EE566 Solid State Devices

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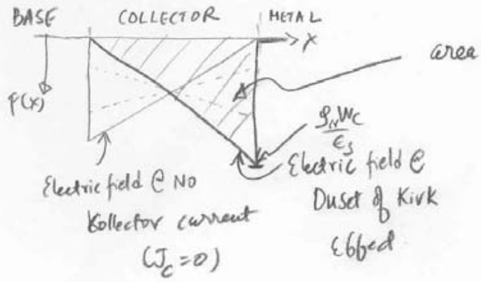
Assignment 8
SOLUTIONS

Problem 1: Solution

PROBLEM II : HBT KIRK- EFFECT (BASE PUSHOUT)

a)



$$\text{area} = (V_{CB} + V_{bi}) = \frac{1}{2\epsilon_s}\Big(\underbrace{-qN_{DC}^{+} + \overset{\text{has to be negative!}}{\frac{J_{Kirk}}{v_{sat}}}}_{\rho_{cr} \leftarrow \text{critical carrier density!}}\Big)W_c^2$$

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

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

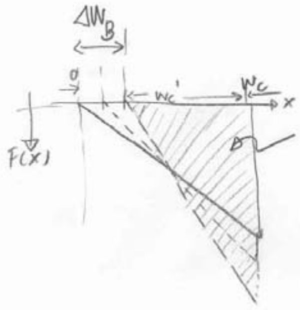
$$V_{bi} = \frac{kT}{q}\ln\left(\frac{N_{DC}N_{AB}}{n_i^2}\right) = 1.34 \text{ Volt} \qquad v_{sat}(\text{GaAs}) \approx 10^7 \text{ cm/s}$$

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

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

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

b)



$$\text{Area still} \rightarrow V_{CB} + V_{bi} = \frac{1}{2\epsilon_s}\left[-qN_{DC}^{+} + \frac{J_c}{v_{sat}}\right]W_c'^2$$

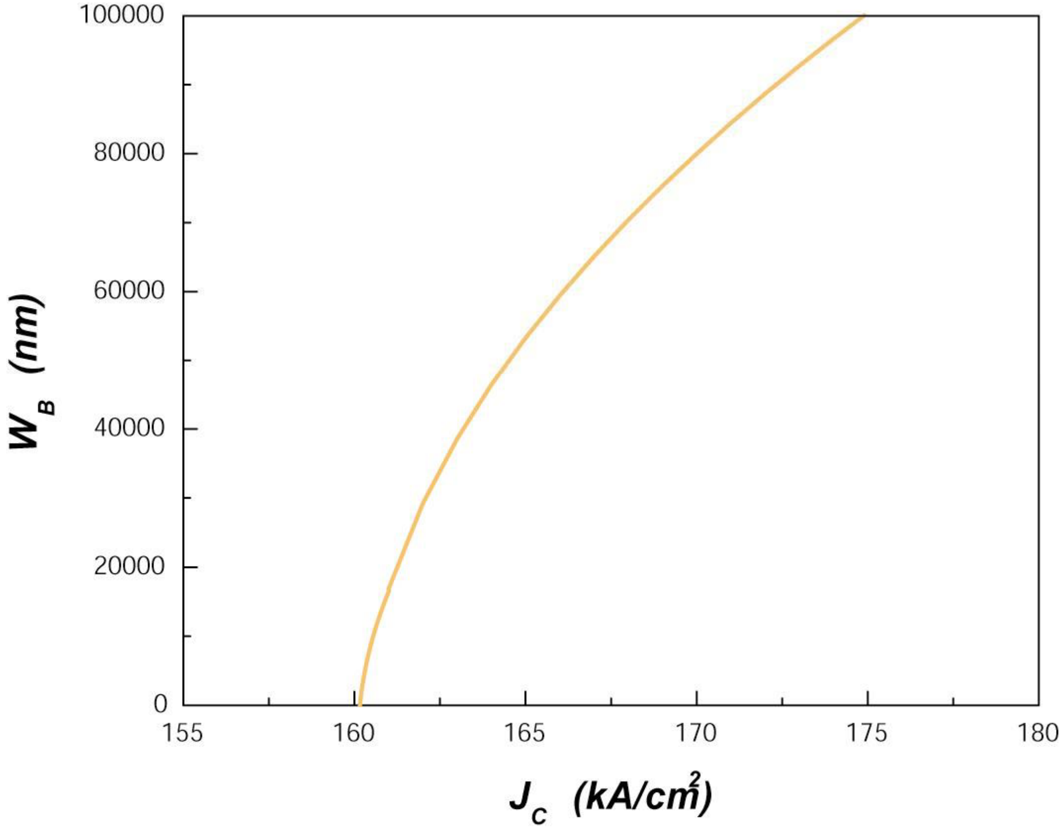
$$\text{also,} \quad V_{CB} + V_{bi} = \frac{1}{2\epsilon_s}\left[-qN_{DC}^{+} + \frac{J_{Kirk}}{v_{sat}}\right]W_{c0}^2$$

$$\therefore \Delta W_B = W_{c0} - W_c'$$

$$= \left(1 - \frac{W_c'}{W_{c0}}\right)W_{c0} = W_{c0} * \left[1 - \frac{\sqrt{J_c - qN_{DC}^{+}v_{sat}}}{\sqrt{J_{Kirk} - qN_{DC}^{+}v_{sat}}}\right]$$

$$\Rightarrow \boxed{\Delta W_B = W_{c0} * \left[1 - \sqrt{\frac{J_c - qN_{DC}^{+}v_{sat}}{J_{Kirk} - qN_{DC}^{+}v_{sat}}}\right]}$$

Plot on next page.



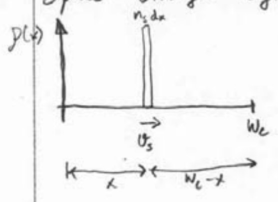
④ ASSIGNMENT 8 - SOLN^S CONT:

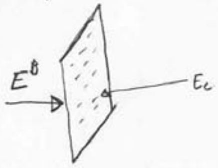
ⓒ Kirk-effect widens the base $\Rightarrow GN_B \uparrow \Rightarrow \beta_F \downarrow$

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

Problem 2: Solution

3. The e^-'s in the depletion are terminated partly on the base and partly on the collector. Why? Consider the following (which is completely analogous to finding the delay through the collector region. In the space charge region.



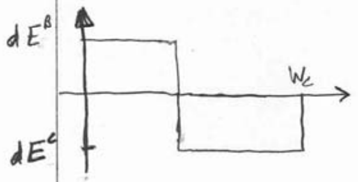


from Gauss' Law we know for the a sheet charge

$$\oiint \bar{E} \cdot dA = \iint_s \frac{\sigma}{\epsilon}$$

$$E^B A - E^C A = \frac{\sigma A}{\epsilon}$$

$$E^B - E^C = \frac{\sigma}{\epsilon}$$



$$dE^B - dE^C = \frac{q n_s dx}{\epsilon}$$

$$x\,dE^B + dE^C(W - x) = 0$$ Current flowing through the depletion cannot produce a change in Voltage

$$dE^C = -dE^B\left(\frac{x}{W_c - x}\right).$$

$$n_s = \frac{J_c}{q v_{sat}}$$

$$dE^B\left(1 + \frac{x}{W_c - x}\right) = \frac{q n_s dx}{\epsilon}$$

$$= \frac{J_c\, dx}{v_{sat}\epsilon}$$

$$dE^B = \frac{dQ_B}{\epsilon} = \frac{J_c\, dx\,(W_c - x)}{v_{sat}\epsilon\ \ W}$$

$$Q_B = \frac{J_c}{v_{sat}}\int_0^{W_c}\left(1 - \frac{x}{W_c}\right)dx$$

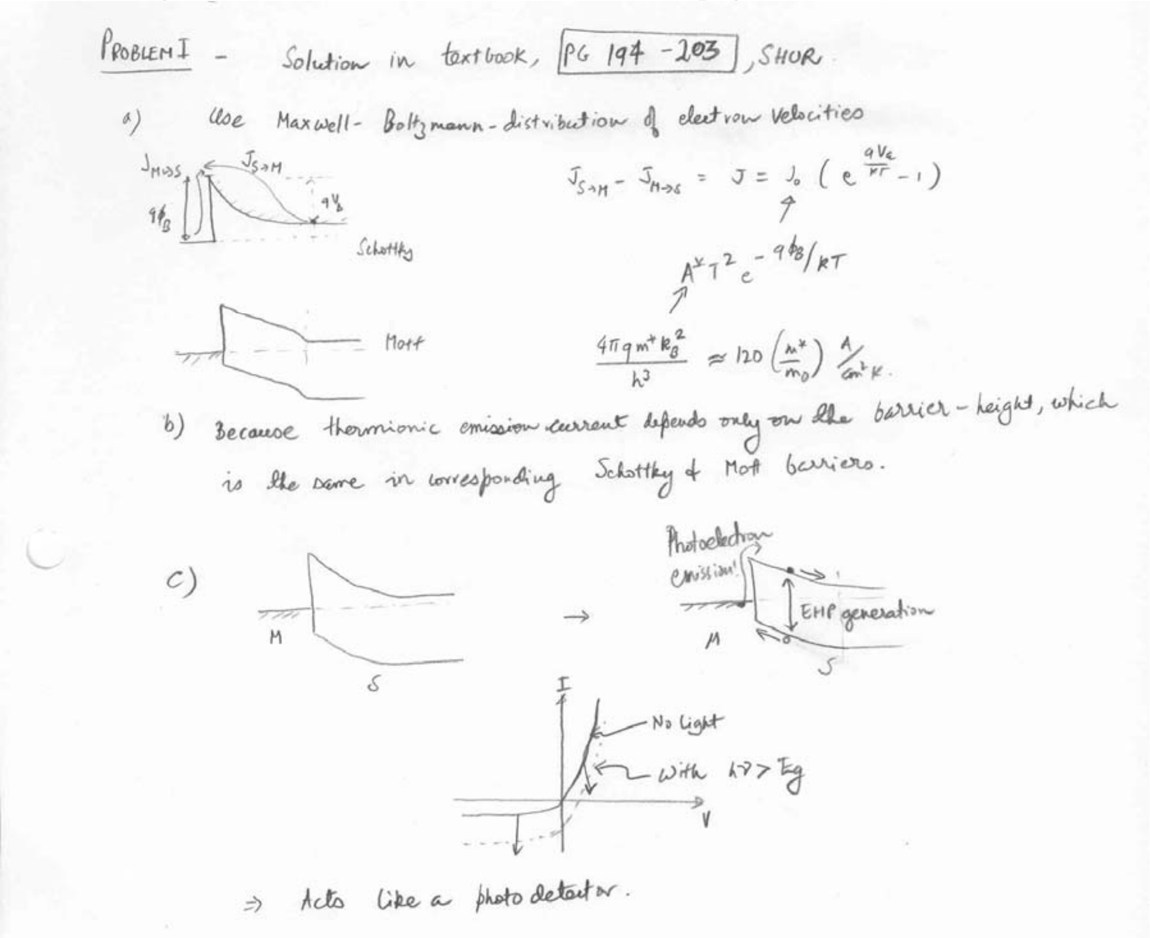
~~Good.~~

$$\tau_{BC} = \frac{Q_B}{J_c} = \frac{1}{v_{sat}}\int_0^{W_c}\left(1 - \frac{x}{W_c}\right)dx$$

$$= \frac{W_c}{2 v_{sat}}$$

Problem 3: Solution

Derivation of Richardson’s constant given in various books (Textbook - page 234, and derived using a different flavor in Muller & Kamins – pages 152-155).



PROBLEM I - Solution in textbook, $\boxed{\text{PG } 194 - 203}$, SHUR

a) Use Maxwell-Boltzmann-distribution of electron velocities

$$J_{S \to M} - J_{M \to S} = J = J_0 \left(e^{\frac{qV_a}{kT}} - 1 \right)$$

$$J_0 = A^* T^2 e^{-q\phi_B/kT}$$

$$A^* = \frac{4\pi q m^* k_B^2}{h^3} \approx 120 \left(\frac{m^*}{m_0} \right) \text{A/cm}^2\text{K}.$$

b) Because thermionic emission current depends only on the barrier-height, which is the same in corresponding Schottky & Mott barriers.

c)

$\Rightarrow$ Acts like a photo detector.

Problem 4 was open-ended.
Most of the answers are found in the review paper handed out in class –
“Silicon Device Scaling to the Sub-10-nm Regime”
by Ieong et al,
Science vol 306, page 2057 (2004).

Additional up-to-date information may be found at
http://public.itrs.net/

and at
http://www.intel.com/research/
Look at the “Silicon” section in the drop-down menu “Technology and Research” at the top of the page – lot of latest information, including the 45nm MOSFET technology.