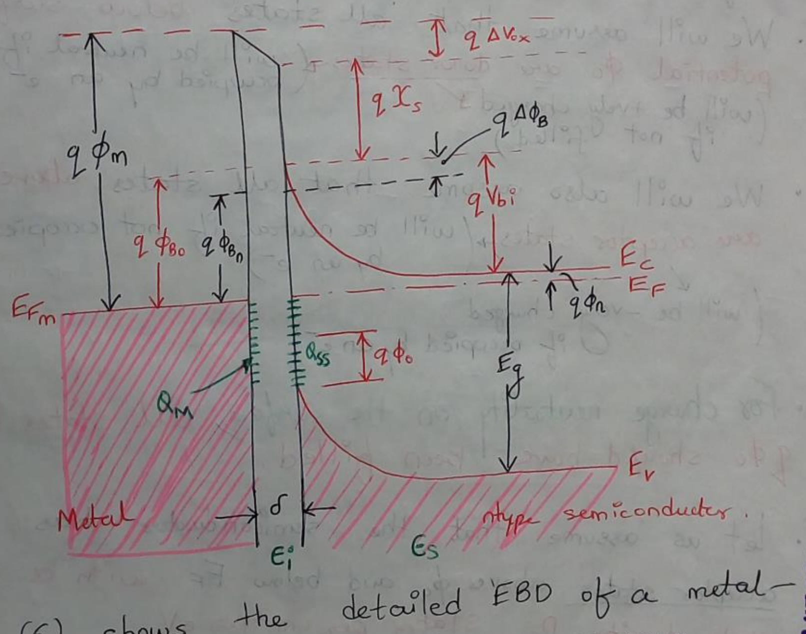
* Detailed energy band diagram of a metal – ntype semiconductor contact in thermal equilibrium showing effect of interfacial layer, presence of interface states and barrier lowering due to Schottky effect.

fig 6:



- Figure (6) shows the detailed EBD of a metal–semiconductor (ntype) contact with an narrow interfacial layer of insulator of thickness 'δ'.
- In this figure, ϕ_{Bn} is the metal-semiconductor barrier height with image force lowering.
- Factor 'δ' – thickness across the interfacial.
- Q_{ss} and Q_m represent surface state density on the semiconductor & surface charge density on the metal.

- The interfacial layer can support a potential difference, but will be transparent to the flow of electrons betⁿ the metal and semiconductor.
- ntype semiconductor also shows a distribution of surface states at the metal-semiconductor interface.
- We will assume that all states below surface potential ϕ_0 are donor states → (will be neutral if occupied by an e^-) (will be +vely charged if not filled)
- We will also assume that all states above ϕ_0 are acceptor states → (will be neutral if not occupied by an e^-) (will be −vely charged if occupied by an e^-)
- For charge neutrality on the surface, all states below $q\phi_0$ should have been filled.
- Let us assume that the semiconductor has some acceptor states above ϕ_0 and below E_F with a surface state density D_s states per cm^2 per eV.
- Let us also assume that the density D_s is constant over the energy range $q\phi_0$ to E_F.

Info:

Without going into the details, we will simply write a final expression relating the various terms (ie surface potential, surface charge density & other semiconductor parameters)

→ Final expression is

$$\boxed{E_g - q\phi_0 - q\phi_{Bn} = \frac{1}{qD_s}\sqrt{2q\epsilon_s N_d(\phi_{Bn} - \phi_n} - \frac{\epsilon_i}{qD_s\delta}\left[\phi_m - (\chi + \phi_{Bn})\right]} \quad (1)$$

Info:

The derivation of eq^n (1) assumes that the interfacial layer has a thickness of a few angstrom's and is essentially transparent to electrons

We now consider two limiting cases,

Case 1: $D_s \to \infty$

In this case, eq^n (1) leads to

$$E_g - q\phi_0 - q\phi_{Bn} = 0$$

$$\Rightarrow \boxed{\phi_{Bn} = \frac{1}{q}(E_g - q\phi_0)} \quad (2)$$

Eqⁿ (2) can be used to conclude the following: 34

i) The barrier height is independent of material parameters such as the work function and semiconductor electron affinity.

ii) Barrier height is dependent upon the semiconductor bandgap and surface state energy $q\phi_0$.

iii) Fermi-level at the interface is pinned at the value $q\phi_0$ above the valence band, by the surface states.

Case (2): $D_s \delta \to 0$

Equation (1) reduces to

$$\boxed{\phi_{Bn} = \phi_m - \chi_s}$$

which is the original ideal expression for Schottky barrier height.

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—x—

The thermionic emission theory postulates that only energetic carriers, those, which have an energy equal to or larger than the conduction band energy at the metal-semiconductor interface, contribute to the current flow.

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* I–V characteristics of a Schottky barrier diode based on Thermionic emission model: (TE)

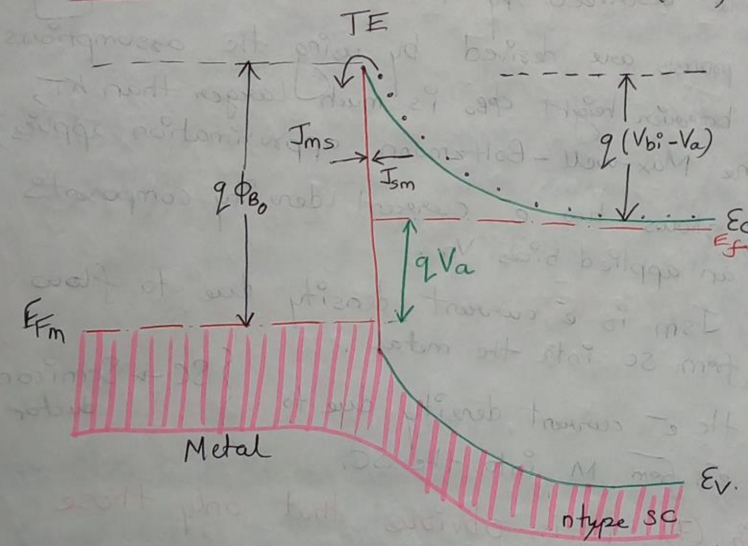

fig 7. EBD of a forward-bias Schottky-barrier diode showing current flow due to TE

Info !

- We will now attempt to model the current flowing in a MSJ (schottky barrier diode) assuming the carrier flow to be due to → Thermionic emission over the carrier.

⇨ This essentially means that we are initially goin to neglect tunnelling effects and image force barrier lowering.

- The current transport mechanism in a MSJ is due to mainly majority carriers. and can be described by thermionic emission theory.

→ The TE process are derived by using the assumptions that the barrier height ϕ_{B0} is much larger than KT, (So that the Max-well - Boltzmann approximation applies)

- In fig 7, shows two e^- current density components with an applied bias V_a.
- Current J_{sm} is e^- current density due to flow of e^-s from SC into the metal.
- J_{ms} is the e^- current density due to flow of e^-s from M into the SC. {SC → Semiconductor}
- From fig (7), it is obvious that only those electron's that have energy higher than $q(V_{bi} - V_a)$ can reach the top of the barrier

According to thermionic emission theory, net current flow is $J = J_{sm} - J_{ms}$;

$$\boxed{J = A^* T^2 \exp\left(-\frac{\phi_{B0}}{KT}\right)\left[\exp\left(\frac{qV_a}{KT}\right) - 1\right]} \quad (a)$$

where, $\boxed{A^* = \frac{4\pi q m_n^* k^2}{h^3}}$

Now, $J_0 = A^* T^2 \exp\left(-\frac{q\phi_{B0}}{KT}\right)$ — (b)

where, $A^* = \frac{4\pi m_n^* q K^2}{h^3}$ is Richardson constant for the thermionic emission of electrons from the metal into the semiconductor having electron effective mass M_n^*.

- Under an applied forward bias V_a, the effective barrier in the semiconductor becomes $q(V_{bi} - V_a)$ as shown in fig (7).

→ The electron flow from the semiconductor into the metal thus gets boosted by a factor $\exp(qV_a/KT)$.

→ The I-V characteristics of a schottky-barrier diode or M-ntype SC, therefore can be written as,

$$\boxed{J = J_0\left[\exp\left(\frac{qV_a}{KT}\right) - 1\right]} \quad \text{— (c)}$$

where, J_0 = reverse-saturation current density

* **Implications** :

We know that Schottky barrier hight ϕ_{B0} changes because of image-force lowering.

$$\phi_{Bn} = \phi_{B0} - \Delta\phi_B \quad \text{—(d)}$$

• From (b) and (d), we have

$$J_0 = A^* T^2 \exp\left[-\frac{(\phi_{B0} - \Delta\phi_B)}{KT}\right] \quad -(e)$$

where, $\Delta\phi_B = \left(\frac{qE}{4\pi\epsilon_s}\right)^{1/2}$ −(f)

As $\exp\left(\frac{\Delta\phi_B q}{KT}\right)$ ↓ses

J_0 ↑ses.

→ The change in barrier height $\Delta\phi_B$, will ↑se with an ↑se in E-field, or with an ↑se in the applied reverse-bias voltage.

• The ↑se in the reverse-bias current with ↑se in reverse-bias voltage in Schottky barrier diode is due to barrier-lowering effect.

Info 💡!

• Thermionic emission is usually the dominant mechanism in Si and GaAs Schottky barrier diodes and leads to ideal diode characteristics.