TFE4171

Semiconductor physics with lab

Notes

2018

Contents

Chapter 4

Haluleder - Chapter 4

- $E = hf = h\frac{c}{\lambda}$, absorbed if $h\nu > E_g$.
- Fast luminescent process: flourescence
- Slow —— " ⟶ phosphorescence

$\Big\}$ Transient decay.

- E_t = impurity energy level.
- Photoconductivity: increased conductivity originated from excess EHPs from light.

- α_r = constant of proportionality for recombination.
- $\delta n(t) = \delta p(t)$ = excess carrier concentrations.
- Δn = initial excess electron concentration at $t=0$.

→ p-type: $\frac{d\delta n(t)}{dt} = -\alpha_r p_0 \delta n(t) \Rightarrow \delta n(t) = \Delta n e^{-\alpha_r p_0 t} = \Delta n e^{-t/\tau_n}$

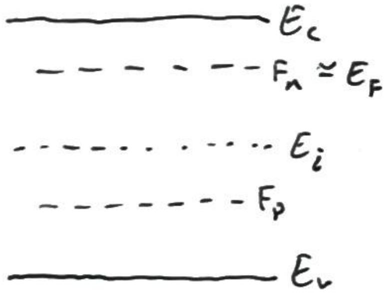
- $\tau_n = (\alpha_r p_0)^{-1}$ = recombination lifetime or minority carrier lifetime ($\uparrow p$).

  $\tau_p = (\alpha_r n_0)^{-1}$

→ generally: τ_n = carrier lifetime = $\frac{1}{\alpha_r(n_0 + p_0)}$

- E_r = recombination energy level. If an electron falls from E_r to valence band, and then another falls from conduction band to E_r, we have had an indirect recombination.
  - → Temporary trapping, ↓↑, can also occur.
- Conductivity during photoconductive decay: $\sigma(t) = q(n(t)\mu_n + p(t)\mu_p)$
  - → Process of photoconductive decay measurements can be used for characterization
- $g(T) = g_i$ = EHP generation at equilibrium (thermal generation).
  - → $g(T) = \alpha_r n_i^2 = \alpha_r n_0 p_0$
- g_{op} = optical EHP generation rate (light source)
  - → $g(T) + g_{op} = \alpha_r np = \alpha_r(n_0 + \delta n)(p_0 + \delta p)$
  - Steady state and no trapping: $g(T) + g_{op} = \alpha_r n_0 p_0 + \alpha_r\left((n_0 + p_0)\delta n + \delta n^2\right)$
- Equilibrium: no external excitation except temperature, no net motion of charge.

- Steady state: non-equilibrium, all processes constant and balanced by opposing forces.
- $g_{op} = \alpha_r (n_0 + p_0)\, \delta n = \dfrac{\delta n}{\tau_n}$, $\delta n = \delta p = g_{op} \tau_n$.
- $n_i^2 = n_0 p_0$ at equilibrium. $n_i^2 \neq np$ if excess carriers are present.
  $\rightarrow n = n_0 + \delta n$
- Quasi fermi levels: F_n, F_p, fermi levels for each band.



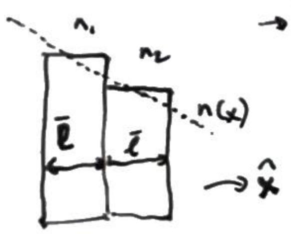
$F_n - E_i > E_i - F_p$ here.

$$\boxed{\begin{aligned} n &= n_i e^{(F_n - E_i)/k_B T} \\ p &= p_i e^{(E_i - F_p)/k_B T} \end{aligned}}$$

$\hookrightarrow$ In this case, the excitation causes a large percentage change in minority carrier hole concentration and a relatively small change in electron concentration.

- Photons with $h\nu \gg E_g$ are absorbed at the surface and contribute little to the bulk conductivity.
- $\Delta\sigma = q\, g_{op} (\tau_n \mu_n + \tau_p \mu_p)$ ~ photoconductive response.
  $\rightarrow$ If trapping is present: $\delta n = \tau_n g_{op}$, $\delta p = \tau_p g_{op}$, and $\tau_n \neq \tau_p$.
- Diffusion: movement from high potential to low potential, due to random motion.
- Current conduction consists of diffusion due to carrier gradient, and drift in an electric field.
- Ex.: pulse spread by diffusion.

- Mean free path $\bar{l}$ increases as $n(x,t)$ diffuses.



$\rightarrow$ The rate of electron flow in the $\hat{x}$-direction per unit area:

$$\phi_n(x_0) = \frac{\bar{l}}{2\bar{t}} (n_1 - n_2)$$

MATH gives: $\phi_n(x) = -\frac{\bar{\ell}^2}{2\tau} \cdot \frac{dn(x)}{dx} = -D_n \frac{dn(x)}{dx}$

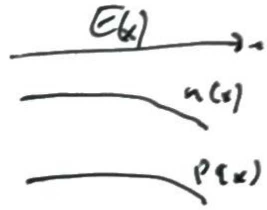
where D_n is called the electron diffusion coefficient, $[D_n] = cm^2/s$.

and $\phi_p(x) = -D_p \frac{dp(x)}{dx}$

$$\boxed{\begin{aligned} J_{n,diff.} &= +q D_n \frac{dn(x)}{dx} \\ J_{p,diff} &= -q D_p \frac{dp(x)}{dx} \end{aligned}}$$

If electric field is also present:

$$\boxed{\begin{aligned} J_n(x) &= q\mu_n \underbrace{n(x) E(x)}_{\text{drift}} + q \underbrace{D_n \frac{dn(x)}{dx}}_{\text{diffusion}} \\ J_p(x) &= q\mu_p p(x) E(x) - q D_p \frac{dp(x)}{dx} \\ J(x) &= J_n(x) + J_p(x) \end{aligned}}$$



$\phi_{p,drift} \rightarrow$

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$J_p \rightarrow$

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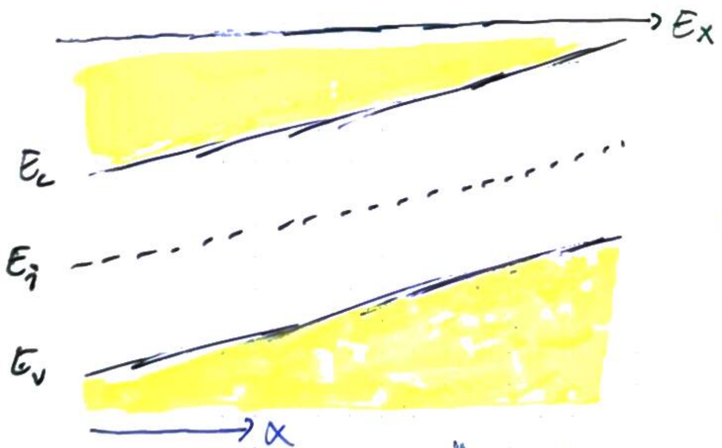
→ Minority carrier currents through diffusion can sometimes be as large as majority carrier currents. (gradient).



$$\left.\begin{aligned} E(x) &= -\frac{dV(x)}{dx} \\ V(x) &= \frac{E(x)}{-q} \end{aligned}\right\} E(x) = \frac{1}{q}\frac{dE_i}{dx}$$

"Electrons drift downhill".

→ $E(x) = \frac{D_p}{\mu_p} \frac{1}{p(x)} \frac{dp(x)}{dx}$, so $\boxed{\frac{D}{\mu} = \frac{k_B T}{q}}$ ← Einstein relation.

$\frac{D}{\mu} \approx 0.026\,V$.

· One-dimensional continuity equation for holes:

$$\frac{\partial \delta p(x,t)}{\partial t} = \frac{1}{q}\frac{\partial J_p(x)}{\partial x} - \frac{\delta p(x,t)}{\tau_p}$$

→ Electrons: $\frac{\partial \delta n}{\partial t} = \frac{1}{q}\frac{\partial J_n}{\partial x} - \frac{\delta n}{\tau_n}$.

· When currents is carried strictly by diffusion, we get the diffusion equations: $\boxed{\frac{\partial \delta n}{\partial t} = D_n \frac{\partial^2 \delta n}{\partial x^2} - \frac{\delta n}{\tau_n}, \quad \frac{\partial \delta p}{\partial t} = D_p \frac{\partial^2 \delta p}{\partial x^2} - \frac{\partial p}{\tau_p}}$

Steady state: $\boxed{\frac{d^2 \delta n}{dx^2} = \frac{\delta n}{D_n \tau_n} \equiv \frac{\delta n}{L_n^2}, \quad \frac{d^2 \delta p}{dx^2} = \frac{\delta p}{D_p \tau_p} \equiv \frac{\delta p}{L_p^2}}$

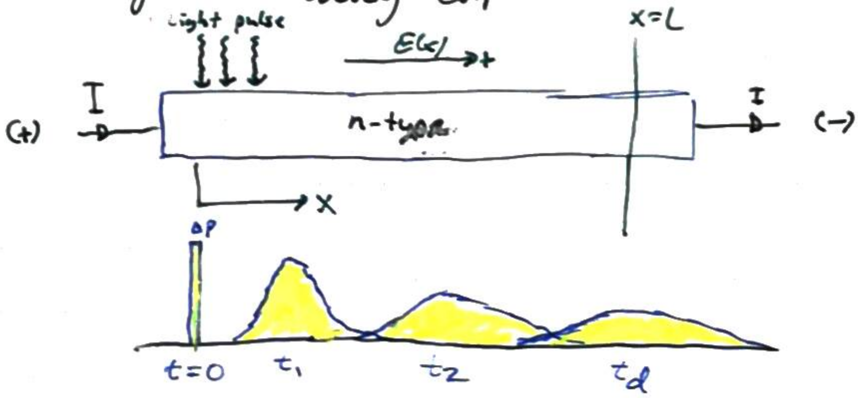
· Electron diffusion length $L_n \equiv \sqrt{D_n \tau_n}$, hole ... $L_p \equiv \sqrt{D_p \tau_p}$.

· Solution to steady state eqns.: $\delta n(x) = \Delta n e^{-x/L_n}$, $\delta p(x) = \Delta p e^{-x/L_p}$.

Average distance a carrier diffuses before recombining.

→ $J_p(x) = -q D_p \frac{dp}{dx} = -q D_p \frac{d\delta p}{dx} = q \frac{D_p}{L_p} \Delta p e^{-x/L_p} = q \frac{D_p}{L_p} \delta p(x)$

· The Haynes-Shockley experiment:



Haluleder - Chapter 4

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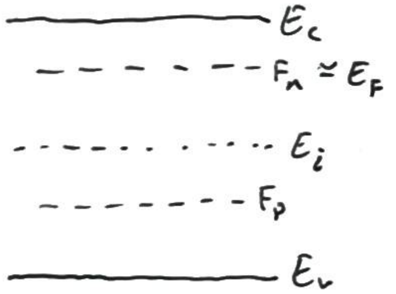

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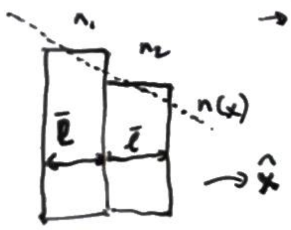

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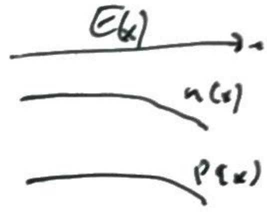

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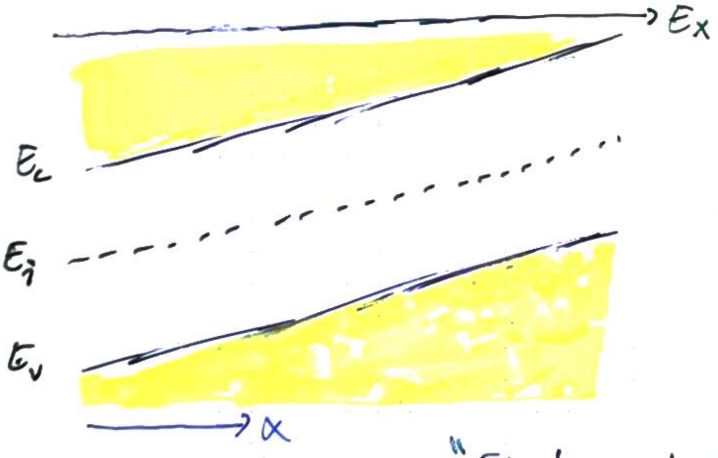

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