Riley Worstell

ECE 542

HW 2

Riley Worsteil | ECE 542 | HW #2 | Page #1

① Name one accepter dopant element for Silicon.

Boron

② Name two donor dopant elements for Silicon:

Nitrogen, Phosphorus

③ SiC is doped with accepter atoms at a concentration $N_A = 10^{15}\ cm^{-3}$

a) What is electron mobility? $\mu = \mu_{min} + \dfrac{\mu_{max} - \mu_{min}}{1 + \left(\frac{N}{N_{ref}}\right)^{\gamma}}$

$\mu_{min} = 35$; $\mu_{max} = 900$, $N_{ref} = 2\cdot 10^{17}$, $\gamma = 0.72$

$$\mu = 35 + \frac{(900-35)}{1+\left(\frac{10^{15}}{2\cdot 10^{17}}\right)^{0.72}} = 35 + \frac{865}{1.02204238} = 881.35\ \frac{cm^2}{V\cdot s} = \mu_n$$

b) What is the hole mobility? $\mu_{min} = 33$, $max = 117$, $N_{Ref} = 1\cdot 10^{19}$, $\gamma = 0.5$

$$33 + \frac{(117-33)}{\left(1+\left(\frac{10^{15}}{10^{19}}\right)^{0.5}\right)} = 116.168\ \frac{cm^2}{V\cdot s} = \mu_p$$

c) What is electron concentration? $n_0 = \dfrac{n_i^2}{p_0} = \dfrac{(3.1\cdot 10^{-9})^2\ cm^{-6}}{10^{15}\ cm^{-3}} = 9.61\cdot 10^{-33}\ cm^{-3} = n_0$

d) What is the hole concentration? $n_i = 3.1\cdot 10^{-9}$

$p_0 = 10^{15}\ cm^{-3}$

e) What is the majority carrier? holes

f) What is the minority carrier? electrons

g) What is the resistivity? $\rho = \dfrac{1}{\sigma} = \dfrac{1}{q\mu_p p_0 + q\mu_n n_0} = \dfrac{1}{q\mu_p p_0} = 53.79\ \Omega\cdot cm$

h) What is the conductivity? $\sigma = q\mu_p p_0 + q\mu_n n_0$

$$\sigma = q\mu_p p_0 = (1.6\cdot 10^{-19} C)(10^{15} cm^{-3})\left(116.168\ \frac{cm^2}{V\cdot s}\right) = 0.01859\left(\frac{1}{\Omega\cdot cm}\right)$$

i) Where is the Fermi level located relative to the middle of the bandgap?

near valence band because it's P-type

Riley Worstell ECE 542 Page #2

(4) A Piece of Silicon is doped with donor atoms at a Concentration of $N_D = 10^{18}\,cm^{-3}$. The Piece is 1mm long, 10μm wide, 10 μm thick.

a) What is electron mobility? $\mu_{n_{min}} = 88.3$, $\mu_{n_{max}} = 1330.3$, $N_{ref} = 1.295 \cdot 10^{17}$, $\gamma = 0.891$

$$\mu = \mu_{min} + \frac{\mu_{max} - \mu_{min}}{\left(1 + \left(\frac{N}{N_{ref}}\right)^{\gamma}\right)} = 88.3 + \frac{1242}{(1+(6.179))} = 261.305\ \frac{cm^2}{V \cdot s} = \mu_n$$

b) What is the hole mobility? $\mu_{p_{min}} = 54.3$; $\mu_{max} = 461.2$, $N_{ref} = 2.35 \cdot 10^{17}$, $\gamma = .88$

$$\mu = 54.3 + \frac{(461.2 - 54.3)}{\left(1 + \left(\frac{10^{18}}{2.35 \cdot 10^{17}}\right)^{.88}\right)} \quad 4.5765 \quad = 143.21\ \frac{cm^2}{V \cdot s} = \mu_p$$

c) What is the electron concentration? $n_o = 10^{18}\,cm^{-3}$

d) What is the hole concentration? $p_o = \frac{n_i^2}{n_o} = \frac{(10^{10})^2}{(10^{18})} = 100\,cm^{-3} = p_o$ or $10^2\,cm^{-3}$

e) What is the resistivity? $\frac{1}{\sigma} = \frac{1}{q\mu_p p_o + q\mu_n n_o}$ (donors) $= \frac{1}{q\mu_n n_o} =$

$$= \frac{1}{(1.6 \cdot 10^{-19}\,C)(261.305\,\frac{cm^2}{V \cdot s})(10^{18}\,cm^{-3})}$$

$$\rho = 0.02392\ \Omega \cdot cm$$

f) What is the resistance of the Piece of Silicon

$$R = \frac{\rho L}{A} = \frac{(0.02392 \cdot 10^{-2}\ \Omega \cdot m)(1 \cdot 10^{-3}\ m)}{(10 \cdot 10^{-6})(10 \cdot 10^{-6})\,m^2} = 2392\ \Omega$$

g) 1V is applied across the length. How much current flows?

$\mathcal{E}_{1V} = \frac{1}{(1 \cdot 10^{-3})10^{2}} = 10^{1}\ \frac{V}{cm} < \mathcal{E}_{s,n}$ $\quad V = IR \Rightarrow I = V/R = \frac{1V}{2392\,\Omega} = 0.000418A = 0.418\,mA$

h) 1000V is applied How Much Current flows

$V_{sat,n} = 1.05 \cdot 10^{7}\ cm/s$ $\quad I = \frac{1000}{2392} = 0.418\,A$

$$\mathcal{E}_{s,n} = \frac{V_{sat,n}}{\mu_n} = \frac{1.05 \cdot 10^{7}\ cm/s}{261.305\ cm^2/V \cdot s} = 40,182.93\ V/cm$$

$$\mathcal{E}_{1000V} = \frac{1000}{(1 \cdot 10^{-3})10^{2}}\ \frac{V}{cm} = 10,000 < 40,182.93\ V/cm;\quad \mathcal{E} < \mathcal{E}_{sat}$$

	μ_{min}	μ_{max}	N_{ref}	γ
μ_n	88.3	1330.3	$1.295 \cdot 10^{17}$	0.891
μ_p	54.3	461.2	$2.35 \cdot 10^{17}$	0.88

(5) A Piece of Silicon is doPed with accepter atoms at a Concentration of $N_A = 10^{17}\ cm^{-3}$. The Piece is $10\ \mu m$ long, $2\mu m$ wide, $2\mu m$ thick

a) What is the electron mobility? $\mu = \mu_{min} + \dfrac{\mu_{max} - \mu_{min}}{1 + \left(\frac{N}{N_{ref}}\right)^{\gamma}}$

$$= 88.3 + \frac{1330.3 - 88.3}{1 + \left(\frac{10^{17}}{1.295 \cdot 10^{17}}\right)^{.891}} = 780.5 \frac{cm^2}{V \cdot s} = \mu_n$$

b) What is hole mobility? $54.3 + \dfrac{461.2 - 54.3}{1 + \left(\frac{10^{17}}{2.35 \cdot 10^{17}}\right)^{.88}} = 330.821 \frac{cm^2}{V \cdot s} = \mu_p$

c) What is the electron Concentration? $n_0 = \dfrac{n_i^2}{P_0} = \dfrac{10^{20}}{10^{17}} = 10^3\ cm^{-3} = n_0$

d) What is the hole Concentration? $P_0 = N_A = 10^{17}\ cm^{-3} = P_0$

e) What is the resistivity? $\dfrac{1}{q\mu_p P_0} = \dfrac{1}{(1.6 \cdot 10^{-19} C)(10^{17} cm^{-3})(330.821 \frac{cm^2}{V\,s})}$

$= 0.1889\ \Omega \cdot cm$

f) What is the resistance of the Piece of Silicon?

$$R = \frac{\rho L}{A} = \frac{(0.1889 \cdot 10^{-2}\ \Omega \cdot m)(10 \cdot 10^{-6} m)}{(2 \cdot 10^{-6})(2 \cdot 10^{-6})\ m^2} = 4{,}722.5\ \Omega$$

g) 1V is applied across the length. How much Current flows

$\mathcal{E}_{1V} = \dfrac{1}{(10 \cdot 10^{-6}) 10^2} \left(\frac{V}{cm}\right) = 1000 \frac{V}{cm} < \mathcal{E}_{sat}$ $\quad V = IR \Rightarrow I = V/R = \dfrac{1\ V}{4{,}722.5\ \Omega} = 0.0002118 A$

h) 100V is applied across length.

$$J_{drift} = q(V_{d,p} P_0 + V_{d,n} n_0) = 1.6 \cdot 10^{-19}\left(0.94 \cdot 10^{7}(10^{17}) + (1.05 \cdot 10^{7})(10^{3})\right) = 150400 \frac{A}{cm^2}$$

$$\mathcal{E}_{s,p} = \frac{V_{sat,p}}{\mu_p} = \frac{0.94 \cdot 10^{7}\ cm/s}{330.821\ cm^2/V \cdot s} = 28414.16 \frac{V}{cm}$$

$$\mathcal{E}_{100V} = \frac{100\ V}{(10 \cdot 10^{-6}) 10^{2}\ \frac{cm}{10^{-3}}} = 100{,}000 \frac{V}{cm} > 28{,}414 \frac{V}{cm}$$

$\mathcal{E} > \mathcal{E}_{sat}$

$$(2 \cdot 10^{-6})^2 \left(150400 \frac{A}{cm^2}\right) = 0.000000602 A$$

6)

CODE:

```
import pylab
import matplotlib.pyplot as plt
import math

Si_NC = (3.51*(10**19))
Si_NV = (1.87*(10**19))
Si_BG = 1.12
K_b = 0.00008617


my_temps = []
some_temp = 200
for i in range(401):
    my_temps.append(some_temp)
    some_temp = some_temp + 1


Ni_Si = []

for i in my_temps:
    x = Si_NC * ((i/300)**1.5)
    y = Si_NV * ((i / 300) ** 1.5)
    z = ((x*y*(math.exp(-(Si_BG/(i * K_b)))))**.5)
    print(z)
    Ni_Si.append(z)


plt.plot(my_temps, Ni_Si)
plt.yscale('log')
plt.xlabel("Temperature")
plt.ylabel("Intrinsic Carrier Concentration")
plt.show()
```

PLOT:

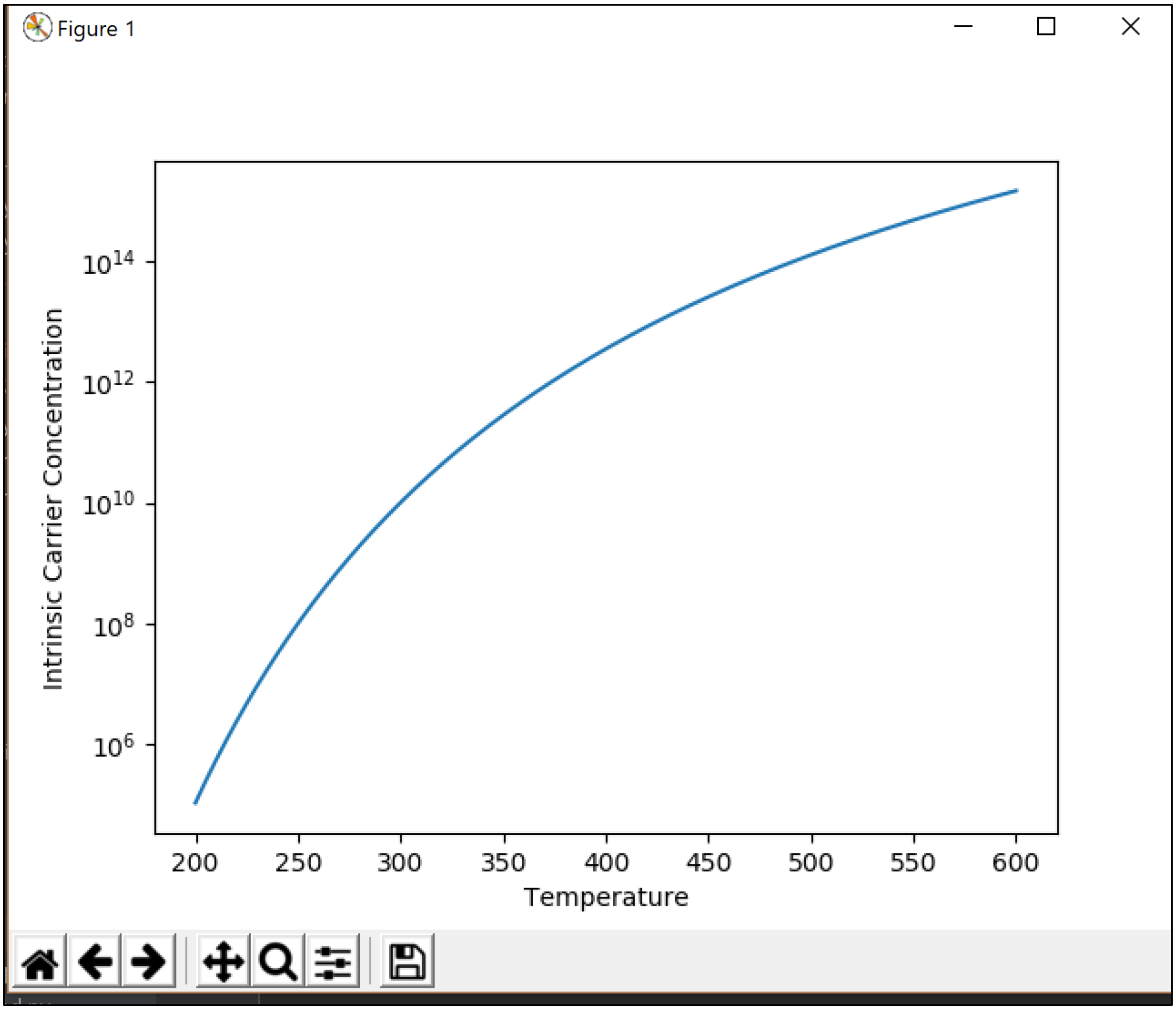
Figure 1
Intrinsic Carrier Concentration
10^{14}
10^{12}
10^{10}
10^{8}
10^{6}
200
250
300
350
400
450
500
550
600
Temperature