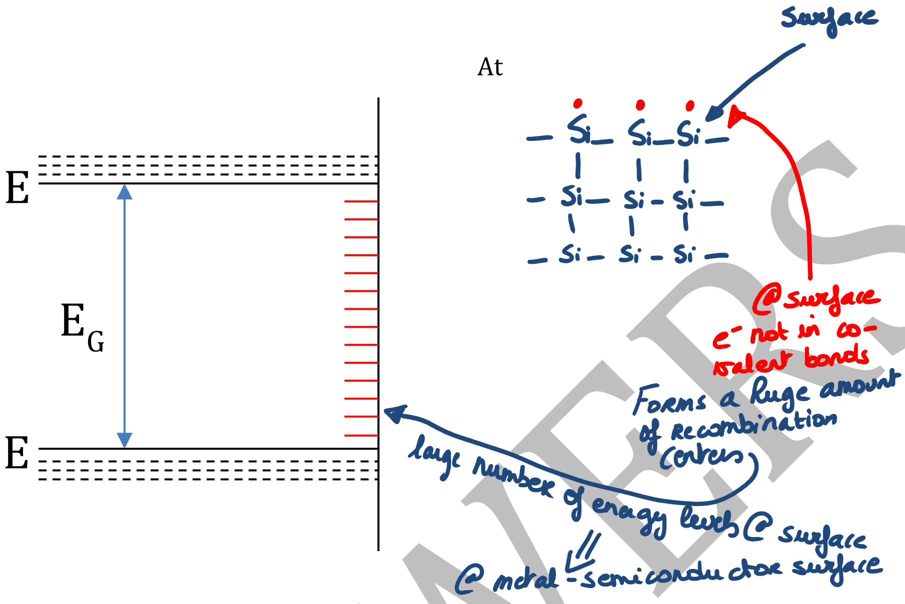
ANSWERS –2015

1. a) With reference to the figures below. At the contact the covalent bonds between the Si atoms at the surface are broken. This leaves a large density of surface electrons in Si near the Si-metal surface that can form bonds with other species or becomes free when those bonds are broken. Thus these electrons form a large number of recombination centres at the surface (electrons recombine and are generated), this is represented by a large number of energy levels within the bandgap at the surface between Si and metal in the Si. The large number of traps increases the recombination and generation rates of carrier. The rates are approximated as being infinite as a consequence. [5]



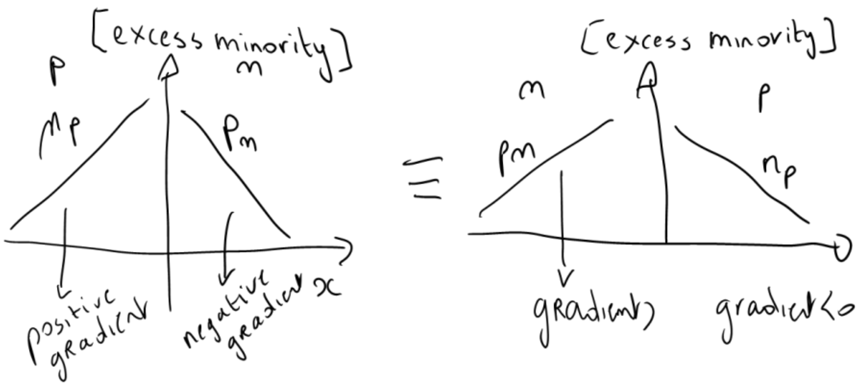
Most were aware it has something to do with generation-recombination but could not explain the effect further. This question is based on information that is explained during the lecture whereby students need to fill in the missing explanation on the ppt slide. Few students (a handful) had this question right.

b)

i) In the p-type region because U_n refers to minority carrier electrons. [2]

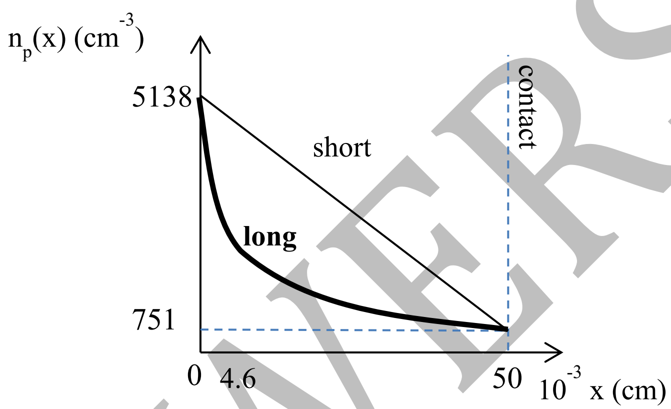
ii) Both are larger than zero because in forward bias, the recombination rate is larger than the generation rate. And thus $\frac{\delta n}{\tau_n}$ and $\frac{\delta p}{\tau_p}$ in the continuity equations (see formulae sheet) must be positive. An equally acceptable explanation is that since $n_p > n_{po}$ and $p_n > p_{no}$ in forward bias the difference in the U equations is positive. [3]

Common mistake was to associate the sign to what is drawn in the solution plot (see below) with Un positive and Up negative. The axis choice can be different, thus cannot be right. The solution comes from the fact that Un and Up are both positive in the differential equation because recombination takes place.



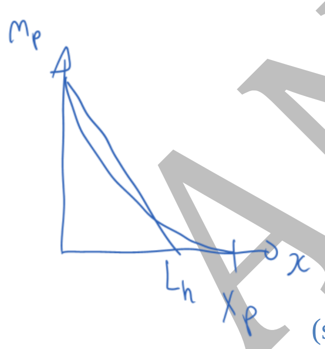
c) i) $n_{po} = n_i^2/N_A = (1.45\ 10^{10})^2/2.8\ 10^{17} = 751\ cm^{-3}$.

$n'_p = n_{po}\ \exp(V/V_T) = 751\ \exp(0.05/0.026) = 5138\ cm^{-3}$. [4]



4.6 10^{-3} cm is the electron minority carrier diffusion length

Common mistake is the following plot:



(short and long approximation should have been drawn for the same device length) and not giving values.

ii) <u>short</u>. [6]

$n_p(x) = -[(n'_p - n_{po})/X_p]\ x + n'_p$

minority carrier charge Qn: excess triangle + equilibrium rectangle

$Q_n = -e\ A\ [(n'_p - n_{po})\ X_p/2 + n_{po}\ X_p]$

$Q_n = -1.6\ 10^{19}\ C\ 10^{-4}\ cm^{-2}\ [(5138-751)\ cm^{-3}\ 50\ 10^{-3}\ cm/2 + 751\ cm^{-3}\ 50\ 10^{-3}\ cm]$

$Q_n = -4.11\ 10^{-21}\ C$

<u>long</u>.

See formulae sheet for expression of excess carrier concentration

$$n_p(x) = \delta n_p + n_{po} = \left(n'_p - n_{po}\right)\exp\left(\frac{-x}{L_n}\right) + n_{po}$$

$$Q_n = -eA\int_0^{X_p}\left[\left(n'_p - n_{po}\right)\exp\left(\frac{-x}{L_n}\right) + n_{po}\right]dx$$

$$Q_n = -eA\left[-\left(n'_p - n_{po}\right)L_n\exp\left(\frac{-x}{L_n}\right) + n_{po}x\right]_0^{X_p}$$

$$Q_n = -eA\left[-\left(n'_p - n_{po}\right)L_n\left\{\exp\left(\frac{-X_p}{L_n}\right) - 1\right\} + n_{po}X_p\right]$$

$$= -1.6\,10^{-19}\,10^{-4}\left[-\left(5138 - 751\right)4.6\,10^{-3}\left\{\exp\left(\frac{-50\,10^{-3}}{4.6\,10^{-3}}\right) - 1\right\} + 751\times 50\,10^{-3}\right]$$

$$= -9.2\,10^{-22}\,C$$

Difference is:

$|\Delta Q| = 4.11\,10^{-21} - 9.2\,10^{-22} = 3.2\,10^{-21}$ C

Thus the short approximation overestimates the charge in the region, consistent with the drawing in 1ci.

Common errors were (but overall question solved OK):

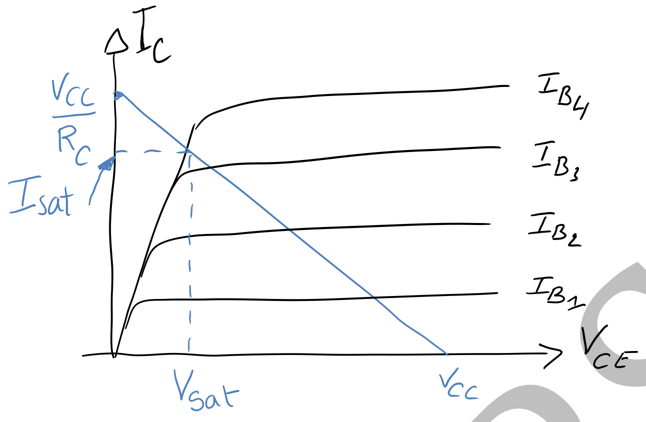
Only calculating excess in one case and then taking equilibrium concentration into account in the other case.

Conversion from μm^2 to cm^2 …..

2.

a) i) see black lines in plot $|I_{B1}| < |I_{B2}| < |I_{B3}| < |I_{B4}|$. [5]

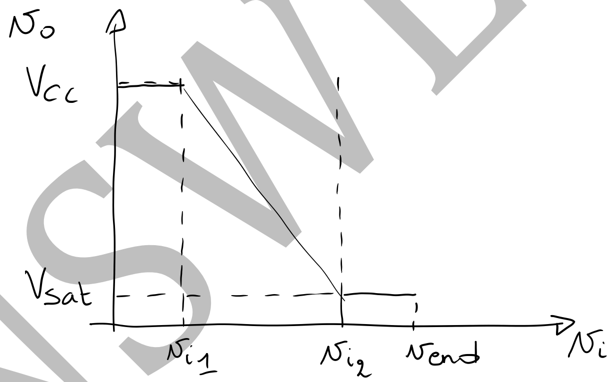
ii) load line: blue line on the plot. [5]



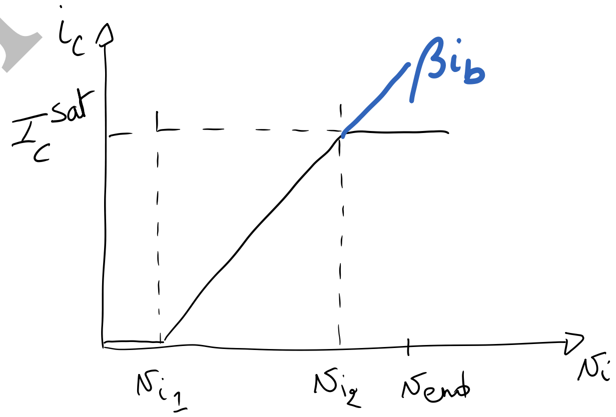
$I_C = -\frac{V_{CE}}{R_C} + \frac{V_{CC}}{R_C}$ note that $V_{CE} = -v_o$

Question answer OK for most.

b) i) . [5]



ii). [5]



Most common mistake is to plot vo low when BJT off and ic high. When BJT is off the current should be low and the BJT is an open switch so voltage high. Many did not plot β ib

c) i) For *t<0* $i_p(t=0)=0$ (switching from zero bias in current and voltage), then $Q_n(t=0)=0$.

For $t \geq 0$ $i_p(t) = I_B$ (EB bias circuit determines the current that is flowing, the potential drop across the diode is small and the depletion region needs to be removed, therefore $I_B = V_{iON}/R_B$). $Q_n(t)$ cannot change immediately. BJT goes into saturation when $i_B > V_{CC}/(\beta \times R_C)$ [5]

$$I_B = \frac{Q_n(t)}{\tau_n} + \frac{dQ_n(t)}{dt}$$

$$\frac{dQ_n(t)}{Q_n(t) - I_B\tau_n} = \frac{-dt}{\tau_n}$$

$$\int_{Q_n(t=0)}^{Q_n(t)} \frac{dQ_n(t)}{Q_n(t) - I_B\tau_n} = \int_0^t \frac{-dt}{\tau_n}$$

$$\ln\left(Q_n(t) - I_B\tau_n\right)\Big|_{Q_n(t)} - \ln\left(Q_n(t) - I_B\tau_n\right)\Big|_{Q_n(0)} = \frac{-t}{\tau_n}$$

$$\ln\left(\frac{Q_n(t) - I_B\tau_n}{-I_B\tau_n}\right) = \frac{-t}{\tau_n}$$

$$Q_n(t) - I_B\tau_n = -I_B\tau_n \exp\left(\frac{-t}{\tau_n}\right)$$

$$Q_n(t) = I_B\tau_n\left(1 - \exp\left(\frac{-t}{\tau_n}\right)\right)$$

For $t < t_s$, thus before the BJT reaches saturation, i_C follows $Q_n(t)$.

$$i_C(t) = \frac{Q_n(t)}{\tau_t} = \frac{I_B\tau_n}{\tau_t}\left(1 - \exp\left(\frac{-t}{\tau_n}\right)\right)$$

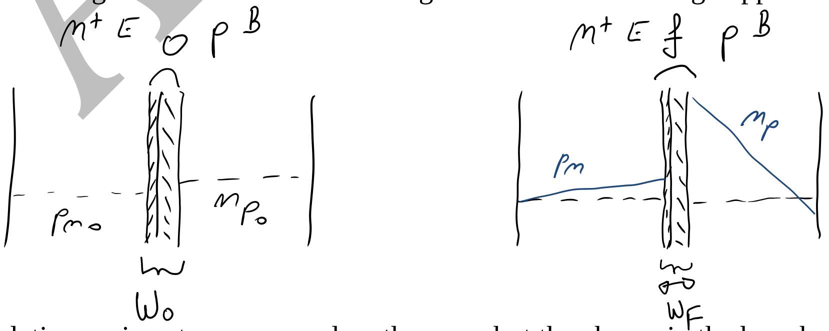
For $t > t_s$

$$i_C(t) \approx \frac{V_{CC}}{R_C}$$

Most common mistake are in the boundary conditions: $Q_n(0) = 0$ & $i_b(0) = I_B$.

ii) The switch-on time will increase. [5]

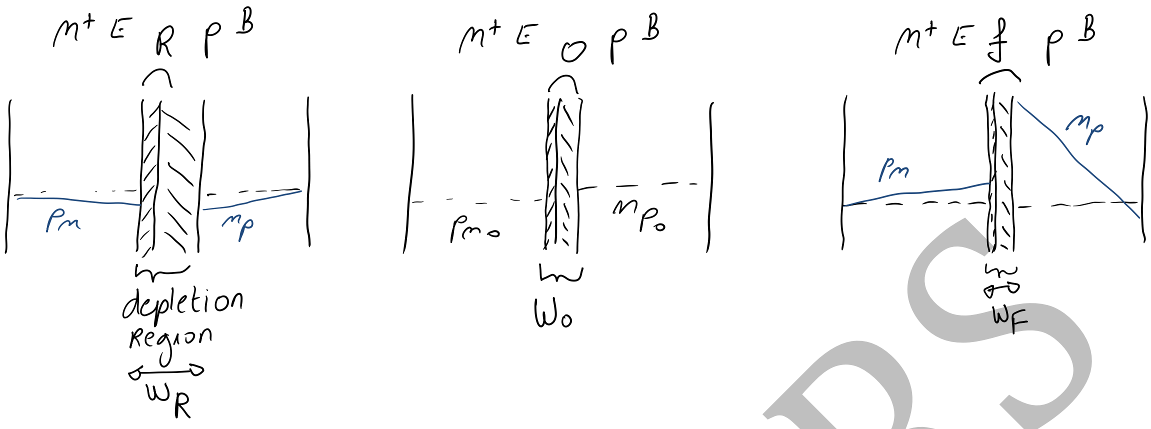
When switching from unbiased and uncharged to ON the following happens:



The depletion region stays more or less the same but the charge in the base builds up (here it is drawn below saturation). The time it takes is as calculated in i)

When the EB junction is reverse biased before t = 0s (the on switch event) then there exists a depletion region across this junction that is far greater than that at zero bias. In order to switch on, first the depletion region needs to be removed by repopulating it with mobile carriers. This can be described as a capacitive effect with a delay approximately given by $C_{depl} * R_B$ with C_{depl} the depletion layer capacitance that is inversely proportional to the depletion width.

This is illustrated in the next sketches:



Thus now switching happens in 3 steps: first capacitive delay to remove depletion region (left fig), then the middle fig. situation is reached and then the base can be charged and i_C can flow.

Very few realised that the delay is mostly due to depletion charge. All calculations with –IB, as done for the switch off from t=0 to t= tsd are wrong because the current through the diode is small now.

There is a deficit in base charge now, most kept on writing about excess.

Note that Cdepl is inversely proportional to the depletion width of the diode.

FINAL REMARK: EVERY YEAR THE TYPE OF QUESTIONS CHANGES, THEREFORE IT IS UNWISE TO RELY SOLELY ON SOLVING PAST EXAM PAPERS TO PREPARE YOURSELF. NEXT YEAR'S PAPER WILL BE COMPLETELY DIFFERENT FROM THIS ONE.
READ THE PPT, READ THE BLUE BOOK, DO THE CLASS QUESTIONS AND THEN DO A VARIETY OF PAST EXAM QUESTIONS.