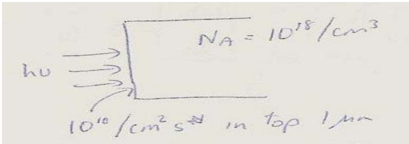
2006 3.15 Exam 1

Problem 1



$$\tau = 10^5 \text{s}, D = 40 \text{cm}^2 \text{s}^{-1}$$

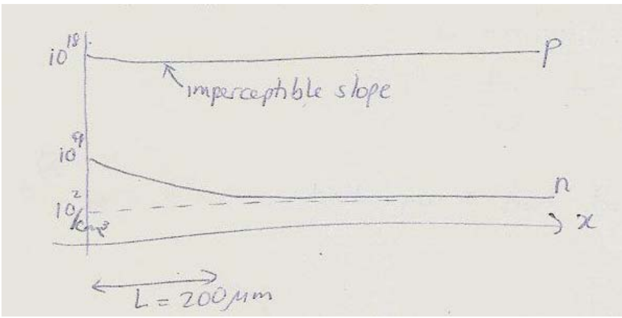
a.

Concentration at $x = 0$: $10^{10}/\text{cm}^2\text{s} \times \frac{1}{10^4}/\text{cm} \times 10^5\text{s} = 10^9/\text{cm}^3$ of photogenerated carriers.

Therefore:

$$p = 10^{18} + 10^{49} \approx 10^{18} \text{cm}^{-3} \text{ at surface}$$

$$n = 10^2 + 10^{49} \approx 10^{90} \text{cm}^{-3} \text{ at surface}$$



$$L = \sqrt{Dt} = \sqrt{40 \times 10^{-5}} = 2\sqrt{10^{-4}} \text{cm or } 0.02\text{cm} = 200\mu\text{m}$$

b.

$$\frac{dn}{dt} = \frac{dn}{dt}_{drift} + \frac{dn}{dt}_{diff} + \frac{dn}{dt}_{thermalRG} + \frac{dn}{dt}_{otherRG} = 0 \text{ at steady state}$$

$$\frac{dn}{dt}_{drift} = 0 \text{ no } \epsilon, \frac{dn}{dt}_{otherRG} = 0 \text{ except near surface}$$

$$\begin{aligned} 0 &= \frac{dn}{dt}_{diff} + \frac{dn}{dt}_{thermal} \\ &= \frac{d^2n}{dx^2} D + \frac{-(n-n_p)}{\tau} \end{aligned}$$

$$\frac{-(n-n_p)}{\tau} = \text{excess carrier concentration}$$

$$\Rightarrow \frac{d^2n}{dx^2} = \frac{(n-n_p)}{D\tau} \text{ gives the variation in } n(x)$$

This has a solution:

$$(n-n_p) = n(x=0)\exp\left(\frac{-x}{\sqrt{Dt}}\right) = 10^9 \exp\left(\frac{-x}{\sqrt{Dt}}\right)$$

c.

The Si is thinner than L, so the concentration of electrons does not drop off very much as we go into the Si. It has dropped to $\exp\left(-\frac{1}{2}\right) = 0.6$ of its initial value so on average the electron concentration is somewhere between 0.6×10^9 and 1.11/cm^3.

Initially: $n = 10^2$, $p = 10^{18}$.
With light: $n \approx 0.8 \times 10^9$, $p = 10^{18}$.

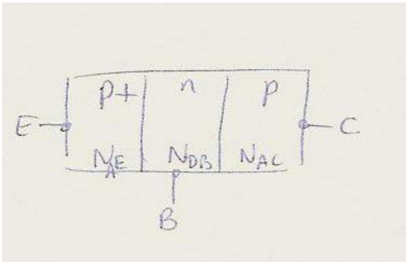
$$0 = e(n\mu_n + p\mu_p) \propto (n+p) \text{ if } \mu \text{ are the same.}$$

$$\text{Ratio is } \left(\frac{-10^9 + 10^{18}}{10^2 + 10^18}\right) \approx 1$$

The change is insignificant.

Problem 2

a.



The EB jn is fwd biased ⇒ large *diffusion* currents flow.
Diffusion current of holes from $E \rightarrow B$
Diffusion current of electrons from $B \rightarrow E$
Magnitude of $\frac{\text{hole current}}{\text{e current}} = \frac{N_{AE}}{N_{DB}} >> 1$ by design.

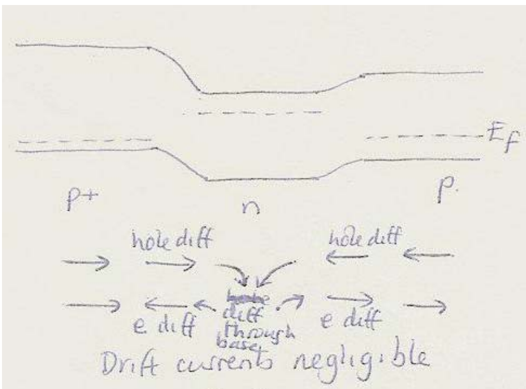
$$\text{Current Gain}\beta = \frac{I_{EC}}{I_{EB}}$$

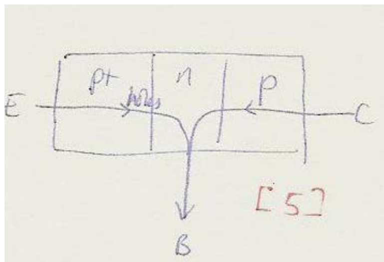
I_{EB} has 3 components: the diffusion current of electrons across BE, the drift of electrons from CB and a recombination current. In practice, the first term is largest.

$$\Rightarrow \frac{I_{EC}}{I_{EB}} = \frac{N_{AE}}{N_{DB}} \text{ usually } \approx 100 \text{ or so.}$$

b.

Saturated ⇒ both jns in fwd bias.





Large currents flow from E to B and from C to B. The current exits at B.

Problem 3

InSb

$E_g = 0.2$

$\mu_n = 80000$ cm^2/Vs, $m_n^* = 0.001m_o$, $N_C = 10^{18}$cm^{-3}

$\mu_p = 750$ cm^2/Vs, $m_n^* = 0.1m_o$, $N_C = 10^{19}$cm^{-3}

a.

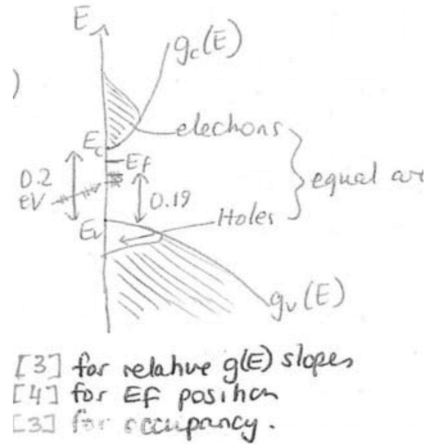
$$\begin{aligned} n_i^2 &= N_C N_V \exp(-E_g/kT) \\ &= 10^{18} 10^{19} \exp\left(-\frac{0.2}{0.0258}\right) \\ &= 4.3 \cdot 10^{33} \end{aligned}$$

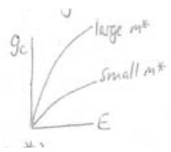
$$n_i = 6.5 \cdot 10^{16}\text{cm}^{-3}$$

$\sigma = (n\mu_n + p\mu_p)e = 1.6 \cdot 10^{-19} \times (10^{18} \times 80000 + 4.3 \cdot 10^{15} \times 750) = 1.3 \cdot 10^4 \Omega^{-1}\text{cm}^{-1}$

Here $p = n_i 2/N_o = 4.3 \cdot 10^{33}/10^{18} = 4.3 \cdot 10^{15}\text{cm}^-3$.

b.





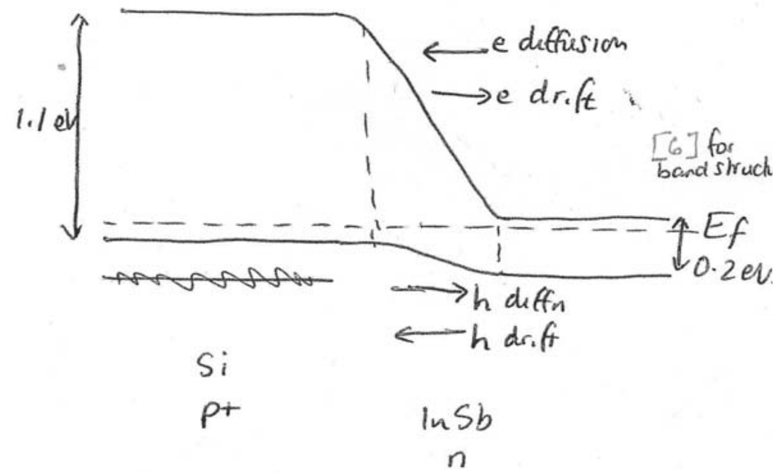
g_c vaires more rapidly than g_v because m_n^* is smaller.

$$g_c(E_\propto (m_n^*)^{\frac{3}{2}} \sqrt{E}$$

$$
\begin{aligned}
E_i &= (\text{midpoint}) + \frac{3}{4}kT\ln\left(\frac{m_p^*}{m_n^*}\right) \\
&= (\text{midpoint}) + \frac{3}{4} \times 0.0258\ln 100 \\
&= 0.09\text{eV}
\end{aligned}
$$

It is at $0.1 + 0.09 = 0.19$ eV above E_v (near E_c).

c.



Electron currents and hole currents only in the depletion region. No net current.