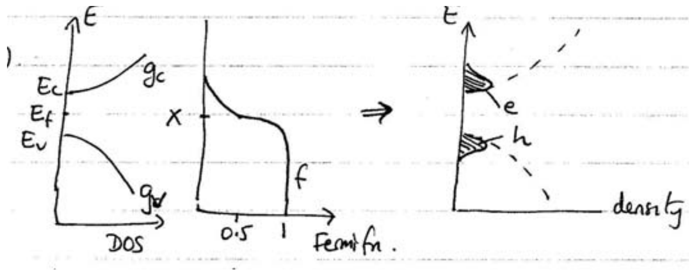
Sample Exam 1 - Solutions

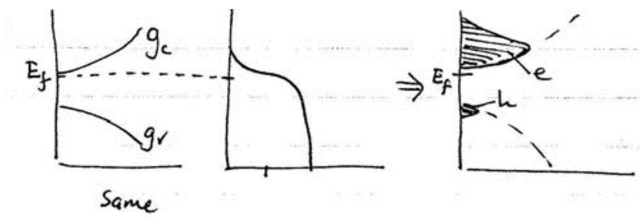
Problem 1

a.

i.



ii.



b.

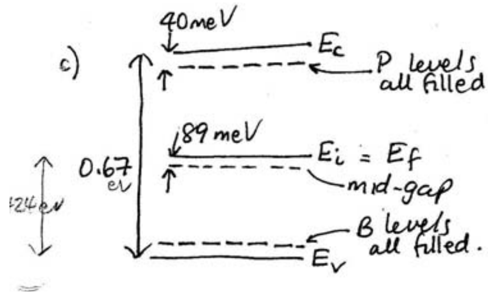
$$n_i = \sqrt{N_c N_v} \exp \frac{-Eg}{2kT}$$

For Si: $n_i = 10^{10}\text{cm}^3,\ E_g = 1.12\text{eV}$

$$\begin{aligned} \text{Therefore: } \sqrt{N_c N_v} &= 10^{10} \exp(1.12/2 \times 0.0258) \\ &= 2.167 \times 10^{19}\text{cm}^{-3} \end{aligned}$$

$$\begin{aligned} \text{For Ge: } n_i &= 2.167 \times 10^{19} \exp -(0.67/2 \times 0.0258) \\ &= 6.1 \times 10^{13}\text{cm}^{-3} \end{aligned}$$

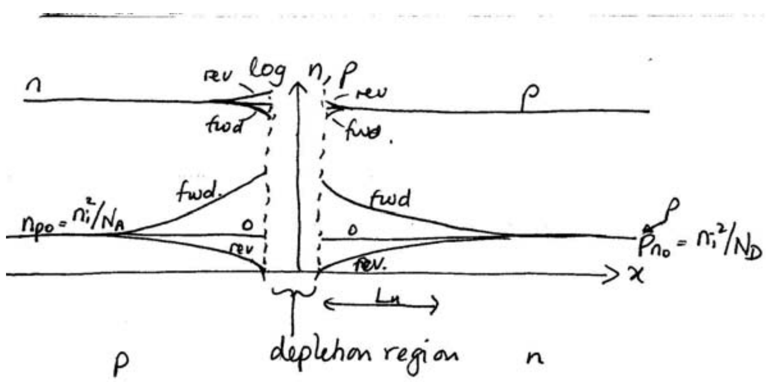
This is 6000 times larger because band gap is smaller.
c. This is *compensated* (donors and acceptors cancel). Since $N_A = N_D$,



$E_f = E_i$, and $n = p = n_i$. Difference between E_i and midgap:

$$
\begin{aligned}
E_i &= \text{midgap} + \frac{3}{4} kT \ln \frac{m_p^*}{m_n^*} \\
&= \frac{3}{4} \times 0.0256 \ln 100 \\
&= 89 \text{ meV}
\end{aligned}
$$

d. Lower because compenstated material's dopants scatter carriers, lowering mobility.



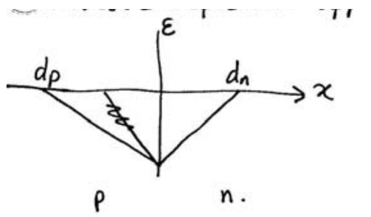
Problem 2

Problem 1

a.
FIGURE
Forward Bias: e^- injected into p side, leads to high e concentration near depletion region, decays away with characteristic length L_n (10s of μm) slight reduction of electron concentrtion near depletion region of n side.
Reverse Bias: e collected from p side, pins $n = 0$. (Very slight increase in n on the n side.)

b.
Breakdown: ϵ in depletion region = 10^5V/cm.
Assume depletion approximation: if $N_D = N_A$, $d_n = d_p$.

$$\text{Max } \epsilon = \frac{N_A e d_p}{E_D E_R} \text{ or } \frac{N_D e d_n}{E_D E_R}$$



$$\text{We know: } d_n = \left(\frac{2 E_D E_R V_0}{e} \frac{N_A}{N_D(N_A + N_D)} \right)^{\frac{1}{2}}$$

and

$$V_0 = \frac{kT}{e} \ln\left(\frac{N_A N_D}{n_i^2} \right) = 0.0258 \ln\left(\frac{10^{15} \cdot 10^{15}}{10^{20}} \right.$$

So:

$$\begin{aligned} d_n &= \left(\frac{2 \times 1.05 \cdot 10^{-12} \times 0.59}{1.6 \cdot 10^{-19}} \times \frac{10^{15}}{10^{15}(2.5 \times 10^{15})} \right)^{\frac{1}{2}} \\ &= 6.2 \times 10^{-5}\text{cm or } 0.6\mu\text{m} \end{aligned}$$

Therefore:

$$\epsilon = \frac{N_D e d_n}{E_D E_r} = \frac{10^{15} \times 1.6 \cdot 10^{-19} \times 6 \cdot 10^{-5}}{1.05 \cdot 10^{-12}} = 0.9 \cdot 10^4 \text{V/cm}$$

For breakdown, applying voltage V_A extends the depletion region, and raises ϵ. d_n increases by a factor of $\sqrt{\frac{V_0+V_A}{V}}$ and so does ϵ.
If avalanche occurs at 10^5 V/cm:

$$\frac{10^5}{0.9 \times 10^4} = \sqrt{\frac{V_0 + V_A}{V_0}}$$
$$V_0 + V_A = 72.8\text{V}$$

So reverse bias of ≈72V is needed for breakdown.

c.

We collect carriers in reverse bias pn jn so we might bias both jns in reverse. Then any holes produced in base will go across either EB or BC jn, depending on which direction they go. A large hole current flows into E and C from B. Electrons flow out of the base contact. $I_B \propto$ light intensity. (In fact it would work even without bias.)

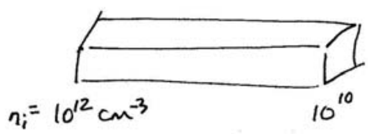
Note: Putting EB in fwd bias means a large current already flows through E→C, so the light-generated carriers would not add much to this.

Problem 3

a.
As T increases, μ decreases
As doping level increases, μ decreases
As lattice defects increase, μ decreases

All since greater scattering $\mu = \frac{e\tau}{m^*}$. Also, μ is lower for heavier carriers.

b.



p type: $p = N_A = 10^{18}\text{cm}^{-3}$ for both temperatures. Fully ionized.
Hot End: $n = 10^5\text{cm}^{-3} = n_i^2/N_A$
Cold End: $n = 10^2\text{cm}^{-3}$
So we have diffusion of electrons until the electric field balances the concentration gradient. Neglect hole diff.

Thermal R & G occurs everywhere, but more carriers at hot end.

$$J_n = eD_n\frac{dn}{dx} = en\mu_n\epsilon \text{ at steady state. Diffusion = Drift.}$$

$$\text{Concentration Gradient} = \frac{10^6 - 10^2}{1\text{cm}}\text{cm}^{-3} \approx 10^6\text{cm}^{-4}$$

Substitute:

$$D_n = kT\mu_n/e$$

$$\text{Therefore, } kT\mu_n\frac{dn}{dx} = en\mu_n\epsilon$$

$$\epsilon = \frac{kT}{en}\frac{dn}{dx}$$

At the hot end:

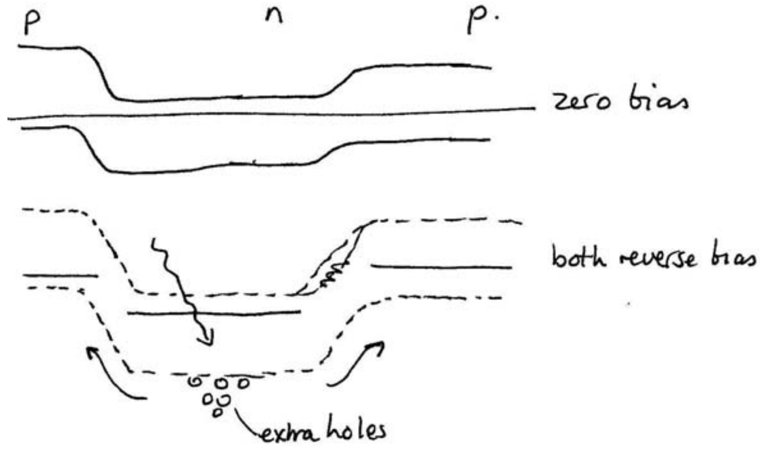
$$n = 10^6\text{cm}^{-3}, \epsilon = \frac{kT}{e} \cdot \frac{10^6\text{cm}^{-4}}{10^6\text{cm}^{-3}} = \frac{kT}{e} = 0.026\text{V/cm}$$

At the cold end:

$$n = 10^2\text{cm}^{-3}, \epsilon = 260\text{V/cm}.$$

d.

We collect carriers in reverse bias pn jn so we might bias both jns in reverse. Then any holes produced in base will go across either EB or BC jn, depending on which direction they go. A large hole current flows into E and C from B. Electrons flow out of the base contact. $I_B \propto$ light intensity. (In fact it would work even without bias.)



Note: Putting EB in fwd bias means a large current already flows through E $\rightarrow$ C, so the light-generated carriers would not add much to this.