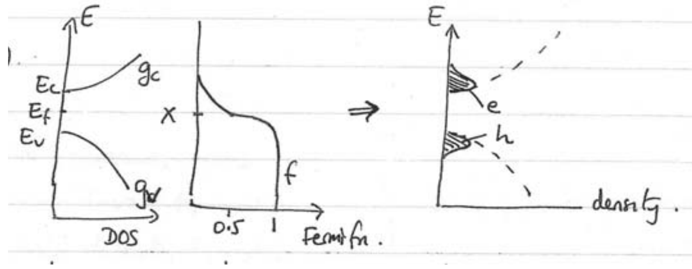
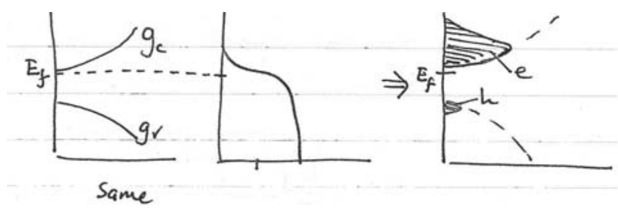
3.15 - Problem Set 1 Solutions

2.
a. (i)



(ii)



b.

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

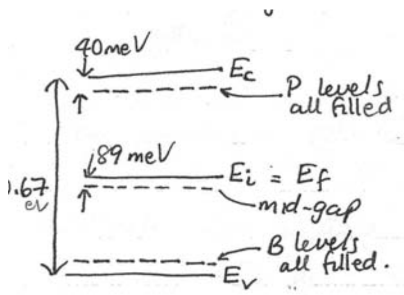
For Si: $n_i = 10^{10}\text{cm}^{-3}$, $E_g = 1.12\text{eV}$

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

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

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:

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

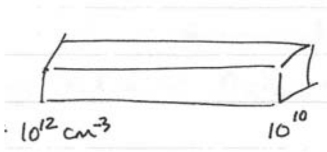
d. Lower because compenstated material's dopants scatter carriers, lowering mobility.

Problem 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:

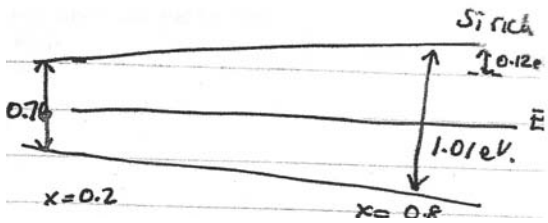
$$n = 10^6\text{cm}^{-3}, \epsilon = \frac{kT}{e}\cdot\frac{10^6\text{cm}^{-4}}{10^6\text{cm}^{-3}} = \frac{kT}{e} = 0.026\text{V/cm}$$

At the cold end:

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

Problem 4

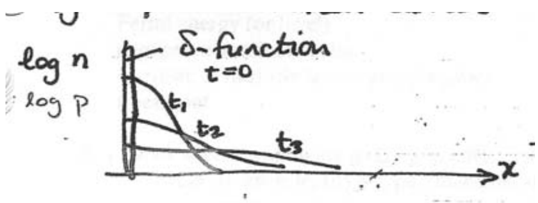
x=0, 0.67 eV
x=0.2, 0.76 eV
x=0.8, 1.01 eV
x=1.0, 1.1 eV



Intrinsic - assume E_f is very close to midgap.
Electrons $\leftarrow$ drift due to band slope.
Electrons $\rightarrow$ diffuse since more e^- in narrow gap.
Holes $\rightarrow$ diffuse.
Holes $\leftarrow$ drift.
The only R & G is thermal.

Problem 5

Light produces excess carriers at surface.



Intrinsic so $n = p$. Area under curve decreases due to recombination. Curve spreads due to diffusion.

$$\frac{\partial n}{\partial t} = \frac{\partial n}{\partial t}_{\text{drift}} + \text{ diffusion} + \text{R \& G.}$$

Drift $\rightarrow 0$ because no fields.
Diffusion $\rightarrow \frac{1}{e}\nabla J = \frac{1}{e}\frac{d^2n}{dx^2}$.
R & G: $\frac{dn}{dt} = \frac{-n_e}{\tau}$ where $n_e =$ excess carrier concentration.

$$\frac{dn}{dt} = D_n\frac{d^2n}{dx^2} + -\frac{n_e}{\tau}$$

Same type of expression for holes.
τ is due to recombination at traps, since it's intrinsic material. These are more effective than band to band recombination but there are relatively few of them. $\tau = 1/r_2N_\tau$. $r_2 >> r$ but $N_\tau <$ typical.