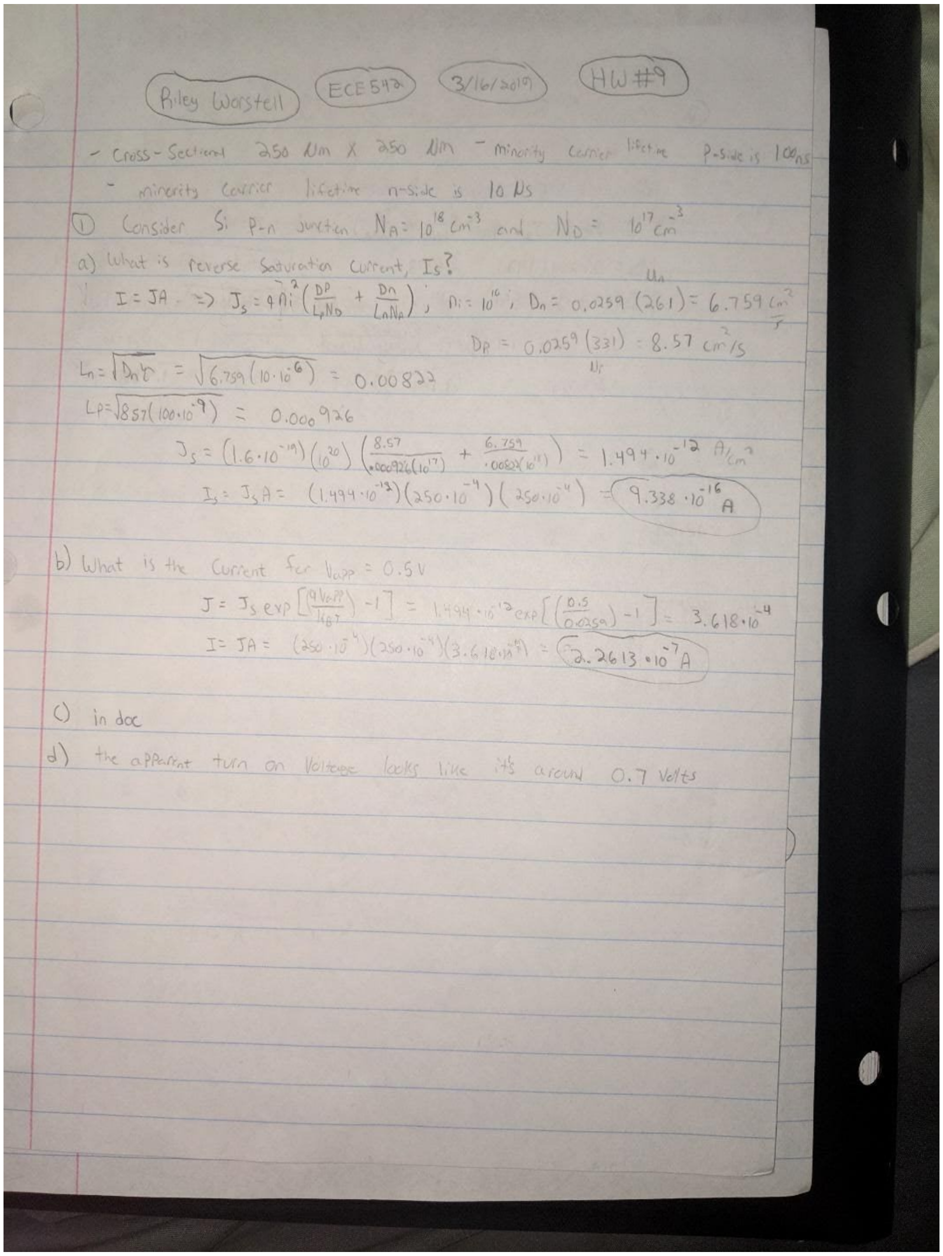
ECE 542

HW # 9

Riley Worstell

3/20/2019

1)



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- Cross-Sectional 250 μm X 250 μm – minority carrier lifetime p-side is 100 ns
- minority carrier lifetime n-side is 10 μs

① Consider Si p-n junction $N_A = 10^{18}\ cm^{-3}$ and $N_D = 10^{17}\ cm^{-3}$

a) What is reverse saturation current, I_s?

$I = JA \Rightarrow J_s = q n_i^2 \left(\frac{D_P}{L_P N_D} + \frac{D_n}{L_n N_A}\right)$; $n_i = 10^{10}$; $D_n = 0.0259\,(261) = 6.759\ cm^2/s$

$D_P = 0.0259\,(331) = 8.57\ cm^2/s$

$L_n = \sqrt{D_n \tau} = \sqrt{6.759\,(10 \cdot 10^{-6})} = 0.00822$

$L_P = \sqrt{8.57\,(100 \cdot 10^{-9})} = 0.000926$

$J_s = (1.6 \cdot 10^{-19})(10^{20})\left(\frac{8.57}{.000926(10^{17})} + \frac{6.759}{.00822(10^{18})}\right) = 1.494 \cdot 10^{-12}\ A/cm^2$

$I_s = J_s A = (1.494 \cdot 10^{-12})(250 \cdot 10^{-4})(250 \cdot 10^{-4}) = 9.338 \cdot 10^{-16}\ A$

b) What is the current for $V_{app} = 0.5\,V$

$J = J_s \exp\left[\left(\frac{qV_{app}}{k_B T}\right) - 1\right] = 1.494 \cdot 10^{-12} \exp\left[\left(\frac{0.5}{0.0259}\right) - 1\right] = 3.618 \cdot 10^{-4}$

$I = JA = (250 \cdot 10^{-4})(250 \cdot 10^{-4})(3.618 \cdot 10^{-4}) = 2.2613 \cdot 10^{-7}\ A$

c) in doc

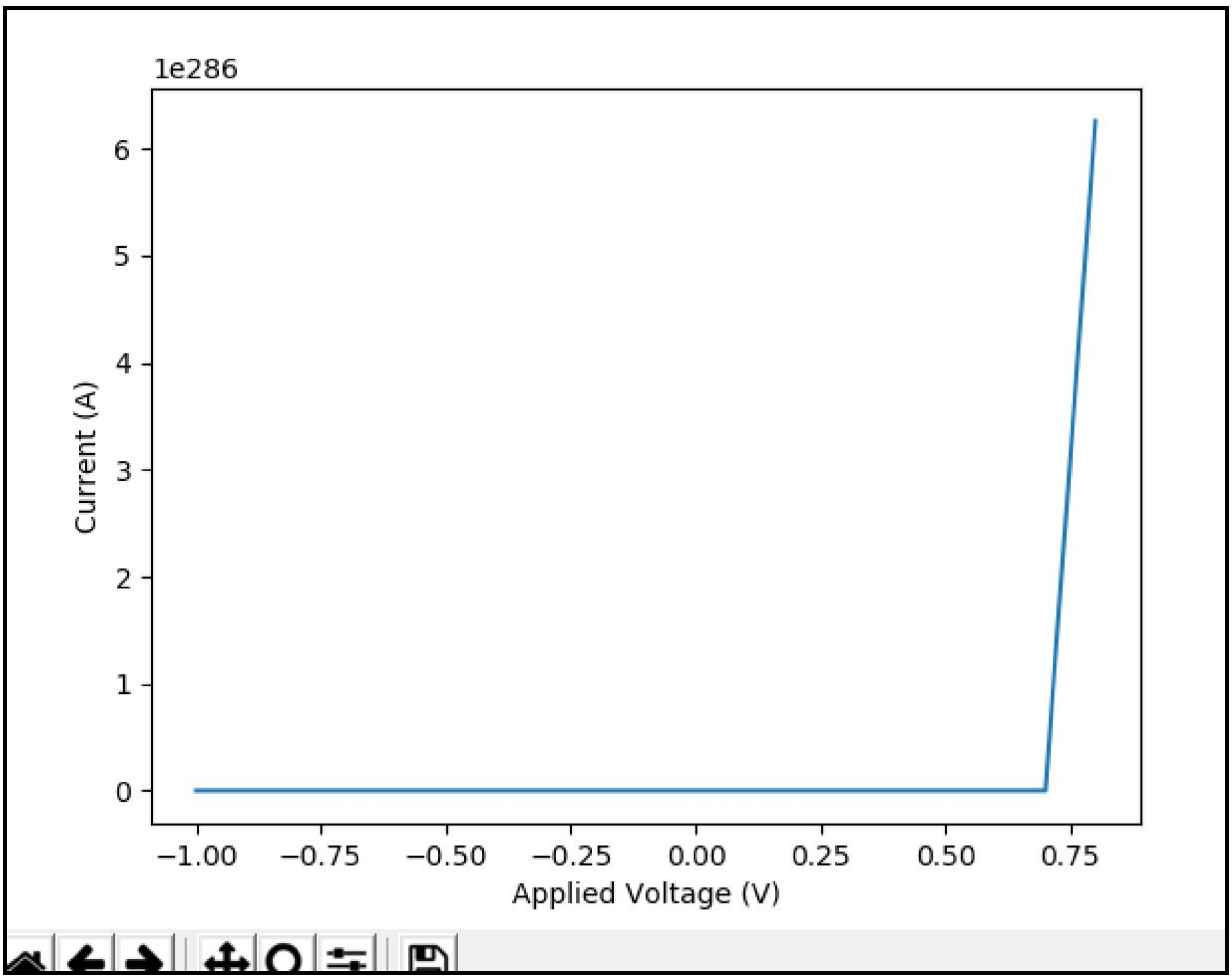
d) the apparent turn on voltage looks like it's around 0.7 Volts

Code:

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

J_s = 1.494 * (10**(-12))
a_list = []
x = -1
I_list = []
area = (250 * (10**(-4))) * (250 * (10**(-4)))
```

```
for i in range(19):
    a_list.append(x)
    x = x + 0.1
    h1 = i / 0.0259
    J = J_s * (math.exp(h1)-1)
    I_1 = J * area
    I_list.append(I_1)


plt.plot(a_list, I_list, label="Current Versus Applied Voltage")
#plt.legend(loc="upper left", shadow=True, title="Key", fancybox=True)
plt.xlabel("Applied Voltage (V)")
plt.ylabel("Current (A)")
plt.show()
```

PLOT:



2)

(2) Consider GaN p-n junction with $N_A = 10^{18}\ cm^{-3}$ & $N_D = 10^{17}\ cm^{-3}$.

a) What is reverse saturation current, I_s?

$I = JA$; $J_s = qn_i^2 \left(\frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A}\right)$; $n_i = 1.77 \cdot 10^{-10}$

$D_p = 0.0259(142) = 3.6778$ $\quad L_p = \sqrt{3.6778(100 \cdot 10^{-9})} = 0.0006064$

$D_n = 0.0259(551) = 14.271$ $\quad L_n = \sqrt{14.271(10 \cdot 10^{-6})} = 0.01195$

$J_s = (1.6 \cdot 10^{-19})(1.77 \cdot 10^{-10})^2 \left(\frac{3.6778}{10^{17}(0.0006064)} + \frac{14.271}{10^{18}(0.01195)}\right) = 3.1 \cdot 10^{-52}\ A/cm^2$

$I_s = J_s A = (3.1 \cdot 10^{-52})(250 \cdot 10^{-4})(250 \cdot 10^{-4}) = 1.938 \cdot 10^{-55}\ A$

b) in doc

c) the apparent turn on voltage looks the same as before 0.7V

d) The Silicon diode has a greater current for same voltage

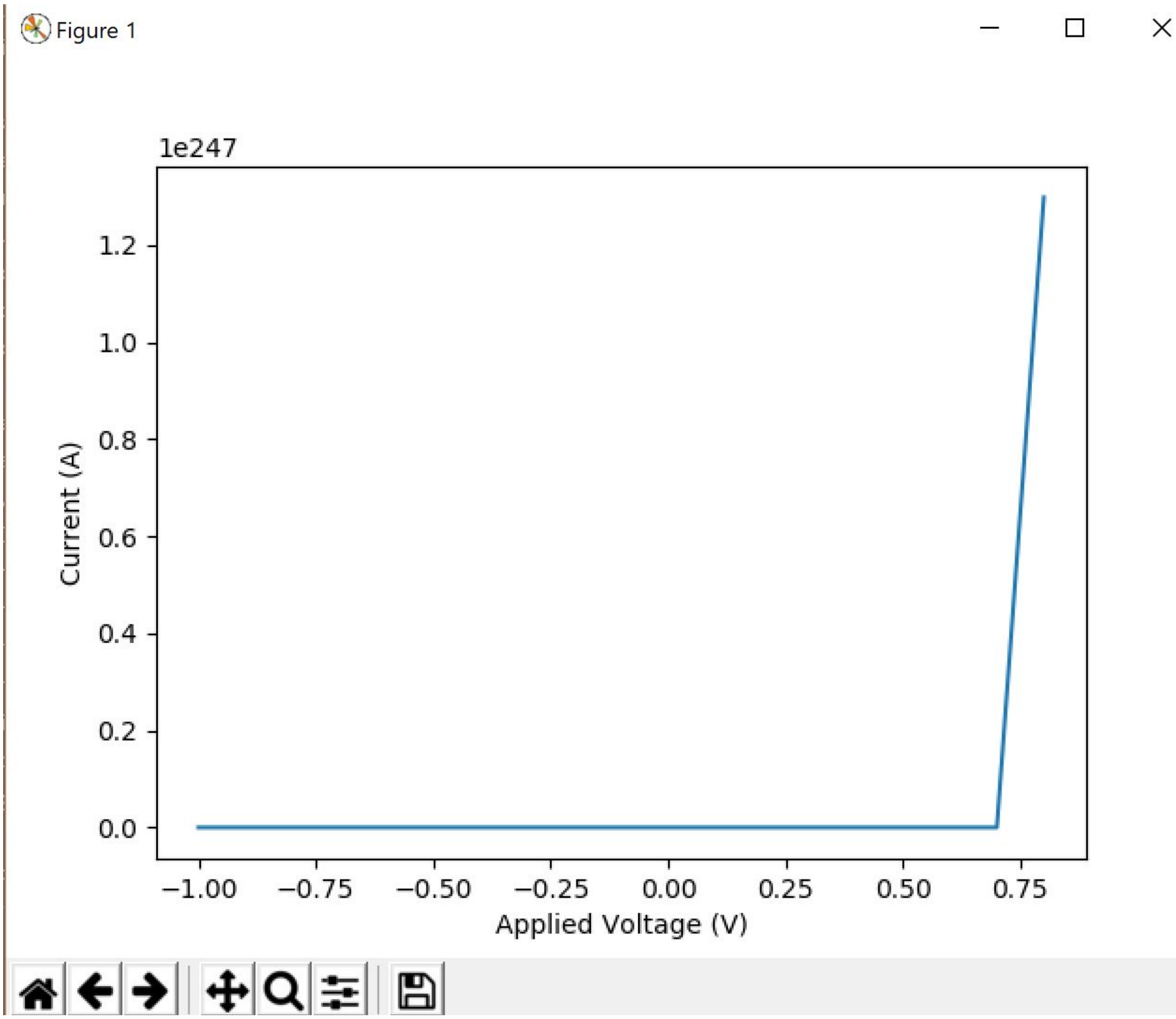
c)

Code:

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

J_s = 3.1 * (10**(-52))
a_list = []
x = -1
I_list = []
area = (250 * (10**(-4))) * (250 * (10**(-4)))


for i in range(19):
    a_list.append(x)
    x = x + 0.1
```

```
    h1 = i / 0.0259
    J = J_s * (math.exp(h1)-1)
    I_1 = J * area
    I_list.append(I_1)


plt.plot(a_list, I_list, label="Current Versus Applied Voltage")
plt.xlabel("Applied Voltage (V)")
plt.ylabel("Current (A)")
plt.show()
```

PLOT:



3)

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(3) Consider Si p-n junction with $N_A = 10^{18}\,cm^{-3}$ & $N_D = 10^{17}\,cm^{-3}$. The length of n-region is 200 nm, and length of p-region is 20 nm. What are:

a) breakdown voltage considering only avalanche breakdown?

$$V_{BR} = -V_{app} = \mathcal{E}^2_{crit}\left(\frac{\varepsilon_s\varepsilon_0}{2q}\right)\left(\frac{N_D+N_A}{N_DN_A}\right) + V_{bi}$$

$$0.0259\ln\left(\frac{10^{18}10^{17}}{10^{20}}\right) = 0.8946$$

$$= \left(3\cdot10^{5}\tfrac{V}{m}\right)^2\left(\frac{11.8\cdot8.854\cdot10^{-14}\ F/cm}{2(1.6\cdot10^{-19}\ C)}\right)\left(\frac{10^{18}+10^{17}}{10^{18}10^{17}}\right) = 3.23V$$

$$+0.8946$$

$$= 4.1246V$$

(b) breakdown voltage considering punch-through on n-side?

$$V_{BR} = \frac{(1.6\cdot10^{-19})(10^{18})}{2(11.8)(8.854\cdot10^{-14})}\left[\frac{10^{18}+10^{17}}{10^{17}}\right](1.0624\cdot10^{-10}) = 88.56V$$

$$-0.8946$$

$$= -0.8946V$$

$$X_N^2 = \sqrt{\frac{2\cdot11.8\cdot8.854\cdot10^{-14}}{1.6\cdot10^{-19}(10^{17})}\left(\frac{10^{18}}{10^{17}+10^{18}}\right)(0.8946)}$$

$$= 1.062\cdot10^{-10}$$

(c) Breakdown voltage considering punch-through on p-side?

$$V_{BR} = \frac{qN_A}{2\varepsilon_s\varepsilon_0}\left(\frac{N_D+N_A}{N_D}\right)\left[\frac{2\varepsilon_s\varepsilon_0}{qN_A}\left(\frac{N_D}{N_D+N_A}\right)(V_{bi}-V_{app})\right] - V_{bi}$$

$$= \frac{(1.6\cdot10^{-19})(10^{18})}{2\cdot11.8\cdot8.854\cdot10^{-14}}\left(\frac{10^{18}+10^{17}}{10^{17}}\right)(1.0621\cdot10^{-12}) = 3.36\cdot10^{-22}V - 0.8946$$

.000044

$$= -0.000004816\,V$$

$$X_p^2 = \frac{2\cdot11.8\cdot8.854\cdot10^{-14}}{(1.6\cdot10^{-19})(10^{18})}\left(\frac{10^{17}}{10^{17}+10^{18}}\right)(0.8946) =$$

(d) 88.56V

4)

(4) Using diode from #1, find current that flows when $V_{app} = 5V$. Consider $(R_N + R_P)$, and numerically solve

a) Resistance of n-region? $R_N = \frac{W_N'}{qA\mu_n N_D} = \frac{(W_N - x_N - L_P)}{qA\mu_n N_D}$

$L_P = 0.000926$

$L_n = 0.00822$

$$R_N = 250 \cdot 10^{-4}\,cm - \sqrt{\frac{2 \cdot 11.8 \cdot 8.854 \cdot 10^{-14}}{1.6 \cdot 10^{-19}(10^{18})}\left(\frac{10^{17}}{10^{18}+10^{17}}\right)\left(0.0259 \ln\left(\frac{10^{17}10^{18}}{10^{20}}\right) - 0\right)} - 0.000926$$

$1.306 \cdot 10^{-11}$ $\quad$ 0.090909

$$= 0.0241 / [(1.6 \cdot 10^{-19})(250 \cdot 10^{-4})^2 (10^{17})(261)] = 9.23$$

b) $R_P = \frac{W_P - x_P - L_n}{qA\mu_n N_D} = 250 \cdot 10^{-4} - \sqrt{\frac{2 \cdot 11.8 \cdot 8.854 \cdot 10^{-14}}{(1.6 \cdot 10^{-19})(10^{17})}\left(\frac{10^{18}}{10^{17}+10^{18}}\right)\left(0.0259 \ln\left(\frac{10^{17}10^{18}}{10^{20}}\right)\right)} - 0.00822$

0.000010306

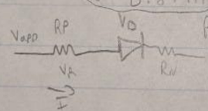
$$= 0.0168 / [(1.6 \cdot 10^{-19})(250 \cdot 10^{-4})^2 (10^{18})(331)] = 0.5076$$

c) Voltage across diode

$$V_D = V_{app} - I_S \exp\left(\frac{qV_D}{kT}\right)(R_P + R_N) = 5 - (9.338 \cdot 10^{-16})\exp\left(\frac{V_D}{0.0259}\right)(0.5076 + 9.23)$$

$V_D = 0.87411V$ in Wolfram Alpha

d)



$R = \frac{V_{app} - V_D}{I} \Rightarrow RI = V_{app} - V_D \Rightarrow V = V_{app} - V_D$

$= 5 - 0.87411$

$= 4.1259\,V$

e) Current $\left(\frac{V_D - V_{app}}{R_P + R_N}\right) = 0.424\,A$