Problem 1

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

a.

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

Therefore:

\[ p = 10^{18} + 10^{49} \approx 10^{18} \text{cm}^{-3} \text{ at surface} \]
\[ n = 10^2 + 10^{49} \approx 10^{90} \text{cm}^{-3} \text{ at surface} \]

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

b.
\[
\frac{dn}{dt} = \frac{dn}{dt_{\text{drift}}} + \frac{dn}{dt_{\text{diff}}} + \frac{dn}{dt_{\text{thermalRG}}} + \frac{dn}{dt_{\text{otherRG}}} = 0 \text{ at steady state}
\]

\[
\frac{dn}{dt_{\text{drift}}} = 0 \text{ no } \frac{dn}{dt_{\text{otherRG}}} = 0 \text{ except near surface}
\]

\[
0 = \frac{dn}{dt_{\text{diff}}} + \frac{dn}{dt_{\text{thermal}}}
= \frac{d^2n}{dx^2}D + \frac{-(n - n_p)}{\tau}
\]

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

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

This has a solution:

\[
(n - n_p) = n(x = 0) \exp\left(\frac{-x}{\sqrt{D\tau}}\right) = 10^9 \exp\left(\frac{-x}{\sqrt{D\tau}}\right)
\]

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 \(0.6 \times 10^9\) and \(1.11/\text{cm}^3\).

Initially: \(n = 10^2, p = 10^{18}\).

With light: \(n \approx 0.8 \times 10^9, p = 10^{18}\).

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

\[
\text{Ratio is } \frac{-10^9 + 10^{18}}{10^2 + 10^{18}} \approx 1
\]

The change is insignificant.
Problem 2

a.

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

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.

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

b.

Saturated ⇒ both junctions in forward bias.
Large currents flow from E to B and from C to B. The current exits at B.
Problem 3

InSb

\( E_g = 0.2 \)
\( \mu_n = 80000 \text{ cm}^2/\text{Vs}, \ m_n^* = 0.001m_0, \ N_C = 10^{18}\text{cm}^{-3} \)
\( \mu_p = 750 \text{ cm}^2/\text{Vs}, \ m_n^* = 0.1m_0, \ N_C = 10^{19}\text{cm}^{-3} \)

a.

\[
\begin{align*}
    n_i^2 &= N_C N_V \exp(-E_g/kT) \\
          &= 10^{18} \times 10^{19} \exp\left(-\frac{0.2}{0.0258}\right) \\
          &= 4.3 \times 10^{33}
\end{align*}
\]

\( n_i = 6.5 \times 10^{16}\text{cm}^{-3} \)

\( \sigma = (n\mu_n + p\mu_p)e = 1.6\times10^{-19} \times (10^{18} \times 80000 + 4.3 \times 10^{15} \times 750) = 1.3 \times 10^4\Omega^{-1}\text{cm}^{-1} \)

Here \( p = n_i/2N_o = 4.3 \times 10^{18}/10^{19} = 4.3 \times 10^{15}\text{cm}^{-3} \).

b.

\( g_c \) varies more rapidly than \( g_v \) because \( m_n^* \) is smaller.

\( g_c(E)(m_n^*)^{\frac{3}{2}}\sqrt{E} \)
\[
E_i = (\text{midpoint}) + \frac{3}{4} kT \ln\left(\frac{m_e^*}{m_n^*}\right)
\]
\[
= (\text{midpoint}) + \frac{3}{4} \times 0.0258 \ln 100
\]
\[
= 0.09\text{eV}
\]

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.