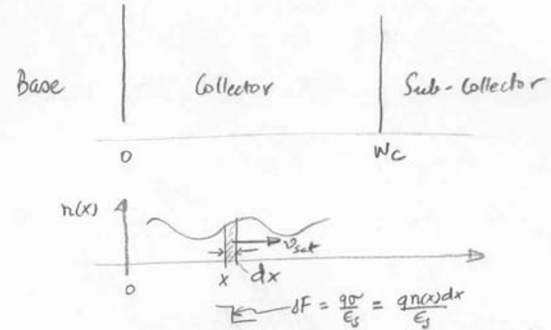
ASSIGNMENT 8 - SOLUTIONS

Soln. by Debdeep Jena

EE 566 - SOLID STATE DEVICES

PROBLEM I : To show that collector - transit time is $W_C/2v_{sat}$

a)



$$\delta F = \frac{q\sigma}{\epsilon_s} = \frac{q\,n(x)\,dx}{\epsilon_s}$$

Consider a slice of the charge of thickness dx @ x. The slice travels at a velocity v_{sat} from base to collector. I'll give a solution given in the solution by Qin Zhang, which is elegant →

$$\frac{dJ_D}{dx} = \frac{\partial}{\partial x}\left(\frac{\partial D}{\partial t}\right) = \frac{\partial}{\partial t}\left(\underbrace{\frac{\partial D}{\partial x}}_{\rho_f \to \text{free charge}}\right) = \frac{\partial \rho_f}{\partial t} = \frac{1}{A\cdot W_c}\,\overset{q\,n(x)A}{\frac{\partial Q_f}{\partial x}}\underbrace{\left(\frac{\partial x}{\partial t}\right)}_{v_{sat}}$$

$$= \frac{q\,v_{sat}\,n(x)}{W_c}$$

$$\Rightarrow \quad J_D = \frac{q\,v_{sat}}{W_c}\int_0^{W_c} dx\; n(x) \; .$$

b)

$$|J_D| = \left|\frac{q v_{sat}}{W_c}\int_0^{W_c} dx\; n(x)\right| = \frac{q v_{sat}\, n_0}{W_c}\left|\underbrace{\int_{x=0}^{W_C} dx\; e^{-i\omega\frac{x}{v_{sat}}}}_{\text{evaluates to } 2W_C * \left(\frac{\sin \omega\tau_c}{\omega\tau_c}\right) \text{ where } \tau_c = \frac{W_c}{2v_{sat}}.}\right| \cdot \left|e^{i\omega t}\right|$$

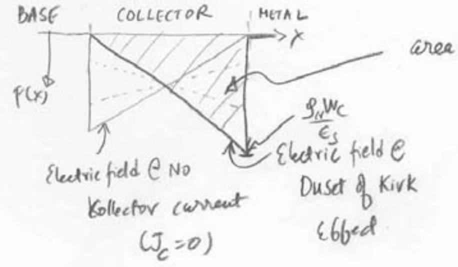
$$\Rightarrow \quad |J_D| = q\, n_0 v_{sat}\left|\frac{\sin(\omega\tau_c)}{\omega\tau_c}\right| \quad \& \quad \boxed{\tau_C = \frac{W_c}{2v_{sat}}}$$

ASSIGNMENT 8 - SOLN^S - CONTD ...

Soln. by Dalideep Jena

PROBLEM II : HBT KIRK-EFFECT (BASE PUSHOUT)

a)



$$\text{area} = (V_{CB} + V_{bi}) = \frac{1}{2\epsilon_S}\Big(\underbrace{-qN_{DC}^{+} + \frac{J_{Kirk}}{v_{sat}}}_{\rho_{cr}}\Big) W_C^2$$

ρ_{cr} ← critical carrier density!

has to be negative!

$$\therefore \quad J_{Kirk} = \left[\frac{2\epsilon_S}{W_C^2}(V_{CB} + V_{bi}) + qN_{DC}^{+}\right] * v_{sat}$$

$$\boxed{J_{Kirk} = \frac{2\epsilon_S v_{sat}(V_{CB} + V_{bi})}{W_C^2} + qN_{DC}^{+} v_{sat}}$$

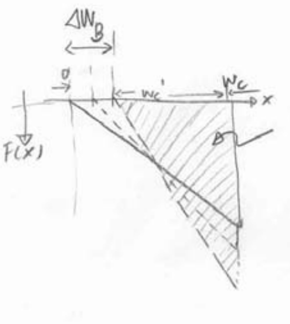
$$V_{bi} = \frac{kT}{q}\ln\left(\frac{N_{DC}N_{AB}}{n_i^2}\right) = 1.34 \text{ Volt} \qquad v_{sat}(\text{GaAs}) \approx 10^7 \text{ cm/s}$$

$$\Rightarrow \quad J_{Kirk} = \left[\frac{2 * 12.9 * 8.85 * 10^{-14} * 10^7 * (4 + 1.34)}{(10^4 * 10^{-7})^2} + 1.6 * 10^{-19} * 10^{17} * 10^7\right] \text{A/cm}^2$$

$$\approx 122 \ \frac{\text{A}}{\text{cm}^2} + 160 \text{ kA/cm}^2$$

$$\boxed{J_{Kirk} \approx 160 \text{ kA/cm}^2}, \quad J_{Kirk} - qN_{DC}^{+} v_{sat} \approx 122 \text{ A/cm}^2$$

b)



$$\text{Area still} \rightarrow V_{CB} + V_{bi} = \frac{1}{2\epsilon_S}\left[-qN_{DC}^{+} + \frac{J_C}{V_{sat}}\right] W_C'^2$$

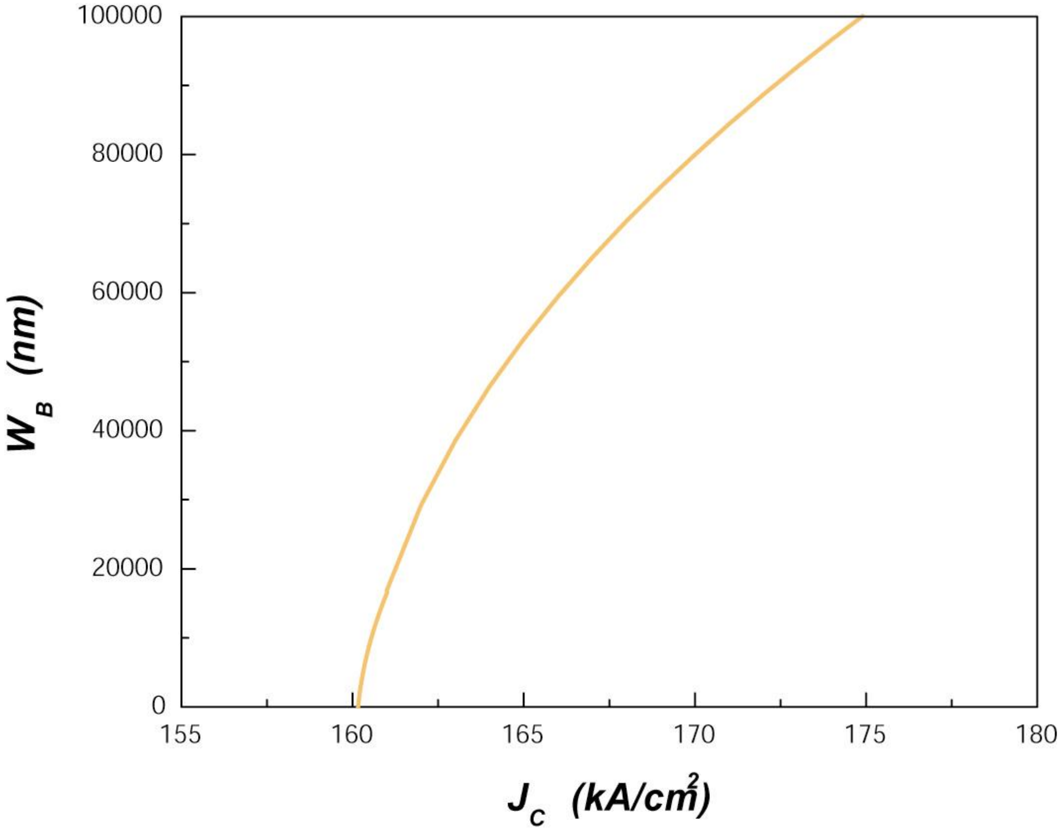
$$\text{also,} \quad V_{CB} + V_{bi} = \frac{1}{2\epsilon_S}\left[-qN_{DC}^{+} + \frac{J_{Kirk}}{v_{sat}}\right] W_{C0}^2$$

$$\therefore \Delta W_B = W_{C0} - W_C'$$

$$= \left(1 - \frac{W_C'}{W_{C0}}\right) W_{C0} = W_{C0} * \left[1 - \frac{\sqrt{J_C - qN_{DC}^{+} v_{sat}}}{\sqrt{J_{Kirk} - qN_{DC}^{+} v_{sat}}}\right]$$

$$\Rightarrow \quad \boxed{\Delta W_B = W_{C0} * \left[1 - \sqrt{\frac{J_C - qN_{DC}^{+} v_{sat}}{J_{Kirk} - qN_{DC}^{+} v_{sat}}}\right]}$$

Plot on next page.



ASSIGNMENT 8 - SOLN^S CONT'D:

ⓒ Kirk-effect widens the base $\Rightarrow$ $GN_B \uparrow$ $\Rightarrow$ $\beta_F \downarrow$.

To reduce the effect, $W_C \downarrow$, dope slightly heavily, but not too much since ~~V_{EB}~~ B_C Breakdown @ C-B j^n will suffer!