Riley Worstell

HW #10

3/27/2019

ECE 542

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HW#10

(1) For light to be absorbed, $E_{Ph} \geq E_g$

$\underbrace{E_{Ph}}_{\text{Photon energy}}$ $\underbrace{E_g}_{\text{Semiconductor Bandgap}}$

(2) A Silicon Chip ($N_D = 10^{16}\ cm^{-3}$) has transparent electrodes attached to the top & bottom. The Chip measures 2mm x 2mm, & is 0.5 mm thick.

(a) Red light with wavelength 650 nm is illuminated on the top. What is the absorption length in Um.

absorption Coefficient (α) = 3080.934 cm^{-1}

$I_{Ph}(x) = I_{Ph,0}\exp(-\alpha x)$; $I_{Ph} = \frac{P_{Ph}}{E_{Ph}}$; $E_{Ph} = \frac{1.24}{0.65}$.

$\frac{\ln\left(\frac{I_{Ph}}{I_{Ph,0}}\right)}{-\alpha} = x$ $\quad -\frac{x}{L_\alpha} = -\alpha x \Rightarrow \alpha = 1/L_\alpha \Rightarrow L_\alpha = 0.00032458$ cm

$= 0.32458$ Um

(b) The red light has intensity of 10 mW/cm². What is intensity at Silicon surface, in Photons/cm²s

$E_{Ph} = 1.908eV \quad P_{Ph} = 10\ mW/cm^2$

$I_{Ph,0} = \frac{10 \cdot 10^{-3}\ W/cm^2}{1.908eV}\left(\frac{1}{1.6 \cdot 10^{-19}}\right) = 3.28 \cdot 10^{16}\ cm^{-2}s^{-1}$

(c) The light absorbed by Silicon as it Propagates. Plot light intensity (Photons/cm²s) Plot light intensity versus distance for 1st 20Um. Python Plot

(d) Python Plot

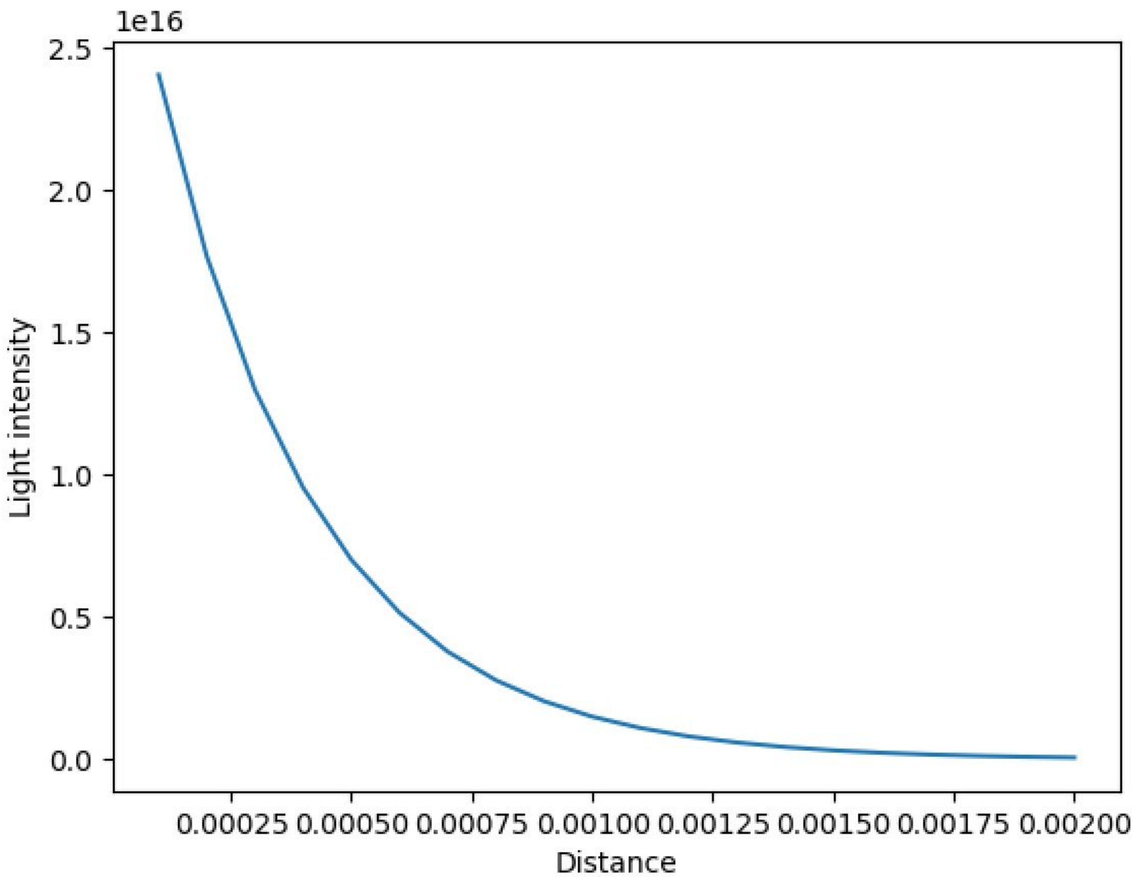
2c)

Code:

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


dist_list = []
LI_list = []
const = 1.6 * (10**-19)
```

```
IPH = (10*(10**-3)/1.908)/const
x = 0
La = .00032458

for i in range(20):
    x = x + (1*(10**-4))
    dist_list.append(x)
    I1 = IPH*math.exp(-x/La)
    LI_list.append(I1)


plt.plot(dist_list, LI_list, label="")
plt.xlabel("Distance")
plt.ylabel("Light intensity")
plt.show()
```

Plot:



2d)

Code:

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


dist_list = []
G_list = []
const = 1.6 * (10**-19)
IPH = (10*(10**-3)/1.908)/const
x = 0
La = .32458

for i in range(20):
    x = x + (1*(10**-4))
    dist_list.append(x)
    I1 = (IPH/La)*math.exp(-x/La)
    G_list.append(I1)


plt.plot(dist_list, G_list, label="")
plt.xlabel("Distance (CM)")
plt.ylabel("Generation Rate (cm^-3 s^-1)")
plt.show()
```

Plot:

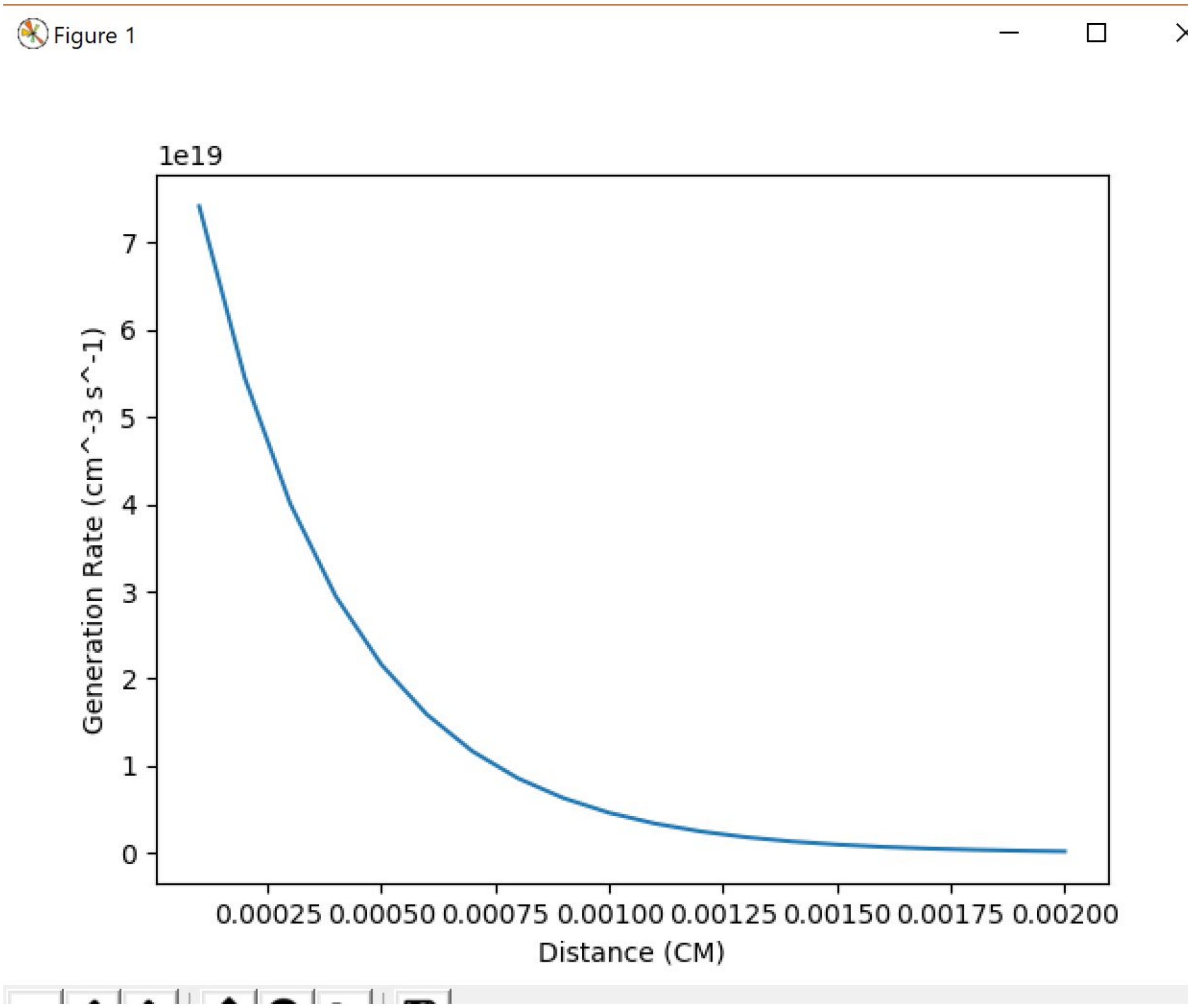


Figure 1
1e19
7
6
5
4
3
2
1
0
Generation Rate (cm^-3 s^-1)
0.00025 0.00050 0.00075 0.00100 0.00125 0.00150 0.00175 0.00200
Distance (CM)

(3) Consider Silicon p-n junction with $N_A = 10^{17}\,cm^{-3}$ & $N_D = 10^{16}\,cm^{-3}$. the minority carrier lifetime on p-side is $1\mu s$, and minority carrier lifetime on n-side is $10\mu s$

(a) What is depletion width, W?

$J_{op} = q(L_p + L_n + W)\frac{I_{on,10}}{LA}$; $W_D = x_p + x_N = \sqrt{\frac{2(11.8)(8.854\cdot10^{-14})}{(1.6\cdot10^{-19})}\left(\frac{10^{16}+10^{17}}{10^{16}10^{17}}\right)(V_{bi} - V_{app})}$

$= 0.00003337 = 3.337\cdot10^{-5}\,cm$ $\quad V_{bi} = 0.0259\ln\left(\frac{10^{17}10^{16}}{10^{20}}\right)$

(b) What is the reverse saturation current density, J_o

$L_p = \sqrt{D_p\tau} = \sqrt{(10\cdot10^{-6}s)(0.0259)(437)} = 0.0106$

$L_n = \sqrt{D_n\tau} = \sqrt{(1\cdot10^{-6}s)(0.0259)(781)} = 0.004498$

$J_o = qn_i^2\left(\frac{D_P}{L_PN_D} + \frac{D_N}{L_NN_A}\right) = (1.6\cdot10^{-19})(10^{20})\left(\frac{11.32}{0.0106(10^{16})} + \frac{20.23}{0.004498(10^{17})}\right)$

$= 2.428\cdot10^{-12}\,A/cm^2$

(c) What is current density for $V_{app} = -3V$? $J = J_s\left[\exp\left(\frac{-3}{0.0259}\right)-1\right] = -2.428\cdot10^{-12}\,A/cm^2$

(d) for $V_{app} = 0.5$; $J = J_s\left[\exp\left(\frac{0.5}{0.0259}\right)-1\right] = 0.000588\ A/cm^2$

(e) Python

(f) light shines on semicond with uniform illumination. gen rate is $10^{18}\,cm^{-3}/s$. What is J_{op}?

$J_{op} = 1.6\cdot10^{-19}(0.0106 + 0.004498 + 3.337\cdot10^{-5})(G(x))$ $\quad J_{op} = \left(J_s\left[\exp\left(\frac{qV_{app}}{k_BT}\right)-1\right]\right) - J$

$= 0.002421\ A/cm^2$

(g) Python

(h) $-0.002421\,\frac{A}{cm^2}$ is short circuit current

0.5 V is open circuit voltage

(i) Python

(j) Max power: $-0.0008\cdot0.5 = -0.0004\,W/cm^2$

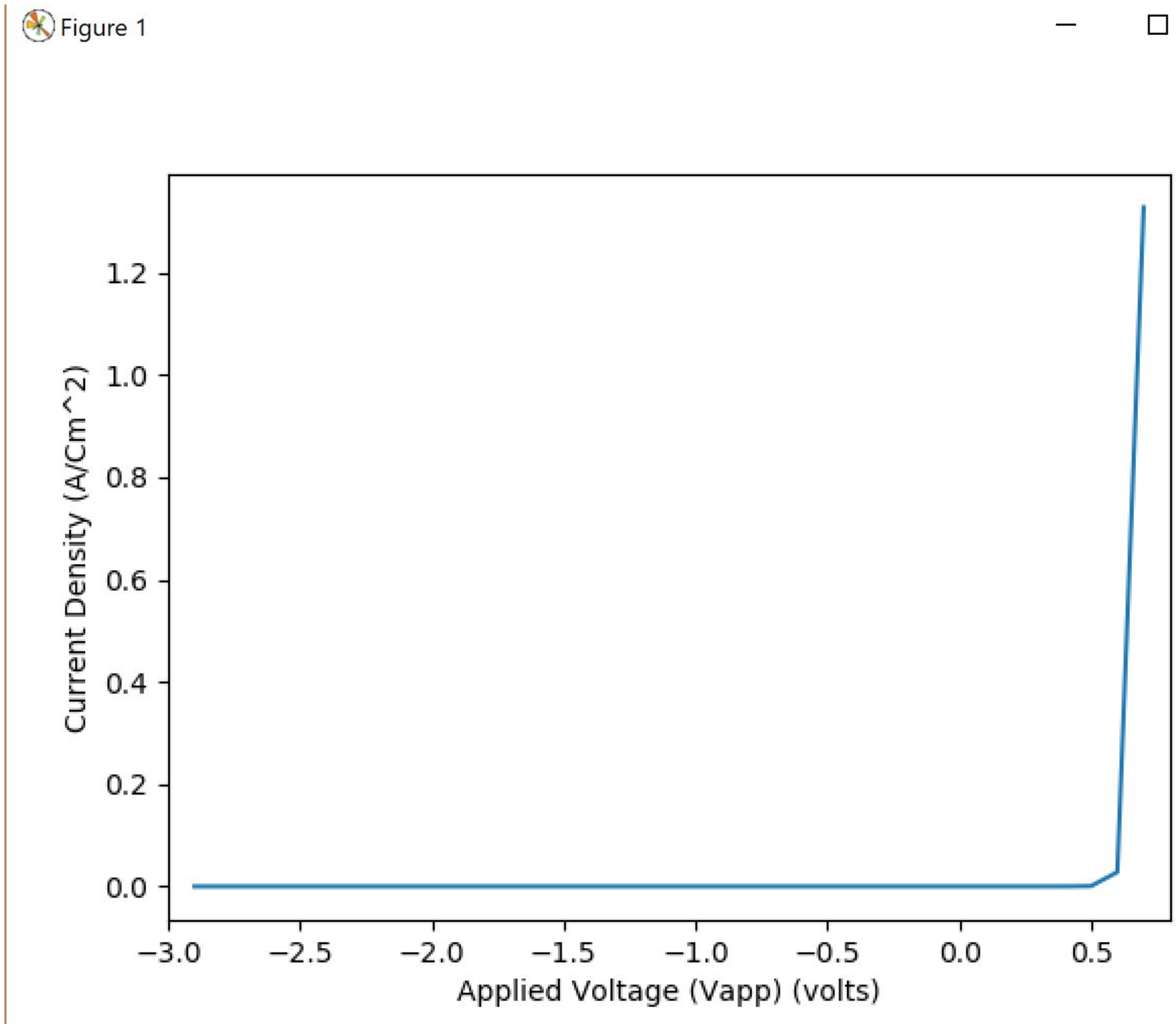
3e)

Code:

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


Current_Density_list = []
VApp_list = []
VApp = -3
```

```python
Js = 2.428 * (10**-12)
Current_Wlight_list = []
Jop = 1.739*(10**16)

for i in range(37):
    VApp = VApp + 0.1
    VApp_list.append(VApp)
    J = Js*(math.exp(VApp/0.0259)-1)
    Current_Density_list.append(J)
    J1 = Js*(math.exp(VApp/0.0259)-1) - Jop
    Current_Wlight_list.append(J1)


plt.xlim(-3, 0.8)
plt.plot(VApp_list, Current_Density_list, label="Current Density versus Applied Voltage")
#plt.plot(VApp_list, Current_Wlight_list)
plt.xlabel("Applied Voltage (Vapp) (volts)")
plt.ylabel("Current Density (A/Cm^2)")

plt.show()
```

PLOT:



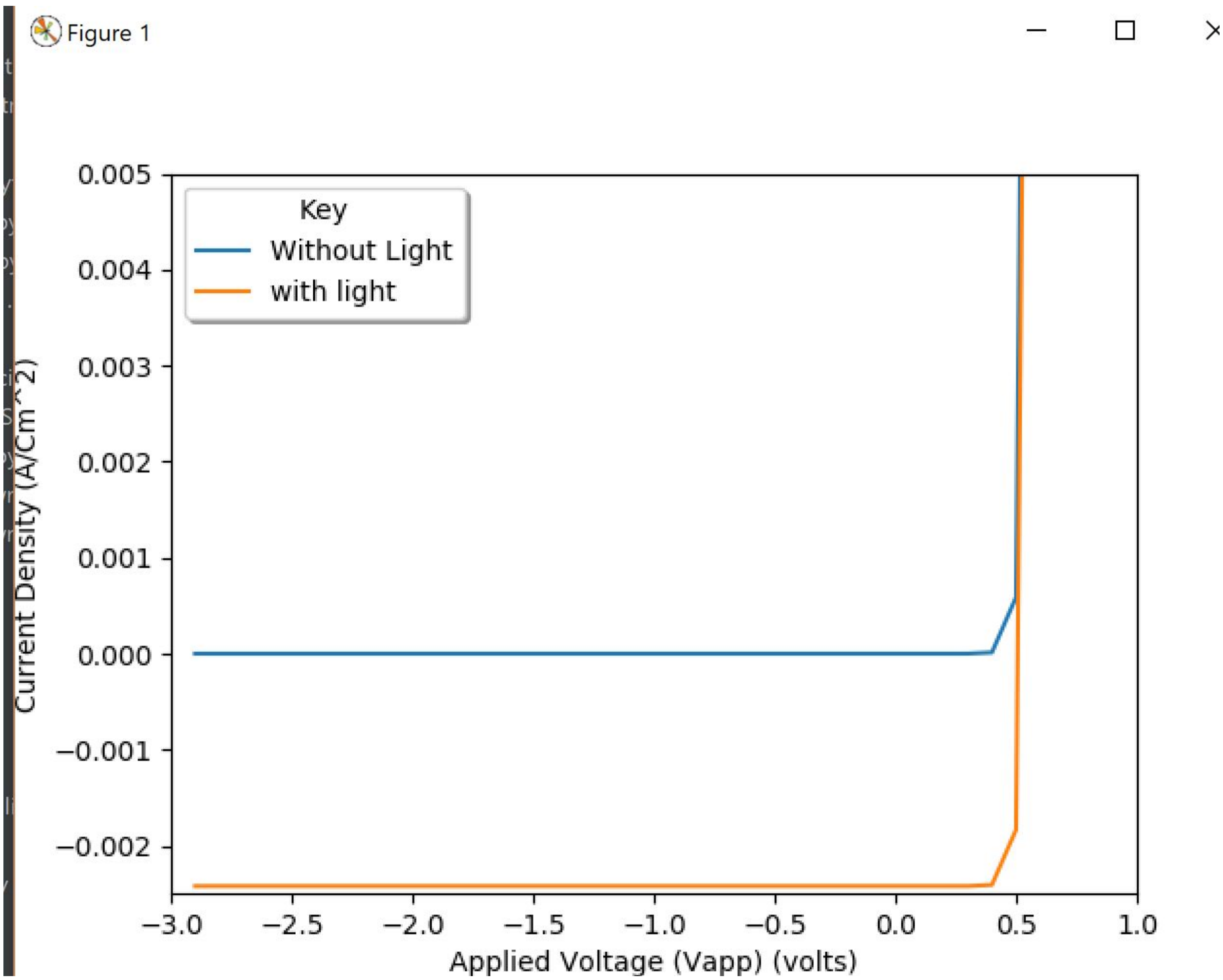
3g)

Code:

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


Current_Density_list = []
VApp_list = []
VApp = -3
Js = 2.428 * (10**-12)
Current_Wlight_list = []
Jop = .002421


for i in range(38):
    VApp = VApp + 0.1
    VApp_list.append(VApp)
    J = Js*(math.exp(VApp/0.0259)-1)
    Current_Density_list.append(J)
```

```
    J1 = Js*(math.exp(VApp/0.0259)-1) - Jop
    Current_Wlight_list.append(J1)


plt.xlim(-3, 1)
plt.ylim(-.0025, .005)
plt.plot(VApp_list, Current_Density_list, label="Without Light")
plt.plot(VApp_list, Current_Wlight_list, label="with light")
plt.xlabel("Applied Voltage (Vapp) (volts)")
plt.ylabel("Current Density (A/Cm^2)")

plt.legend(loc="upper left", shadow=True, title="Key", fancybox=True)

plt.show()
```

PLOT:



3i)

Code

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


Current_Density_list = []
VApp_list = []
VApp = -3
Js = 2.428 * (10**-12)
Current_Wlight_list = []
Jop = .002421
power_list = []


for i in range(38):
    VApp = VApp + 0.1
    VApp_list.append(VApp)
    J = Js*(math.exp(VApp/0.0259)-1)
    Current_Density_list.append(J)
    J1 = Js*(math.exp(VApp/0.0259)-1) - Jop
    z = VApp * J1
    power_list.append(z)
    Current_Wlight_list.append(J1)


plt.xlim(-3, 1)
plt.ylim(-0.0025,0.005 )
plt.plot(VApp_list, power_list)
#plt.plot(VApp_list, Current_Density_list, label="Without Light")
#plt.plot(VApp_list, Current_Wlight_list, label="with light")
plt.xlabel("Applied Voltage (Vapp) (volts)")
plt.ylabel("Current Density (A/Cm^2)")

plt.legend(loc="upper left", shadow=True, title="Key", fancybox=True)

plt.show()
```

PLOT:

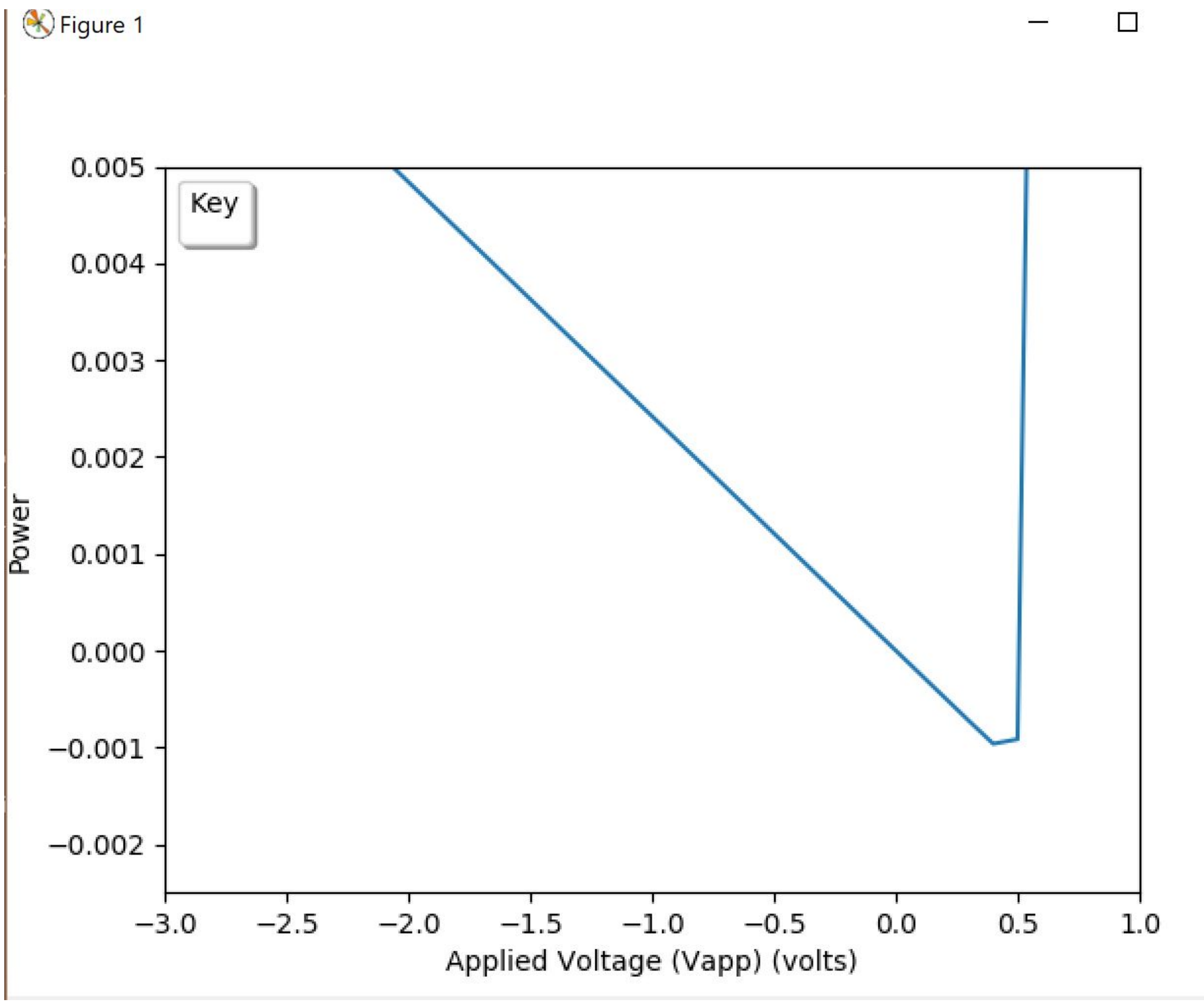


Figure 1
Key
Power
0.005
0.004
0.003
0.002
0.001
0.000
−0.001
−0.002
−3.0
−2.5
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
Applied Voltage (Vapp) (volts)

.