm^{-3} rank, most of the semiconductor impurities are located in the subjective domain at higher (T) temperatures higher than (T_c) (where T_c depends on the concentration, type of impurities and semiconductor type) For example, it can be calculated from the relationship of the number of electrons due to the Nd-type impurities of the semiconductor (n-type) by means of transitions (2) and the number of holes in the valence-band produced by transitions (1) through the donor centers (at temperatures higher than T_c). The dominant and conditional transitions $(n_i = p_i)$ are transitions 1. At T_c , $p_i = N_d$, since the number of electrons in a Then its conductivity is equal to $(n_i = p_i + N_d)$ is $(n_i = 2N_d)$ then easy to note that the temperature of the transition from half of the carrier to the pure Taataan tinged relationship:

$$n_i^2 = n_i p_i = N_c N_v e^{-E_g / K_B T} \Rightarrow T_c = E_g \left(K_B \ln \frac{N_c N_v}{2 N_d^2} \right)^{-1} \dots\dots(8)$$

Where $(n_i p_i = 2N_d^2)$

From relationship (8), we find that the increase (T_c) of the semiconductor is related to the increase (N_d) , and therefore the temperature (T) necessary to achieve the condition $(n_i = p_i)$.

B - Self-field: At low temperature (temperatures below T_c) the condition $(n_i = p_i)$ becomes disturbed and the semiconductor becomes the self-field. In the non-conductive semiconductor field of a particular type of impurity, the concentration of impulse charge carriers is greater than that of the self-propelled carriers.

(N-type semiconductor) $N_d \gg n_i$

(P-type semiconductor) $N_d \gg p_i$

We distinguish in this area two cases: the case where all impurities or donations received and ionized and called the field of impurities and the situation in which not all impurities ionized. The occurrence of one of the two previous cases depends on the temperature of the semiconductor.

The theoretical study of the inertial field is applied from statistical calculations showing that the probability of a donor-electron level in (T) is:

$$F_e(E) = \left(\frac{1}{2} e^{E-E_F/K_B T}\right)^{-1}$$

Where ($E = E_g - E_d$), the probability that the receiving level is occupied by holes is given by:

$$F_h(E) = \left(\frac{1}{2} e^{E_F-E/K_B T} + 1\right)^{-1}$$

Where: ($E = E_a$).

We will study the n-carrier semiconductor where the concentration of donor atoms (N_d) and their ionization energy (E_d). At temperature ($T = 0$ K), all the levels of the donating atoms are occupied by electrons, and at low temperatures, when only a portion of the donor is ionized, we expect the Fermi level to be located approximately halfway between the energy level (E_d) and the bottom . For simplicity, we assume that E_F is more than several $K_B T$ away from the bottom of the conductivity band. In this case, the concentration of electrons (n_i) in the conductivity band is given by the relationship (4).

This number should be equal to the concentration of the donated ionized atoms. Assuming that E_F is more than several $K_B T$ above the level of the donating atoms at $E_g - E_d$ (where we take the principle of energy measurement at the top of the valence league), the concentration of electrons in the donor impurity level at T is equal. :

$$n_e = N_d F_e(E) = \frac{N_d}{\left(\frac{1}{2} e^{\frac{E_g - E_d - E_F}{K_B T}} + 1\right)}$$

The concentration of thermally excited electrons to the conductivity band is equal to:

$$n = N_d - n_e = \frac{N_d}{\left(2e^{\frac{-(E_g - E_d - E_F)}{K_B T}} + 1\right)}$$

The source of the electrons of the vector is mainly the electrons of the excited donor atoms.

Considering the typical deformation (1510 cm^{-3}) and depending on the temperature we distinguish two cases:

1) The very low temperature range ($T \ll T_c$) in this case is:

$$E_F = E_g - \frac{E_d}{2} + \frac{K_B T}{2} \ln \frac{N_d}{2N_c} \dots\dots(8)$$

$$n = \left(\frac{N_c N_d}{2}\right)^{\frac{1}{2}} e^{-E_d/2K_b}$$

The concentration of holes in this case is given by:

$$p = \frac{n_i^2}{n}$$

And (p) here is very small.

2) The field of high temperatures and near (T_c). Then it is:

$$8 \frac{N_d}{N_c} e^{E_d/K_B T} \ll 1 \text{ or } N_c \gg 8 N_d$$

Here ($\ln \frac{N_d}{N_c} < 0$) all the atoms are ionized (impurities run out). The concentration of the basic pregnant (holes)

It is given by the relationship: ($p = \frac{n_i^2}{n}$), which is a small amount due to the small (n_i), but increases exponentially by increasing the temperature until reaching the subjective field.

The transition mode between the near high temperature field (T_c) and the very high temperature field (subjective field) of the n-type semiconductor is described in relation to:

$$n = p + N_d = \frac{n_i^2}{n} + N_d$$

This relationship is true in the case where the impurity atoms are ionized.

Then we find that:

$$n^2 - nN_d - n_i^2 = 0$$

$$n = \frac{N_d}{2} \left(1 + \sqrt{1 + \frac{4n_i^2}{N_d^2}} \right) > 0$$

If the inequality is achieved ($\frac{4n_i^2}{N_d} \ll 1$) we are in the field of high temperatures near (T_c).

If the inequality is achieved ($\frac{4n_i^2}{N_d} \gg 1$) we are in the field of very high temperatures and corresponding to the subjective field. So the sum of the equations we get is consistent with the state of the self-carrier. The relationship (8) shows that the location of the Fermi level of the n-type semiconductor is located in the middle between the bottom of the conduction band and the impurities at 0 K and then increases its energy by increasing the temperature passing through a maximum value and then falling until it reaches the center of the energy separator ($E_F \approx \frac{1}{2} E_g$). Where we get to the pure conductivity.

References

- [1]. Zbigniew D. Gastrebski, 1986, The Nature and Properties of Engineering Material, Volume 2, John Wiley and Sons.
- [2]. Mohammad Saeed Mahasneh, 1981 Physics of Solid Body, Part II., Directorate of University Books and Publications, University of Aleppo.
- [3]. Riad Al-Rashi and Malik Hassan, 1994, Physics of Solid Body, Directorate of University Books and Publications, University of Aleppo 1994.
- [4]. Mohammad Saleh Hamami, 1987 Physics of Solid Body, Directorate of University Books and Publications, University of Aleppo
- [5]. Abdul Wahab Dwaidri, 1994 Foundations of Electronics, Directorate of University Books and Publications, Aleppo University, 1994.
- [6]. Free Encyclopedia (Wikipedia).