Sudan University of science and Technology

College of graduate studies

Study of Temperature Effect on the Energy Gap for Diodes with Different Doping Consentration

دراسة تأثير درجة الحرارة في نطاقات الطاقة لمجموعة ثنائيات مختلفة تركيز التشويب

A Thesis submitted for a partial fulfillment for the degree of Master of Solid State physics (M.Sc.)

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بسم الله الرحمن الرحيم

الإستهلال

قال تعالى :

لَقَدْ أَرْسَلْنَا رُسُلَنَا بِالْبَيِّنَاتِ وَأَنْزَلْنَا مَعَهُمْ الْكِتَابَ (
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صدق الله العظيم

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Dedication

To my mother

Unknown soldier in our home

To my father

It is the greatest love that he holds

To science and knowledge

To my sisters and brothers

To my teachers

To all my friends

Acknowledgement

First of all, the prays and thanks be to Allah whom to be ascribed all perfection and majesty.

Thanks after Allah must be to my virtuous Supervision Dr Mahmoud Hilo who supervised this research and guide me in patience until the result of research are obtained.

I wish to express my thanks to the Sudan University of science and technology. Department of physics.

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Abstract

In this research, three light emitting diodes, were connected separately in a simple circuit, at a reverse bias, the values of current, and voltage varies with temperature are recorded. For each diode.

The Temperature is found to increase the current at constant voltage, which implies the exist of an energy gap.

Also we found that the values of energy gap are less than the normal. The increasing of temperature Assume that it increases the velocity of electrons which jumps the barrier between, valence and convection band

ملخص البحث

في هذا البحث تم توصيل ثلاث ثنائيات ضوئية كل على حدة في وضع انحياز عكسي في دائرة كهربية بسيطة ثم أخذت قراءات للتيار مع ثبات قراءة الفولتميتر مع تغير درجة الحرارة لكل ثنائي ضوئي .

وُجد أن زيادة درجة الحرارة تؤدي إلى زيادة التيار المقابل مع ثبات الجهد ، وهذا يقود إلى أن هناك فجوة طاقة

و أن القيم المقابلة لفجوات الطاقة أقل من القيم المعتادة و أن زيادة درجة الحرارة توافق حقيقة أن الحرارة تزيد من سرعة الإلكترونات التي تجتاز الحاجز بين مستوى التوصيل و التكافؤ الذي يشير إلى وجود الفجوة في الطاقة المطلوبة موضع الدراسة .

Subject index

Chapter tow

Theoretical Background

Chapter one

Introduction

1.1 Band Theory and Band Diagrams

Recall from physics that electron energy is quantized; electrons of a given element can only occupy specific, discrete energies, and those closest to the nucleus have the least energy and are most tightly bound to the atom. In, some elements (like diamond, carbon, silicon, etc.), when many atoms are brought together to form a solid, a crystal, lattice structure is created which has many unique properties (note: this is the origin of the term “solid-state”). In a crystal lattice, the available electron energy levels get “blurred” a bit and we find the discrete energy levels becomes thick *bands* of energy which electrons can occupy.

1.2 Band diagrams

A tool used in solid-state physics to illustrate what is going on in the outer electron shells (energy levels) of a group of atoms held together in a tightly-packed crystal structure (like a silicon wafer). Band diagram help illustrate where the outer electrons are in a given situation. All have a band at the top which is the *conduction band* and a band at the bottom which is the *valence band*. These bands represent the outermost energy levels that electrons can occupy. Generally speaking (i.e. without getting into too many details) electrons the valence band are still tightly bound to the atom and cannot move around to other atoms in the crystal. However, electrons in the conduction band have enough energy [1] that they can freely move throughout the crystal material thus acting as mobile charge carriers which can conduct current. (Recall that electrons try to occupy the lowest energy levels available, and an electron at a higher energy

level will always move to a lower level if it is available. Just remember that electrons are “happiest” when they are as close as possible to the nucleus.[2]

Another important factor in the band diagram is the *energy gap*, Eg, which is the energy difference between the valance and conduction bands. Because electrons can only occupy energies within the two bands, the gap between energy electrons need before they will jump up to the conduction band and be available to conduct current. The two bands is a forbidden region called the *band gap*. The band gap is significant because it tells us how much band gap is a constant for each material (although it varies slightly with temperature, a fact that is exploited in a class of circuits appropriately called *band gap circuits* which we will discuss near the end of the semester). For Si at room temperature, Eg = 1.1eV.[3]

1.3 Research problem

This research is intended to search with the following problems

* Apure semiconductor is an insulator at absolute zero temperature apure semicoductors become electrically conductive when supplied with heat

* semiconductors are a key technology leader

* Energy gap of light Emitting Diodes depends on the Delivery had to be reversed pias

* The relationship between the saturation current and Temperature

1.4 Aims of the work

is to design asimple electrical circuit to find the energy gaps for bulk materials, namely semiconductors.the effect of temperature on the energy gap band is also investigated and discussed.

1.5 Lay out

chapter one is an introduction ,chapter tow is concerned with the literature , the experimental work in chapter three then chapter four is studied for the discussion, result, analysis, and conclusion

1.6 presentation of thesis

Different attempts were made to determine energy levels and bands, like Frank Hertz experiments (2). The magnetic field and temperature effect of energy levels and bands as shown by some researches (j-Burns, solid state physics (Academic press. Florida .1985)

Chapter tow

Theoretical Background

2-1 introduction

Measuring the Band-Gap of a Semiconductor According to the band theory of solids, insulators and semiconductors are materials which possess a band-gap (i.e., a range of forbidden energy values) at the Fermi level. Thus, these materials have a completely filled energy band below the gap and an empty band above the gap. The width of this band-gap is what distinguishes insulators from semiconductors. In semiconductors the band-gap is small enough (<2eV) that at finite temperatures thermal excitation of electrons across the gap, into the empty "conduction" band, is possible leading to a small but measurable conductivity. The band-gap in insulators is simply too large to have any appreciable concentration of charge carriers excited into the conduction band. The temperature dependence of the resistivity of a pure (i.e., intrinsic) semiconductor is given by [4]

$$\rho = B(T) \exp(Eg/2kBT)$$

Temperature. To a good approximation we can take $B(T)$=constant. Thus, we can easily measure where Eg is the width of the gap and the function $B(T)$ is only very weakly dependent on the gap energy of a semiconductor material by measuring the resistance of a sample over a range semiconductor material used in the devic semiconductor can have large effects on the conductivity. This is desirable in designing many semiconductors devices but can complicate the measurement of the intrinsic gap energy. These impurity effects can be minimized by working at high enough temperatures that all dopant-type impurities are fully ionized (the intrinsic regime of a doped semiconductor). According to the equation given above, the resistivity of an intrinsic semiconductor is very sensitive to changes in temperature.[5] This property is the basis for solid-state temperature measurement devices known as a thermistors. In this lab we will measure the resistance of a of temperatures. One additional complication here is that very small amounts of impurities in a - thermistor as a function of temperature and thereby determine the gap energy for the

2-2 Classification of metal , CONDUCTORS AND Semiconductors

2-2-1On the basis of conductivity

On the basis of the relative values of electrical conductivity (σ) or resistivity

(ρ = 1/σ), the solids are broadly classified as:

(i) ***Metals:***

They possess very low resistivity (or high conductivity).

$\rho \sim 10^{-2} – 10^{-8}$ Ω m

$\rho \sim 10^{2} – 10^{8}$ S m–1

(ii) ***Semiconductors:***

They have resistivity or conductivity intermediate to metals and insulators.

$\rho \sim 10^{-5} - 10^{6}\ \Omega\,m$

$\sigma \sim 10^{5} - 10^{-6}$ S m–1

(iii)*Insulators:*

They have high resistivity (or low conductivity).

$\rho \sim 10^{11} - 101^{9}\ \Omega\,m$

$\sigma \sim 10^{-11} - 10^{-19}$ S m–1

The values of ρ and σ given above are indicative of magnitude and could well go outside the ranges as well. Relative values of the resistivity are not the only criteria for distinguishing metals, insulators and semiconductors from each other. There are some other differences, which will become clear as we go along in this chapter. Our interest in this chapter is in the study of semiconductors which could be:

(i) *Elemental semiconductors*: Si and Ge

(ii) *Compound semiconductors*: Examples are:

- Inorganic: CdS, GaAs, CdSe, InP, etc.[6]

2-3 BAND THEORY OF SOLIDS

Consider that the Si or Ge crystal contains *N* atoms. Electrons of each atom will have discrete energies in different orbits. The electron energy will be same if all the atoms are *isolated,* i.e., separated from each other by a large distance. However, in a crystal, the atoms are close to each other (2 to 3 Å) and therefore the electrons interact with each other and also with the neighbouring atomic cores. The overlap (or interaction) will be more felt by the electrons in the outer most orbit while the inner orbit or core electron energies may remain unaffected. Therefore, for understanding electron energies in Si or Ge crystal, we need to consider the changes in the energies of the electrons in the outer most orbit only. For Si, the outer most orbit is the third orbit (n = 3), while for Ge it is the fourth orbit (n = 4). The number of electrons in the outermost orbit is 4 (2*s* and 2*p* electrons). Hence, the total number of outer electrons in the crystal is 4*N*. The maximum possible number of outer electrons in the orbit is 8 (2*s* + 6*p* electrons). So, out of the 4*N* electrons, 2*N* electrons are in the 2*N* *s-states* (orbital quantum number l = 0) and 2N electrons are in the available 6*N* *p-states*. Obviously, some *p*-electron states are empty[7]

This is the case of well separated or isolated atoms ,Suppose these atoms start coming nearer to each other to form a solid. The energies of these electrons in the outermost orbit may change (both increase and decrease) due to the interaction between the electrons of different atoms. The 6*N* states for l = 1, which originally had identical energies in the isolated atoms, spread out and form an *energy band.* Similarly, the 2*N* states for l = 0, having identical energies in the isolated atoms, split into a second band ,separated from the first one by an *energy gap*. At still smaller spacing, however, there comes a region in which the bands merge with each other. The lowest energy state that is a split from the upper atomic level appears to drop below the upper state that has come from the lower atomic level. In this region *,no energy gap exists where the upper and lower energy states get mixed*. Finally, if the distance between the atoms further decreases, the energy bands again split apart and are separated by an *energy gap Eg* The total number of available energy states 8*N* has been *re-apportioned* between the two bands (4*N* states each in the lower and upper energy bands). Here the significant point is that there are exactly as many states in the lower band (4*N*) as there are available valence electrons from the atoms (4*N*). Therefore, this band (called the *valence band*) is completely filled while the upper band is completely empty. The upper band is called the *conduction band*.[8]

2-4 Semiconductor Materials

The lowest energy level in the conduction band is shown as *EC* and highest energy level in the valence band is shown as *EV* . Above *EC* and below *EV* there are a large number of closely spaced energy levels, The gap between the top of the valence band and bottom of the conduction band is called the *energy band gap* (Energy gap *Eg*). It may be large, small, or zero, depending upon the material. These different situations. [9]

Case one : This refers to a situation, metal either when the conduction band is partially filled and the balanced band is partially empty or when the conduction and valance bands overlap. When there is overlap electrons from valence band can easily move into the conduction band. This situation makes a large number of electrons available for electrical conduction. When the valence band is partially empty, electrons from its lower level can move to higher level making conduction possible. Therefore, the resistance of such materials is low or the conductivity is high[9]

Case tow : In this case, a large band gap *Eg* exists (*Eg* > 3 eV). There are no electrons in the conduction band, and therefore no electrical conduction is possible. Note that the energy gap is so large that electrons cannot be excited from the valence band to the conduction band by thermal excitation. This is the case of *insulators*. *Case three :* This situation Here a finite but small band gap (*Eg* < 3 eV) exists. Because of the small band gap, at room temperature some electrons from valence band can acquire enough energy to cross the energy gap and enter the *conduction band*. These electrons (though small in numbers) can move in the conduction band. Hence, the resistance of *semiconductors* is not as high as that of the insulators. In this section we have made a broad classification of metals, conductors and semiconductors. In the section which follows you will learn the conduction process in semiconductors. [9]

2-5 INTRINSIC SEMICONDUCTOR

We shall take the most common case of Ge and Si whose lattice structure These structures are called the diamond-like structures. Each atom is surrounded by four nearest neighbours. We know that Si and Ge have four valence electrons. In its crystalline structure, every Si or Ge atom tends *to share* one of its four valence electrons with each of its four nearest neighbour atoms, and also *to take share* of one electron from each such neighbour. These shared electron pairs are referred to as forming a *covalent bond* or simply a *valence bond*. The two shared electrons can be assumed to shuttle back-and forth between the associated atoms holding them together strongly. the 2-dimensional representation of Si or Ge structure which over emphasises the covalent bond. It shows an idealised picture in which no bonds are broken (all bonds are intact) Such a situation arises at low temperatures. As the temperature increases, more thermal energy becomes available to these electrons and some of these electrons may break–away (becoming *free* electrons contributing to conduction). The thermal energy effectively ionises only a few atoms in the crystalline lattice and creates a *vacancy* in the bond). The neighbourhood, from which the free electron (with charge $-q$) has come out leaves a vacancy with an effective charge ($+q$). This *vacancy* with the effective positive electronic charge is called a *hole*. The hole behaves as an *apparent free particle* with effective positive charge. In intrinsic semiconductors, the number of free electrons, ne is equal to the number of holes, nh. That is $ne = nh = ni$. where ni is called intrinsic carrier concentration. Semiconductors posses the unique property I which, apart from electrons, the holes also move. [10]

2-6 EXTRINSIC SEMICONDUCTOR

The conductivity of an intrinsic semiconductor depends on the temperature, but at room temperature its conductivity is very low. As such, no important electronic devices can be developed using these semiconductors. Hence there is a necessity of improving their conductivity. This can be done by making use of impurities. When a small amount, say, a few parts per million (ppm), of a suitable impurity is added to the pure semiconductor, the conductivity of the semiconductor is increased manifold. Such materials are known as e*xtrinsic semiconductors* or *impurity semiconductors*. The deliberate addition of a desirable impurity is called *doping* and the impurity atoms are called *dopants*. Such a material is also called a *doped semiconductor*. The dopant has to be such that it does not distort the original pure semiconductor lattice. It occupies only a very few of the original semiconductor atom sites in the crystal. A necessary condition to attain this is that the sizes of the dopant and the semiconductor atoms should be nearly the same. There are two types of dopants used in doping the tetravalent Si or Ge[11]

(i) (valency 5); like Arsenic (As), Antimony (Sb), Phosphorous(P)

(ii) Trivalent (valency 3); like Indium (In), Boron (B), Aluminium (Al),. We shall now discuss how the doping changes the number of charge carriers (and hence the conductivity) of semiconductors. Si or Ge belongs to the fourth group in the Periodic table and, therefore, we choose the dopant element from nearby fifth or third group, expecting and taking care that the size of the dopant atom is nearly the same as that of Si or Ge. Interestingly, the pentavalent and trivalent dopants in Si or Ge give two entirely different types of semiconductors as discussed below.[11]

2-6-1 n-type semiconductor

Suppose we dope Si or Ge with a pentavalent . When an atom of +5 valency element occupies the position of an atom in the crystal lattice of Si, four of its electrons bond with the four silicon neighbours while the fifth remains very weakly bound to its parent atom. This is because the four electrons participating in bonding are seen as part of the effective core of the atom by the fifth electron. As a result the ionisation energy required to set this electron free is very small and even at room temperature it will be free to move in the lattice of the semiconductor. For example, the energy required is ~ 0.01 eV for germanium, and 0.05 eV for silicon, to separate this electron from its atom. This is in contrast to the energy required to jump the forbidden band (about 0.72 eV for germanium and about 1.1 eV for silicon) at room temperature in the intrinsic semiconductor. Thus, the pentavalent dopant is donating one extra electron for conduction and hence is known as *donor* impurity. The number of electrons made available for conduction by dopant atoms depends strongly upon the doping level and is independent of any increase in ambient temperature. On the other hand, the number of free electrons (with an equal number of holes) generated by Si atoms, increases weakly with temperature. In a doped semiconductor the total number of conduction electrons *ne* is due to the electrons contributed by donors and those generated intrinsically, while the total number of holes *nh* is only due to the holes from the intrinsic source. But the rate of recombination of holes wouldincrease due to the increase in the number of electrons. As a result, the number of holes would get reduced further. Thus, with proper level of doping the number of conduction electrons can be made much larger than the number of holes. Hence in an extrinsic semiconductor doped with pentavalent impurity, electrons become the *majority carriers* and holes the *minority carriers*. These semiconductors are, therefore, known as n-*type semiconductors*. For n-type semiconductors, we have, $ne >> nh$[11]

2-6-2 p-type semiconductor

This is obtained when Si or Ge is doped with a trivalent impurity like Al, B, In, etc. The dopant has one valence electron less than Si or Ge and, therefore, this atom can form covalent bonds with neighbouring three Si atoms but does not have any electron to offer to the fourth Si atom. So the bond between the fourth neighbour and the trivalent atom has a vacancy or hole . Since the neighbouring Si atom in the lattice wants an electron in place of a hole, an electron in the outer orbit of an atom in the neighbourhood may jump to fill this vacancy, leaving a vacancy or hole at its own site. Thus the *hole* is available for conduction. Note that the trivalent foreign atom becomes effectively negatively charged when it shares fourth electron with neighbouring Si atom. Therefore, the dopant atom of p-type material can be treated as *core of one negative charge* along with its associated hole It is obvious that one *acceptor* atom gives one *hole*. These holes are in addition to the intrinsically generated holes while the source of conduction electrons is only intrinsic generation. Thus, for such a material, the holes are the majority carriers and electrons are minority carriers. Therefore, extrinsic semiconductors doped with trivalent impurity are called p-*type semiconductors*. For p-type semiconductors, the recombination process will reduce the number (ni)of intrinsically generated electrons to ne. We have, for p-type semiconductors $nh >> ne$ Note that *the crystal maintains an overall charge neutrality as the charge of additional charge carriers is just equal and opposite to that of the ionised cores in the lattice.* In extrinsic semiconductors, because of the abundance of majority current carriers, the minority carriers produced thermally have more chance of meeting majority carriers and thus getting destroyed. Hence, the dopant, by adding a large number of current carriers of one type, which become the majority carriers, indirectly helps to reduce the intrinsic concentration of minority carriers. The semiconductor’s energy band structure is affected by doping. In the case of extrinsic semiconductors, additional energy states due to donor impurities (ED)

and acceptor impurities (*EA*) also exist. In the energy band diagram of n-type Si semiconductor, the donor energy level *ED* is slightly below the bottom *E*C of the conduction band and electrons from this level move into the conduction band with very small supply of energy. At room temperature, most of the donor atoms get ionised but very few (~10–12) atoms of Si get ionised. So the conduction band will have most electrons coming from the donor impurities, Similarly.[12]

2-7 Semiconductors Dives

Each elemental and binary semiconductor has a specific band-gap at a given temperature. If the choice of semiconductors were restricted to elemental and binary semiconductors (Binary semiconductors - compounds made from the elements of two different groups of the periodic table (For example: III and V, II and IV, etc.)) only, then the available wavelengths would be rather limited, But as we know, light is emitted by solid solutions of semiconductors as well. By mixing two or more binary semiconductors, we can create ternary or quaternary crystalline solid solutions. The energy band-gap, refractive index, and lattice constant of such solid solutions can be adjusted by varying the composition of the contributing materials and the growth conditions of the solutions.[12]

2-8 Semiconductor Diodes

So far we have looked at only so-called passive electronic devices: capacitors and resistors respond to voltages applied across them by accumulating charge or passing currents, respectively. In the next two labs, we'll take a look at two *active* devices which behave very differently depending upon what voltages are applied to them. The *diode* essentially acts as a one-way switch controlled by voltage. For one polarity of voltage, if the voltage across the diode is greater than a threshold value (often ~0.6 Volts), it conducts current with essentially no resistance. If the voltage is below that value, or has the opposite polarity, the diode acts as an open switch and conducts no current. The *transistor* differs from the other devices we've considered so far in that it has three leads or connections. The voltage applied between two of these leads controls whether current can be conducted between two others. Although the transistor also acts as a switch, it does not merely shift between fully off and fully on. Its importance lies in the fact that a relatively low-power voltage supply can control the flow of a more powerful current over a range of values. It is this switching and decision-making property of diodes and transistors, which makes all of modern day electronics, including computers and telecommunications, possible.[3]

The study of semiconductors and the devices made from them falls under the category of solid state physics. In this experiment, we will work with one useful device: the diode. Although we will discuss the theory briefly, you will mainly be expected to be able to understand how diodes function in circuits.[4]

2-9 Energy Bands

The electrons of an isolated atom have discrete allowed energies that we call energy levels. The Pauli Exclusion Principle states that at most two electrons can occupy any allowed energy level. For example, Figure 1 shows schematically the energy levels for a Lithium atom. The vertical scale is associated with increased energy. The dots denote electrons occupying a given level. In order to minimize energy the electrons fill the levels from the bottom up.

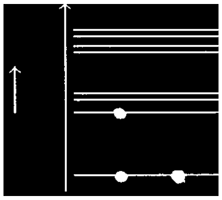

Figure 1: Energy levels of an isolated ato

When two isolated atoms are brought close together their electric fields interact and cause a splitting of the energy levels. Each original energy level splits into two, one going slightly higher and the other going lower (see Figure 2). (A detailed explanation of the cause of this will have to be postponed until a quantum mechanics course.) In a crystalline solid, where many atoms exist close together, this effect is multiplied many times over. Each energy level spreads out over a small continuous range of energies called an <u>energy band.</u>

far apart

both close together

many atoms close together

Figure 2: Energy level splitting due to atomic interaction [13]

If the original energy levels were spaced closely together the associated energy bands might overlap, resulting in a larger continuous band. Sometimes, however, the energy levels are spaced far enough apart that the bands don't overlap. This "gap" between bands is what provides the interesting physics of semiconductor devices. Remember that energy level diagrams represent allowed or accessible states that an electron may occupy. A gap between bands indicates a forbidden energy range for electrons.[13]

2-10 Conduction and Valence Bands

Conceptually, we can imagine gradually filling up the electronic states with electrons until all of them are accommodated, even though solids aren't really made that way. In order to minimize the energy, the lowest states of the system fill first. Each band can hold 2 electrons for each atom in the crystal, since each band is derived from one atomic energy level for each atom, and each atomic energy level can hold two electrons (one spin up and one spin down). The ***highest*** fully occupied band is called the valence band. The next band above that, which may be partially filled, is called the conduction band. For an electron to participate in conduction it must be able to gain energy in small amounts from the applied electric field, *i.e.*, there must be empty levels close in energy to that occupied by the electron. Thus the valence band electrons are immobile and cannot contribute to the conductivity, whereas electrons in the conduction band can contribute to conduction (as the name suggests).[13]

2-11 Light Emitting Diodes

A light emitting diode (LED) is a semiconductor p-n junction that is optimized to release light of approximately the band gap energy under forward bias, when electrons fall from the conduction band to the valence band. The electrons and holes migrate toward the junction where they recombine and release light whose energy corresponds to the band gap energy.

The energy (E) of the light emitted by an LED is related to the electric charge (q) of an electron and the voltage (V) required to light the LED by the expression: $E = qV$ Joules.

This expression simply says that the voltage is proportional to the electric energy, and is a general statement which applies to any circuit, as well as to LED's. The constant q is the electric charge of a single electron, -1.6×10^{-19} *Coulomb*.[13]

2-12 Colours of LEDs

LEDs are made from gallium-based crystals that contain one or more additional materials such as phosphorous to produce a distinct color. Different LED chip technologies emit light in specific regions of the visible light spectrum and produce different intensity levels.

LEDs are available in red, orange, amber, yellow, green, blue and white. Blue and white LEDs are much more expensive than the other colours. The colour of an LED is determined by the semiconductor material, not by the colouring of the 'package' (the plastic body). LEDs of all colours are available in uncoloured packages which may be diffused (milky) or clear (often described as 'water clear'). The coloured packages are also available as diffused (the standard type) or transparent. [12]

Chapter three

Experimental setup

3.1 Introduction

In this chapter the circuit which is designed to find the energy gaps of some semi conductor devices is presented. The samples which are selected beside the experimental procedures are also discussed. This can be done relating current to temperature at three different value of voltage (2.5 V , 5 V and 7 V) and see the position where the current changes abruptly depending on the effect of temperature.

3.2 Samples

The samples which are utilized are electronic components which made from semiconductors, and shown in different tables with the results (3.1)

3.3 Circuit Design

The Circuit is designed as shown in fig (3.1) to find energy gap. The circuit consists of power supply having voltage range (0– 20 V). The semiconductor device is connected in series with a meter of current range of microamperes (μ A). This semiconductor is connected in parallel to a voltammeter, temperature source and thermometer. To assure whether heat affect the energy band gap.

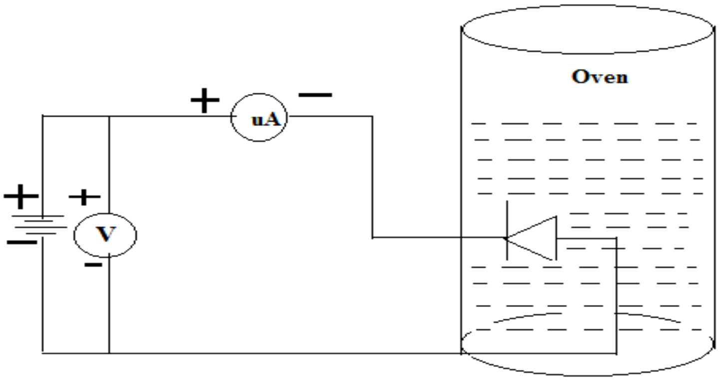

Fig (3.1) circuit designed to find the energy band gap

3.4 Experimental procedures

The following setup were use to find the energy band gap :

1- Circuit connected as shown in Fig (3.1) i.e. positive of (0 – 20 V) power supply to N – side of diode and to positive of voltmeter.

Connect negative of power supply to negative of voltmeter and negative of micrommeter (µA) and positive of micrommeter to P – side of diode.

2- Temperature kept under control.
3- Switched on the instrument using on/of.
4- Adjusted the voltage at 2.5V DC and note down the reverse current.
5- Adjusted the temperature control at maximum position. Temperature starts increasing and the reading of the current start increasing.
6- When temperature reaches 80^0 C, Note down the maximum reading shown by microammeter.
7- As the temperature start falling, record the values of micrommeter reading in observation table after every 10^0 C drop in temperature.
8- Repeat the whole procedure for 5 V DC and 7 V DC
9- Plot a graph between 10^3 / T along X axis and Ln is a long Y axis and the slope of the line is determined from the graph.

Observation table 3.4.1:

This table for sample of ($GaP_{0.40}As_{0.60}$) (red)

No	**Current I_s in micrompere**			**Temperature of the junction diode**		**Ln I_s**			**10^3/T**
	V= 2.5 v	**V=5v**	**V= 7v**	**In c°**	**In k**	**V= 2.5v**	**V= 5v**	**V= 7v**	
1	**800**	**2500**	**3500**	**80**	**353**	**6.68**	**7.82**	**8.16**	**2.83**
2	**700**	**1800**	**1900**	**70**	**343**	**6.55**	**7.50**	**7.55**	**2.91**

3	**600**	**1200**	**1400**	**60**	**333**	**6.39**	**7.09**	**7.24**	**3.00**
4	**300**	**600**	**1000**	**50**	**323**	**5.70**	**6.40**	**6.90**	**3.09**
5	**200**	**400**	**800**	**40**	**313**	**5.30**	**5.99**	**6.68**	**3.19**
6	**200**	**300**	**700**	**30**	**303**	**5.30**	**5.70**	**6.55**	**3.30**

V = 2.5 V

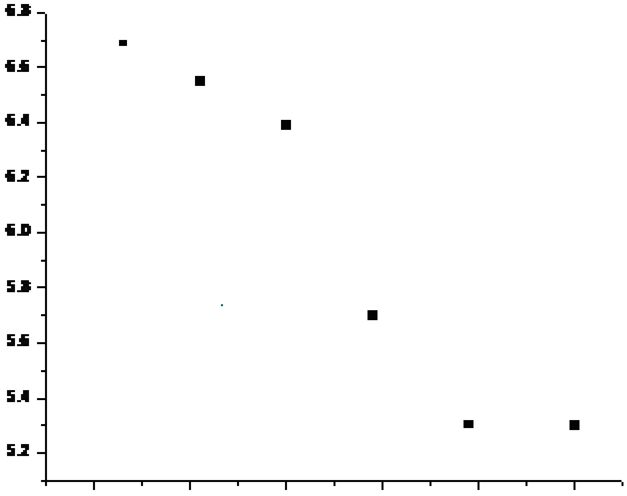

Fig (3.1) 10^3/ T(Kelvin) vrs ln I_s (μ A), at voltage 2.5 volts

V = 5 V

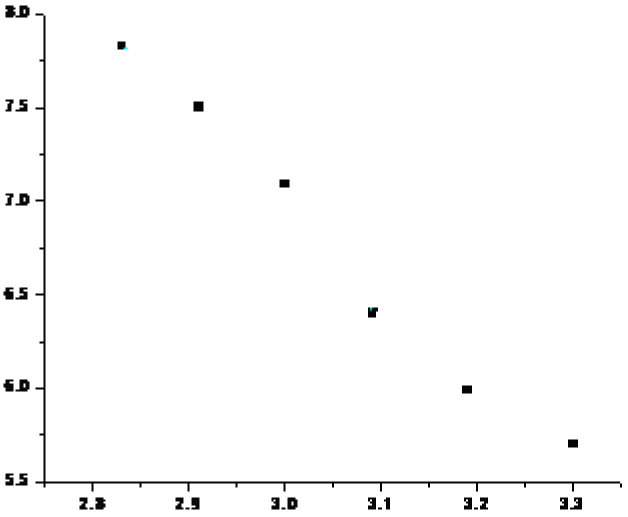

Fig (3.2) 10^3/ T(Kelvin) vrs ln I_s (μ A), at voltage 5 volts

V = 7 V

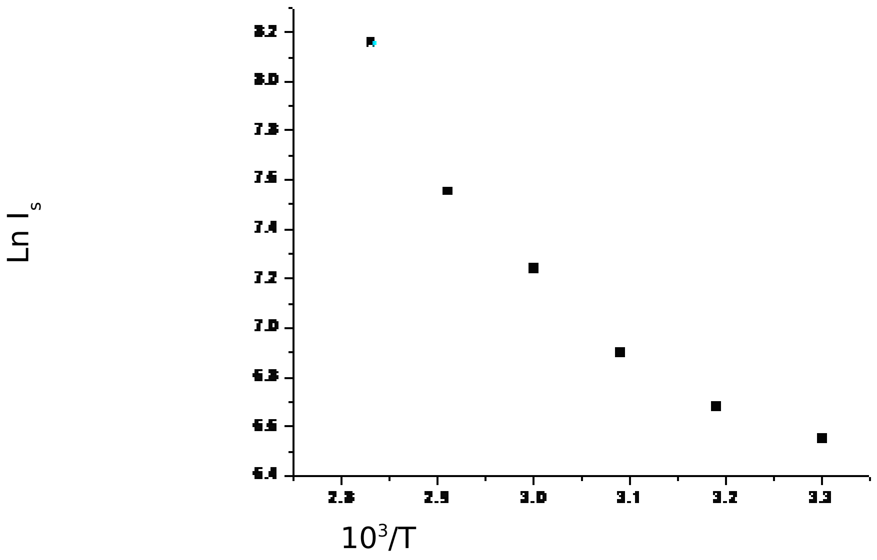

Fig (3.3) 10^3/ T(Kelvin) vrs ln I_s (μ A), at voltage 7 volts

V = 2.5 V

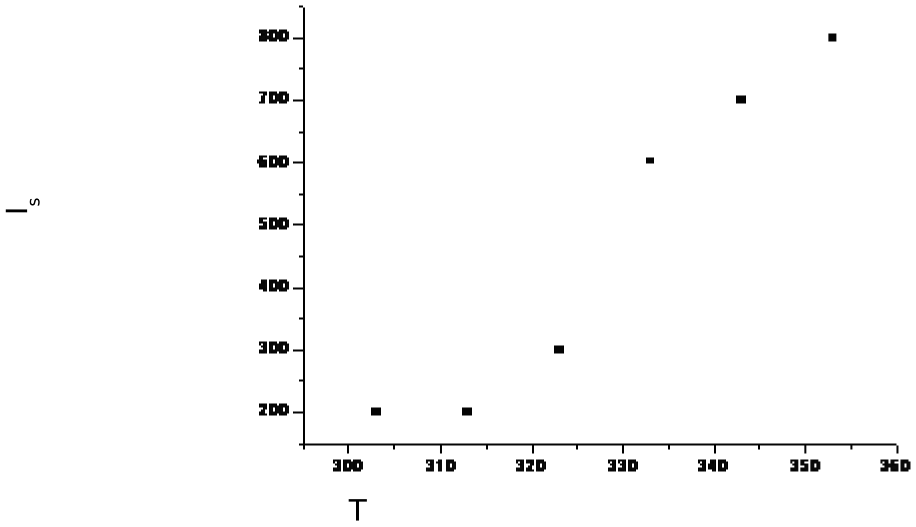

Fig (3.4) T (kelvin)) vrs I_s (μ A), at voltage 2.5 volts

V = 5 V

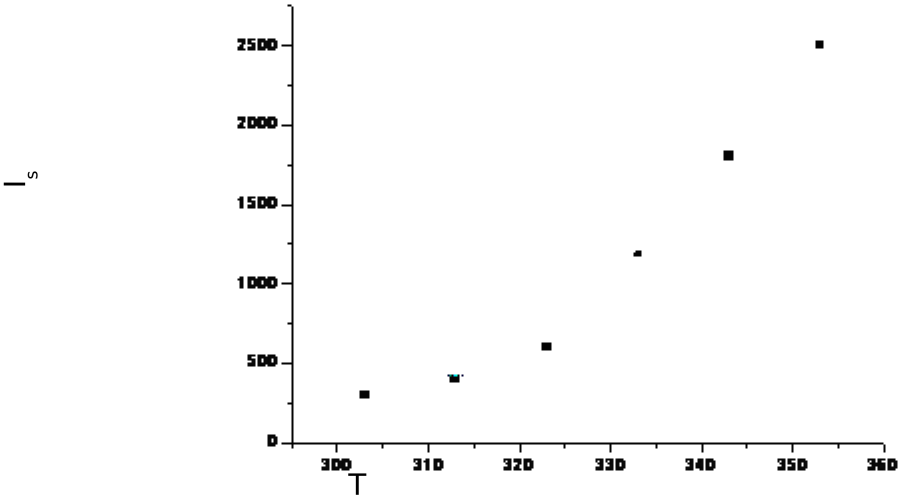

Fig (3.5) T (kelvin)) vrs I_s (μ A), at voltage 5 volts

V = 7 V

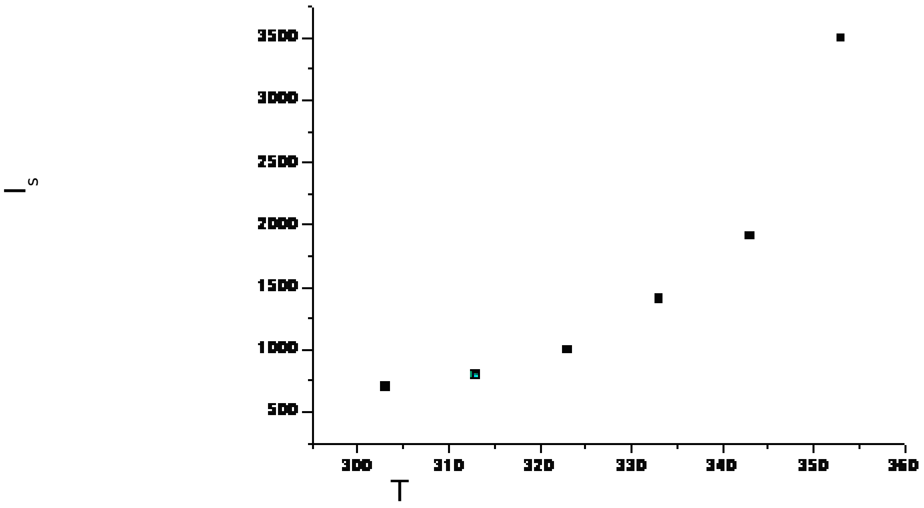

Fig (3.6) T (kelvin)) vrs I_s (μ A), at voltage 7 volts

Observation table 3.4.2

This table for sample of ($GaP_{0.65} As_{0.35}$) (Orange)

No	Current I_s in micrompere			Temperature of the junction diode		Ln I_s			$10^3/T$
	V= 2.5 v	V=5v	V= 7v	In c°	In k	V= 2.5v	V= 5v	V= 7v	
1	600	1200	1400	80	353	6.40	7.09	7.24	2.83
2	500	1100	1300	70	343	6.21	7.00	7.17	2.91
3	400	1000	1200	60	333	5.99	6.90	7.09	3.00
4	400	800	1000	50	323	5.30	6.68	6.90	3.09
5	100	600	800	40	313	4.60	6.40	6.68	3.19
6	100	500	700	30	303	4.60	6.21	6.55	3.30

V = 2.5 V

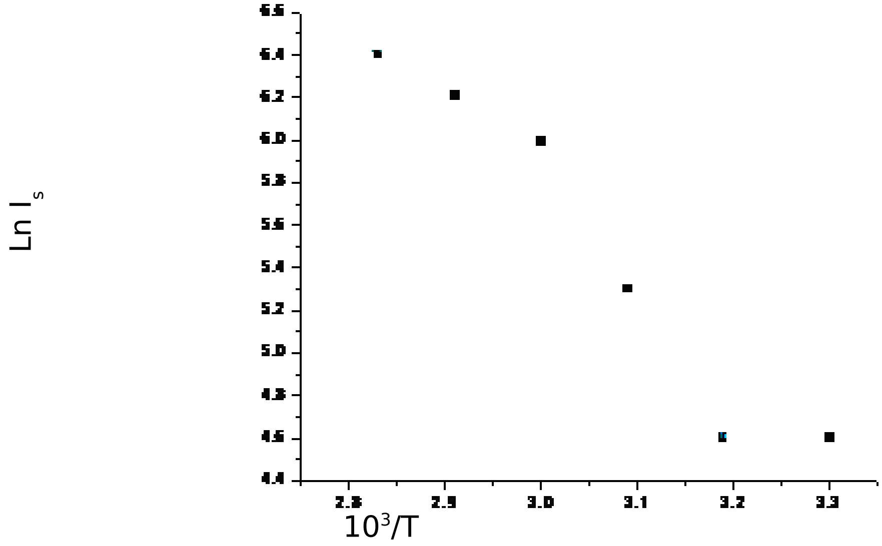

Fig (3.7) 10^3/ T(Kelvin) vrs ln I_s (μ A), at voltage 2.5 volts

V = 5 V

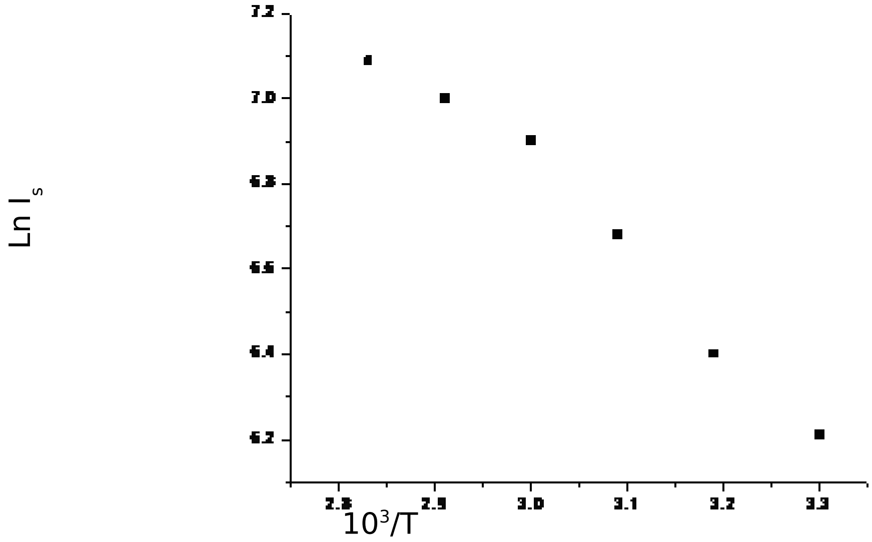

Fig (3.8) 10^3/ T(Kelvin) vrs ln I_s (μ A), at voltage 5 volts

V = 7 V

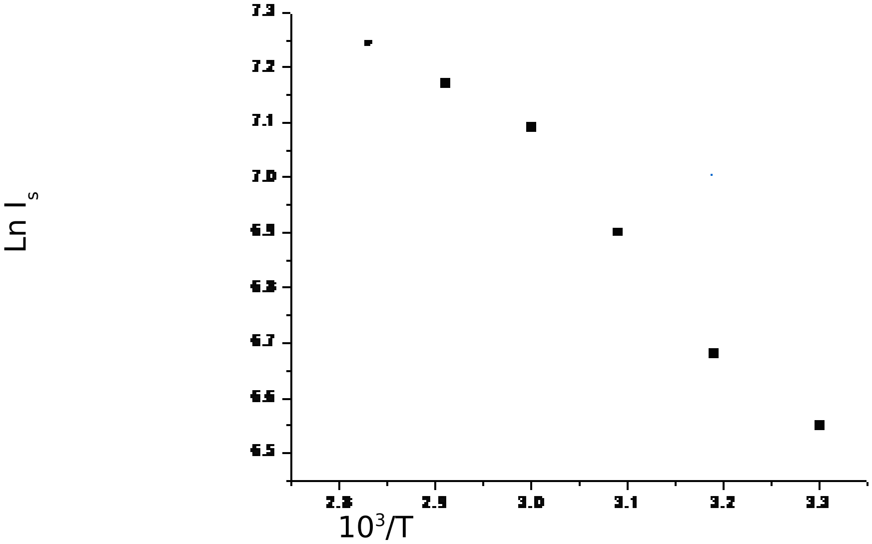

Fig (3.9) 10^3/ T(Kelvin) vrs ln I_s (μ A), at voltage 7 volts

V = 2.5 V

T

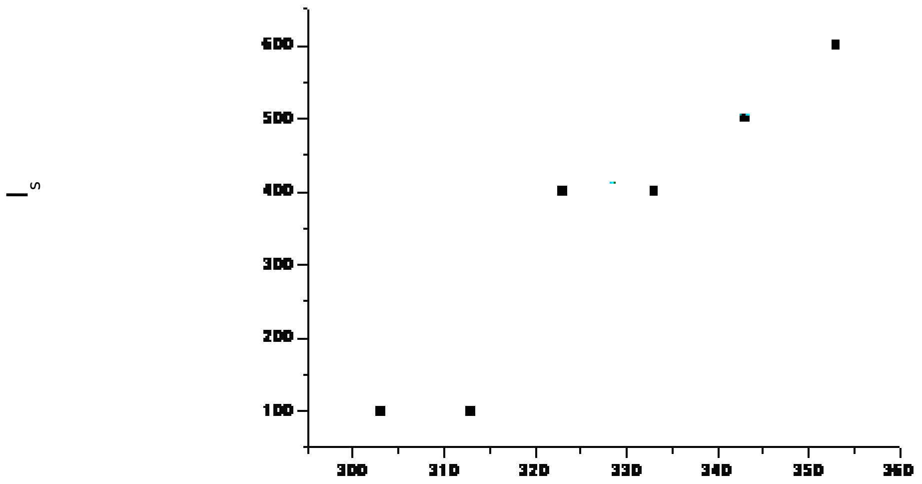

Fig (3.10) T (kelvin)) vrs I_s (µ A), at voltage 2.5 volts

V = 5 V

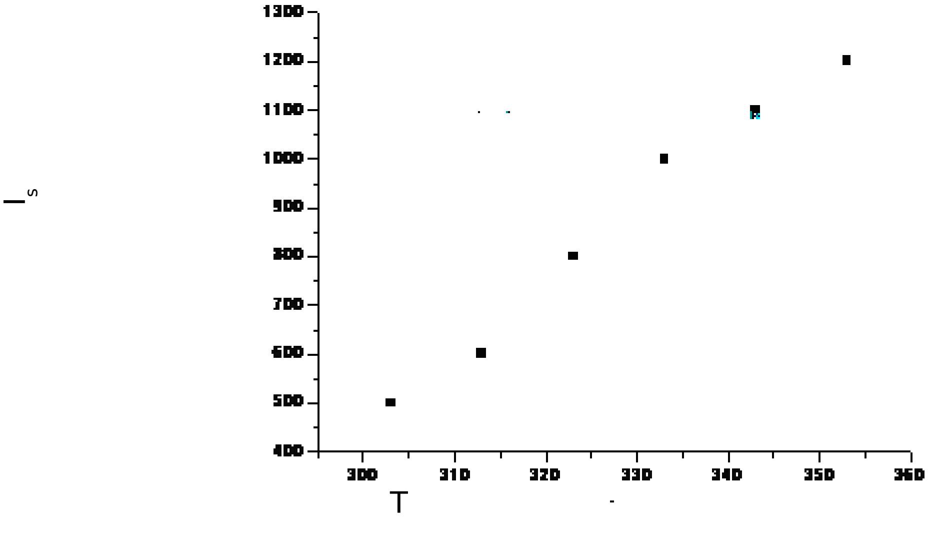

Fig (3.11) T (kelvin)) vrs I_s (µ A), at voltage 5 volts

V = 7 V

T

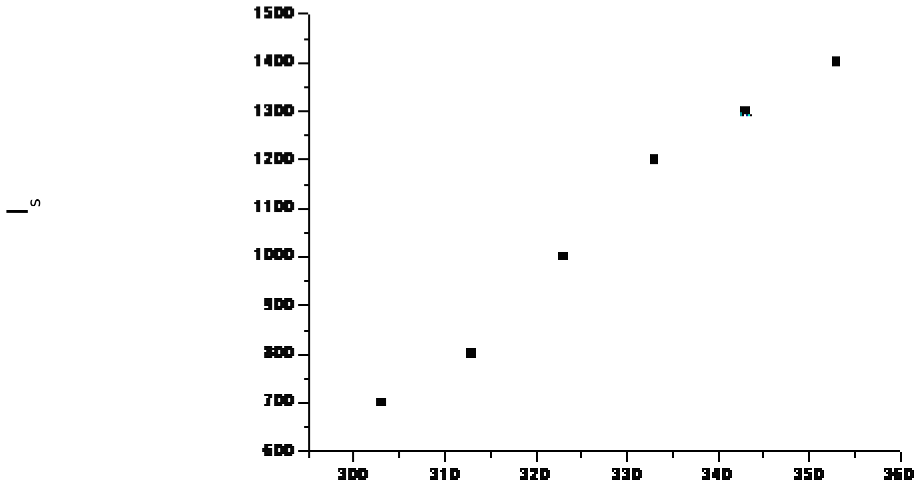

Fig (3.12) T (kelvin)) vrs I_s (μ A), at voltage 7 volts

Observation table 3.4.3

This table for sample of ($GaP_{0.85} As_{0.15}$) (Yellow)

No	Current I_s in micrompere			Temperature of the junction diode		Ln I_s			$10^3/T$
	V= 2.5 v	V=5v	V= 7v	In c°	In k	V= 2.5v	V= 5v	V= 7v	
1	700	1500	1600	80	353	6.68	7.31	7.38	2.83
2	600	800	1500	70	343	6.55	7.09	7.31	2.91
3	500	600	1400	60	333	6.40	6.68	7.24	3.00
4	400	500	1300	50	323	5.99	6.21	7.17	3.09
5	200	300	1000	40	313	5.30	5.70	6.90	3.19
6	100	200	900	30	303	4.60	5.30	6.80	3.30

V = 2.5 V

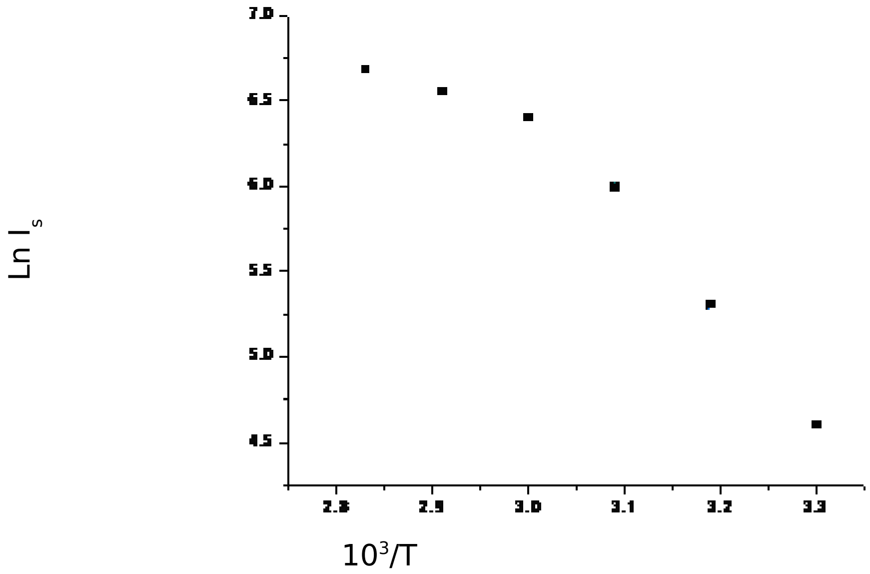

Fig (3.13) 10^3/ T(Kelvin) vrs ln I_s (μ A), at voltage 2.5 volts

V = 5 V

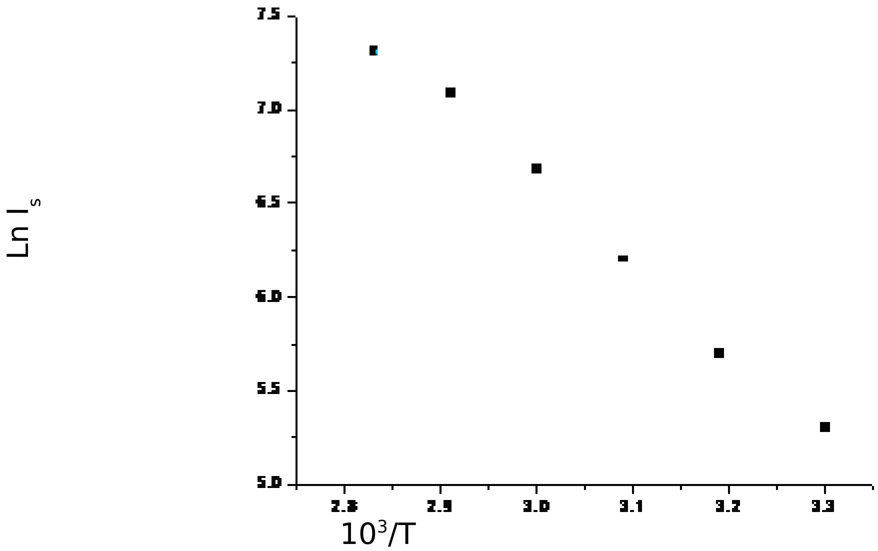

Fig (3.14) 10^3/ T(Kelvin) vrs ln I_s (μ A), at voltage 5 volts

V = 7 V

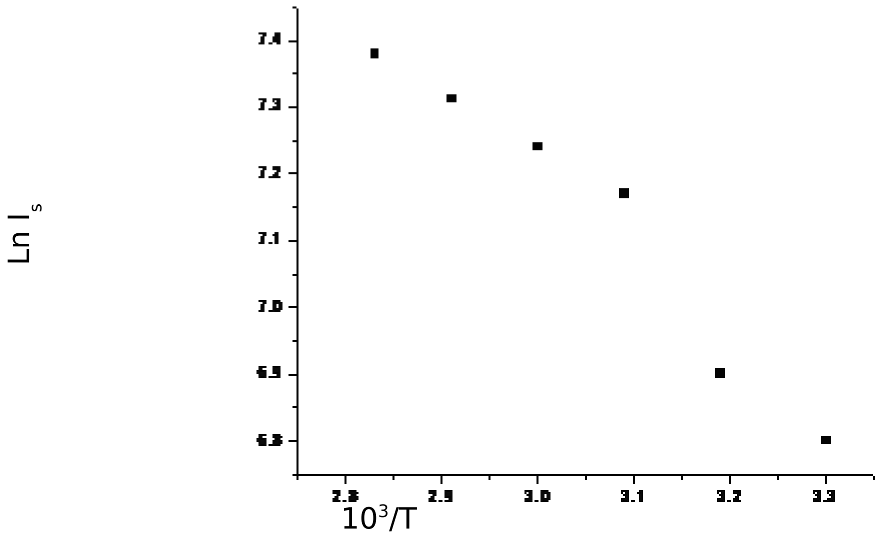

Fig (3.15) 10^3/ T(Kelvin) vrs ln I_s (µ A), at voltage 7 volts

V = 2.5 V

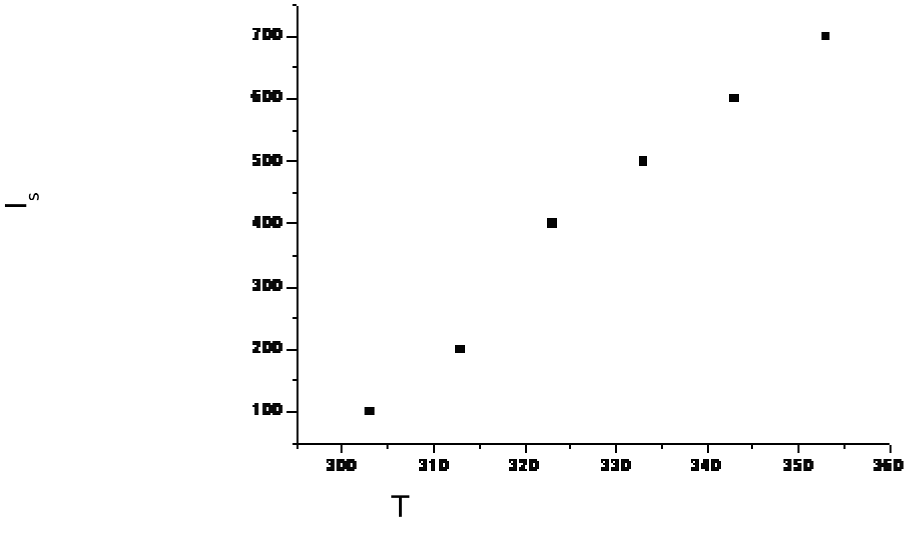

Fig (3.16) T (kelvin)) vrs I_s (µ A), at voltage 2.5 volts

V = 5 V

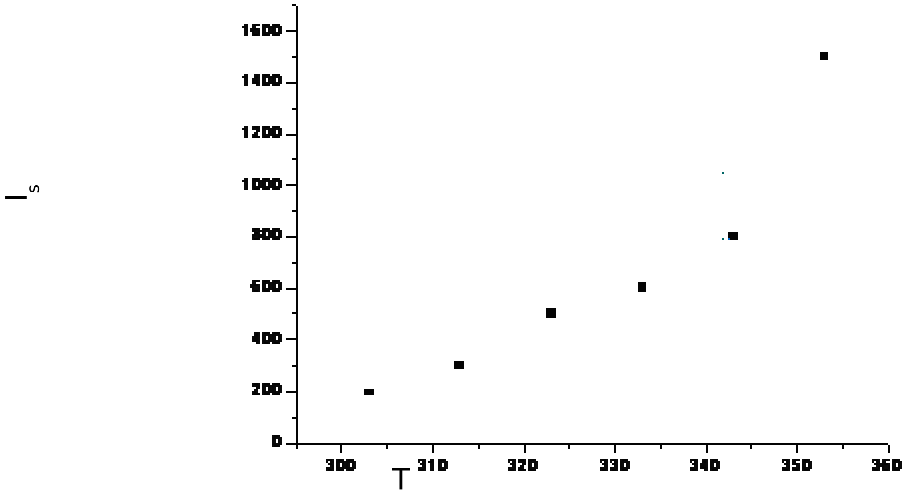

Fig (3.17) T (kelvin)) vrs I_s (µ A), at voltage 5 volts

V = 7 V

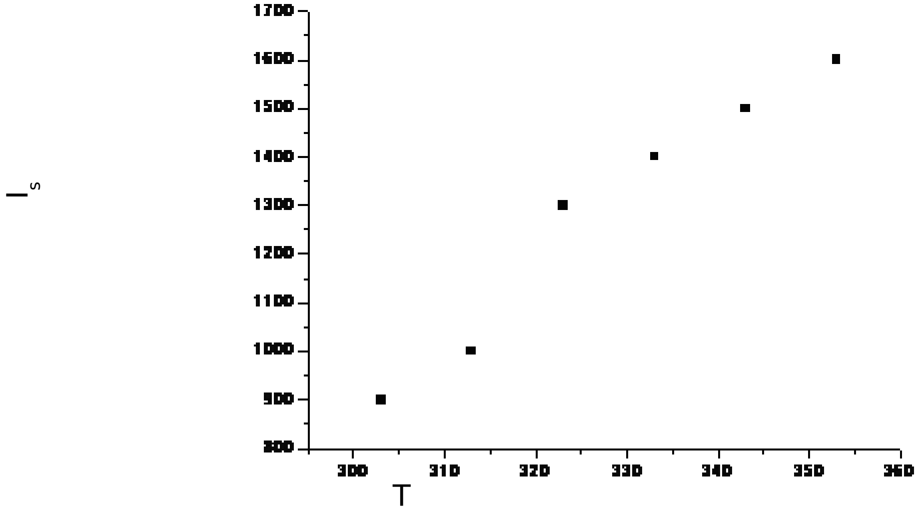

Fig (3.18) T (kelvin)) vrs I_s (µ A), at voltage 7 volts

3.5 Calculations

The energy gap of semiconductor divces is given by the formula

$$Eg = \frac{\text{slope}}{5.04} \qquad (1)$$

From the graphs find(the slop of the stright line) the energy gap of the semiconductor divces practical resolving are shown in table **3.5.1**

		The slop of line (at volt)			Eg (at volt)			Mean Eg
Composition	Samble	2.5 V	5 V	7 V	2.5 V	5 V	7 V	
$GaP_{0.40}As_{0.60}$	Red	8.064	8.7696	5.0047	1.6	1.74	.993	1.44
$GaP_{0.85}As_{0.15}$	Yellow	9.02	9.9792	9.5760	1.79	1.98	1.9	1.894
$GaP_{0.65}As_{0.35}$	Orange	10.0362	8.0640	7.767	1.9913	1.60	1.5476	1.7110

Chapter four

Result and analysis

4.1 Result

Energy gap (Eg) of semiconductor divces are calculated by Equation (1) using above table. Were found to be (1.44ev) and (1.86ev)

4.2 Percentage Error

The ercentage error was estimated to be found using the formula

$$\% \text{ error} = \frac{\text{standard value} - \text{experimental value}}{\text{Standard value}} \times 100$$

Then the Percentage error is recorded at the table (4.1.1) below

Composition	Samble	Standard value	experimental value	Error %
$GaP_{0.40} As_{0.60}$	Red	1.62	1.44	17%
$GaP_{0.85} As_{0.15}$	Yellow	2.15	1.894	12%
$GaP_{0.65} As_{0.35}$	Orange	2.08	1.711	17%

Discussion

The values of (Eg) in table (3.5.1) is calculated at constant value of voltage , but at different value of temperature, the value of band gap remain the same, hence band gap is the characteristic physical value of any material used to defines that material, same way like physical property such as thermal properties, electrical properties, optical properties ect....

Results (in table 3.5.2) were taken by keeping constant voltage at different temperature, so temperature plays a significance role to define the band gap.

It was also observed from saturation current column of saturation current that the corresponding slope and Energy gap show little variation with changing voltage. This may be due to the temperature which caused to change in current this shown by the graphs of (current V temperature).

Conclusion

This work shows that simple electric circuits can be utilized to find the (E_{gs})

And levels for semiconductors, this requires to take about so or more readings for(I and V).

The position where the current remains almost constant or increases abruptly indicates the values of the E_{gs}

Future work

1) The determination of Energy gaps and levels can be extended to include conductors as well as insulators.

2) The energy levels for gases and liquids can also be found by taking the atomist benefit of this work.

3) More sensitive voltmeters and ammeter are need to get more accurate result.

References and sources

[1] Demystified David Mc Mohon Quantum

Mechanics, 1999

[2] (http://www.webelements.com)

Mark Winter (the University of Sheffield and web Elements ltd, UK, 2010

[3] J. Burns, solid state physics (Academic press, Florida, 1985)

[4] B.H. Bransden & C.J.Joachain, Quantum chemistry of solid second edition, 2000

[5] David . J.Griffiths. introduction of Quantum mechanics second edition, 2003

[6] Charles Kittel, introduction of solid state physics, 2003

[7] S.O. Kasap, principles of electronic materials and devices, second edition, electrical engendering university of saskat chewan , Canada, 2000

[8] Charles.M.Wolf, Nick Holonyak, JR, Gregory, E.Stillman physical properties of semiconductors , 2001

[9] Sakurai, J. Modern quantum mechanics, 1985

[10] J.J. Sokurai Modern quantum mechanics, Rev. ed, Addison wesly pub.co. reading 1994

[11] D.J. Griffiths introduction quantum mechanics, printice Hall, engle wood clitts, 1995

[12] Donald A. Neamen, semiconductor physics & devices, second edition , 1997

[13] P.S.Kireev, semiconductor physics, first published, 1975

[14] أسماء محمد الحسين جاد الله ، تعيين نطاقات الطاقة لبعض أجهزة أشباه الموصلات ، ماجستير الفيزياء جامعة السودان ، السودان، 2010

[15] حياة الطيب محمد صالح ، إيجاد قسم الطاقة الممنوعة ومستويات الطاقة لبلورات ووصلات ثنائية عادية وضوئية بطريقة كهربية ، ماجستير الفيزياء جامعة الزعيم الأزهري، 2009م