* Metal Semiconductor Junctions

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06/10/2014
(10-15 Marks)
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Topics:

- Schottky barrier diode: Qualitative characteristics, Ideal junction properties, non-ideal effects on barrier height and I-V characteristics
- Metal Semiconductor ohmic contacts: Ideal non-rectifying barrier, Tunneling barrier, specific contact resistance.

Introduction

- P-N junctions are called "homojunctions" because the p and n regions of the junction are formed in the same semiconductor material.
- Apart of pn junctions, there are two interesting junctions.

a) Heterojunctions: The two sides of the pn junction may be formed in different materials

b) Metal-semiconductor junction: One of the sides of a junction may be a metal and other side of a junction can be a semiconductor made.

- These devices are important and need to be understood well to fully exploit their potential.

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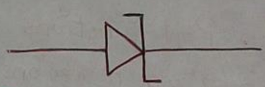
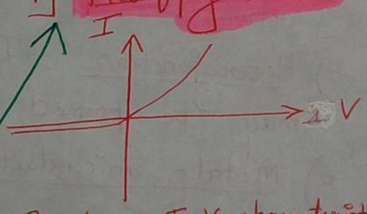
- Metal-semiconductor junctions can be either rectifying or ohmic in nature.
- In order to understand whether a metal-semiconductor contact is rectifying or non-rectifying (Ohmic), we have to investigate → the mechanism of barrier formation at the Metal-semiconductor interface.
- Ohmic contacts play a vital role in deciding the characteristics of semiconductor devices.
- The rectifying metal-semiconductor junctions are called "Schottky barrier Diode." ⇒



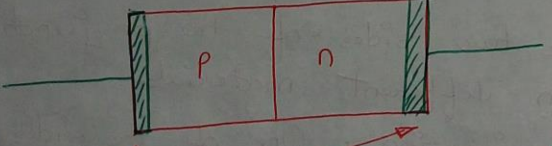
Symbol

[Majority Carrier device]

1] Rectifying Contact

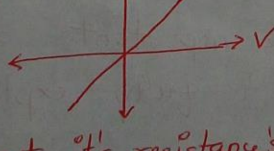


- They have I-V characteristics as pn junction.



Metal-semiconductor contacts

2] Ohmic Contacts



In a good ohmic contact, it's resistance's should be v. small ie large current should flow in both forward and reverse directions with very small voltage drop

* Important Terms in Metal-Semiconductor junction

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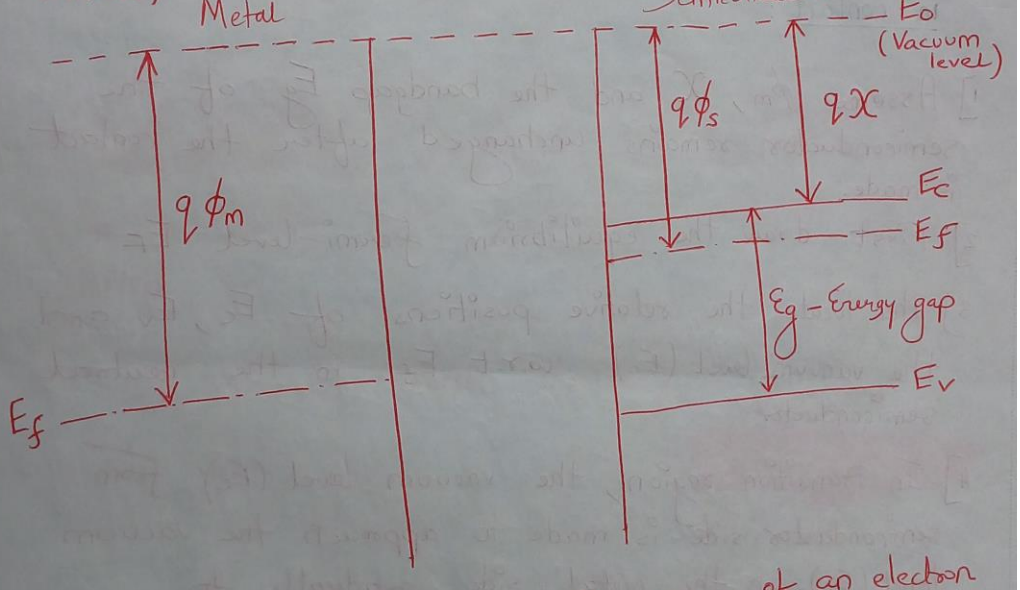
· Lets look at the energy band diagram of a metal - ntype semiconductor contact with $\phi_m > \phi_s$ when two materials isolated from each other (Before contact)



· **Vacuum level**: It represents the energy of an electron at rest outside the material. Vacuum level is taken as reference level with which all other energy level's are measured.

· **Work function** of a material is the energy required to bring an electron from fermi-level to vacuum level.

ϕ_m - Metal work function ; ϕ_s - Semiconductor work function

• **Electron affinity** (χ) of the semiconductor is the energy difference between conduction band (E_c) and vacuum level (E_0). 04 [R]

✱ Steps to draw the EBD of any two materials in contact:

1] Assume ϕ_m, χ and the bandgap E_g of the semiconductor remains unchanged after the contact is made.

2] First draw the equilibrium fermi-level E_F

3] Then locate the relative positions of E_c, E_v and the vacuum level (E_0) w.r.t E_f in the neutral semiconductor.

4] In transition region, the vacuum level (E_0) from semiconductor side is made to approach the vacuum level (E_0) on the metal side gradually to preserve its continuity.

5] The band edges E_c and E_V follow the same variations as the vacuum level (E_0), because $q\chi$ remains unchanged.

The Schottky barrier diode – Metal Semiconductor contact/junction : (Rectifying contact)

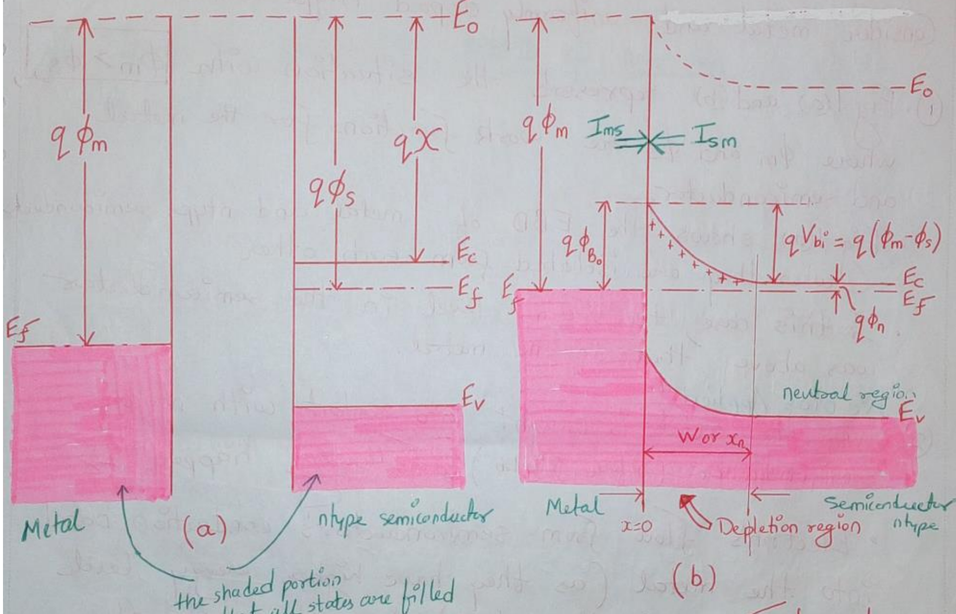


fig 1 : EBD of a metal-ntype semiconductor for $\phi_m > \phi_s$

a) Before contact (Two materials are isolated from each other)

b) Thermal equilibrium situation after the contact is made

* Formation of Schottky Barrier :

- Qualitative Analysis :

Consider metal and uniformly doped ntype semiconductors

1. Fig 1(a) and (b) represents the situation with $\phi_m > \phi_s$, where ϕ_m and ϕ_s are work functions for the metal and semiconductor.
   - Fig 1(a) shows the EBD of metal and ntype semiconductor when they are isolated from each other
   - In this case, the Fermi level in the semiconductor was above that in the metal.

"No bias Applied"

2. When the metal is brought into contact with ntype semiconductor (refer fig 1.b), following happens ⇒
   - Electron's flow from semiconductor's conduction band into the metal (as they have higher energy levels than electron's in the metal), by the process of "thermionic emission."
   - This process continues till Fermi levels in metal and ntype semiconductor are aligned.
   - This results in upward bending of energy bands in the semiconductor (fig 1.b)

- Electrons that flow into the metal leave behind a positively charged ionized donor's, creating a depletion layer of thickness 'W' in the semiconductor. 07

- It is evident from fig 1.b that the band-bending in the semiconductor is equal to the difference' metal and semiconductor work function.

- On the semiconductor side, V_{bi} is build-in potential barrier. ie $V_{bi} = \phi_m - \phi_s$

  V_{bi} → Potential barrier ($\phi_m - \phi_s$) the electrons in the C.B of ntype Semiconductor face in trying to reach the metal side.

- Also, $V_{bi} = \phi_{B0} - \phi_n$

- Parameter "ϕ_{B0}" is the ideal barrier height (viewed from Metal towards semiconductor)

- ϕ_{B0} – Potential barrier seen by electrons in the metal trying to move into the semiconductor.

  → It is also known as "Schottky Barrier."

$$\phi_{B0} = \phi_m - \chi$$

where χ is electron affinity in the semiconductor

- In thermal equilibrium case (refer fig 1.b)
  At a temperature T ⇒
  a) A small fraction of CB e^-s will have sufficient energy to cross the barrier.
  b) These e^-s flow into the metal and cause a current I_{ms}, which flows from Metal to semiconductor.
  c) This current is exactly balanced by an equal and opposite current I_{sm} caused by the electron flow from the metal into semiconductor

(3) Forward Bias (Semiconductor -ve w.r.t Metal):

- When the semiconductor is biased negative w.r.t the metal by a voltage V_a, the barrier for electrons in the ntype Semiconductor decreases from qV_{bi} to $q(V_{bi} - V_F)$.

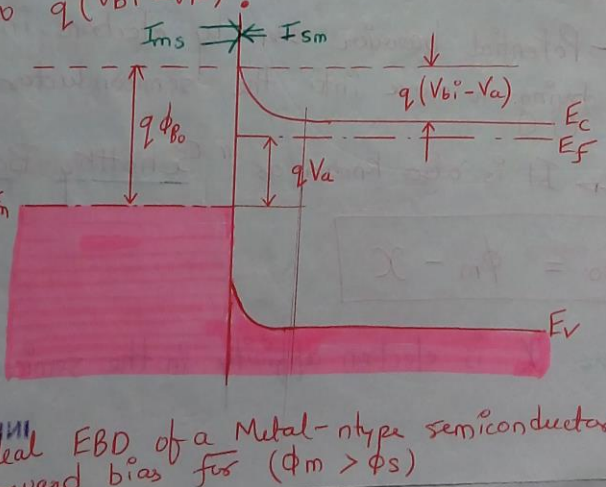
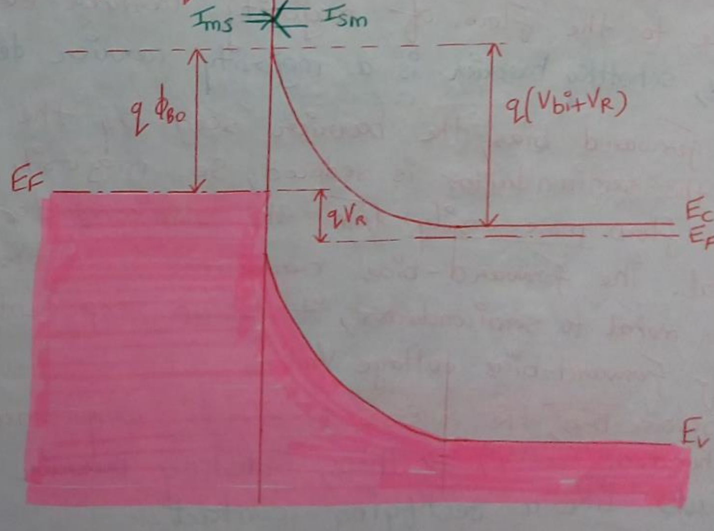


fig (1.c): Ideal EBD of a Metal-ntype semiconductor under forward bias for ($\phi_m > \phi_s$)

- That is, more electrons can now flow from the n-type semiconductor to the metal and I_{ms} ↑ses above its equilibrium value.
- In this case, the barrier $\boxed{\phi_{B0} = \phi_m - \chi}$ remains relatively unaffected by the applied voltage. Thus, I_{sm} remains unchanged from equilibrium case because there is no voltage drop across the metal and $q\phi_{B0}$ remains almost unaltered.
- Therefore, there is a net current flow from metal to semiconductor.

④ **Reverse bias (Semiconductor is +ve w.r.t Metal):**

- When semiconductor is biased positive w.r.t metal by a voltage V_R, the semiconductor-to metal barrier height ↑ses from qV_{bi} to $q(V_{bi}+V_R)$.



fig(1.d) EBD of a metal-ntype semiconductor under reverse bias for the case $\phi_m > \phi_s$

- Thus, e⁻s in the semiconductor see a larger barrier to cross and reach to metal. ie I_{ms} reduces below the equilibrium value, while the barrier height ϕ_{B0} remains constant ie I_{sm} is constant (almost unaffected. Thus
- Thus, a small reverse current flows.

Justify why a metal-ntype semiconductor is a rectifying contact (Schottky barrier diode) : for ($\phi_m > \phi_s$)

- The EBDs versus bias voltage for the metal-semiconductor junction shown in fig(1.c) and (1.d) are similar to those of pn junction.
- Because of the similarity, we expect the I-V characteristics of Schottky barrier junction to be similar to the <u>exponential behavior</u> of pn junction.
- The current mechanism in such case, however, is due to the flow of majority carrier electrons. (Hence, schottky barrier is a majority carrier device)
- In forward bias, the barrier seen by the electrons in the semiconductor is reduced, so majority carrier e⁻s flow <u>more easily</u> from the semiconductor into the metal. The forward-bias current is in the direction from metal to semiconductor, it is an exponential function of forward-bias voltage Va.
- In reverse bias, the reverse current is very small & saturates. (ideally) ⇒ Thus, Schottky barrier junction acts like a rectifying contact.