Sudan University of Science and Technology

College of Graduate Studies

Increasing The Electrical Conductivity of the semiconductor by Doping and Heating

زيادة الموصلية الكهربية لاشباه الموصلات بالتشويب و الحرارة

Thesis Submitted For Partial Fulfillment of the Requirement for Degree of Master in Physics

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الآيـــــــــــة

قال تعالى:

بسم الله الرحمن الرحيم

يُكَلِّفُ اللَّهُ نَفْسًا إِلاَّ وُسْعَهَا لَهَا مَا كَسَبَتْ وَعَلَيْهَا مَا اكْتَسَبَتْ رَبَّنَا لاَ
تُؤَاخِذْنَا إِن نَّسِينَا أَوْ أَخْطَأْنَا رَبَّنَا وَلاَ تَحْمِلْ عَلَيْنَا إِصْرًا كَمَا حَمَلْتَهُ عَلَى
الَّذِينَ مِن قَبْلِنَا رَبَّنَا وَلاَ تُحَمِّلْنَا مَا لاَ طَاقَةَ لَنَا بِهِ وَاعْفُ عَنَّا وَاغْفِرْ لَنَا
وَارْحَمْنَا أَنتَ مَوْلاَنَا فَانصُرْنَا عَلَى الْقَوْمِ الْكَافِرِينَ)

صدق الله العظيم

سورة البقرة الأية (286)

Dedication

To whom he strives to bless comfort and welfare and never stints what he owns to push me in the success way who

taught me to promote life stairs wisely and patiently, to my dearest father

To the Spring that never stops giving, to my mother who weaves my happiness with strings from her merciful heart

To whose love flows in my veins, and my heart always remembers them, to my brothers ,sisters and my fiends

To those who taught us letters of gold and words of jewel of the utmost and sweetest sentences in the whole knowledge. Who reworded to us their knowledge simply and from their thoughts made a lighthouse guides us through the knowledge and success path, To our honored teachers and professors.

Acknowledgement

Before of all, the praise and thanks be to Allah whom to be ascribed all perfection and majesty. The thanks after Allah must be to my virtuous teacher Dr. **Ahmed ELhassan ELfaki** who supervised this research and guide me in patience until the results of this research are obtained. I wish to express my thanks to Sudan university of science and technology and department of physics. My humble thanks to everyone help and encourage me during this work. I also would like to thanks my friends and classmates for any support that make me complete this research.

Abstract

In this research was done discussion of the semiconductor by details whence structure, refinement, types and conductivity. And charge carrier properties whence density, effective mass, and concentration in intrinsic and extrinsic semiconductor .Also found there's proportioning between the carrier density and electrical conductivity, then increasing the density of this carrier increases the electrical conductivity of the semiconductor. Position of Fermi level in this research was determined. The heating and doping are increase the electrical conductivity of the semiconductor. The research was taken up germanium element the intrinsic semiconductor and subjugated to theoretical and practicalstudy.

مستخلص

في هذا البحث تمت مناقشة اشباه الموصلات بالتفصيل من حيث البنية والنقاء والتوصيلية الكهربية وكذلك أقسام اشباه الموصلات الذاتية وغير الذاتية, كما نوقشت خصائص حاملات الشحنة من حيث الكثافة والكتلة الفعالة والتركيز و التنقل. ووجد أن هنالك تناسب بين كثافة الحاملات والتوصيلية الكهربية, كما تم تحديد موقع فيرمي في شباه االموصلات الذاتية.وكذالك تم التعرف على تأثير الحرارة والتشويب على خصائص أشباه الموصلات بما في ذلك التوصيلية الكهربية حيث وجد أن التشويب وزيادة درجة الحراره تزيد من التوصيلية الكهربية لها. وتمت دراسة وصفية وعملية لعنصر الجرمانيوم كشبه موصل ذاتي ووجد ان التشويب وزيادة درجة الحرارة تزيد من التوصيلية الكهربية له وبذلك يمكن الإستفادة من الجرمانيوم والعناصر التي تشاكله.

Cotenant

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Chapter One
Introduction

1.1 Introduction

Dependent on the electrophysic properties we classification all substancesin three large group .The metal it good conductor for heat and electricitysemiconductor it conduct electricity under some condition and insulator itno conduct the electricity and heat at all[1]. I will focus in this research inthe semiconductor.The characteristic of the semiconductor leads tomanufacture different deviseslike (diode) use to current apprised and(transistor) use to generation and amplification resonance an(lightelement)use to convert the thermal andradiologic energy to electrical energyand(light diode and leasers) use to conversion the electrical energy to light.Sothe devise mad on thesemiconductor use in other extensive disciplinessuch that the temperature measurement, pressure,radiation andmagnetic fields[2]. No difference between the semiconductor and insulatoratabsolute zerorange except the energy gap .hence the semiconductor isinsulator at absolute zero range .but increase the temperature increasingthe electrical conductivity of the semiconductor and can be higher thaninsulatorbut in gases less than metals and increasing by high temperature.In solid-state physics, the electron mobility characterizes how quickly anelectron can move through a semiconductor, when pulled by an electricfield. In semiconductor, there is an analogous quantity for holes, called holemobility. The term carrier mobility refers in general to both electron andhole in semiconductors. Electron and hole mobility

are special cases ofelectrical mobility of charged particles in a fluid under an applied electricfield.is applied a cross a piece of material, the electrons respond by movingwith an average velocity called the drift velocity Conductivity is proportionalto the product of mobility and carrier concentration. The same conductivitycould come from small number of electrons with high mobility for each, or alarge number of electrons with a small mobility for each. Therefore mobilityis a very important parameter for semiconductor materials The semiconductor group contain elements: Si, Ge , Ga and other [3].

1.2 Problem definition

The problem is know the method con be narrowing the energy gap of semiconductor by doping and heating and effect of this processes on thesemiconductor properties.

1.3 Aim of the Research

The searcher is endeavoring to achieve the following objectivesthroughresearch:

1. Know the semiconductor application in the daily life.
2. Discussion the primary processes ofthe charge carriers inside the semiconductor i.e diffusion, drift.
3. Identify the methods which the germanium obtained.
4. Providing the maininformation aboutthe semiconductor generally andgermanium specially.
5. Identifywhat the germanium integrated circuitcan be made and givinggeneral ideaabout the physics structure of this (Ge ICs).

1.4 Assumption

This research assumed the following points:

1. Possibility of increasing the electricalconductivity of the semiconductor bythe doping and heating.
2. Possibility of all semiconductors can be benefit.

1.5 The methodof Research

In this research weused thetheoretical and practical methods.

1.6 Presentation of the Research

This research includes four chapter, chapter one includes introduction, importance of the study, aim of the study and thesis out line. Chapter two includes general study in semiconductors and pn-junction, electrons and holes in semiconductors, effective mass, and conductivity of this carriers, carrier concentration, carrier drift, drift and diffusion current. Chapterthree includes general study in germaniumwhenceproperties production, applications and the practical experiment of theresearch. Chapter four includes the discussionrecommendations of the research.

Chapter Tow
Semiconductor

2.1 Introduction

A semiconductor is defined as a solid crystalline material whose electricalconductivity intermediate between that of a metal and an insulatorrecognizedas wonder materials only after the by SchlockyBardeen andBrattain in1940.[3The bonding between atoms in the solid accounts at widerange ofelectrical conductivity .Metallic boning produces electric fieldmaterials form electrical conductor . in other types of bonding suchcovalent bonding the valence electrons are bound to a pair of atoms .suchmaterial should therefore form insulator .The electrical conductivity ofsolids ranges from 10^{-4}–10^{-11} ohm^{-1} m^{-1} in case of semiconductors while it'soptimum value for good conductors is 10^{7} and minimum value is 10^{-19} $ohm^{-1}m^{-1}$[4].

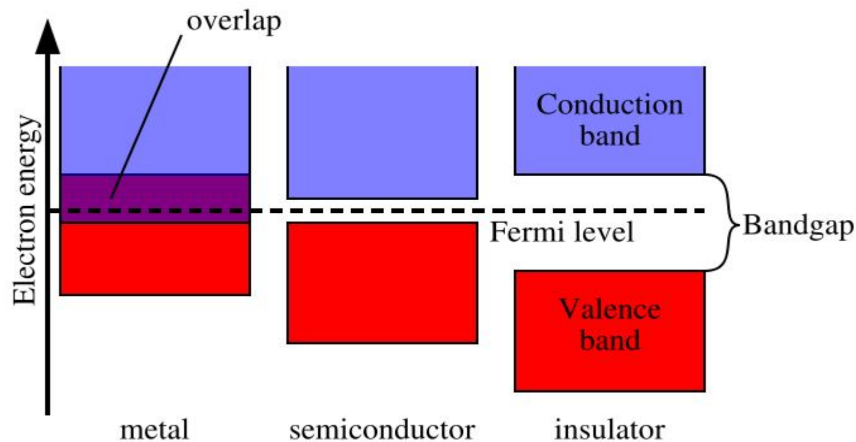


Figure (2.1)The energy gap between the metal and semiconductor andinsulator[5].

2.2 The Refinement:

At added a few relics from duo atoms to the semiconductor leads to highchanges in electrical properties of the substance. For present mustaccurately control in refinement of the semiconductor components. Themodern semiconductor is most pure at all.But the impurity addedintended differs from element to another [6].

2.3 Doping of Semiconductors:-

Pure semiconductors, such as a Gecrystal without any impurities, are called intrinsic semiconductors. When as semiconductor is doped with impurities, it becomes extrinsic and impurity energy levels are introduced. The doping occurs when some atoms in the lattice are replaced with for eking atoms, altering the lattice structure. Shows a Ge lattice where one of the atoms havebeen replaced by a type-V atom, e.g. phosphor.Four of the phosphor valence electrons formcovalent bonds to the nearest neighboring Ge -atoms, while the fifth becomes a conduction electron that is 'donated' tothe conduction band. Thus, the material is called an n-type donator because of the additional negative charge carrier, or simply an n-type material. A complement are situations seen in, where a Ge atom is replaced by a type-III atom .eg boron. Here the local lattice deficiency of one electron can receive an electron from one of the neighboring atoms, or a free conduction band electron. Thus, the material is called a p-type acceptor because of the positive charge released by accepting an electron. The convention of viewing this occurrence as a movement of apositive charge rather than a negative electron, will become clearA

germaniumlattice with a single impurity atom(Phosphorus ,P) added. As compared to Ge, the Phosphorus has one extra valence electron which, after all bonds are made, has very weak bonding[5].

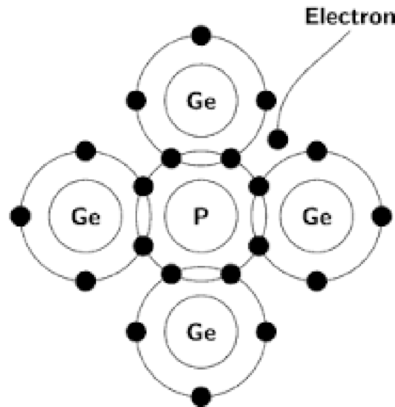


Figure 2.2 Germanium atoms doping by phosrus

2.4 The structure:

Acrystal structure is characterized by having a well –structured periodicplacement of atoms. The smallest assembly of atoms that can be repeatedto form the entire crystal iscalled a Primitive Cellwith a dimension oflattice constant many important semiconductors have diamond orzincblende lattice structures which belong to the tetrahedral phases, thatatoms is surrounded by four equidistant nearest neighbors which lie at thecorner of tetrahedron .The bond between two nearest neighbors is formed by two electrons with opposite spins. The diamond and the zincblende latticecan be considered as two interpenetratingface centered cubic (fcc) lattice [7].

2.5 Conduction in semiconductor

The electrical conductivity in this type depended on the density of charge carrierelectrons and holes; in this research we determine the number ofelectron in the conduction band and the number of holes in the valenceband.Electric current is caused due to the motion of electrons, althoughunder someconditions such as high temperature the motion of ions maybe importantas well .The

basic distinction between conduction in metal and semiconductor arises from the energy bands occupied by the conduction electrons .This can be explained better if we take into accountthe case ofan isolate carbon atom which contain six electrons (twoeach inthe 1s, 2s,2b)[8].

2.6 The semiconductor is find in tow types

2.6.1 Intrinsic semiconductor

Intrinsic semiconductor is pure crystal with no impurity atoms or defects.We understand that conduction in a semiconductor is entirely motion of charge carriers i.e, electrons and holes, which are generates by thermalexcitation from the valence band to theconduction band. This processarises from the thermal disruption of the covalent bonds. The materialsexhibit this phenomenon is known as intrinsic semiconductor [9].

The intrinsic semiconductors such as pure Ge or Si are undoes semiconductors. The electrical conductivity of this type of semiconductors is solely determined by thermally generated carriers. To understand the mechanism of conduction, we consider the bonding between atoms in these semiconductors. Each germanium atom has four valence electrons and can form four covalent bonds with four neighboring silicon atoms which are directed along the corners of a regular tetrahedron. Therefore, exhibits a three-dimensional regular network type structure which, for simplicity, is represented by a two-dimensional network as, all the valence electrons in a germanium crystal participate in the formation of covalent bonds and no electron is free to case conduction particularly at 0k. As the temperature increase above 0k, some of the valence electrons may acquire sufficient thermal energy to break their covalent bonds and become free from the influence of cores of the atoms [6].

2.6.1.1 The essential properties of an intrinsic semiconductor

The concentration of the electrons in the conduction band is equal to theconcentration of the holes in valence band.

$$ni = pi$$

- The impurity content should be less than 1 part in 100 million parts of the semiconductor.
- The Fermi energy level for intrinsic semiconductor is called intrinsic Fermi energy $E_F = E_{Fi}$

We can describe intrinsic semiconductors based on a tow-dimension
representation of a germanium crystal at T =0 (fig 2.1) .At room temperature the energy required to break a covalent bond is not very large for example energy required to break a bound in silicon and germanium is 1.2 and 0.72eV.respectively[10].

2.6.1.2 Conduction of the charge carriers

The number of electrons and holes is not very important, but the density of thecharge carrier (the number of carrier per unit volume) is significant.If thenumber of electrons is n and number of holes is p,then for an intrinsic here ni is the carrier concentration in an intrinsic (pure) semiconductorwhichvaries with temperature and is different fordifferent semiconductors.If σn the conductivity due to free electrons and σp is dueto holes then specific conductance (σi) is given by the expression:

$$\sigma_i = \sigma_n + \sigma_p \qquad (2.1)$$

Since n and p are number of electrons and holes having charge e their correspondingmotilities are$ni$and μprespectively. ThereforeEq (2.1) becomes

$$\sigma_i = n_e\mu_n + p_e\mu_p \qquad (2.2)$$

Since $n = p = ni$,*Eq* (3.2) can be rewritten as

$$\sigma_i = n_i e(\mu_e + \mu_p) \qquad (2.3)$$

Where α and β are constant of proportionality and .Substituting

Υ is equal $(\alpha + \beta)$Since it has already been stated that the mobility of charge carriers depends on temperature, the power law (μ∝1/T$^{3/2}$) in case of the mobility ofelectronsand holes plays a role :

$$(\mu_e + \mu_p) = (\alpha + \beta)T^{\frac{3}{2}} \quad (2.4)$$

$$(\alpha + \beta) = \gamma T^{3/2} \quad (2.5)$$

Substituting equation in eq (2.5) ,we get:

$\sigma_i = n_i e \Upsilon T^{3/2}$(2.6)

using certain equation for driving the intrinsic (semiconductor) carrierconcentration, we get

$$n_i = 4.83 \times 10^{21}\, T^{3/2} \exp\left[-\frac{E_g}{2k_\beta T}\right] \quad (2.7)$$

Using this expression in Eq (2.7) we find

$$\sigma_i = \gamma \times 4.83 \times 10^{21}\, T^{3/2} \exp[-\frac{E_g}{2kk_\beta T}] \quad (2.8)$$

Where Aisequal $\gamma \times 4.83 \times 10^{21}$. This becomes an expression for conductivityofanintrinsicsemiconductor. which is expressed as

$$\sigma_i = A \times T^{3/2} \exp[-\frac{E_g}{2kk_\beta T}] \quad (2.9)$$

Fig(2.2) (a) A plot of resistivity versus temperature [1/T(k)]on a logarithmicscale.(b) conductivity versus 1/T(k) .

$$B = \frac{1}{A}, \qquad p_i = 1/\sigma_i$$

$$p_i = Bexp\frac{E_g}{2k_\beta T} \quad (2.10)$$

Where B is reciprocal of A . Taking logarithm ofEq (2.10) we get

$$\log p_i = \frac{E_g}{2k_\beta T} + logB \quad (2.11)$$

Here E_g is energy gap of an intrinsic semiconductor. Eq(2.11)shows that theconductivity of intrinsic semiconductor varies exponentially with increase intemperature [11].

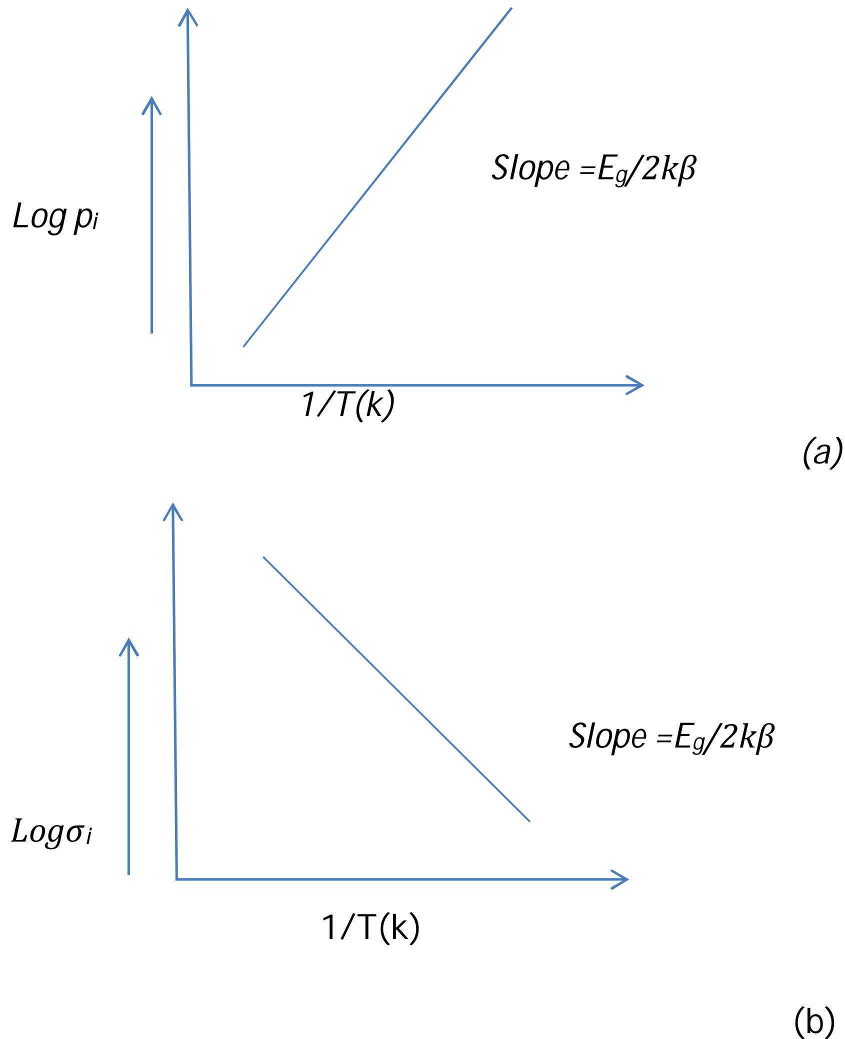


Figure 2.2 (a) A plot of resistivity versus temperature [1/T (k)] on a logarithmic scale. (b) Conductivity versus 1/T (k).

The above discussion leads us to the following conclusions about intrinsicsemiconductors:

1. The resistivity (or conductivity) of an intrinsic semiconductor is dependenton the concentration of charge carrier (electrons and holes) .
2. The conductivity of charge carrier is a function of their mobility.
3. The mobility is influenced by the presences of impurity atoms (defects).
4. The conductivity also depends upon the number of charge carriers which are in thermal equilibrium.

2.6.1.3 Effective Mass:-

When an electric field, is applied, an electron or a hole will accelerate according to:

Acceleration= $-\frac{q}{m_n}$ for electrons

Acceleration = $\frac{q}{m_p}$ for hols

Where m_n and m_p is mass of electron and hole respectively. In order to describe the motion of electrons and holes with the lawsof motion of the classical particles, we must as sign effective masses (m_n and m_p) to them. The electron and hole effective masses of a few semiconductors are listed in Table 3.1[9].

Table 2.1 Electron and hole effective masses, m_n and m_p, normalized to the free electron mass.

Effectivemasses	Si	Ge	GaAs	InAs	AlAs
m_n/m_0	0.26	0.12	0.068	0.023	2.0
m_p/m_0	0.39	0.30	0.50	0.30	0.3

2.6.1.4 Carrier concentration in intrinsic semiconductor

The charge carrier in semiconductors are regarded as free carriers whichare actually electrons and holes .The carrier concentration in thermalequilibrium condition is the steady-state condition at a given temperaturewithout any external condition(such as light pressure or electric field) atgiven temperature increase the excitation potential of electrons . Thisresults in the excitation of electrons from the valence band to theconduction band and subsequent creation of an equal number of holes inthe valence band. In order to determine the number of free carriers weneed to make use of some basic result of statistical physics. The probabilitythat anelectron occupies an electronic state with energy E is given by theFermi Dirac distribution Functionintrinsic electron or holeconcentration. The Fermi energy level for the intrinsicsemiconductor is called the intrinsic Fermi energy, or $E_F = E_{Fi}$.The equation intrinsic can be written as:

$$n_0 = n_i = N_C \exp\left[\frac{-(E_C - E_{Fi})}{kT}\right] \qquad (2.12)$$

And

$$p_0 = p_i = N_v \exp\left[\frac{-(E_{Fi} - E_v)}{kT}\right] \qquad (2.13)$$

Where

n_0Electrondensity inthermal equilibrium.

p_0 Hole density in thermal equilibrium.

n_iIntrinsic carrierdensity of electron.

N_vEffective density ofstates in the valence band.

N_cEffective density of states in the conduction band.

p_iIntrinsic carrier density of hole.

E_CConduction band energy.

E_vValenceband energy.

E_{Fi}Intrinsic Fermi energy.

If we take product of equations (2.12)and(2.13) we obtain

$$n_i^2 = N_c N_v \exp\left[\frac{-(E_c - E_{Fi})}{kT}\right] \exp\left[\frac{-(E_{Fi} - E_v)}{kT}\right] \qquad (2.14)$$

Or

$$n_i{}^2 = N_c N_v \exp\left[\frac{-(E_c - E_v)}{kT}\right] = N_c N_v \exp\left[\frac{-E_g}{kT}\right] \quad (2.15)$$

2.6.1.5 Electron concentration in the conduction band:-

The number of free electrons per unit volume in an energy range $E$and$E + dE$can be written as:

$$dn = D(E) f(E) dE \quad (2.16)$$

Where $D(E)$is the density of states defined as the total number of allowedelectronic states per unit volume in a semiconductors and $f(E)$is the Fermidistribution function representing the probability of occupation of a state with energy E. the expression for $f(E)$ is given by

$$f(E) = \frac{1}{exp\left[\frac{E-E_F}{KT}\right]} + 1 \quad (2.17)$$

where

$$D(E) = \frac{4\pi}{h^3}(2m)^{3/2}E^{1/2} \quad (2.18)$$

Using Eq(2.17) and (2.18) we obtain:

$$dn = \frac{4\pi}{h^3}(2m)^{\frac{3}{2}}E^{\frac{1}{2}}f(E)dE \quad (2.19)$$

Therefore in Eq(2.19), E must be replaced by $(E - E_c)$. Thus Eq.(2.19)becomes

$$dn = \frac{4\pi}{h^3}(2m_n^*)^{3/2}(\mathrm{E} - E_C)^{1/2}\frac{1}{\exp\left[\frac{\mathrm{E}-E_F}{KT}\right]+1}dE \quad (2.20)$$

Where m_n^* is the effective mass of the electron in the conduction band . Theconcentration of electron, n, in the conduction band is obtained byintegrating Eq(2.20) from $E = E_C$ to $E = \infty$

$$n = \frac{4\pi}{h^3}(2m_n^*)^{3/2}\int_{E_C}^{\infty}\frac{(E-E_C)^{1/2}}{\exp\left[\frac{E-E_F}{KT}\right]+1}dE \quad (2.21)$$

Now near room temperature, KT=0.026 eV. Therefore, for energies greater than E_C, we have

$$1 + \exp\left[\frac{\mathrm{E}-E_F}{KT}\right] \cong \exp\left[\frac{\mathrm{E}-E_F}{KT}\right] \quad (2.22)$$

$$n = \frac{4\pi}{h^3}(2m_n^*)^{3/2}\int_{E_C}^{\infty}(E - E_C)^{1/2}\exp\left[-(\frac{\mathrm{E}-E_F}{KT})\right]dE \quad (2.23)$$

$$= \frac{4\pi}{h^3}(2m_n^*)^{3/2}\exp\left(\frac{E_F-E_C}{KT}\right)\int_{E_C}^{\infty}(E - E_C)^{\frac{1}{2}}\exp\left[-\left(\frac{\mathrm{E}-E_C}{KT}\right)\right]dE \quad (2.24)$$

Let

$$\frac{\mathrm{E}-E_C}{KT} = x \therefore dE = KTdx \text{ , } for E = E_C \text{ , } X = 0$$

$$n = \frac{4\pi}{h^3}(2m_n^*)^{\frac{3}{2}} \exp\left(\frac{E_F - E_C}{KT}\right) \int_0^\infty x^{\frac{1}{2}} e^{-x}\, dx \quad (2.25)$$

Now

$$\int_0^\infty x^{\frac{1}{2}} e^{-x}\, dx = \left(\frac{\pi}{4}\right)^{\frac{1}{2}} \quad (2.26)$$

$$\therefore n = 2\left(\frac{2\pi m_n^*}{h^2}\right)^{3/2} \exp\left[-\left(\frac{E_C - E_F}{KT}\right)\right] \quad (2.27)$$

From Eq.(2.27) , the probability of occupancy of level E_C is given by

$$f(E_C) = \frac{1}{1+\exp\left(\frac{E_C - E_F}{KT}\right)} \cong \mathrm{ex}\left[-\left(\frac{E_C - E_F}{KT}\right)\right] \quad (2.28)$$

Therefore Eq.(3.21) becomes

$$n = 2\left(\frac{2\pi m_n^* \mathrm{KT}}{\mathrm{h}^2}\right)^{\frac{3}{2}} f(E_C) \quad (2.29)$$

Denoting it by N_C, we have

$$n = N_C \exp\left[-\left(\frac{E_C - E_F}{KT}\right)\right] \quad (2.30)$$

where

$$N_C = 2\left(\frac{2\pi m_n^* \mathrm{KT}}{\mathrm{h}^2}\right)^{\frac{3}{2}} \quad (2.31)$$

2.6.1.6 Holes Concentration in the Valence Band

An expression for the number of hole per unit volume in the energy range$E$ and$E + dE$ can be written as:

$dp = D(E)[1 - f(E)]dE$(2.32)

Where we havereplaced $f(E)\ by\ [1 - f(E)]$ which represent the probability of an energy state E not to be occupied by an electron, theprobability of finding a hole in the energy state E.

Now

$$1-f(E) = 1-\frac{1}{1+\exp\left(\frac{E-E_F}{KT}\right)} = \frac{\exp\left(\frac{E-E_F}{KT}\right)}{1+\exp\left(\frac{E-E_F}{KT}\right)} \quad (2.33)$$

In the valence band, since$E < E_F$ the exponential term in the denominatormay be neglected in comparison to unity. Thus, we get:

$$1-f(E) \cong \exp\left(\frac{E-E_F}{kT}\right) \quad (2.34)$$

it follows that the probability of finding holes decreases exponentially withincrease in depth into the valence band. Also, the kinetic energy of a holethe energy state E in the valence band is $(E_V - E)$. Therefore the density ofstate per unit volume can be written as:

$$D(E) = \frac{4\pi}{h^3}\left(2m_p^*\right)^{3/2}(E_V - E)^{\frac{1}{2}} \quad (2.35)$$

Where $m_p^*$is the effective mass of a hole in the valence band using Eq.(2.35)and (2.23) in Eq.(2.25) and integrating from E=-∞ to E=E_V, we obtain thehole concentration in the valence band as:

$$p = \frac{4\pi}{h^3}\left(2m_p^*\right)^{3/2}\int_{-\infty}^{E_V}(E_V - E)^{1/2}\exp\left(\frac{E-E_F}{KT}\right)dE \quad (2.36)$$

$$= \frac{4\pi}{h^3}\left(2m_p^*\right)^{3/2}\exp\left(\frac{E_V-E_F}{KT}\right)\int_{-\infty}^{E_V}(E_V - E)^{\frac{1}{2}} \quad (2.37)$$

Let

$\frac{E_V-E}{KT}$, $dE = -KTdx$ for $E = E_V$, x=0

$$\therefore p = \frac{4\pi}{h^3}\left(2m_p^*\right)^{\frac{3}{2}}\exp\left(\frac{E_V-E_F}{KT}\right)\int_{\infty}^{0} x^{\frac{1}{2}}KT^{\frac{1}{2}}e^{-X}(-KT)dx =$$

$$\frac{4\pi}{h^3}\left(2m_p^*\right)^{\frac{3}{2}}exp\left(\frac{E_V-E_F}{KT}\right)(KT)^{3/2}\int_0^{\infty} x^{1/2}\,e^{-x}dx =$$

$$\frac{4\pi}{h^3}\left(2m_p^*KT\right)^{\frac{3}{2}}exp\left(\frac{E_V-E_F}{KT}\right)(\frac{\pi}{4})^{1/2}$$

$$\therefore p = 2(\frac{2\pi m_p^* KT}{h^2})^{\frac{3}{2}} \exp\left[-\left(\frac{E_F - E_C}{KT}\right)\right] \quad (2.38)$$

Or

$$p = N_V \exp\left[-\left(\frac{E_F - E_V}{KT}\right)\right] \quad (2.39)$$

Where

$$N_V = 2\left(\frac{2\pi m_P^* KT}{h^2}\right)^{3/2} \quad (2.40)$$

The electron and hole concentrations given by Eqs(2.30)and (2.39)
respectively are valid for Both intrinsic and extrinsic materials. For intrinsic materials, these equations can also be written as:

$$n_i = N_C \exp\left[-\left(\frac{E_C - E_i}{KT}\right)\right], \; p_i = N_V \exp\left[-\left(\frac{E_i - E_V}{KT}\right)\right] \quad (2.41)$$

2.6.1.7 Fermi Level

Foran intrinsicsemiconductor $n = p = n_i$. Therefore from Eqs.(2.30)and(2.39)

$$N_C \exp\left[-\left(\frac{E_C - E_F}{KT}\right)\right] = N_V \exp\left[-\left(\frac{E_F - E_V}{KT}\right)\right] \quad (2.42)$$

$$\exp\left(\frac{2E_F - E_C - E_V}{KT}\right) = \frac{N_V}{N_C}$$

Or

$$\frac{2E_F - E_C - E_V}{KT} = \ln(\frac{N_V}{N_C}) \quad (2.43)$$

$$E_F = E_i = \frac{E_C + E_V}{2} + \frac{KT}{2}\ln(\frac{N_V}{N_C}) \quad (2.44)$$

Using Eqs.(3.23) and(3.29) in Eq.(3.32) we obtain

$$E_F = \frac{E_C + E_V}{2} + \frac{3}{4}KT\ln(\frac{m_p^*}{m_n^*}) \quad (2.45)$$

At 0k the Fermi level lies in the middle of the conduction band and valenceband as shown in figure 3.2. This is also true at all other

temperaturesprovided$m_p^* = m_n^*$.

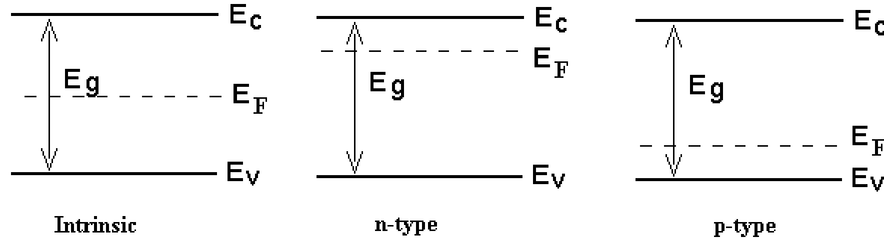


Figure 2.2 position of Fermi level in intrinsic, n and p type

(2.6.1.8) Position of Fermi Level

We discussed qualitatively in this section how the electron and hole
concentrations change as the Fermi energy level moves through the band gap energy. Then we calculated the electron and hole concentration as afunction of donor and acceptor impurity concentrations . We can determinethe position of the Fermi energy levelas a function of the dopingconcentration and a function of temperature .The position of the Fermienergy level within the band gap can be determined using equationsdeveloped for the thermal-equilibrium electron and holeconcentration. Ifwe assume the Boltzmann approximation to be valid, then we have

$$n_0 = N_c \exp[-(E_c - E_F)] / kT \quad (2.46)$$

We can solve for$E_c - E_F$from this equation and obtain:

$$E_c - E_F = kT \ln\left(\frac{N_c}{n_v}\right) \quad (2.47)$$

We$n_0$is given by Eq (2.43). If we consider an n_ type semiconductor inWhich$N_d \gg n_i$,then$n$ $n_0 = N_d$ so that

$$E_c - E_F = kT \ln\left(\frac{N_c}{n_d}\right) \quad (2.48)$$

The distance between the bottom of conduction band and the Fermi
Energyis a logarithmic function of the donor concentration .As the donorconcentration increase, the Fermi level moves closer to the conductionband and conversely .We may develop a slightly

different expression for thepositionof the Fermi level .We had from Equation (2.1)

$$n_0 = n_i \exp[\frac{E_F - E_{Fi}}{kT} \tag{2.49}$$

We can solve$E_F - E_{Fi}$ for as

$$E_F - E_{Fi} = kT\ ln\frac{n_0}{n_i} \tag{2.50}$$

If the net effective donor concentration is zero, that$N_d - N_a = 0$, then$n_0 = n_i\ and\ E_F = E_{Fi}$.We can drive the same types of p-type semiconductor wehave

$$p_0 = N_V \exp\left[-\left(\frac{E_F - E_V}{KT}\right)\right] \tag{2.51}$$

So that

$$E_F - E_v = kT \ln\left(\frac{N_v}{p_0}\right) \tag{2.52}$$

If we assume that $N_a \gg n_i$then Equation (2.49)can be written as

$$E_F - E_v = kT \ln\left(\frac{N_v}{N_a}\right) \tag{2.53}$$

The distance between the Fermi energy level and the top of the valenceband energy for a p-type semiconductor is a logarithmic function of theacceptor concentration as the acceptor concentration increases ,the Fermilevel moves closer to the valence band .We can also derive an expressionfor the between the Fermi level and the intrinsic Fermi level in term ofthe hole concentration we have

$$p_0 = n_i \exp\left[-\frac{E_F - E_{Fi}}{kT}\right] \tag{2.54}$$

Which yields

$$E_{Fi} - E_F = kT\ ln\frac{p_0}{n_i} \tag{2.55}$$

Equation(2.55) can be used to find the difference between the intrinsic Fermiand Fermi energy in term of the acceptor concentration.

2.6.1.9 Electron and hole mobility

The average velocity of the carriers is no longerzero when an electric field is applied to the semiconductor. This none zero velocity is called the drift velocity. The drift velocity is super imposed on the thermal motion .The drift velocity is so much more importantthan the thermal velocity in semiconductor device. A faster carrier velocity is desirable, for it allows a semiconductor device or circuit too higher speed. We can develop a model for the drift velocity. Consider the case for holes. Assume that the mean free time between collisions is τ_{mp} and that the carrier loses its entire drift momentum, $m_p v$, after each collision .The drift momentum gained between collisions is equal to the force , q E ,times the mean free time .Equating the loss to the gain, we can find the steady state drift velocity , v

$$m_p v = qE\tau_{mp} \tag{2.56}$$

$$v = \frac{qE\tau_{mp}}{m_p} \tag{2.57}$$

Where τ_{mp} mean free time between collision for holes, E is electric field, v is Where τ_{mp} mean free time between collision for holes, E is electric field, v is velocity. Eq.(2.2) is usually written as[12]:

$$v = \mu_p E$$

Where

$$\mu_p = \frac{q\tau_{mp}}{m_p} \tag{2.58}$$

Equation (2.58) simply says that the drift velocity is proportional to the electric field. The proportionalityconstantμ_p is the hole mobility, a metric of how mobile the holesare. Similarly, electron drift velocity and electron mobility are:

$$v = -\mu_n E \quad (2.59)$$

$$\mu_n = \frac{q\tau_{mn}}{m_n} \quad (2.60)$$

The negative sign in Eq. (2.59) means that the electrons drift in a direction opposite to the field. They do so because the electron is negatively charged. We should memorize the restatements rather than the negative sign. Carrier mobility has the same dimension as v/E, i.e.,cm^2/V·s.Table4.1 shows some mobility values. Notice that Ga As has a much higher $\mu_n$than Si(due to a smaller m_n). Thus, higher-speed transistors can be made with Ga As, which are typically used in communications equipment. In as has an even higher μ_n, butthe technology of fabricating In As devices has not yet been fully developed[12].

.

Mobility	Si	Ge	GeAs
$\mu_n(cm^2/V.s)$	1400	3900	8500
$\mu_p(cm^2/V.s)$	470	1900	400

. Table 2.2 Electron and holemobility at room temperature of selected a lightly doped semiconductors.

2.1.7 Extrinsic Semiconductor

Extrinsic semiconductor is an impurity semiconductor that is required newPropertiesafter added defects atoms.Extrinsic semiconductor are basically of two types :

2.1.7.1 N-type semiconductor:

It's a material defected by the acceptor atoms,andit's semiconductorwhich the number of electrons large than the number of holes.The doping atoms added to the semiconductor crystal in this case are donoratoms. For germanium, we can use phosphorus (P), arsenic (As) or antimony(Sb) as donors. These are column V elements, with five electrons in theiroutermost shell. When these atoms are included in the germanium crystal,one of the electrons in this shell can easily jump to the conduction band,leaving a positively chargedatom behind. This process is sometimes called"activation"or "ionization" of the donor atoms. Figure 2.3a shows therequired "activation" energies for these atoms in silicon; you can see thatthese are very small compared to the silicon band gap. The positively chargeddonor atom that is left behind after ionization is immobile and does no contribute to conduction. The electron leaving the atom by ionization does,and is counted in the electron concentration n. Because the activation energyis low, at room temperature almost all of the donor atoms included in thecrystal will give an electron to the conduction band. So if N_D is the donorconcentration, for an n-type material at equilibrium:

$$n_0 \approx N_D \left(\frac{1}{cm^3}\right) \quad (2.61)$$

Where$n_0$is thermal equilibrium concentration, $N_D$is donor concentration [4].

2.1.7.2 P-type Semiconductor

It's a material defected by the donor atoms and it's the semiconductor contains the number of the holes large than number of electron[6].Semiconductors boron (B), Aluminum (Al)

and Gallium (Ga) as acceptors. These are column III thedoping atoms in this case are acceptor atoms. For germanium, we can use elements, with three electrons in their outermost shell. When these atoms are included in the germanium crystal, one of the electrons in thegermanium valence band can easily jump to the valence shell of one of the acceptor atoms, leaving a hole behind and making the acceptor atom negatively charged. Figure 2.2 shows where the valence shell energy level is for these atoms relative to the germanium valenceband.The negativelycharged acceptor atom after an electron joins its valence shell is immobile and doesnot contribute to conduction. The hole left behind by that electron does, and is counted in the holeconcentration. Because the activation energy is low, at room temperature almost all of the acceptoratoms included in the crystal will accept an electron from the valence band. So if $N_A$is the acceptorconcentration, for a p-type material at equilibrium:

2.2Carrier Transport Phenomena

We considered the semiconductor in equilibrium and determined electron and hole concentration in the conduction and valence bandrespectively . A knowledge ofthe densities of this charged particles is important toward an understanding of theelectrical properties of thesemiconductor material. The net of flow of the electrons and holes insemiconductor willgenerate currents.The process by which these charged particle moves iscalled transport .The carrier transport phenomena are the foundation for afinallydetermining the current-voltage characteristics of

semiconductor devices .We consider two basic transport mechanisms crystal.

2.2.1The drift:

The movement of charge caused by an electric field produces drift current whichis function of the concentration of the electrons an holes and also function of the net drift velocityof this charge carrier . The average drift velocity of a carrier is related to the electric field by a parameter called mobility. The mobility gives indication of how well a carrier move in a semiconductor.

2.2.2 Drift Current

The current that flows in a semiconductor as a result of carrier drift the current density,J,is the charge per second crossing a unit area plane normal to the direction of current flow in the P-type semiconductor by unit of area. The whole current density is:

$$j_{p,drift} = qpv \quad (2.62)$$

but

$$v = \mu_p E \quad (2.63)$$

where E is electric field and v is drift velocity and μ_p is hole mobility.

Eq (2.64)becomes

$$j_{p,drift} = qp\mu_p \quad (2.64)$$

Similarly, the electron current density can be expressed as $j_{n,drift} j_{n,drift} = qnv = qn\mu_n E$ (2.65)

The total drift current density is the sum of the electron and the hole components:

$$j_{drift} = j_{p,drift} + j_{n,drift} = (p\mu_p + qn\mu_n)E \quad (2.66)$$

$$conductivity \quad \sigma = p\mu_p + q\, n\mu_n, j_{drift} = \sigma E \quad (2.67)$$

$Resistivity p = 1/\sigma = 1/(p\mu_p + q\mu_n)$ (2.68)

WhereJ current$j_p$hole current density.$j_n$electron current density

2.2.3The diffusion

Is the process whereby particles flow from a region of high concentrationto a region of low concentration .If these particles are charged. As electrons or holes, then the diffusion of these particles lead to a diffusion current.The diffusioncurrent density is related to the gradient of the carrier concentration by a parameter called the diffusion coefficient. The diffusion coefficient is gives an indication of how well a particle diffuses through a semiconductordue to a density gradient.

2.2.4 Diffusion Current

In addition to the drift current, there is a second component of current called the diffusion current. Diffusion current is generally not important consideration in metals because of their high conductivities. The low conductivity and the ease of creating non uniform carrier densities make diffusion an important process in semiconductors. Diffusion is the result of particles undergoing the normal motion as depicted. It is the familiar process by which particles move from a point of higher particle density to ward a point to lower density. It is known that the rate of particle movement by diffusion is proportional to the concentration gradient .If the electron centration is not uniform, there will be an electron diffusion current, which is proportional to the gradient of the electron concentration.

$$j_{n.diffusion} \propto \frac{dn}{dx}, j_{n.diffusion} = qD_n \frac{dn}{dx} \quad (2.69)$$

Where D_n is electron diffusion, for holes:

$$j_{p.diffusion} = -qD_p \frac{dp}{dx} \quad (2.70)$$

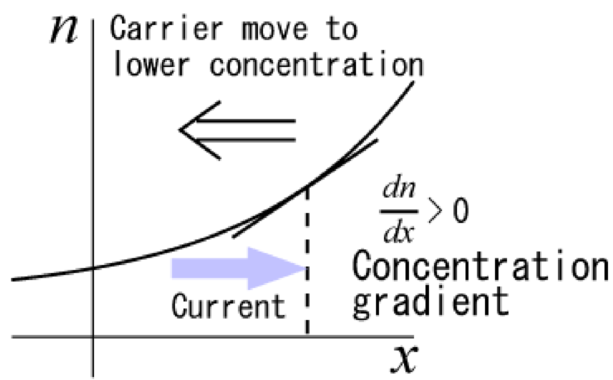
Equation (2.69) has anegativesign,while Eq. (2.70) has apositive sign. In stead of memorizing the signs, memorize,(a) shows positive dn/dx(n increased as x increased)and (b) shows

appositive dp/dxIn(a), electrons diffuse to the left (to ward the lower concentration point). Because electrons carrying active charge, the current flows to the right .In(b), hole diffuse to the left, too. Because holes are positively charged, the hole current flows to the left ,i.e the current negative. In general, both drift and diffusion may contribute to the current. Therefore,

$$j_n = j_{n.drift} + j_{n.diffusion} = qn\mu_n E + qD_n \frac{dn}{dx} \quad (2.71)$$

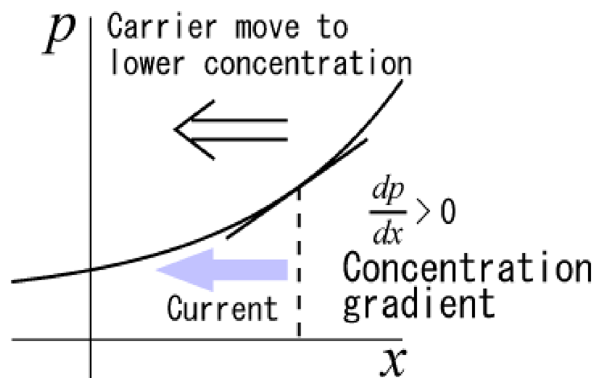
$$j_p = j_{p.drift} + j_{p.diffusion} = qp\mu_p E - qD_p \frac{dp}{dx} \quad (2.72)$$

$$j = j_n + j_p$$



(a)

Figure 2.3 A positive slope of carrier concentration produce positive electron diffusion current (a).



(b)

Figure 2.4A negative slope of carrier concentration produce a negative hole diffusion current (b).

Chapter Three

The Practical Part

3.1 Introduction

Germanium Geis a chemical element with symbol Ge and atomic number 32.It is a lustrous, hard, grayish-white metalloid in the carbon group, chemically similar to its group neighbors tin and silicon .Pure germanium is semiconductor with an appearance similar to elemental silicon. Like silicon, germanium, naturally reacts and forms complexes with oxygen in nature. Unlike silicon, it is too reactive befound naturally on Earth in the free germanium was discovered comparatively late in the history of chemistry. Germaniumranks fiftieth in relative abundance of the elements in the Earth's crust. In1869, Dmitri Mendeleev predicted its properties from its Positionhis periodic table

3.2 Physical properties of germanium

Atomic number	32
Group block	Group 14 (carbon groub)
Period	Period 4
Element category	metalloid
tandard atomic weigh (±) (Ar)	72.63
Electron configuration	[Ar] $3d^{10}\ 4s^2\ 4p^2$

Vapor pressure

P(Pa)	1	10	100	1K	10K	00K
At T (K)	1440	1814	2023	2287	2633	3104

Atomic properties

Oxidation state	4,3,2,1,0,-1,-2,-3 Amphoteric oxide
Electro negativity	Pauling scale:2.01
Ionization energies	1st :762 kJ/mol 2nd:1537.5 kJ/mol 3rd:3302.1 kJ/mol
Atomic radius	Empirical: 122pm
Covalent radius	122 pm
Van deer Waals radius	211 pm

3.1.2 Germanium Production

Germanium is fins in rawest germinate , but it's go out accidental outputfromthe many mining operation , like the charcoal burning operations and thedusts ofZink smelting flues , It's separates and purity from the metallic faults by the fractional distillation of quadrilateral chloride .

3.1.3 Applications

Germanium is an important semiconductor, mainly used in transistors and integrated circuits .they are often made from germanium to which small amounts of arsenic gallium, or other metals. Germanium forms manycompounds, germanium oxide is added to glass to increase the index of refraction, and such glass is used in wide –angle lenses and infrared devices.Numerous alloys containing germanium have been prepared High purity germanium single crystal detectors can precisely identify radiation source(eg for airport security).The major end use for germanium in 2007, Worldwide were estimated to be:35% for fiber-optics, 30% infrared optics ,15% polymerization catalysts and 15% electronics and electric applications and solar electric applications , The remaining 5% went into such uses as phosphors metallurgy , and chemotherapy.

3.2 The practical study

Objective

Determination of electrical conductivity of germanium (diode) by the heating.

Principle and task

The electrical conductivity of the germanium as a function of temperature

Instruments

Power supply, heatingfurnace,galvanometer, germanium test piece (diode) , resistances box , thermometer , connecting cord.

The method

In this experiment was used test-piece of germanium (diode) ,then done connected all the devices and choose resistance (200Ω) from the resistances box and opened the heater furnace ,then the diode was begun warm up gradually and inscribed the analogous resistance of each poise point with each temperature by the rule:

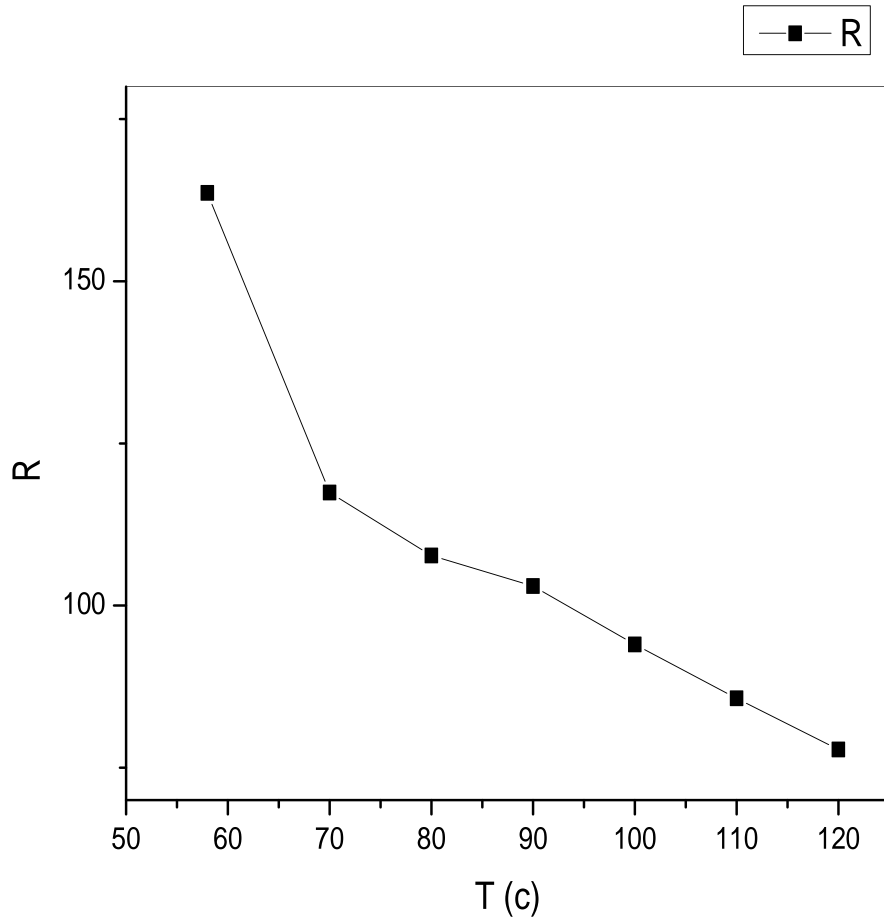
$$R_t = (L_2/L_1)\ R$$

WhereR_t is resistance at t =...c^o .

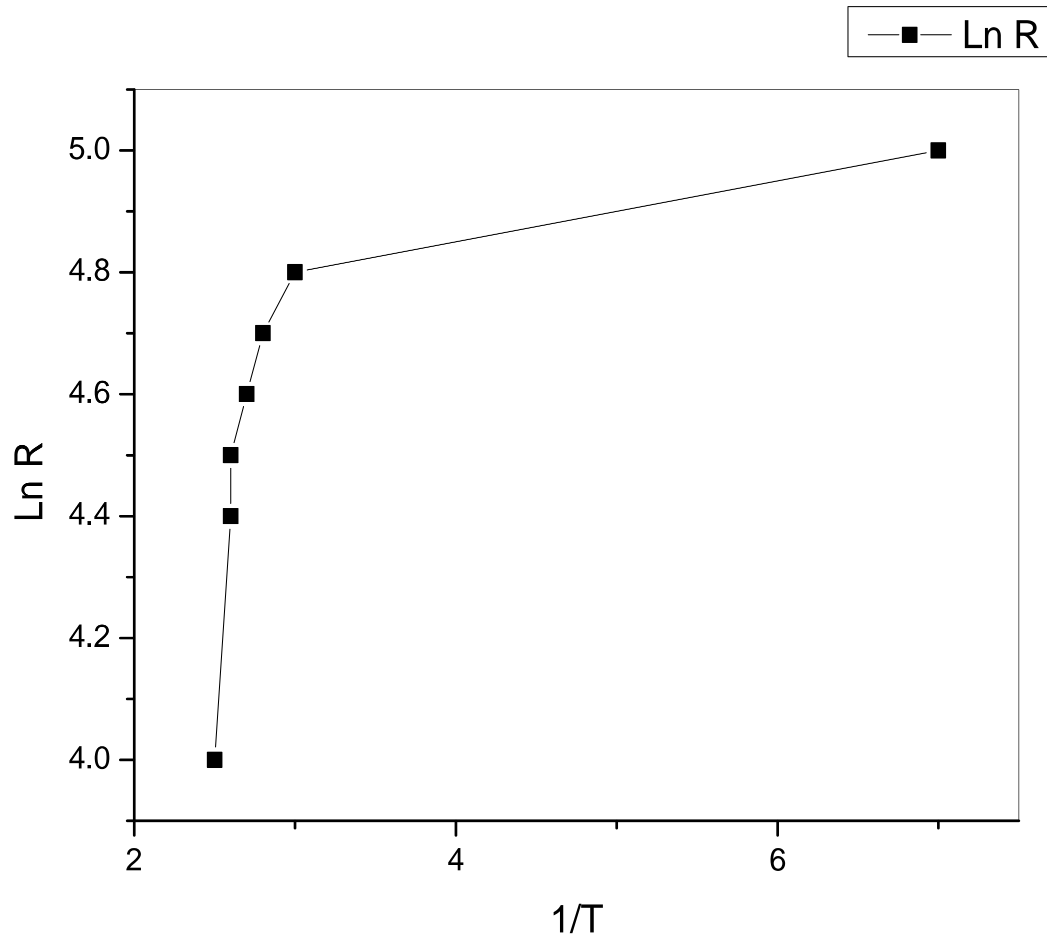
L_1andL_2 are length , R = 200Ω.

Results

No	L_1/cm	L_2/cm	t/c^o	R_t/Ω	k^o(t+273)	Ln Rt	1/T K^{-1}
1	55	54	58	163.6	131	5	0.007
2	63	37	70	117.4	343	4.8	0.003
3	65	35	80	107.7	353	4.7	0.0028
4	66	34	90	103	363	4.6	0.0027
5	68	32	100	94	373	4.5	0.0026
6	70	30	110	85.7	383	4.4	0.0025
7	72	28	120	77.8	393	4	0.0024



Graphic 3. 1 shows the relation between the resistance R (Ω) and temperature t(c°)



Graph 3.2 show the relation between ln (R_t) and1/T (K^{-1})

Discussion

The table indicates to the relation between the resistivity andtemperature is inverting relation,sense increasing temperature isdecrease the resistance and increase the electrical conductivity of the substance .wherewe was can achieved one of the research aims , It's beneficial from the heat in the converting the semiconductor substance to conductor substance by the heating.Graphic diagram noting to the exponential relation between temperatureand electrical conductivity, and it's not depend on $T^{3/2}$ fromequations, also was founded the energy gap less by increasing temperature.

Recommendations

1. Focusing in the application study in these disciplines.
2. Opened scope of germanium integrated circuits in Sudan and dispenses anent importation of this integrated circuits.

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