01
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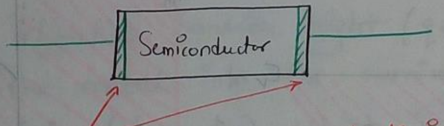
* Metal Semiconductor Ohmic contacts :

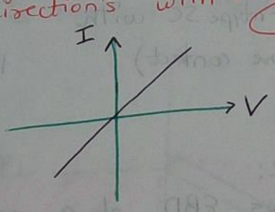
Ideal non-rectifying barrier, Tunneling barrier, Specific contact resistance.

- Ohmic contacts refer to Low-resistance, bias-independent metal-semiconductor contacts.
- An ohmic contact is a Low-resistance junction providing conduction in both directions between the metal and the semiconductor.



Metal-Semiconductor contact is "ohmic", if it's resistance's is v.small ie large current should flow in both forward and reverse direction's with very small voltage drop. (Ideally)

"ohmic contact I-V curve" ⇨



* Two general types of ohmic contacts are possible

1) Ideal nonrectifying contact (barrier)
2) Tunneling barrier. (Tunneling dominated MS contacts)

"Refer pg 41 & 42 of MSJ notes"

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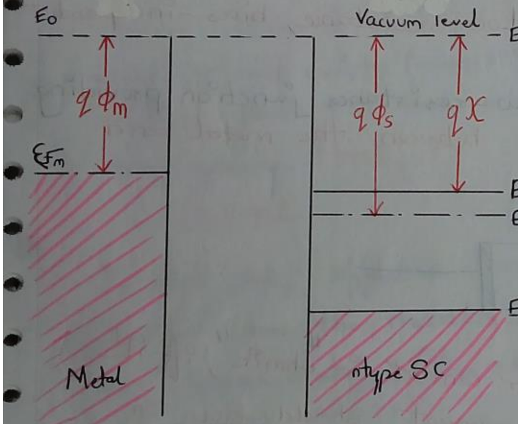
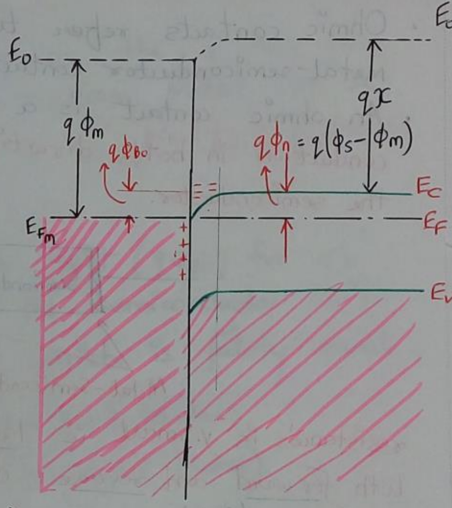
* Ideal Non-rectifying barriers/ contact:-

* Energy band diagram (EBD) for a metal-ntype semiconductor junction for $\phi_m < \phi_s$:



1.a) EBD of a M-ntype SC with $\phi_m < \phi_s$ (before contact)



1.b) EBD of a metal-ntype SC with $\phi_m < \phi_s$ (After contact) at thermal equilibrium

① No bias case:

- Fig 1.a) shows EBD of a metal-ntype semiconductor(SC) with $\phi_m < \phi_s$ when materials are isolated from each other (before contact)

After the contact is made (fig 1.b), to achieve thermal equilibrium, electrons will flow from metal (electron's at higher energy) into the conduction band (electrons at Lower energy) of the semiconductor, until both fermi-levels are aligned. (fig 1.b)

- This causes a "potential drop" ($\phi_S - \phi_m$) across the semiconductor.
- This situation creates '-ve' charge (ie e^-s accumulates in SC near surface) on surface of semiconductor and '+ve' charge in the metal surface.
- Since there is no depletion region in the semiconductor → no barrier exists (almost) → so the e^- can flow either from SC into metal or from Metal into SC very easily. Hence, it is known as Non Rectifying / ohmic contact.
- In this case, effective barrier height ($q\phi_{B0}$) for e^-s flowing from the metal into the semiconductor will be approximately ($\phi_{B0} = \phi_n$), which is fairly small.

b) Forward bias (Semiconductor is -ve w.r.t Metal)

c) Reverse bias (Semiconductor is +ve w.r.t Metal)

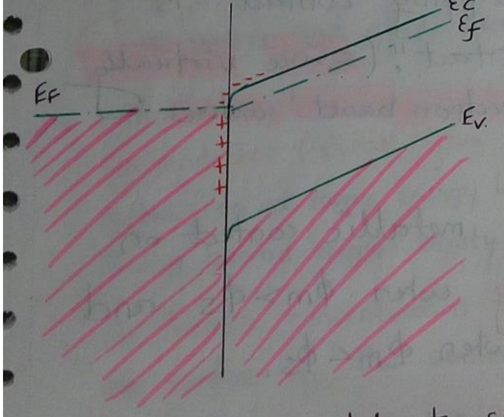


fig 1.c) EBD of a metal - ntype SC (Forward bias)

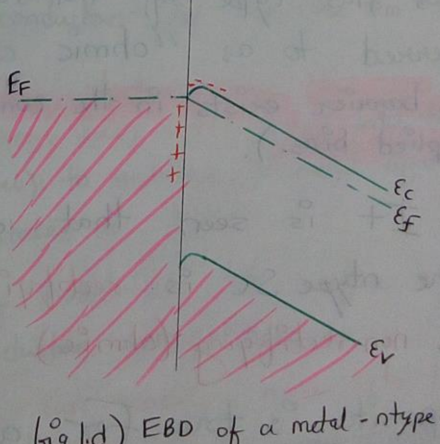


fig 1.d) EBD of a metal - ntype SC (Reverse bias)

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Energy band diagram for a Metal-ptype Semiconductor ($\phi_m > \phi_s$)

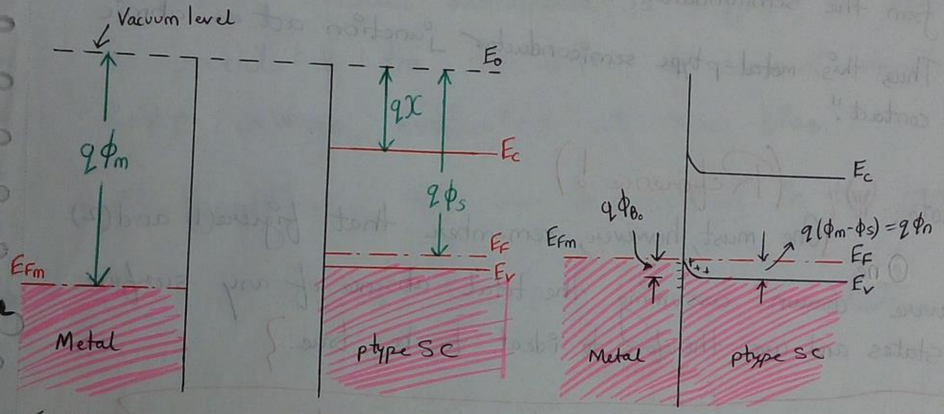

Fig 2 a) Before contact b) After contact

Fig 2: Energy-band diagram for a metal-ptype semiconductor junction for $\phi_m > \phi_s$ (Ohmic contact)

- Fig 2. shows an ideal non-rectifying contact between a metal and ptype semiconductor. for the case $\phi_m > \phi_s$.
- When contact is made (fig 2b), electrons from the semiconductor ($\bar{e}s$ at higher energy level) will flow into the metal ($\bar{e}s$ at lower energy level) to achieve thermal equilibrium, leaving behind more empty states or holes.
- The excess concentration of holes at the surface makes the surface of the semiconductor more p type.
- Electron's from the metal can readily move into the empty states in the semiconductor.

- This charge movement corresponds to holes flowing from the semiconductor into the metal.
- Thus this metal-ptype semiconductor junction act as "ohmic contact".

Note: (Reference !)
{One must, however, remember that figure(1) and (2) were drawn assuming the total absence of any surface states and are therefore, to ideal to be true.}

Al → Most common metal to make contact

1) Al - pSi → gives a ohmic contact
2) Al-nSi → is a rectifying contact
3) Al - n^+Si → is a ohmic contact

→ Schottky diode → Majority Carrier diode

* Specific Contact Resistance (R_c) :-

- Specific contact resistance is defined as the reciprocal of the derivative of current density w.r.t voltage, evaluated at zero bias.

- Mathematically, this can be written in the form,

$$R_c = \left(\frac{\partial J}{\partial V}\right)^{-1}\Bigg|_{V=0} \quad \text{——} ①$$

and has units of $\Omega - cm^2$

- Specific contact resistance, R_c, is usually taken as a figure of merit for the quality of ohmic contacts.

- We require R_c to be as small as possible for an good ohmic contact ($< 10^{-6}\ \Omega cm^2$ is considered good).

- For a metal-semiconductor junction, according to the emission model (conduction is due to thermionic emission), the I-V relation is

$$J = A^{*} T^{2} \exp\left(-\frac{q\phi_{Bn}}{KT}\right)\left[\exp\left(\frac{qV}{KT}\right) - 1\right] \quad — ②$$

Using eq^n (1) and (2), we get

$$\boxed{R_C = \frac{(KT/q)\exp\left(\frac{q\phi_{Bn}}{KT}\right)}{A^{*} T^{2}}} \quad — ③$$

→ This expression is correct, since it is evaluated at V=0

From ③, Rc ↓ses rapidly as the barrier height ↓ses.

- For a metal-semiconductor junction with a high impurity doping concentration, the tunneling process will dominate.

Tunnelling current is governed by the expressions,

$$J_t \propto \exp\left(\frac{-q\phi_{Bn}}{E_{00}}\right) \quad — (a)$$

and $E_{00} = \frac{q\hbar}{2}\sqrt{\frac{N_d}{\epsilon_s m_n^*}}$ — (b)

From eq^n (a) and (b), R_c is found to be,

$$R_c \propto \exp\left[\frac{2\sqrt{\epsilon_s m_n^*}}{\hbar}\,\frac{\phi_{Bn}}{\sqrt{N_d}}\right] \quad — ④$$

Equation ② shows that, for a tunneling contact, the specific contact resistance is a strong function of semiconductor doping. (N_d)

Note: (Reference) !!

. For low doping concentrations, R_c values are dependent on the barrier height (ϕ_{Bn}) and become almost independent of the doping (N_d).

. To form a good ohmic contact, we need to create a low barrier and use a highly doped semiconductor at the surface.

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