Homework 8

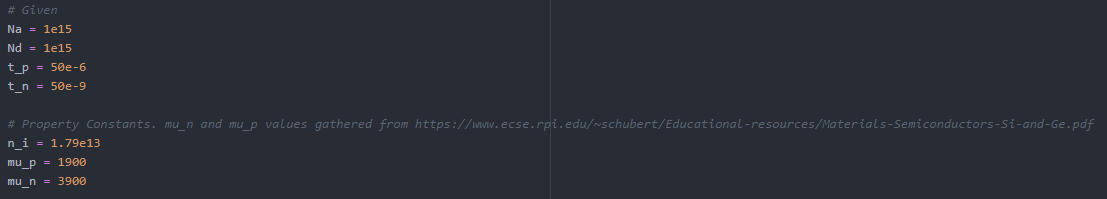
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Semiconductor Development Fundamentals

March 20, 2020

## \*Note: I tried to copy and paste code in as it was relevant. I also copied the entire source code at the very end.\*

# Consider a Germanium p-n junction with 𝑁𝐴 = 1015 cm-3 and 𝑁𝐷 = 1015 cm-3 . The minority carrier lifetime on the p-side is 50 μs, and the minority carrier lifetime on the nside is 50 μs



## What is the built-in voltage, 𝑉𝑏𝑖?





0.208389 [V]

## What is the excess electron concentration at 𝑥 = −𝑥𝑝, for 𝑉𝑎𝑝𝑝 = −3 𝑉?



-320,410,000,000 [cm ^ -3]

## What is the excess electron concentration at 𝑥 = −𝑥𝑝, for 𝑉𝑎𝑝𝑝 = 0.5 𝑉?

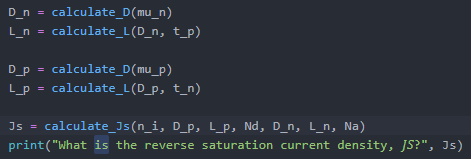
7.75835e+19 [cm ^ -3]

## What is the reverse saturation current density, 𝐽s?





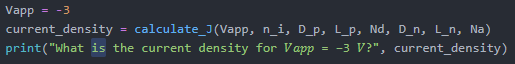




0.001681168 [A / cm^2]

## What is the current density for 𝑉𝑎𝑝𝑝 = −3 𝑉?





-0.001681168 [A / cm^2]

## What is the current density for 𝑉𝑎𝑝𝑝 = 0.5 𝑉?



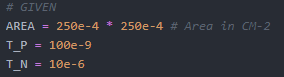
407075.0774 [A / cm^2]

### *For the following problems, assume:*

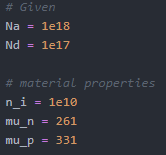
### *The cross-sectional area is 250 μm x 250 μm.*

### *The minority carrier lifetime on the p-side is 100 ns.*

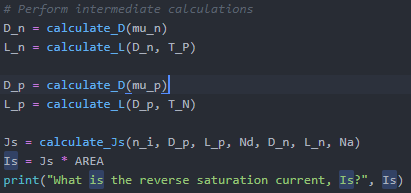
### *The minority carrier lifetime on the n-side is 10 μs*



# Consider a Si p-n junction with 𝑁𝐴 = 1018 cm-3 and 𝑁𝐷 = 1017 cm-3 .

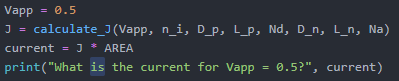


## What is the reverse saturation current, 𝐼s?



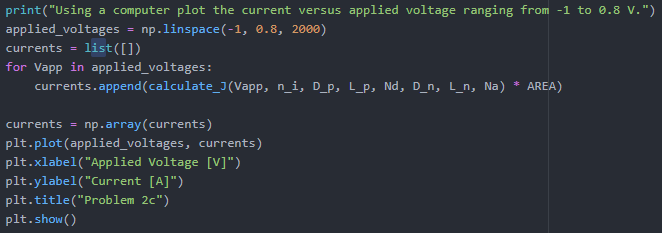
1.748085672905745e-16 [A]

## What is the current for 𝑉𝑎𝑝𝑝 = 0.5 𝑉 ?



4.2327836289216224e-08 [A]

## Using a computer, plot the current versus applied voltage, ranging from -1 V to 0.8 V. Turn in your code.



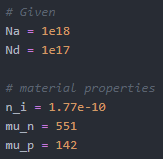
A screenshot of a social media post

Description automatically generated

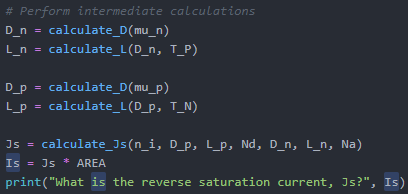
## What is the apparent turn-on voltage?

Approximately 0.75 [V]0

# Consider a GaN p-n junction with 𝑁𝐴 = 1018 cm-3 and 𝑁𝐷 = 1017 cm-3 .

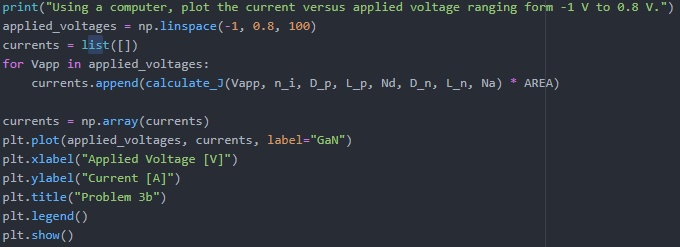


## What is the reverse saturation current, 𝐼s?



5.6425327326520155e-56 [A]

## Using a computer, plot the current versus applied voltage, ranging from -1 V to 0.8 V. Turn in your code.



A screenshot of a social media post

Description automatically generated

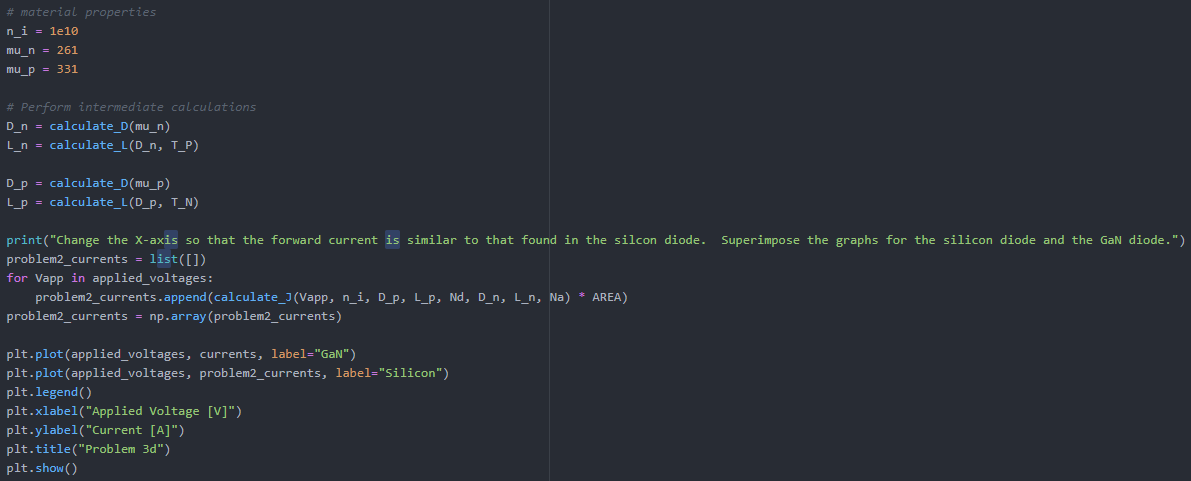
## What is the apparent turn-on voltage?

0.75 [V]

## Compare this graph with the graph from problem #2. For the same voltage, which diode has greater current: the silicon diode or the GaN diode?

The silicon diode has a much greater current than the GaN diode.

## Change the x-axis so that the forward current is similar to that found for the silicon diode. Superimpose the graphs for the silicon diode and the GaN diode. Make a single, nice graph. Turn in your code.



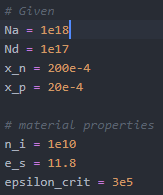
A screenshot of a social media post

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## What is the apparent turn-on voltage for the silicon diode and the GaN diode?

0.75 [V]

# Consider a Si p-n junction with 𝑁𝐴 = 1018 cm-3 and 𝑁𝐷 = 1017 cm-3 . The length of the n-region is 200 μm, and the length of the p- region is 20 μm. What are:



## The breakdown voltage considering only avalanche breakdown?





4.126817683628187 [V]

## The breakdown voltage considering only punch-through on the n-side?





3369155.246689906 [V]

## The breakdown voltage considering only punch-through on the p-side?





3369155.246689906 [V]

## The overall breakdown voltage?



6738314.620197495 [V]

import math

import numpy as np

import matplotlib.pyplot as plt

KBT\_Q = 0.0259

q = 1.6e-19

e\_0 = 8.854e-14

def calculate\_excess\_electron\_concentration(n\_i, Na, Vapp):

return n\_i\*\*2 / Na \* (math.exp(Vapp / KBT\_Q) - 1)

def calculate\_built\_in\_voltage(n\_i, Nd, Na):

return KBT\_Q\*math.log(Na \* Nd / n\_i\*\*2)

def calculate\_Js(n\_i, D\_p, L\_p, Nd, D\_n, L\_n, Na):

return q \* n\_i\*\*2 \* ((D\_p / (L\_p \* Nd)) + (D\_n / (L\_n \* Na)))

def calculate\_J(Vapp, n\_i, D\_p, L\_p, Nd, D\_n, L\_n, Na):

Js = calculate\_Js(n\_i, D\_p, L\_p, Nd, D\_n, L\_n, Na)

return Js \* (math.exp(Vapp/KBT\_Q) - 1)

def calculate\_D(mu):

return KBT\_Q \* mu

def calculate\_L(D, t):

return (D \* t)\*\*0.5

def calculate\_avalanche\_breakdown(n\_i, Nd, Na, e\_s, epsilon\_crit):

Vbi = calculate\_built\_in\_voltage(n\_i, Nd, Na)

return epsilon\_crit\*\*2 \* (e\_s \* e\_0 / (2 \* q)) \* ((Nd + Na)/(Na\*Nd)) + Vbi

def calculate\_punch\_through\_n(n\_i, Nd, Na, e\_s, x\_n):

Vbi = calculate\_built\_in\_voltage(n\_i, Nd, Na)

return q \* Nd / (2 \* e\_s \* e\_0) \* ((Na + Nd) / Na) \* x\_n\*\*2 - Vbi

def calculate\_punch\_through\_p(n\_i, Nd, Na, e\_s, x\_p):

Vbi = calculate\_built\_in\_voltage(n\_i, Nd, Na)

return q \* Na / (2 \* e\_s \* e\_0) \* ((Nd + Na) / Nd) \* x\_p\*\*2 - Vbi

def problem\_1():

print("\nProblem 1")

print("Consider a Germanium p-n junction with NA = 1015 cm-3 and ND = 1015 cm-3. The minority carrier lifetime on the p-side is 50 micro-s, and the minority carrier lifetime on the nside is 50 micro-s.")

# Given

Na = 1e15

Nd = 1e15

t\_p = 50e-6

t\_n = 50e-9

# Property Constants. mu\_n and mu\_p values gathered from https://www.ecse.rpi.edu/~schubert/Educational-resources/Materials-Semiconductors-Si-and-Ge.pdf

n\_i = 1.79e13

mu\_p = 1900

mu\_n = 3900

Vbi = calculate\_built\_in\_voltage(n\_i, Nd, Na)

print("What is the built-in voltage, 𝑉𝑏𝑖?", Vbi)

Vapp = -3

excess\_electron\_concentration = calculate\_excess\_electron\_concentration(n\_i, Na, Vapp)

print("What is the excess electron concentration at 𝑥 = −xp, for Vapp = −3 𝑉?", excess\_electron\_concentration)

Vapp = 0.5

excess\_electron\_concentration = calculate\_excess\_electron\_concentration(n\_i, Na, Vapp)

print("What is the excess electron concentration at 𝑥 = −xp, for Vapp = 0.5 𝑉?", excess\_electron\_concentration)

D\_n = calculate\_D(mu\_n)

L\_n = calculate\_L(D\_n, t\_p)

D\_p = calculate\_D(mu\_p)

L\_p = calculate\_L(D\_p, t\_n)

Js = calculate\_Js(n\_i, D\_p, L\_p, Nd, D\_n, L\_n, Na)

print("What is the reverse saturation current density, 𝐽𝑆?", Js)

Vapp = -3

current\_density = calculate\_J(Vapp, n\_i, D\_p, L\_p, Nd, D\_n, L\_n, Na)

print("What is the current density for 𝑉𝑎𝑝𝑝 = −3 𝑉?", current\_density)

Vapp = 0.5

current\_density = calculate\_J(Vapp, n\_i, D\_p, L\_p, Nd, D\_n, L\_n, Na)

print("What is the current density for 𝑉𝑎𝑝𝑝 = 0.5 𝑉?", current\_density)

# GIVEN

AREA = 250e-4 \* 250e-4 # Area in CM-2

T\_P = 100e-9

T\_N = 10e-6

def problem\_2():

print("\nProblem 2:")

print("Consider a Si p-n junction with 𝑁𝐴 = 1018 cm-3 and 𝑁𝐷 = 1017 cm-3")

# Given

Na = 1e18

Nd = 1e17

# material properties

n\_i = 1e10

mu\_n = 261

mu\_p = 331

# Perform intermediate calculations

D\_n = calculate\_D(mu\_n)

L\_n = calculate\_L(D\_n, T\_P)

D\_p = calculate\_D(mu\_p)

L\_p = calculate\_L(D\_p, T\_N)

Js = calculate\_Js(n\_i, D\_p, L\_p, Nd, D\_n, L\_n, Na)

Is = Js \* AREA

print("What is the reverse saturation current, Is?", Is)

Vapp = 0.5

J = calculate\_J(Vapp, n\_i, D\_p, L\_p, Nd, D\_n, L\_n, Na)

current = J \* AREA

print("What is the current for Vapp = 0.5?", current)

print("Using a computer plot the current versus applied voltage ranging from -1 to 0.8 V.")

applied\_voltages = np.linspace(-1, 0.8, 2000)

currents = list([])

for Vapp in applied\_voltages:

currents.append(calculate\_J(Vapp, n\_i, D\_p, L\_p, Nd, D\_n, L\_n, Na) \* AREA)

currents = np.array(currents)

plt.plot(applied\_voltages, currents)

plt.xlabel("Applied Voltage [V]")

plt.ylabel("Current [A]")

plt.title("Problem 2c")

plt.show()

print("What is the apprent turn-on voltage?")

print("Approximately 0.75V")

def problem\_3():

print("\nProblem 3:")

print("Consider a GaN p-n junction with Na = 1018 cm-3 and Nd = 1017 cm-3")

# Given

Na = 1e18

Nd = 1e17

# material properties

n\_i = 1.77e-10

mu\_n = 551

mu\_p = 142

# Perform intermediate calculations

D\_n = calculate\_D(mu\_n)

L\_n = calculate\_L(D\_n, T\_P)

D\_p = calculate\_D(mu\_p)

L\_p = calculate\_L(D\_p, T\_N)

Js = calculate\_Js(n\_i, D\_p, L\_p, Nd, D\_n, L\_n, Na)

Is = Js \* AREA

print("What is the reverse saturation current, Js?", Is)

print("Using a computer, plot the current versus applied voltage ranging form -1 V to 0.8 V.")

applied\_voltages = np.linspace(-1, 0.8, 100)

currents = list([])

for Vapp in applied\_voltages:

currents.append(calculate\_J(Vapp, n\_i, D\_p, L\_p, Nd, D\_n, L\_n, Na) \* AREA)

currents = np.array(currents)

plt.plot(applied\_voltages, currents, label="GaN")

plt.xlabel("Applied Voltage [V]")

plt.ylabel("Current [A]")

plt.title("Problem 3b")

plt.legend()

plt.show()

print("What is the apparent turn-on voltage?")

print("Approximately 0.75V")

# material properties

n\_i = 1e10

mu\_n = 261

mu\_p = 331

# Perform intermediate calculations

D\_n = calculate\_D(mu\_n)

L\_n = calculate\_L(D\_n, T\_P)

D\_p = calculate\_D(mu\_p)

L\_p = calculate\_L(D\_p, T\_N)

print("Change the X-axis so that the forward current is similar to that found in the silcon diode. Superimpose the graphs for the silicon diode and the GaN diode.")

problem2\_currents = list([])

for Vapp in applied\_voltages:

problem2\_currents.append(calculate\_J(Vapp, n\_i, D\_p, L\_p, Nd, D\_n, L\_n, Na) \* AREA)

problem2\_currents = np.array(problem2\_currents)

plt.plot(applied\_voltages, currents, label="GaN")

plt.plot(applied\_voltages, problem2\_currents, label="Silicon")

plt.legend()

plt.xlabel("Applied Voltage [V]")

plt.ylabel("Current [A]")

plt.title("Problem 3d")

plt.show()

print("What is the apparent turn-on voltage for the silicon diode and the GaN diode?")

print("Approximately 0.75V")

def problem\_4():

print("\nProblem 4:")

print("Consider a Si p-n junction with 𝑁𝐴 = 1018 cm-3 and 𝑁𝐷 = 1017 cm-3 . The length of the n-region is 200 micro-m, and the length of the p- region is 20 micro-m. ")

# Given

Na = 1e18

Nd = 1e17

x\_n = 200e-4

x\_p = 20e-4

# material properties

n\_i = 1e10

e\_s = 11.8

epsilon\_crit = 3e5

Vbr\_avalanche = calculate\_avalanche\_breakdown(n\_i, Nd, Na, e\_s, epsilon\_crit)

print("What is the breakdown voltage considering only avalanche breakdown?", Vbr\_avalanche)

Vbr\_punch\_through\_n = calculate\_punch\_through\_n(n\_i, Nd, Na, e\_s, x\_n)

print("What is the breakdown voltage considering only punch-through on the n-side?", Vbr\_punch\_through\_n)

Vbr\_punch\_through\_p = calculate\_punch\_through\_p(n\_i, Nd, Na, e\_s, x\_p)

print("What is the breakdown voltage considering only punch-through on the p-side?", Vbr\_punch\_through\_p)

print("What is the overall breakdown voltage?", Vbr\_avalanche + Vbr\_punch\_through\_n + Vbr\_punch\_through\_p)

if \_\_name\_\_ == "\_\_main\_\_":

problem\_1()

problem\_2()

problem\_3()

problem\_4()