MIT 6.772 / SMA 5.111 LECTURE #4

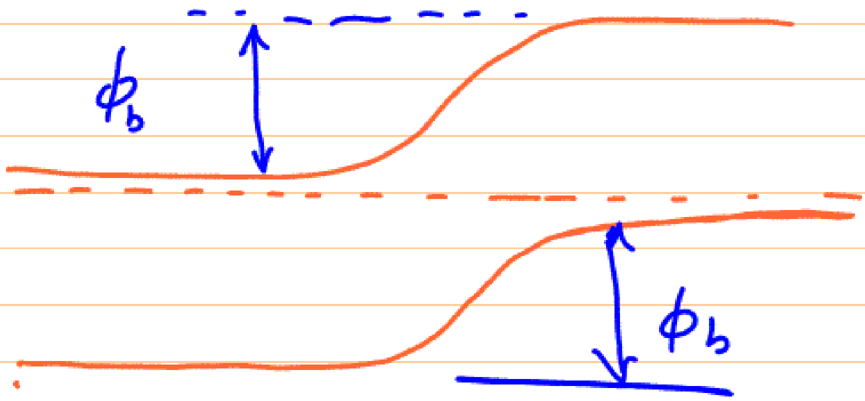
13 FEB. 2003

Note Title 2/10/2003

HETEROJUNCTION CURRENTS

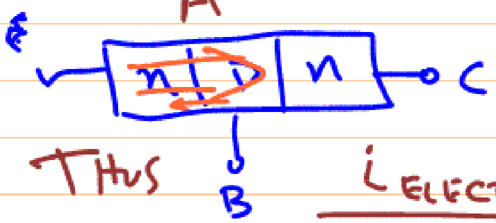
a) NORMAL TO JUNCTION

IN HOMOJUNCTION HOLES AND ELECTRONS SEE THE SAME POTENTIAL BARRIER,



WE FIND $i_D = \underline{\underline{I_S}}\left(e^{qV_{AB}/kT} - 1\right)$

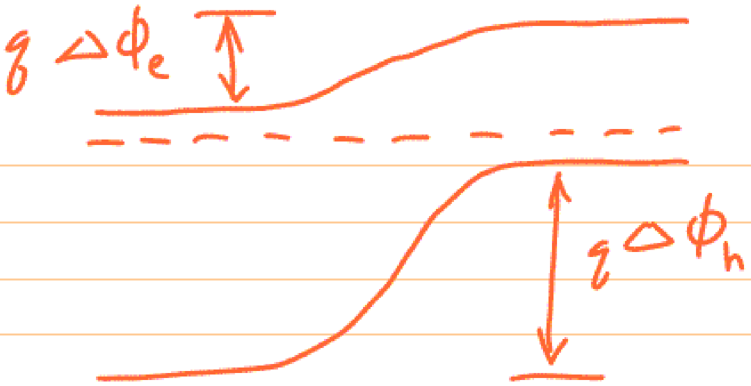
$$\frac{I_S}{A} = q n_i^2 \left(\underbrace{\frac{D_e}{W_p N_{Ap}}}_{\text{electrons}} + \underbrace{\frac{D_h}{W_n N_{Dn}}}_{\text{holes}} \right)$$



THUS $\dfrac{i_{ELECTRON}}{i_{HOLE}} = \dfrac{D_e}{D_h} \times \dfrac{W_n}{W_p} \times \dfrac{N_{Dn}}{N_{Ap}} = \eta_{en}$

$\dfrac{D_e}{D_h}$: 2-3, $\dfrac{W_n}{W_p}$: ≈ 1

TO MAKE $i_E \gg i_H$, MAKE $\underline{\underline{N_{Dn}}} \gg \underline{\underline{N_{Ap}}}$

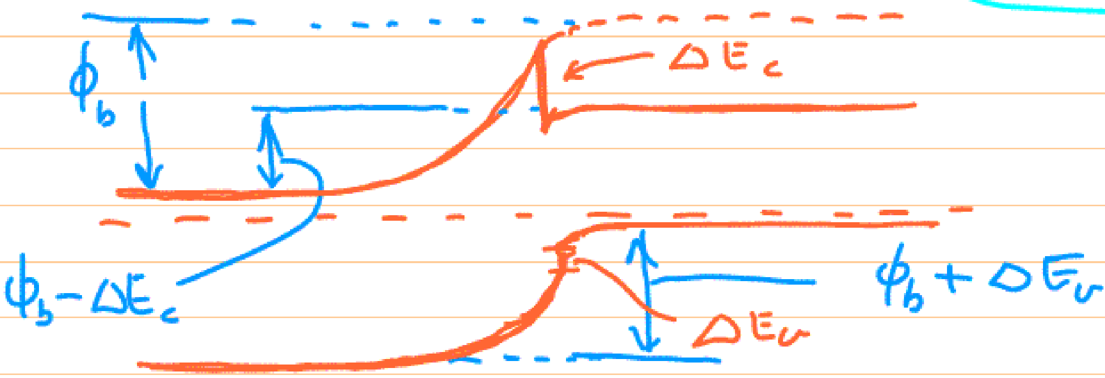


$$\frac{i_{ELECT}}{i_{HOLE}} = \frac{D_e}{D_h} \times \frac{W_n}{W_p} \times \frac{N_{Dn}}{N_{Ap}} \times e^{\frac{q}{KT}(\Delta\phi_h - \Delta\phi_e)}$$

$\frac{D_e}{D_h} \approx 1$, $\frac{W_n}{W_p} \approx 1$

* NOW WE CAN HAVE $i_E \gg i_H$ EVEN IF $N_{Ap} \gg N_{Dn}$

IMPACT OF SPIKE



N - p+

BARRIERS:	W.O. SPIKE	W. SPIKE
ELECTRONS SEE:	$\phi_b - \Delta E_c$	$\sim \phi_b$
HOLES SEE	$\phi_b + \Delta E_v$	$\phi_b + \Delta E_v$
DIFFERENCE	ΔE_g	ΔE_v

AN ASIDE — a useful observation

60mV RULE

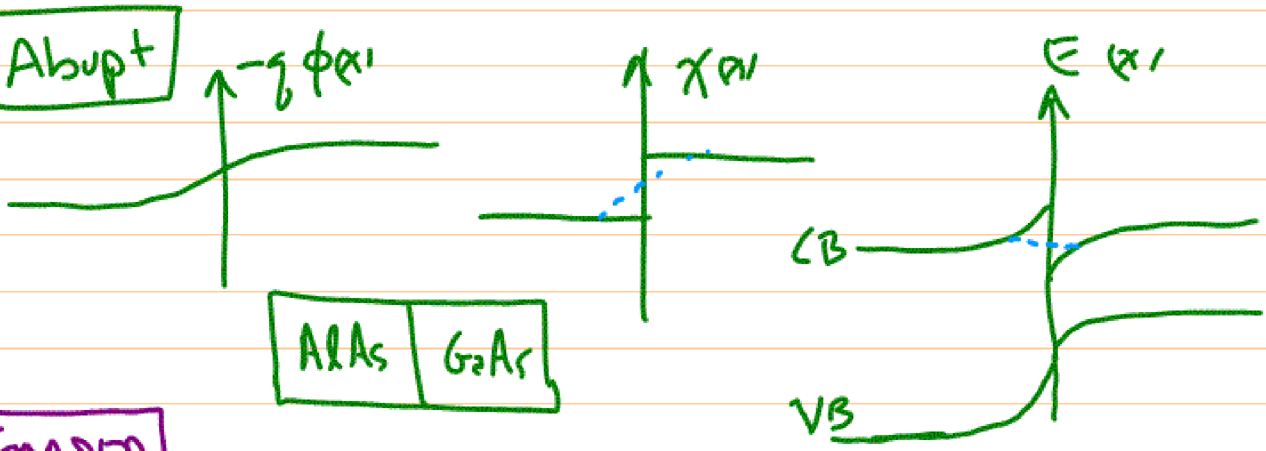
AT R.T. $e^{q(0.06)/kT} \approx 10$

AND $e^{qn(0.06)/kT} \approx 10^{n}$

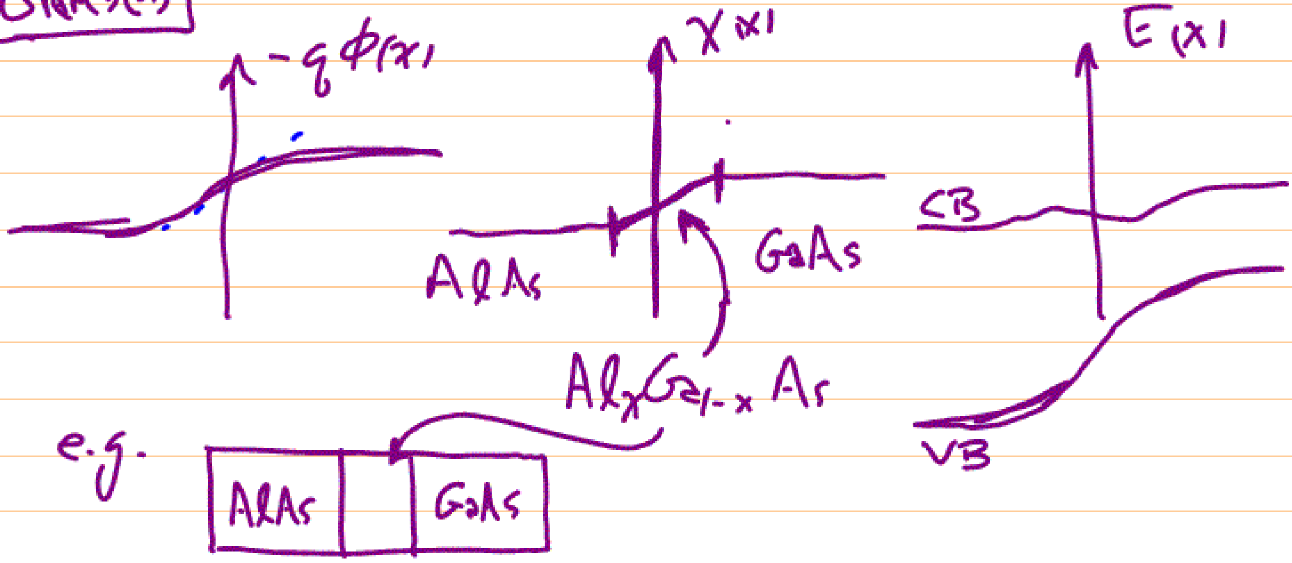
ELIMINATING A SPIKE

RECALL: $E_c(x) = -q\phi(x) - \chi(x)$

Abrupt



GRADED



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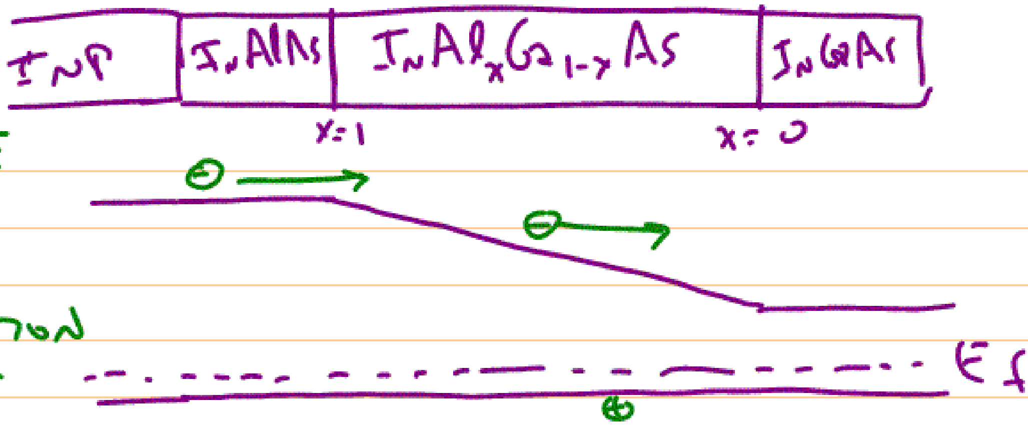
EFFECTIVE FIELD DUE TO COMPOSITION GRADING



IN THERMAL EQUILIB.

$$n_0(x) = N_c e^{-(E_c - E_f)/kT}$$

FERMI LEVEL.

$$p_0(x) = N_v = e^{-(E_f - E_v)/kT}$$

*We use the same relation to define QFL's when not in T.E.

$$n(x) = N_c e^{-(E_c - E_{fn})/kT}$$

QFL for electrons

$$p(x) = N_v e^{-(E_{fp} - E_v)/kT}$$

Quasi Fermi level for holes

QUASI-FERMI LEVELS

$$E_{fn}(x) = \underbrace{E_c(x)}_{-q\phi(x) - \chi(x)} + kT \ln\left[n(x)/N_c(x)\right]$$

$$E_{fp}(x) = \underbrace{E_v(x)}_{-q\phi(x) - [\chi(x) + E_g(x)]} - kT \ln\left[p(x)/N_v(x)\right]$$

USE IN:

$$J_e = n \mu_e \frac{\partial E_{fn}}{\partial x}$$

$$J_h = p \mu_n \frac{\partial E_{fp}}{\partial x}$$

FIND FOR ELECTRONS

$$J_e = \underbrace{-q n \mu_e \frac{\partial \phi}{\partial x}}_{\substack{q n \mu_e \mathcal{E}_x \\ \text{DRIFT}}} \underbrace{- n \mu_e \frac{\partial \chi}{\partial x}}_{\text{New factor}} + \overbrace{q D_e \frac{\partial n}{\partial x}}^{\text{DIFFUSION}} \cancel{- q D_e \frac{n}{N_c} \frac{\partial N_c}{\partial x}}$$

New also but small ∴ neglect

FOR HOLES WE FIND SIMILARLY:

$$J_h \approx \text{DRIFT} + \text{DIFFUSION} - p \mu_h \frac{\partial}{\partial x}(\chi + E_g)$$

("$\approx$" BECAUSE WE NEGLECT $\partial N_v / \partial x$)

WE CAN THINK OF $\partial \chi / \partial x$ AND $\partial(\chi + E_g)/\partial x$ AS "EFFECTIVE" ELECTRIC FIELDS THAT ADD TO THE DRIFT ALONG WITH OUR "TRADITIONAL" ELECTRIC FIELD, $-q\,\partial\phi/\partial x$. CLEARLY THE EFFECTIVE FIELD IS DIFFERENT FOR HOLES AND ELECTRONS.