Project Report -

SEMICONDUCTORS

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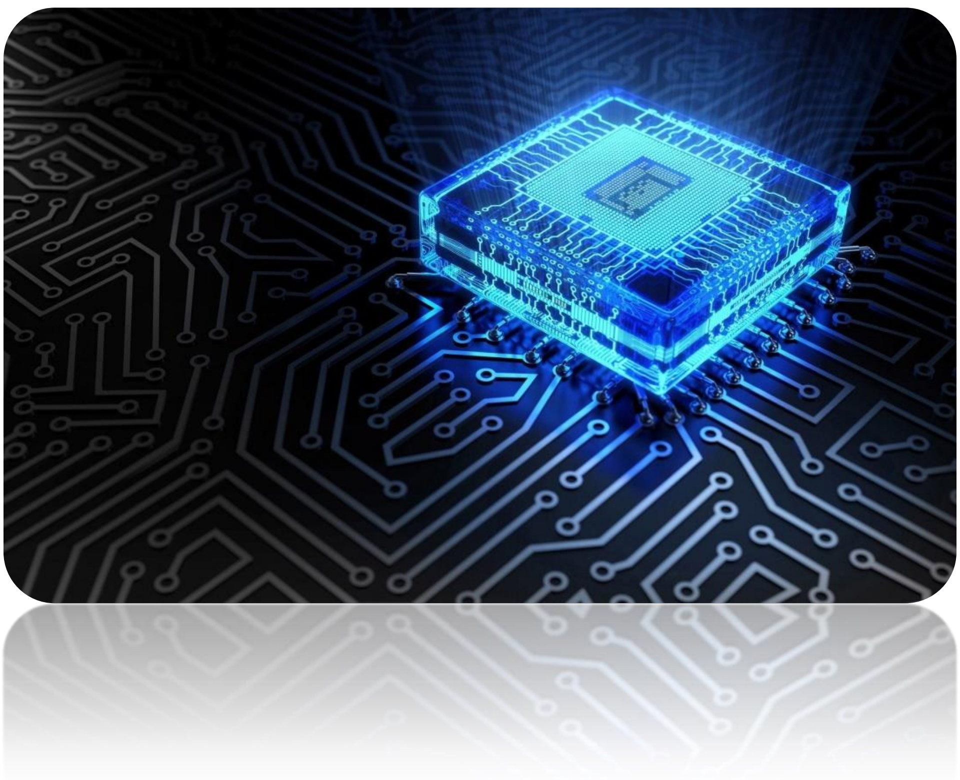

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DEPARTMENT OF APPLIED PHYSICS,
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CONTENT:

ABSTRACT:

In physics, a semiconductor is a material that has a resistivity value in between that of a conductor and an insulator.
The conductivity of a semiconductor material can be varied under an external electric field. Devices made from semiconductor materials are the foundation of modern electronics, including ratio, computers, telephones, and may other devices. Semiconductor devices include the transistor, many kinds of diodes including the light emitting diode, the silicon controlled rectifier, and digital and analogue integrated circuits.
Solar photovoltaic panels are large semiconductor devices that directly convert light energy into electrical energy.

CLASSICAL FREE ELECTRON THEORY:

Metal atoms have one or more loosely bound valence electrons. Such electrons get detached easily even with small thermal energy. The detached electrons are neither shared nor acquired by any of the atoms of the metal. Hence they are free. The electrostatic interaction of detached electrons with the positive ion cores and with other electrons is assumed to be negligible.

A consequence of this assumption is that the detached electrons can move freely everywhere within the confinements of the metal piece. Hence these electrons are called as free electrons or conduction electrons. When an electric field is applied, free electrons will experience slow drift motion in the positive direction of the field and produce a current in the metal.

Successes of Classical Free Electron Theory:

1. It proved the validity of ohms law

2. It could give a satisfactory explanation to the mechanism of electrical current in conductors and thermal conductivity of metals

Successes of Classical Free Electron Theory:

1. Temperature dependence of resistivity of metals could not be established correctly.

2. It could not predict correct values to the mean free path of electrons.

QUANTUM FREE ELECTRON THEORY:

Somerfield developed this theory during 1928. He considered Drude's assumption on the free electrons as it is. In addition to that, the applied Pauli's exclusion principle to the electron gas and applied FermiDirac statistics in place of Maxwell-Boltzmann statistics. The results of these modifications indicated
that no all free electrons would contribute to the processes like electrical and thermal conductivities of metals. Rather only a small fraction of the free electron gas of the metal would participate in such properties.

CLASSIFICATION OF MATERIALS ON THE BASIS OF BAND THEORY:

Insulators:

1. Forbidden gap is very wide. Electron cannot jump from VB to CB.

2. They have completely filled VB and completely empty CB.

3. Resistivity of Insulators is very high.

4. Insulators are bad conductors of electricity

Semiconductors:

1. Band gap is very small (0.7eV for Ge and 1.1eV for Si).

2. At 0K, there are no electrons in the CB and VB is completely filled.

3. As temperature increases, electrons from VB jumps to CB.

4. Resistivity varies from 10^{-14} to 10^{7} ohm meter.

5. Electrical properties between those of insulators and conductors.

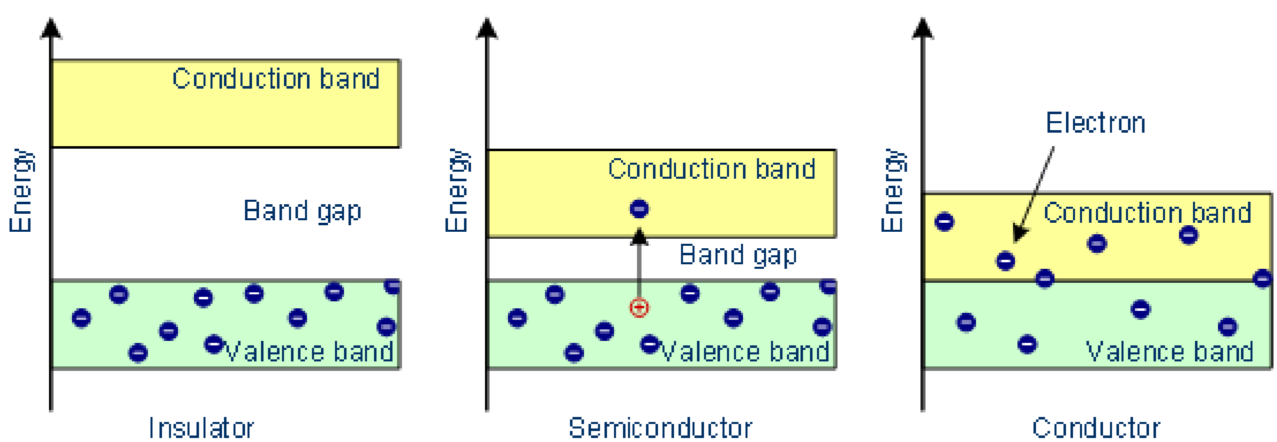
Conductors:

1. There is no forbidden gap and the VB and CB overlaps each other.

2. Plenty of free electrons are available for electrical conduction.

3. Possess very low resistivity and very high conductivity values.

4. Metals are best examples of conductors.

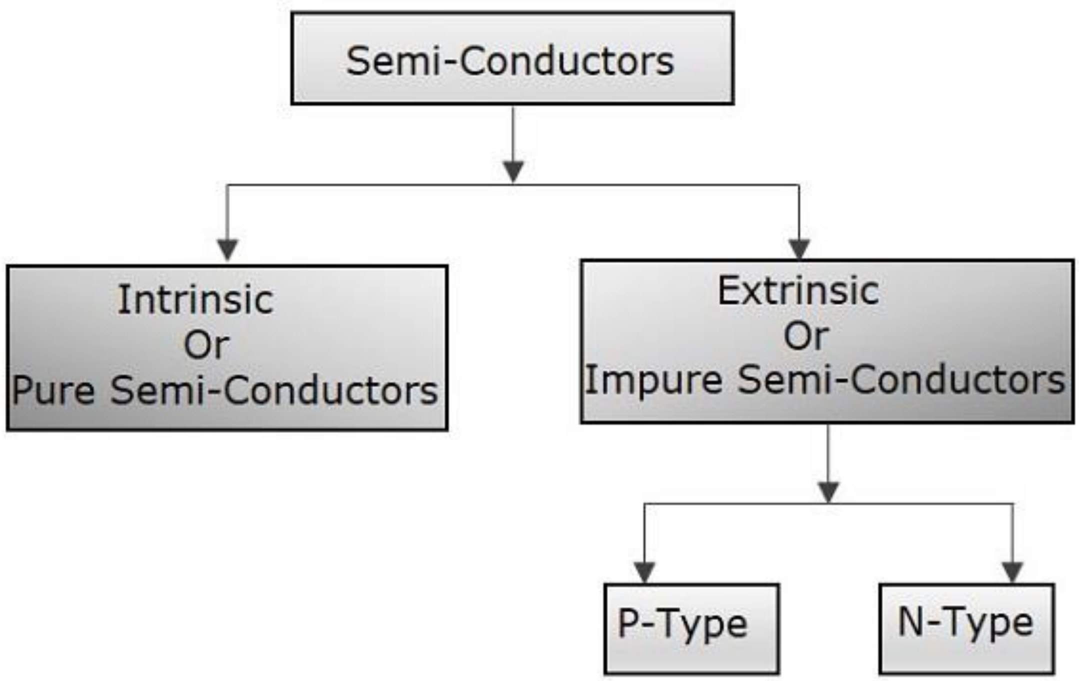


INTRODUCTION TO SEMICONDUCTORS:

A semiconductor is a material that has a resistivity value in between that of a conductor and an insulator. The conductivity of a semiconductor material can be varied under an external electric field.

Devices made from semiconductor materials are the foundation of modern electronics, including ratio, computers, telephones, and may other devices. Semiconductor devices include the transistor, many kinds of diodes including the light emitting diode, the silicon controlled rectifier, and digital and analogue integrated circuits. Solar photovoltaic panels are large semiconductor devices that directly convert light energy into electrical energy.

In a metallic conductor, current is carried by the flow of electrons. In semiconductors, current can be carried either by the flow of electrons or by the flow of positively charged holes in the electron structure of the material. Silicon is used to create most semiconductors commercially. So many other materials are used, including germanium, gallium arsenide. A pure semiconductor is often called an intrinsic material and then allowing the melt to solidify into a new and different crystal. This process is called **doping**.



INTRINSIC SEMICONDUCTORS:

A pure semiconductor is called intrinsic semiconductor. A pure crystal of Germanium and Silicon is an example for intrinsic semiconductor. At T=0K, the semiconductor acts as insulator.

Germanium and silicon are tetravalent atoms (i.e. four valence electrons) and both have diamond crystal structure. In order to gain stability each germanium atom makes four covalent bonds with the four surrounding germanium atoms by sharing of their valence electrons.

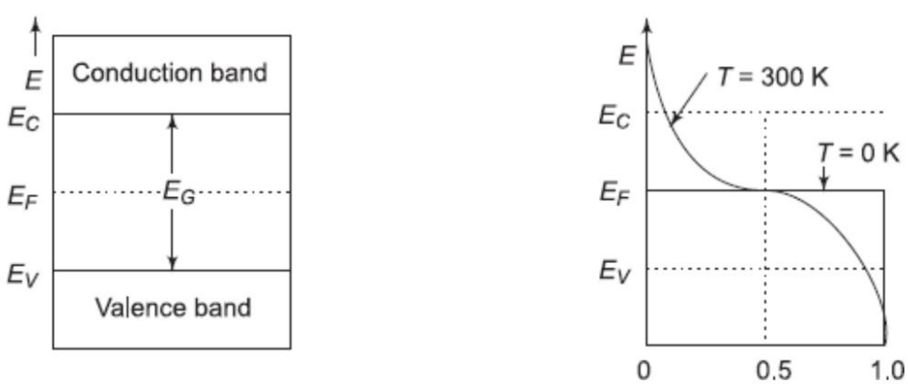
At 0K, the semiconductor crystal acts as a perfect insulator since the covalent bonds are strong and no free electrons are available.

At room temperature (T>0K) the semiconductor gives some conductivity since some of the covalent bonds are broken due to the thermal energy supplied to the crystals. The vacancy of an electron in the covalent is called **hole**. Thus the valence band has holes and conduction band has electrons.

For **silicon energy gap is 1.12eV** and for **germanium energy gap is 0.78eV**. In intrinsic semiconductor the electron concentration is equal to the hole concentration. In intrinsic semiconductors Fermi level is always lies between valence band and conduction band.

$$E_f = \frac{E_G}{2} + \frac{3KT}{4} log\left(\frac{m_h}{m_e}\right)$$

$$n_e = n_h = 2\left(\frac{2\Pi KT}{h^2}\right)^{\frac{3}{2}} (m_e m_h)^{\frac{3}{4}} e^{\frac{-E_G}{2KT}}$$



(a) Fermi level E_F at T = 0K (b) Upward shift of E_F near E_C at T> 0k

EXTRINSIC SEMICONDUCTORS:

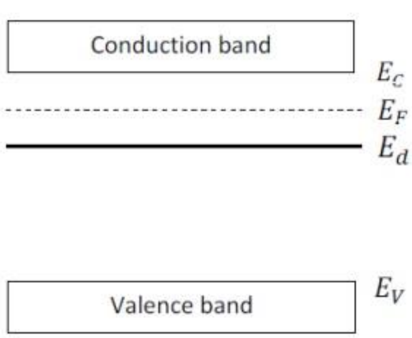
The extrinsic semiconductors are those in which impurities of large quantity are present. In general, the impurities can be either III group elements or V group elements. Based on the impurities present in the extrinsic semiconductors, they are classifies into two categories.

1. n-type semiconductors

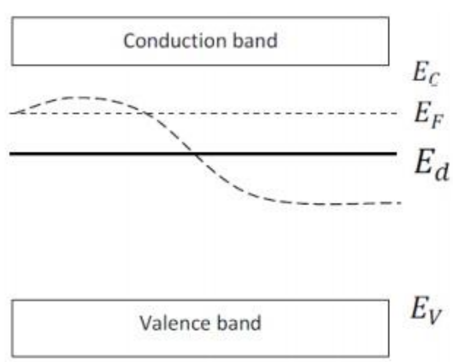
2. p-type semiconductors

n-type semiconductors:

In order for silicon crystal to conduct electricity, we need to introduce an impurity atom such as Arsenic, Antimony or phosphorus into the crystalline structure. These atoms have five outer electrons in their outermost covalent bond to share with other atoms and are commonly called **pentavalent impurities**. This allows four of the five electrons to bond with its neighbouring silicon atoms leaving one free electron to move about when electrical voltage is applied. As each impurity atom donates one electron, pentavalent atoms are generally known as **donors**. Antimoney (Sb) is frequently used as pentavalent additive as it has 51 electrons arranged in 5 shells around the nucleus.
The resulting semiconductor material has an excess of current carrying electrons, each with a negative charge, and is therefore referred to as n-type material with the **electrons** called **majority carriers** and the resultant holes minority carriers. Electron concentration in conduction band increases.



Fermi level position in n -Type Extrinsic Semiconductor



Variation of Fermi level with temperature in n -Type Semiconductor

p-type semiconductors:

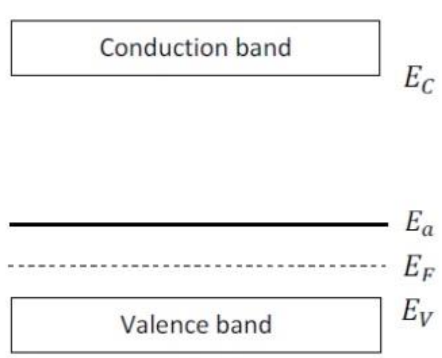
In contrast to n-type of semiconductor, if we introduce a **trivalent** (3 electron) **impurity** into the crystal structure, such as aluminium, Boron or indium , only three valence electrons are available in the outermost covalent bond meaning that the fourth bond cannot be formed. Therefore, a complete connection is not possible, giving the semiconductor material an abundance of positively charged carriers known as holes in the structure of the crystal. As there is a hole an adjoining free electron is attracted to it and will try move into the hole to fill it. However, the electron filling the hole leaves another hole behind, and is forth giving the appearance that the holes are moving as a positive charge through the crystal structure (conventional current flow).

As each impurity atom generates a hole, trivalent impurities are generally known as **acceptors** as they are continually accepting extra electrons.

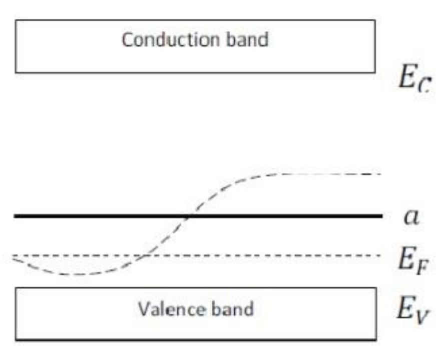
Boron (B) is frequently used as trivalent additive as it has only 5 electrons arranged in 3 shells around the nucleus. Addition Boron causes conduction to consists mainly of positive charge carriers results in a p-type material and the positive **holes** are called **majority carriers** while the free electrons are called minority carriers.

In p-type semiconductor, the Fermi level is always lies between valence level and acceptor level at lower temperatures but at higher temperatures the Fermi level moves towards the intrinsic Fermi level.

Number density of holes increases in valence band.



Fermi level position in p - Type Extrinsic Semiconductor



Variation of Fermi level with temperature in p -Type Semiconductor

Law of Mass Action:

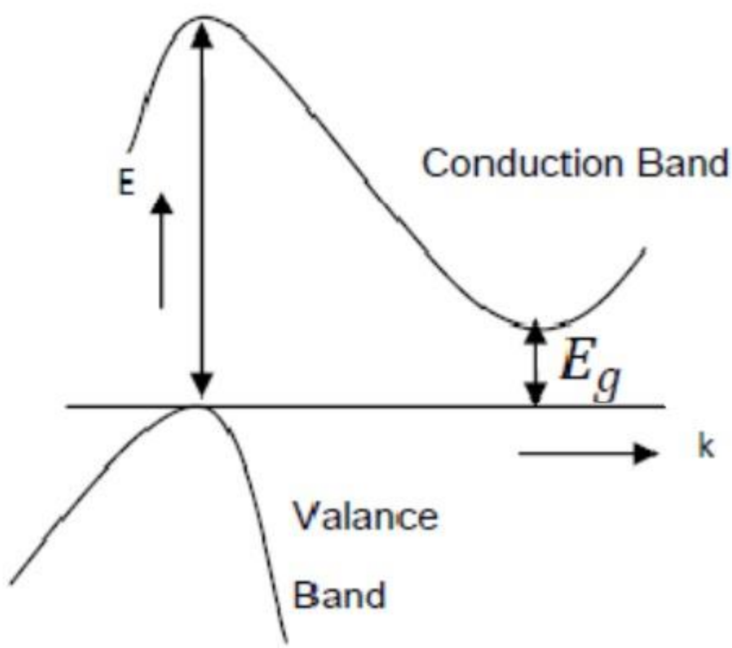
According to law of mass action "the product of majority and minority charge carrier concentration at a particular temperature is equal to the square of intrinsic carrier concentration at that particular temperature."

$$n_e n_h = n_i^2$$

Indirect Band Gap Semiconductor:

In indirect band gap semiconductors, the maximum of the valance band and minimum of the conduction band present at the different values of wave vector, k. In Indirect band gap semiconductors, when an **electron recombines** with the hole, emits their energy in terms of **heat**. So indirect band gap semiconductors are not used in the preparation of semiconductor laser. **Life time** (recombination time) of charge carriers is more. **Elemental semiconductors** like germanium and silicon are examples for in-direct gap semiconductors.

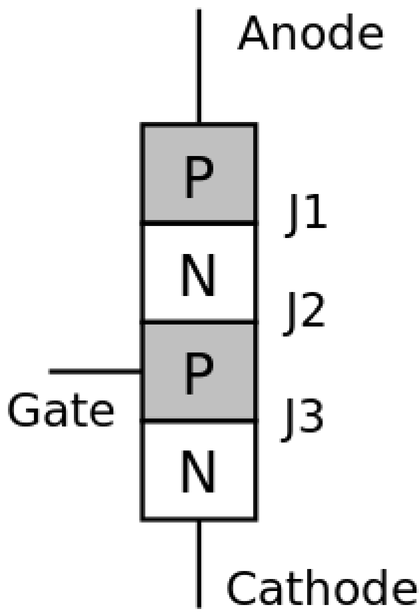
Band gap of Ge=0.7eV and Si =1.12eV. Indirect band gap semiconductor is **used to fabricate diodes and transistors**.



Indirect band gap semiconductor

SILICON CONTROLLED RECTIFIER:

A silicon controlled rectifier or semiconductor controlled rectifier is a four-layer solid-state current-controlling device. The name "silicon controlled rectifier" is General Electric's trade name for a type of thyristor. The principle of four layer p–n–p–n switching was developed by Moll, Tanenbaum, Goldey and Holonyak of Bell Laboratories in 1956.



HEATING & COOLING IN SEMICONDUCTOR DEVICES:

Understanding of heating and cooling in semiconductor devices helps us to understand

1. Thermal Induced failure in semiconductor devices.

2. Energy conversion in Thermoelectric/ Thermionic devices.

High Temperature leads to,

1. Increased threshold current.

2. Decreased output power.

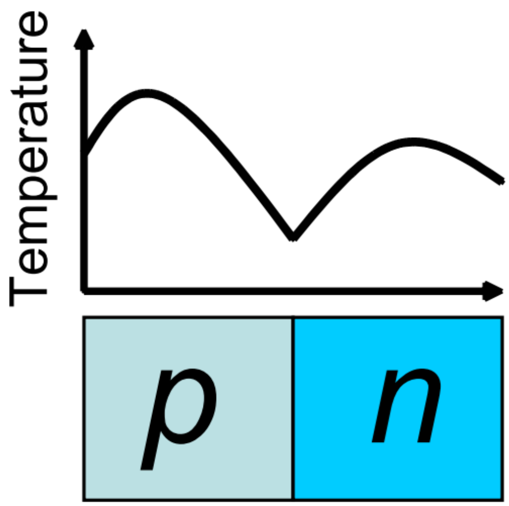
3. Decreased device lifetime.

INTERNAL COOLING EFFECTS:

When an external electric field or external current is applied to a p-n junction, then an internal electric field is set up in the p-n junction.

The internal electric field will be in the reverse direction of the applied electric field. The internal electric field will reduce the velocity of the moving charge carrier reducing the temperature associated with the charge carrier.

That is simply the external field will increase the temperature and internal induced electric field will reduce the temperature.



In Steady state,

Total energy per unit time per meter cube is given as,

$$\dot{q} = Recombination\ Energy + Resistive\ Energy$$

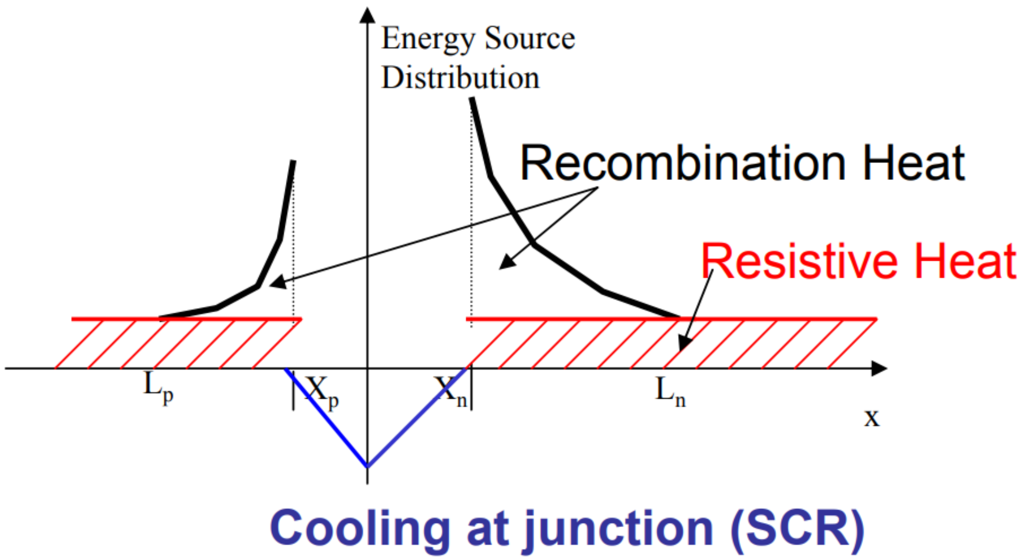
$$\dot{q} = -(E_g + 3k_BT)\nabla\vec{J_e} + \frac{\nabla E_V}{e}J$$

In Silicon Controlled Rectifier,

$\dot{q} = \vec{E}.\vec{J}$

Total cooling at the junction of SCR is given as,

$$Q = \int_{-x_p}^{x_n} \dot{q}\,dx = \frac{1}{2}E_{max}J_{max}$$

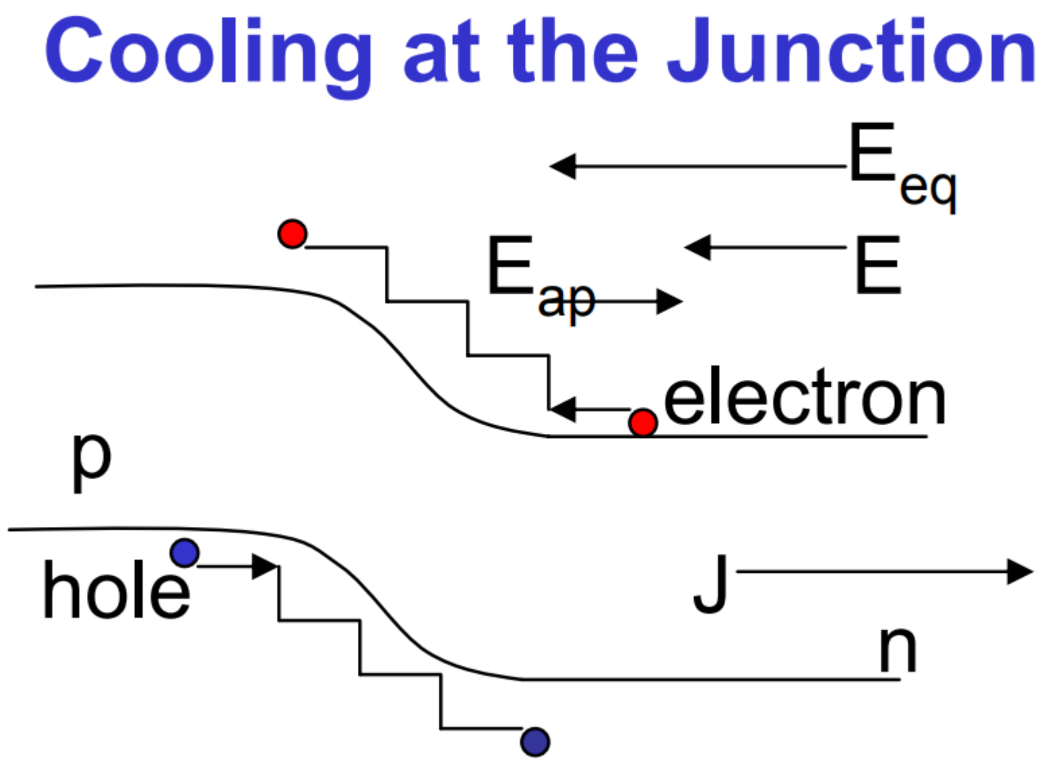


Dependency of cooling and heating effect under forward and reverse bias:

Forward Bias:
In forward bias external electric field will be in direction of p-n junction.
In forward bias, current is due to majority charge carriers and potential barrier is very small with low resistance.
So, to overcome potential barrier less amount of energy is needed. (Cooling)
In simple words, low resistive heat is required i.e. cooling (comparatively).

Reverse Bias:
In reverse bias external electric field will be in direction of n-p junction.
In reverse bias, current is due to minority charge carriers and potential barrier is very large with very high resistance.
So, to overcome potential barrier great amount of energy is needed. (Heating)
In simple words, high resistive heat is required i.e. heating (comparatively).

Cooling under forward bias
Heating under reverse bias



CONCLUSIONS:

- Studied about Classical Free Electron Theory, Quantum Free Electron Theory and Band Theory of material.
- Studied about the properties Conductors, Insulators and Semiconductors.
- Deeply discuss about different types of semiconductors (p-type and n-type semiconductors) and Indirect Band Gap Semiconductors.
- In n-type semiconductor, electron concentration in conduction band increases.
- In p-type semiconductor, number density of holes increases in valence band.
- Temperature decreases near the junction of p-n junction.
- Cooling effect occur at forward bias.
- Heating effect occur at reverse bias.

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