The University Of Sheffield.

EEE105
“Electronic Devices”

Professor Richard Hogg,
Centre for Nanoscience & Technology, North Campus
Tel 0114 2225168,
Email - r.hogg@shef.ac.uk

Lecture 9

- Majority and Minority Carriers
- Generation and Recombination of Carriers
  - Steady State
- Excess Minority Carriers
  - Minority Carrier Lifetime

Extrinsic Semiconductor

Extrinsic Si

$$\sigma_{Drift} = nq\mu_e + pq\mu_h$$

– p-doped with B to give
$p_p = 10^{21}$ m^{-3}
$n_p = 10^{15}$ m^{-3}

Holes = majority carriers, Electrons = minority carriers

– n-doped with As to give
$n_n = 10^{21}$ m^{-3}
$p_n = 10^{15}$ m^{-3}

Electrons = majority carriers, Holes = minority carriers

Equilibrium (G=R)

- Extrinsic Semiconductor
- n-doped $n \gg n_i$, p_n is hole concentration in the n-doped material

$$G = R = Bn_n p_n$$

From before for intrinsic case $G = R = B n_i^2$

So $n_i^2 = n_n p_n$

same analysis for p-type gives $G = R = Bp_p n_p$

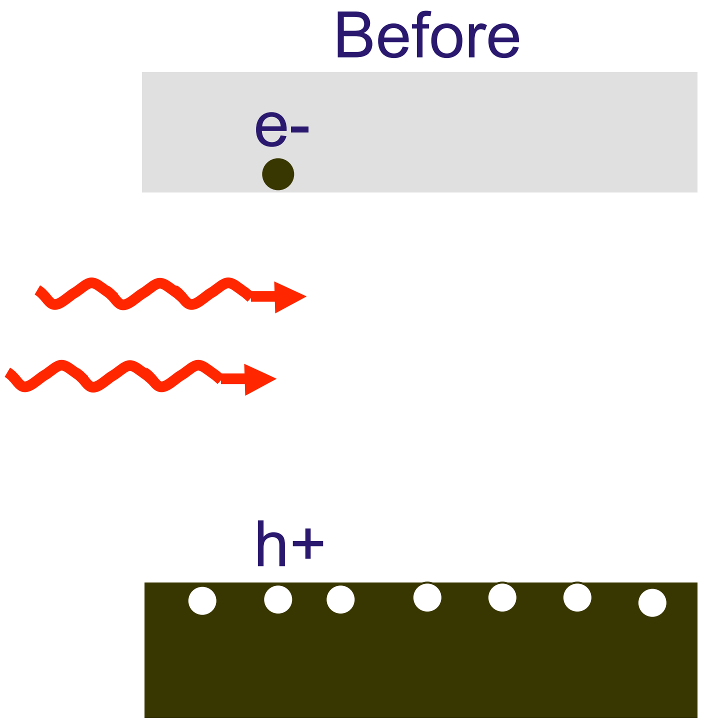
$$n_i^2 = p_p n_p$$

Minority Carrier Density

- The minority carrier density is *less* than in the intrinsic semiconductor case
- Qualitatively - thermally generated minority carriers experience greater recombination

Disturbing The Equilibrium

- For the moment consider exciting carriers instantaneously with a light pulse

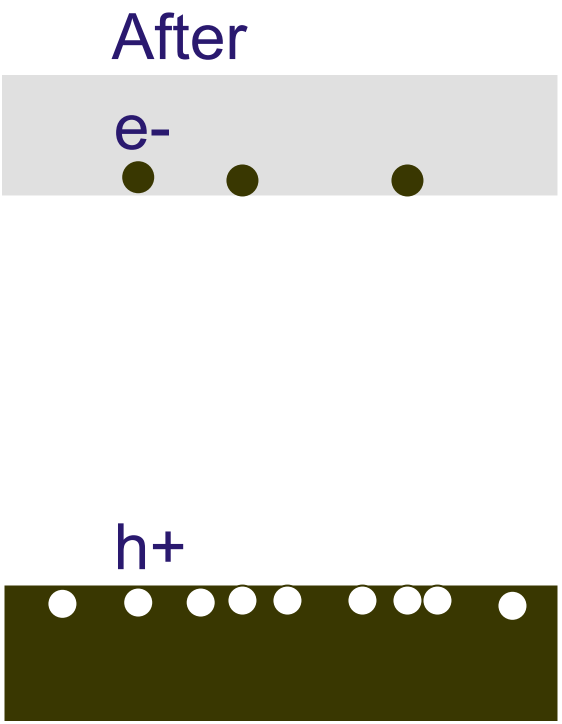


electron density = n_p

hole density = p_p

Disturbing The Equilibrium (2)

- New carrier densities....



electron density = $n_p + \delta n$

hole density = p_p

As we assume $n_p \ll \delta n \ll p_p$

What Happens Next?

- The thermal generation rate is constant
- Our recombination rate is now $R = Bp(n_p + \partial n_p)$

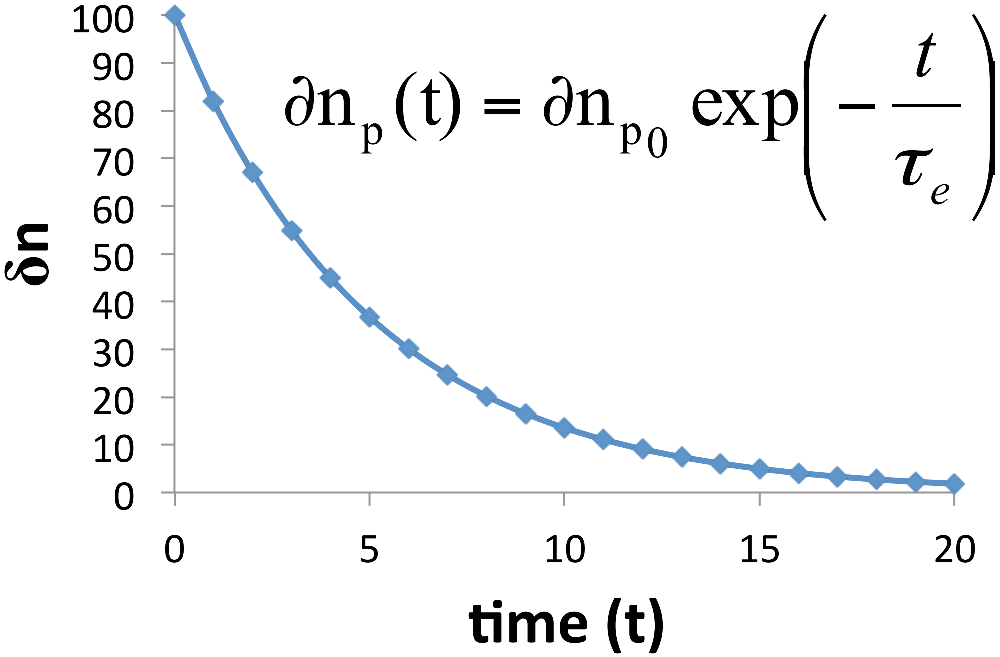
The rate of change of electron density

$$\frac{dn}{dt} = G - R = G - \left[Bp_p n_p + Bp_p \partial n_p\right]$$

At equilibrium $G = Bp_p n_p$

So $\dfrac{dn}{dt} = -Bp_p \partial n_p$ ....1st order differential equation

Solution



$$\partial n_p(t) = \partial n_{p0} \exp\left(-\frac{t}{\tau_e}\right)$$

(δn_{p0} = 100, τ_e=5)

τ_e=minority carrier lifetime

n.b. Don't confuse with carrier scattering time discussed previously

– in this case e is minority carrier

$$\tau_e = \left(\frac{1}{Bp_p}\right)$$

Minority Carrier Lifetime

If excess electrons are introduced instantaneously their concentration decays exponentially until we return to equilibrium (G=R)

τ_e is average time excess electrons exist in a semiconductor

τ_e decreases as p increases – more holes for electrons to recombine with

Summary

- In thermal equilibrium the rate of generation of free carriers is equal to the rate of recombination
- The rate of recombination of free carriers is proportional to the density of free electrons and holes
- The thermal generation is governed by the band-gap and temperature - it is the same in intrinsic and doped materials
- The density of minority carriers is suppressed in a heavily doped material compared to the intrinsic case
- The effect of perturbing the equilibrium has been discussed
- Modulating the carrier density temporally shows that the excess carriers can be ignored and a minority carrier lifetime can be derived

