Band Gap Measurement (Four Probes Method)

Nvis 6105

Learning Material

Ver 1.2

An ISO 9001: 2008 company

Designed & Manufactured in India by :

Nvis Technologies Pvt. Ltd.
141-A, Electronic Complex, Pardesipura, Indore - 452 010 India
Tel.: 91-731-4211500, E-mail: info@nvistech.com, Website : www.NvisTech.com

CERTIFICATE OF COMPLIANCE

ICS

INTERNATIONAL CERTIFICATION SERVICES PVT. LTD.

This is to certify that the

QUALITY MANAGEMENT SYSTEM of

NVIS TECHNOLOGIES PVT. LTD.

141-A, Electronic Complex, Pardesipura, Indore - 452 010,
Madhya Pradesh, India.

has been assessed and registered as complying with the requirements of the following International Standard:

ISO 9001:2015

The Quality Management System applicable to:

Scope : Design And Manufacture Of Didactic Products And Clean Technologies Products Such As Solar Solutions.

Registration No. : RQ91/7763
Registered Date : 17th June, 2012
Reassessment Date : 28th June, 2018
Issue Date : 30th June, 2018
Expiry Date : 16th June, 2021

www.jas-anz.org/register

RED
Invalid After
12/06/2019
Unless
Hologram
Pasted

GREEN
Invalid After
12/06/2020
Unless
Hologram
Pasted

Managing Director
International Certification Services

Accredited by Joint Accreditation System of Australia and New Zealand

Validity of this certificate is based on periodic audits of the management system defined by the above scope and is contingent upon prompt, written notification of significant changes to the management system and/or its components thereof shall be immediately communicated to ICS.
Further clarifications regarding the scope of this certificate and the applicability of ISO 9001:2015 requirements may be obtained at www.icsasian.com

22/23, Goodwill Premises, Swastik Estate, 178 CST Road, Kalina, Santacruz (E), Mumbai – 400 098, Maharashtra, India. Tel.: 022-42200900

Band Gap Measurement

Nvis 6105

Table of Contents

Nvis 6105 Band Gap Measurement

Introduction

Nvis 6105 Band Gap Measurement of semiconductor is a versatile and useful system for physics and basic electronics Laboratories. In Nvis 6105, we find band gap by using four probes method. This is one of the widely used methods for measuring the Resistivity and Band gap of semiconductor. A collinear four-probe arrangement has been used. In this system, we provide the pressure contacts with sample to take quick measurement on different positions. Using this method, we can reduce error in measurement of Band Gap and Resistivity.

The properties of the bulk material used for the fabrication of transistor and other semiconductor devices are essential in determining the characteristics of the completed device. Resistivity and lifetime (of minority carriers) measurement are generally made on in particular, must be measures accurately since its value is critical in many devices. The value of some transistor parameter, like the equivalent base resistances are at least linearly related to the Resistivity.

Nvis 6105 Band Gap Measurement

Features

- A complete setup for measuring the Resistivity and Band gap
- Four individually spring loaded probes arrangement is provided
- Collinear and equally spaced probes
- Octal Socket is provided on the front panel for connecting Probe
- LCD to measure Current, Voltage, temperature
- The probes are mounted in a Teflon bush, which ensure a good electrical insulation between the probes
- Germanium crystal in the form of a chip is provided
- Oven arrangement with safety precaution

Technical Specifications

Four Probes:

Contacts with sample : Spring loaded

Space between probes : 2mm ±2%

Probes : Collinear

Sample:

Material : Germanium crystal

Oven:

Maximum Temperature : Room temperature to 130°C

Heater Resistance : 37ohms (approximately)

Heater Voltage : 50V

Temperature Sensor : LM35 (0 to 150 **°C**)

Measurement Unit:

Display : LCD 16x2

Constant Current Generator:

Current range : 0 to 12mA (Approximately)

Resolution : 1mA

Power Supply : 230V AC ± 10%

Safety Instructions

Read the following safety instructions carefully before operating the instrument. To avoid any personal injury or damage to the instrument or any product connected to the instrument.

Do not operate the instrument if suspect any damage to it.

The instrument should be serviced by qualified personnel only.

For your safety:

Use proper Mains cord : Use only the mains cord designed for this instrument. Ensure that the mains cord is suitable for your country.

Ground the Instrument : This instrument is grounded through the protective earth conductor of the mains cord. To avoid electric shock, the grounding conductor must be connected to the earth ground. Before making connections to the input terminals, ensure that the instrument is properly grounded.

Use in proper Atmosphere : Please refer to operating conditions given in the manual.

1. **Do not operate in wet / damp conditions.**
2. **Do not operate in an explosive atmosphere.**
3. **Keep the product dust free, clean and dry.**

Theory

Before starting about semiconductor band gap we should know what is atomic structure of a material.

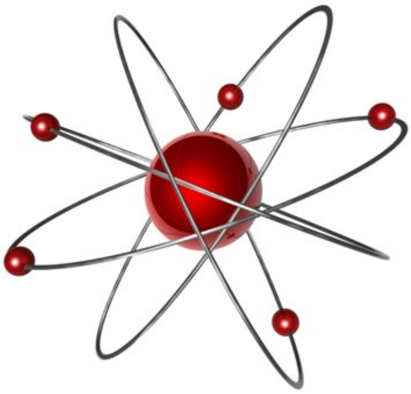
The structure of atoms

Atomic structure is the foundation of Materials Science.

Fundamentals

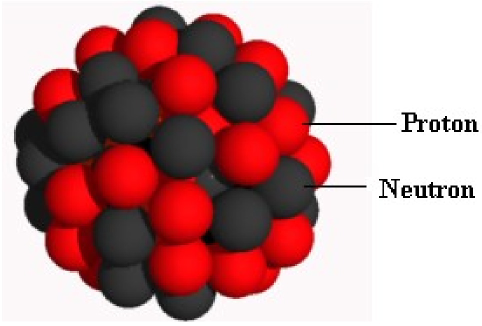
Atoms consist of nuclei and electrons. Nuclei are composed of protons and neutron Protons carry a positive charge of 1.69x10-19 coulombs and have a mass at rest of 1.67x10-24 g Neutrons have no charge and have the same rest mass as protons. Overall the nucleus is thus positively charged.

This charge is balanced by an equal charge due to a number of electrons equal to the number of protons (for neutral atoms).Each electron carries a charge of –1.69x10-19 coulombs.



Nucleus

The number of protons in the nucleus is called the atomic number (this defines the elemental identity). Atom's dense center, where most of it mass is.



The number of neutrons in a nucleus is larger than or equal to the number of protons, with the larger excess of neutrons occurring for the larger atomic numbers. Many elements have isotopes, i.e. their nuclei contain an equal number of protons but have different numbers of neutrons; some of these isotopes are stable while others decompose via radioactive decay.

Atomic Weight.

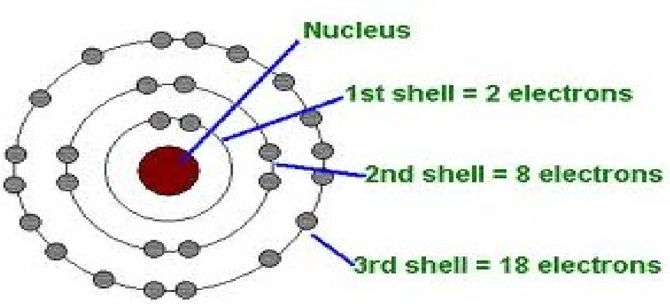
The atomic weight is given in terms of atomic mass units (amu) and indicates the mass of the atom in units of 1/12 the mass of the carbon isotope with 6 protons and 6 neutrons. The isotope therefore has an arbitrary atomic weight of 12 amu and is represented as 6C12.Here the subscript is the atomic number and the superscript the mass number, i.e. the sum of the number of protons and neutrons.

Atomic weights are not whole numbers except for C12 by definition. The actual masses of the nuclei are not equal to the sum of the masses of all protons and neutrons but differ from that sum by the binding energy expresses as mass according to E=mc2. Atomic weights are normally weighted according to the natural abundance of the isotopes. For elements with large atomic masses, the binding energy is such that if an atom is split, the sum of the binding energies of the two resulting smaller nuclei is smaller than that of the parent nucleus. The difference is liberated as energy (fission).For the case of elements with small atomic masses such as hydrogen, energy is liberated when nuclei are fused (fusion).

Electronic Structure.

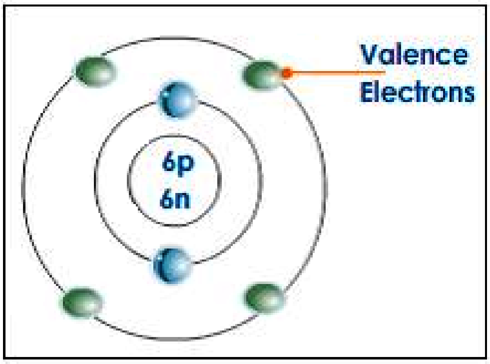
From a basic materials science point of view, the arrangement of the electrons is the most important aspect of atomic structure. The electronic structure determines the type and strength of the chemical bonds that can be established with other atoms and hence determines many important materials properties. For our purpose, we can consider electrons as particles, which surround the nucleus in some particular fashion such that their number is equal to the atomic number of the element (for neutral atoms).

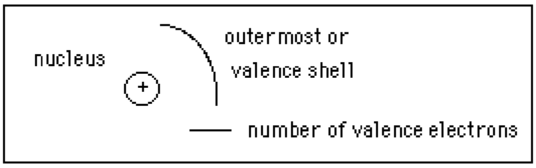
Example: the carbon atom: outside the nucleus it has six electrons. Using the Bohr Theory of atomic structure, these were believed to be arranged in orbits of increasing distance from the nucleus. These orbits corresponded to gradually increasing levels of energy, that of the lowest energy, the 1s, accommodating two electrons, the next 2s, also accommodating two electrons and the remaining two electrons of the carbon atom going into the 2p level, which is actually capable of accommodating a total of six electrons. The Heisenberg uncertainty principle and the wave mechanical view of the electron have made it necessary to do away with anything so precisely defined as actual orbits. Instead, the wave-like electrons are now symbolized by wave functions such that the precise classical orbital of Bohr are superseded by three-dimensional atomic orbital of differing energy level. Thus, from quantum theory it can be established that electrons have different energies; discrete electron energy levels can be described in terms of quantum numbers.

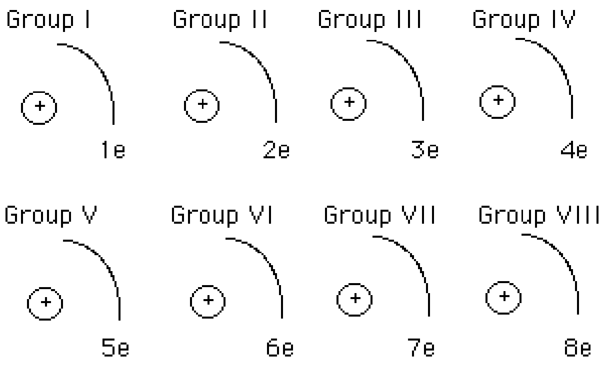


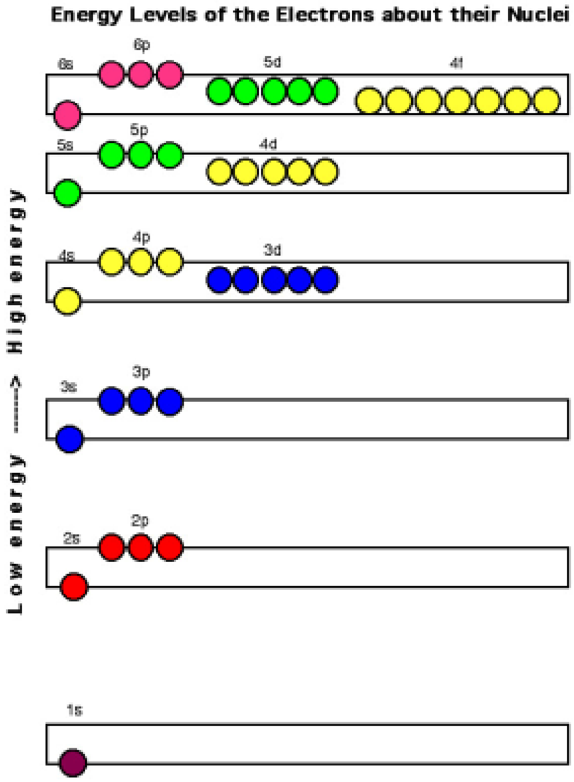
Valence Electrons

Valence electrons are defined as electrons that are found in the outermost energy levels of an atom. The number of valence electrons in any atom of a Representative Element corresponds to its Group Number. All elements within a Group or Family, have the same number of electrons in their outermost energy levels. This outermost energy level is referred to as an element's valence shell, as sketched below.









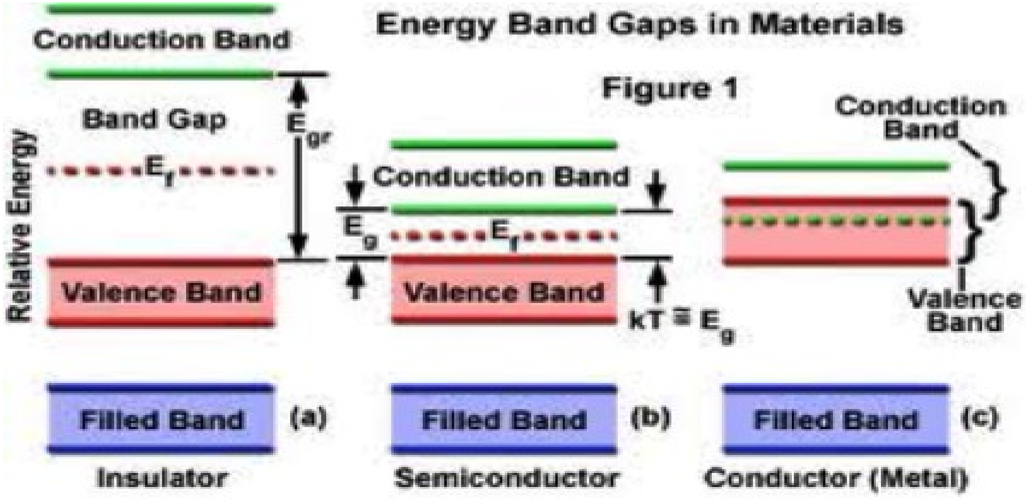
Conduction band

The conduction band in the range of electron energy, higher than that of the valence band, sufficient to make the electrons free to accelerate under the influence of an applied electric field and thus constitutes an electric current. Semiconductors may cross this conduction band when they are excited.

Valence band

The valence band is the highest range of electron energies where electrons are normally present absolute zero. In semiconductors and insulators, there is a band gap above the valence band, followed by conduction band above that. In metals, the conduction band has no energy gap separating it from the valence band. Semiconductors and insulators owe their high conductivity to the properties of the balance band in those materials. It just so happens that the number of electrons is precisely equal to the number of states available up to the top of the valence band. There are no available states in the band gap. This means that when an electric field is applied, the electrons can not increase their energy because there are no states available to the electrons where they would be moving faster than they are already going. There is some conductivity in insulators, however this is due to thermal excitation of some of the electrons get enough energy to jump the band gap in one go. Once they are in the conduction band, they can conduct electricity, as the hole they left behind in the valence band. The hole is an empty state that allows electrons in the valence band some degree of freedom.

Nvis 6105 Band Gap Measurement



A conductor is a material which permits a flow of energy. A material which allows the flow of charged particles is an electrical conductor. A material which allows the transfer of thermal energy is a thermal conductor or heat conductor.

An insulator is a poor conductor because it has a high resistance to such flow. It blocks or retards the flow of electric current or heat Electrical insulators are commonly used to hold conductors in place, separating them from one another and from surrounding structures to form a barrier between energized parts of an electric circuit and confine the flow of current to wires or other conducting paths. Electrical insulators include rubber, plastic, porcelain, and mica. Thermal insulators. which break up the heat-flow path by absorbing radiant heat, include fiberglass, cork, and rock wool

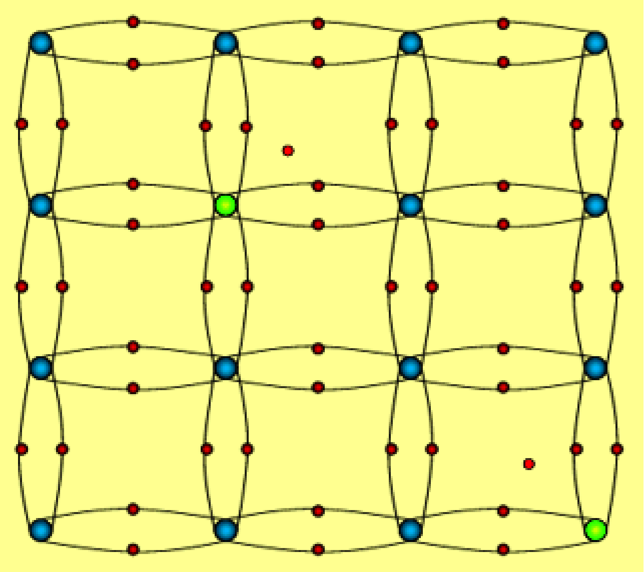
A semiconductor is a material which has electrical conductivity between that of a conductor such as copper and an insulator such as glass. The conductivity of a semiconductor increases with increasing temperature, the opposite behavior to a metal. Semiconductors can display a range of useful properties such as passing current more easily in one direction than the other. Because the conductive properties of a semiconductor can be modified by controlled addition of impurities or by the application of electrical fields or light, semiconductors are very useful devices for amplification of signals, switching, and energy conversion.

Those semiconductors in which some impurity atoms are embedded are known as extrinsic semiconductors.

Extrinsic semi conductors are basically of two types:

1. P-type semi conductors
2. N-type semi conductors

N-type Semi conductors: Let's take an example of the silicon crystal to understand the concept of N-type semi conductor. We have studied the electronic configuration of the silicon atom. It has four electrons in its outermost shell. In N-type semi conductors, the silicon atoms are replaced with the pentavalent atoms like phosphorous, bismuth, antimony etc. So, as a result the four of the electrons of the pentavalent atoms will form the covalent bonds with the silicon atoms and the one electron will revolve around the nucleus of the impurity atoms with less binding energy. These electrons are almost free to move. In other words we can say that these electrons are donated by the impure atoms. So, these are also known as donor atoms. So, the conduction inside the conductor will take place with the help of the negatively charged electrons. Electrons are negatively charged. Due to this negative charge these semiconductors are known as N-type semiconductors.

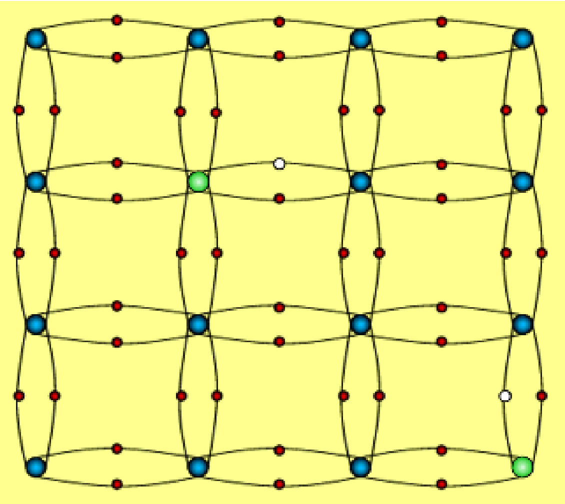


Each donor atom has denoted an electron from its valence shell. So, as a result due to loss of the negative charge these atoms will become positively charged. The single valence electron revolves around the nucleus of the impure atom. Some experiments were performed. It was found that .01eV and .05eV energy is required to make the electron free from the nuclear forces.

When the semi conductors are placed at room temperature then the covalent bond breakage will take place. So, more free electrons will be generated. As a result, same no of holes generation will take place. But as compared to the free electrons the no of holes are comparatively less due to the presence of donor electrons.

We can say that major conduction of n-type semi conductors is due to electrons. So, electrons are known as majority carriers and the holes are known as the minority carriers.

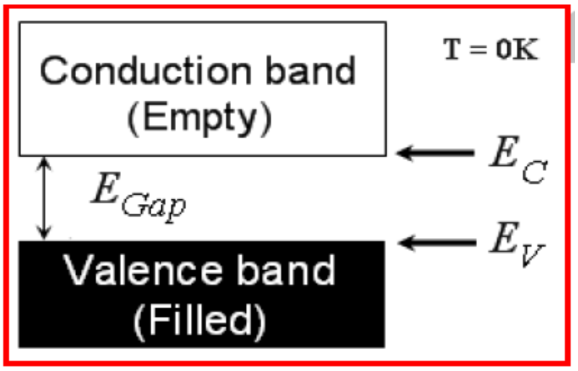
P-type semi conductors: In a p-type semi conductor doping is done with trivalent atoms .Trivalent atoms are those which have three valence electrons in their valence shell. Some examples of trivalent atoms are Aluminum, boron etc. So, the three valence electrons of the doped impure atoms will form the covalent bonds between silicon atoms. But silicon atoms have four electrons in its valence shell. So, one covalent bond will be improper. So, one more electron is needed for the proper covalent bonding. This need of one electron is fulfilled from any of the bond between two silicon atoms. So, the bond between the silicon and indium atom will be completed. After bond formation the indium will get ionized. As we know that ions are negatively charged. So, indium will also get negative charge. A hole was created when the electron come from silicon-silicon bond to complete the bond between indium and silicon. Now, an electron will move from any one of the covalent bond to fill the empty hole. This will result in a new holes formation. So, in p-type semi conductor the holes movement results in the formation of the current. Holes are positively charged. Hence these conductors are known as p-type semiconductors or acceptor type semi conductors.



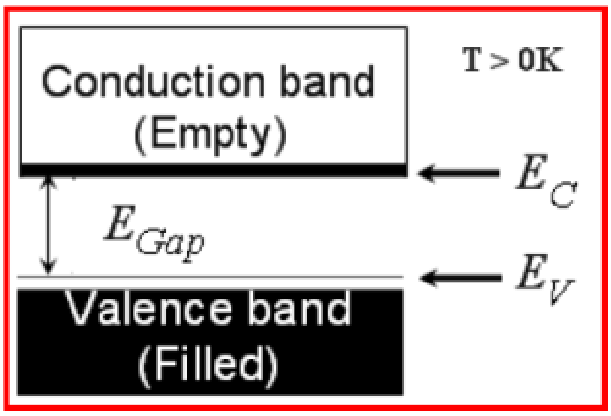
When these conductors are placed at room temperature then the covalent bond breakage will take place. In this type of semi conductors the electrons are very less as compared to the holes. So, in p-type semi conductors holes are the majority carriers and electrons are the minority carriers.

Intrinsic semiconductors:

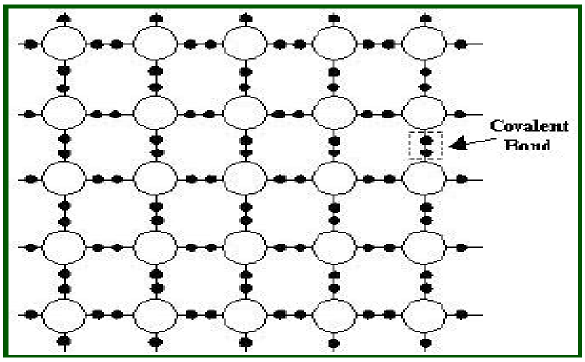
Intrinsic semiconductors are those in which impurities are not present and therefore called pure semiconductors. In these semiconductors few crystal defects may be present. Fermi level exists exactly at mid way of the energy gap. When a semiconductor is taken at 0 K then it behaves as an insulator and conduction occurs at higher temperature due to thermal excitation of electrons from the valence band to the conduction band. Examples: Germanium and Silicon. Figure shows the intrinsic semiconductors at T = 0 K and T >0 K.



In order to get insight view of an intrinsic semiconductor, let us consider silicon, which has four valence electrons. In order to gain stability it has to make four covalent bonds. In this regard each silicon atom makes four covalent bonds with for other silicon atoms as shown in figure.



The electrons which are participating in the covalent bonds are known as valence electrons. If some energy is supplied then covalent bonds break, electrons will come and move freely, resulting in the formation of vacant sites in the covalent bonds. These are known as positive charge carriers named as holes. The electrons which came out from the valence bands move freely without any constraints and have more energy than the electron in the covalent bonds or valence bond. The number of conduction electrons will be equal to the number of vacant sites in the valence band.



Nvis 6105 Band Gap Measurement

Band Gap

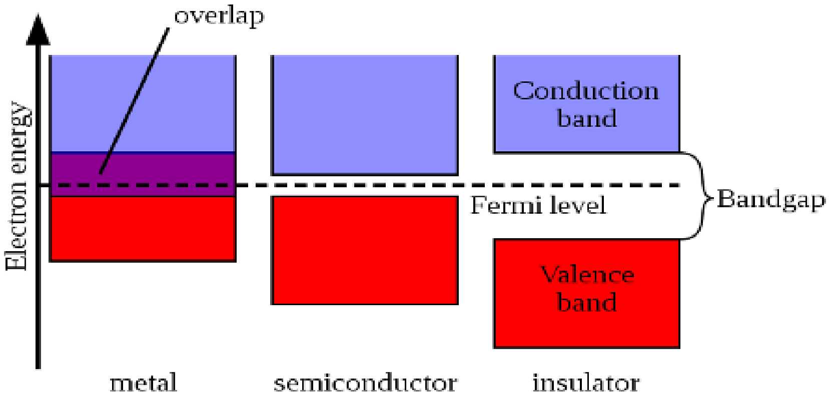
In solid state physics and related applied fields, the band gap, also called an energy gap or stop band, is a region where a particle or quasi particle is forbidden from propagating. For insulators and semiconductors, the band gap generally refers to the energy difference between the top of the valence band and the bottom of the conduction band.

Band Theory of Solids

A useful way to visualize the difference between conductors, insulators and semiconductors is to plot the available energies for electrons in the materials. Instead of having discrete energies as in the case of free atoms, the available energy states form bands. Crucial to the conduction process is whether or not there are electrons in the conduction band. In insulators the electrons in the valence band are separated by a large gap from the conduction band, in conductors like metals the valence band overlaps the conduction band, and in semiconductors there is a small enough gap between the valence and conduction bands that thermal or other excitations can bridge the gap. With such a small gap, the presence of a small percentage of a doping material can increase conductivity dramatically.

An important parameter in the band theory is the Fermi level, the top of the available electron energy levels at low temperatures. The position of the Fermi level with the relation to the conduction band is a crucial factor in determining electrical properties.

Energy Bands for Solids



1) Insulator Energy Bands

Most solid substances are insulators, and in terms of the band theory of solids this implies that there is a large forbidden gap between the energies of the valence electrons and the energy at which the electrons can move freely through the material (the conduction band). Glass is an insulating material which may be transparent to visible light for reasons closely correlated with its nature as an electrical insulator. The visible light photons do not have enough quantum energy to bridge the band gap and get the electrons up to an available energy level in the conduction band. The visible properties of glass can also give some insight into the effects of "doping" on the properties of solids.

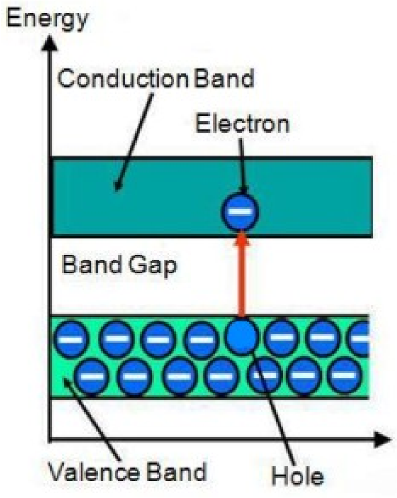
A very small percentage of impurity atoms in the glass can give it color by providing specific available energy levels which absorb certain colors of visible light. The ruby mineral (corundum) is aluminum oxide with a small amount (about 0.05%) of chromium which gives it its characteristic pink or red color by absorbing green and blue light.

While the doping of insulators can dramatically change their optical properties, it is not enough to overcome the large band gap to make them good conductors of electricity. However, the doping of semiconductors has a much more dramatic effect on their electrical conductivity and is the basis for solid state electronics.

INSULATOR

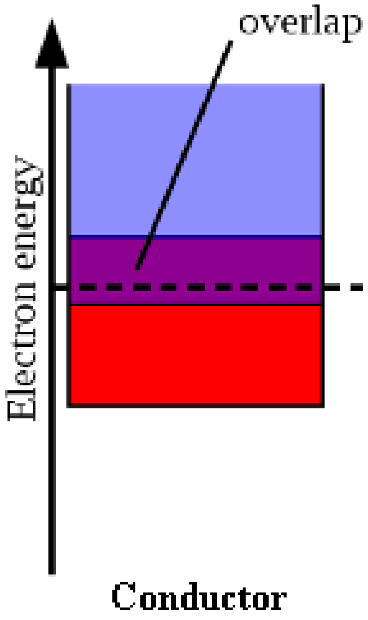
2) Semiconductor Energy Bands

For intrinsic semiconductors like silicon and germanium, the Fermi level is essentially halfway between the valence and conduction bands. Although no conduction occurs at 0 K, at higher temperatures a finite number of electrons can reach the conduction band and provide some current. In doped semiconductors, extra energy levels are added. The increase in conductivity with temperature can be modeled in terms of the Fermi function, which allows one to calculate the population of the conduction band



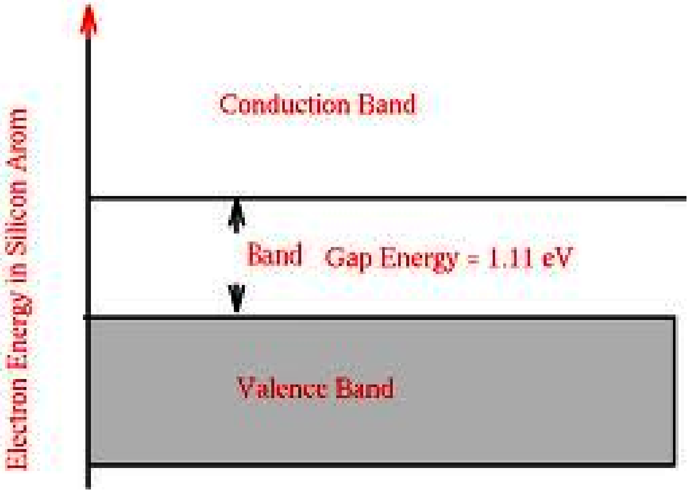
3) Conductor Energy Bands

In terms of the band theory of solids, metals are unique as good conductors of electricity. This can be seen to be a result of their valence electrons being essentially free. In the band theory, this is depicted as an overlap of the valence band and the conduction band so that at least a fraction of the valence electrons can move through the material.



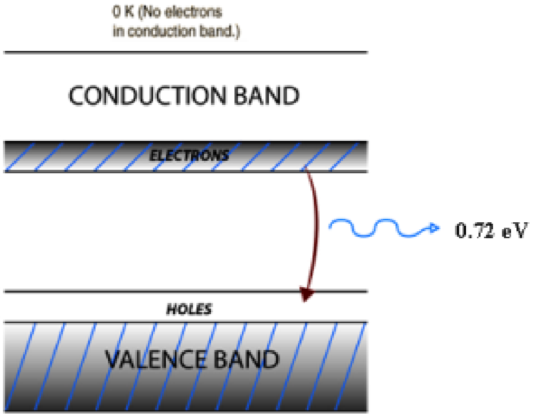
4) Silicon Energy Bands

At finite temperatures, the number of electrons which reach the conduction band and contribute to current can be modeled by the Fermi function. That current is small compared to that in doped semiconductors under the same conditions.



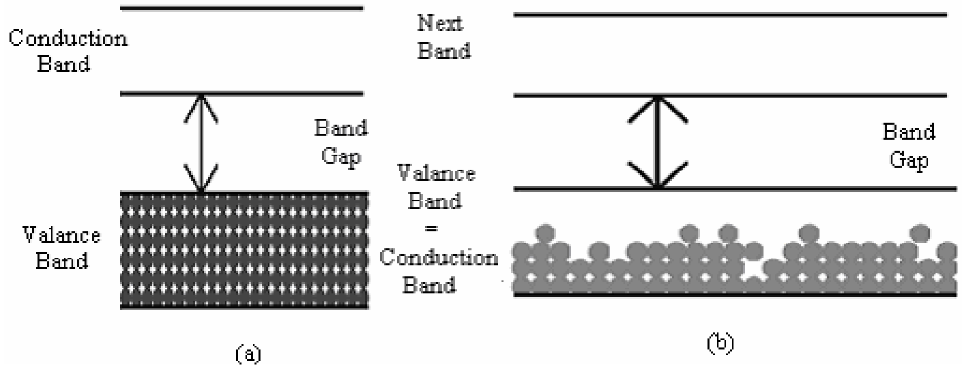
5) Germanium Energy Bands

At finite temperatures, the number of electrons which reach the conduction band and contribute to current can be modeled by the Fermi function. That current is small compared to that in doped semiconductors under the same conditions.



6) Conduction in Solids

The (electrical) conductivity of a material represents how easily charges will flow through the material. Materials with high conductivity are called conductors. Materials that do not readily conduct electricity are called insulators. From these definitions, one might deduce that semiconductors form a third category of material with conductivities somewhere between conductors and insulators, but that is not exactly the case. Semiconductors, despite the name, form a subgroup of insulators and have properties that differ greatly from the properties of conductors. Pure crystalline silicon, in fact, is a rather poor conductor. To understand how the term semiconductor arose, we return to the concepts of electron states and energy bands. Electric current is generally due to the motion of valence electrons. An electron can move through a material only by moving from one allowed energy state to another. But most materials are formed by bonds that completely fill a valence band, as shown in figure below. Electrons in this filled valence band have no empty states to move into, unless they somehow gain enough energy to jump across the forbidden band gap into the empty conduction band above. Conduction is therefore very difficult. As you might imagine this energy band diagram represents an insulator



Electrons in an insulator fill all available states in the valence band. Electrons must jump to the next higher band before they can move freely. This band where electron motion occurs is called the "conduction band" Electrons in a conductor only partially fill the valence band, so electrons can move freely without gaining extra energy. The conduction band is the same as the valence band. Other materials are formed by bonds that only partially fill a valence band, as shown in figure (b) above. Electrons in this partially filled valence band have plenty of empty states available, so they can move freely from the vicinity of one atom to another. A partially-filled valence band is also called the conduction band, since electrons in that band can be responsible for conduction. Not surprisingly, materials with partially-filled valence bands are conductors.

7) Semiconductor Basics

A semiconductor is a solid material that has electrical conductivity in between that of a conductor and that of an insulator; it can vary over that wide range either permanently or dynamical. Semiconductors are tremendously important in technology. Semiconductor devices, electronic components made of semiconductor materials, are essential in modern electrical devices. Examples range from computers to cellular phones to digital audio players. Silicon is used to create most semiconductors commercially, but dozens of other materials are used as well.

Overview

Semiconductors are very similar to insulators. The two categories of solids differ primarily in that insulators have larger band gaps - energies that electrons must acquire to be free to move from atom to atom. In semiconductors at room temperature, just as in insulators, very few electrons gain enough thermal energy to leap the band gap from the valence band to the conduction band, which is necessary for electrons to be available for electric current conduction. For this reason, pure semiconductors and insulators in the absence of applied electric fields, have roughly similar resistance. The smaller band gaps of semiconductors, however, allow for other means besides temperature to control their electrical properties.

Semiconductors' intrinsic electrical properties are often permanently modified by introducing impurities by a process known as doping. Usually, it is sufficient to approximate that each impurity atom adds one electron or one "hole" that may flow freely. Upon the addition of a sufficiently large proportion of impurity dopants, semiconductors will conduct electricity nearly as well as metals. Depending on the kind of impurity, a doped region of semiconductor can have more electrons or holes, and is named N-type or P-type semiconductor material, respectively. Junctions between regions of N- and P-type semiconductors create electric fields, which cause electrons and holes to be available to move away from them, and this effect is critical to semiconductor device operation. Also, a density difference in the amount of impurities produces a small electric field in the region which is used to accelerate non-equilibrium electrons or holes.

In addition to permanent modification through doping, the resistance of semiconductors is normally modified dynamically by applying electric fields. The ability to control resistance/conductivity in regions of semiconductor material dynamically through the application of electric fields is the feature that makes semiconductors useful. It has led to the development of a broad range of semiconductor devices, like transistors and diodes. Semiconductor devices that have dynamically controllable conductivity, such as transistors, are the building blocks of integrated circuits devices like the microprocessor. These "active" semiconductor devices (transistors) are combined with passive components implemented from semiconductor material such as capacitors and resistors, to produce complete electronic circuits. In most semiconductors, when electrons lose enough energy to fall from the conduction band to the valence band (the energy levels above and below the band gap), they often emit light, a quantum of energy in the visible electromagnetic spectrum. This photoemission process underlies the light-emitting diode (LED) and the semiconductor laser, both of which are very important commercially. Conversely, semiconductor absorption of light in photo detectors excites electrons to move from the valence band to the higher energy conduction band, thus facilitating detection of light and vary with its intensity. This is useful for fiber optic communications, and providing the basis for energy from solar cells. Semiconductors may be elemental materials such as silicon and germanium, or compound semiconductors such as gallium arsenide and indium phosphide, or alloys such as silicon germanium or aluminum gallium arsenide.

Band Structure

The band structure described on the previous page seems to have no room for semiconductors. Conductors have half-filled valence bands, so electrons move freely. Insulators have full valence bands, making it difficult for electrons to move. But if an electron in an insulator can gain enough energy to jump to the (empty) conduction band, available states abound.

Properties we now associate with semiconductors were first identified in the early 1800s, but they remained little more than a scientific curiosity until the 1900s. Over time, scientists discovered that they could control the conductivity of certain materials, turning a good insulator into a decent conductor by changing certain attributes, such as the temperature of the substance or the amount of impurities found in it. These materials that could conduct upon demand were called semiconductors. Semiconductors made of one material (such as silicon) with no impurities are called pure, or intrinsic, semiconductors.

Resistivity:

Electrical resistivity (also known as specific electrical resistance) is a measure of how strongly a material opposes the flow of electric current. A low resistivity indicates a material that readily allows the movement of electrical charge. The SI unit of electrical resistivity is the ohm metre.

Definitions:

The electrical resistivity ρ (rho) of a material is given by

$$\rho = RA/L$$

Where,

ρ is the static resistivity (measured in ohm meters, Ω-m)

R is the electrical resistance of a uniform specimen of the material (measured in ohms, Ω)

L is the length of the piece of material (measured in meters, m)

A is the cross-sectional area of the specimen (measured in square meters, m^2).

Electrical resistivity can also be defined as

$$\rho = E/J$$

Where,

E is the magnitude of the electric field (measured in volts per meter, V/m);

J is the magnitude of the current density (measured in amperes per square meter, A/m^2).

Finally, electrical resistivity is also defined as the inverse of the conductivity σ (sigma), of the material, or

$$\rho = 1/\sigma$$

Table of Resistivity

This table shows the resistivity & temperature coefficient of various materials at 20°C (68°F).

Material	Resistivity (Ω-m) at 20 °C
Silver	1.59×10−8
Copper	1.68×10−8
Gold	2.44×10−8
Aluminum	2.82×10−8
Tungsten	5.60×10−8
Nickel	6.99×10−8
Brass	0.8×10−7
Iron	1.0×10−7
Tin	1.09×10−7
Platinum	1.1×10−7
Lead	2.2×10−7
Maganies	4.82×10−7
Constantan	4.9×10−7
Mercury	9.8×10−7
Nichrome	1.10×10−6
Carbon	3.5×10−5
Germanium	4.6×10−1
Silicon	6.40×102
Glass	1010 to 1014
Hard rubber	approximately 1013
Sulfur	1015
Paraffin	1017
Quartz (fused)	7.5×1017
PET	1020
Teflon	1022 to 1024

The numbers in this column increase or decrease the significant portion of the esistivity. For example, at 30°C (303.15 K), the resistivity of silver is 1.65×10−8. This is calculated as Δρ = α ΔT ρo where ρo is the resistivity at 20°C and α is the temperature coefficient.

Temperature Dependence

In general, electrical resistivity of metals increases with temperature, while the resistivity of semiconductors decreases with increasing temperature. In both cases, electron-phonon interactions can play a key role. At high temperatures, the resistance of a metal increases linearly with temperature. As the temperature of a metal is reduced, the temperature dependence of resistivity follows a power law function of temperature. Mathematically the temperature dependence of the resistivity ρ of a metal is given by the Bloch-Gruneissen formula:

$$\rho\ (T) = \rho\ (0) + A(T/\theta R)^{n} \int_{0}^{\theta R} x^{n}/(e^{x} - 1)\ (1-e^{-x})\ dx$$

Where ρ (0) is the residual resistivity due to defect scattering, A is a constant that depends on the velocity of electrons at the fermisurface, the Deye radius and the number density of electrons in the metal. ΘR *is* the Debye temperature as obtained from resistivity measurements and matches very closely with the values of Debye temperature obtained from specific heat measurements. **n** is an integer that depends upon the nature of interaction:

1. n = 5 implies that the resistance is due to scattering of electrons by phonons (as it is for simple metals)
2. n = 3 implies that the resistance is due to s-d electron scattering (as is the case for transition metals)
3. n = 2 implies that the resistance is due to electron-electron interaction.

As the temperature of the metal is sufficiently reduced (so as to 'freeze' all the phonons), the resistivity usually reaches a constant value, known as the residual resistivity. This value depends not only on the type of metal, but on its purity and thermal history. The value of the residual resistivity of a metal is decided by its impurity concentration. Some materials lose all electrical resistivity at sufficiently low temperatures, due to an effect known as superconductivity.

An even better approximation of the temperature dependence of the resistivity of a semiconductor is given by the Steinhart-Hart equation:

$$1/T = A + B\ \mathrm{In}(\rho) + C(\ \mathrm{In}(\rho))^{3}$$

Where A, B and C are the so-called Steinhart-Hart coefficients. This equation is used to calibrate thermistors.

In non-crystalline semi-conductors, conduction can occur by charges quantum tunneling from one localised site to another. This is known as variable range hopping and has the characteristic form of $\rho = Ae\ (T)^{-1/n}$, where n = 2, 3, 5 depending on the dimensionality of the system.

Semiconductor Band Gaps

Materials	Energy gap (eV)	
	0K	300K
Si	1.17	1.11
Ge	0.74	0.66
InSb	0.23	0.17
InAs	0.43	0.36
InP	1.42	1.27
GaP	2.32	2.25
GaAs	1.52	1.43
GaSb	0.81	0.68
CdSe	1.84	1.74
CdTe	1.61	1.44
ZnO	3.44	3.2
ZnS	3.91	3.6

Concentration of intrinsic carriers

The concentration of intrinsic carriers i.e., the number of electrons in conduction band per unit volume is given by the expression:

$$n = 2\left(\frac{m_e K.T}{2\Pi\, h^2}\right)^{3/2} \text{Exp (u-Eg) Kt} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

And the concentration of holes in valence band is given by the expression:

$$P = 2\left(\frac{m_h .K.T}{2\Pi\, h^2}\right)^{3/2} \text{Exp (Eg-u/kt)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$1/T = A + B\ \ln(\rho) + C(\ln(\rho))^3$$

Where A, B and C are the so-called Steinhart-Hart coefficients. This equation is used to calibrate the rmistors.

In non-crystalline semi-conductors, conduction can occur by charges quantum tunneling from one localized site to another. This is known as variable range hopping and has the characteristic form of $\rho = Ae\ (T)^{-1/n}$, where n = 2, 3, 5 depending on the dimensionality of the system.

Semiconductor Band Gaps

Materials	Energy gap (eV)	
	0K	300K
Si	1.17	1.11
Ge	0.74	0.66
InSb	0.23	0.17
InAs	0.43	0.36
InP	1.42	1.27
GaP	2.32	2.25
GaAs	1.52	1.43
GaSb	0.81	0.68
CdSe	1.84	1.74
CdTe	1.61	1.44
ZnO	3.44	3.2
ZnS	3.91	3.6

Concentration of intrinsic carriers

The concentration of intrinsic carriers i.e., the number of electrons in conduction band per unit volume is given by the expression:

$$n = 2\left(\frac{m_e K.T}{2\Pi\, h^2}\right)^{3/2} \text{Exp (u-Eg) Kt .} \qquad (1)$$

And the concentration of holes in valence band is given by the expression:

$$P = 2\left(\frac{m_h .K.T}{2\Pi\, h^2}\right)^{3/2} \text{Exp (Eg-u/kt) ..} \qquad (2)$$

If we multiply together the expression for n and ρ to obtain

$$np=4\left(\frac{K.T}{2\Pi\, h^2}\right)^{3.} (m_e m_h)\ \text{Exp (-Eg/kT)} \qquad (3)$$

This does not involve the Fermi level is known as the expression of law of mass action.

Where,

m_e = effective mass of an electron

m_h = effective mass of a hole

k = Boltzmann constant,

f = Fermi level

Eg = Band gap

T= temperature in ^{0}K

In case of intrinsic (highly purified) crystals, the number of electrons is equal to the number of holes. Because the thermal excitation of an electron leave behind a hole in the valence band. Thus from equation (3) we have letting the subscript I denote intrinsic.

$$ni = Pi = 4 \left(\frac{K.T}{2\Pi\, h^2} \right)^{3.} (m_e m_h)^{3/4} \text{ Exp } (\text{-Eg/kT}) \qquad (4)$$

Thus we see that the concentration of intrinsic carrier doped exponentially on (-Eg / 2kT).

Conductivity of intrinsic semiconductor

The electrical conductivity will be the sum of the contribution of both electrons and holes.

$$\sigma = n_i \; e \, \mu_e + P_i \; e \, \mu_h \qquad (5)$$

Where e is the electron charge, μ_e and μ_h are the average velocities acquired by the electrons and holes in an electric field and holes n a unit electric field and are known as mobility.

$$\sigma = n_i \; e \, (\mu_e + \mu_h) \qquad (6)$$

Since $n_{i\,=}\,P_i$

$$\sigma = (k)\; T^{3/2} \; (\mu_n + \mu_p) \text{ - EXP } \frac{\text{-Eg}}{2kT} \qquad (7)$$

Using equation (4), where k is a constant.

The factor $T^{3/2}$ and the mobility change relatively slow with temperature compared the exponential term and hence the logarithmic of resistivity ρ =1/σ varies linearly with 1/T. The width of the energy gap may be determined from the slope of the curve.

Thus we have,

$$\log_e p = \frac{Eg}{2kT} \text{ - log e k}$$

$$\log_e \rho = \{\frac{E_g}{2K}\} \frac{1}{T} - \log_e K$$

$$2.3026 \log_{10} \rho = \frac{E_g}{2X1000XK} \left(\frac{1000}{T}\right) - \log_e K$$

$$\log_{10} \rho = \frac{E_g}{2X2.3026X1000XK} \left(\frac{1000}{T}\right) - \left(\frac{1}{2.3026}\right) log_e K$$

Nvis 6105 Band Gap Measurement

Above equation shows the straight line equation between $\log_{10}\rho$ and (1000/T)

Thus

$$\text{Slope} = \frac{E_g}{2X2.3026X1000XK}$$

To find the value of E_g graph is plotted b/w $\log_{10} \rho$ V/S $\frac{1000}{T}$ and slope is calculated

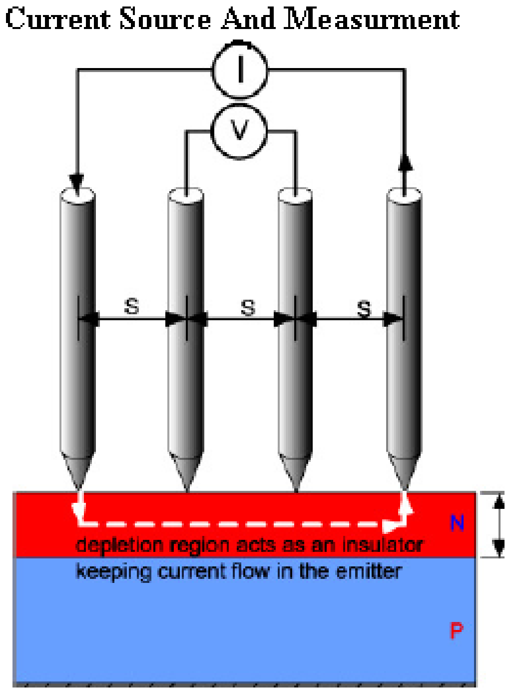
$$E_g = 2 \times 2.3026 \times 1000 \times K \times \text{slope} \tag{8}$$

Experimental Consideration

1. High resistance or rectification appears fairly often in electrical contacts to semiconductor and in fact is one of the major problem.
2. In single crystal material resistivity may vary smoothly from point to point. In fact this is generally the case. The question is the amount of this variation rather than any question of its presence. Often however, it is ignored.
3. Soldered probe contacts may disturb the current flow (shorting out part of the sample) and to the ambiguity in the measurement of the probe spacing. Soldering directly to the body of the sample can affect the sample properties by heating effect and by contamination unless care is taken. These problems can be avoided by using pressure contacts. The principle drawbacks of this kind of contacts are that they may be noisy.
4. The current through the sample should not be large enough to cause heating. A further precaution is necessary to prevent injecting effect from affection the measured value of even good contacts, to germanium, for example, May inject. This is minimized by keeping the voltage drop at the contacts low. If the surface near the current contacts is rough and electric flow in the crystal is low, these injected carriers will recombine before reaching the measuring probes.
5. Since ρ is independent of current, it is possible to determine whether or not any of these effects are interesting with the measuring of at several values of I. It should be kept in mind that these points experimental technique affect essentially all the measurements and not the resistivity measurement only.

Four probe method

Many conventional methods for measuring resistivity are unsatisfactory for semiconductor because metal-semiconductor contacts are usually rectifying in nature. Also there is generally minority carrier injection by one of the current carrying contacts. Excess concentrations of minority carriers will affect the potential of other contacts and modulate the resistance of the material.



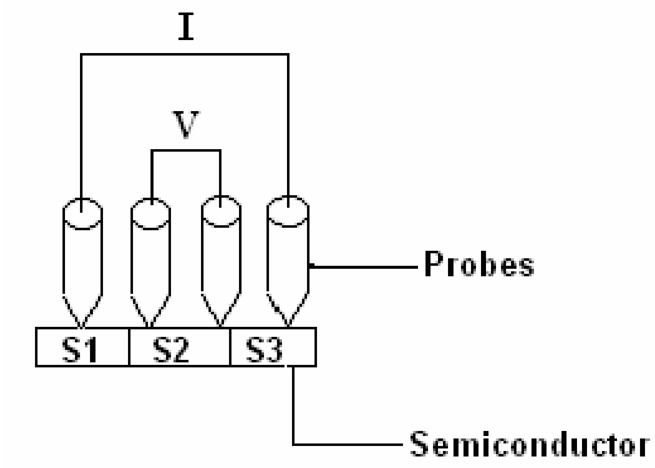
The method describes here overcome the difficulties mentioned above and also offers several other advantages. It permits measurements of resistivity y in sample having a wide verity of shapes, including the resistivity of small volumes within bigger pieces of semiconductor. In this manner the resistivity on both sides of p-n junction can be determined with good accuracy before the material is also applicable to silicon and other semiconductor materials. The basic model for all these measurements is indicated in figure 10. Four sharp probes are placed on a flat surface of the material to be measured, current is passed through the two outer electrodes and the floating potential is measured across the inner pairs. If the flat surface on which the probes rest is adequately large and the crystal is big. The semiconductor may be considered to be a semi-infinite volume. To prevent minority carriers injection and make good constant, the surface on which the probes rest may be mechanically lapped.

Nvis 6105 Band Gap Measurement

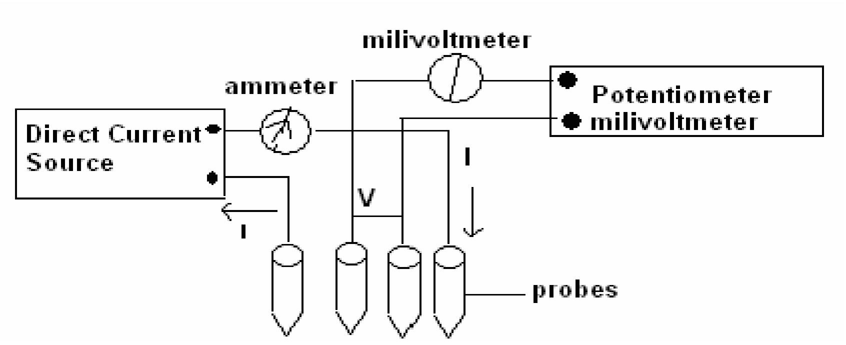
The experimental circuit used for measurement is illustrated schematically in figure11. A nominal value of probe spacing which has been found satisfactory is an equal distance 1.25mm between adjacent probes. This permits measurement with reasonable currents of n – type or p-type semiconductor from 0.001 to 50ohm cm.

In order to use this four probe method in semiconductor crystals or slices, it is necessary to assume that:

1. The resistivity of semiconductor is uniform in the area of measurement.
2. If there is minority carriers injection into the semiconductor by the current carrying electrons, most of the carriers recombine near the electrodes so that their effect on the conductivity is negligible, (this means that the measurement should be made on surfaces which have a high recombination rate, such as mechanically lapped surface).
3. The surface on which the probes rest is flat with no surface leakage.
4. The four probes used for Resistivity measurements contact the surface at points that lie in a straight line.
5. The diameter of the contact between the metallic probes and the semiconductor should be small compared to the distance between probes.
6. The boundary between the current carrying electrodes and the bulk material is hemispherical and small in distance.
7. The surfaces of the semiconductor crystal may be either conducting or non conducting.
    - A conducting boundary is one on which a material of much lower Resistivity than semiconductor (such as copper) has been plated.
    - A non conducting boundary is produced when the surface of the crystal is in contacts an insulator.



Model for four probe resistivity measurements



Circuit used for resistivity measurement

Case 1:Resistivity measurement on a large sample:

One added boundary condition is required to treat this case ,namely that the probe are far from any of the other surface of the sample and the sample can thus be considered a semi-infinite volume uniform resistivity material figure 10 shows the geometry of this case four probes are spaced S1, S2 and S3 apart. Current I is passed through the outer probes 1 and 4 and the potential V is measured across the inner pair of probes 2 and 3.

The floating potential Vf a distance r from an electrode carrying a current I in a material of resistivity ρ0 is given by

$$V_f = \frac{\rho_0 I}{2\pi r}$$

Case 2: Resistivity measurements on a thin slice-conducting bottom surface:

Two boundary condition must be met on this case; the top surface of the slice must be reflecting (non-conducting) surface and the bottom surface must be an absorbing (conducting) surface. Since the two boundaries are parallel a solution by the method of images requires for each current source, an infinite series of images along a line normal to the planes and passing through the current source.

The model for this case is shown in figure. The side surface of the die is assumed to be far from the area of measurement and, therefore only the effect of the bottom surface needs to be considered. In this analysis equal probe spacing 's' shall be assumed. The width of the slice is 'w'. The array of images needed is indicated in figure.

The floating potential Vf2 at electrode 2 is:

$$V_{f2} = \frac{\rho I}{2\Pi\left[\dfrac{\sum\limits_{n=-\infty}^{n=\infty}(-1)^n}{(\sqrt{S^2+\{2nw\}^2})} - \dfrac{\sum\limits_{n=-\infty}^{n=\infty}(-1)^n}{(\sqrt{2S+\{2nw\}^2})}\right]} \quad \text{...(10)}$$

Likewise, the floating potential at electrode 3 can be obtained and

$$V_{f2} = \frac{\rho I}{2\Pi\left[\left(\frac{1}{S}\right)\frac{\sum_{n=-\infty}^{n=\infty}(-1)^n \times 4}{(\sqrt{S^2+\{2nw\}^2})} - \frac{\sum_{n=-\infty}^{n=\infty}(-1)^n \times 4}{(\sqrt{2S+\{2nw\}^2})}\right]} \quad \text{... ....(11)}$$

The resistivity then becomes

$$\rho = \rho_{0\,/}\, G_6\,(w/s). \qquad (12)$$

Where resistivity 0 is computable and can be used if the point spacing is different, but approximately equal. The function (w/s) is computed from

$$G_6\left(\frac{w}{s}\right) = 1 + 4\left(\frac{s}{w}\right)\left[\sum_{n=1}^{n=\infty}(-1)^n\left\{\frac{1}{\sqrt{\left(\frac{S}{w}\right)^2+(2n)^2}}\right\} - \left\{\frac{1}{\sqrt{\left(\frac{2s}{w}\right)^2+(2n)^2}}\right\}\right] \quad \text{..................(13)}$$

This is tabulated in Table 1.

Table 1

w/s	G6 (w/s)	G7 (w/s)
0.100	0.0000019	13.863
0.141	0.00018	9.704
0.200	0.00342	6.931
0.333	0.0604	4.159
0.500	0.228	2.780
1.000	0.683	1.504
1.414	0.848	1.223
2.000	0.933	1.094
3.333	0.9838	1.0228
5.000	0.9948	1.0070
10.000	0.9993	1.00045

To find the values in between the values supplied in the table, extrapolate the reading by the following formula

$$y = \frac{(x - x_1)y_2 - (x - x_2)y_1}{(x_2 - x_1)}$$

Where y = extrapolated value of G6 or G7 which is to be found

x = the value of w/s at which G6 or G7 is to be found

x_1 = the value of w/s just less than x (from the table)

x_2 = the value of w/s just greater than x (from the table)

y_1 = the value of G6 or G7 at x_1 (from the table)

y_2 = the value of G6 or G7 at x_2 (from the table)

For example

If the value of G6 is to be found for w/s = 0.25

Then from the table

$$y = \frac{(0.25-0.2)0.0604-(0.25-0.333)0.00342}{(0.333-0.2)}$$

y = 0.02484

Thus the value of G6 (0.25) is 0.02484

Case 3: Resistivity measurement on a thin slice-non-conducting bottom surface

The model for this measurement is like for case no. 2 expects that the bottom surface of the slice is none conducting. This means that all the images of figure have the same charge as the current source. Thus all the images on a row have equal charges and describes the potential difference across the inner part of probes if $(-1)^n$ is removed from the equation. Then,

$$\rho = \rho_0 / G_7\,(w/s) \ldots\ldots\ldots\ldots\ldots\ldots \qquad (14)$$

Where,

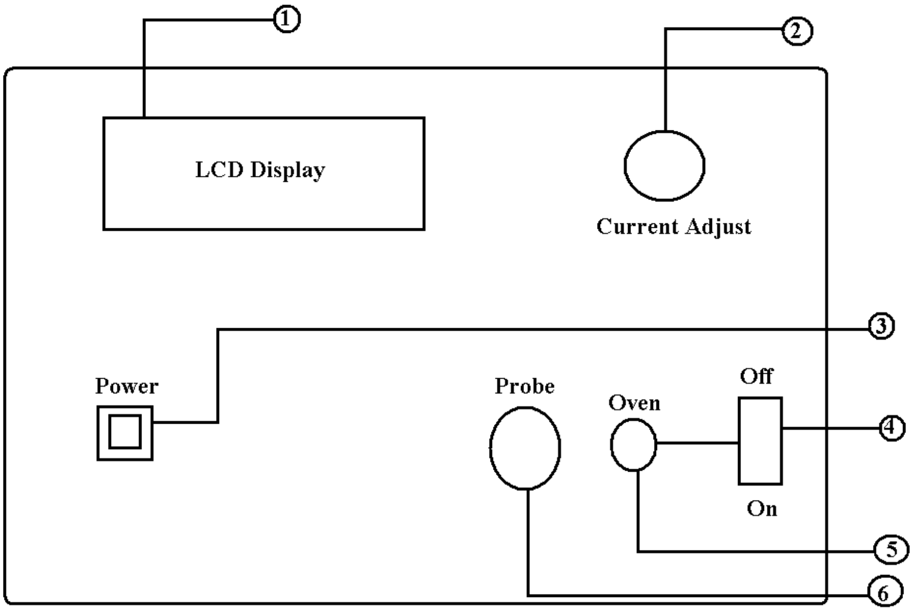
$$G_7\left(\frac{w}{s}\right) = 1 + 4\left(\frac{s}{w}\right)\left[\sum_{n=1}^{n=\infty}(-1)^n\left\{\frac{1}{\sqrt{\left(\frac{S}{w}\right)^2+(2n)^2}}\right\} - \left\{\frac{1}{\sqrt{\left(\frac{2s}{w}\right)^2+(2n)^2}}\right\}\right] \ldots\ldots\ldots\ldots \quad (15)$$

This function G7 (w/s) is tabulated in Table-T1, for smaller values of w/s the function G7 (w/s) approaches the case for an infinitely thin slice.

$$G_7\,(w/s) = 2s/w \ldots\ldots\ldots\ldots\ldots\ldots \qquad .(16)$$

Precaution: Make sure that all four probe hold the semiconductor crystal tightly otherwise it can be lost.

Front Panel Controls of Measurement Unit



1. **LCD Display:** It displays current, voltage and temperature
2. **Current Adjust:** By this we can adjust the current.
3. **Power:** It is power on/off switch.
4. **On–Off Switch:** For switching on or off the oven.
5. **Three Pin Connector:** To provide Supply to oven.
6. **Octal Socket:** To connect Probe.

Setting of instrument before starting experiment

1. Take Measurement Unit of Band Gap and connect mains cord and switch ‘On’ the instrument.
2. At starting Current & Voltage will be zero & the oven temperature will display.
3. Now rotate current adjust pot clockwise if in case current is not increasing to a desired value, then open the screws of oven and take out the four probe assembly.
4. Sample crystal is attached with the probe arrangement, if it is not making proper contact with probes then adjusts the horizontal screw provided on the four probe arrangement such that all four probes hold the crystal tightly. The Ge crystal is very brittle so handle it carefully, use only the minimum pressure required for proper electrical contacts.
5. Now place the four probe arrangement in the oven.

Precautions: Make sure that the entire four probes hold the semiconductor crystal tightly otherwise it can be lost

Nvis 6105 Band Gap Measurement

Experiment 1

Objective:

Determination of Resistivity and Band Gap of Semiconductors by Four Probe Method at different temperatures

Items Required:

1. Measurement unit
2. Oven arrangement
3. Four probe arrangement

Procedure:

1. Take Measurement Unit of Band Gap and connect mains cord.
2. Sample crystal is attached with the probe arrangement, in case if it is not making proper contact with probes then adjust the horizontal screw provided on the four probe arrangement such that all four probe hold the crystal tightly. The Ge crystal is very brittle so handle it carefully.
3. Place the four probe arrangement in the oven.
4. Connect four probe (eight pin connector) to the given eight pin socket of measurement unit.
5. Connect the heater terminals (three pin socket) of the oven to the Measurement unit.
6. Set the controls of measurement unit as follows:
   - Oven toggle switch at ‘Off’ position.
   - Potentiometer at fully anticlockwise.
7. Connect the heater terminals (three pin socket) of the oven to the Measurement unit.
8. Switch ‘On’ the Measurement unit of four probe setup.
9. At starting Current & Voltage will be zero & the oven temperature is displayed.
10. Adjust the constant current to a desire value say 5 mA.
11. Now keep Oven toggle switch at ‘On’ position.
12. Now temperature will increase slowly.
13. Record the value of voltage corresponding to the fixed interval of temperature rise.(Eg: -For every 5°C rise in temperature.) The temperature increases upto 120°C.
14. Now using following equation we can find the value of ρ.

$$\rho = \frac{\rho_0}{G_7\,(W/S)}$$

Where

$$\rho_0 = \frac{V}{I}\,2\pi s$$

V = voltage and I = Current

Distance between probes (s) = 2.0mm, W is thickness of the crystal (if W=0.23mm).

And correction factor G_7 (w/s) = $G_7 \frac{(0.23)}{2.0}$

= $G_7(0.115)$ is 12.36 (obtained from table –I)

Note:

To find the values in between the values supplied in the table, extrapolate the reading by the following formula

$$y = \frac{(x - x_1)\,y_2 - (x - x_2)\,y_1}{(x_2 - x_1)}$$

Where y = extrapolated value of G6 or G7 which is to be found

x = the value of w/s at which G6 or G7 is to be found

x_1 = the value of w/s just less than x (from the table)

x_2 = the value of w/s just greater than x (from the table)

y_1 = the value of G6 or G7 at x_1 (from the table)

y_2 = the value of G6 or G7 at x_2 (from the table)

For example:

If the value of G6 is to be found for w/s = 0.25

Then from the table

$$y = \frac{(0.25 - 0.2)0.0604 - (0.25 - 0.333)0.00342}{(0.333 - 0.2)}$$

y = 0.02484

Thus the value of G6 (0.25) is 0.02484

$\therefore$ $\rho = \rho_0/12.36$

Observation Table 2:

Current I = 5mA (constant for whole experiment)

S. No.	Temperatu (in 0C)	Temperature T (in 0K)	Voltage V(volt)	Resistivity (ρ) (in Ohm x cm)	$\frac{1}{T}$ x1000 (in K)	Log10(ρ)

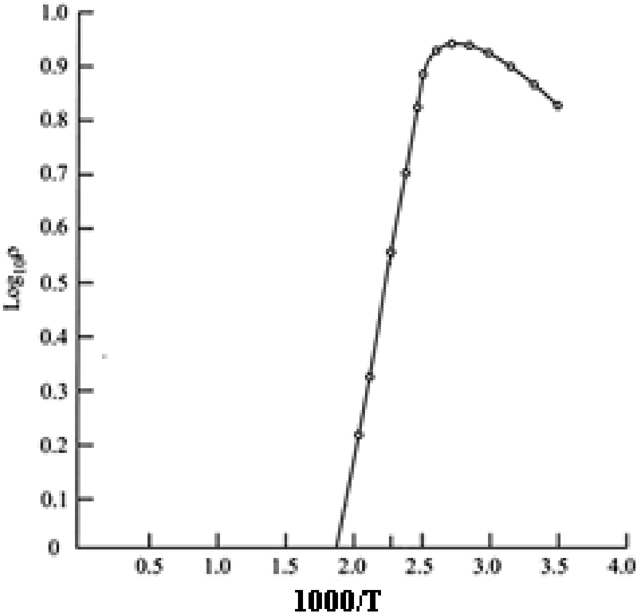
15. Plot a graph for Log$_{10}$(ρ) v/s 1000/T and find the value of slope for the intrinsic region of the semiconductor. The slope can be calculated by fitting a straight line in the straight portion (intrinsic region) of the graph.

16. From Slope E_g Can be calculated as

$$E_g = 2 \times 2.3026 \times 1000 \times K \times \text{slope}$$

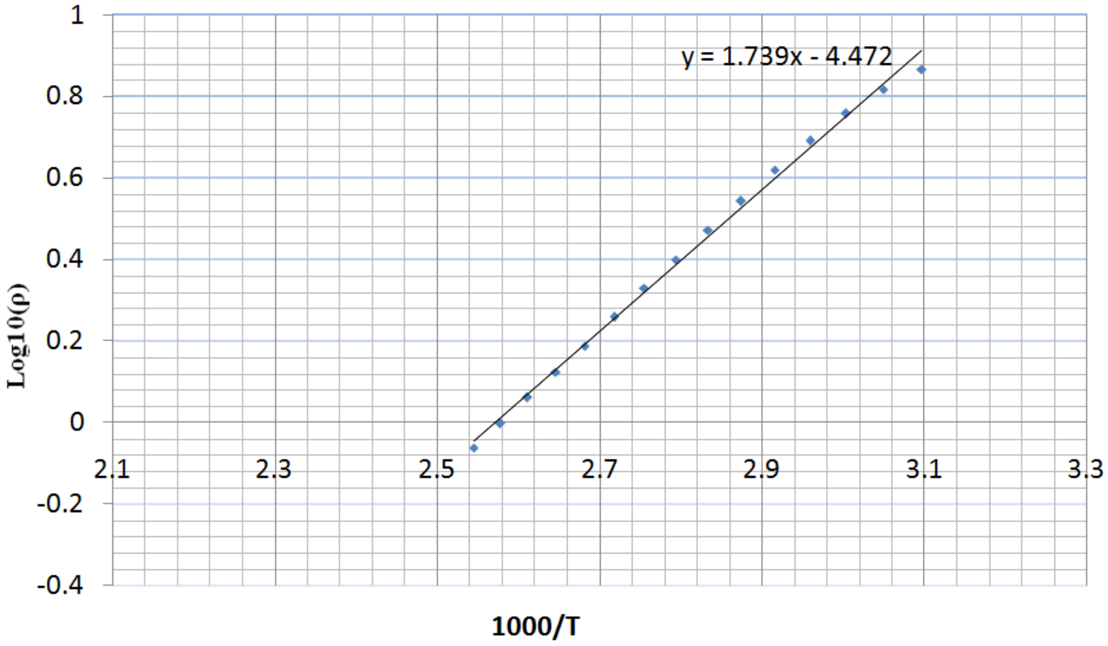
Where K is Boltzmann's constant = 8.6×10^{-5} eV & Eg is Band Gap.

A typical graph is shown in figure.



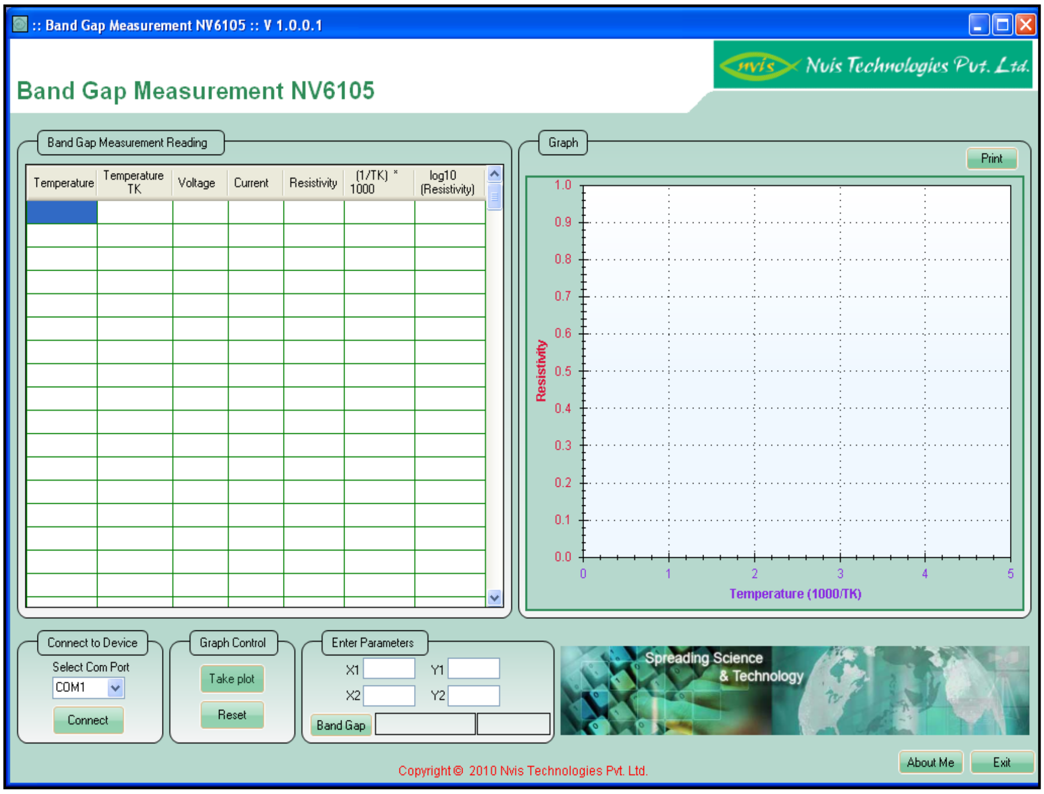
Above is a ideal graph for band gape but practically it varies due to some variables such as crystal structure, temperature etc.

Practical graph could be like given below on room temperature



Procedure for Performing above experiment with PC Interface:

1. Install the software provided with the setup. (If not done already).
2. Open the software window by double clicking on its icon
3. Following window will appear on your computer screen, as you open the software.



4. Take Measurement Unit of Band Gap and connect mains cord.
5. Sample crystal is attached with the probe arrangement, in case if it is not making proper contact with probes then adjust the horizontal screw provided on the four probe arrangement such that all four probe hold the crystal tightly. The Ge crystal is very brittle so handle it carefully.
6. Place the four probe arrangement in the oven.
7. Connect four probe (eight pin connector) to the given eight pin socket of measurement unit.
8. Connect the heater terminals (three pin socket) of the oven to the Measurement unit.
9. Set the controls of measurement unit as follows:
   - Oven toggle switch at 'Off' position.
   - Potentiometer at fully anticlockwise.

Nvis 6105 Band Gap Measurement

10. Connect the heater terminals (three pin socket) of the oven to the Measurement unit.
11. Switch ‘On’ the Measurement unit of four probe setup.
12. At starting Current & Voltage will be zero & it will be display oven temperature.
13. Adjust the constant current to a desire value say 5mA.
14. Now connect the instrument to the computer using a RS232 cable or USB cable.
15. Select the appropriate com port & connect the device with PC.
16. Now keep Oven toggle switch at ‘On’ position.
17. Now temperature will increase slowly.
18. Click on Take plot button on the software window at the fixed interval of temperature rise. (Eg.:- For every 5^0C rise in temperature.)
19. The software will display all the readings corresponding to that temperature and the graph between resistivity and temperature (1000/T K) is seen on computer screen.
20. From Slope E_g Can be calculated as

    $$E_g = 2 \times 2.3026 \times 1000 \times K \times \text{slope}$$

    Where K is Boltzmann’s constant = 8.6×10^{-5} eV/K & Eg is Band Gap.

    Thus Eg may be obtained from the slope of the graph. Note that $\log_e \rho = 2.3026$ *log10 and the equation 1 is applicable only in the intrinsic region of the semiconductor.

21. Enter the two values of temperature X1 and X_2 and the corresponding reading of resistivity Y1 and Y_2 on the section Enter Parameters seen on your screen for determining slope.

    Note: The value of Temperature and Resistivity should be selected such that it lies on the linear portion of the curve.)

    Precautions: Make sure that the entire four probes hold the semiconductor crystal tightly otherwise it can be lost

Sample Results

Calculation:

Distance b/w probe (s) =2 mm = 0. 2 cm (Given)

Thickness of crystal (w) = .23 mm (Given on Probe)

Current I = 5 mA = 0.005 A

Y = G7(.23/2) = G7 (0.115)

w/s	G6 (w/s)	G7 (w/s)
0.100	0.0000019	13.863
0.141	0.00018	9.704

To find the values in between the values supplied in the table 1 , extrapolate the reading by the following formula $y = \frac{(x-x_1)y_2 - (x-x_2)y_1}{(x_2 - x_1)}$

$x = 0.115$,

$x_1 = 0.100$, $x_2 = 0.141$

$y_1 = 13.863$, $y_2 = 9.704$

From substituting the following values in above Formula

$$y = \frac{(0.115-0.100)9.704-(0.115-0.141)13.863}{(0.141-0.100)}$$

y = 12.36

G7 (0.115) = 12.36

Now

$$\rho_0 = \frac{V}{I} 2\pi s$$

$$= \left(\frac{V}{I}\right) \times 2 \times 3.14 \times 0.2$$

$$= \left(\frac{V}{I}\right) \times 1.256 \text{ (in Ohm .cm)}$$

Nvis 6105 Band Gap Measurement

Observation Table:

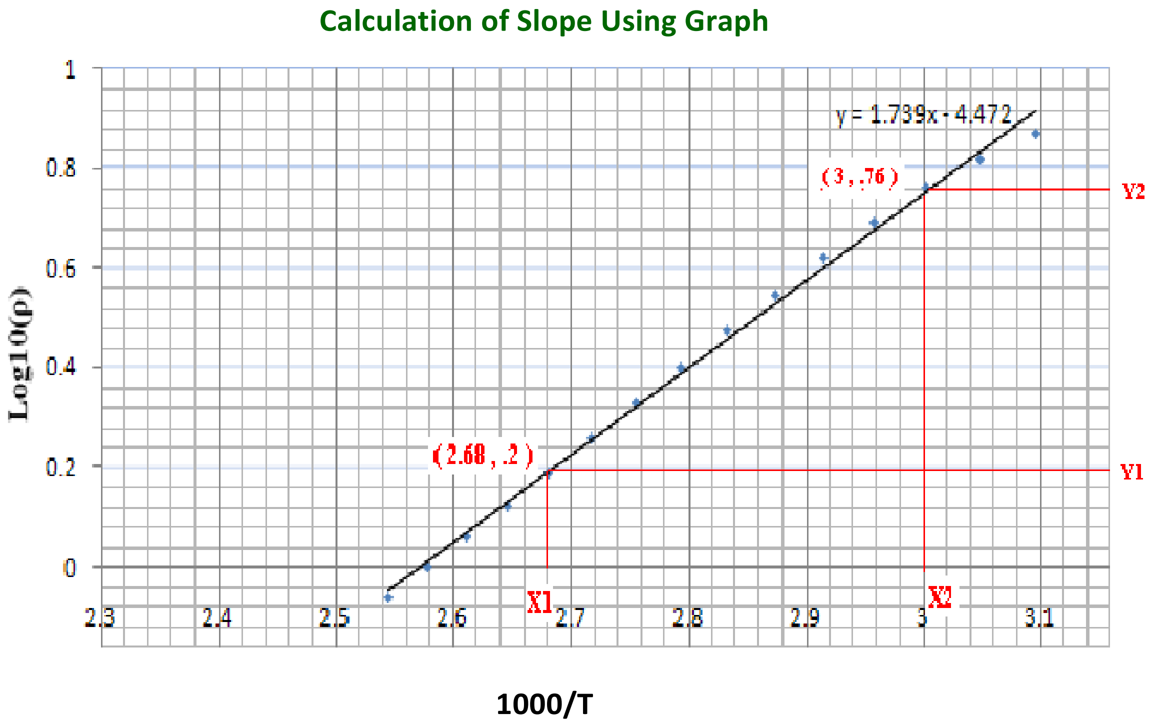
Temperature ℃	Temperature T(K)	Voltage (Volt)	ρ_0 =[V/ I (in A)]*1.256	Resistivity $\rho = \rho_0/1236$	1/T * 1000 (K)	Log10(ρ)
30	303	0.4172	104.80064	8.479016181	3.300330033	0.928345464
35	308	0.4165	104.6248	8.464789644	3.246753247	0.92761617
40	313	0.4092	102.79104	8.316427184	3.194888179	0.919936789
45	318	0.3901	97.99312	7.928245955	3.144654088	0.899177115
50	323	0.3623	91.00976	7.363249191	3.095975232	0.867069498
55	328	0.3235	81.2632	6.574692557	3.048780488	0.817875449
60	333	0.2822	70.88864	5.735326861	3.003003003	0.758558174
65	338	0.242	60.7904	4.918317152	2.958579882	0.69181653
70	343	0.2049	51.47088	4.16431068	2.915451895	0.619543123
75	348	0.1721	43.23152	3.497695793	2.873563218	0.543782035
80	353	0.1459	36.65008	2.965216828	2.83286119	0.472056456
85	358	0.1236	31.04832	2.512	2.793296089	0.400019635
90	363	0.1051	26.40112	2.136012945	2.754820937	0.32960388
95	368	0.0894	22.45728	1.816932039	2.717391304	0.259338683
100	373	0.0758	19.04096	1.540530744	2.680965147	0.18767037
105	378	0.0655	16.4536	1.331197411	2.645502646	0.124242464
110	383	0.0567	14.24304	1.152349515	2.610966057	0.061584223
115	388	0.049	12.3088	0.995857605	2.577319588	-0.001802756
120	393	0.0427	10.72624	0.86781877	2.544529262	-0.061570961

Calculation of Slope

The slope can be obtained by fitting a straight line curve between the points in intrinsic region of the graph. The straight line can be obtained by using any graph analysis software like MS Excel, Origin etc. Alternatively, a straight line can be drawn by hand and slope is calculated manually by the following formula

$$\text{Slope} = \frac{Y2 - Y1}{X2 - \text{X}1}$$

Nvis 6105 Band Gap Measurement


Calculation of Slope Using Graph

Here

$X_1 = 2.68$, $X_2 = 3$, $Y_1 = .2$, $Y_2 = .76$

Substituting above values in

$$\text{Slope} = \frac{Y2 - Y1}{X2 - X1}$$

$$= \frac{.76 - .2}{3 - 2.68}$$

$$= \frac{.56}{.32}$$

$= 1.75$

Nvis 6105 Band Gap Measurement

From Eqn. (8)

E_g = 2 x 2.3026 x 1000 x K x slope

= 2 x 2.3026 x 1000 x 8.6 x 10^{-5} x 1.75

= .69 ev

Standard Value of E_g for Ge is 0.66eV

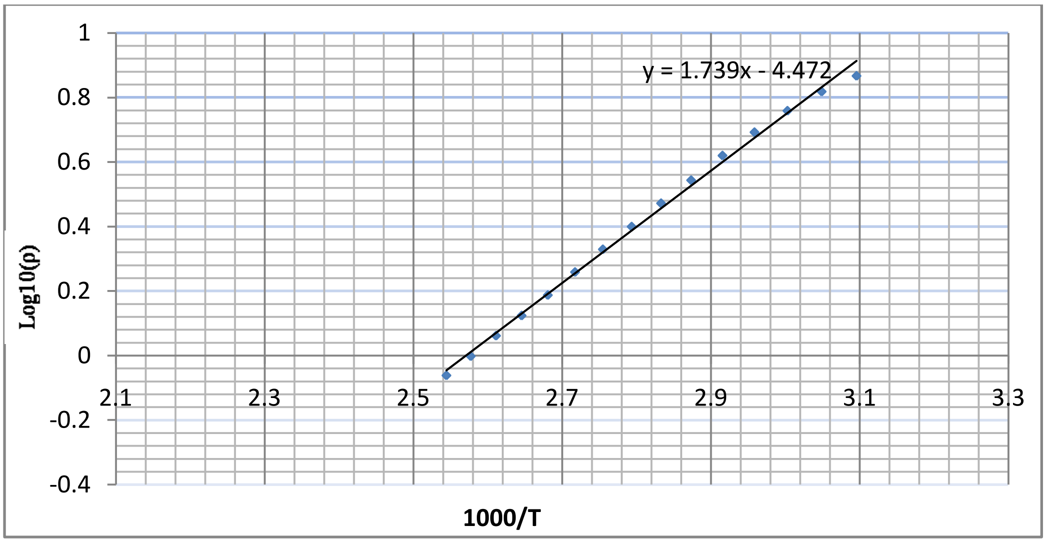
Percentage Error

$$\frac{Calculated\ Value\ -\ Exact\ Value}{Exact\ Value}\ X\ 100\%$$

$$= \frac{.69 - .66}{.66} \times 100\%$$

= 4.5 %

Calculation of Slope Using Excel Graph



From Eqn. (8)

E_g = 2 x 2.3026 x 1000 x K x slope

= 2 x 2.3026 x 1000 x 8.6 x 10^{-5} x 1.739

= 0.68 eV

Standard Value of E_g for Ge is .66eV

Percentage Error

$$\frac{Calculated\ Value\ -\ Exact\ Value}{Exact\ Value}\ X\ 100\%$$

$$= \frac{.68 - .66}{.66} \times 100\%$$

= 3%

Glossary

1. **Alternating current**: Electric current that reverses direction periodically, usually many times per second.
2. **Ammeter:** An instrument used for measuring the electrical current flow in a portion of a circuit.
3. **Atomic orbital**: The region in space around the nucleus of an atom in which an electron with a given set of quantum numbers is most likely to be found.
4. **Band**: A collection of orbital, each delocalized throughout the solid that are so closely spaced in energy as to be nearly continuous.
5. **Band gap**: The energy separation between the top of the valence band and the bottom of the conduction band.
6. **Bias:** Voltage applied to the electrodes in an electrical device, considering polarity.
7. **Biasing**: Applying a voltage, often done to alter the electrical and optical output of a device such as a light emitting diode (LED).
8. **Charge coupled devices**: A charge transfer device that stores charge in potential wells and transfers it almost completely as a packet by translating the position of the potential well.
9. **Choke coil**: An inductance device used in a circuit to present high impedance to high frequencies without appreciably limiting the flow of direct current.
10. **Cleaved-coupled-cavity**: Two or more aligned semiconductor lasers which through destructive and constructive interference are able to output light of a particular wavelength.`
11. **Conduction band:** The unfilled energy levels into which electrons can be excited to become conductive electrons; a band that when partially occupied by mobile electrons, permits their net movement in a particular direction, producing the flow of electricity through the solid.
12. **Conductor**: A material with a high electrical conductivity such as copper or aluminum.
13. **Crystal**: A solid composed of atoms, ions, or molecules arranged in an orderly pattern that is repeated in three dimensions.
14. **Delocalized (electrons):** Electrons that are no longer bound to a given atomic nucleus and are highly mobile.
15. **Diode**: A two electrode semiconductor device that utilizes the rectifying properties of a p-n junction or a point contact.
16. **Direct current**: Electric current which flows in one direction only.
17. **Dopant:** An impurity element that is deliberately added to a semiconductor.
18. **Drift velocity:** The average velocity of a carrier that is moving under the influence of an electric field in a conductor, semiconductor, or electron tube.

19. **Electrical conductivity:** The ability of a material to carry an electric current; it is the reciprocal of resistivity with units of ohm $^{[-1]}$ cm$^{[-1]}$.
20. **Electrical resistance:** The measure of the difficulty of electric current to pass through a given material; its unit is the ohm ([[Omega]]).
21. **Electricity:** Current passing through a conductor from a region of high potential to low potential.
22. **Electric generator:** A device which takes mechanical energy as an input and produces electricity (AC/DC) as an output.
23. **Electromagnetic radiation** (waves)**:** A series of energy waves that travel in a vacuum at the speed of 3 x 10^{-8}m/s; includes radio waves, microwaves, visible light, infrared, and ultraviolet light, x-rays, and gamma rays.
24. **Electron:** A negatively charged sub-atomic particle whose mass is 9.1 x 10^{-31} kg.
25. **Electron energy level:** In quantum mechanics, an energy which is allowed for an electron.
26. **Electronics:** A branch of applied physics and engineering concerned with controlling the movement of electrons in circuits.
27. **Extrinsic semiconductor:** A semiconductor material that has been doped with an n-type or p-type element.
28. **Forward bias:** Bias applied to a p-n junction in the conducting direction, majority carrier electrons and holes flow toward the junction so that a large current flows.
29. **Galvanometer:** An instrument for measuring a small electric current.
30. **Germanium:** Element 22, used mostly in early semiconductor devices.
31. **Hole:** A fictitious mobile particle that behaves as though it is a positively charged particle; holes are produced in the valence band when electrons from the valence band are promoted to the conduction band or an acceptor level of a p-type dopant.
32. **Incandescent light:** A gas filled (argon) bulb containing a metallic filament (tungsten) that produces light when a sufficient voltage is applied; an ordinary light bulb.
33. **Insulator:** A material with a low electrical conductivity; a type of material having a lower energy valence band that is nearly completely filled with electrons and a higher conduction band that is nearly completely empty of electrons as a result of a large energy gap between the two bands.
34. **Integrated circuit (IC):** A single semiconductor chip or wafer which now contains thousands or millions of circuit elements per square centimeter.
35. **Intrinsic semiconductors:** A semiconductor material that is essentially pure.
36. **Laser diode:** A solid-state semiconductor device that is capable of emitting coherent light.

37. **Leads.** Wire segments used to connect devices in electric circuits.
38. **Light emitting diode (LED):** A semiconductor p-n junction device that is optimized to release light of approximately the band gap energy when electrons fall from the conduction band to the valence band.
39. **Metal:** A material with a partially filled energy band; metals are generally malleable, ductile, good reflectors of electromagnetic radiation, and good conductors of heat and electricity; metals are usually identified by having electrical conductivities that decrease with increasing temperature.
40. **Monolithic IC technology:** A technique of circuit fabrication where all of the devices in a circuit are placed on the same chip.
41. **Multimeter:** A volt-ohm-millimeter combined into one device.
42. **N-type semiconductor:** A semiconductor that has been doped with an electron donor.
43. **Ohmmeter:** An instrument for measuring electric resistance.
44. **Opto-electronic:** Materials that can either produce an electric current from light or produce light from a current.
45. **Photocell:** A solid state photosensitive device whose current-voltage characteristic is a function of incident radiation; "electric eye" or "photoelectric cell".
46. **Photoconductivity:** Light shining on the surface of a material increasing the conductivity.
47. **Photon:** A mass less particle, the quantum of the electromagnetic field carrying energy, also known as the light quantum.
48. **Photo resistor:** A device for measuring or detecting electromagnetic radiation. The conductivity of the resistor changes with exposure to light.
49. **P-n junction:** A boundary between p-type and n-type regions within a single crystal of a semiconductor material, a diode.
50. **P-type semiconductor:** A semiconductor that has been doped with an electron acceptor.
51. **Quantum mechanics:** Physical laws governing the behavior of matter and energy on a very small scale.
52. **Quantum numbers:** A set of four numbers necessary to fully characterize the state of each electron in an atom.
53. **Rectifier:** A circuit component, usually a diode, that allows current to flow in one direction unimpeded but allows no current flow in the other direction.
54. **Resistor:** A device used in electric circuits to limit the current flow or to provide a voltage drop.
55. **Reverse bias:** Bias applied to a p-n junction in a direction for which the flow of current is inhibited; majority carrier electrons and holes flow away from the junction.

56. **Rectify:** To convert into direct current.

57. **Reverse breakdown voltage:** The amount of reverse bias that will cause a diode to break down and conduct in reverse.

58. **Semiconductor:** A material whose electrical conductivity is midway between that of an good conductor and a good insulator; a type of material having a lower energy valence band that is nearly completely filled with electrons and a higher energy conduction band that is nearly completely empty of electrons, with a modest energy gap between the two bands; pure materials usually exhibit electrical conductivity that increases with temperature because of an increase in the number of charge carriers being promoted to the conduction band.

59. **Silicon:** Element 14, the most commonly used semiconductor.

60. **Thermostat:** A resistive circuit component having a high negative temperature coefficient of resistance so that its resistance decreases as temperature increases.

61. **Transformer:** A magnetic coupling device in an AC circuit; they are capable of changing voltages as needed.

62. **Transistor:** A solid state semiconductor device able to amplify a signal in forward bias.

63. **Valence band:** The energy band containing the valence (outer) electrons; in a conductor the valence band is also the conduction band; the valence band in a metal is not full, so electrons can be energized to other levels and become conductive.

64. **Voltmeter:** An instrument used for measuring the potential difference between two points in volts.

Frequently Asked Questions

Q1. What is a p-type semiconductor?

Ans. Semiconductors formed by adding trivalent impurities in which the majority carriers are holes is called a P-type semiconductor.

Q2. What is a p-type semiconductor?

Ans. Semiconductors formed by adding trivalent impurities in which the majority carriers are electrons is called a P-type semiconductor.

Q3. What is dopping?

Ans. The process of changing the performance of a semiconductor by introducing a small number of suitable replacements as impurities into the semiconductor lattice is called as dopping.

Q4. Due to what phenomenon does the reverse saturation current arise?

Ans. The reverse saturation current arises in a junction diode due to the diffusion of minority charge carriers. (Electrons in p-region and holes in n-region are respective minority charge carriers.)

Q5. Why the reverse bias should be kept below the break down voltage?

Ans. Then only the reverse saturation current remains constant.

Q6. Why the reverse saturation current does depend on temperature?

Ans. This is because the reverse saturation current is due to diffusion of minority charge carriers which are thermally generated .The diffusion is also temperature dependent. Hence the reverse saturation current is highly sensitive to temperature.

Q7. What is diffusion?

Ans. The motion of charge carriers that take place when there is a non uniform distribution of Charged particles .This process is called diffusion.

Q8. Why reverse bias current is called as reverse saturation current?

Ans. Because the reverse current becomes saturated quickly with the increase in the reverse bias.

Q9. What are the values of band gap for metals, semiconductors and insulators?

Ans. For metal = 0 eV, semiconductors = .5 - 3 eV and for insulator greater than 3.

Q10. Can we use silicon diode to do the band gap experiment?

Ans. Yes, But the reverse current silicon varies slowly with temperature and magnitude at room temp. is less in comparison with a Ge diode . If we use silicon we need to raise the temperature to higher value.

Q11. How the resistances of a semiconductor decrease with temperature?

Ans. Semiconductors, by classification, have a forbidden energy band bound by the valence band on the low-energy end and the conduction band on the high-energy side. At a very low temperature, most charge carriers are inactive -- very few free electrons in the conduction band and free holes in the valence band, where these charge carriers can roam free and complete the circuit when an electrical source (a battery) is connected to a bar of the material. As the temperature rises, the probability of finding free electrons in the conduction band and free holes in the valence band increases, resulting in more free charge carriers available, hence lower resistance.

Q12. Why four probe methods is used to measure resistivity?

Ans. Four probe method avoids the necessity of finding cross sectional area of a given material but in two probe method we must first find the cross sectional area of material.

Q13. What is semiconductor?

Ans. A semiconductor is called a semiconductor because it is a type of material that has an electrical resistance which is between the resistance typical of metals and the resistance typical of insulators, so it kind of, or "semi"-conducts electricity. Semiconductors are used in many electrical circuits because we can control the flow of electrons in this material

Q14. What is Zener diode?

Ans. A Zener Diode is a special kind of diode which permits current to flow in the forward direction as normal, but will also allow it to flow in the reverse direction when the voltage is above a certain value - the breakdown voltage known as the Zener voltage. It is generally used as a voltage regulator in reverse bias.

Q15. On what factor does the breakdown voltage of diode depends?

Ans. In a p-n junction diode the reverse break down voltage depends on the level of doping of n-type and p-type regions.

Q16. What is breakdown voltage? Explain.

Ans. The voltage measured at a specified current in the electrical breakdown region of a semi conductor diode. Also known as Zener voltage.

Q17. What is the difference between ordinary diode and zener diode?

Ans. Diode is the uncontrolled rectifier and Zener diode is a controlled rectifier. Diode has practically no limits of voltage range to work in, whereas zener diode works only in a voltage range(e.g. -4V to +4V).So, Zener diode is known as voltage regulator

Q18. What do you mean by forward and reverse biasing?

Ans. This is a characteristics of semiconductor diode {pn junction}.In forward biasing here we connect p to positive terminal and n -ve terminal when external voltage is applied in such a direction that cancels out potential barrier thus permitting current flow In reverse biasing the connection of pn junction is inverted but in this the potential barrier increases and offers resistance to current flow but at a certain voltage current increases suddenly(the break down voltage)the zener diode works in this principle

Q19. What are the applications of Semi conductor diode?

Ans. A number of applications are there:

1. As rectifiers or power diodes in d.c. power supplies.
2. As signal diodes in communication circuits .
3. As zener diodes in voltage stabilizing circuits.
4. As varactor diodes in radio and TV receivers.
5. As a switch in logic circuits used in computers.

Q20. Name the types of breakdown in semiconductor diode.

Ans. They are Zener breakdown and avalanche breakdown.

Warranty

- We warranty the product against all manufacturing defects for 12 months from the date of sale by us or through our dealers. Consumables like dry cell etc. are not covered under warranty.
- The warranty will become void, if
    - The product is not operated as per the instruction given in the learning material.
    - The agreed payment terms and other conditions of sale are not followed.
    - The customer resells the instrument to another party.
    - Any attempt is made to service and modify the instrument.
- The non-working of the product is to be communicated to us immediately giving full details of the complaints and defects noticed specifically mentioning the type, serial number of the product and date of purchase etc.
- The repair work will be carried out, provided the product is dispatched securely packed and insured. The transportation charges shall be borne by the customer.

List of Accessories

• Four Probe with Oven Arrangement	1 No.
• Band gap measurement unit	1No.
• Mains Cord	1 No.
• USB Cable.	1 No.
• Serial Cable.	1 No.
• Learning Material CD	1 No.

References

- http://wiki.answers.com/Q/Why_four_probe_method_is_used_to_measure_resistivity
- http://www.colorado.edu/engineering/MCEN/MCEN5024/Part%20one%20-%20The%20structure%20of%20atoms.pdf
- .http://www.colorado.edu/engineering/MCEN/MCEN5024/Part%20one%20-%20The%20structure%20of%20atoms.pdf
- http://makahiki.kcc.hawaii.edu/chem/valence_electrons.html
- http://www.thebigger.com/physics/conductors-insulators-and-semi-conductors/what-are-extrinsic-semiconductors/