CONJUGATED MATERIALS DEVICES

(OLED, FET, PV CELLS)

n-type semiconductor

W depletion region

$$W = \sqrt{\frac{2(\phi_m - \chi)\varepsilon_s}{N_D q^2}}$$

N_D = dopant concentration

χ = EA of the semiconductor

ε_s = permittivity

$\phi_m - \chi$ = Schottky barrier

BLOCKING CONTACT

(for electrons)

MR

FOR AN APPLIED BIAS V:

$$W = \sqrt{\frac{2(\phi_m - X + qV)\varepsilon_s}{N_D q^2}}$$

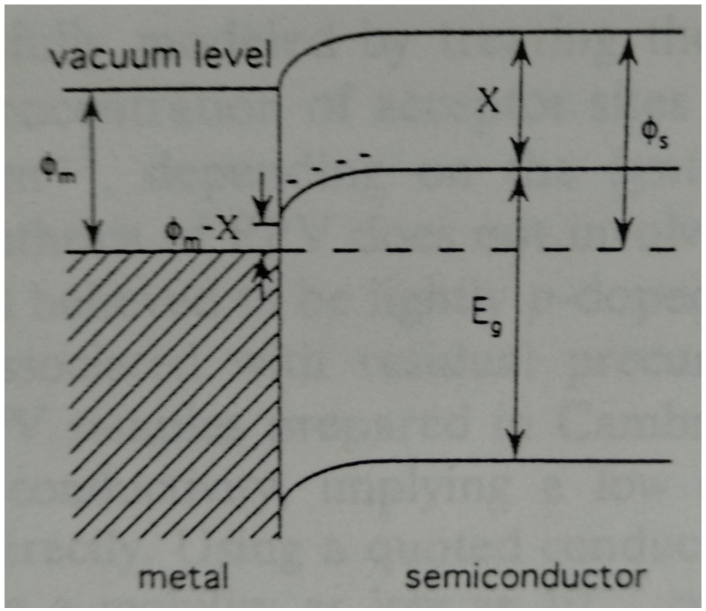
→ IF the Fermi energy of the semiconductor layer from ϕ_m → electrons flows in the semiconductor.

In the case of insulators or semiconductors with traps, it is the density of traps that determines W

W is of outmost importance since it localize where the charges are localized in your device

$$W_t = \frac{\pi}{2}\sqrt{\frac{2kT\varepsilon_s}{q^2 N_t}} \exp\left(\frac{E_g/2 - E_t}{2kT}\right)$$

DEPLETION REGION FOR MATERIALS WITH TRAPS



CARRIER TRANSPORT IN DEVICES

Single carrier current → drift current J_n (function of the carriers mobility μ_0)

$$J_n = n_f \, q \, \mu_0 \, F$$

n_f → density of free carriers

F → applied field

with traps $n = n_f + n_t$ → effective mobility

$$\mu_e = \mu_0 \frac{n_f}{n_f + n_t}$$

$$J_n = n \mu_e F$$

CARRIERS ARE INJECTED BY

- THERMOIONIC EMISSION $J \sim T^2 \exp\left(-\frac{\phi_b}{kT}\right)$
- QUANTUM MECHANICAL TUNNELLING (FIELD EMISSION)

$\alpha = \frac{4\pi (2m^*)^{1/2}}{h}$ → $J \sim \frac{T^2}{\phi_b} \left(\frac{qF}{\alpha kT}\right)^2 \exp\left(-\frac{2\alpha \phi_b^{3/2}}{3qF}\right)$

INORGANIC SEMICONDUCTORS

$\mu(RT) \sim 10^{2} - 10^{4}\ cm^{2}\ V^{-1} s^{-1}$

ORGANIC SEMICONDUCTORS

$\mu_{holes} \sim 10^{-4}\ cm^{2}\ V^{-1} s^{-1}$

$\mu_{elect} \sim \frac{\mu_{holes}}{100}$

The carriers mobility is limited by:

- hopping rate.
- increased disorder at large distances.
- traps.
- oxygen.

→ TWO THEORIES HAVE BEEN PROPOSED FOR DESCRIBING CHARGE-TRANSPORT

1. POLARON MODEL
2. DISORDER MODEL (SAME HOPPING MODEL ~~FOR~~ USED FOR EXCITONS)

NEITHER THEORY EXPLAIN ALL THE AVAILABLE DATA

PRACTICAL PROBLEM: vary too much the temperature induces modifications to the material that affects the experimental results

SPACE-CHARGE LIMITED CURRENT

$$J_{SCL} = \frac{9}{8} \varepsilon_s \mu \frac{V^2}{d^3} \quad \text{if } n \gg n_0$$

where d is the sample thickness.
The current density achievable is limited by charge of the semiconductor. (MAXIMUM SINGLE CARRIER CURRENT ACHIEVABLE)

at low voltages

$$J_{\Omega} = q n_0 \mu \frac{V}{d} \quad \text{if } n_0 > n$$

ohmic behavior

WITH TRAPS:

$$J_{SCL} = \frac{9}{8} \varepsilon_s \mu_e \frac{V^2}{d^3}$$

- if the injected charge density is high enough that Fermi level moves above the trap level, all the traps are filled
  TRAP-FILLED LIMIT (TFL) → the currents revert to the trap free regime

FOR DEVICES IS IMPORTANT TO KNOW IF THE CURRENT IS LIMITED BY POOR INJECTION OR SCL

TWO CARRIERS CURRENT

In electroluminescent devices the carriers of opposite sign are injected from either side of the semiconductor.

The total charge must be now considered in calculating space charge effects.

The total charge is also determined by the capture of electrons and holes to form stable bound states, the excitons.

CAPTURE RADIUS $$r_C = \frac{q^2}{4\pi\varepsilon_s kT}$$ (the coulombic energy is equal than the thermal energy kT)

- external field and anisotropy are neglected

Generation rate for excitons

$$G_E = np\,v\,\sigma_r \qquad \sigma_r = \pi r_c^2$$

v = average relative thermal speed for n and p

In the limit when thermal hopping rate is << than the field induce hopping rate

$$G_E = np\,F(\mu_e + \mu_h)\,\sigma_r$$

The SCL effects are therefore strongly determined by the effectiveness of recombination in the trap free core and considering the contacts as infinite reservoir of charges

$$J_{SCL} = \frac{9}{8} \varepsilon_s \mu_{eff} \frac{V^2}{d^3}$$

μ_{eff} is a function of μ_e, μ_h and σ_r → very complex

~~Considering μ_e ≈ μ_h~~

TWO MAIN LIMIT CASES:

$v\sigma_r \to 0$ | no recombination. The negative and positive space charges cancel, thus no limit to the current due to space charge.

$v\sigma_r \to \infty$ | The current is given by the sum of the electron and holes SCL current and ($\mu_{eff} = \mu_e + \mu_h$). The position of the recombination zone depends on the relative magnitude of μ_e and μ_h

For intermediate $v\sigma_r$ values approximate solutions can be found.