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*Determination of the Hall coefficient of a
Germanium doped p*

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Before the jury:

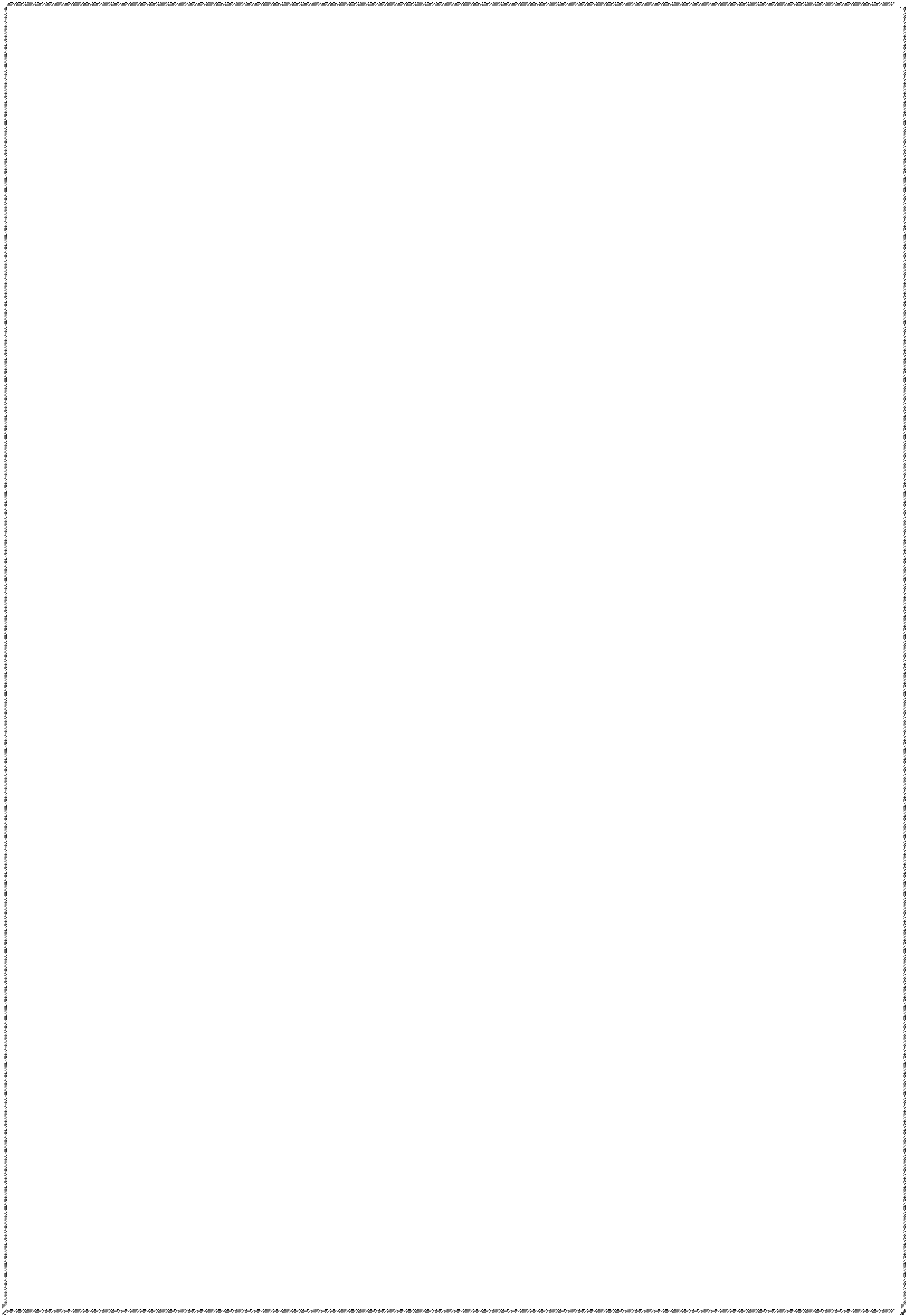
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Dedications

I dedicate this modest work:

To my very dear parents who have always supported me in waiting for my goals.

As I think it will not be enough to thank them, but to satisfy them, and to give back some of their best because my joy depends on their joy.

To my husband fathi and his family.

To my sister and brothers.

To my supervisor Dr: Bouhdjer lazhar and my colleagues for their precious advice who accompanied me throughout my work, who have in me a great confidence, and for the unforgettable moments that we lived together.

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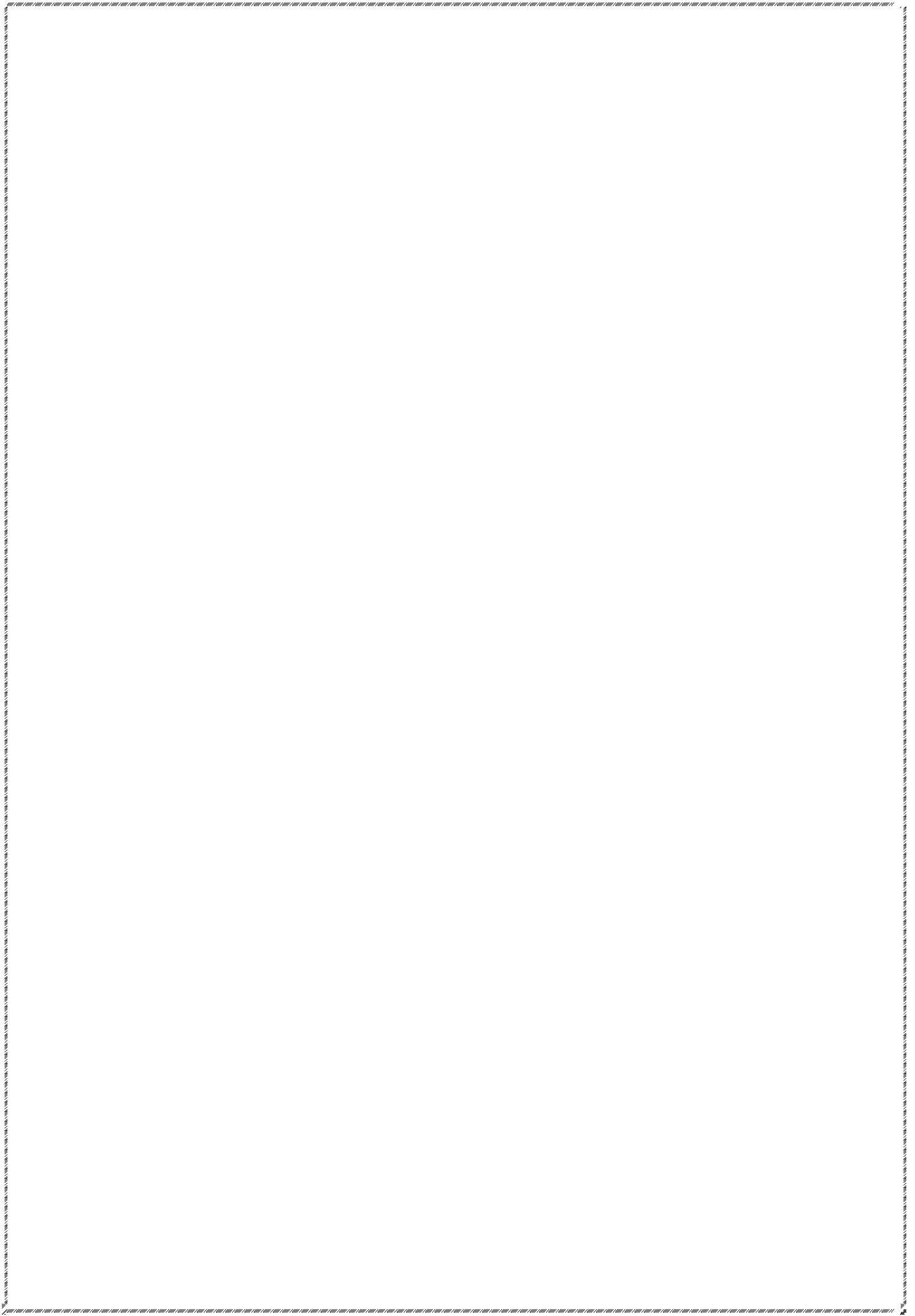
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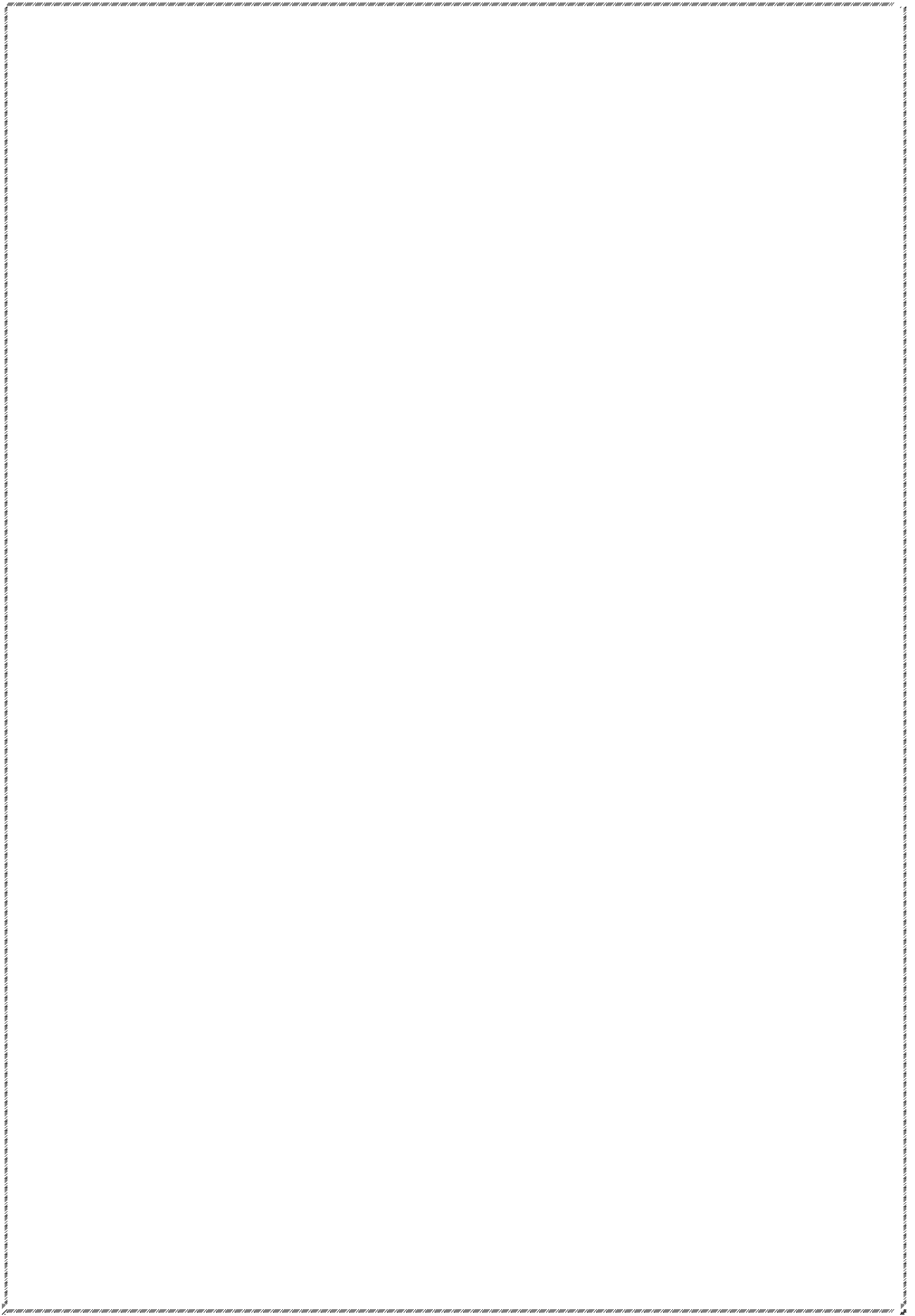
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General Introduction





General Introduction

Solid materials can be classified into three groups: insulators, semiconductors and conductors. Insulators are considered to be conductivity materials (diamond 10^{-14} S/cm), such as semiconductor materials such as (silicon 10^{-5} S/cm at 10^3 S/cm) and as conductor materials such as (silver 10^6 S/cm), the electrical properties of a material are a function of the electronic populations of the different allowed bands. Electrical conduction results from the movement of electrons within each band. Under the action of the electric field applied to the material, the electron acquires a kinetic energy in the opposite direction of the electric field. Now consider a band of empty energy, it is obvious by the fact that it does not contain electrons, it does not participate in the formation of an electric current. It's the same for a full band.

In reality, an electron can move only if there is a free space (a hole) in its energy band. Thus, a material whose energy bands are empty or solid is an insulator. Such a configuration is obtained for gap energies greater than $\sim 9\text{eV}$, because for such energies, the thermal agitation at 300K can not pass the electrons of the valence band to the conduction by breaking electron bonds. The bands of energy are thus all empty or all full. A semiconductor is an insulator for a temperature of 0K. However, this type of material having a gap energy of less than the insulator ($\sim 1\text{eV}$) well, due to thermal agitation ($T = 300\text{K}$), a conduction band slightly populated with electrons and a slightly depopulated valence band. Knowing that the conduction is proportional to the number of electrons for a band of almost empty energy and that it is proportional to the number of holes for an almost full band, it is deduced that the conduct of a semiconductor can be qualified as "wrong." [1] For a conductor, the interpenetration of the valence and conduction bands implies that there is no gap energy. The conduction band is then partially full (even at low temperatures) and thus the conduction of the material is "high". It's characterized by a non-zero conductivity at $T = 0\text{K}$.

We distinguish a special type who is superconductors, it's have infinite conductivity for $T < T_c$ and, furthermore, exhibits the Meissner effect: they expel magnetic fields [2].

Our memory is interested to study the concept of hole in the Germanium doped P semiconductor.

To determinate this concept the American physician Edwin Herbert hall discovered in 1879 the Hall Effect, which stated as follows: "an electric current through a conducting material immersed in a magnetic field generates a voltage perpendicular to it [3].

Chapter I: Growth Techniques Of Semiconductors

Chapter I Growth techniques of semiconductors

I-1-Introduction

The semiconductor is an insulator material with a short forbidden gap (of the order of 1 eV) and small energy levels of electrons bound to impurities it means they have a resistivity too low to be called an insulator but at the same time, too high to be called a conductor [4].

I-2- types of doping of semiconductor

Generally, in the industrial sector, the extrinsic semiconductors are used. However, the passage, at first, through the ideal case (*intrinsic semiconductors*) is useful to understand the complicated case (*extrinsic semiconductors*). In this context, this chapter will be highlighting the different technics of elaboration of semiconductors.

I-2-A-The intrinsic semiconductor

Or pure semiconductor, an intrinsic semiconductor is an ideal crystal. When an electron in an intrinsic semiconductor gets sufficient energy, it can pass to the conduction band and leave behind a hole. This process is called ((electron hole pair (EHP) creation)). It means the number of electrons was equal them of holes

$$n = p = n_i \quad (0.1)$$

Where “ n_i ” is the symbol for “intrinsic carrier concentration.”

I-2-B-Extrinsic semiconductors

Are made by introducing different atoms, called dopant atoms, into the crystal.

- ✓ In pure form, Si wafer does not contain any free charge carriers.

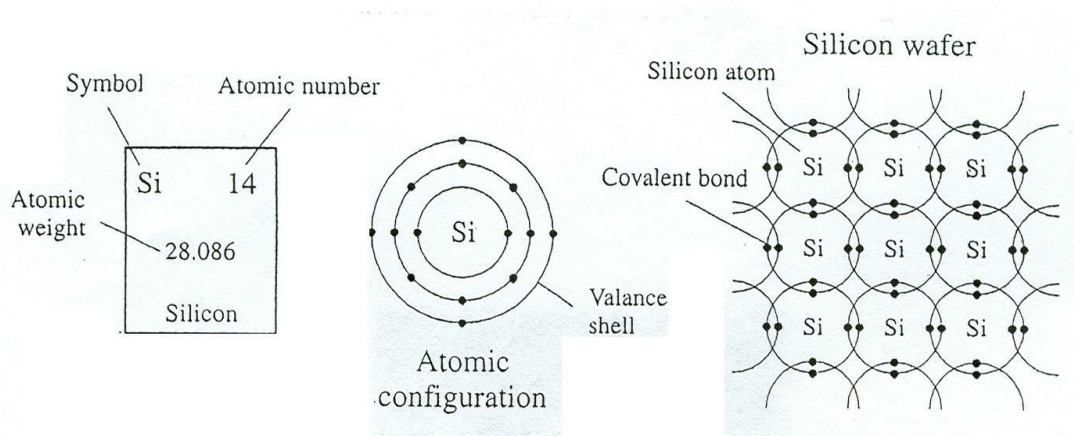


Figure I-1: Crystal of pure silicon atoms

We can get two types of extrinsic material:

Chapter I Growth techniques of semiconductors

I-2-B-1-n-type: The dopant atoms added to the semiconductor crystal are donor atoms as P atom has 5 electrons in their outermost shell of the column V of the periodic table [6].

- ✓ For example, in the time when phosphorus impurity is added to Si, every phosphorus atom's four valence electrons are made up in a covalent bond with valence electrons of four neighboring Si atoms. However, the 5th valence electron of the phosphorus atom does not find a binding electron and thus remains free to float. When a voltage is applied across the silicon-phosphorus mixture, free electrons migrate toward the positive voltage end.
- ✓ When phosphorus is added to Si to yield the above effect, we say that Si is doped with phosphorus. The resulting mixture is called N-type silicon (N: negative charge carrier silicon) [8].

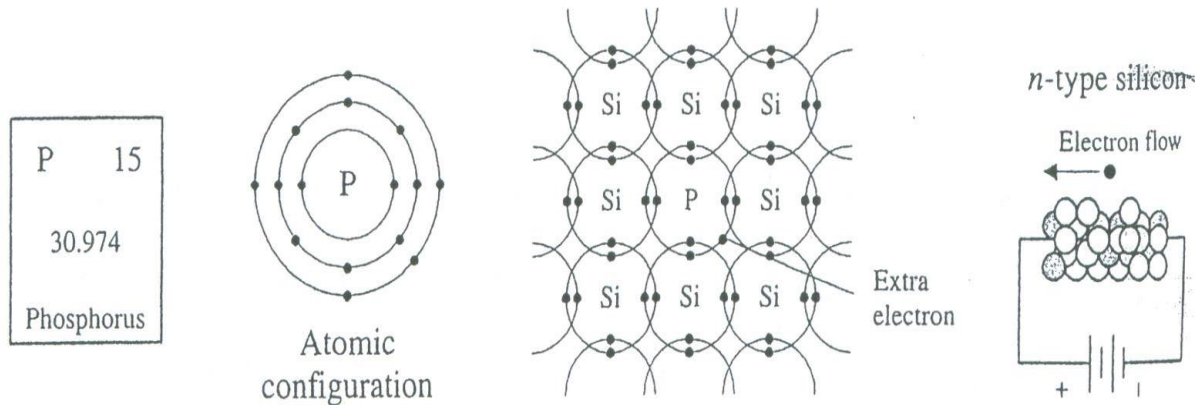


Figure I-2: structure of silicon doped by phosphorous atom having N-type semiconductor

- ✓ This type of impurity donates an electron to CB and so is called donor impurity atoms, which add electrons to contribute the CB current, without creating holes in VB.
- ✓ The energy state of donor impurity defined by the energy level E_d
- ✓ If a small quantity of energy, for example, thermal energy is added to the donor electron, it can be elevated into the CB, leaving behind a positively charged P ion [7].

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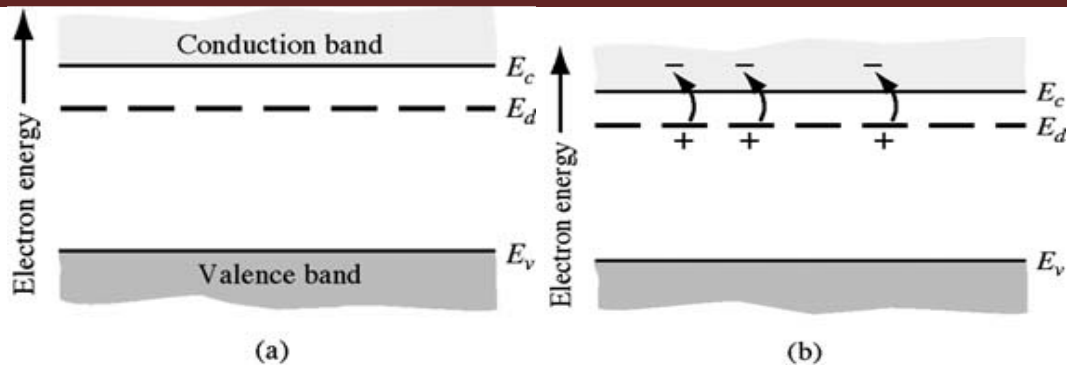


Figure I-3: donor ionization energy levels.

I-2-B-2: p-type semiconductor

- ✓ In this type, a group III element, like B atom is added. 3 valence electrons are all taken up in covalent bonding; one covalent bonding position appears to be empty.
- ✓ The empty positions in the VB are thought of as holes.
- ✓ The elements of group III atom accepts an electron from the VB and so is referred to as an acceptor [7].

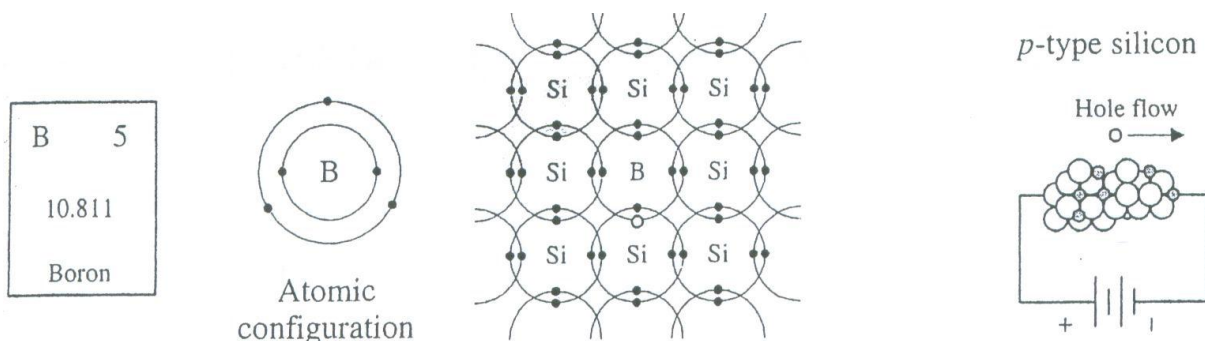


Figure I-4: structure of silicon doped by boron atom having P-type semiconductor

The hole of Boron atom points goes to the negative terminal.

- The electron of neighboring silicon atom points passes to the positive terminal.
- The electron from neighboring silicon atom falls into the boron atom filling the hole in boron atom and creating a “new” hole in the silicon atom.
- It’s clear as though a hole moves toward the negative terminal [8].

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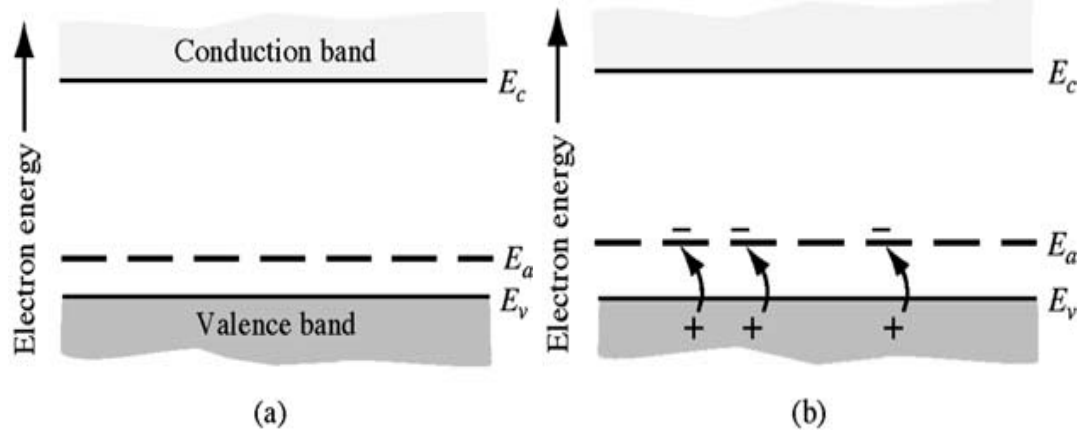


Figure I-5: Acceptor ionization energy levels

I-3-Growth Techniques

The historical starting point for virtually all semiconductor devices has been on the synthesis of single crystals. Today, three major methods have been developed to realize large-volume semiconductor crystals under thermodynamic equilibrium conditions: the Czochralski, Bridgman, and float-zone methods, which are discussed in the following subsections.

I-3-A-Czochralski Method

The Czochralski (CZ) crystal growth method was developed in 1916 by accident. Jan Czochralski, an engineer at the AEG Company in Berlin at that time, accidentally dipped his pen into a crucible containing molten tin and withdrew it quickly.

He observed a thin wire of solidified metal hanging at the tip. This small observation later led to the development of the Czochralski method for obtaining single crystals. [9]. The idea of this method was based on pulling of fibers of different metals from their melts. The obtained in such way metallic wires proved to be single crystals. The results of the experiments Czochralski published in Zeitschrift für Physikalische Chemie in 1918. This new technique allowed him to obtain the best quality single crystals of pure metals like Sn, Pb, Zn has grown in air later this method was adopted for crystal growth of semiconductors and oxides for electronic application.

Moreover, a modified Czochralski method allowed to obtain the single crystal of the intermetallic compounds, containing components even very reactive, sensitive to oxygen and other contamination. After separation of the growing crystal from the air, by use of growth chamber, an application of the protective atmosphere of inert gas e.g. Argon was possible. The application of the chamber additionally allows to heat starting materials under dynamic vacuum to remove adsorbed gases and additionally to control the gas pressure during the growth process. The next source of a possible contamination of the crystal is a contact of the melt with material of crucible. To eliminate this problem a water cooled cold crucible or

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levitating coil, divided into segments with a proper profile, can be used. The levitation of ingot additionally allows to avoid the transport of the heat from the melt to the crucible and thus melting the materials even with high melting point. For investigation of the compounds containing the expensive noble elements a reduction of the cost of starting materials is available by the decrease of the ingot mass. However, there is a limitation of the Czochralski method to the growth from an ingot which melt congruent [10] [11] .

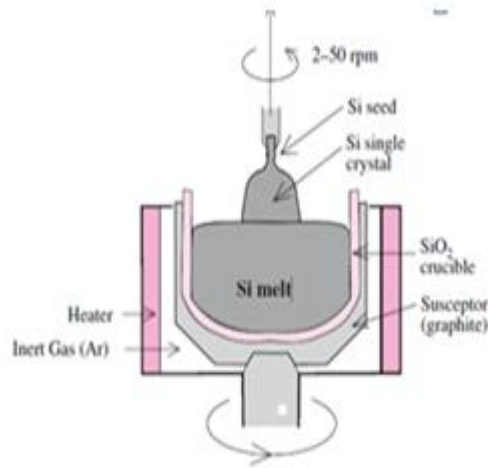


Figure I-6: Schematic setup for Czochralski process

Figure I-7: Growth equipment



Figure I-8: AlSb single crystal obtained by CZ process

Advantages and disadvantages of Czochralski method

The Czochralski method possesses the several features as:

- ✓ Extraction of the crystal in the opposite direction to the gravitation.
- ✓ Crystallized materials are withdrawn from an ingot which melts congruently (without decomposition into the different phases). However, if the separation between the temperature of liquid and peritects line is narrow in the phase diagram, crystallization of the required compound is observed.

Chapter I Growth techniques of semiconductors

- ✓ Spontaneous nucleation or by use of the oriented nucleus. The Czochralski immersed capillary in the melt for spontaneous nucleation of a single crystal. However, the spontaneous nucleation is also possible by necking of the withdrawn crystal in order to isolate single grain. This grain would expand into single crystal during the growth process;
- ✓ Free growth, without tension caused by the limitations of the crucible;
- ✓ The possibility of applying the protective atmosphere;

Two disadvantages of the method belong

- ✓ Tensions during the cooling down, necessity of warming up of the grown crystal, especially large;
- ✓ Possible segregation of the constituents [10].

I-3-B-Bridgman Method

The Bridgman method based for a seed crystal is usually kept in contact with a melt, as in the Czochralski method. However, a temperature gradient is created along the length of the crucible so that the temperature around the seed crystal is below the melting point.

The crucible can be positioned either horizontally or vertically to control convection flow. As the seed crystal grows, the temperature profile is translated along the crucible by controlling the heaters along the furnace or by slowly moving the ampoule containing the seed crystal within the furnace [10] .

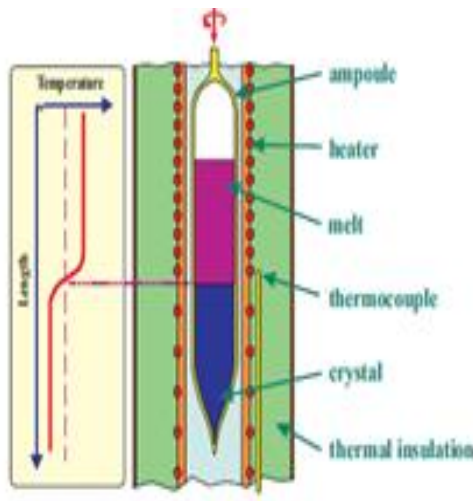


Figure I-9: Schematic setup for the Bridgman process



Figure I-10: Growth equipment

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I-3-C-The float zone method

Unlike the previous two methods, the float-zone (FZ) technique proceeds directly from a rod of polycrystalline material obtained from the purification process. The float Zone (FZ) method is based on the zone-melting principle and was invented by There in 1962. A schematic setup of the process is shown in (Fig I-11) the production takes place under vacuum or in an inert gas atmosphere. The process starts with a high-purity polycrystalline rod and a monocrystalline seed crystal that are held face to face in a vertical position and are rotated [9].

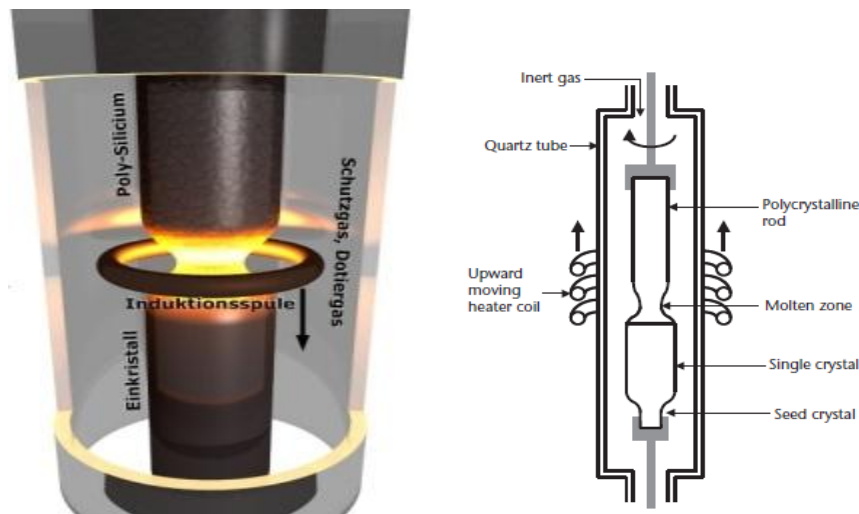


Figure I- 11: Schematic setup of the Float Zone (FZ) process.

With a radio frequency field, both are partially melted. The seed is brought up from below to make contact with the drop of melt formed at the tip of the poly rod. A necking process is carried out to establish a dislocation free crystal before the neck is allowed to increase in diameter to form a taper and reach the desired diameter for steady-state growth. As the molten zone is moved along the polysilicon rod, the molten silicon solidifies into a single Crystal and, simultaneously, the material is purified. Typical oxygen and carbon concentrations in FZ silicon are below $5 \cdot 10^{15} \text{ cm}^{-3}$. FZ crystals are doped by adding the doping gas Phosphine (PH^3) or di-Borane (B_2H_6) to the inert gas for n- and p-type, respectively. Unlike CZ growth, the silicon molten Zone is not in contact with any substances except ambient gas, which may only contain doping gas. Therefore FZ silicon can easily achieve much higher purity and higher resistivity [9].

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I-4. Conclusion

In this chapter, we discuss the most three famous techniques of crystal growth: the Czochralski, Bridgman, and float-zone methods; those used habitually in the industrial sector and we cited the different advantages of each technique.

CHAPTER II: Basic Theory Of Semiconductors

II-I-Introduction

If the transverse electric fields increase in a solid material when it carries an electric current and is situated in a magnetic field that is perpendicular to the current. The electric field (Hall field), is a product of the force that the magnetic field exerts on the affecting positive or negative particles that create the electric current. Whether the current is a movement of positive particles, negative particles in the opposed direction, or a combination of the two, a perpendicular magnetic field displaces the affecting electric charges in the same direction to one side at right angles to both the magnetic field and the direction of current flow. The accumulation of charge on one side of the conductor leaves the other side oppositely charged and produces a difference of potential. A suitable meter (chapter 3) may detect this difference as a positive or negative voltage. The sign of this Hall voltage determines whether positive or negative charges are carrying the current.

In metals, the Hall voltages are usually negative, signifying that the electric current is collected by moving negative charges, or electrons. The Hall voltage is positive, on the other hand, for a little metal such as beryllium, zinc, and cadmium, indicating that these metals conduct electric currents by the movement of positively charged carriers called holes.

In semiconductors, in which the current consists of a movement of positive holes in one direction and electrons in the opposite direction, the sign of the Hall voltage shows which type of charge carrier is majorities. The Hall effect can be used also to measure the density of current carriers, their free will of movement, or mobility, as well as to detect the presence of a current in a magnetic field.

The Hall voltage that develops across a conductor is directly proportional to the current, to the magnetic field, and to the nature of the particular conducting material itself; the Hall voltage is inversely proportional to the thickness of the material in the direction of the magnetic field. Because various materials have different Hall coefficients, they develop different Hall voltages under the same conditions of size, electric current, and magnetic field. Hall coefficients may be determined experimentally and may vary with temperature.

Chapter II Basic theory of semiconductors

II-II -Energy band theory

II-II-1-Energy band model

If we will speak of the concept of the band energy, our understandings of the quantum mechanics will be the most useful model involves the concept of energy bands. Recall that electrons in an atom occupy discrete energy levels as shown in (Fig II- 1-a).

If two atoms are in close nearness, each energy level will divide into two due to the Pauli exclusion principle that states that each quantum state can be Occupied by no more than one electron in an electronic system such as an atom molecule, or crystal. When many atoms are brought into close proximity as in a crystal, the discrete energy levels are replaced with bands of energy states separated by gaps between the bands as shown in (Fig II- 1-b). One may think of an energy band as a semi continuum of a very large number of energy states.

Naturally, the electrons tend to fill up the small energy bands first. The lower the energy, the more totally a band is full. In a semiconductor, the majority of the energy bands will be basically totally filled (at absolute zero), while the high energy bands are basically totally empty. Between the (basically) totally filled and totally empty bands lie two bands that are only nearly filled and nearly empty as shown in (Fig II- 1-b).

The top nearly filled band is called the valence band and the lowest nearly empty band is called the conduction band.

The level between them is called the band gap. The electrons in a totally filled band do not have a net velocity and do not conduct current, just as the water in a totally filled bottle does not slosh about. Similarly, a totally empty band cannot contribute to current conduction. These are the reasons the valence band and the conduction band are the only energy bands that contribute to current flows in a semiconductor.

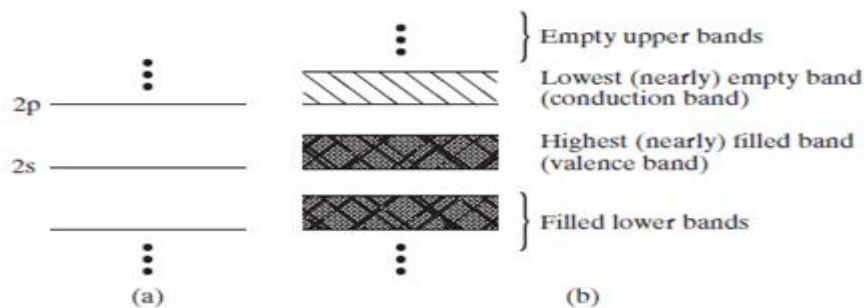


Figure II-1: the discrete energy states of atom (a) are replaced by the energy bands in crystal (b) [12].

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II-II-2-The free electron model

The behavior of an electron in a crystalline solid is determined by studying the suitable Schrodinger equation. We study that this electron doesn't in interaction with every one of the crystal, it may be written as:

$$\left[-\frac{\hbar^2}{2m} \nabla^2 + v(r) \right] \Psi(r) = E\Psi(r) \quad (2-1)$$

Where

$V(\mathbf{r})$ is the crystal potential "seen" by the electron,

$\Psi(\mathbf{r})$ are the state function

E energy of this electron.

After resolution of eq (2-1) we get the solution

$$\Psi(r) = c_1 \exp(ikx) + c_2 \exp(-ikx) \quad (2-2)$$

Where

$$k = \sqrt{\frac{2m_0 E}{\hbar^2}} \quad (2-3)$$

When K represents the vector of the reciprocal space her unit is m^{-1}

We can get the value of the energy from the expression of K we have:

$$E = \frac{\hbar^2 k^2}{2m} \quad (2-4)$$

According the equation (2-4), we will say that the energy of free electron has a discontinue value, but in reality, it's not free in crystal it's in interaction with nearly potentials of others electron in the lattice, then we pass to study the model with a periodic potential.

II-II-3-Periodic potentials

In most crystals, the interaction with the nuclei, or lattice atoms, is not negligible. However, the lattice has sure symmetries that the energy structure must also possess. The most important is periodicity, which is represented in the potential that will be seen by a

Chapter II Basic theory of semiconductors

nearly-free electron. Suppose we consider a one-dimensional crystal, which will suffice to illustrate the point, then for any vector L , which is a vector of the lattice, we will have:

$$V(x+L) = V(x)$$

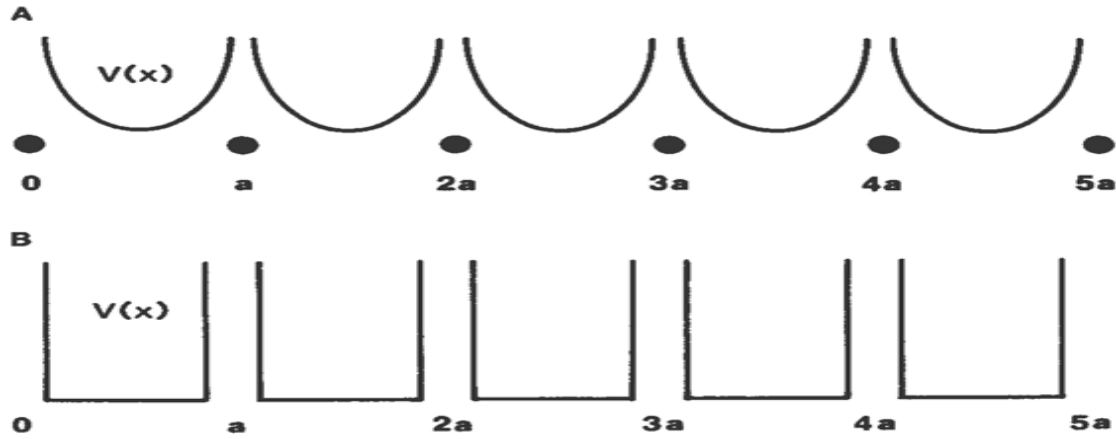


Figure II-2: **A:** periodic potential in a one-dimensional crystal, **B:** The Kronig–Penney model for a 1-D periodic lattice [13].

When we say that L is a vector of the lattice, this means that it may be written as $L = na$, Where n is an integer and a is the spacing of the atoms in the lattice. Thus, L can take only some values and is not a continuous variable. L then represents the periodicity of the lattice. The essential dot is that this periodicity must be imposed upon the wave functions arising from the Schrödinger equation, in this case with doing our study to two regions according the value of the potential, the first where $v=0$, and the second where $V=V_0$

$$\frac{-\hbar^2}{2m_0} \frac{\partial^2 \psi(x)}{\partial x^2} + V(x)\psi(x) = E\psi(x) \quad (2-5)$$

We start the resolution in the first region $v=0$

The Schrödinger equation will be written as

$$\frac{-\hbar^2}{2m_0} \frac{\partial^2 \psi(x)}{\partial x^2} = E\psi(x) \quad (2-6)$$

It means

$$\frac{\partial^2 \psi(x)}{\partial x^2} + \frac{2m_0 E}{\hbar^2} \psi(x) = 0 \quad (2-7)$$

Chapter II Basic theory of semiconductors

The solution of this secondary equation is

$$\psi_I(x) = Ae^{i\alpha x} + Be^{-i\alpha x} \quad (2-8)$$

Where

$$\alpha = \sqrt{\frac{2m_0 E}{\hbar^2}} \quad (2-9)$$

In the second region: $V=V_0$, the Schrodinger equation rewrites as:

$$\frac{-\hbar^2}{2m_0} \frac{\partial^2 \psi(x)}{\partial x^2} + V_0(x)\psi(x) = E(x)\psi(x) \quad (2-10)$$

We rearranged (2-10)

$$\frac{-\hbar^2}{2m_0} \frac{\partial^2 \psi(x)}{\partial x^2} + [V_0(x) - E(x)]\psi(x) = 0 \quad (2-11)$$

$$\frac{\partial^2 \psi(x)}{\partial x^2} - \frac{2m_0}{\hbar^2} [V_0(x) - E(x)]\psi(x) = 0 \quad (2-12)$$

The solution of this secondary equation is

$$\psi_{II}(x) = Ce^{\beta x} + De^{-\beta x} \quad (2-13)$$

Where

$$\beta = \sqrt{\frac{2m_0(V - E)}{\hbar^2}} \quad (2-14)$$

If the wave function satisfies the Bloch theorem; it means Ψ is a periodic function, we can rewrite as:

$$\psi(x) = U_k(x)e^{ikx} \quad (2-15)$$

Where $U_k(x)$ is a periodic function with period $x+L$; and

$$U_k(x+L) = U_k(x) \quad (2-16)$$

Then the wave equation will reword in the two regions as:

Chapter II Basic theory of semiconductors

$$\psi_I(x) = \Psi_I(x)e^{i\alpha(x+L)} \quad (2-17)$$

And in the second region

$$\psi_{II}(x) = \Psi_{II}(x)e^{i\beta(x+L)} \quad (2-18)$$

Now we will set on these equations to get values to the constants A, B, C, and D

For that we established the conditions of continuities at $x=0$ and $x=a$ with the first derivation at this point

1- $\Psi(x)$ is continuous it must be $\psi_I(0) = \Psi_{II}(0)$ at $x=0$

We get

$$A+B=C+D \quad (2-19)$$

And

$$\psi_I(a) = \Psi_{II}(a) \text{ At } x=a$$

We used the Bloch theorem we get

$$\exp(ik(a+b))[A\exp(-iab) + B\exp(iab)] = C\exp(\beta a) + D\exp(-\beta a) \quad (2-20)$$

2- The continuity of derivation at $x=0$ and $x=a$ means

$$\frac{d\Psi_I(x)}{dx} = \frac{d\Psi_{II}(x)}{dx} \quad (2-21)$$

At $x=0$ we have

$$i\alpha(A - B) = \beta(C - D) \quad (2-22)$$

In $x=a$

$$\exp(ik(a+b))i\alpha[A\exp(-iab) - B\exp(iab)] = \beta[C\exp(\beta a) - D\exp(-\beta a)] \quad (2-23)$$

The solution of this system of equations with four unknowns is represented as 4×4 matrix form with determinant will be equal 0

$$\begin{pmatrix} 1 & 1 & -1 \dots \dots \dots -1 \\ i\alpha & -i\alpha & -\beta \dots \dots \dots \beta \\ \exp(ik(a+b))\exp(-iab) & \exp(ik(a+b))\exp(iab) & -\exp(\beta a) \dots \dots -\exp(-\beta a) \\ \exp(ik(a+b))i\alpha \exp(-iab) & -\exp(ik(a+b))i\alpha \exp(iab) & -\beta \exp(\beta a) \dots \dots \beta \exp(-\beta a) \end{pmatrix} \begin{bmatrix} A \\ B \\ C \\ D \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (2-24)$$

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The solution of this determinant with A, B, C and D not equal zero donated in this formulate

$$\frac{\alpha^2 - \beta^2}{2\alpha\beta} \sinh(\alpha a) \sin(\beta b) + \cosh(\alpha a) \cos(\beta b) = \cos(k(a + b)) \quad (2-25)$$

The first member of this equation depends only on E, through a and b are constants, so we can therefore be written as P (E). gets so

$$P(E) = \cos k(a + b) \quad (2-26)$$

The figure II-3 shows P (E). By the Bloch theorem, k must be real. As a result, there is no possible solution to (2-26) for $-1 \leq P(E) \leq 1$. This condition defines permissible energy ranges, hatched in (Figure II-3), called permissible energy bands, separated by ranges of forbidden energies, called band of forbidden energy.

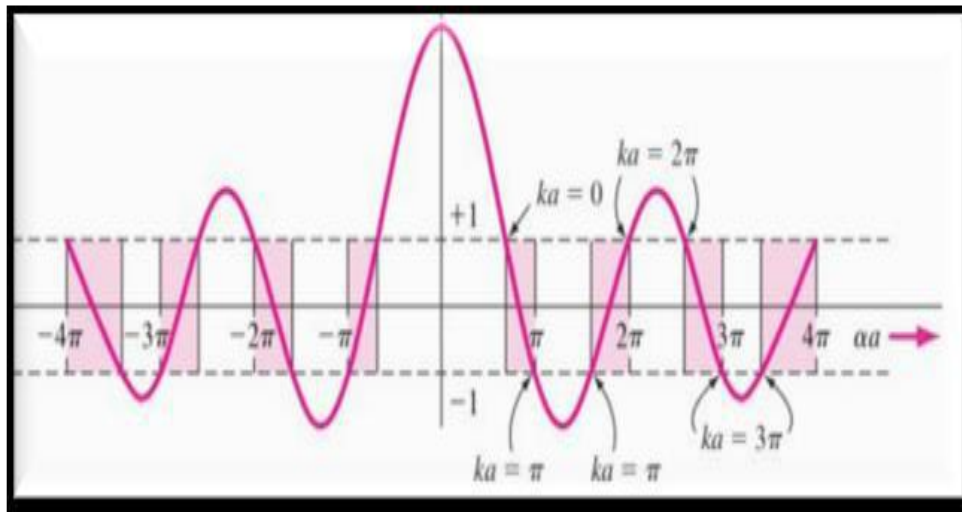


Figure II-3: Graphical solution of the compatibility equation $(P/qa) \sin qa + \cos qa = \cos ka$ of the Kronig-Penney model.

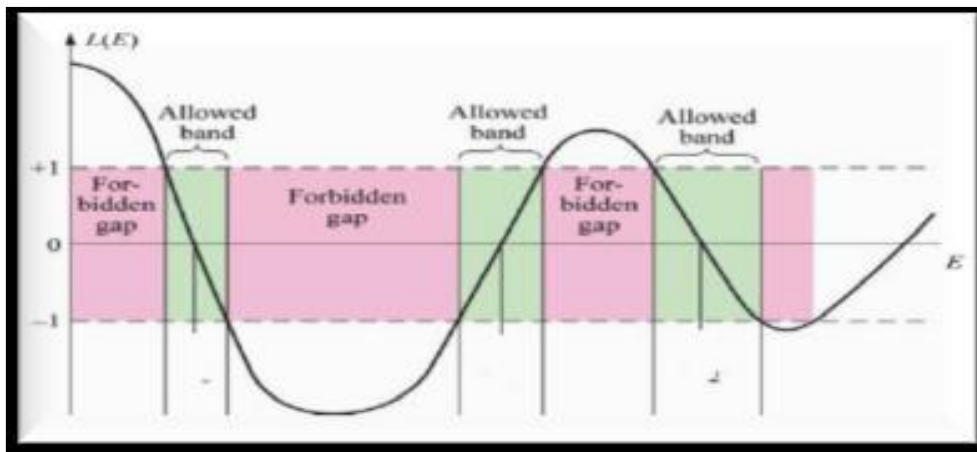


Figure II-4: representation of the bands energies

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We can also obtain from Equation (2-25), the energy of an electron depending on k . This calculation provides a diagram $E(k)$ such that shown in (Figure II-5).

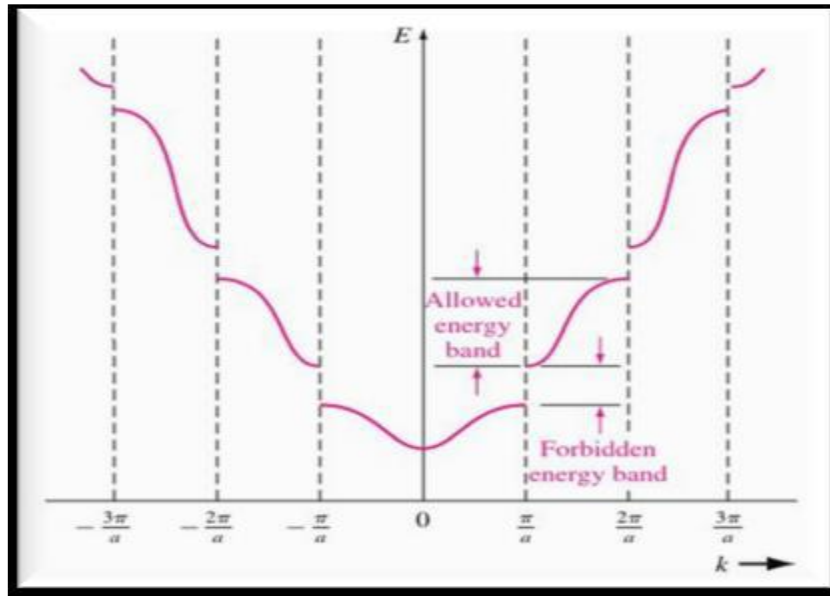


Figure II-5: the energy as function of k

Given the periodicity of the crystal lattice, whose period is equal to $a + b$, and that of the reciprocal lattice, in the space of k , of periodicity $\frac{2\pi}{a+b}$; extend the curve of $E(k)$ from $-\infty$ to $+\infty$ with a period $\frac{2\pi}{a+b}$ which gives the permissible energies according to k for all the crystal dimensional [14].

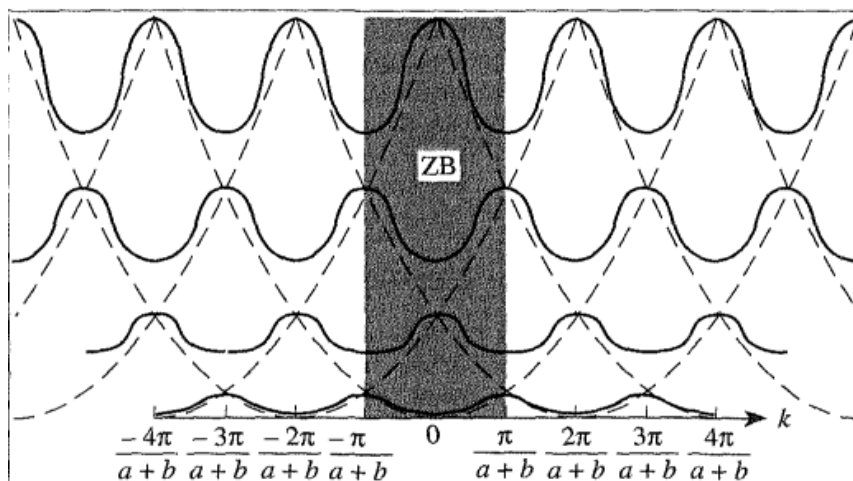


Figure II-6: Energy as a function of k , repeated with $\frac{2\pi}{a+b}$. The first zone of Brillouin (ZB) is represented in gray.

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Applying the Born-von Karman boundary conditions for the expression of k for the one-dimensional crystal yields the values for k :

$$\exp(ikN(a+b)) = 1 \rightarrow k = \frac{2\pi n}{N(a+b)} \quad (2-27)$$

Where

N , the number of atoms in the case of a one-dimensional crystal

The length of the crystal is equal to $N(a+b)$. Since we limit our study of the first Brillouin zone, the k values which have to be considered are given by the following relationship.

$$\frac{-\pi}{a+b} \leq k < \frac{\pi}{a+b} \quad [14].$$

II-II-4-The Effective Mass Concept

The concept of effective mass is extremely helpful, in that it a lot enables us to treat the Bloch electron in an approach analogous to a free electron. Nonetheless, the Bloch electron exhibits many extraordinary properties which are unknown to those of a free electron [15].

We can define the group velocity as the velocity of the wave function of the electrons (analogous to the speed of sinusoidal wave) this can be written as:

$$\phi_k(\mathbf{r}, t) = U_k(\mathbf{r})e^{i(\mathbf{k} \cdot \mathbf{r} - \omega t)} \quad (2-28)$$

Since the wave function for a Bloch-type wave packet extends over the entire crystal lattice, the group velocity for such a wave packet is given by

$$\mathbf{v}_g = \frac{d\omega}{dk} = \left(\frac{1}{\hbar} \right) \frac{dE}{dk} \quad (2-29)$$

The group velocity of an electron wave packet is in the direction perpendicular to the constant-energy surface at a given wave vector k in k -space. It's can be determined by the gradient of energy with respect to the wave vector k .

If a Lorentz force F , which may be due to either an electric field or a magnetic Field, applies to the electrons in a crystal, then the wave vector of electrons will change with the applied Lorentz force, according to the following relation:

$$F = -q(\varepsilon + \mathbf{v}_g \wedge B) = \hbar \left(\frac{dk}{dt} \right) \quad (2-30)$$

Where

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E is the electric field.

B is the magnetic flux density.

The product $\hbar \left(\frac{dk}{dt} \right)$ is referred to as the change of crystal momentum. Equation (2-30) shows that the external applied force acting on an electron tends to change the crystal momentum or the electron wave vector in a crystal lattice. The electron effective mass in a crystal lattice can be defined by

$$F = m^* a = m^* \left(\frac{dv_g}{dt} \right) \quad (2-31)$$

[15]

Replaced F and a by his value:

$$m^* = \frac{F}{a} = \left[\hbar \left(\frac{dk}{dt} \right) \right] / \frac{d}{dt} \left[\frac{1}{\hbar} \frac{dE}{dt} \right] \quad (2-32)$$

And the final expression of effective mass is:

$$m^* = \hbar^2 \left[\frac{d^2 E}{dk^2} \right]^{-1} \quad (2-33)$$

II-II-4-1-Effective Mass Tensor

In three dimensional crystals the electron acceleration will not be collinear. Thus, in general we have an effective mass tensor.

$$\frac{dv_g}{dt} = m_{xx}^{-1} F_x \hat{x} + m_{yx}^{-1} F_x y + m_{zx}^{-1} F_x \hat{z} \quad (2-34)$$

$$\frac{1}{m^*} = \begin{pmatrix} m_{xx}^{-1} & m_{xy}^{-1} & m_{xz}^{-1} \\ m_{yx}^{-1} & m_{yy}^{-1} & m_{yz}^{-1} \\ m_{zx}^{-1} & m_{zy}^{-1} & m_{zz}^{-1} \end{pmatrix} \quad (2-35)$$

The crystal and therefore the k -space can be aligned to the principal axis of the system centered at a band extrema. Since E_K relationship is parabolic at that point, all off-diagonal terms in the tensor will disappear [16].

II-II-4-2-Sign of effective mass

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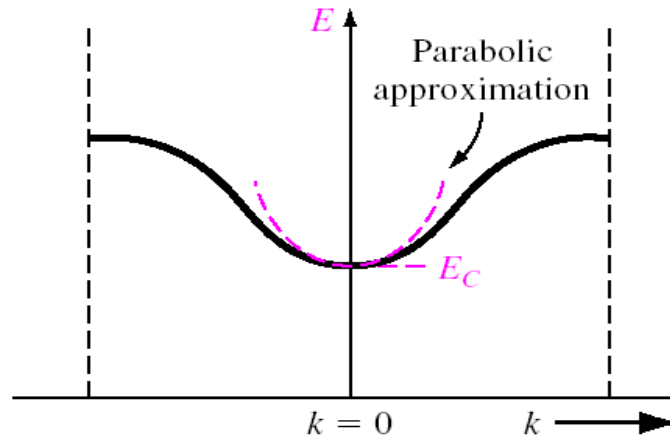


Figure II-7: parabolic approximation for E-k diagram in the conduction band

If we are in the conduction band the values of energy written as

$$E_k = E_c + \frac{\hbar^2 k^2}{2m_e^*} \quad (2-36)$$

In this case the effective mass is in the lowest band, they have a positive sign

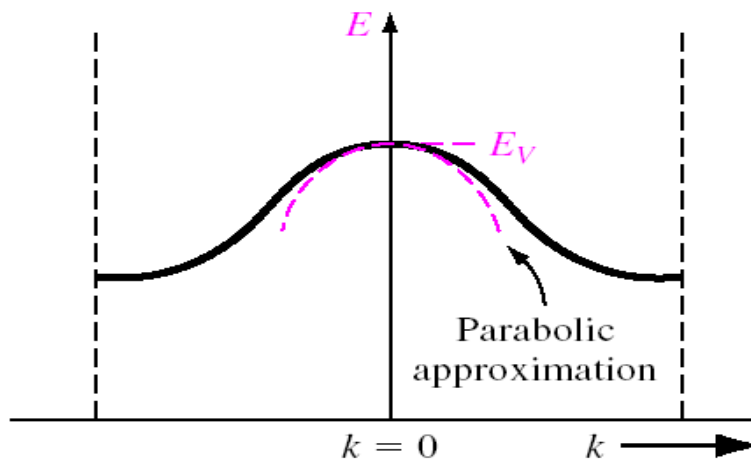


Figure II-8: parabolic approximation for E-k diagram in the valence band.

In the second time, the values of energy were little to that of the valence band, it's can written as:

$$E_k = E_v + \frac{\hbar^2 k^2}{2m_h^*} \quad (2-37)$$

We observed that E, k, \hbar is a positive constant, and the values of E_k decrease, it means that the value of the mass is negative[17].

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II-III-Equilibrium Properties of Semiconductors

II-III-1-Carrier Concentration and Fermi Level

We first consider the intrinsic case without impurities added to the semiconductor. The number of electrons (occupied conduction-band levels) is given by the total number of states $N(E)$ multiplied by the occupancy $F(E)$, integrated over the conduction band,

$$n = \int_{E_c}^{\infty} N(E)F(E)dE \quad (2-38)$$

The density of states $N(E)$ can be approximated by the density near the bottom of the conduction band for low-enough carrier densities and temperature:

$$N(E) = M_c \frac{\sqrt{2} m_{de}^{*3/2} (E - E_C)^{1/2}}{\pi^2 \hbar^3} \quad (2-39)$$

M_c , is the number of equivalent minima in the conduction band

M_{de}^* is the density-of-state effective mass of electrons [18].

General expressions for the equilibrium densities of electrons and holes in a semiconductor can be derived using the Fermi–Dirac (F-D) distribution function and the density-of-states function. For undoped and lightly doped Semiconductors, the Maxwell–Boltzmann (M-B) distribution function is used instead of the F-D distribution function. If one assumes that the constant-energy surfaces near the bottom of the conduction band and the top of the valence band are spherical, then the equilibrium distribution functions for electrons in the conduction band and holes in the valence band may be described in terms of the F-D distribution function[19] .

The F-D distribution function for electrons in the conduction band is given by:

$$f_n(E) = \frac{1}{\left[1 + e^{(E-E_f)/K_B T}\right]} \quad (2-40)$$

Now to evaluate the integral (2-36)

$$n = \frac{1}{2\pi^2 \hbar^3} (2m_e^*)^{3/2} \int_{E_c}^{\infty} (E - E_C)^{1/2} \exp\left[-\frac{(E - E_F)}{KT}\right] dE \quad (2-41)$$

We make a change of variables $y = (E - E_C)/K_B T$ we get:

$$n = \frac{1}{2\pi^2 \hbar^3} (2m_e^* K_B T)^{3/2} \exp\left[-\frac{(E - E_F)}{KT}\right] \int_0^{\infty} \sqrt{y} \exp(-y) dy \quad (2-42)$$

After resolution, the result is

$$n = \frac{1}{2\pi^2 \hbar^3} (2m_e^* K_B T)^{3/2} \exp\left[-\frac{(E_C - E_F)}{KT}\right] \frac{\sqrt{\pi}}{2} = N_c \exp\left[-\frac{(E_C - E_F)}{KT}\right] \quad (2-43)$$

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With:

$$N_C = 2 \left(\frac{2\pi m_e^* KT}{\hbar^2} \right)^{3/2}$$

(2-44)

N_C : called the "effective density of states in the conduction band"[13][18].

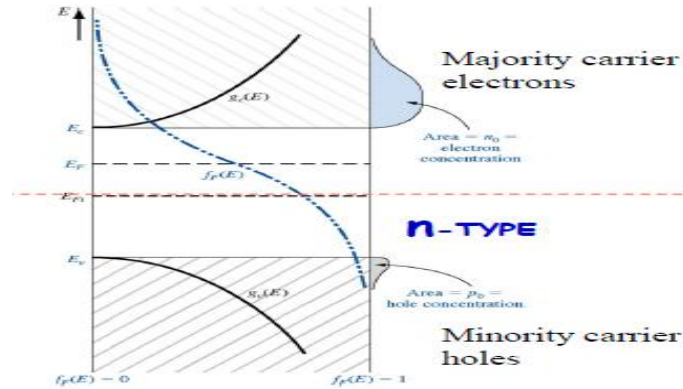


Figure II-9: graphic representation of density of state for a semiconductor type-n.

And the F-D distribution function for holes in the valence band can be expressed by:

$$f_n(E) = \frac{1}{\left[1 + e^{(E_F - E)/K_B T} \right]} \quad (2-45)$$

Doing the same work as in the case of distribution for electron, we get:

$$p = N_v \exp \left[-\frac{(E_F - E_v)}{KT} \right] \quad (2-46)$$

With:

$$N_v = 2 \left(\frac{2\pi m_h^* KT}{\hbar^2} \right)^{3/2} \quad (2-47)$$

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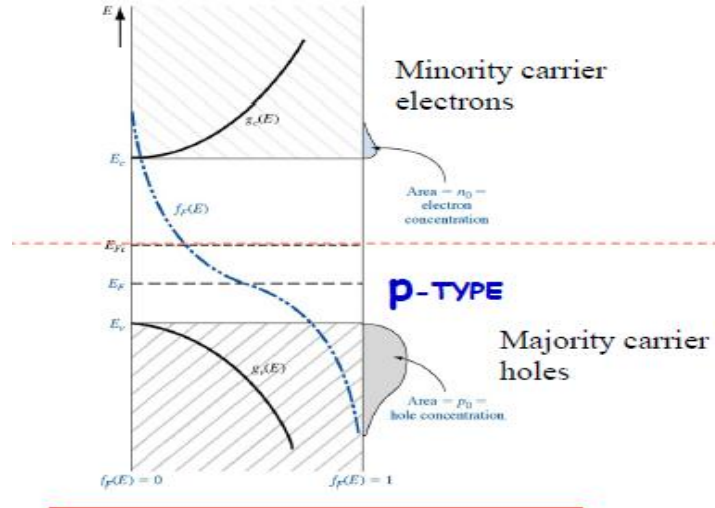


Figure II-10: graphic representation of density of state for a semiconductor type-p.

II-III-2-Mass action law

$$np = n_i^2 \quad (2-48)$$

$$np = N_c N_v \exp\left[-\frac{(E_c - E_F)}{KT}\right] \exp\left[-\frac{(E_F - E_v)}{KT}\right]$$

$$np = N_c N_v \exp\left[\frac{(E_v - E_c)}{KT}\right] = N_c N_v \exp\left(\frac{-E_g}{KT}\right) \quad (2-49)$$

This is true in general for non-degenerate semiconductors. For the case of intrinsic semiconductors we have the added constraint that $n_i = p_i$ so that

$$n_i = p_i = \sqrt{n_i p_i} = \sqrt{N_c N_v} \exp\left(\frac{-E_g}{2KT}\right) \quad (2-50)$$

Or

$$n_i = p_i = 2 \left(\frac{K_B T}{2\pi\hbar^2}\right)^{3/2} (m_e^* m_h^*)^{3/4} \exp\left(\frac{-E_g}{2KT}\right) \quad (2-51)$$

The expression of energy of Fermi level is obtained from equations (2-43) and (2-46)

$$n = N_c \exp\left[-\frac{(E_c - E_F)}{KT}\right]; \quad p = N_v \exp\left[-\frac{(E_F - E_v)}{KT}\right]$$

Electron concentration

hole concentration

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$$E_{Fi} = \frac{1}{2}(E_c + E_v) + \frac{1}{2}KT \ln \left(\frac{N_v}{N_c} \right) \quad (2-52)$$

$$E_{Fi} = \frac{1}{2}(E_c + E_v) + \frac{3}{4}KT \ln \left(\frac{m_h^*}{m_e^*} \right) \quad (2-53)$$

We have:

$$E_{midgap} = \frac{1}{2}(E_c - E_v)$$

$$E_{Fi} - E_{midgap} = \frac{3}{4}KT \ln \left(\frac{m_h^*}{m_e^*} \right) \quad (2-54)$$

According the equation (2-54) we conclude that in intrinsic semiconductor, the Fermi level is not exactly at the center between conduction and valence bands.

II-III-3-Ionization of impurity atoms in the extrinsic semiconductors

Let us consider,

n : thermal-equilibrium concentration of electrons

p : thermal-equilibrium concentration of holes

n_d : concentration of electrons in the donor energy state

p_a : concentration of holes in the acceptor energy state

N_d : concentration of donor atoms

N_a : concentration of acceptor atoms

N_d^+ : concentration of positively charged donors (ionized donors)

N_a^- : concentration of negatively charged acceptors (ionized acceptors)

By definition,

$$N_d^+ = N_d - n_d \quad (2-55)$$

$$N_a^- = N_a - p_a \quad (2-56)$$

By the charge neutrality condition,

$$n_0 + N_a^- = N_d^+ + p_0 \quad (2-57)$$

$$n_0 + (N_a - p_a) = p_0 + (N_d - n_d) \quad (2-58)$$

Assume complete ionisation,

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$$n_d = p_a = 0$$

Then, eq (2-58) becomes,

$$n + N_a = p + N_d$$

Arranged the equation:

$$n - p = N_d - N_a \tag{2-59}$$

At the room temperature:

$$N_a = N_a^- \quad ; \quad N_d = N_d^+$$

By eq (2-59) and the Mass-Action law we get:

$$(p+n)^2 = (p-n)^2 + 4pn \tag{2-60}$$

$$(p+n)^2 = (N_d - N_a)^2 + 4n_i^2$$

$$(p+n) = \sqrt{(N_d - N_a)^2 + 4n_i^2} \tag{2-61}$$

Where

(2-59)+ (2-61) we get:

$$n = \frac{1}{2} \left[(N_d - N_a) + \sqrt{(N_d - N_a)^2 + 4n_i^2} \right] \tag{2-62}$$

(2-61) - (2-59) we get:

$$p = \frac{1}{2} \left[(N_a - N_d) + \sqrt{(N_d - N_a)^2 + 4n_i^2} \right] \tag{2-63}$$

Using Relationships (2-61) and (2-48); for an N-type semiconductor, $N_d \gg N_a$ and $N_d \gg n_i$

The electron and hole concentrations are given by:

$$\left\{ \begin{array}{l} n \equiv N_d \\ p \equiv \frac{n_i^2}{N_d} \end{array} \right\} \tag{2-64}$$

In the case of semiconductor type p, the concentration of electron and hole we have a condition of $N_a \gg N_d$ and $N_a \gg n_i$, so:

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$$\left\{ \begin{array}{l} p \equiv N_a \\ n \equiv \frac{n_i^2}{N_a} \end{array} \right\} \quad (2-65)$$

II-III-4-Position of Fermi level

Sc type N:

We have $n = N_d = N_c \exp\left[-\frac{(E_c - E_d)}{KT}\right]$

Doing the logarithm of this expression we get:

$$E_c - E_F = KT \ln\left(\frac{N_c}{N_d}\right) \quad (2-66)$$

Similarly for a p-doped material it is easily shown by combining equations (2-46) and (2-65) that

$$E_F - E_v = KT \ln\left(\frac{N_v}{N_a}\right) \quad (2-67)$$

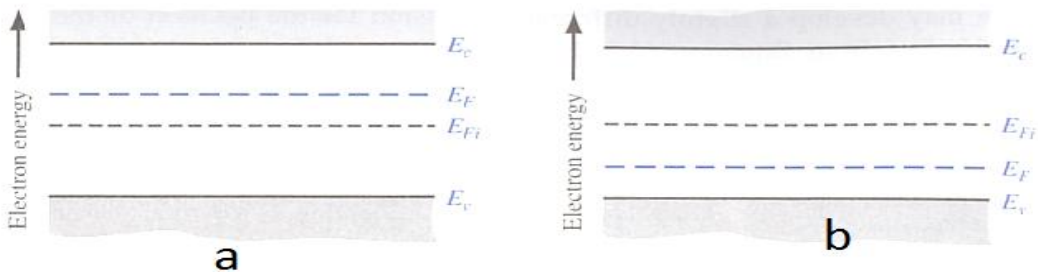


Figure II-11: Position of Fermi level for an (a) n-type and (b) p-type semiconductor

It is seen that for high donor concentrations, the difference $(E_c - E_F)$ is reduced, hence the Fermi level will move closer to the bottom of the conduction band. Similarly, a high acceptor concentration will move the Fermi level closer to the valence band. This means that for extrinsic semiconductors, the Fermi level is different from the intrinsic Fermi level, i.e. $E_F \neq E_i$ [20].

II-IV-Semiconductor hors equilibrium

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Any motion of free carriers in a semiconductor leads to a current. This motion can be caused by an electric field due to an externally applied voltage, since the carriers are charged particles. We will refer to this transport mechanism as carrier drift. In addition, carriers also move from regions where the carrier density is high to regions where the carrier density is low. This carrier transport mechanism is due to the thermal energy and the associated random motion of the carriers. We will refer to this transport mechanism as carrier diffusion. The total current in a semiconductor equals the sum of the drift and the diffusion current.

As one applies an electric field to a semiconductor, the electrostatic force causes the carriers to first accelerate and then reach a constant average velocity, v , due to collisions with impurities and lattice vibrations. The ratio of the velocity to the applied field is called the mobility. The velocity saturates at high electric fields reaching the saturation velocity. Additional scattering occurs when carriers flow at the surface of a semiconductor, resulting in a lower mobility due to surface or interface scattering mechanisms.

Diffusion of carriers is obtained by creating a carrier density gradient. Such gradient can be obtained by varying the doping density in a semiconductor or by applying a thermal gradient.

Both carrier transport mechanisms are related since the same particles and scattering mechanisms are involved. This leads to a relationship between the mobility and the diffusion constant called the Einstein relation.

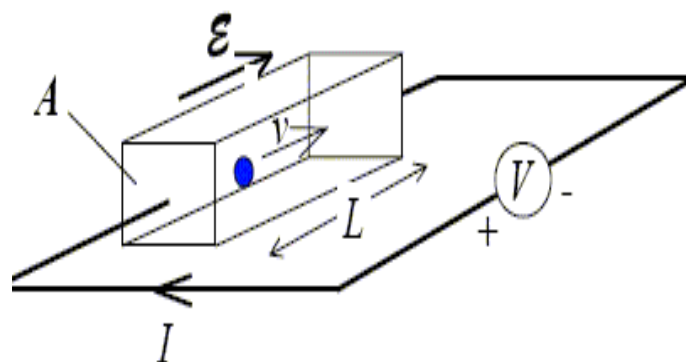


Figure II-12: Drift of a carrier due to an applied electric field.

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Assuming that all the carriers in the semiconductor move with the same average velocity, the current can be expressed as the total charge in the semiconductor divided by the time needed to travel from one electrode to the other, [20]or:

$$I = \frac{Q}{t_r} = \frac{Q}{L/v} \quad (2-68)$$

Where t_r is the transit time of a particle, traveling with velocity, v , over the distance L .

The current density, J , can then be rewritten as a function of the charge density :

$$\vec{J} = \frac{\vec{I}}{A} = \frac{Q}{AL} \vec{v} = \rho \vec{v} \quad (2-69)$$

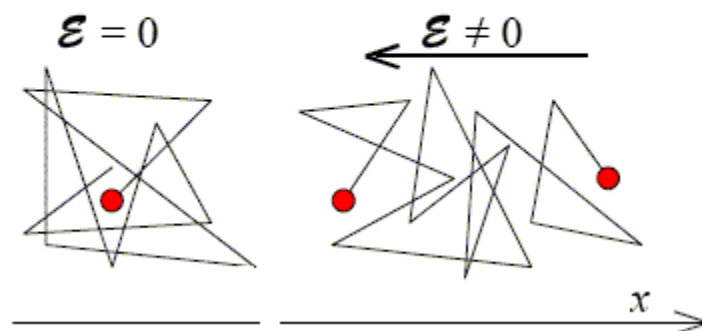
If the carriers are negatively charged electrons, (sc type N) the current density equals:

$$\vec{J} = -en \vec{v} \quad (2-70)$$

And for sc type p the current density is:

$$\vec{J} = en \vec{v} \quad (2-71)$$

It should be celebrated that carriers do not follow a straight path beside the electric field lines. in its place they bounce around in the semiconductor and constantly change direction and velocity due to scattering. This action occurs even when no electric field is applied and is due to the thermal energy of the carriers. Thermodynamics teaches us that electrons in a non-degenerate and non-relativistic electron gas have a thermal energy of $kT/2$ per particle per degree of freedom. A typical thermal velocity at room temperature is around 10^7 cm/s, which exceeds the typical drift velocity in semiconductors. The carrier motion in the semiconductor in the absence and in the presence of an electric field can therefore be visualized as in (Figure II-13)



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Figure II-13: Random motion of carriers in semiconductors with and without an applied electric field

$$dn = -\frac{1}{\tau_n} n(t) dt \quad (2-72)$$

$$\int \frac{dn}{n} = \int_{t_0}^t -\frac{dt}{\tau_n}$$

$$n(t) = n(t_0) \exp\left[\frac{-(t-t_0)}{\tau_n}\right] \quad (2-73)$$

Amid all the electrons in the conduction band there are $n(t_0)$ electrons which, at the instant $t = t_0$ undergo a collision event. Let us follow the evolution of this electron population. At $t > t_0$ some of these electrons will already have undergone new collisions. Therefore, at $t > t_0$ there is a smaller number of electrons, $n(t)$, which have not yet undergone a collision result. The population of these electrons, $n(t)$, decreases between t and $t+dt$ by an amount dn according to the following equation:

In the absence of an applied electric field; we now analyze the carrier motion considering only the average velocity, $\langle \vec{v} \rangle$ of the carriers. Applying Newton's law, we state that the acceleration of the carriers is proportional to the applied force:

$$F = ma = m^* \frac{dv}{dt} = -e\xi \quad (2-74)$$

$$v(t) = v(t_0) - \frac{1}{m^*} e(t-t_0)\xi \quad (2-75)$$

If the collision is isotropic

$$v(t) = -\frac{1}{m^*} e(t-t_0)\xi$$

In the case of application of electric field, the expression of velocity will rewrite as:

$$\langle v \rangle = -\frac{e}{n(t_0)m^*} \int_{n(t_0)}^{n(t)} (t-t_0)\xi(-dn)$$

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$$\langle v \rangle = -\frac{e}{n(t_0)m^*} \int_{t_0}^t (t-t_0) \frac{n(t_0)}{\tau_n} \exp\left(-\frac{t-t_0}{\tau_n}\right) dt$$

After evaluating the integral the final expression is:

$$\langle v \rangle = -\frac{e\tau_n}{m^*} \xi = -\mu_n \xi \quad (2-76)$$

Where μ_n is the mobility of a particle in the conduction band in a semiconductor, it's large if its mass is small and the time between scattering events is large.

Then we can describe the drift current as a function of the mobility, yielding:

for electron

$$\vec{J}_n = en\mu_n \vec{\xi} \quad (2-77-a)$$

For holes

$$\vec{J}_p = ep\mu_p \vec{\xi} \quad (2-77-b)$$

Where

$$\begin{aligned} \vec{J} &= \vec{J}_n + \vec{J}_p \\ \vec{J} &= en\mu_n \vec{\xi} + ep\mu_p \vec{\xi} = e(n\mu_n + p\mu_p) \vec{\xi} \end{aligned} \quad (2-78)$$

We can write also

$$\vec{J} = \sigma \vec{\xi}$$

Where

σ Represent the conductivity of material and

$$\sigma = e(n\mu_n + p\mu_p) \quad (2-79)$$

In the other time we can defined the resistivity of the material as the inverse of the conductivity [21].

$$\rho = \frac{1}{\sigma} = \frac{1}{e(n\mu_n + p\mu_p)} \quad (2-80)$$

II-IV-1-The Hall Effect

The Hall effect is used in common practice to measure certain properties of semiconductors: explicitly, the carrier concentration (even down to a low level of $10^{12} \sim m^{-3}$),

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the mobility, and the type (n or p). It is a key analytical instrument since a simple conductance measurement [18].

The hall effect is a phenomenon that occurs in a semiconductor carrying a current when it is located in a magnetic field perpendicular to the current .the charge carriers in the semiconductor become deflected by the magnetic field and give rise to an electric field (Hall field)that is perpendicular to together the current and magnetic field .if the current density J_x is along x and the magnetic field B_z along z then the hall field is also along +y or -y depending on the polarity of the charge carriers in the material[21].

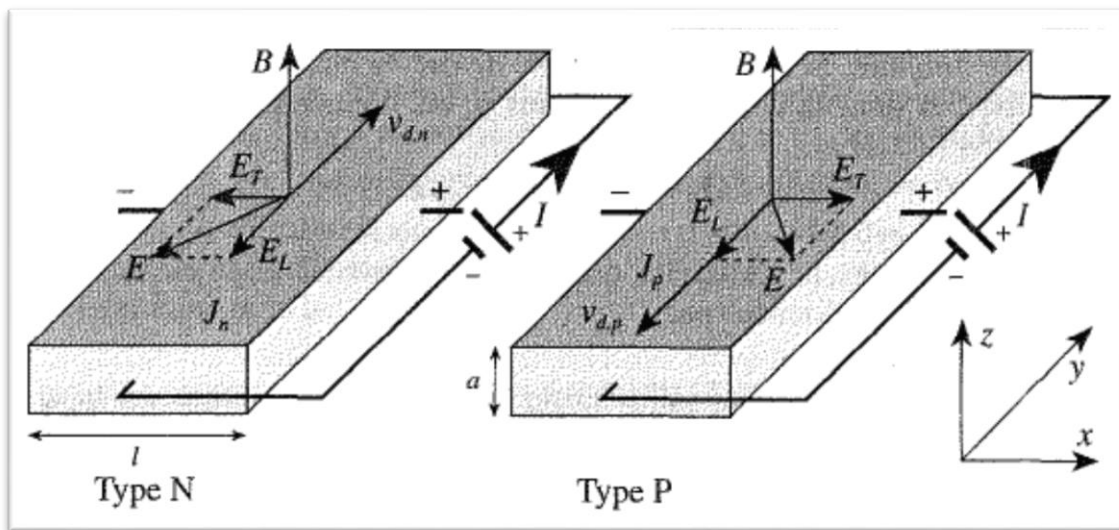


Figure II-14: Hall Effect geometry in sc type n and sc type p

We may calculate the Hall field in the following manner. The Lorentz force acting on an electron is:

$$F = q(E + v \wedge B) = 0 \quad (2-81)$$

This becomes:

$$qE_y = qv_x B_z$$

We can write:

$$V_H = +E_H W$$

Where

$$v_x \text{ is the drift velocity } v_x = \frac{J}{ne}$$

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Where n is the number of charge carriers per unit volume.

$$E_H = \frac{J}{ne} B_z = R_H JB \quad (2-82)$$

Where R_H called Hall coefficient, and

$$R_H = -\frac{1}{ne} \quad (2-83-a)$$

Generally for N-type material from the Hall field is developed in a negative direction compared to the field developed in a P-type material, a negative sign is used while denoting hall coefficient R_H

For sc type p $R_H = \frac{1}{pe}$ (2-83-b)

For a semiconductor with significant concentrations of both types of carriers:

$$R_H = \frac{E_H}{JB} = \frac{p\mu_h^2 - n\mu_e^2}{e(n\mu_e + p\mu_h)} \quad (2-84)$$

II-IV-1-1_Hall Effect and Mobility:

When one carrier dominates, we can write the conductivity:

We have: $\sigma = ne\mu_e$ for electrons or $\sigma = pe\mu_p$ (for holes)

So the mobility can be written:

$$\mu = R_H / \sigma \quad (2-85)$$

II-IV-1-2-Diffusion current

In semiconductors, current can be created due to a concentration gradient of carriers. The current in this case is called diffusion current and is derived below. Consider a piece of semiconductor in which, for whatever cause, there is an electron concentration gradient.

By analogy with the laws of diffusion in gases or liquids one can simply imagine that electrons will diffuse from the region where their concentration is highest in the region where it is lowest. The flux of electrons, F_n resulting from the diffusion process is directly proportional to the electron concentration gradient, $\frac{dn}{dx}$. This flux, when multiplied by $-q$, is

equal to the diffusion current density of the electrons: [13]

In the absence of electric field, $E=0$

$$F_n = -D_n \frac{dn}{dx} \quad (2-86)$$

Where

$$J_n = -qF_n = D_n \frac{dn}{dx}$$

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(2-87)

Similarly for holes we have:

$$F_p = -D_p \frac{dp}{dx} \quad (2-88)$$

So:

$$J_n = qF_n = -qD_p \frac{dp}{dx} \quad (2-89)$$

D_n And D_p are constants called "diffusion coefficients" for electrons and holes, respectively. They represent the ease or the "fluidity" with which the carriers can move and diffuse in the semiconductor material.

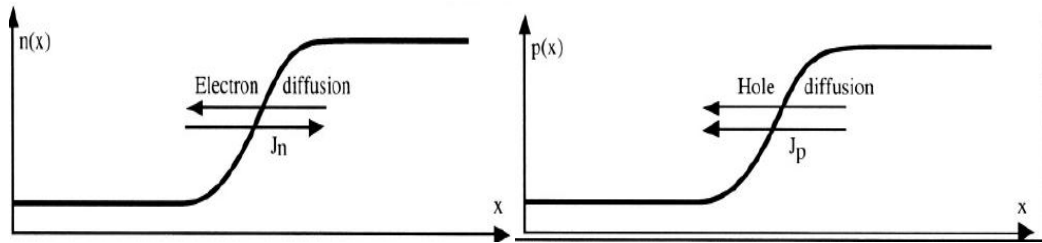


Figure II-15: carriers concentration gradient and the resulting diffusion currents.

In the presence of electric field:

At 1D:

$$J_n = q\mu_n n\xi + qD_n \frac{dn}{dx} \quad (2-90-a)$$

$$J_p = q\mu_p p\xi + qD_p \frac{dp}{dx} \quad (2-90-b)$$

At 3D:

For electron:

$$J_n = q\mu_n n\xi + qD_n \text{grad}(n) \quad (2-91-a)$$

For holes:

$$J_p = q\mu_p p\xi + qD_p \text{grad}(p) \quad (2-91-b)$$

Where:

$$J = J_n + J_p$$

II-IV-1-3-Einstein relationships:

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In the case when no electric field applied, $J=0$

For electron

$$J_n = q\mu_n n \xi + qD_n \frac{dn}{dx} = 0$$

Where

$$\xi = -\frac{dv}{dx}$$

Replacing the value of energy in the equation, we get:

$$J_n = -q\mu_n n \frac{dv}{dx} + qD_n \frac{dn}{dx} = 0$$

$$\mu_n n \frac{dv}{dx} = D_n \frac{dn}{dx}$$

Replacing n by her value:

$$\frac{dn}{dv} = n_0 \frac{e}{KT} \exp\left(\frac{ev}{KT}\right) = \frac{ne}{KT}$$

The final expression of mobility is:

$$\mu_n = D_n \frac{e}{KT} \quad (2-92-a)$$

For holes same works and

$$\mu_p = D_p \frac{e}{KT} \quad (2-92-b)$$

II-V-conclusion

In the material semiconductor the displacement of charge carriers between the conduction and valence bands who is responsible for the conduction phenomenon, we can distinguish two types of charge carriers n and p and same one of them have a characteristic different from another.

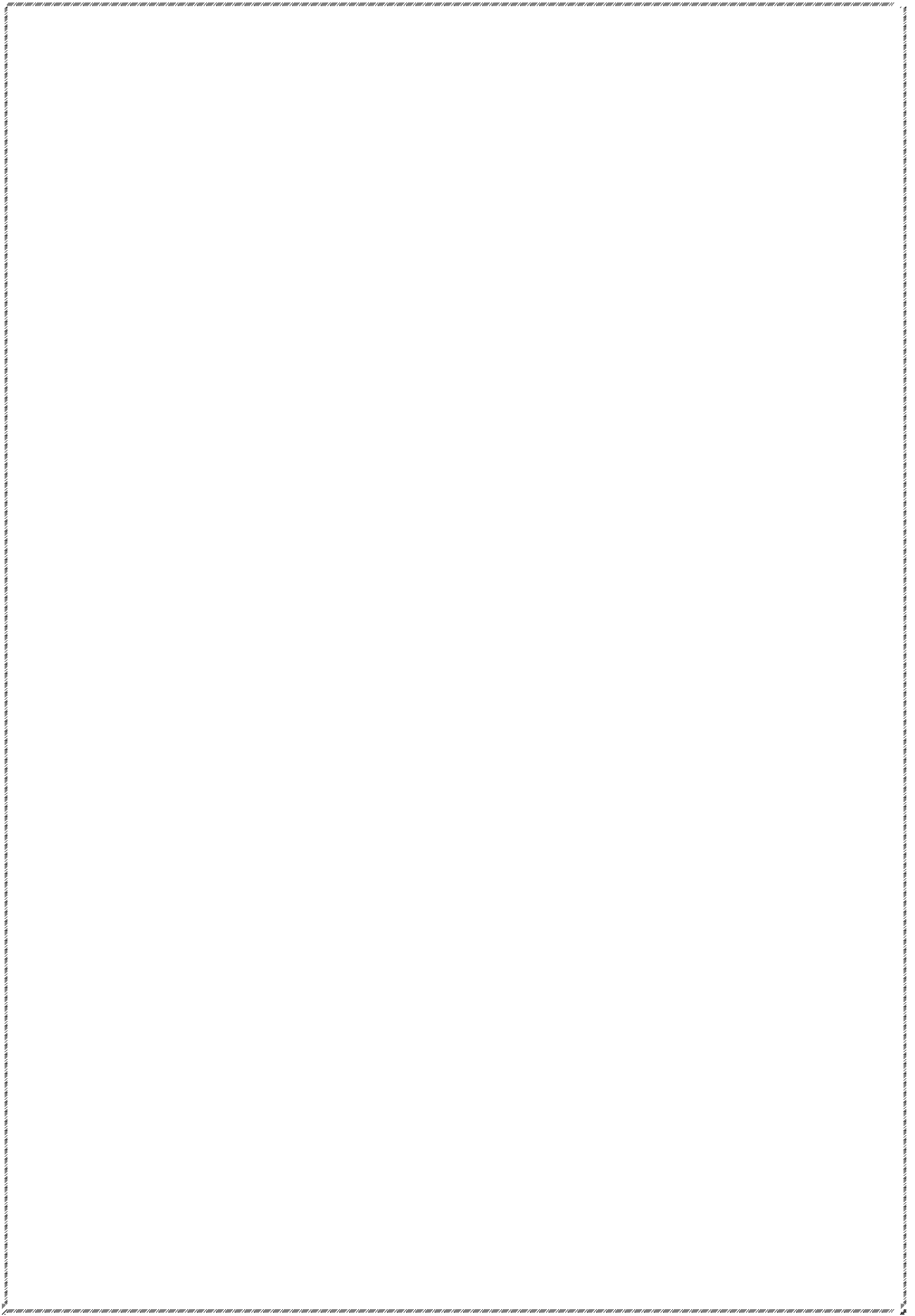
To develop the conductivity of the material we used different technic as variation in concentration of dopant and the variation in temperature and the external applied forces as electric and magnetic fields

The Hall Effect is the best and useful technique to determine the type of charge carriers in the conductive material experimentally.

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The conductivity of material has a direct relationship with the concentration of dopant and the temperature.

Chapter III: Results and Discussions



III-1-Objective of the experiment:

- Determination of hall coefficient for Germanium doped p
- Observation of the Hall Effect, and measurement of the Hall constant of a Ge type P semiconductor

III-2-Manipulation:

The following figure presents the materials that used in our laboratory. In fact, we can measure the Hall coefficient using two baths, first one is direct measure and the second bath is measured with the help of Cassy lab 2 program; we took the second bath.

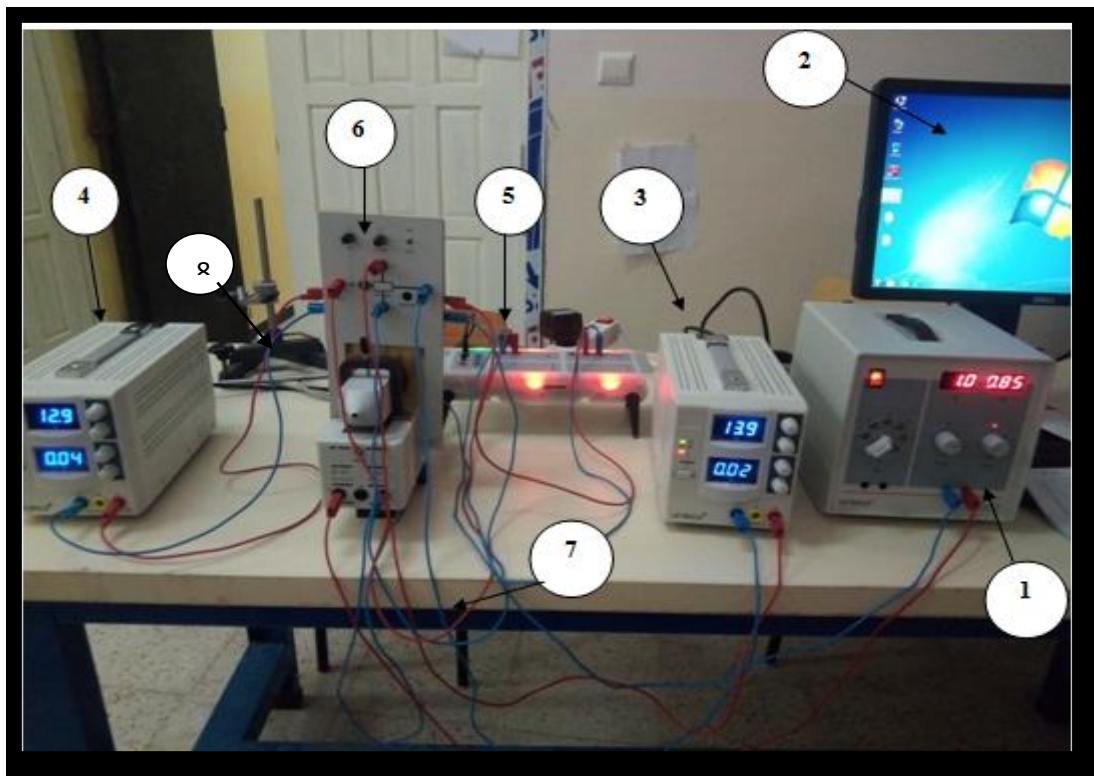


Figure III-1: Materials of manipulation.

Apparatus

- 1- DC Power Supply
- 2- PC with Windows
- 3&4- DC Power Supply
- 5- Leybold Multi clamp
- 6- Base unit for Hall effect
- 7- Extension cable, 15-pole blue and red

8- P-doped Ge plug-in board (Figure 2)

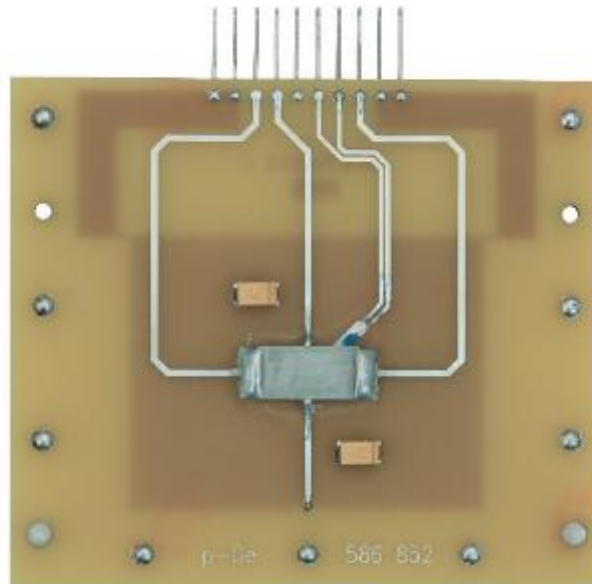


Figure III- 2: P-doped germanium on plug-in board

Technical characteristics

Crystal dimensions: 20mm x 10mm x 1mm

Multiple socket for connecting the printed circuit board to the base unit for studying the Hall effect

Dimensions: 10 cm x 10 cm x 1 cm

Mass: 200 g.

After realization of montage (Figure III-1) and connect the fill we do the measurement, manual and we take the result.

III-3-Measuring the Hall voltage as a function of magnetic field:

In the first we make the experience with measurement of the Hall voltage as a function of the magnetic field in a constant value of current.

We retry our result with a different value of current $I=10\text{mA}$ and $I= 15\text{mA}$.

For $I=15\text{mA}$:

B / T	U_H / V
0,05	0,002
0,12	0,028
0,17	0,049
0,48	0,161

0,54	0,183
0,70	0,236
0,85	0,389
1,17	0,401
1,32	0,457
1,47	0,512
1,62	0,572

For I= 10mA

B/T	U_H/V
0,05	0,00129
0,32	0,06
0,38	0,07355
0,55	0,1129
0,70	0,14645
1,02	0,21032
1,09	0,23097
1,27	0,27097
1,38	0,29806
1,53	0,33484
1,62	0,36065

After the measurement, we represent these values on the graph using the Origine8 program as following figure

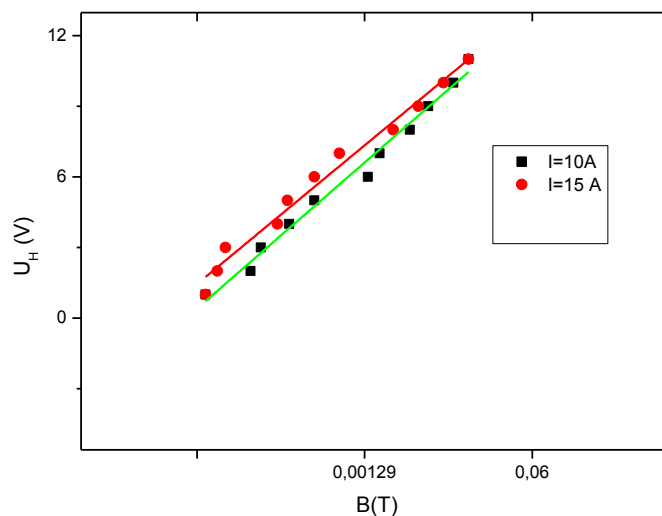


Figure III-3 : Variation of $U_H(v)$ as a function of $B(T)$.

Interpretation of results:

Through the results obtained by the two programs; Cassy lab2 and origin8, we notice a match in the two axes, each of which is a straight line, equivalent to the form $U(B) = K$.

Where K is a constant current.

The term is consistent with the term obtained theoretically, regardless of current intensity

So we conclude that we have proportionally between the hall voltage and the magnetic field passing is the circuit in a constant.

For the measurement with $I=10A$ in the figure 3 the slope:

$$A = \frac{R_H \cdot B}{d} = \frac{2.9806 - 0.07355}{1.38 - 0.38} = 0.22V / T$$

The Hall coefficient R_H is obtained as follows:

$$d = 1 \cdot 10^{-3} \text{m}$$

$$I = 10 \text{ mA}$$

$$R_H = \frac{Ad}{I} = \frac{0.22 \times 10^{-3}}{10^{-2}} = 2.2 \text{mV} / \text{TA}$$

III-4-Measuring the Hall voltage as a function of current:

For the second step we make the experience with measurement of the Hall voltage as a function of the current at a constant value of magnetic field ($B=0.2T$, $B=0.29T$ and $B=0.37T$) and room temperature. For these three different values we measure the $U_H=f(I)$ as the following tables show.

For $B=0.2T$:

$I/A \cdot 10^{-3}$	$U_H/V \cdot 10^{-2}$
1.0	2.61
1.2	2.81
1.3	3.00
1.4	3.20
1.5	3.40
1.6	3.61

1.7	3.8
1.8	4.01
2.0	4.21
2.1	4.42
2.2	4.60
2.3	4.81
2.4	5.00
2.6	5.20
2.7	5.41
2.8	5.58
2.9	5.81
3.0	6.03
3.1	6.21
3.2	6.41
3.3	6.62
3.5	6.80
1.0	7.00
1.2	7.20
1.3	7.40
1.4	7.62

For B=0.29T:

$I/A * 10^{-3}$	$U_H/V * 10^{-2}$
1.2	3.21
1.3	3.41
1.5	3.61
1.6	3.79
1.8	4.01
1.93	4.20
2.08	4.398
2.23	4.596
2.38	4.794

2.53	4.992
2.68	5.19
2.83	5.388
2.98	5.586
3.13	5.784
3.28	5.982

For B=0.37T:

$I/A * 10^{-3}$	$U_H/V * 10^{-2}$
1.3	3.01
1.6	3.21
1.8	3.41
1.9	3.60
2.1	3.80
2.3	4.02
2.5	4.21
2.7	4.41
2.9	4.61
3.1	4.79
3.3	5.01
3.5	5.20
3.7	5.40
3.9	5.61
4.1	5.81
4.3	6.01
4.5	6.22
4.7	6.41
4.8	6.60
5.0	6.81
5.2	7.01

The representation of results by Origin 8 program obtained is donate these illustrates

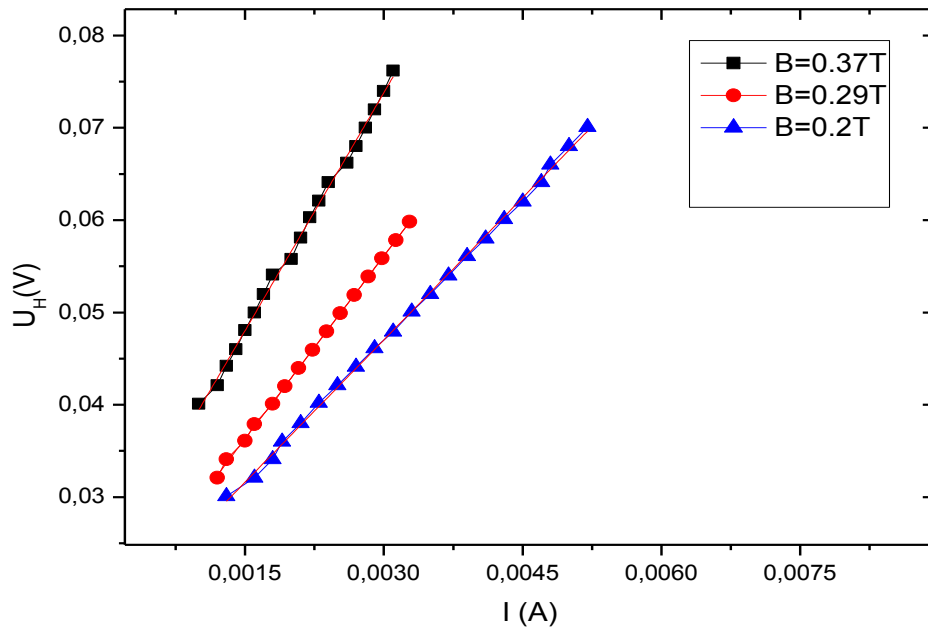


Figure III-4: Hall voltage U_H as function of the current I for different magnetic fields

For the measurement with $B = 0.37$ T in the figure 4 the slope:

$$A = \frac{R_H \cdot B}{d} = \frac{5.20 - 3.41}{3.5 - 1.8} \times 10 = 10.52 \text{ V} / \text{A}$$

Interpretation

The three curves shown in the drawings obtained by Cassy lab2 and origin8 show the change in the hall voltage in terms of t the current passing through the circuit and these results under different values of magnetic field as the three curves is a diagonal line equivalent of the form $U_H (I) = K.I$

III-5-Measuring the Hall voltage as a function of temperature:

To determine our objective of memory we realized this experience, we fixed the current at 30mA and the magnetic field at 300mT, and we change in the values of temperature, started on the room temperature (25C°), and be higher it just (150C°)

T(°C)	U_H/V
92.60	17.51
98.43	13.50
104.01	9.88
107.72	6.76
111.154	3.79
112.23	2.49
114.61	0.03
115.93	-1.27
118.86	-2.83
123.11	-3.986
124.95	-4.50
128.41	-4.76
132.13	-4.76
135.60	-4.76
139.60	-4.76
147.51	-4.76

The result obtained is represented in this graph represented by origin8 program:

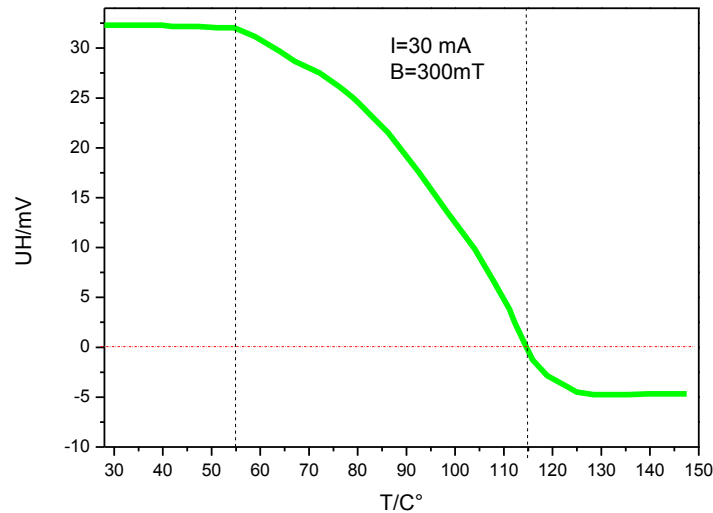


Figure III-5: Hall voltage U_H as function of the temperature T for $I = 30$ mA and different magnetic fields $B=300$ mT.

The tension of hall voltage has a relation to the temperature from the graph, we notice the exponentially decreasing of voltage until there is no value oh tension and there continues to decrease into a gene that takes negative values.

Figure 5 shows first a decrease in Hall voltage with rising temperature. Since the measurements were made with constant current, it is to be assumed that this is attributable to an increase in the number of charge carriers (transition from extrinsic conduction to intrinsic conduction) and the associated reduction in drift velocity v . (Equal currents with increased numbers of charge carriers imply reduced drift velocity). The drift velocity in its turn is connected to the Hall voltage through the Lorentz force. The current in the crystal is made up of both electron currents and hole currents

$$I = A.e(v_n.n + v_p.p)$$

Since in the intrinsic velocity range the concentrations of holes p and of electrons n are approximately equal, those charge carriers will in the end make the greatest contribution to the Hall effect, which have the greater velocity or (since $v = \mu.E$) greater mobility.

Fig. 5 shows accordingly the reversal of the sign of the Hall voltage, typical of p-type materials, above a particular temperature.

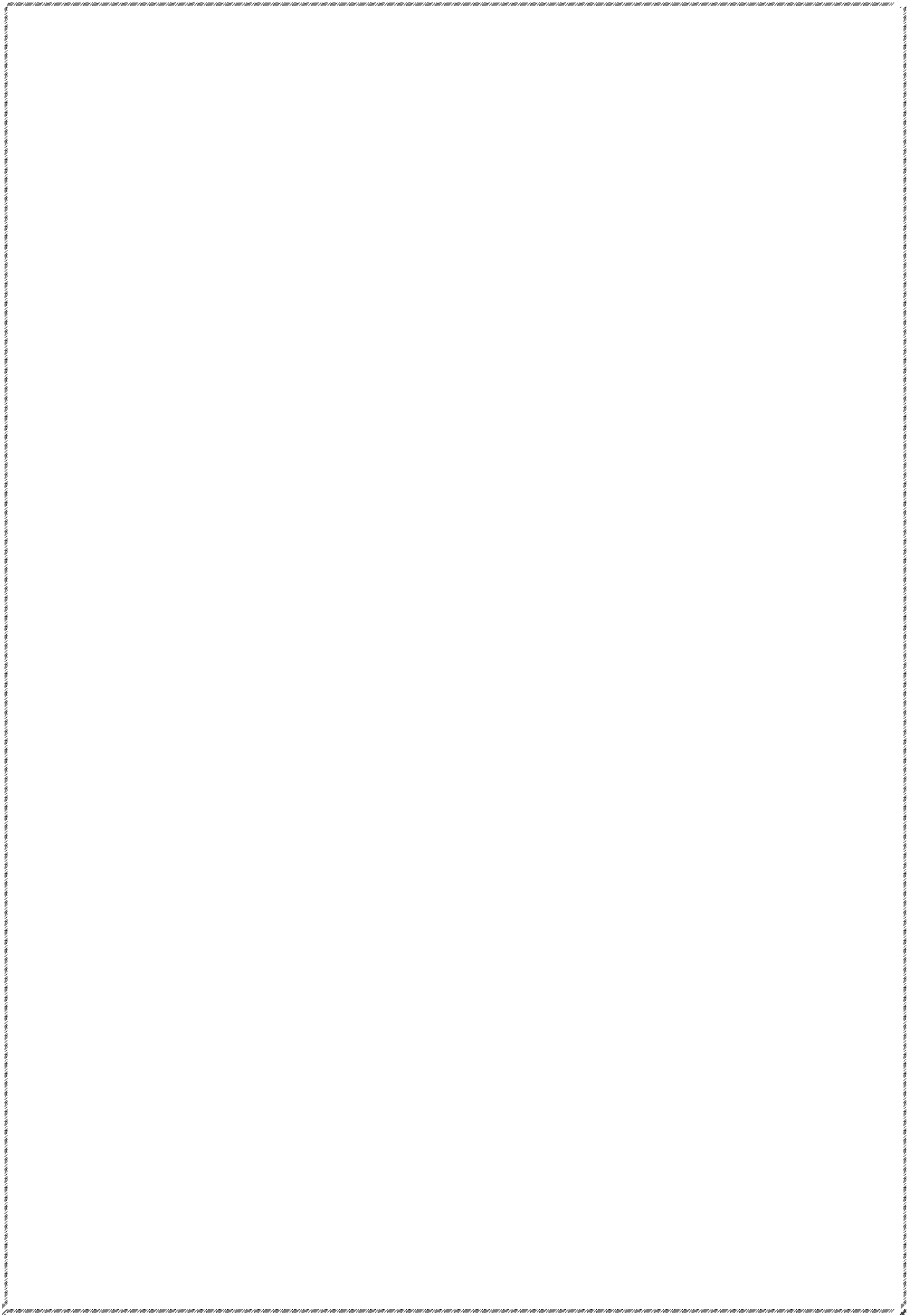
General Conclusion

GENERAL CONCLUSION

In this work we expose an experimental investigation to survey the electrical behavior of Ge-P semiconductor as a function of different parameters: as the first step we change the magnetic field and we measure the Hall voltage; the average is following this equation: $U(B) = K \cdot B$. Where K is constant. Moreover, we extract the Hall coefficient from the slope of the diagram where we found $R_H = \frac{Ad}{I} = \frac{0.22 \times 10^{-3}}{10^{-2}} = 2.2 mV / TA$.

The second party, we investigate the influence of current where we fixed the value of B and we measure the corresponding values of the Hall voltage. We found that the variation is a diagonal line equivalent of the form $U_H(I) = K \cdot I$.

Finally, we report the Hall voltage U_H as function of the temperature T for $I = 30$ mA and different magnetic fields $B = 300$ mT. We notice the exponentially decreasing of voltage until there is no value of tension, and there continues to decrease into a range that takes negative values



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ملخص

يعد اثر هول أحد أهم الطرق البحث التجريبية لتحديد المعاملات المجهرية لانتقال حاملات الشحنة في المعادن و انصاف النواقل المشوبة في شروط التوازن. تتساوى قوة لورنز المؤثرة في حاملات الشحنة المتحركة مع القوة الكهربائية الناتجة في حقل مغناطيسي p عن الحقل الكهربائي لهول لدراسة أثر هول قمنا بوضع عينة نصف ناقلة من مادة الجرمانيوم نوع منتظم . و عند مرور تيار كهربائي بالعينة لا يوازي اتجاه الحقل المغناطيسي تنحرف حاملات الشحنة نتيجة تأثير قوة لورنز و هذا ما يتسبب في نشوء فرق كمون بشكل عمودي على اتجاه كل من الحقل المغناطيسي و التيار و هذا ما يسمى ب كمون هول والذي يعطى بالعلاقة

$$V_H = R_H \frac{IB}{d}$$

Abstract

The Hall effect is one of the most important methods of experimental research to determine the microscopic coefficients of the transport of charge carriers in semiconductor in equilibrium conditions. Lorentz's powerful force in the mobile charge carriers is equal to the electric power generated by the electric field of Hall. To study the effect of Hall, we developed a semi-conductor sample of Germanium doped p in a regular magnetic field. When the current of a sample electric current does not correspond to the direction of the magnetic field, the charge carriers deviate due to the effect of Lorentz force. This causes a quantum difference to be formed vertically in the direction of the magnetic field and current, where

$$V_H = R_H \frac{IB}{d}$$

Résumé

L'effet Hall est l'une des méthodes de recherche expérimentale les plus importantes pour déterminer les coefficients microscopiques du transport des porteurs de charge dans un semi-conducteur dans des conditions d'équilibre. La force puissante de Lorentz dans les porteurs de charge mobiles est égale à la puissance électrique générée par le champ électrique de Hall

Pour étudier l'effet de Hall, nous avons développé un échantillon de semi-conducteur de Germanium dopé p dans un champ magnétique régulier. Lorsque le courant d'un échantillon de courant électrique ne correspond pas à la direction du champ magnétique, les porteurs de charge dévient sous l'effet de la force de Lorentz. Cela provoque la formation d'une différence quantique verticalement sur la direction du champ magnétique et du courant, où :

$$V_H = R_H \frac{IB}{d}$$