Lecture Notes

for

Ohmic & Schottky Contacts

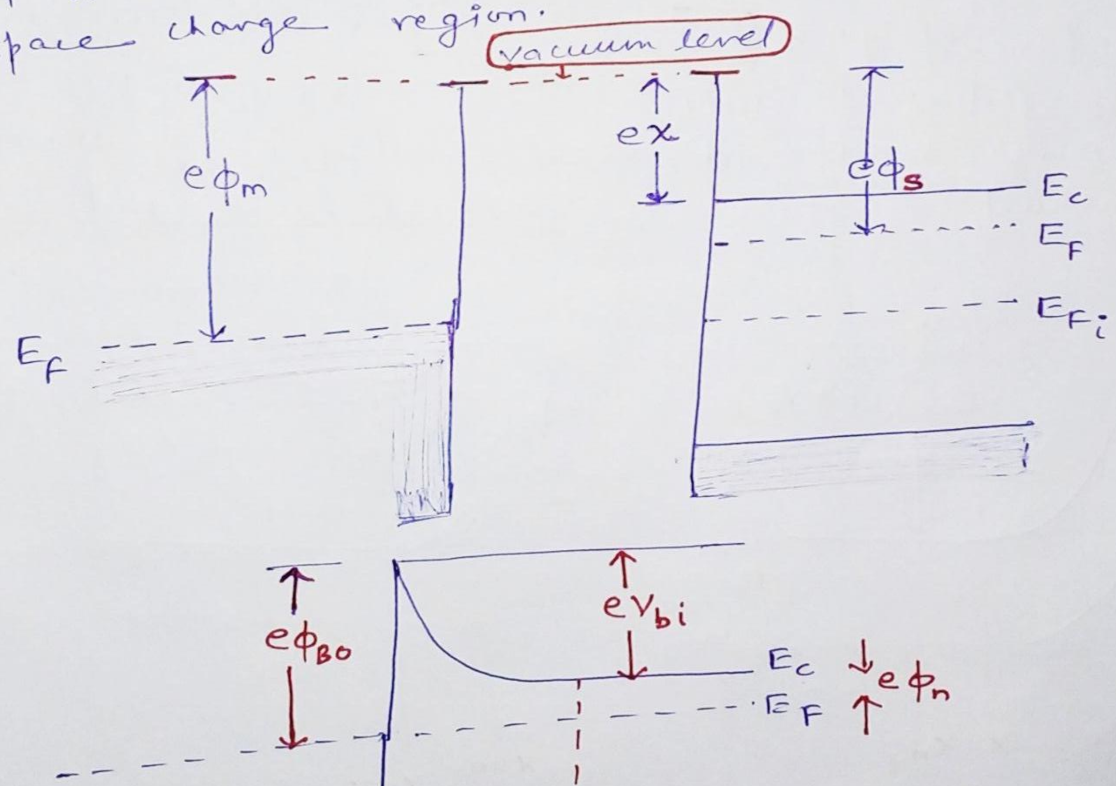
(PHYS4008: Electronics)

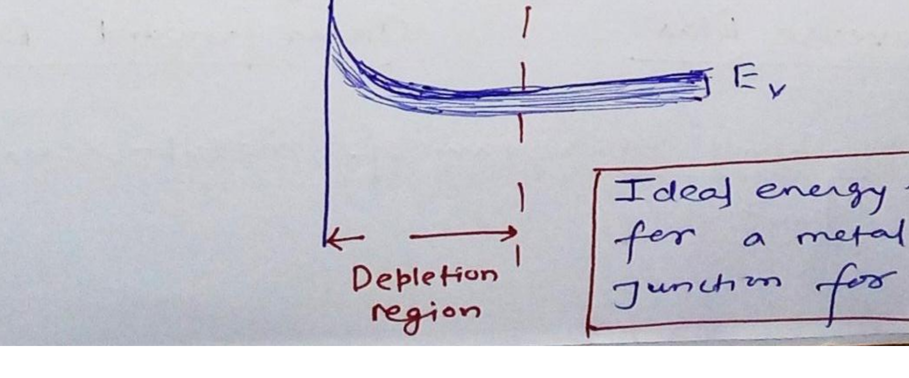
Dr. Pawan Kumar
(Assistant Professor)
Department of Physics
Mahatma Gandhi Central University
Motihari-845401, Bihar

Metal- Semiconductor Junctions

- Ohmic
- Schottky

The ideal energy band diagram for a particular **metal** and **n-type semiconductor** before making contact is shown below. The vacuum level is used as reference level. Here, we will assume $\phi_m > \phi_s$. Before contact, the fermi level in the semiconductor was above that in metal. In order for fermi level to become a constant through the system in thermal equilibrium, electrons from the semiconductor flow into lower energy states in the metal. Positively charged donor atoms remain in the semiconductor, creating a space charge region.





Ideal energy-band diagram for a metal - n- semiconductor junction for $\phi_m > \phi_s$.

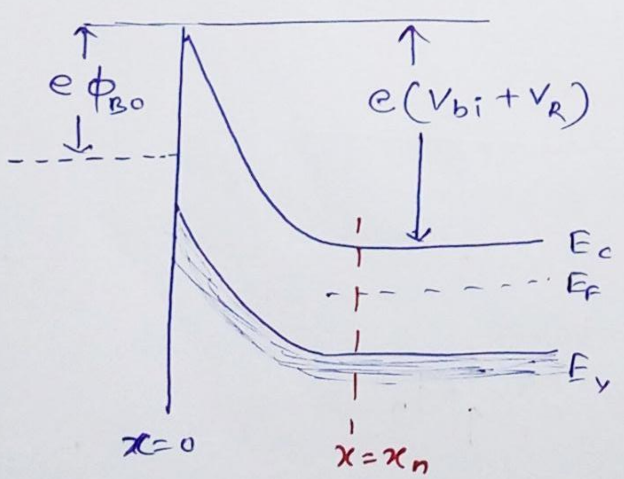
The parameter ϕ_{B0} is the ideal barrier height of the semiconductor contact, the potential barrier seen by the electrons in the metal trying to move into the semiconductor. It is known as Schottky barrier given as

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

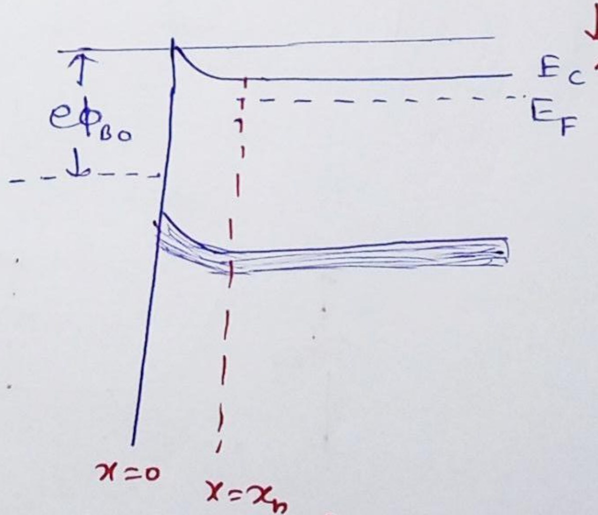
On the semiconductor side, V_{bi} is the built in potential barrier. This barrier, similar to the case of pn junction, is the barrier seen by the electrons in the conduction band trying to move into metal. The built in potential barrier is given by

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

If we apply a +ve voltage to the semiconductor with respect to metal, the semiconductor to metal barrier height increases, while ϕ_{B0} remains constant. It is in reverse bias condition.



Under Reverse Bias



Under forward Bias

Ideal Energy-band diagram of metal-semiconductor junction for $\phi_m > \phi_s$.

Metal - Semiconductor Ohmic contacts :

- An ohmic contact is a low resistance junction providing conduction in both directions between the metal and semiconductor

It is of two general types.

i) ideal non-rectifying barrier

ii) tunneling barrier.

Ideal Nonrectifying Barriers.

We consider $\phi_m < \phi_s$ for ideal metal to n-type semiconductor contact shown in figure. To achieve thermal equilibrium in this junction, electrons will flow from metal into the lower energy states in the semiconductor. The excess electrons charge in the n-type semiconductor exists as surface charge density.

If +ve voltage is applied to the metal, there is no barrier for electrons flowing from semiconductor into metal.

If +ve voltage is applied to the semiconductor, the effective barrier height for electrons flowing from the metal into the semiconductor will be approximately $\phi_{Bn} = \phi_n$, which is fairly small for a moderately to heavily doped semiconductor. Hence, electrons can easily flow from metal into the semiconductor.

Electrons can flow easily in both direction, and hence this types of contacts are known as ohmic contact.

If the +ve voltage is applied to the metal w.r.t the semiconductor, the semiconductor-to-metal barrier V_{bi} is reduced while ϕ_{B0} again remain constant. In this situation, electrons can more easily flow from the semiconductor into metal since the barrier has been reduced. It is called forward bias condition.

Because of similarity, the current-voltage characteristics of the Schottky barrier junction to be similar to the exponential behaviour of the pn junction diode.

The current mechanism here, is due to the flow of majority carriers. The forward bias current is in direction from metal to semiconductor.

*** If the electron from the valence band of semiconductor were to flow into metal, this effect would be equivalent to holes being injected into semiconductor. It will create excess minority carrier holes in the n region. However, the calculations and measurements shows that the i contribution is extremely small in most cases.

*** The Schottky barrier diode, then is a majority carrier device. It means that there is no diffusion capacitance. It makes it suitable for high frequency device than the pn junction diode. Since there is no minority carrier storage time the Schottky diodes can be used in fast-switching applications. The typical switching time is picosecond range while it is nanosecond for pn junction.

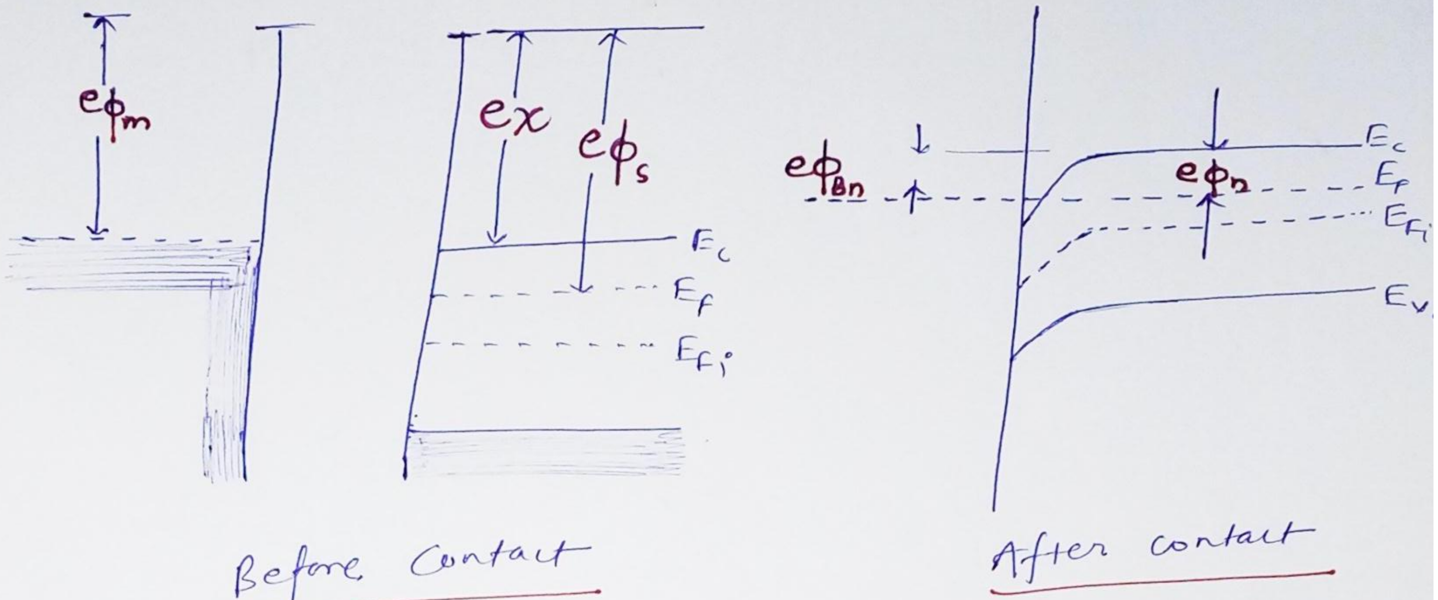
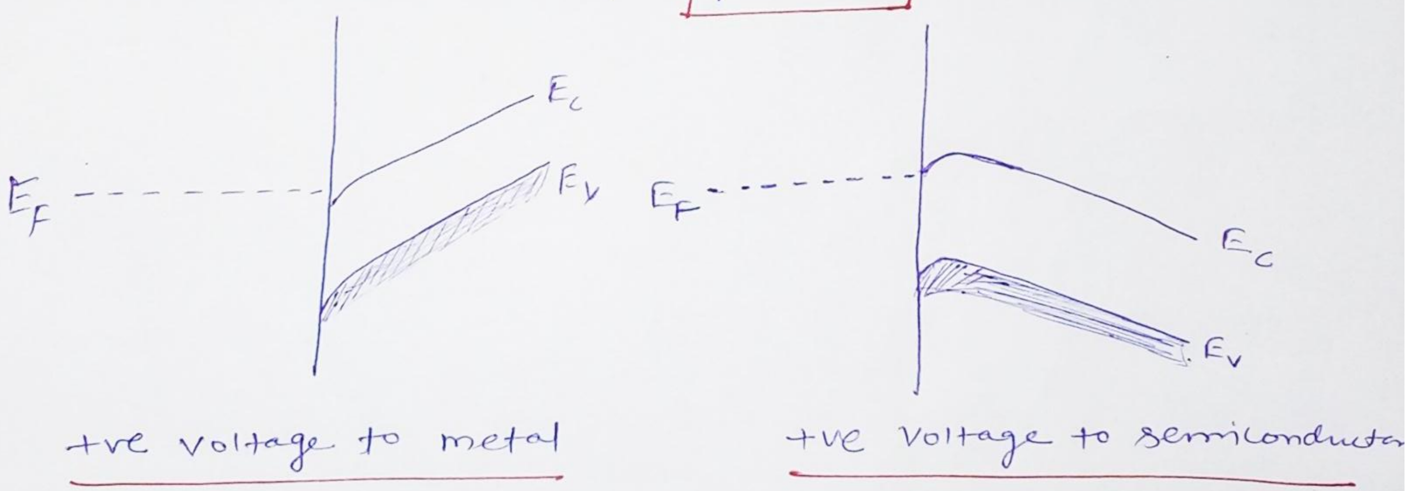


Fig: Ideal energy band diagram for a metal - n-semiconductor junction. for $\phi_m < \phi_s$.



Tunneling Barrier

The space charge width in a rectifying metal - semiconductor contact is inversely proportional to the square root of the semiconductor doping. The width of the depletion region decreases as the doping increases. Hence, as the doping increases the tunneling probablity increases.

Summary

* Metal - semiconductor junction behave as Schottky diodes if the fermi level alignments are such that there is depletion of majority carriers in the semiconductor.

* Metal - semiconductor junction behave as ohmic contacts if there is no depletion region formed in the semiconductor.

* Junctions betn dissimilar semiconductors are called heterojunctions.

* Electrons flow from the high to low fermi level region and holes flows the opposite way.

* There are two components of diode capacitance
  i) depletion capacitance: due to exposed dopant charges in the depletion region. It dominates in reverse bias

* ii) diffusion capacitance: due to stored excess mobile carriers. (It dominates in forward bias)

* For an ideal Schokley diode, one assumes negligible generation - recombination inside the depletion region. In forward bias, the built-in potential barrier is lowered, making it exponentially easier for majority carriers to diffuse across.

* A built-in junction potential barrier is formed betn the p and n sides, which reflects the voltage drop across the depletion region.

References:

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2. Physics of Semiconductors Devices by S. M. Sze.
3. Principles of Electronic Materials and Devices by S.O. Kasap
4. Electronics: Fundamentals and Applications by D Chattopadhyay and P C Rakshit