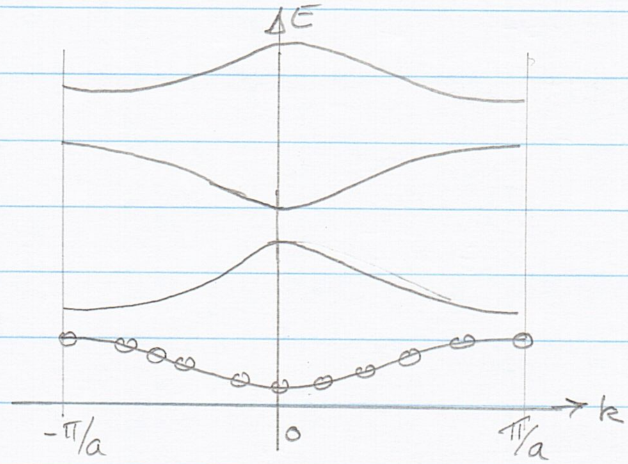
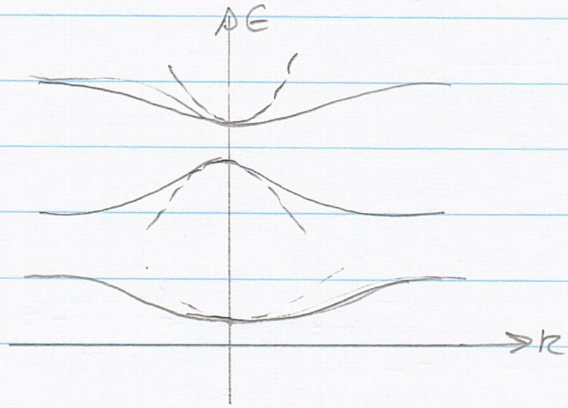
Pre-MT summary EECE 480 2011

LECT. 2.



Energy-band structure
Reduced-zone plot
States (2N / band)
Bandgap

LECT. 3



Parabolic band approximation

$$E = E_{co} + \frac{\hbar^2 k^2}{2m_e^*} \quad \text{for electrons}$$

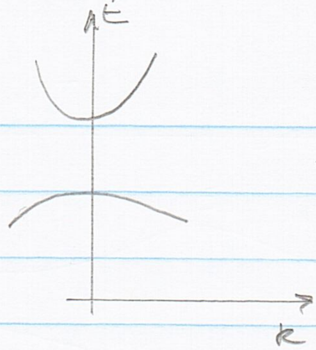
$$m_e^* \propto \left[\frac{d^2E}{dk^2}\right]^{-1}$$

$$F_{ext} = m_e^* \frac{dv}{dt}$$

Factors affected by m_e^* : $\mu \propto 1/m_e^*$ → more easily accelerated
$N_c \propto m_e^*$ → more states / ΔE

Factors affected by E_g : n_i → more E needed to break bond
$J_0 \downarrow$ ($\propto n_i^2$)
$V_{oc} \uparrow$ ($\propto \ln J_{ph}/J_0$)
$J_{ph} \downarrow$ (more transparent)

LECT. 4

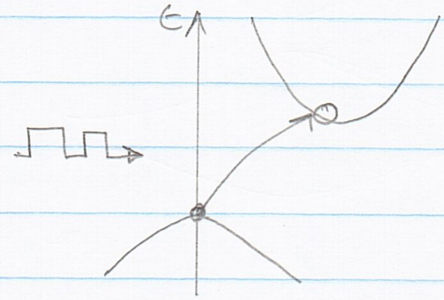


Band diagram

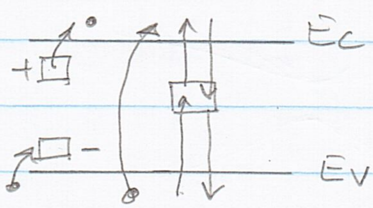
$\rightarrow$

$E_c = E_{c0} + U_M(x)$.

E_v



Indirect bandgap material
phonons



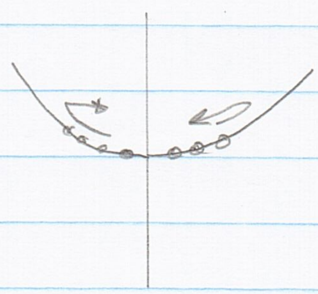
~~I~~ Intrinsic Extrinsic
~~Ac~~ Donors, Acceptors
R-G centres
Thermal Equilib $U = R_{th} - G_{th} = 0$

$R_{RG} = An$ (p-type material)

$U_{RG} = A(n_0 + \Delta n) - An_0 = A\Delta n$

$\hat{=} \Delta n$ (p-type).

$\tau_{e,RG} = f(N_A, N_D)$ $\begin{pmatrix} 3.21 \\ 3.22 \end{pmatrix}$



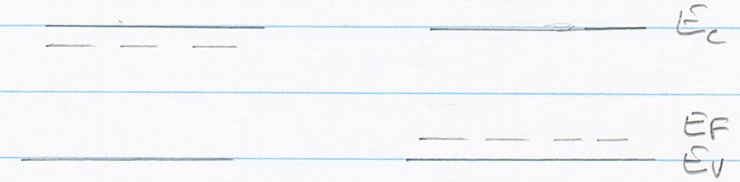
Scattering – randomizing of velocities
– keeps carriers near band extrema.

LECT 5

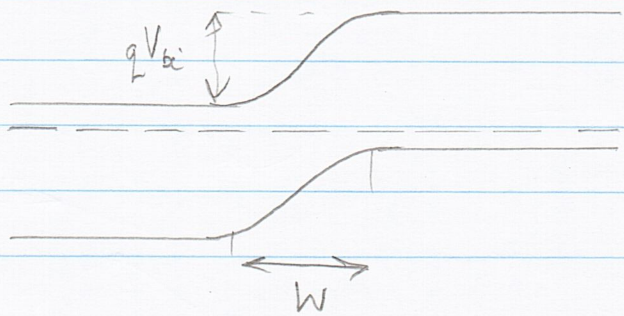
Fermi-Dirac dist^n for state filling

$$f(E) = \frac{1}{1 + \exp^{E-E_F/k_BT}}$$

LECT 5 (cont)



Fermi level

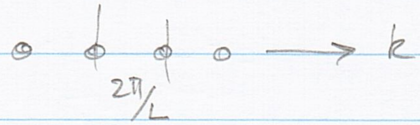


Band diagram (Equilib)

Built-in voltage

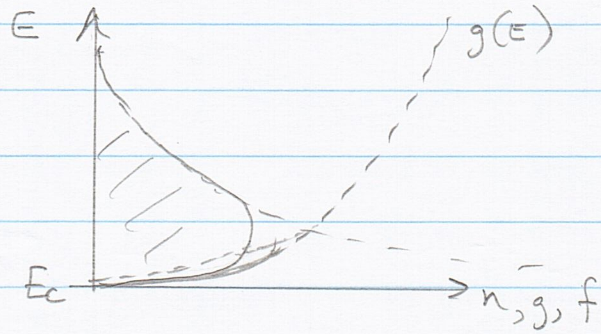
Depletion region

LECT 6



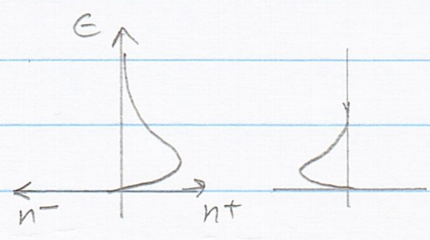
Density of states $g(E)$

$$n_0 = \int_{E_c} g(E)\, f(E)\, dE \rightarrow N_c \exp \frac{E_F - E_c}{k_B T} \quad \text{for MB dist}^n.$$

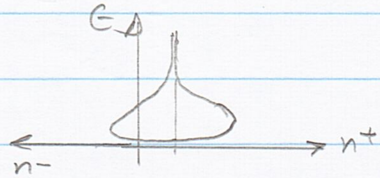


Hemi-maxwellian

$\langle v_x \rangle = 2 v_R \propto \dfrac{1}{m_e^*}$



Diffusion : $J_e = q D_e \dfrac{dn}{dx}$



Displaced Maxwellian

$J_e = -q n v_d$

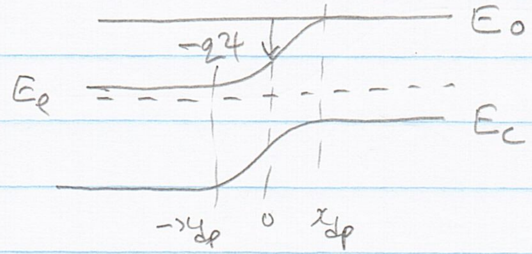
$= +q n \mu \mathcal{E}$

LECT. 7

$$J_e = q n \mu \mathcal{E} + qD\frac{dn}{dx}$$ DDE

$$D_e = \frac{kT}{q}\mu$$ Einstein Relation

$$\mu = f(N_A, N_D)$$ (5.30, 5.31)



Vacuum levels

$-q\psi$

$n_0 \propto \exp^{-(q\psi)/k_BT}$

$$-\frac{d^2\psi}{dx^2} = \frac{\rho}{\varepsilon} = \frac{q}{\varepsilon}\left(-n + p - N_A + N_D\right)$$ $n, p \; f(\psi)$

$$\left.\begin{aligned} n(x), p(x) &\ll N_D \quad -x_p \le x \le 0 \\ &\ll N_A \quad 0 \le x \le x_{dp} \end{aligned}\right\}$$ Depletion Approximation

e.g. $-d^2\psi/dx^2 = -q\frac{N_D}{\varepsilon} \quad -x_{dn} \le x \le 0$

BC's
$$\left.\begin{aligned} -d\psi/dx &= 0 \quad @ \quad x = -x_{dn} \\ -d\psi/dx &= 0 \quad @ \quad x = x_{dp} \\ \psi &= 0 \quad @ \quad x = x_{dp} \end{aligned}\right\}$$ Find $\psi(-x_{dn}) - \psi(x_{dp})$

$= V_J$

$= V_{bi} \quad (V_a = 0)$

$= V_{bi} - V_a$ (biased)

$$\psi(x) = +q\frac{N_D}{\varepsilon}\left(\frac{x^2}{2} - x_{dn}x\right) \quad -x_{dn} \le x \le 0$$ $\psi = f(x)$

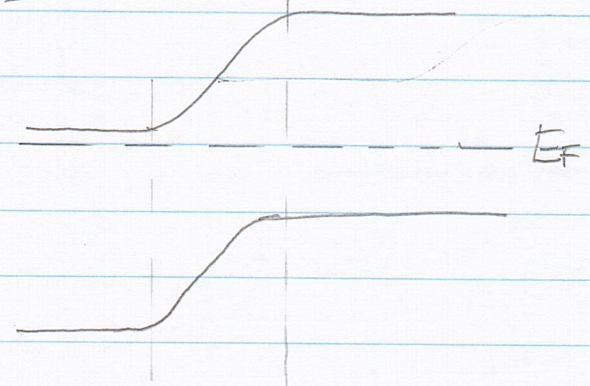
$$qN_D x_{dn} = qN_A x_{dp}$$ charge neutrality

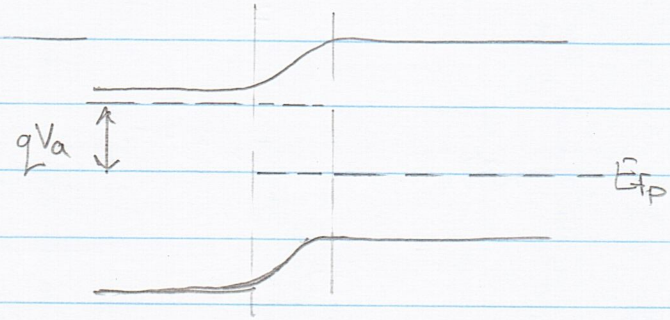
$$x_{dn} + x_{dp} = W$$

$$W = \sqrt{\frac{2\varepsilon}{q} V_J \left(\frac{1}{N_A} + \frac{1}{N_D}\right)}$$

LECT. 8

FORWARD BIAS





W shrinks

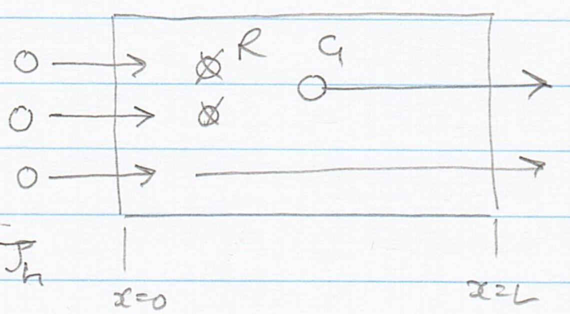
$E_{Fn}(0) - E_{Fp}(L) = |qV_a|$

$V_a = V_J = (V_{bi} + V_a)$

$E_{Fn}, E_{Fp} \approx$ flat across W

$$n = N_c \exp\left(\frac{E_{Fn} - E_c}{k_B T}\right) \equiv n_i \exp\left(\frac{E_{Fn} - E_{Fi}}{k_B T}\right)$$

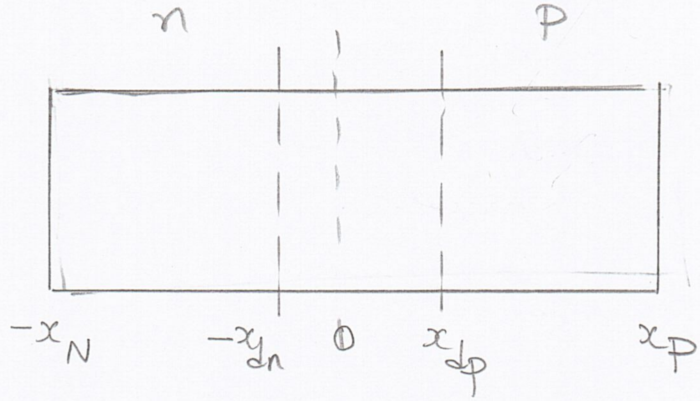
$$E_{Fn} \triangleq k_B T \ln \frac{n}{N_c} + E_c$$



Continuity Equation (for holes)

$$\frac{\partial p}{\partial t} = -\frac{1}{q}\nabla \cdot J_h \underbrace{- R + G}_{-(R-G) \triangleq -U_h}$$

Recall $U_h = \frac{\Delta p}{\tau_h} = \frac{p - p_{on}}{\tau_h}$



8

Sec. 5.3

The master equation set

This is our version of (5.24)

$$\begin{aligned}
-\nabla^2\psi &= \frac{q}{\epsilon}[p - n + N_D - N_A] \\
J_e &= -qn\mu_e\nabla\psi + qD_e\nabla n \\
J_h &= -qp\mu_h\nabla\psi - qD_h\nabla p \\
\frac{\partial n}{\partial t} &= \frac{1}{q}\nabla\cdot J_e - \frac{n-n_0}{\tau_e} + G_{op} \\
\frac{\partial p}{\partial t} &= -\frac{1}{q}\nabla\cdot J_h - \frac{p-p_0}{\tau_h} + G_{op}
\end{aligned}$$

J's are f(n,p), so, essentially, we have

3 equations in 3 unknowns ;

solve numerically. OR simplify & solve analytically

BCs: $x = -x_N$: $p = p_{on}$ OHMIC ; $D_h \frac{dp}{dx} = S_F\left(p(-x_N) - p_{on}\right)$

$x = x_P$: $n = n_{op}$ " ; $-D_e \frac{dn}{dx} = S_B\left(n(x_P) - n_{op}\right)$

$x = x_{dp}$: $n = n_{op}$ SOLAR CELL PHOTOCURRENT

$x = x_{dp}$: $n = n_{op} \exp -qV_a/k_BT$ DARK DIODE

$x = -x_{dn}$: $p = p_{on} \exp -qV_a/k_BT$ DARK DIODE

In p-QNR, e.g.,

$$J_e = q D_e \frac{dn}{dx}$$

$$0 = \frac{1}{q}\frac{dJ_e}{dx} - \frac{(n - n_{op})}{\tau_e}$$

$$\rightarrow \quad 0 = \frac{d^2 n}{dx^2} - \frac{(n - n_{op})}{L_e^2} \qquad L_e = \sqrt{D_e \tau_e}.$$

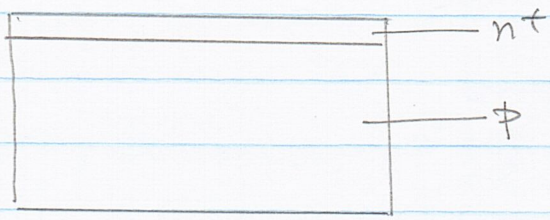
General solution: $n(x) - n_{op} = A e^{x/L_e} + B e^{-x/L_e}$

LECT 9 SOLAR CELL: Add G_{op} to continuity equations

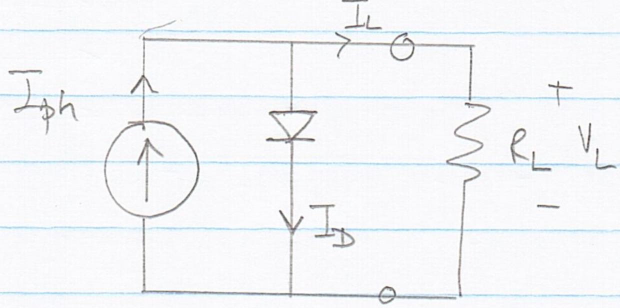
$$G_{op} = \alpha \Phi_0 e^{-\alpha x}$$

α = absorption coeff

Φ = photon flux = $f(\lambda)$

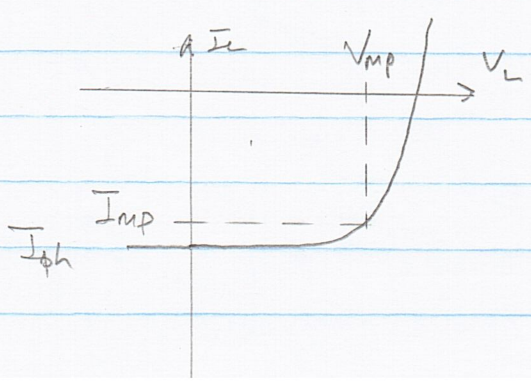


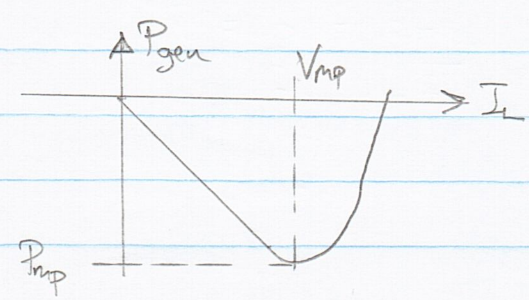
LECT 10



$$I_L = I_{ph} - I_0\left(\exp^{qV_L/k_BT} - 1\right)$$

$$V_{oc} = V_{th} \ln \frac{I_{ph} + I_0}{I_0}$$

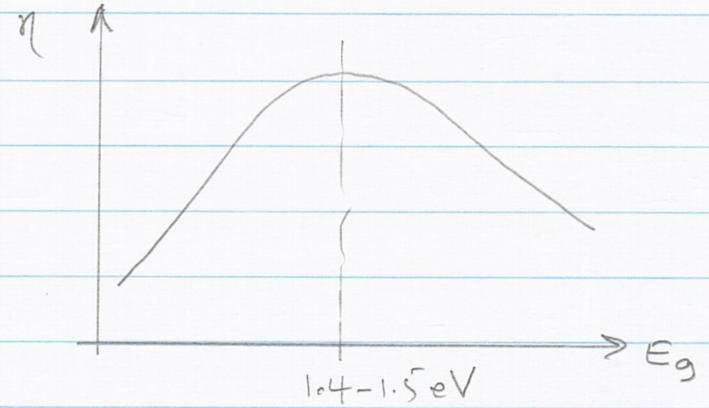




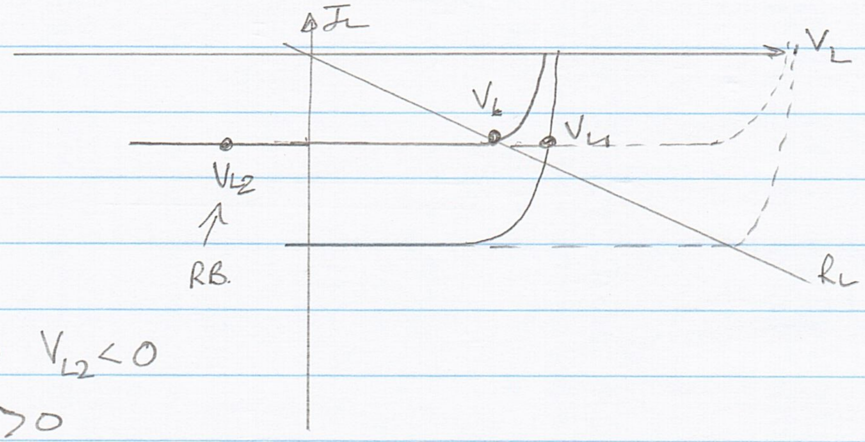
P_{mp} = FF $J_{sc} V_{oc}$

LECT 11

$$\eta = \frac{FF\ J_{sc}\ V_{oc}}{P_{in}}$$



TWO CELLS IN SERIES, ONE SHADED



$I_L < 0 \quad V_{L2} < 0$

$P_{L2} > 0$