بسم الله الرحمن الرحيم

Sudan University of Science and Technology
Collage of Graduate Studies

Effect of High Temperature on Metals and Semiconductors

تأثير الحرارة العالية علي المعادن واشباه الموصلات

Supplementary search for a master's degree
In general Physics

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Supervision

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الأية

بسم الله الرحمن الرحيم

{لَّهُ مُلْكُ السماوات والارض وَإِلَى الله تُرْجَعُ الامور} {5}

صدق الله العظيم

سورة الحديد

Dedication

I dedicate to all those who contributed in

education

Dedicate to my father & my mother

To my brothers and sisters

To my husband

& my teacher &

My colleagues

To all of you dedicate this modest effort

Researcher

Acknowledgements

Thank God first and foremost

Thank everyone who helped me in my career complete educational and completion of this research, and I especially thank my father and My mother

I thank the professors Sudan University of Science and Technology Faculty of Science, Department of Physics

And thanks, Dr.Rawia Abd ElGani

And Mr. Ali Suleiman

God bless all of us

Abstract

The electrical property of noble mineral (platinum) 58 680 sample and semiconductor 586 821were studied , at temperatures up to $100C^{0}$, 373 Kelvin. It was found that the temperature increases mineral resistivity and decreases it is conductivity ,the resistance and conductivity f or the mineral we found to be equal to R = 106.3 Ω and σ = 0. 01176Ω cm^{-1} respectively .

The resistance and conductivity for semiconductor were also obtained . It was found that increasing temperature decreases resistance and increasing of conductivity. Where the resistance and conductivity valves are

. R= $1.4 \times 10^{-29}\Omega$ and $\sigma = 8.93\times 10^{28}\Omega cm^{-1}$ respectively.

The result conforms with theoretic.

المستخلص

درست الخواص الكهربية لعينة من المعادن النبيلة (البلاتين) التي تحمل الرقم 58680 وعينة من مواد شبه موصلة بالرقم 586821 في درجات حرارة حتي 373 كلفن ،وجد ان إرتفاع درجة الحرارة علي المعدن يزيد من المقاومة ويقلل من الموصلية فحسبت المقاومة والموصلية للمعدن تساويان $\sigma = 0.01176\Omega\ cm^{-1}$ و $R=106.3\Omega$ بالترتيب .

و تم ايضاً حساب المقاومة والموصلية لمادة شبه الموصل فوجد ان إرتفاع درجة الحرارة يقلل من المقاومة ويزيد من الموصلية. حيث ان المقاومة والموصلية تساويان بالترتيب.

. $\sigma = 8.93\times 10^{28}\Omega cm^{-1}$ و $R= 1.4 \times 10^{-29}\Omega$.

وقد تتطابقت هذه النتائج مع التوقعات النظرية.

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Chapter One

Introduction

Metals and semiconductors intervene directly in the electrical conductivity process, where we find that some of the metal conductive good for Electricity and intervention in some circumstances that hinder or reduce the conductivity; where they are affected directly Influence of increased temperature working to Artvreet resistance and thus lead to a reduction coefficient of conductivity of the metal, Fadden alnbouaplh of platinum metals has high conductivity of electricity. Semiconductor That'll some electrical conductivity properties, but under certain conditions turn out to conductive materials due to the impact of these conditions, and factors that are helping to transform the semiconducting material into conductive materials are changes within overheating.

1.1 Research problem

The problem for this research in the effect of temperature on metal and semiconductor materials and is working to change the resistance and conductivity.

1.2 Aims

Calculate the resistance of some noble metals and semiconductors at different temperatures

- Determine the effect of high temperature on the resistance of the metal and semiconductor

- Electrical conductivity of the samples coefficient at high temperatures

-compeer between resistance and conductivity coefficient of samples taken

1.3 Research assumes

- The possibility of improving certain semiconductor superconductivity good for electricity increased temperature.

- The possibility of maintaining the quality of metals connected at high temperature.

1.4 Research Methodology

This search process to conduct the experiment on the platinum metal and semiconductor material taken as samples and read the results

1.5 Research Layout

The first chapter contains an introduction, Chapter two Metals, Chapter three Semiconductors, The fourth chapter it contains the practical.

Chapter Two

Metals

2.1 Introduction

A material in which an electric charge moves in the field, The Minerals Metals from the finest materials receipt of electricity, on top of silver and copper followed Vellum. It was because the Turkabad crystalline Crystal Structure, and repeated this organization in three directions perpendicular component of the body that we see, that the electrons of the external orbitals of atoms, which are called valence Valence Electron (and their number ranging from 1 to 3 in the metals) are common all between all the atoms they are not of a particular atom, while we find that the internal electrons orbit the nucleus of atoms are Mirth strong electrical forces and called restricted electrons Bound electrons. Accordingly, the foreign bonding electrons with the nucleus of the atom is weak, she is free to move within the crystal structure of the metal and this is also called electrons loose Free Electron, and this makes Ptnqlha distinct from the other metals in the quality of the delivery of electricity[1].

2.2 Electrical conductivity

Electrical conductivity is a material's ability to conduct an electric current when an electrical potential difference is applied across it. It is also known as specific conductance, and should not be confused with conductance which is a property of a component, whereas conductivity is a property of the substance from which the component is made. The SI unit of electrical conductivity is the Siemens per meter (S/m)[1]. Conductivity is the inverse of resistivity. The conductivity, σ, is given in terms of current density, J, and electric field strength, E, using the expression.

$$J = \sigma E \tag{2.1}$$

Materials of high conductivity include metals, especially copper and silver. Silver actually has the highest electrical conductivity but is too expensive for general use for electrical wiring. Copper is the next best choice and is normally used for any type of electrical wiring. Gold is also a good conductor, although 1not as good as copper and more expensive than silver, but it does have the additional advantage of being corrosion resistant and so is often used as plating for electrical contacts. Aluminum is often used for overhead power lines because it is a reasonable conductor but has the additional advantage of being light in weight [1].

2.3 Electrical properties of metals

2.3.1 Basic laws and electrical properties of metals

When an electrical potential V [volts, J/C] is applied across a piece of material, a current of magnitude I [amperes, C/s] flows. In most metals, at low values of V, the current is proportional to V, and can be described by Ohm's law:

$$I = \frac{V}{R} \qquad (2\text{-}2)$$

Where R is the electrical resistance [ohms, Ω, V/A].R depends on the intrinsic resistivity ρ of the material [Ω-m] and on the geometry (length l and area A through which the current passes)[1]:

$$R = \rho \frac{l}{A} \qquad (2\text{-}3)$$

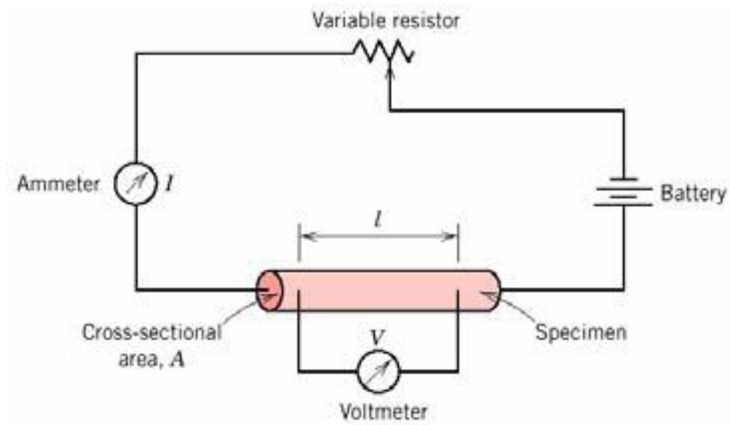


Fig2. 1 shown ohm circuit

In most materials (e.g. metals), the current is carried by electrons (electronic conduction). In ionic crystals, the charge carriers are ions (ionic conduction.

2.2-2 Basic laws and electrical properties of metals

The electrical conductivity (the ability of a substance to conduct an electric current) is the inverse of the resistivity:

$$\sigma = 1/\rho \qquad (2\text{-}4)$$

Since the electric field intensity in the material is $E = V/l$, Ohm's law can be rewritten in terms of the current density.

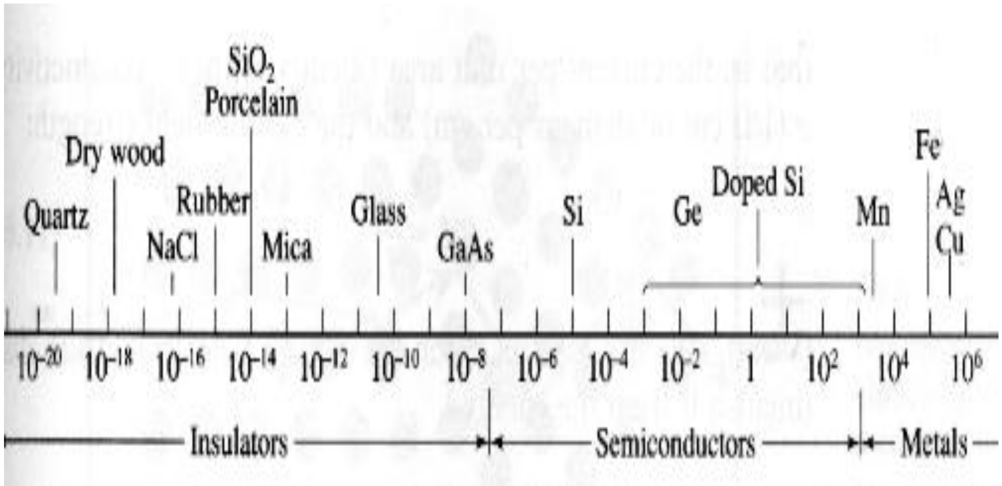
$$J = I/A \qquad (2\text{-}5)$$

as:

$$J = \sigma E \qquad (2\text{-}6)$$

Electrical conductivity varies between different materials by over 27 orders of magnitude, the greatest variation of any physical property[1].

fig2.2   σ (Ω.cm)-1



.

Metals: σ > 105 (Ω .m)-1

Semiconductors: 10-6 < σ < 105 (Ω .m)-1

Insulators: σ < 10-6 (Ω. m)-1

Materials of Choice for Metal Conductors One of the best material for electrical conduction (low resistivity) is silver, but its use is restricted due to the high cost Most widely used conductor is copper: inexpensive, abundant, high σ, but rather soft – cannot be used in applications where mechanical strength is important .Solid solution alloying and cold working in prove strength but decrease conductivity. Precipitation hardening is preferred, e.g. Cu-Be alloy When weight is important one uses aluminum, which is half as good as Cu and more resistant to corrosion .Heating elements require low σ (high R), and resistance to high temperature oxidation[1].

Table2.1 shows the resistivity, conductivity of various metals at 20 °C

Electrical properties of some metals at RT Metal	**Conductivity (-1-m-1)**	**Resistivity (-m)**
Silver	6.8 x 107	1.59 x 10-8
Copper	6.0 x 107	1.68 x 10-8
Gold	4.3 x 107	2.44 x 10-8
Aluminum	3.8 x 107	2.82 x 10-8
Nickel	1.43 x 107	6.99 x 10-8
Iron	1.0 x 107	9.0 x 10-8
Platinum	0.94 x 107	1.06 x 10-7

2.4 Temperature Coefficient

Since the electrical resistance of a conductor such as a copper wire is dependent upon collisional processes within the wire, the resistance could be expected to increase with temperature since there will be more collisions. An intuitive approach to temperature dependence leads one to expect a fractional change in resistance which is proportional to the temperature change[2]:

$\frac{\Delta R}{R0} = \propto \Delta T$ $\propto =$ temperature coefficient of resistance

$\frac{R - R0}{R0} = \propto (T - T0)$ or

$$R = R_0\{1 + \propto (T - T0)\} \quad (2\text{-}7)$$

Or, expressed in terms of the resistances at some standard temperature from a reference table

2.5 Effect of temperature on the Conductors

The outermost shell of conductors is mostly free at room temperature and hence due to the fact that conducting materials leave the outermost electrons, the nucleus of the atom of conducting material is more positive as it is a positive ion[2].

$$Cu \qquad\qquad Cu^{+} + e$$

Hence taking out more electrons from the penultimate shell of the atom is very difficult and when the temperature is increased, the energy supplied is not enough to take out more electrons but due to the energy because of increase in temperature, the nucleus of the atoms start vibrating and hence obstruct the flow of electrons already in the free space. So with increase in temperature, conductivity of the conductors decreases and resistance increases. Hence we say conductors have positive temperature coefficient [2].

fig2.3 shown resistance increases with increases temperature

Chapter Three

Semiconductor

3.1 Introduction

A semiconductor is a substance which has resistivity in between conductors and insulators, e.g. germanium, silicon, selenium, carbon etc.

3.2 Properties of Semiconductor

1. The resistivity of a semiconductor is less than an insulator but more than a conductor.
2. It has negative temperature co-efficient of resistance. That means the resistance of a semiconductor decreases with increase in temperature and vice-versa.
3. When a suitable metallic impurity is added to a semiconductor, its current Conducting properties change appreciably.

3.3 Commonly Used Semiconductors

The two most frequently used semiconductors are (i) germanium (Ge) and (ii) silicon (Si).

It is because the energy required to break their co-valent bonds is very small; being 0.7 eV for Ge and 1.1 eV for Si[3].

3.3.1 Germanium (Ge)

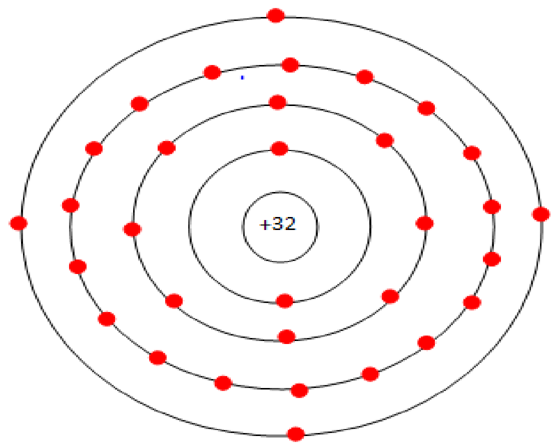


Fig3.1 (i) Atomic number of germanium is 32. So it has 32 protons and 32 electrons

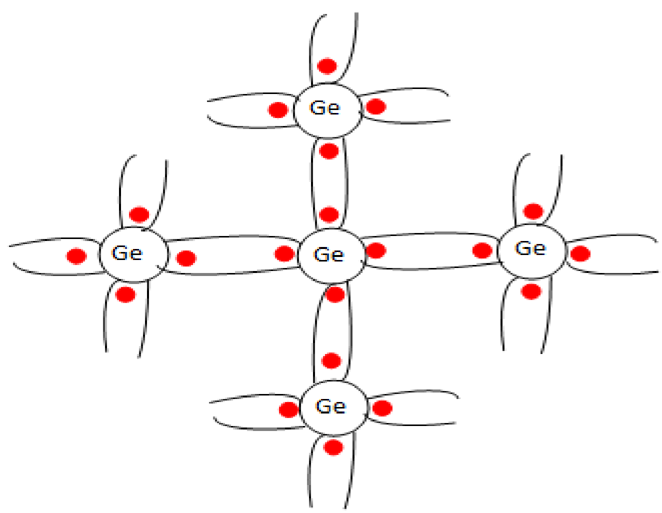
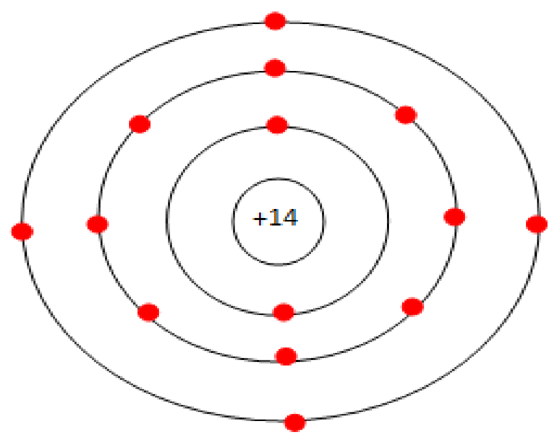


Fig.3.1 (ii) Two electrons are in the first orbit, eight electrons are in the second, eighteen electrons in the third and four electrons in the outer or valence orbit. This is shown in fig.3.1 (i)[3].

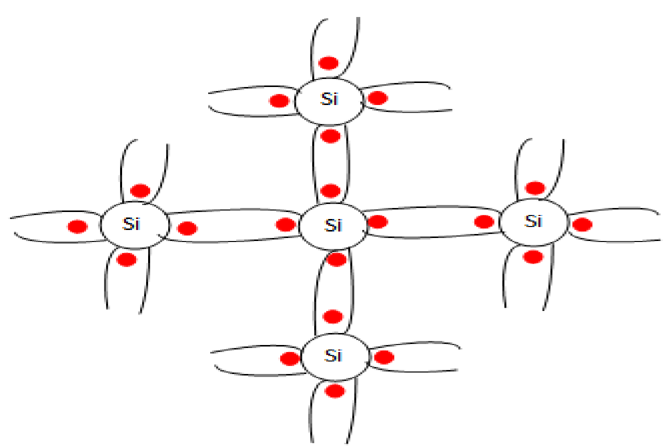
It is clear that germanium atom has four valence electrons i.e. it is a tetravalent element. Fig.3.1 (ii) shows how the various germanium atoms are held through co-valent bonds[3].

3.3.2 Silicon (Si)

Atomic number of silicon is 14. So it has 14 protons and 14 electrons.



(i)



(ii)

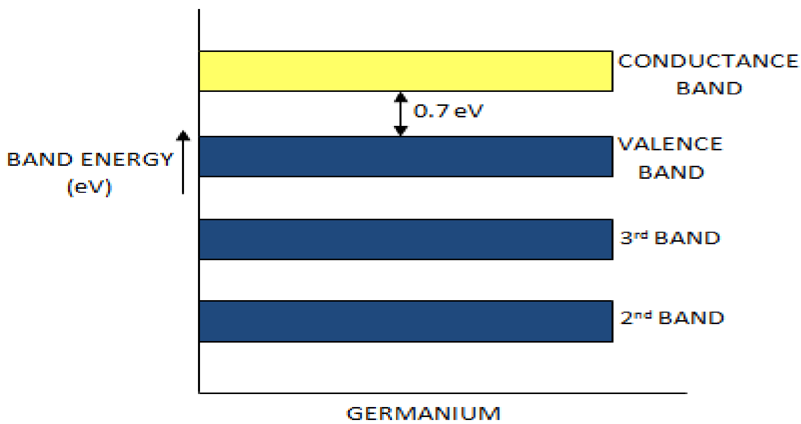
Fig.3.2 (i) and (ii) Two electrons are in the first orbit, eight electrons are in the second orbit and four electrons in the third orbit. This is shown in fig3.2 (i)[3].

It is clear that silicon atom has four valence electrons i.e. it is a tetravalent element.

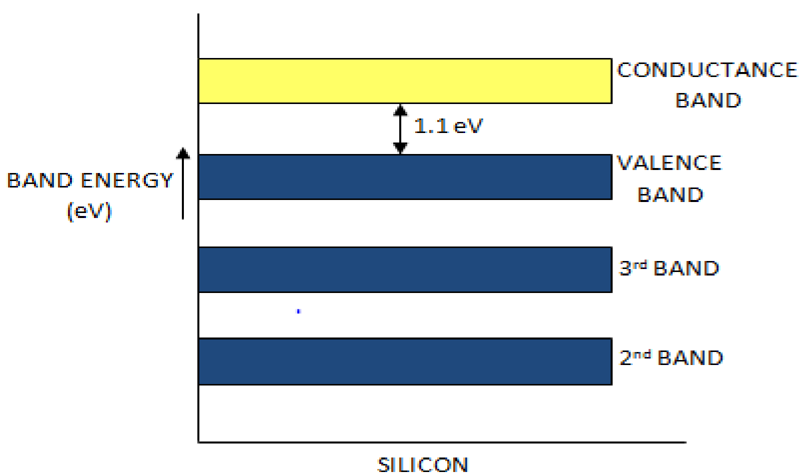
Fig3..2(ii) shows how various silicon atoms are held through co-valent bonds.

3.4 Energy Band Description of Semiconductor

A semiconductor can be defined much more comprehensively on the basis of energy bands as under [3]:



(i)



(ii)

Fig3.3 (i) and (ii) shows the energy band diagrams of germanium and silicon respectively [3].

A semiconductor is a substance which has almost filled valence band and nearly empty conduction band with a very small energy gap (nearly equal to 1 eV) separating the two.

As the forbidden gap is very small; being 0.7 eV for Ge and 1.1 eV for Si, therefore, relatively small energy is needed by their valence electrons to cross over to the conduction band.

Even at room temperature, some of the valence electrons may acquire sufficient energy to enter into the conduction band and thus become free electrons.

However, at this temperature, the number of free electrons available is very small. Hence, at room temperature, a piece of Ge or Si is neither a good conductor nor an insulator. For this reason, such substances are called semiconductors [3].

3.4 Effect of Temperature on Semiconductors

with increase in temperature, resistance decreases.

For the

fig2.3 shown resistance decreases with increase in temperature

semiconductor resistor, the evaluation reveals a dependency with the form

$$R \propto e(- Eg/2kT) \qquad (3\text{-}1)$$

(k = 1.38·10-23 J/K: Boltzmann constant) with the energy band interval Eg [4].

3.4.1 Temperature Dependence of Conductivity for a Semiconductor

The electrical conductivity of a semiconductor changes appreciably with temperature variations. the conductivity can easily be shown to vary with temperature as:

$$\sigma \propto Exp(-E.g/ 2kT) \qquad (3\text{-}2)$$

In this case, conductivity depends only on the semiconductor band gap and the temperature. In this temperature range, measured conductivity data can be used to determine the semiconductor band gap energy, E_g.

3.4.2 at absolute zero

At absolute zero temperature, all the electrons are tightly held by the semiconductor atoms. The inner orbit electrons are bound whereas the valence electrons are engaged in co-valent bonding.

At this temperature, the co-valent bonds are very strong and there are no free electrons. Therefore, the semiconductor behaves as a perfect insulator. This is shown in fig3.4(i) [3].

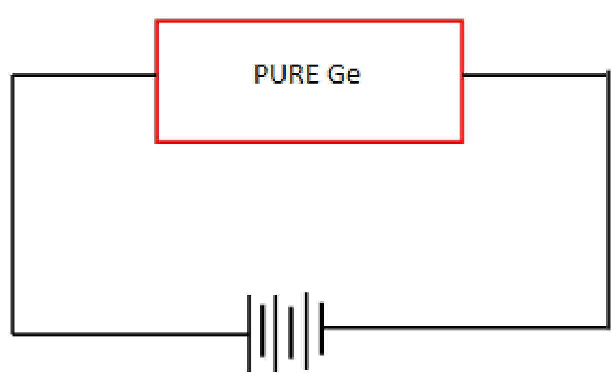


Fig.3.4 (i)

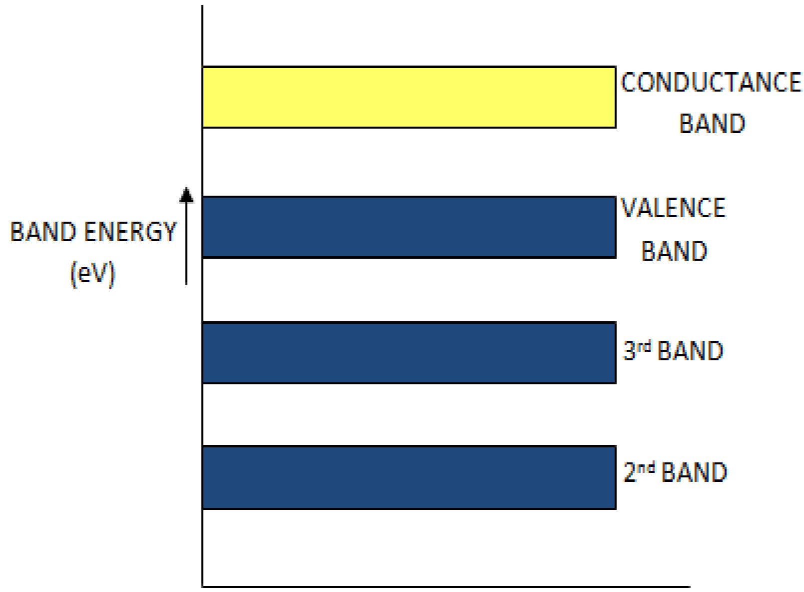


Fig3.4 (ii)

In terms of energy band description, the valence band is filled and there is a large energy gap between valence band and conduction band.

Therefore, no valence electrons can reach the conduction band to become free electron.

Hence, the semiconductor behaves as an insulator due to the non-availability of free electrons [3].

3.4.3 above absolute zero

When the temperature is raised, some of the co-valent bonds in the semiconductor break due to the thermal energy supplied.

The breaking of bonds set those electrons free which are engaged in the formation of these bonds.

These free electrons constitute a tiny electric current if potential difference is applied across the semiconductor. This is shown in fig3.5 (i).

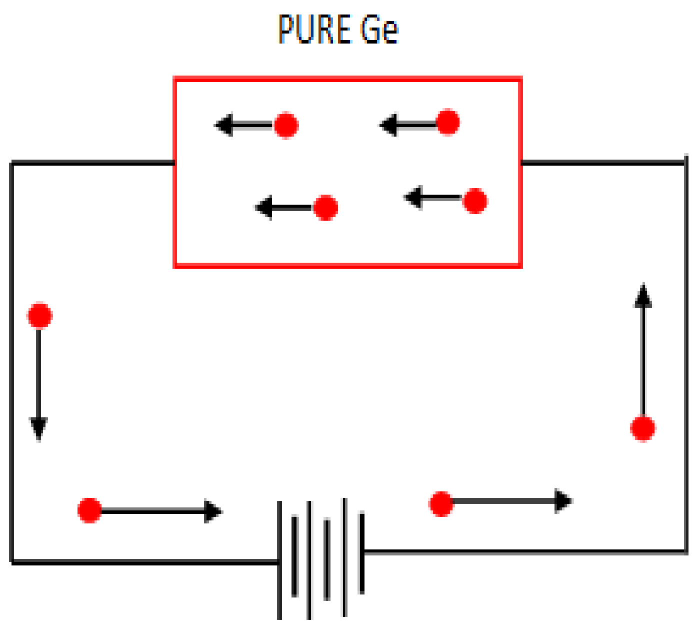


Fig3.5 (i)

This shows that the resistance of a semiconductor decreases with the increase in temperature i.e. it has negative temperature co-efficient of resistance [3].

Fig3.5(ii) shows the energy band diagram

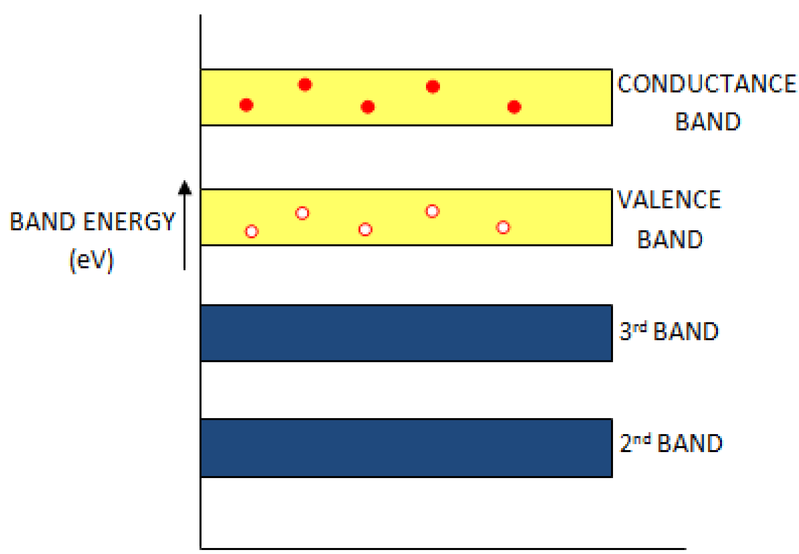


Fig3.5 (ii) shows the energy band diagram

As the temperature is raised, some of the valence electrons acquire sufficient energy to enter into the conduction band and thus become free electrons.

Under the influence of electric field, these free electrons will constitute electric current [3].

It may be noted that each time a valence electron enters into the conduction band, a hole is created in the valence band[3].

3.5 Hole Current

At room temperature, some of the co-valent bonds in pure semiconductor break, setting up free electrons .Under the influence of electric field, these free electrons constitute electric current.

At the same time, another current; hole current, also flows in the semiconductor.

When a covalent bond is broken due to thermal energy, the removal of one electron leaves a vacancy i.e. a missing electron in the covalent bond. This missing electron is called a hole which acts as a positive charge.

For one electron set free, one hole is created. Therefore, thermal energy creates hole-electron pairs. That means number of   free electrons is equal to number of holes [4].

The current conduction by holes can be explained as follows:

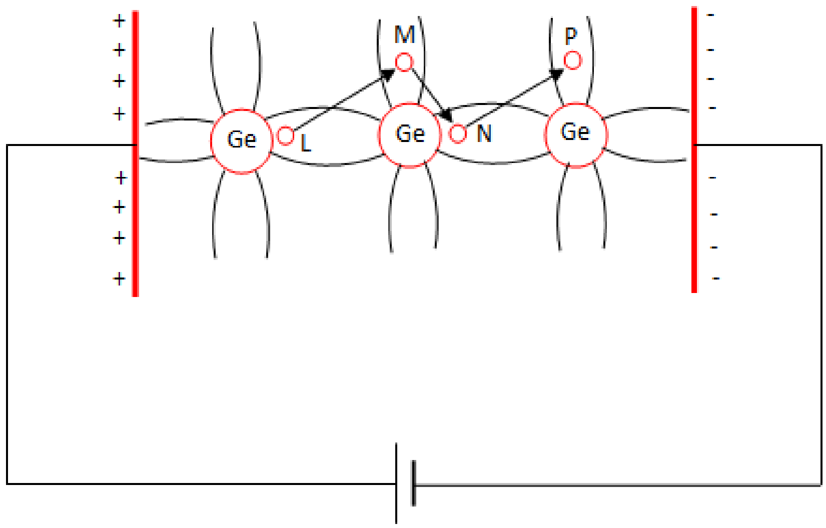


Fig3.6

Suppose the valence electron at L , in fig3.6 has become free electron due to thermal energy.This creates a hole in the co-valent bond a L.

The hole is a strong Centre of attraction for the electron.

A valence electron at M from nearby co-valent bond comes to fill in the hole at L.

This results in the creation of hole at M.

Another valence electron at N in turn may leave its bond to fill the hole at M, thus creating a hole at N.

Thus the hole having a positive charge has moved from L to N i.e. towards the negative terminal of supply. This constitutes hole current [5].

3.6 Energy Band Description

The hole current can be explained in terms of energy bands.

Suppose due to thermal energy, an electron leaves the valence band to enter into the conduction band as shown in fig3.7.

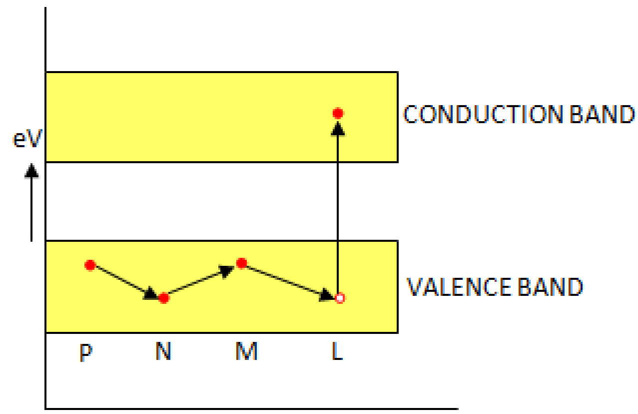


Fig3.7

This leaves a vacancy at L. Now the valence electron at M comes to fill the hole at L. The result is that hole disappears at L and appears at M.

Next, the valence electron at N moves into the hole at M. Consequently, hole is created at N.

It is now clear that valence electrons move along the path PNML whereas holes move in the opposite direction i.e. along the path LMNP [5].

Chapter Four

Practical

4.1Experiment description

The temperature-dependency of the specific resistance R is a simple test for models of electric conductivity in conductors and semiconductors.

In electrical conductors, R rises with the temperature, as the collisions of the quasi-free electrons from the conduction band with the incomplete atoms of the conductor play an increasing role.

In semi-conductors, on the other hand, the resistance decreases as the temperature increases since more and more electrons move from the valence band to the conduction band, thus contributing to the conductivity.

This experiment measures the resistance values of a noble-metal resistor and a semiconductor resistor as a function of the temperature. For the noble metal resistor, the relationship

$R = R0 \cdot (1 + \alpha \cdot \Delta T)$ (R0: resistance at T = 0 °C) (4.1)

Is verified with sufficient accuracy in the temperature range under study, for the semiconductor resistor, the evaluation reveals a dependency with the form

$R \propto \exp \Delta E/2kT$

(k = 1.38·10-23 J/K: Boltzmann constant) with the energy band interval ΔE.

4.2 Used equipment

- Metal resistor 586 80

-Semiconductor resistor 5 KΩ 586 821

-Connection: 4-mm sockets

-Diameter: 3.5 cm

-Length: 12 cm

Nobel metal shown in fig (4.1)

Fig4. 1 Nobel metal

Semiconductor resistor, 5 k Ω shown in fig (4.2)

Fig4. 2 Semiconductor resistors

-connecting wires

-Arcade metric

-Galvanometer

-Thermometer

-Adapter

- Oven shown in fig (4.3)

For heating semiconductor and noble metal resistors (586 80/586 821) and for other experiments in which bodies with a low coefficient of expansion are to be maintained at a constant temperature Electrically heated, ceramic oven with cylindrical heating chamber and hole for thermometer or temperature sensor

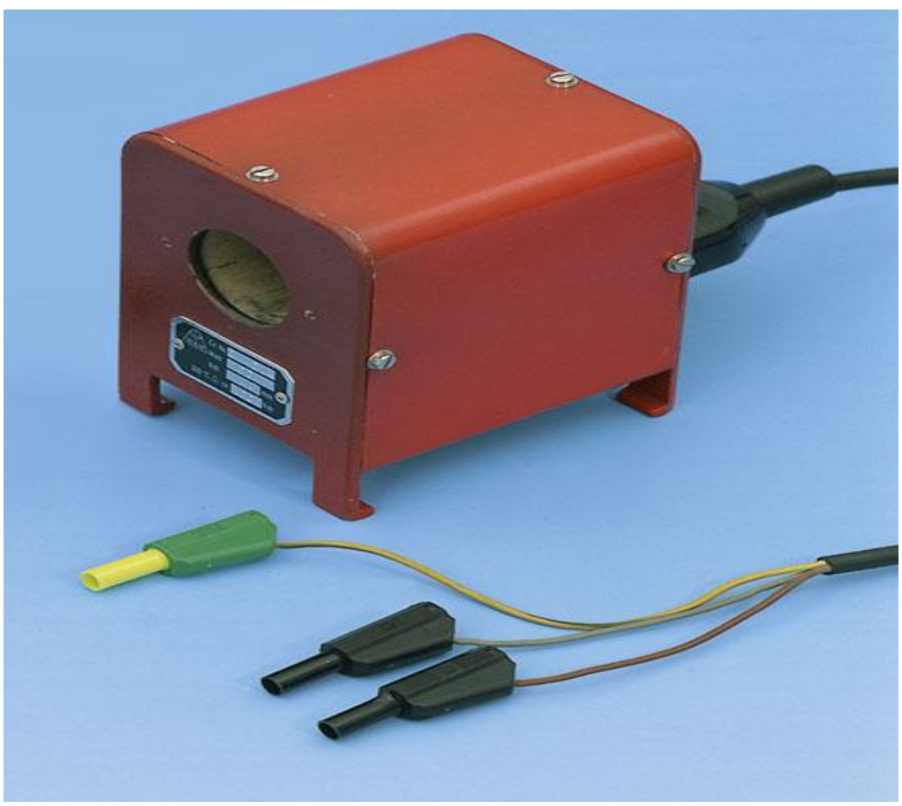


Fig4. 3 Oven

4.3Results

4. 1 Table Results Nobel metal 586 80

R=100 Ω

T/C^{O}	T/ k	L1	L2	R_t=L1/L2*100
100	373	58	42	138
90	363	57.2	42.8	133.6
80	353	56.8	43.2	131.5
70	343	56	44	127.3
60	333	55	45	122.2
50	323	54.1	45.9	117.3
40	313	52	47.2	111.8
30	303	51.9	48.1	107.3
20	293	51	49	104
10	283	50.1	49.9	100

4.4 Calculation

x_1=343 , x_2=363

y_1=127.3 , $y2$=133.6

R_0 =100

Slope = $\frac{y2-y1}{x2-x1}$

Slope = $\frac{133.6-127.3}{363-343}$ = 0.315

Slope = αR_0

α=slope/R_0

$\alpha = \frac{0.315}{100} = 3.15 \times 10^{-3}$

$\Delta T = T2 - T1$ = 20K

R = $R_0 \times (1 + \alpha\Delta T)$

R_t = $100 \times (1 + 3.15 \times 10^{-3} \times 20) = 106.3\ \Omega$

$\sigma = \frac{l}{RA}$

A=$\pi \times r^2$ =1.75× 3.14 =9.6 cm^2

L=12cm

$\sigma = \frac{12}{106.3 \times 9.6}$ =0.01176 Ωcm^{-1}

4. 2Table Result Semiconductor 586 821

R_s=100Ω

T/C^O	**T/k**	$\frac{1}{T\times10^{-3}}$	**L_1**	**L_2**	**$R_t=\frac{l1}{l2}\times100$**	**$\ln Rt$**
100	**373**	**2.6**	**26.8**	**73.2**	**36.6**	**3.6**
90	**363**	**2.7**	**29.1**	**70.9**	**41.04**	**3.7**
80	**353**	**2.8**	**34.8**	**65.2**	**53.4**	**3.9**
70	**343**	**2.9**	**39.9**	**60.1**	**66.4**	**4.2**
60	**333**	**3**	**46.4**	**53.6**	**86.6**	**4.5**
50	**323**	**3.1**	**52.5**	**47.5**	**110.5**	**4.7**
40	**313**	**3.2**	**59.5**	**40.5**	**146.9**	**5**

4.5 Calculation

X_1 = 343 X_2 = 353

Y_1 = 66.4 Y_2 = 53.4

Slope = $\frac{y2-y1}{x2-x1}$

Slope = -1.3

K = 1.38$\times 10^{-23}$ J/K (Boltzmann constant)

Slope = $\frac{-Eg}{2k}$

$-E_g$ = slope×2k

$E_g = 1.3 \times 1.38 \times 10^{-23} = 3.588 \times 10^{-23}$ J

$E_g = 2.24 \times 10^{-4}$ ev

$R_0 = 110\Omega$

$$\frac{1}{T} = (\frac{1}{353} - \frac{1}{343})$$

$R = R_0 \times exp - 2.24 \times 10^{-4}(\frac{1}{353} - \frac{1}{343})/2 \times 1.38 \times 10^{-23} =$

$R = 110 \times (1.23 \times 10^{-31}) = 1.4 \times 10^{-29}\ \Omega$

$A = \pi \times r^2 = 1.75 \times 3.14 = 9.6$ cm^2

L = 12cm

$$\sigma = \frac{l}{RA}$$

$\sigma = \frac{12}{1.4 \times 10^{-29} \times 9.6} = 8.93 \times 10^{28} \Omega cm^{-1}$

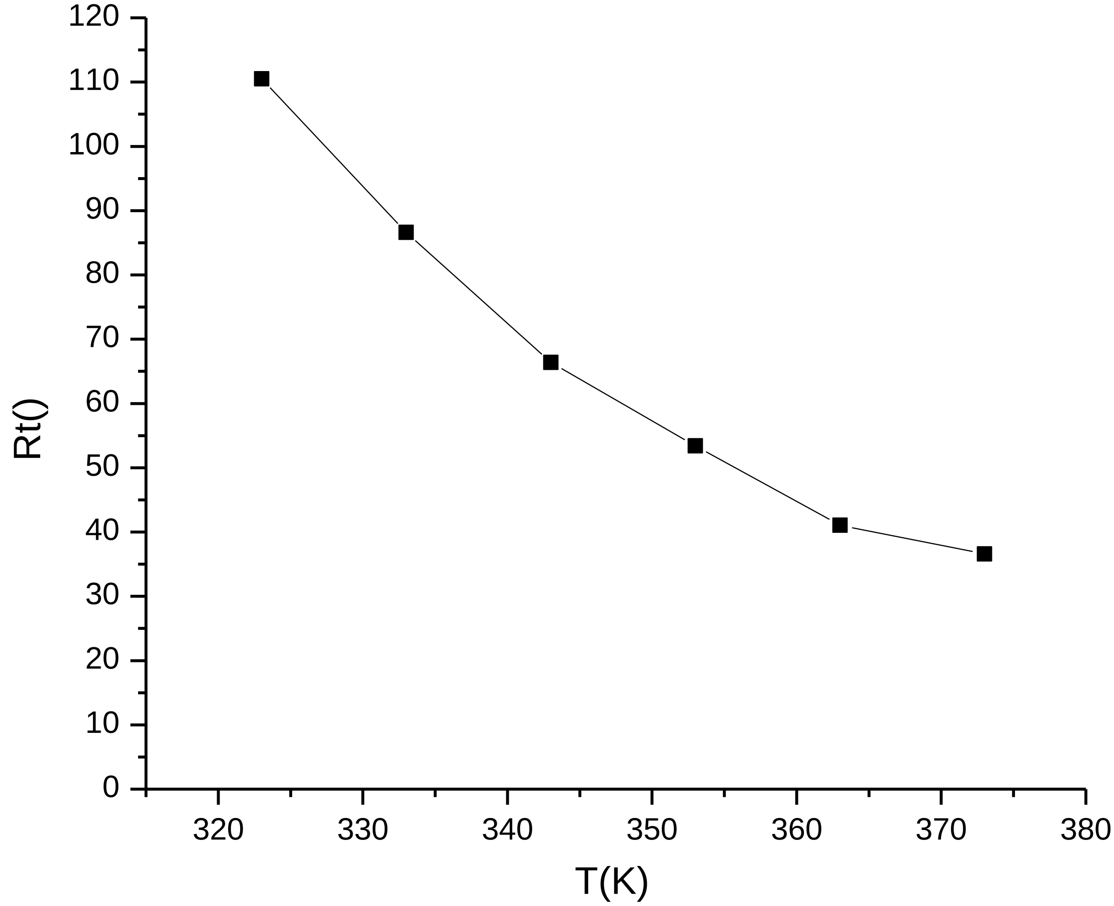


Fig4. 4A graph showing the relationship between the resistance and the temperature of metals

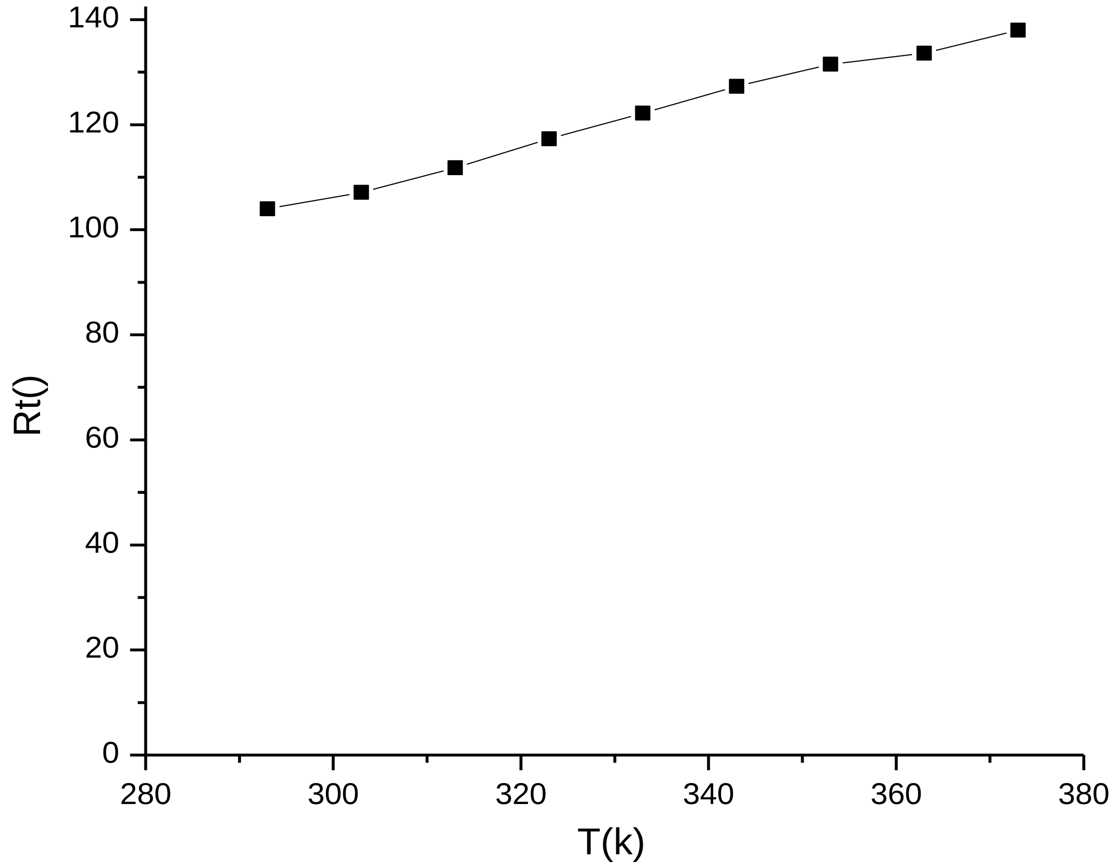


Fig 4.5 a graph showing the relationship between the resistance and the temperature of semiconductor

4.6 Discussion

The sample of the noble metal platinum which 58 680 were heated at different temperatures by an oven and studied the effect of changing temperature rise on resistance and electrical conductivity were found .it was observed that temperature increases the resistance and decreases electrical conductivity was the resistance at T is equal to

R = 106.3 Ω

And the Conductivity equal to

σ = 0.01176Ωc ^ (- 1).

for a sample of semi-conductive material (586 821) the resistance decreases with increase temperature whereas the electrical conductivity, increase the resistance at T is found to be

R = . R= $1.4 \times 10^{-29}\Omega$.

And the Electrical conductivity is equal to

σ $=$ 8.93$\times 10^{28}\Omega cm^{-1}$

The increase of resistance with temperature increase agrees with the theoretical. Relation (4.1) while the decrease of the resistance and increase of conductivity with temperature increase conform with the theoretical relation (3.2).

4.7 Conclusion

The effect of temperature increase on conductor and semiconductor is different. For conductor the resistance increases and the conductivity decreases when temperature increases.

In semiconductor the resistance decreases and the conductivity increases when temperature increases.

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