ENERGY BAND GAP MEASUREMENT KSCIEBGA

1. Key Concepts

- Band structure
- Semiconductors
- Quantum mechanics
- Condensed matter physics

2. Introduction

Atoms and molecules have distinct orbitals (energy levels) around them, each of them corresponding to a unique value of energy. These energy levels are occupied by electrons belonging to the atom/molecule.

When the atoms come closer to each other, they form crystals. This is know as condensed matter state. The energy levels of same value of energy, belonging to the atoms in the crystal that are close enough to each-other and have a coupling between them leading to the formation of energy bands and band structure. The knowledge of band structure and energy band gaps helps us in predicting and modelling the electronic conductivity of various materials.

3. Objective

- To measure the energy band-gap of various semiconductors diodes.

4. Theory

The electrons bound to an atom are modelled to be in a square well attractive potential due to the presence of a positively charged nucleus. In a condensed state of matter, the atoms are arranged in a periodic manner (this is an approximation, because there are amorphous solids also, that are called glassy solids).

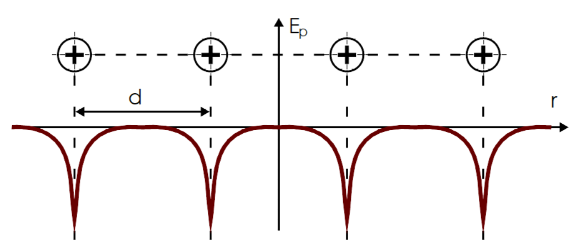

Figure 1: 1d lattice potentia

Figure 1, shows the potential due to a 1D lattice. In metals, the electrons are assumed to be free particles.

the free electrons experience an attractive potential when they come close to the positive ions in the lattice Figure 2 shows the linear combinations of atomic orbitals leading to the formation of energy ban

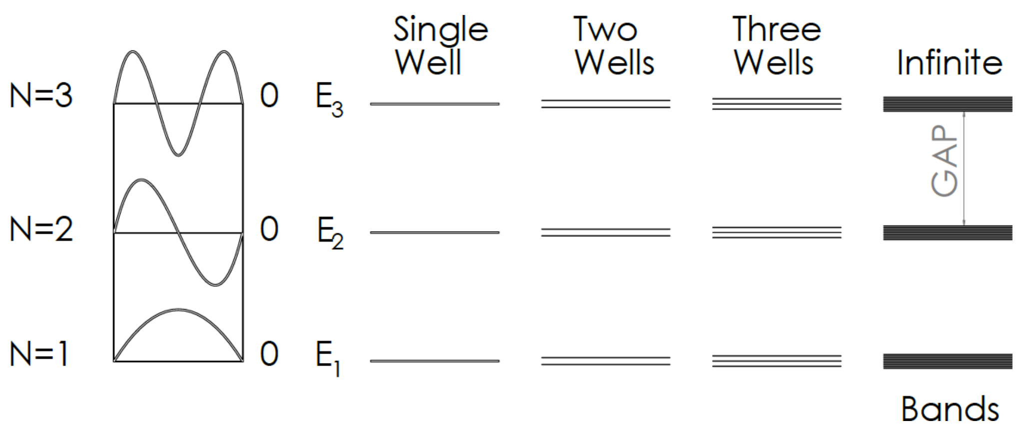

Figure 2: Overlapping and linear combination of atomic orbitals of the individual atoms, leading to the formation of energy bands.

The individual energy levels that make up a given energy band have almost identical energies. We also can see that, there are differences of energy in different bands. This energy difference in bands is called energy band gap.

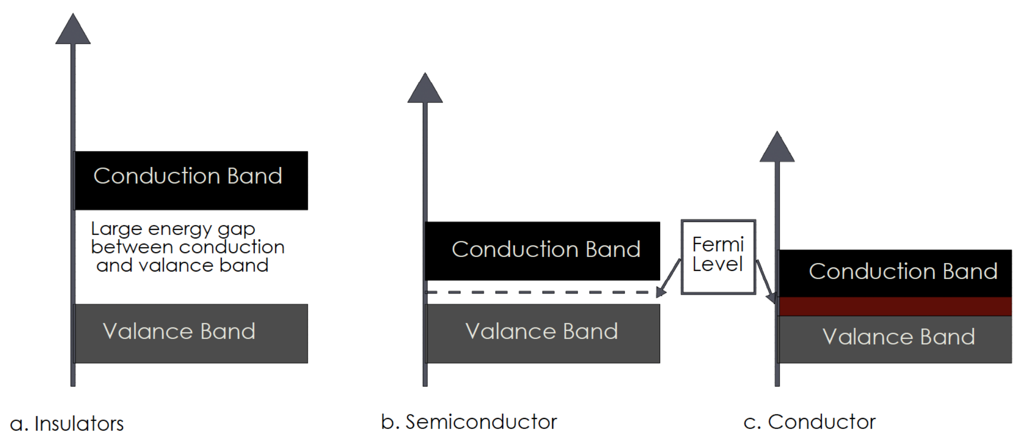

Figure 3: Energy band structure of insulators, semiconductors and conductors. The diagram also shows the energy band gap in these materials.

Another important aspect that determines the conductivity of a given sample is the **Fermi level.** The fermi level is obtained as a consequence of Fermi-Dirac statistics as electronsare fermions. Fermi level (E_F) is the maximum energy level that the electrons can occupy at T= 0° K.

4.1 Fermi function

The probability of occupancy of a given electronic energy state at a given temperature is given by the Fermi function.

$$f(E) = \frac{1}{e^{\frac{(E-E_F)}{KT}}+1} \qquad (1)$$

Where, *f(E):* the fermi function, *E*: energy level under consideration, E_F *: fermi level, K:* Boltzmann constant, and *T:* absolute temperature.

In semiconductors, there is a larger band gap between the fermi level and the conduction band at zero K. See figure 4. Therefore, the semiconductors behave like insulators at zero K. As, the population of electrons in the conduction band is zero.

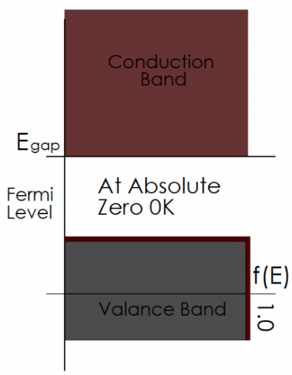

Figure 4: electron population in a semiconductor at 0K

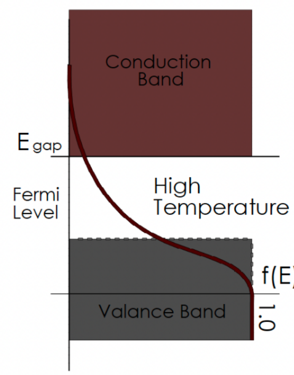

Figure 5: electron population at high temperature in a semiconductor.

At higher temperatures, some of the electrons in the upper levels of the valence band make transitions to the conduction band and are thus able to contribute to the current. See figure 5.

4.2 Energy bands in a semiconductor

The fermi level in intrinsic semiconductors like Si and Ge is halfway between the conduction band and valence band. At T= 0 K, there are no electron in the condition band and hence no current. As T increases the population of electron in the conduction band increases and is given by the Fermi function.

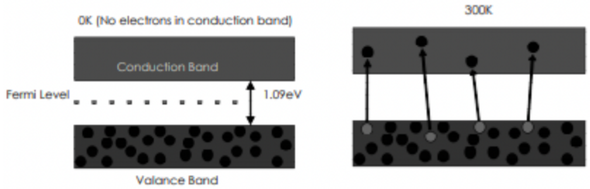

Figure 6: Band gap in Si.

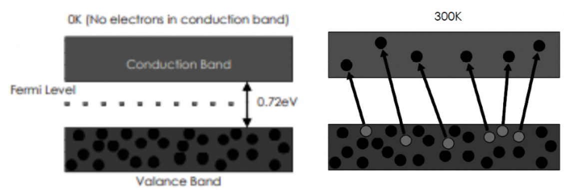

Figure 7: Band gap in Ge.

Figure 6 & 7, show the energy band gap in Si & Ge respectively, Ge has a smaller energy band gap compared to Si. Due to this, at a given temperature say (300 K), there are larger number of electrons in an intrinsic Ge when compared to an intrinsic Si. Resulting in greater conductivity of Ge.

4.3 Effect of doping on the energy band gap of a semiconductor.

The effect of doping alters the energy band gap in a semiconductor. In n-type material there are electron energy levels near the top of the band gap so that they can be easily excited into the conduction band. In p-type materials, extra holes in the band gap allow excitation of valence band electrons, leaving mobile holes in the valence band.

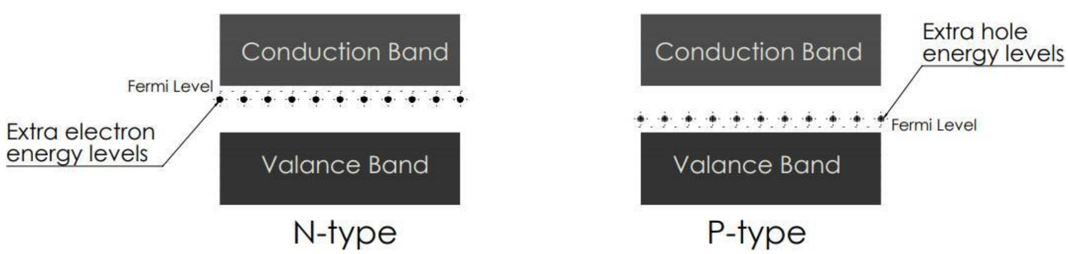

Figure 8: Effect of doping on the carrier energy levels

4.4Temperature dependence of energy band gap

In semiconductor materials, the energy bad gap decreases as temperature increases. As the temperature increases, the amplitude of the thermal vibrations of the atoms in the crystals increases. Due to this, the potential experienced by the electrons in the material reduces. Which in turn, reduces the size of the energy band gap.

The temperature dependence of the energy band gap (E_g) is given by the following equation.

$$E_g(T) = E_g(0) - \frac{\alpha T^2}{T + \beta} \qquad (2)$$

Here, $E_g(T)$ and $E_g(0)$ are the energy bang gap at a temperature T K and 0 K respectively, α and β are the fitting parameters to the curve of the E_g *vs* T graph.

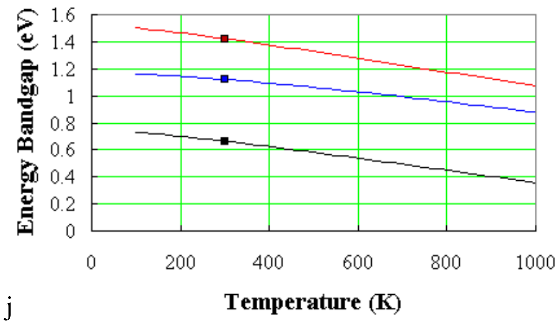

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Figure 9: Energy band gap vs temperature for (germanium, Silicon and GaAS) respectively from the bottom.

5. Equipment

Equipment	Specification	Quantity
DC power supply	0-12 V, 5 A	1
Digital Multimeter		1
Various Semiconductor diodes	LED (green,blue),Si & Ge diode	4
Energy band gap setup that contains the following (digital thermometer, oil bath with heater, connecting wires)		1
Mineral oil	Silicone oil	50 ml
Syringe	50 ml	1

6. Safety Instruction

- Components like power supply are heavy. Take adequate safety measures while handling them.
- The heater assembly will be hot. Use thermal protection gloves when handling it

7. Experimental Setup

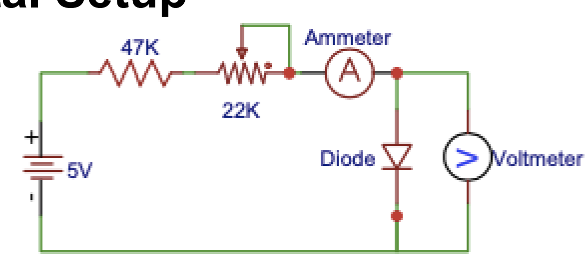

Figure 10: Circuit diagram of the experiment.

The circuit diagram shown above, depicts the internal electrical connections the are present in the energy band gap setup.

The energy band gap setup contains the following

1. Oil bath with heating facility
2. Digital temperature probe along with a digital display
3. Four different semiconductor diodes (Si diode (IN 4007), Ge diode, green LED and blue led). There is a rotary switch that can be used to select the diode that we want for the experiment.
4. A current knob (a variable resistor) that is present below the ammeter connecting ports, that can be used to set an appropriate current through the selected diode during the experiment.
5. Connecting ports to establish electrical connections.
6. Connecting wires, digital multimeter.

8. Experiment

1. First, using the syringe, fill about 15 ml of mineral oil and transfer it into the oil bath.
2. Connect the input ports of the energy band gap set up to the DC power supply. (+ ve terminal to + terminal and -ve terminal to -ve terminal)
3. Connect the multimeter (the multimeter should be in ammeter mode) to the ammeter ports of the energy band gap set up.
4. Using the rotary switch, select the Si diode (IN 4007)
5. Turn on the DC power supply and set the voltage to 5 V and, using the current knob in the energy band setup adjust the current value (indicated in the multimeter) to 90 mA
6. Short the ammeter ports and now connect the multimeter (in DC voltmeter mode) to the voltage ports present on the energy band gap set up.
7. Insert the chosen diode into the heater and switch on the heater. Once the heater is ON, the value of the temperature indicated in the digital increases.
8. Record the value of voltage developed across the chosen diode at intervals of 5^{o} C increase in temperature (room temperature to 120^{o} C).
9. Convert the temperature to ^{o} K
10. Draw a graph of voltage vs temperature in K.
11. The Y axis intercept corresponds to the value of the energy band gap. (The energy gap can be expressed in terms of electron volts if the obtained value is multiplied by the charge of the electron.)
12. The Y axis intercept is considered to yield the value of the energy band gap of the diode because of the constant variation of the E_g vs the temperature curve.
13. Repeat the steps 4 to 12 for other diodes as well. (see appendix for the current value through the green LED)

9. Reference

1. Charles Kittle “Introduction to solid state physics” seventh edition.
2. David W Snoke “Solid state physics Essential concepts”.
3. S. M.Sze “Physics of semiconductor devices”.
4. Experimental setup video (link)

10. Appendix

1. Diode type: IN4007, and the current through the diode: $90\mu A$.
2. Diode type: Green LED, and the current through the diode: $70\mu A$.

11. Sample measurements

Sample reading for Si diode (IN 4007)

Temperature (K)	Voltage (V)
383	0.27
373	0.29
363	0.32
353	0.34
343	0.37
333	0.39

Sample reading for Green led

Temperature (K)	Voltage (V)
393	1.53
383	1.55
373	1.58
363	1.60
353	1.63
343	1.65
333	1.68

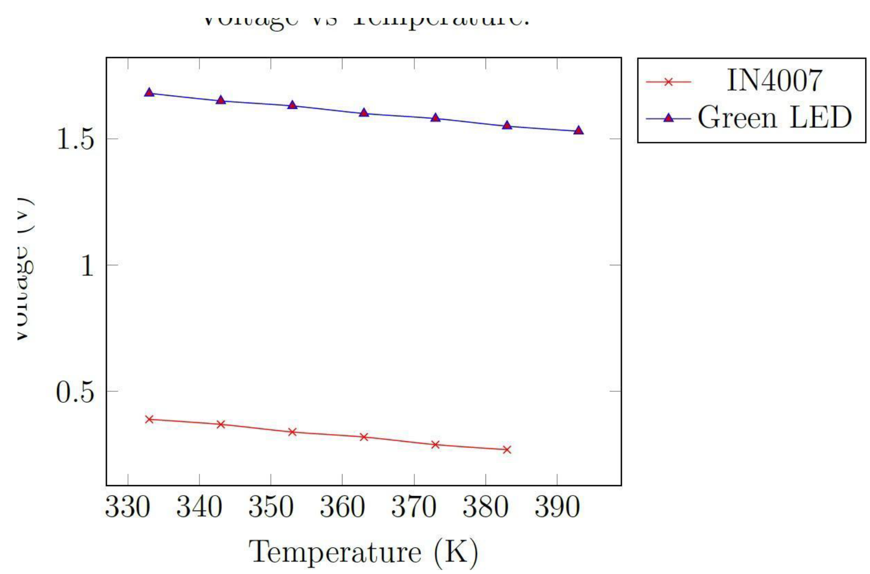

Figure 12 : Graphs for Si diode (red colour trace) and Green led (blue colour trace)