22/1

Solar Cells: 1 hr lecture

Contents to cover

(1) semiconductors
- Intrinsic
- n-type
- p-type
- Fermi level.

(2) absorption:
- carrier-recombination

(3) p-n junction

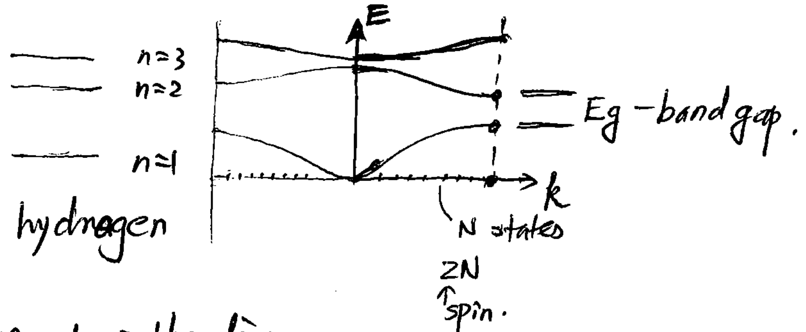
[redacted] I-V characteristics

(4) p-n junction under illumination
- open circuit
- power

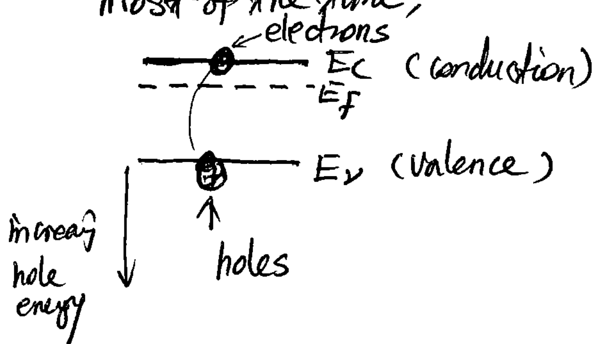
(5) efficiency.

(1) Semiconductors

Recall in lectures 12&13, we talk about electron energy levels in a crystal



Most of the time,



Intrinsic: $n = p$

$n \cdot p = N_i^2$

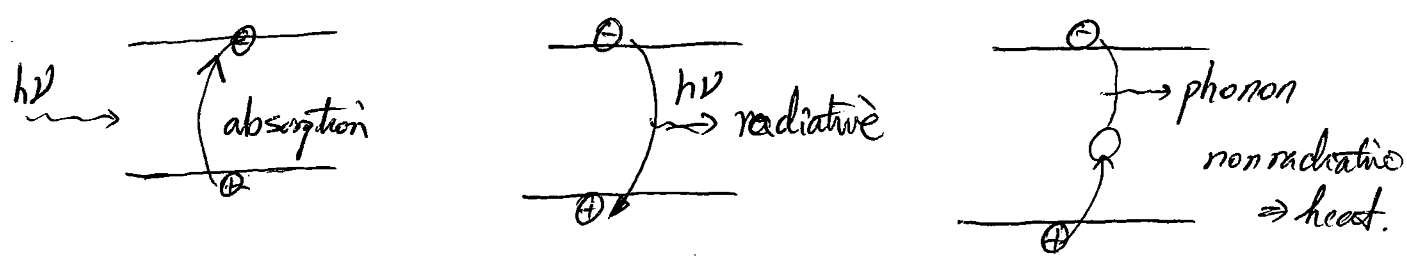
doping phosphor: n-type.

approximately $n_0 = N_c \exp\left(-\frac{E_c - E_f}{k_B T}\right)$ ≈ N_D (# of atoms you put in). $n \gg p$.

In this case $p_0 = \frac{N_i^2}{n_0}$

Similarly for p-type $p_0 = N_v \exp\left(-\frac{E_v - E_f}{k_B T}\right)$

(2) absorption & recombination.

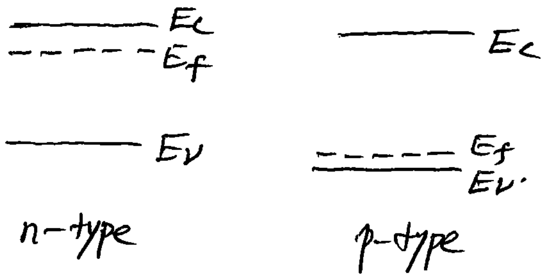


$$\frac{d\Delta n}{dt} = \frac{n - n_0}{\tau}$$

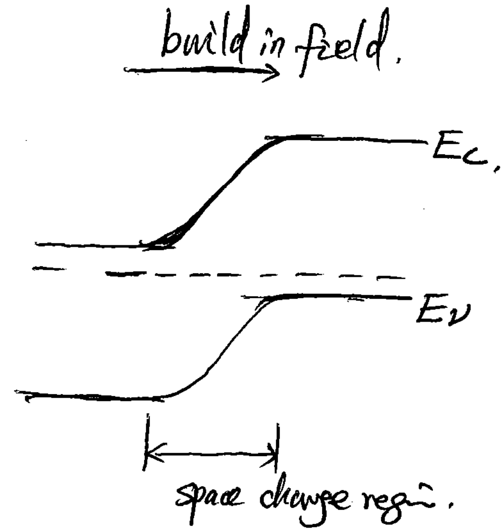
↑ recombination time (τ)

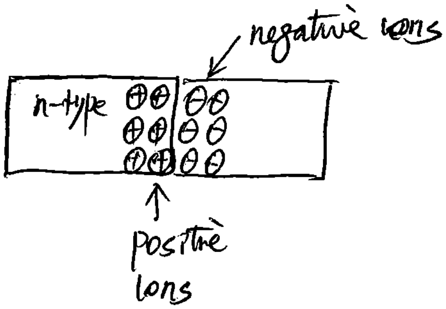
$$\frac{1}{\tau} = \frac{1}{\tau_{rad}} + \frac{1}{\tau_{non\,rad}}$$

③ p-n junction



⇒



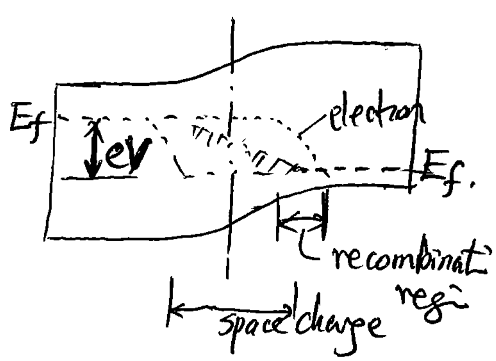


Poisson Equation

$\nabla^2 E_c$

build in field ⟷ diffusion ⇒ equilibrium.

Under an external bias



when electron goes from n into p.

electron in p-regi.

$$D \frac{d^2 n}{d x^2} - \frac{n - n_{op}}{\tau} = 0$$

← equil. in p-type

↑ diffusivity ↑ recombinat.

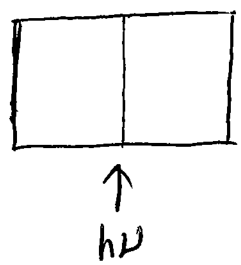
minority carrier device

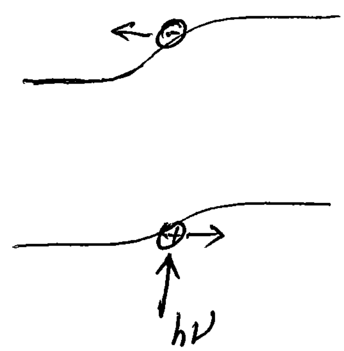
$$J = -J_s \left[\exp\left(\frac{eV}{k_B T}\right) - 1\right]$$

↓ saturation current (in detector, called dark current)

$$J_s = e N_c N_v \left(\frac{1}{N_A}\sqrt{\frac{a_h}{\tau_h}} + \frac{1}{N_D}\sqrt{\frac{a_e}{\tau_e}} \right) \exp\left(-\frac{E_g}{k_B T}\right)$$

④ p-n junction under illumination





$$J_e = -J_s\left(e^{\frac{eV}{k_B T}} - 1\right) + J_g.$$

↑ current source

$$J_g = \int_{E_g/\hbar}^{\infty} \varepsilon_\omega \, \tau_\omega (1-R_\omega) \frac{I_{b\omega}}{\hbar\omega} \, d\omega$$

- τ_ω: transmissivity
- $I_{b\omega}$: source (assuming black)
- ε_ω: emissivity ⇑ this is where you learnt from the class.
- $\frac{I_{b\omega}}{\hbar\omega}$: # of photons per unit solid angle

Open circuit: $J_e = 0$

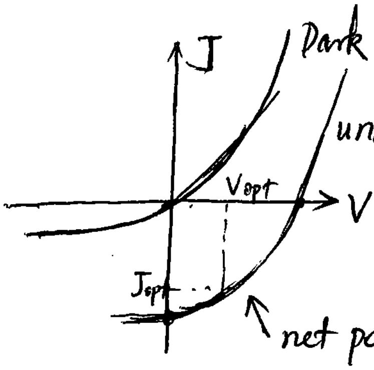
$$V_0 = \frac{k_B T}{e} \ln\left(\frac{J_g}{J_s} + 1\right) = \frac{k_B T}{e}\left\{ \ln\left[\frac{J_g}{A} e^{\frac{E_g}{k_B T}} + 1\right]\right\}$$

(+1: negligible)

$$J_s = A e^{-\frac{E_g}{k_B T}}$$

~~$V_0 = \frac{k_B T}{e}\left[\ln \frac{J_g}{J_s} + \ln(1 \ldots\right.$~~

$$V_0 \approx \frac{E_g}{e} - \frac{k_B T}{e} \ln \frac{A}{J_g}$$

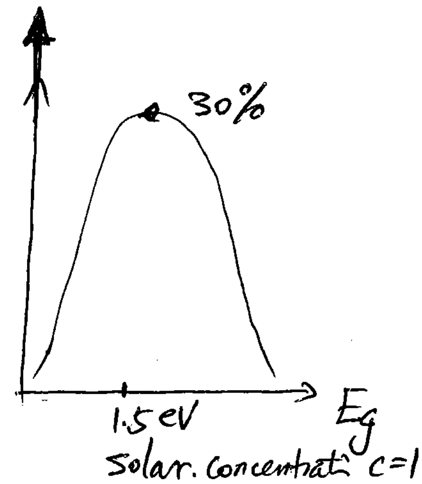


$W_e = J_e V$

↑

an optomal exist.

J_{opt}, V_{opt}

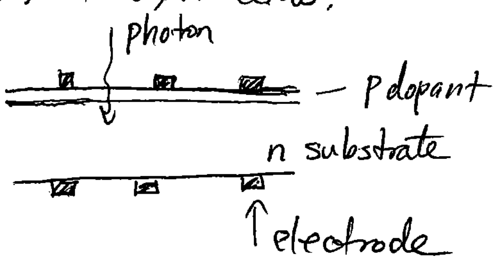


efficiency $\eta = \dfrac{J_{opt} V_{opt}}{\int_0^\infty \varepsilon_\omega I_{b,\omega} d\omega}$

E_g too small → V_0 too small.

E_g too big → useful photon too small.

⑤ Actual solar Cells.



Non Ideal factors

a. electrode shadowing

b. free carrier absorption

c. not all carriers excited in space charge regi.

d. reflection

e.

manufacturing/cost.

⑥. Advanced topics: photoelectrochemical cell, polymer cells

multicarrier excitati