Advanced Solid-State Devices

Atlas Simulation Assignments

Instructor:
Prof. Bizhan Rashidian

Author:
Parsa Aseminia - 99101879

Part 1: P-N Junction

Assume that we are designing a long silicon diode with step junction and doping concentrations of 10^{19} $Atom.cm^{-3}$ for phosphorous and 10^{19} $Atom.cm^{-3}$ for boron

1. Draw electron and hole concentrations (mark depletion regions), electric potential (fermi level), 4 current components (drift and diffusion for both carrier types) and doping concentrations for zero bias, forward bias and reverse bias.

Defining the structure:

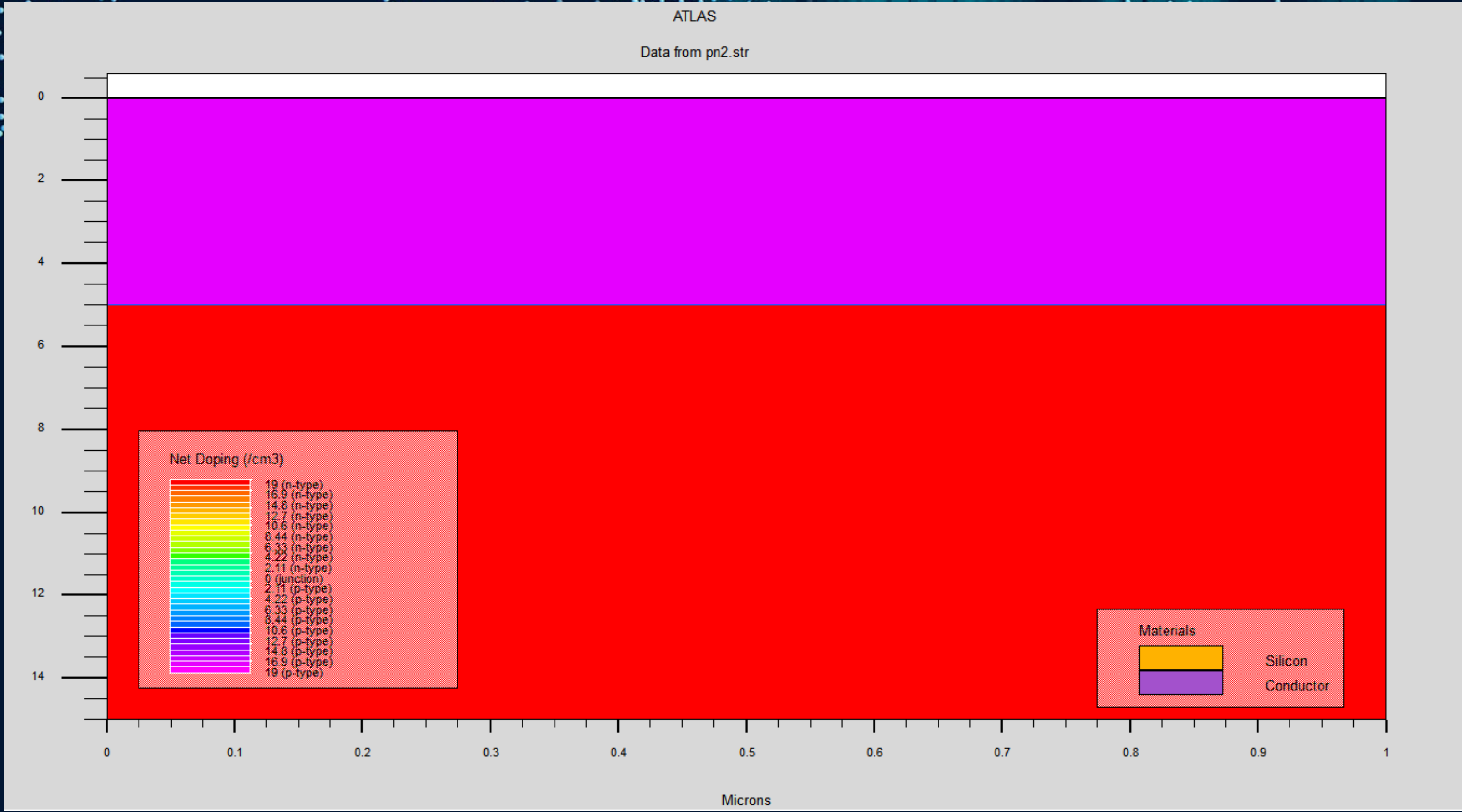
```
go atlas

#Adding the meshings
mesh
x.m l=0.0 spac=1.0
x.m l=1.0 spac=1.0
y.m l=0.0 spac=1.0
y.m l=5.0 spac=0.005
y.m l=15 spac=2.0

region num=1 silicon

#Naming the P-Type Silicon Cathode and N-Type Silicon Anode
electrode top name=cathode
electrode bottom name=cathode

# Doping Concentration
doping uniform p.type conc=1e19 x.l=0 x.r=1 y.t=0.0 y.b=5.0
doping uniform n.type conc=1e19 x.l=0 x.r=1 y.t=5.0 y.b=15.0
```

Higher mesh density around the junction

Adding the Physical and Numerical models:

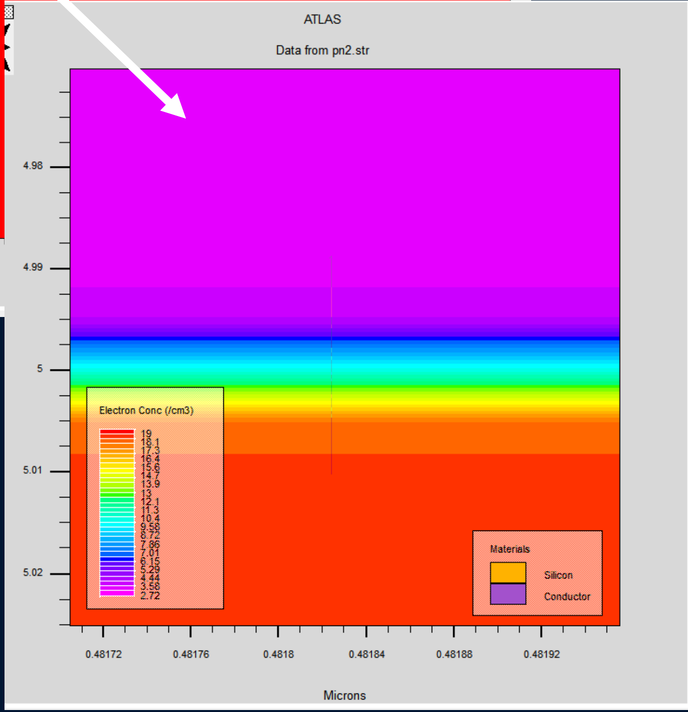
```
#Physical Models
models srh conmob bgn auger fldmob

#Impact Ionization model
impact selb

#Adding newton numerical model
method newton climit=1.e-5

#Solving the P-N junction in equilibirium
solve init

#Getting all the Carrier Concentrations and Energy bands and diagrams
output band.temp

save outf=pn2.str
tonyplot pn2.str
```

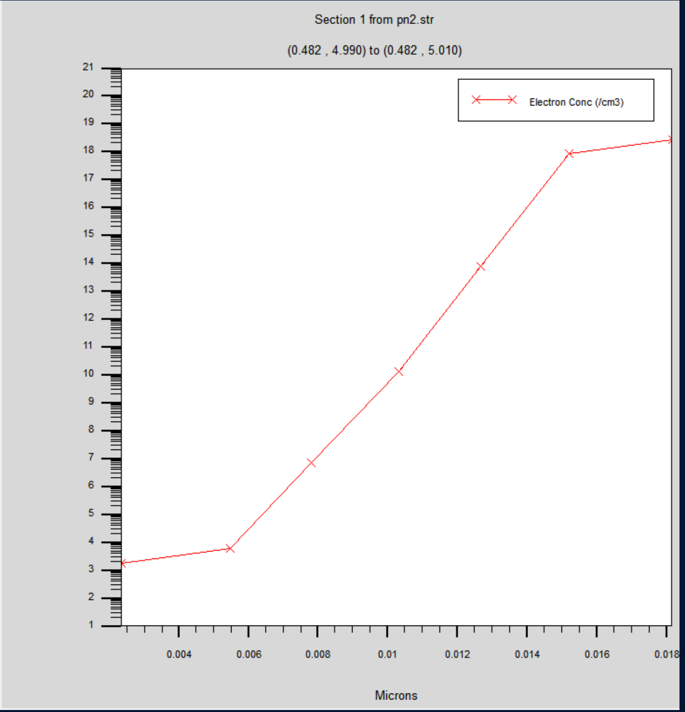
srh: Shockley-Read-Hall recombination model.
conmob: Concentration-dependent mobility model.
bgn: Bandgap narrowing model.
auger: Auger recombination model.
fldmob: Field-dependent mobility model.


ATLAS
Data from pn2.str
Net Doping (/cm3)
19 (n-type)
16.9 (n-type)
14.8 (n-type)
12.7 (n-type)
10.6 (n-type)
8.44 (n-type)
6.33 (n-type)
4.22 (n-type)
2.11 (n-type)
0 (junction)
2.11 (p-type)
4.22 (p-type)
6.33 (p-type)
8.44 (p-type)
10.6 (p-type)
12.7 (p-type)
14.8 (p-type)
16.9 (p-type)
19 (p-type)
Materials
Silicon
Conductor
0
2
4
6
8
10
12
14
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Microns

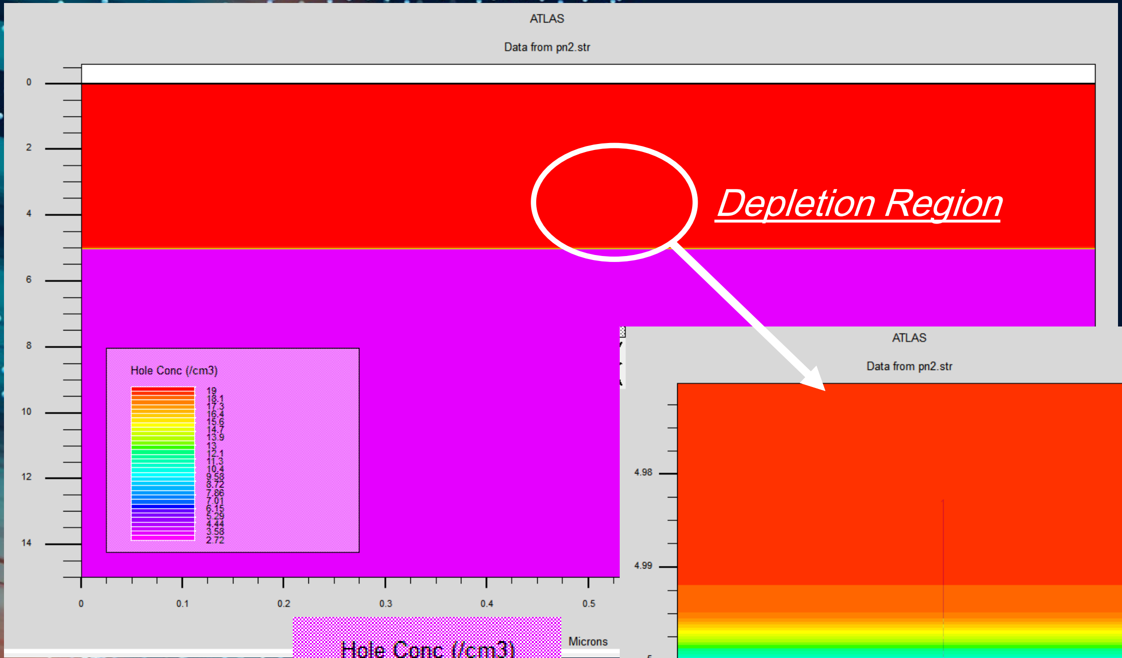
01 Zero Bias

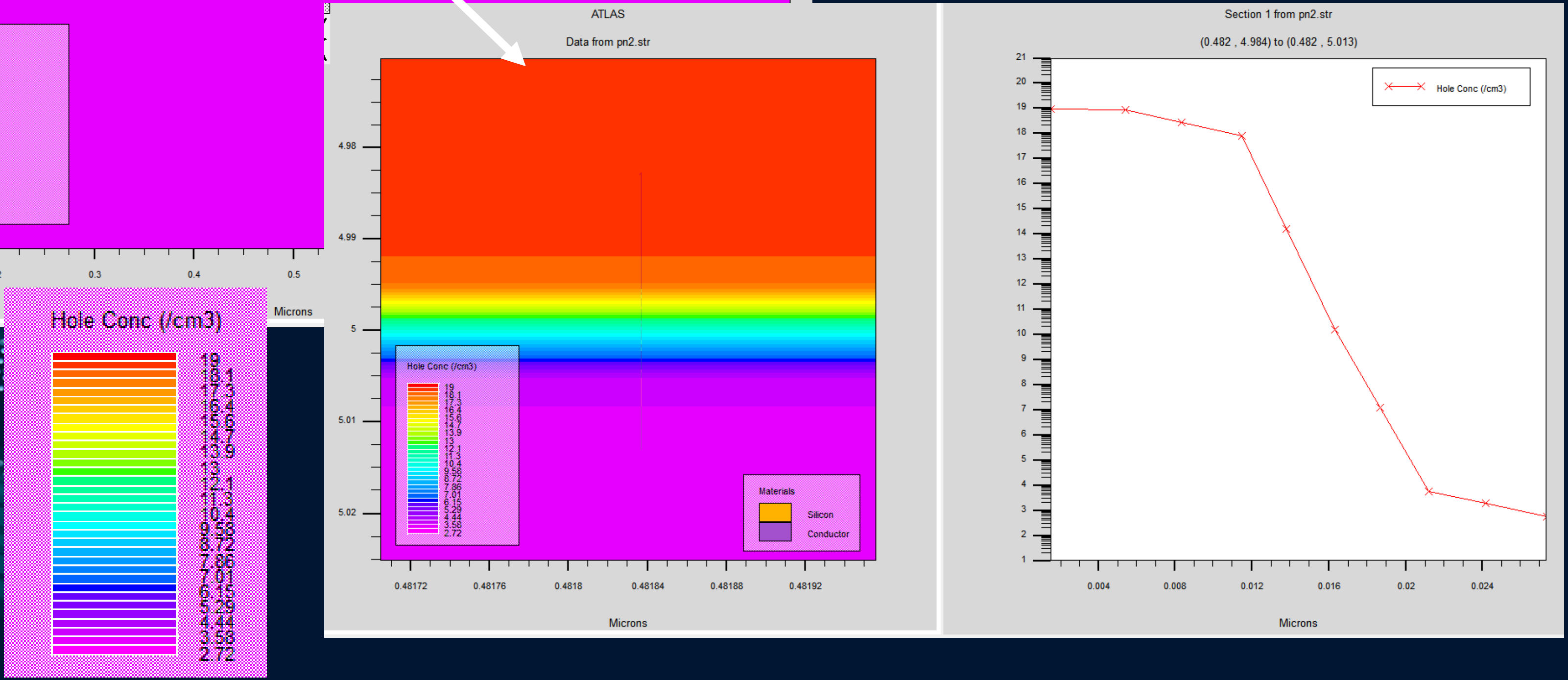
Zero Bias: Electron Concentrations



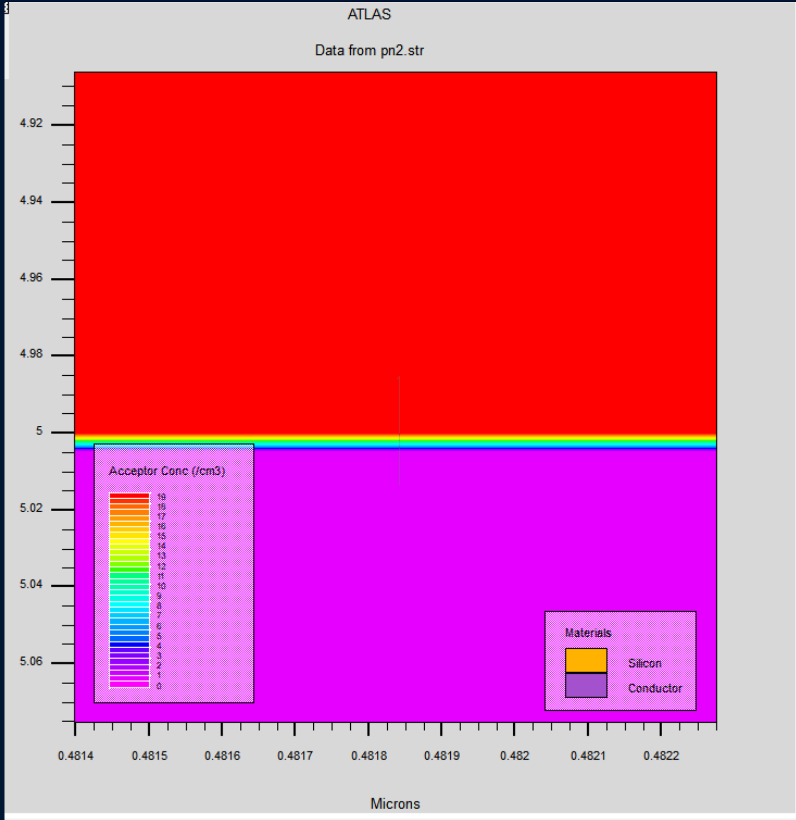


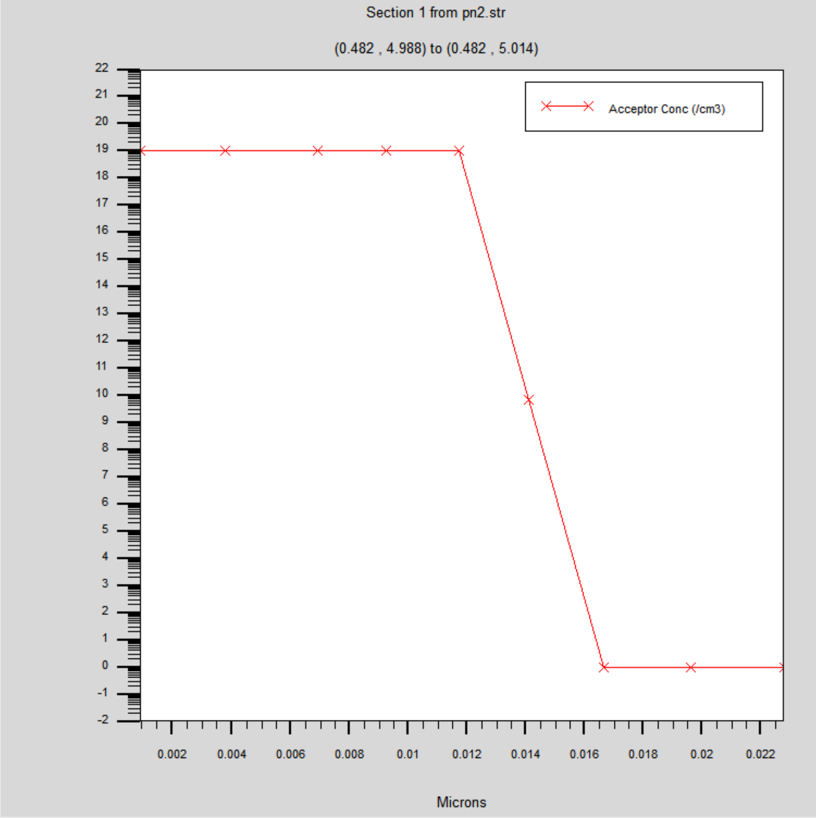
Zero Bias: Hole Concentrations



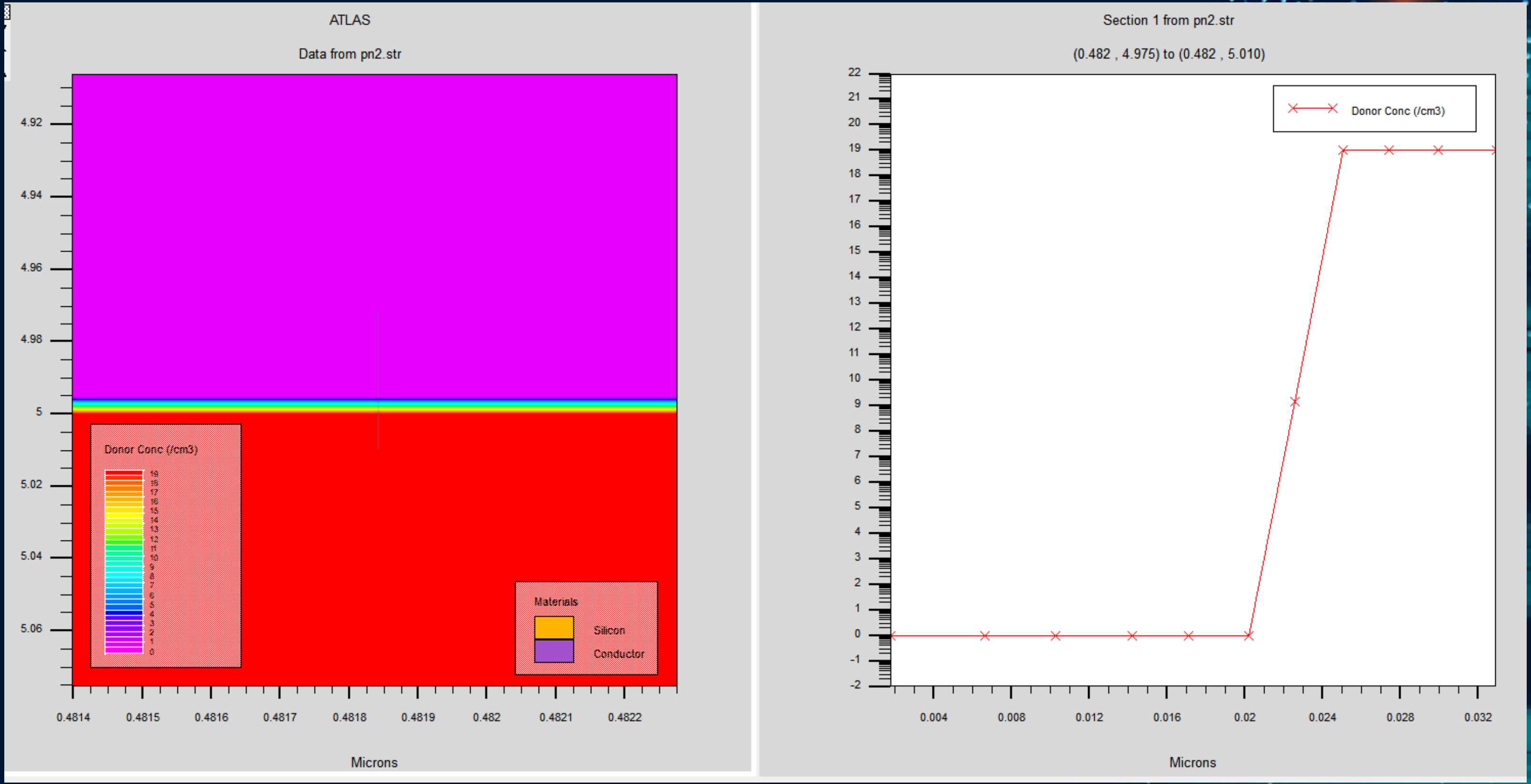


Zero Bias: Acceptor Concentrations

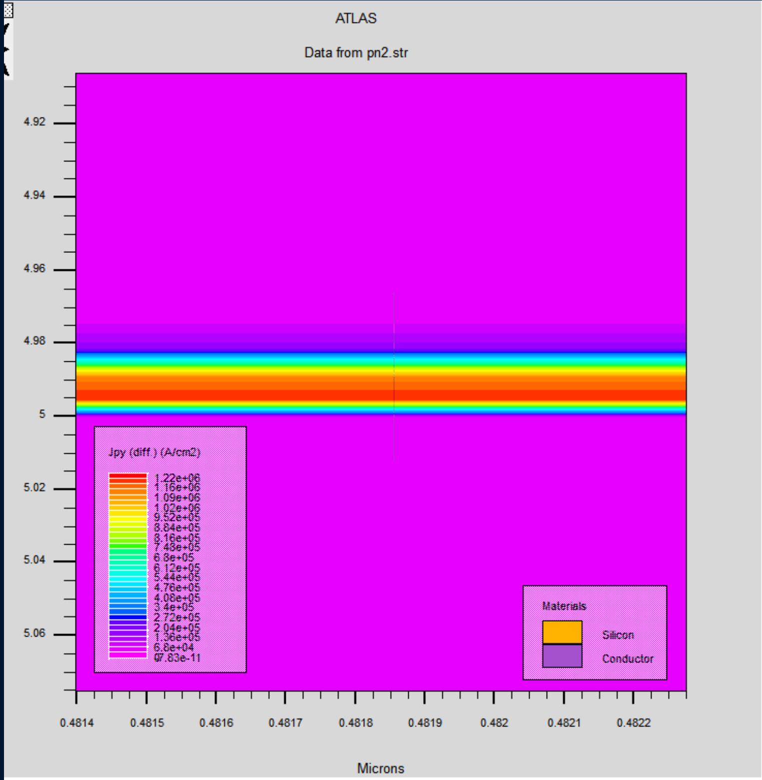


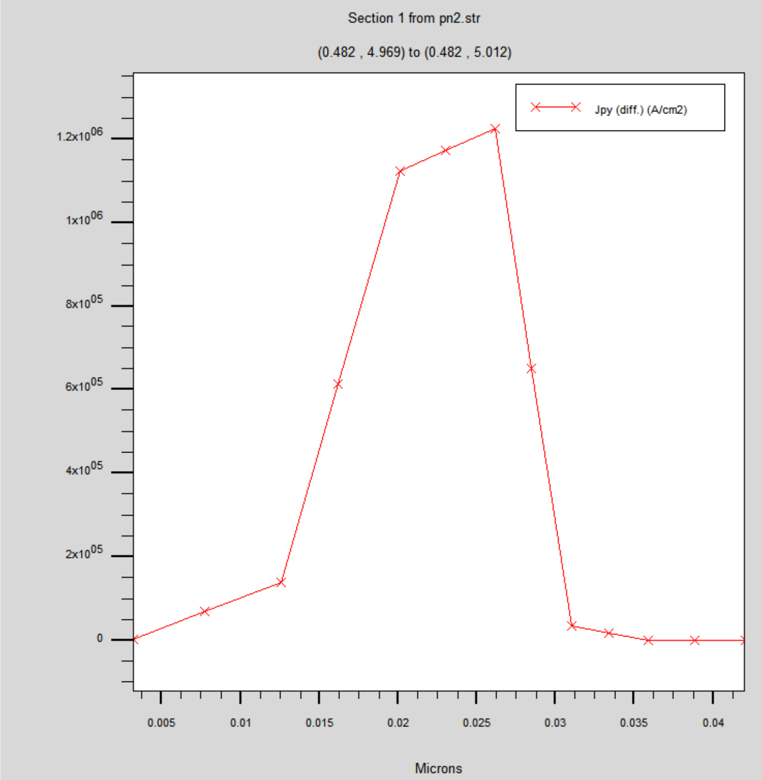


Zero Bias: Donor Concentrations

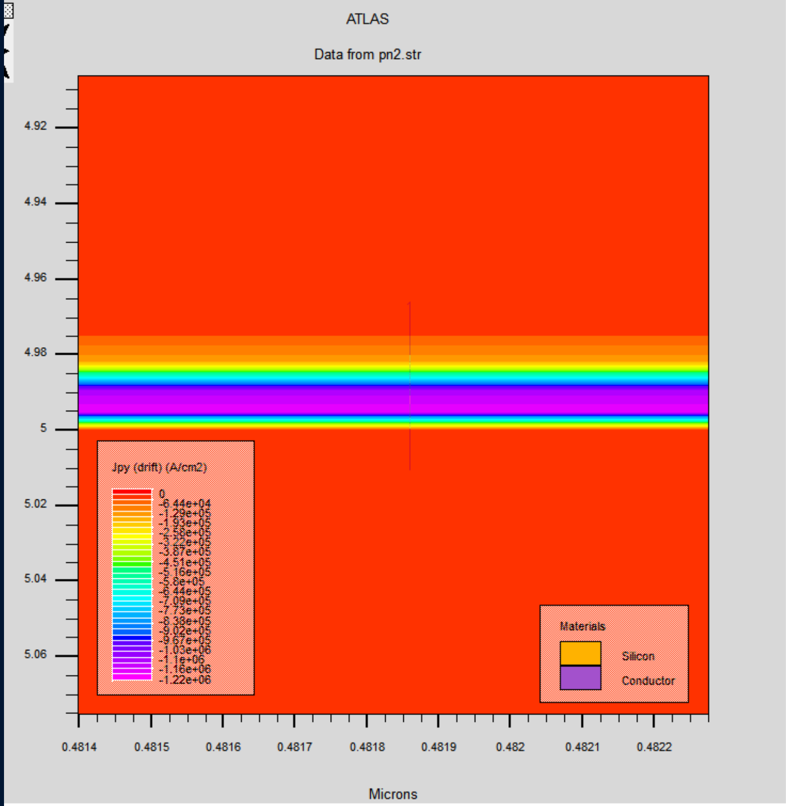


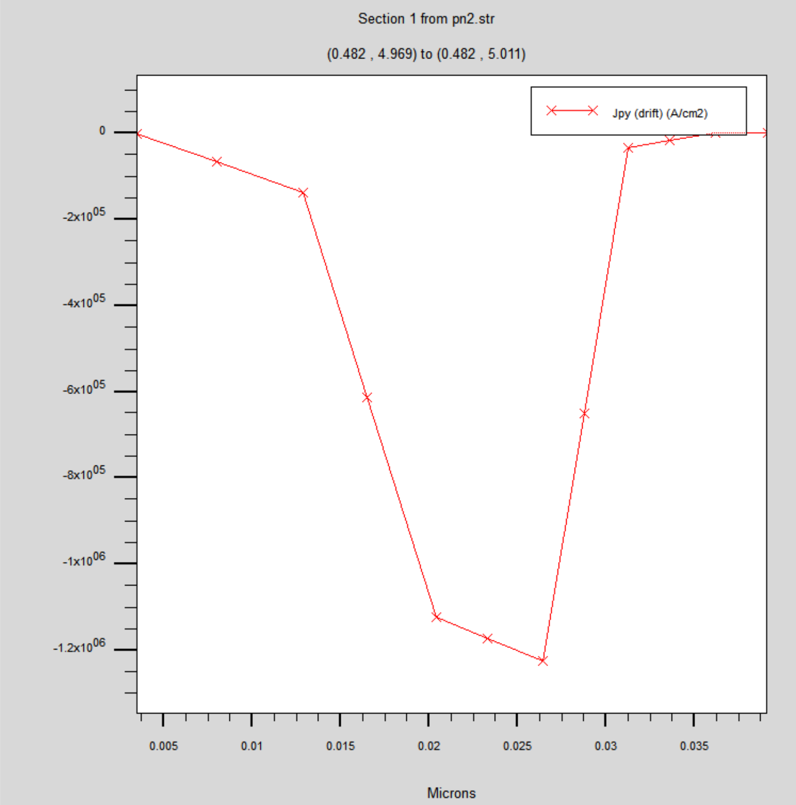
Zero Bias: Jpy (Holes Diffusion Current)





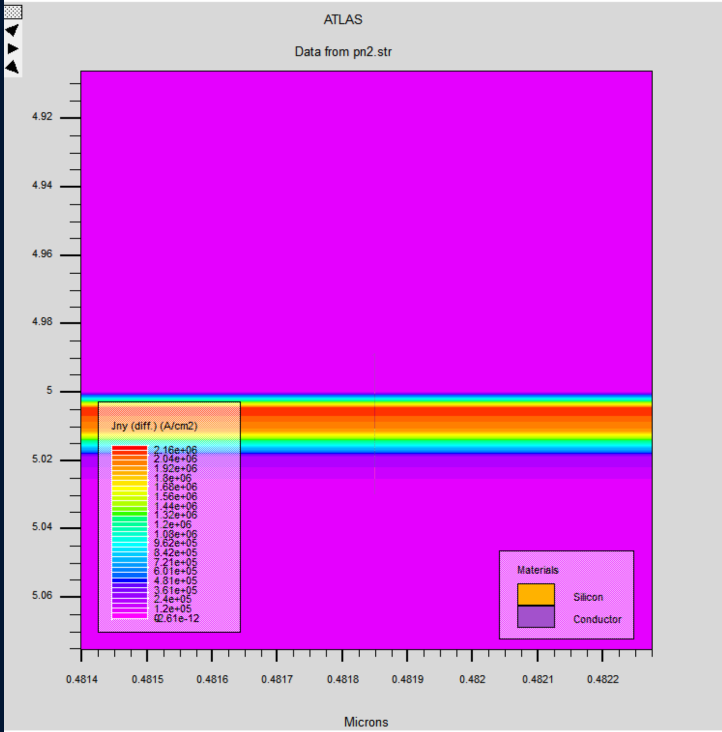
Zero Bias: Jpy (Holes Drift Current)

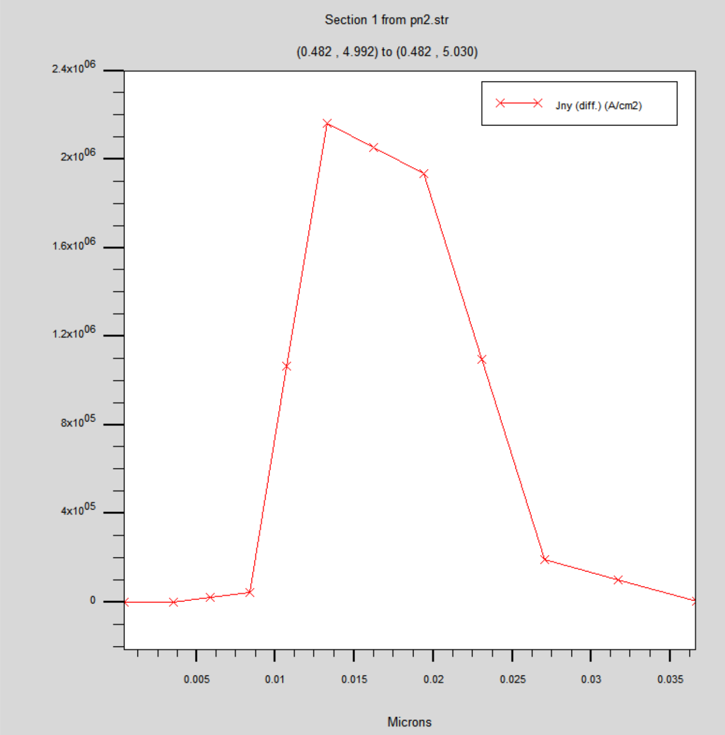




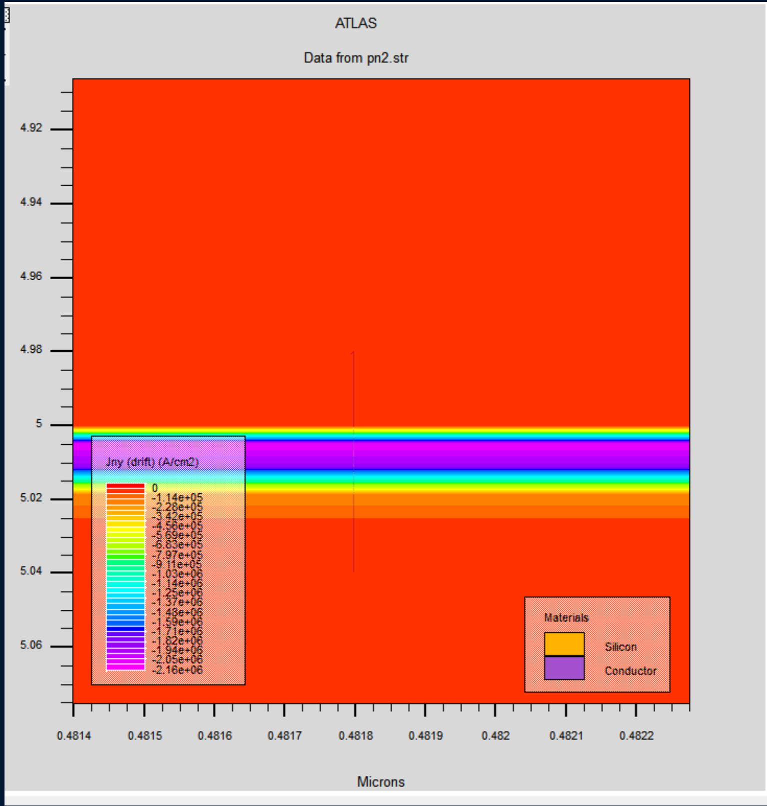
As we expected, the total hole current (Drift + Diffusion) under equilibrium is equal to zero.

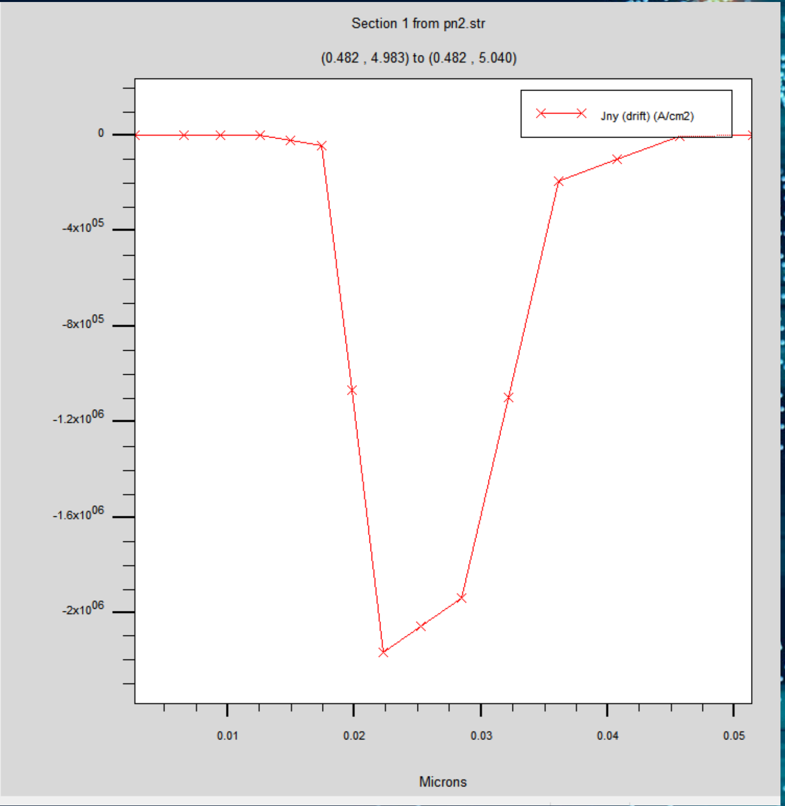
Zero Bias: Jny (Electrons Diffusion Current)



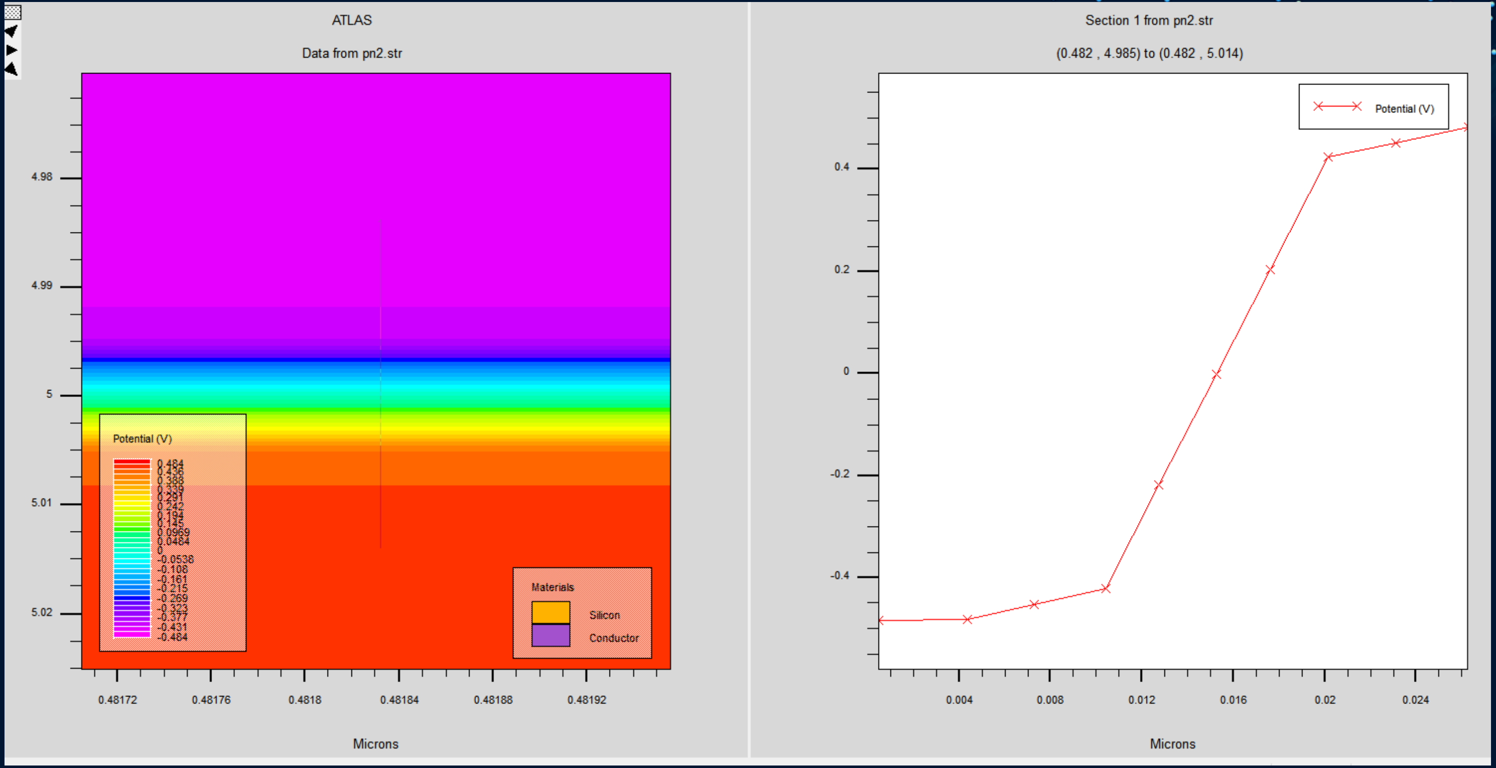


Zero Bias: Jny (Electrons Drift Current)

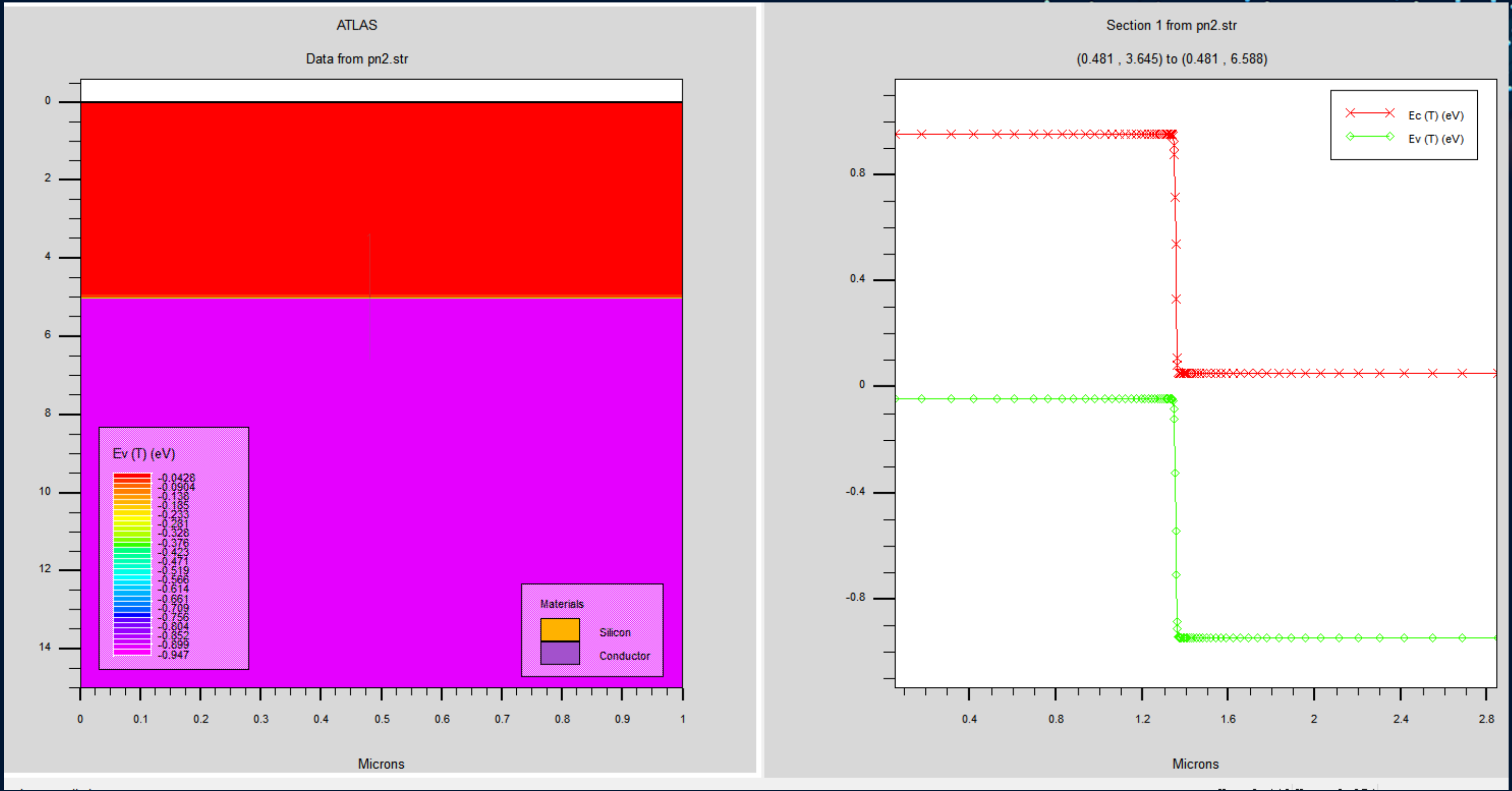




Zero Bias: Electric Potential

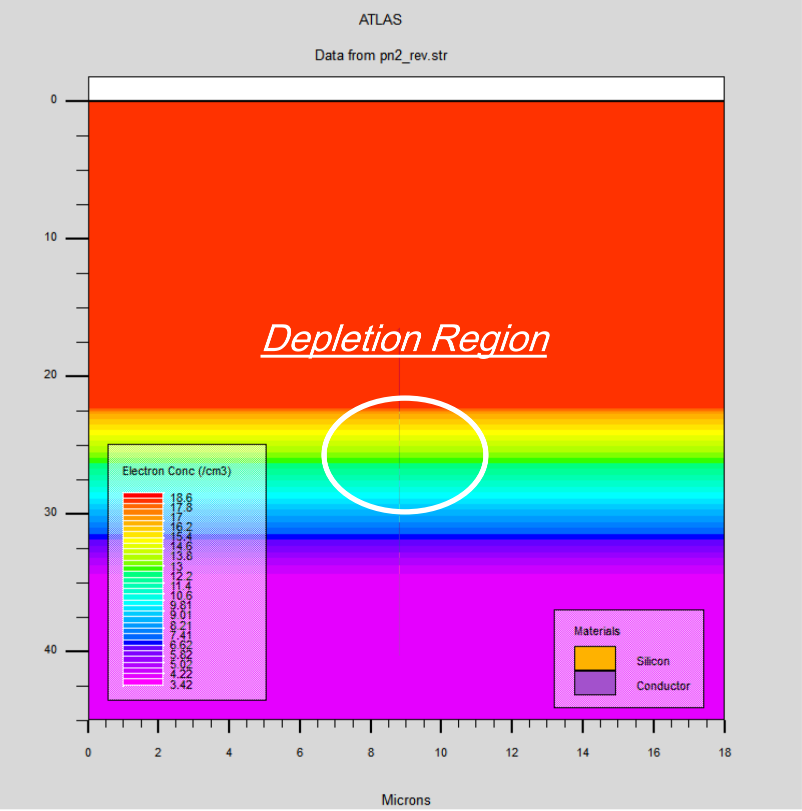


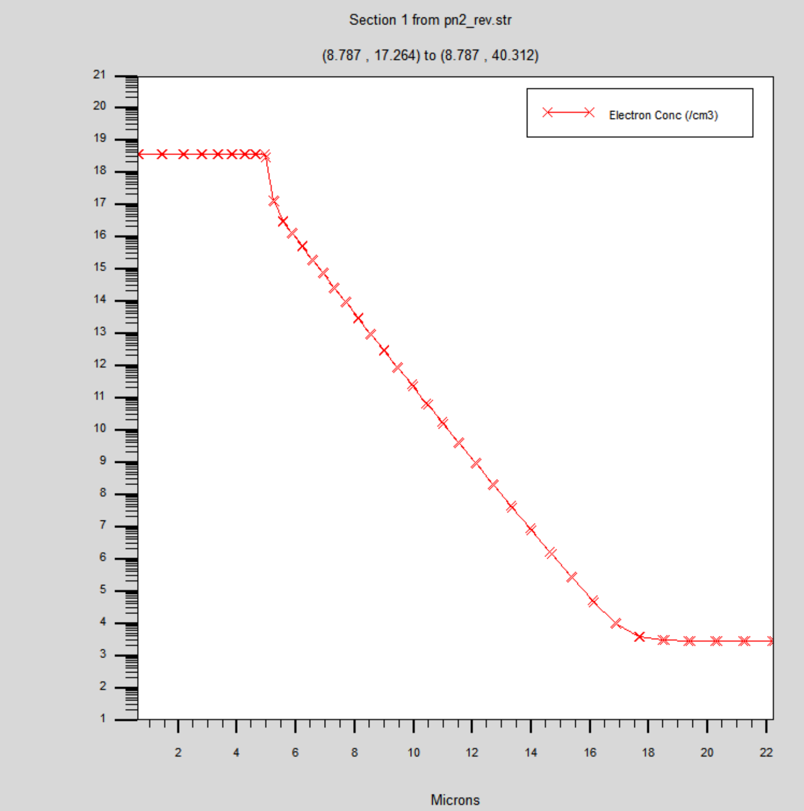
Zero Bias: Energy Band Diagrams



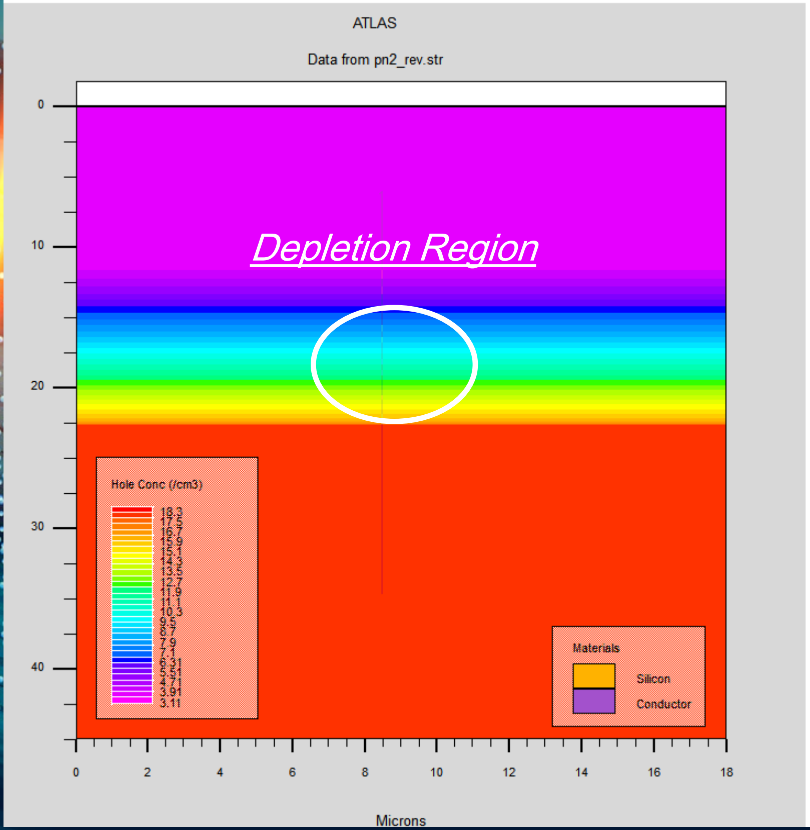
02 | Reverse Bias

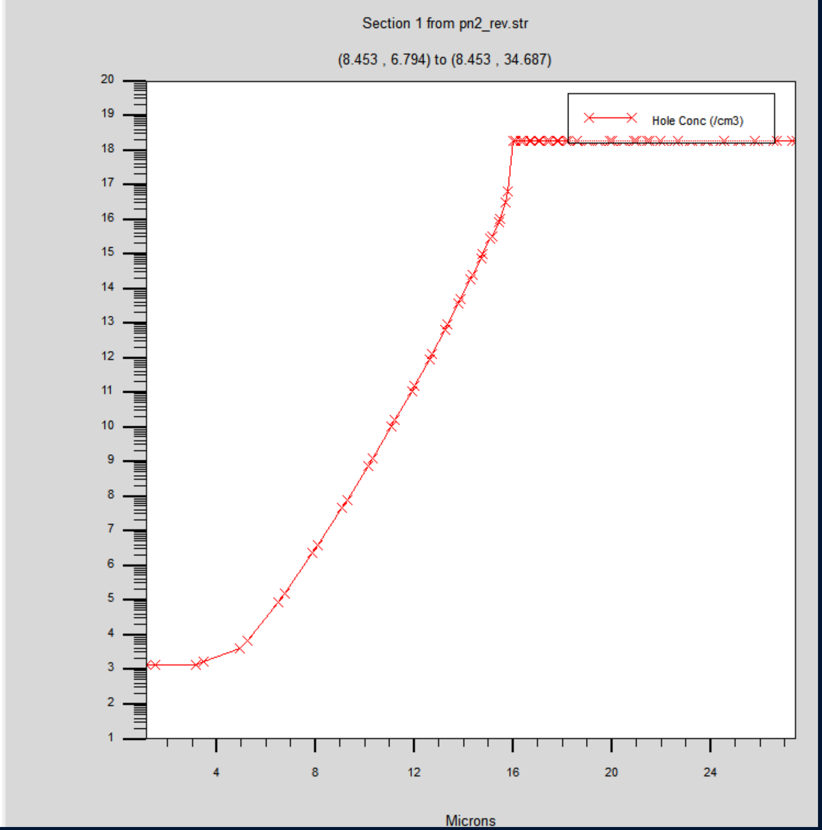
Reverse Bias: Electron Concentrations





Reverse Bias: Hole Concentrations

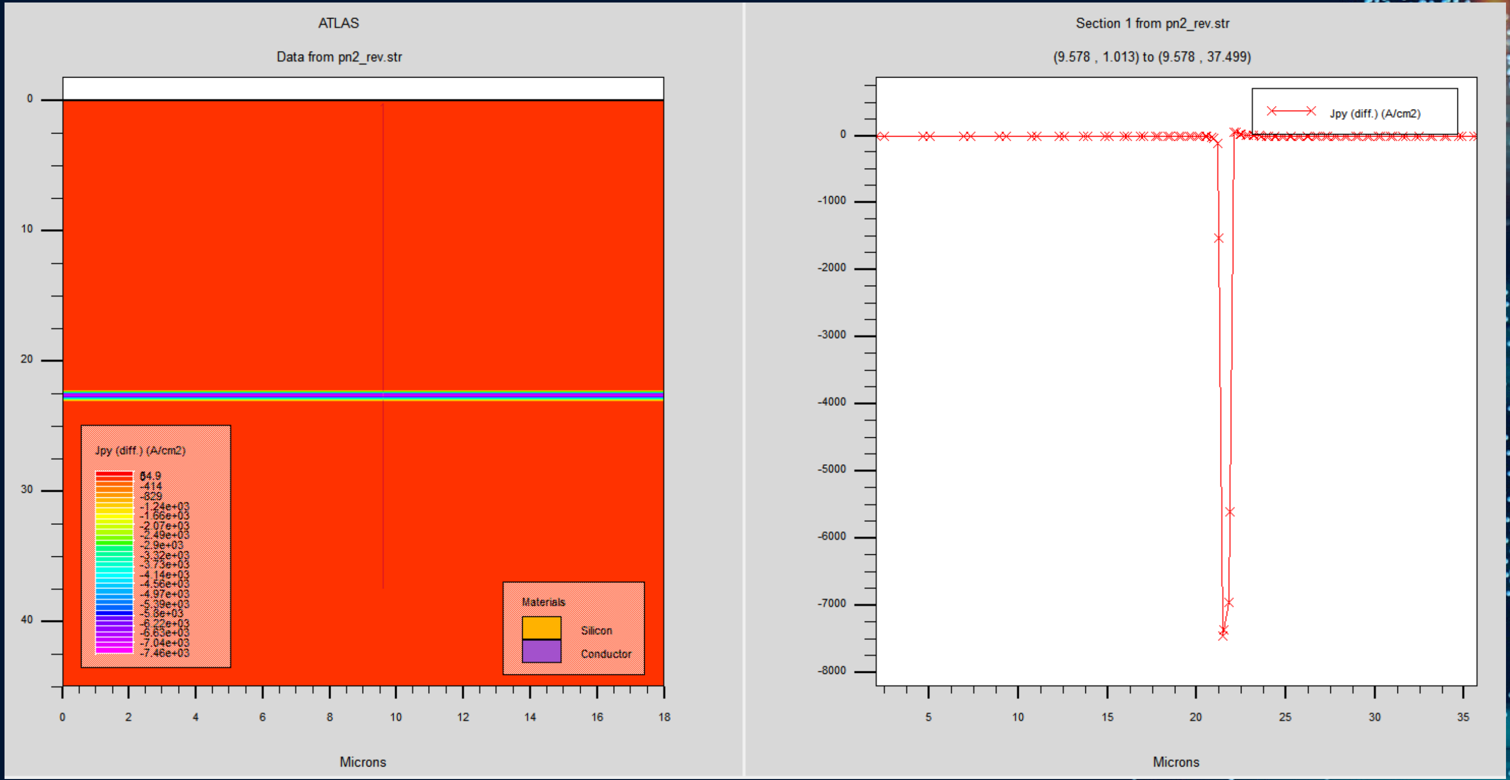




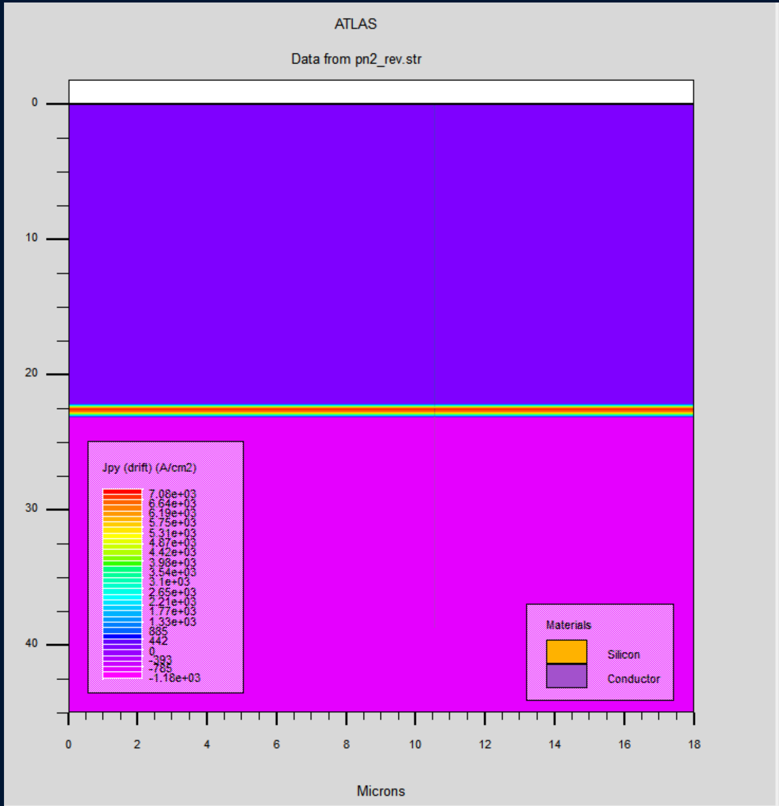
Forward and Reverse Bias: Donor and Acceptor Concentrations

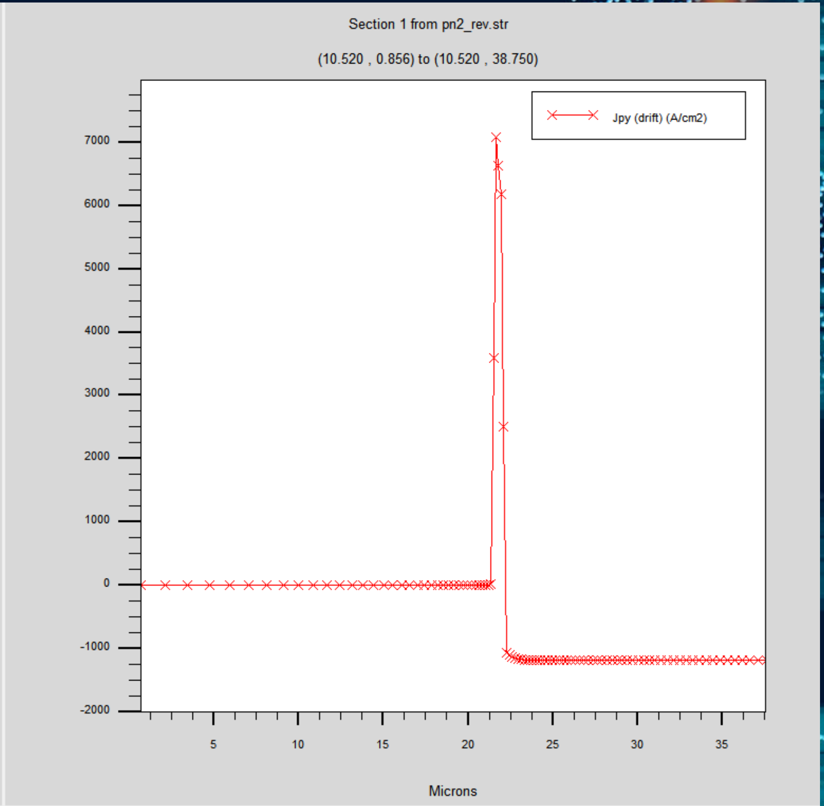
The donor and acceptor concentrations are just the same as the zero bias case on the 8th and 9th slides!

Reverse Bias: Jpy (Holes Diffusion Current)

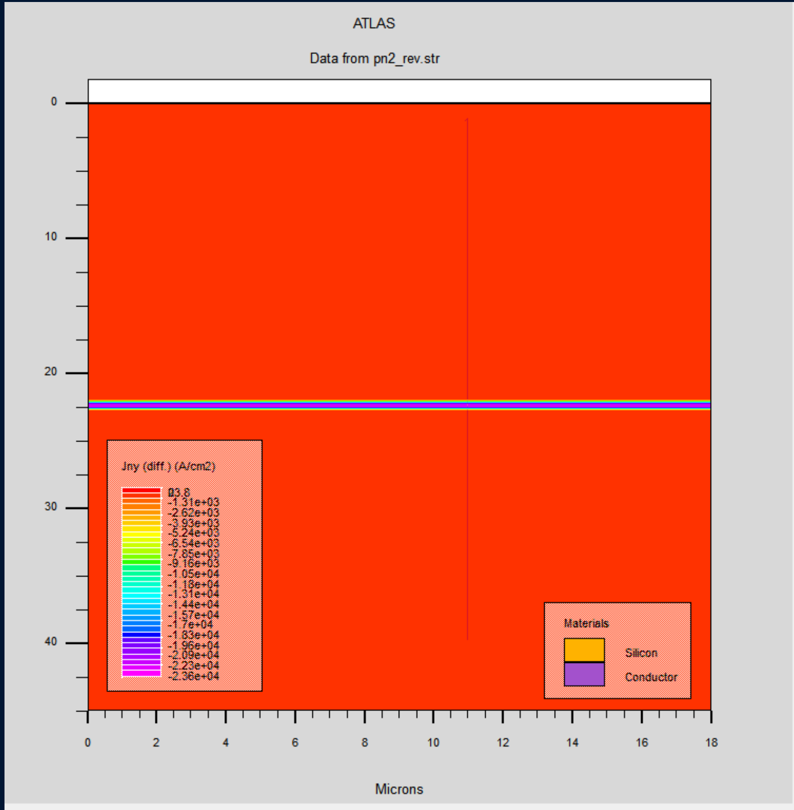


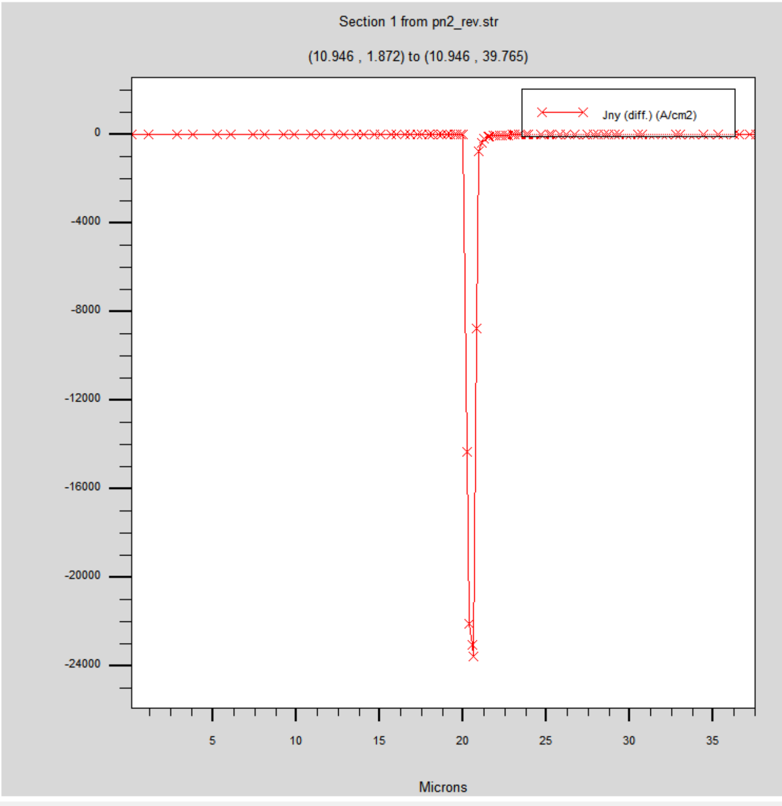
Reverse Bias: Jpy (Holes Drift Current)



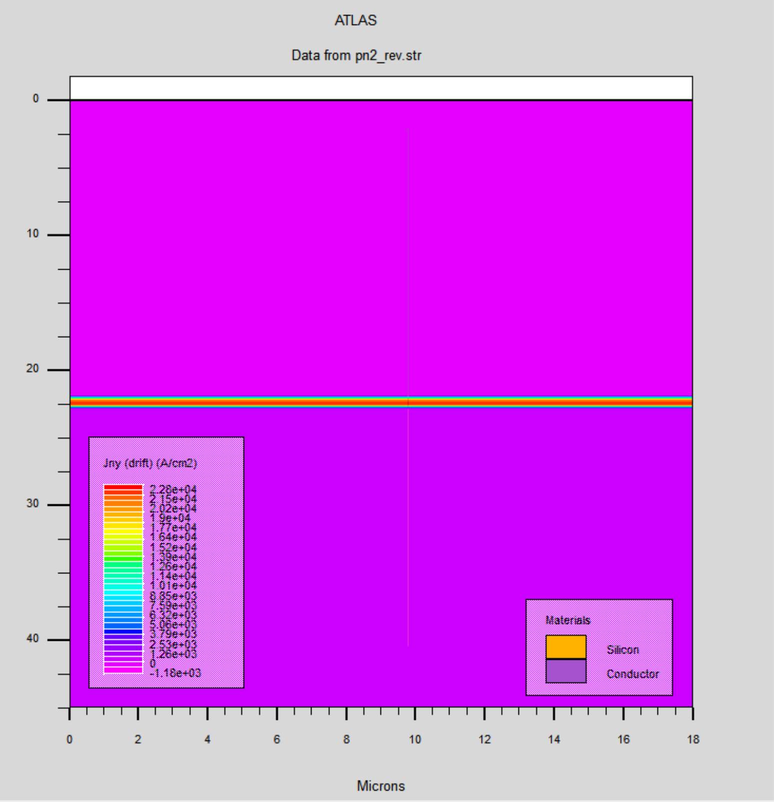


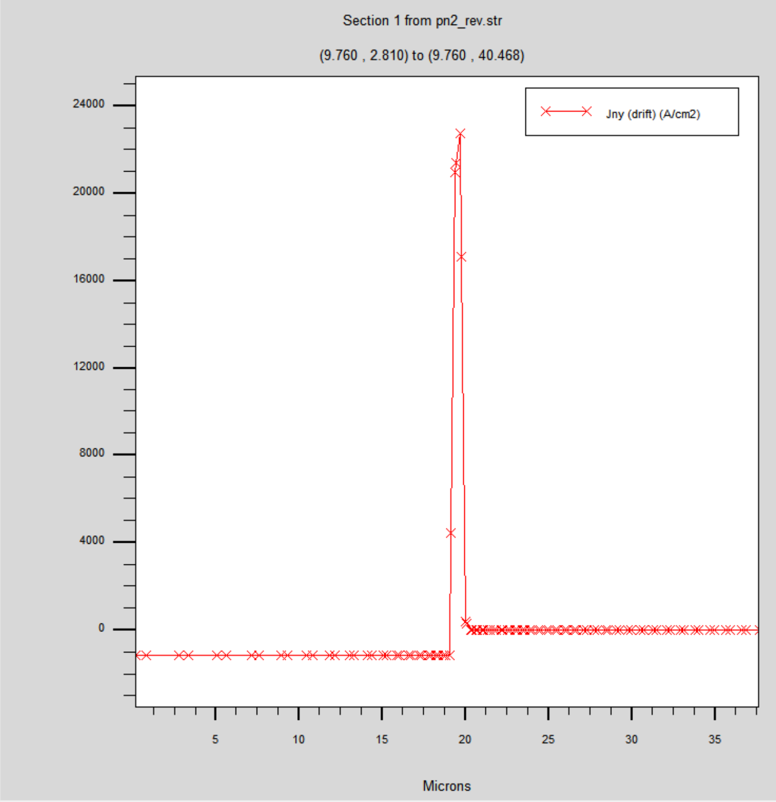
Reverse Bias: Jny (Electrons Diffusion Current)



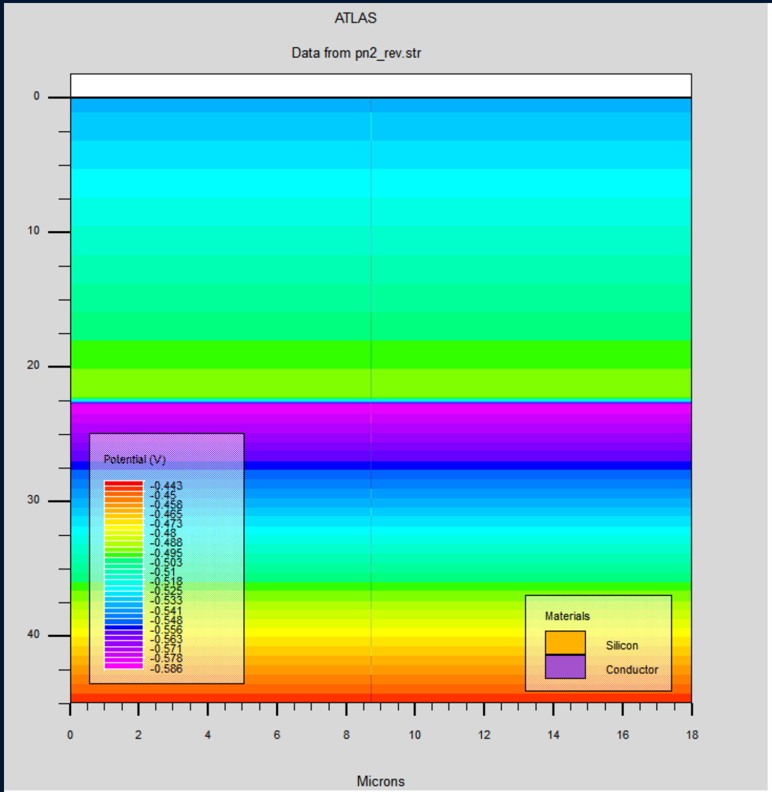


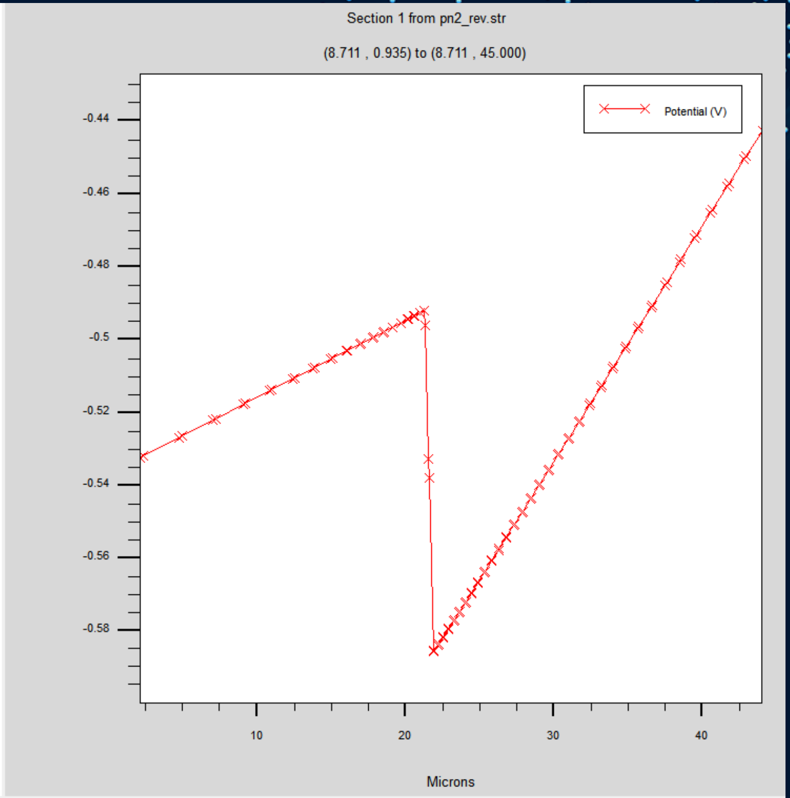
Reverse Bias: Jny (Electrons Drift Current)





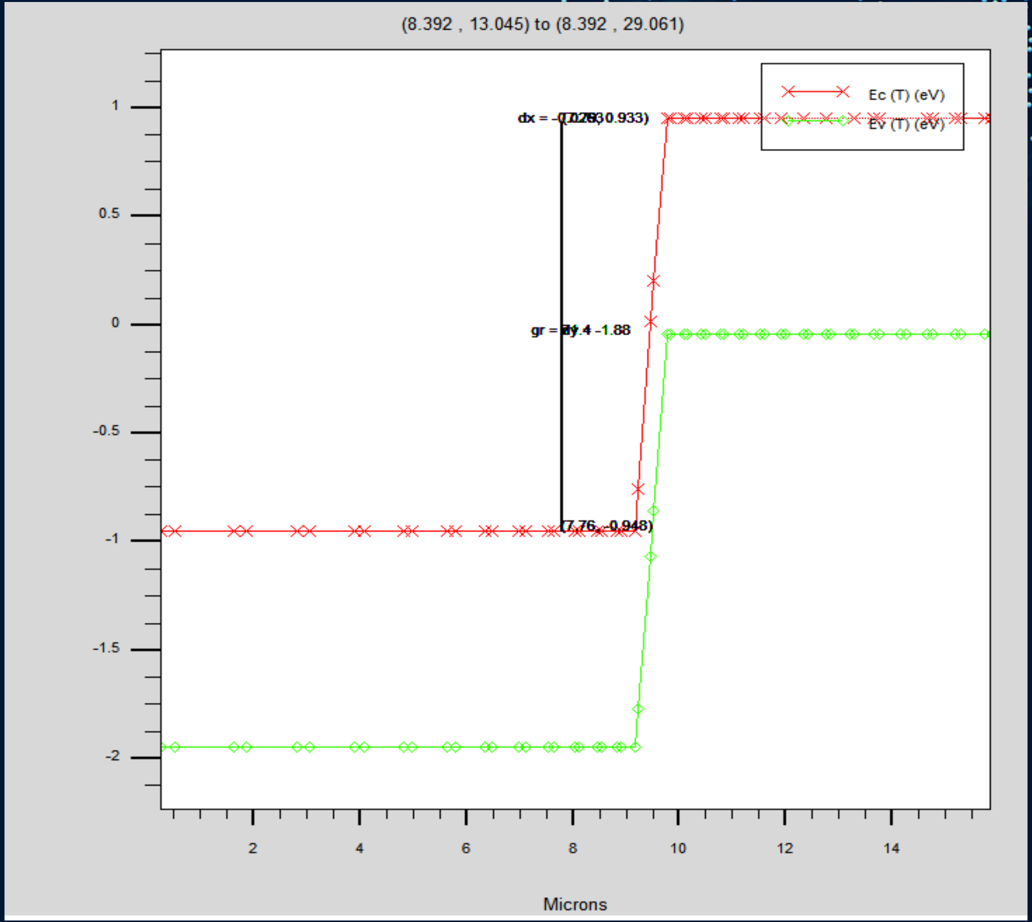
Reverse Bias: Electric Potential





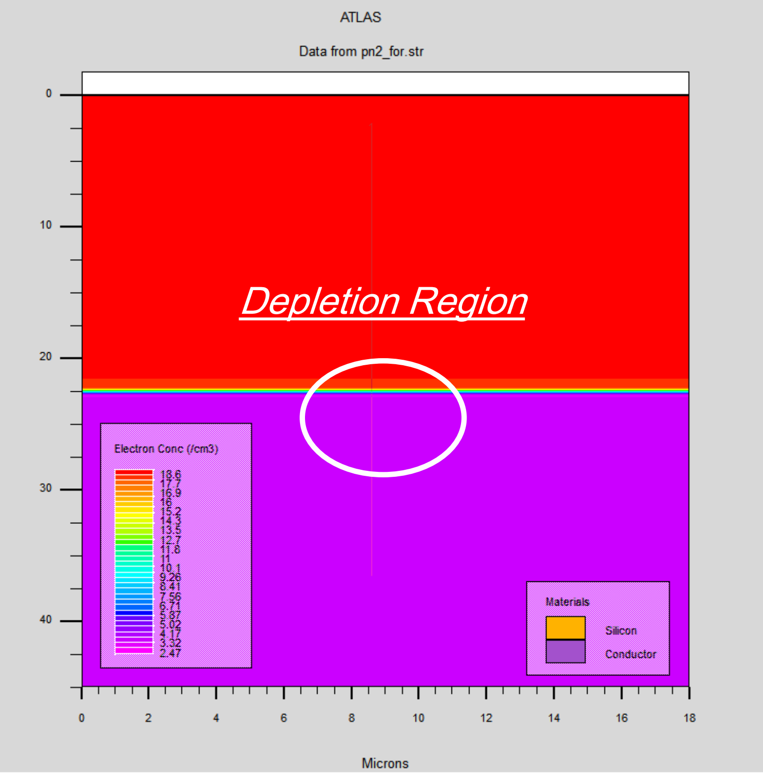
-1 V Reverse Bias : Energy Band Diagrams

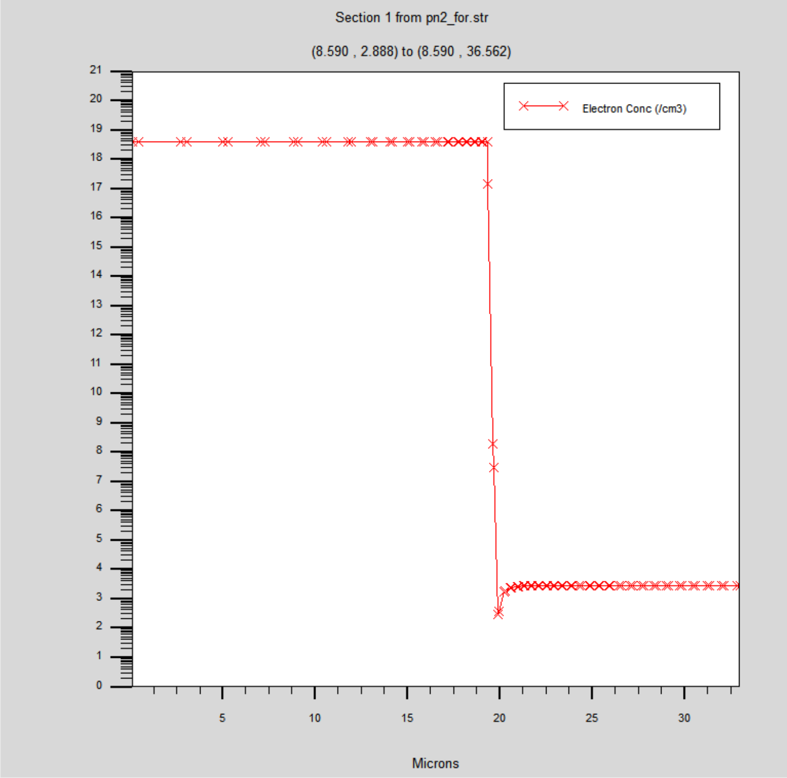
As we can see we have a 1 V shift
In energy band diagrams due to the
applied voltage.
➔ Ec,p-Ec,n = e(Vbi-Va)



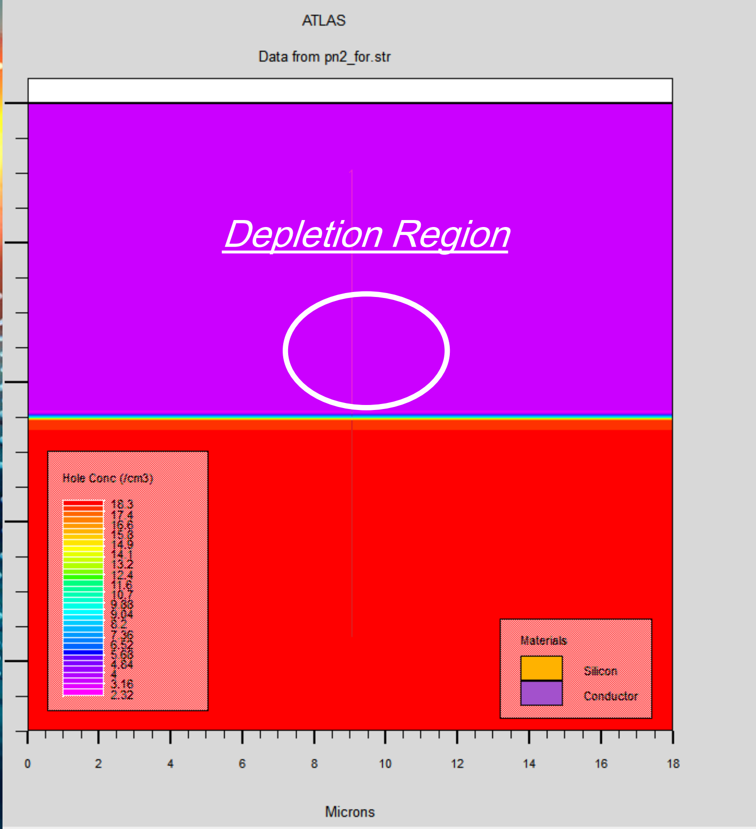
03 Forward Bias

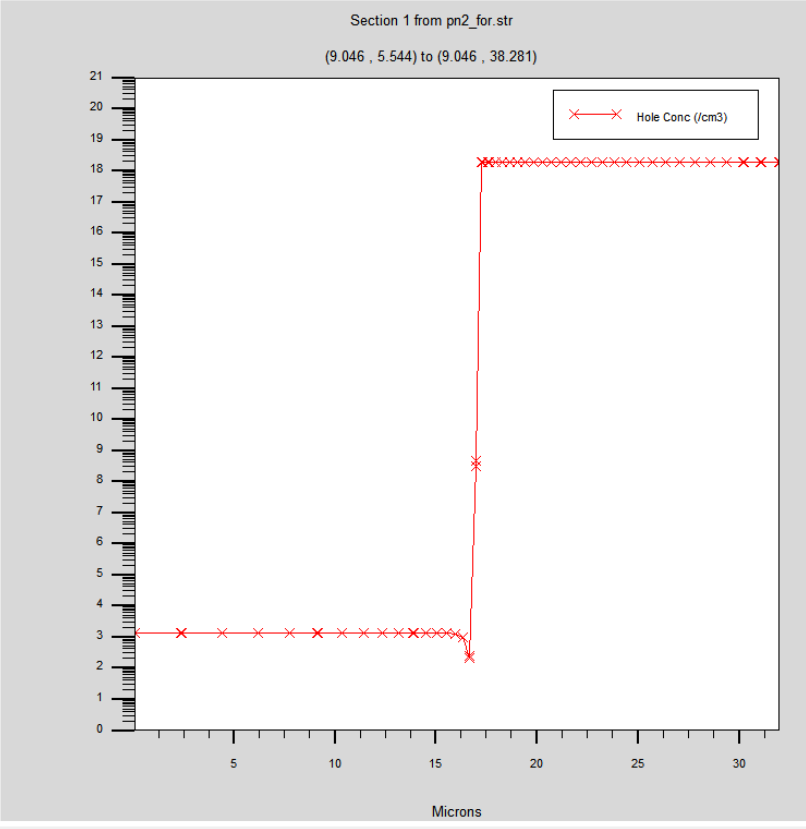
Forward Bias: Electron Concentrations





Reverse Bias: Hole Concentrations

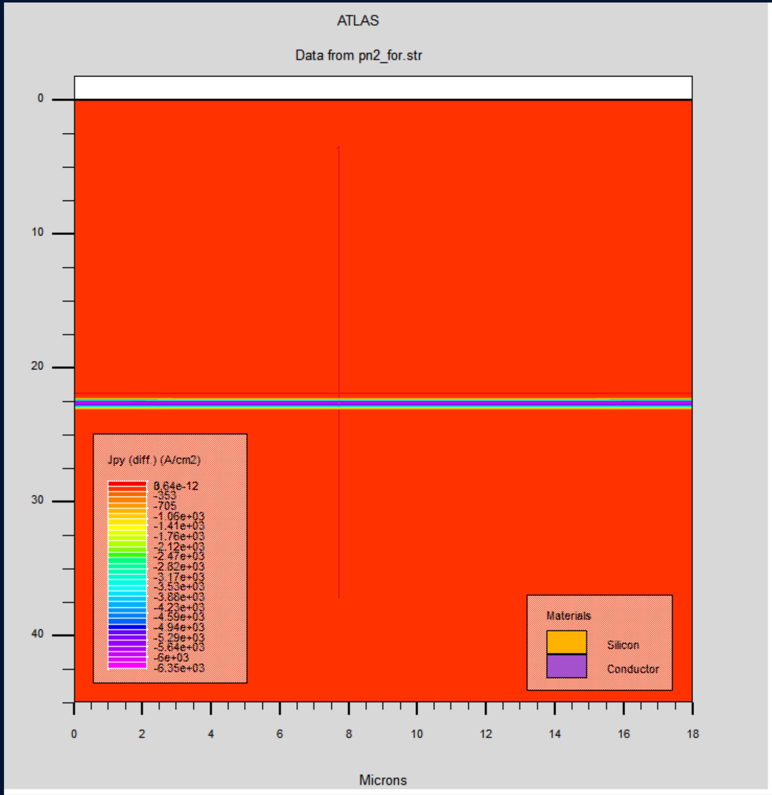


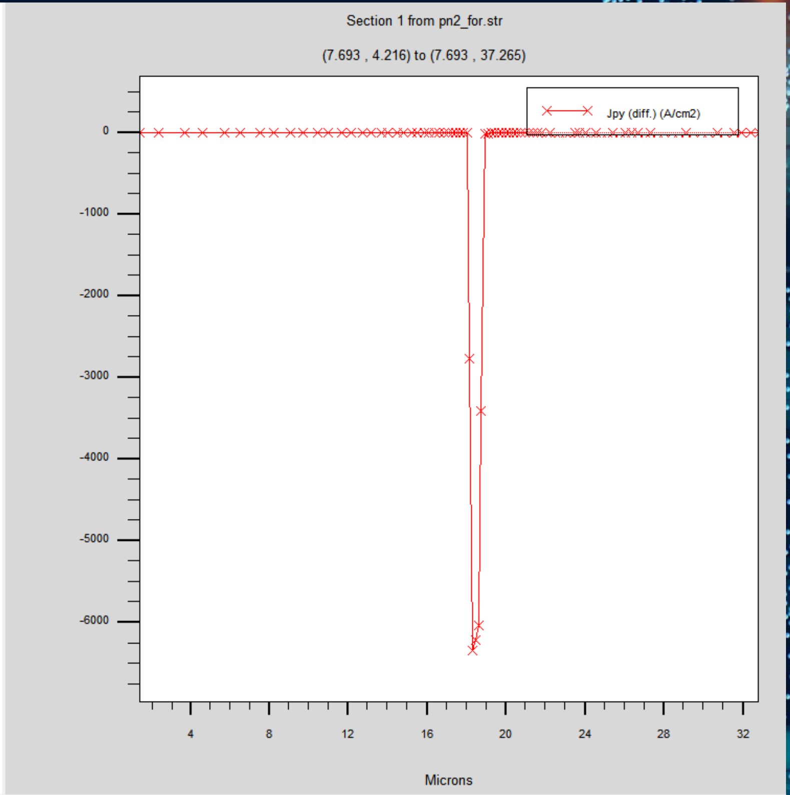


Forward and Reverse Bias: Donor and Acceptor Concentrations

The donor and acceptor concentrations are just the same as the zero bias case on the 8th and 9th slides!

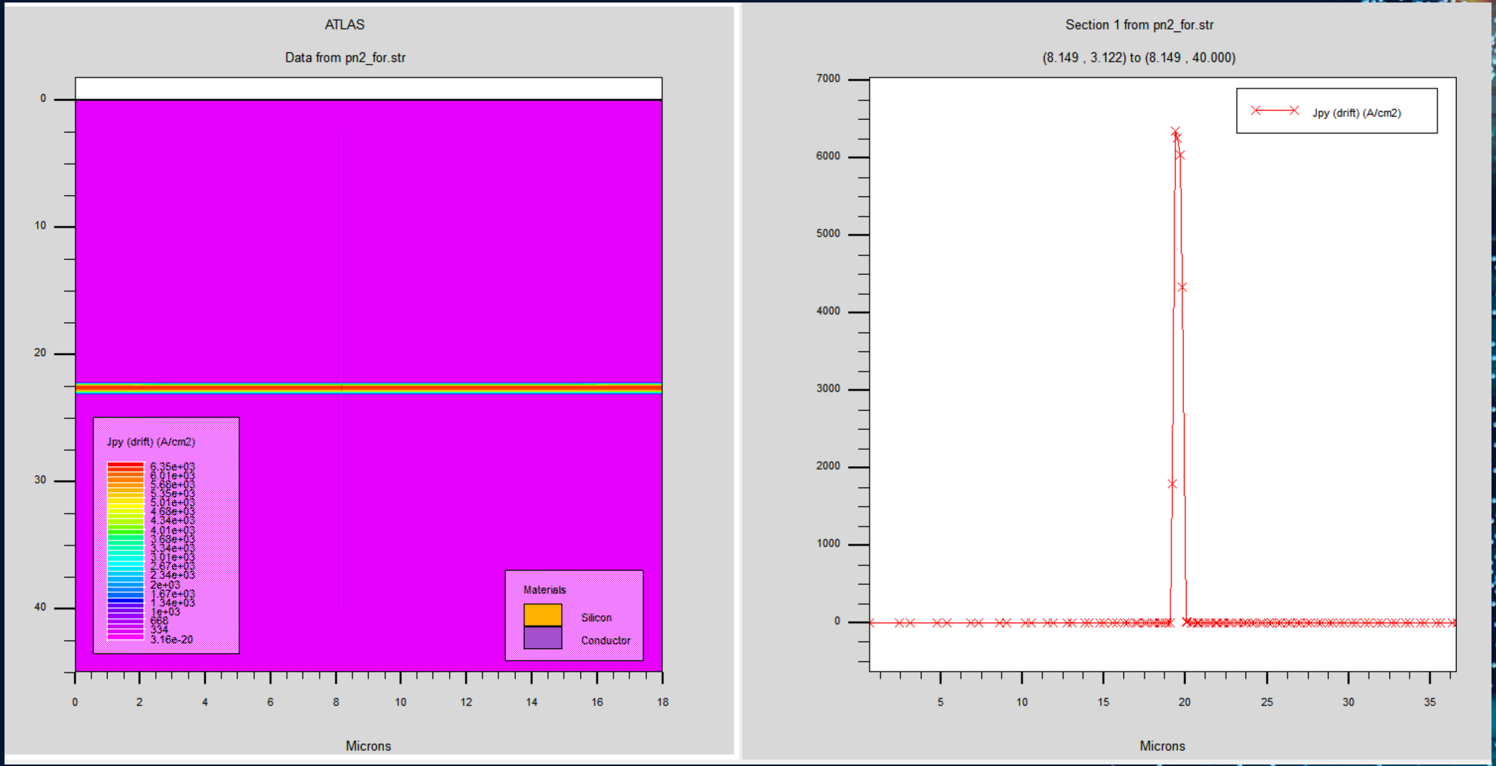
Forward Bias: Jpy (Holes Diffusion Current)





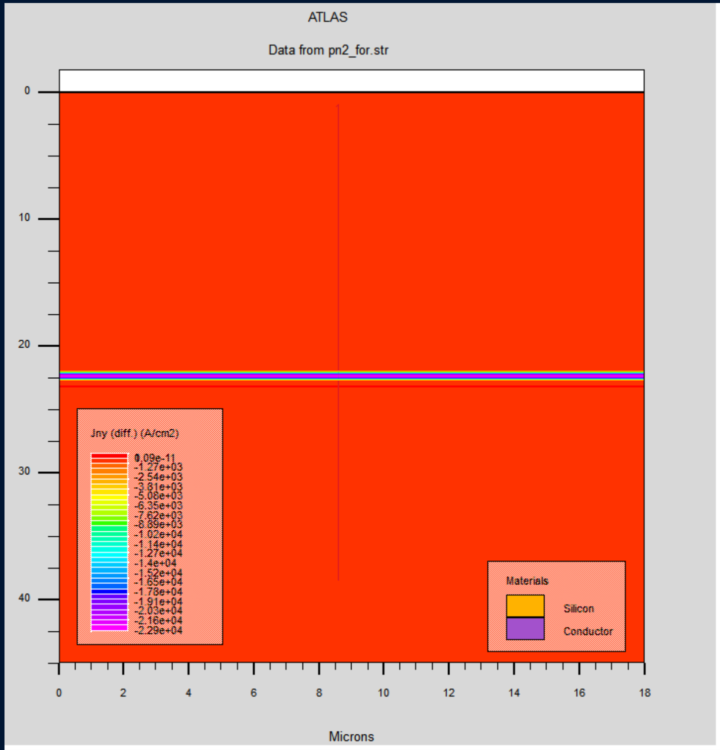
The x component of the current is negligible!

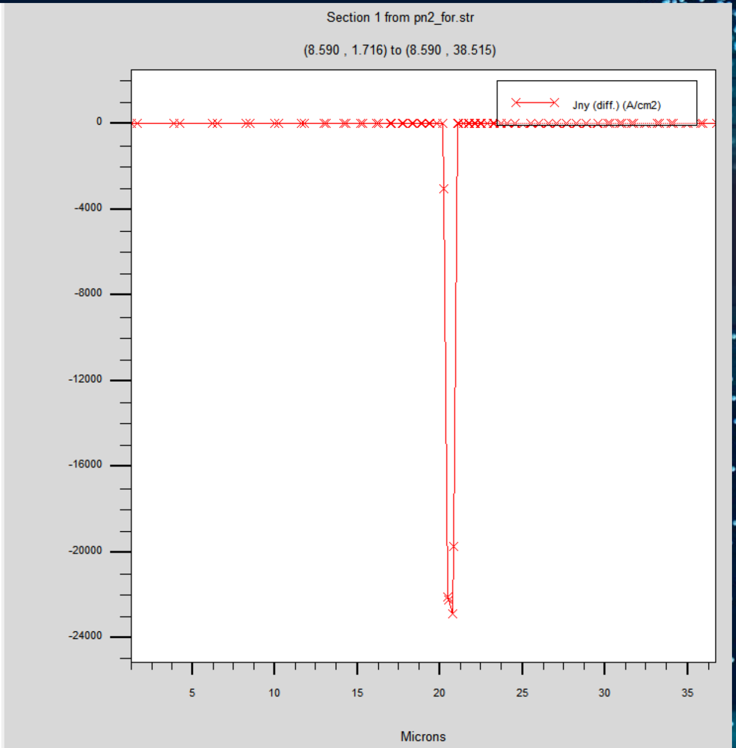
Forward Bias: Jpy (Holes Drift Current)



The x component of the current is negligible!

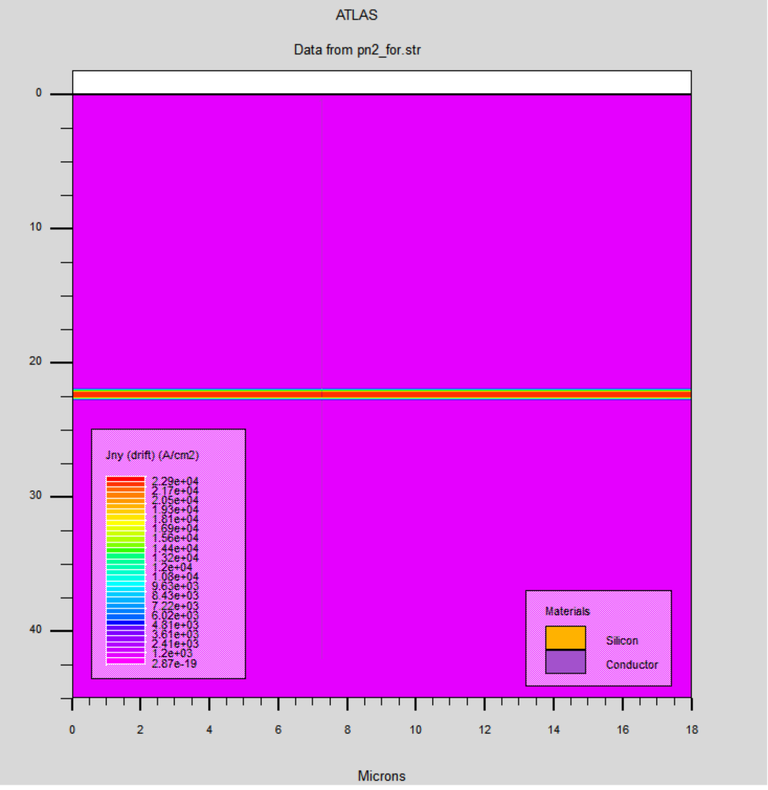
Forward Bias: Jny (Electrons Diffusion Current)

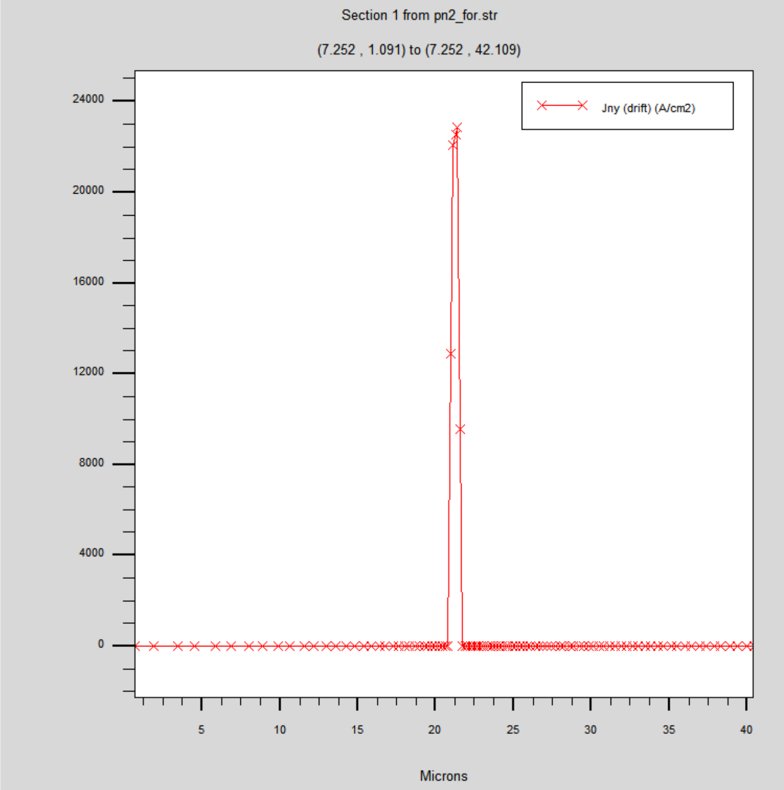




The x component of the current is negligible!

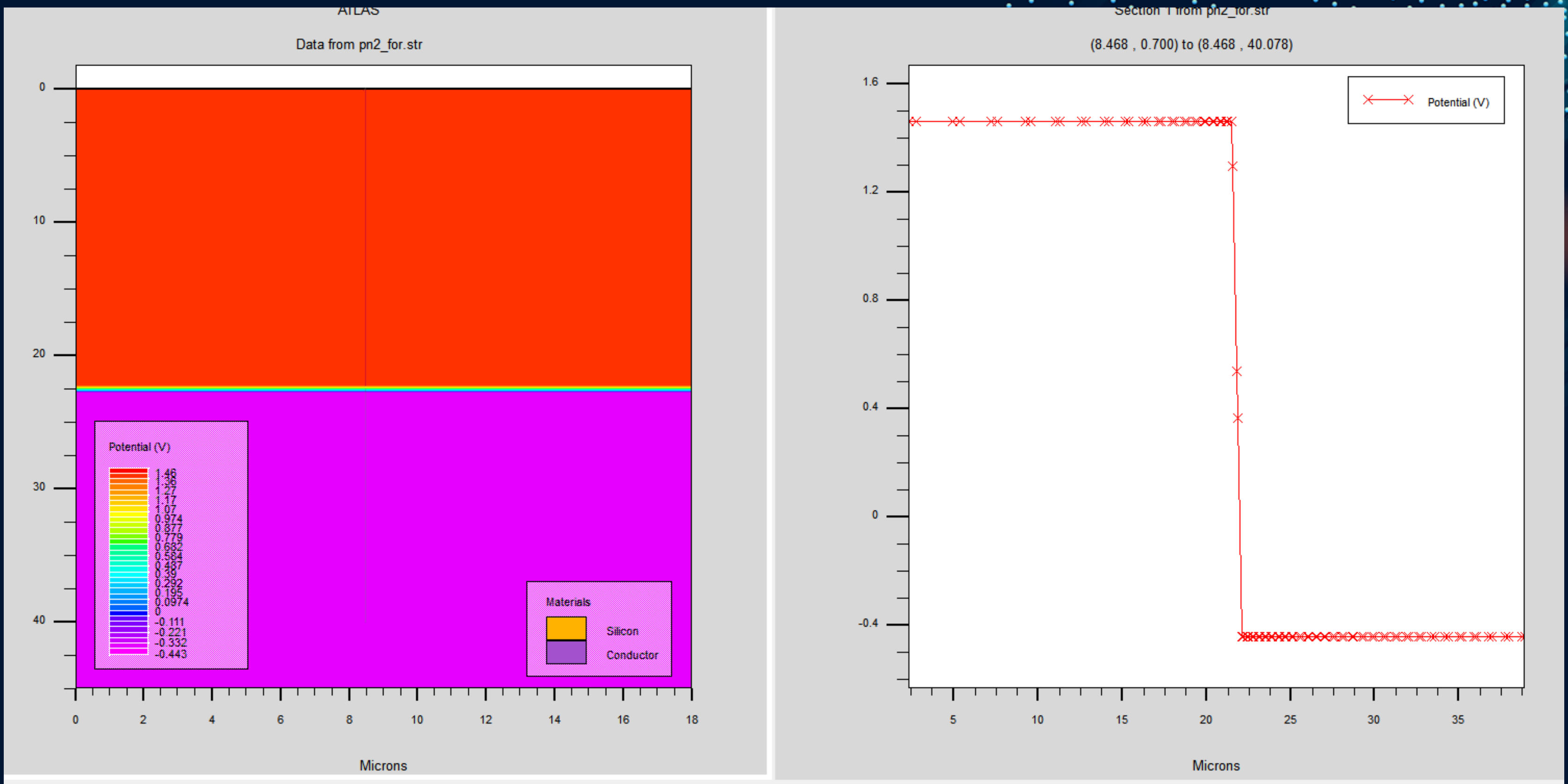
Forward Bias: Jny (Electrons Drift Current)





The x component of the current is negligible!

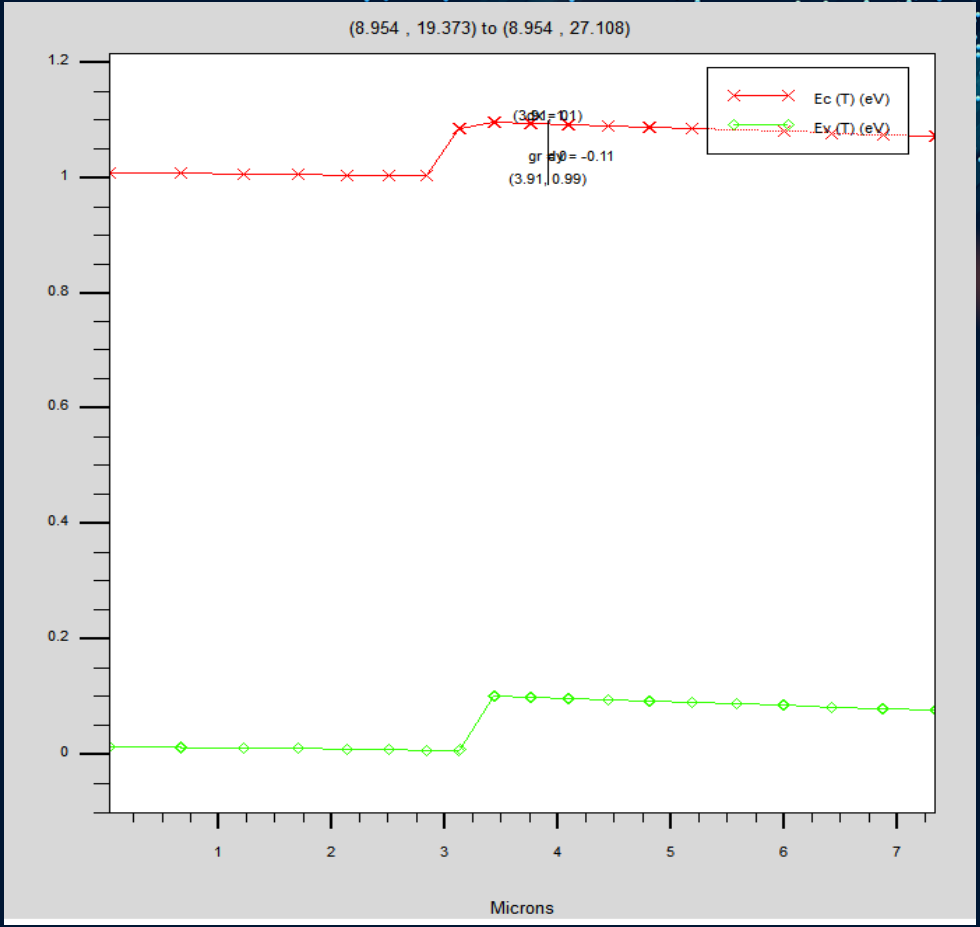
Forward Bias: Electric Potential



+1 V Forward Bias : Energy Band Diagrams

As we can see we have a 1 V shift
In energy band diagrams due to the applied voltage.

➔ $E_{c,p} - E_{c,n} = e(V_{bi} - V_a)$



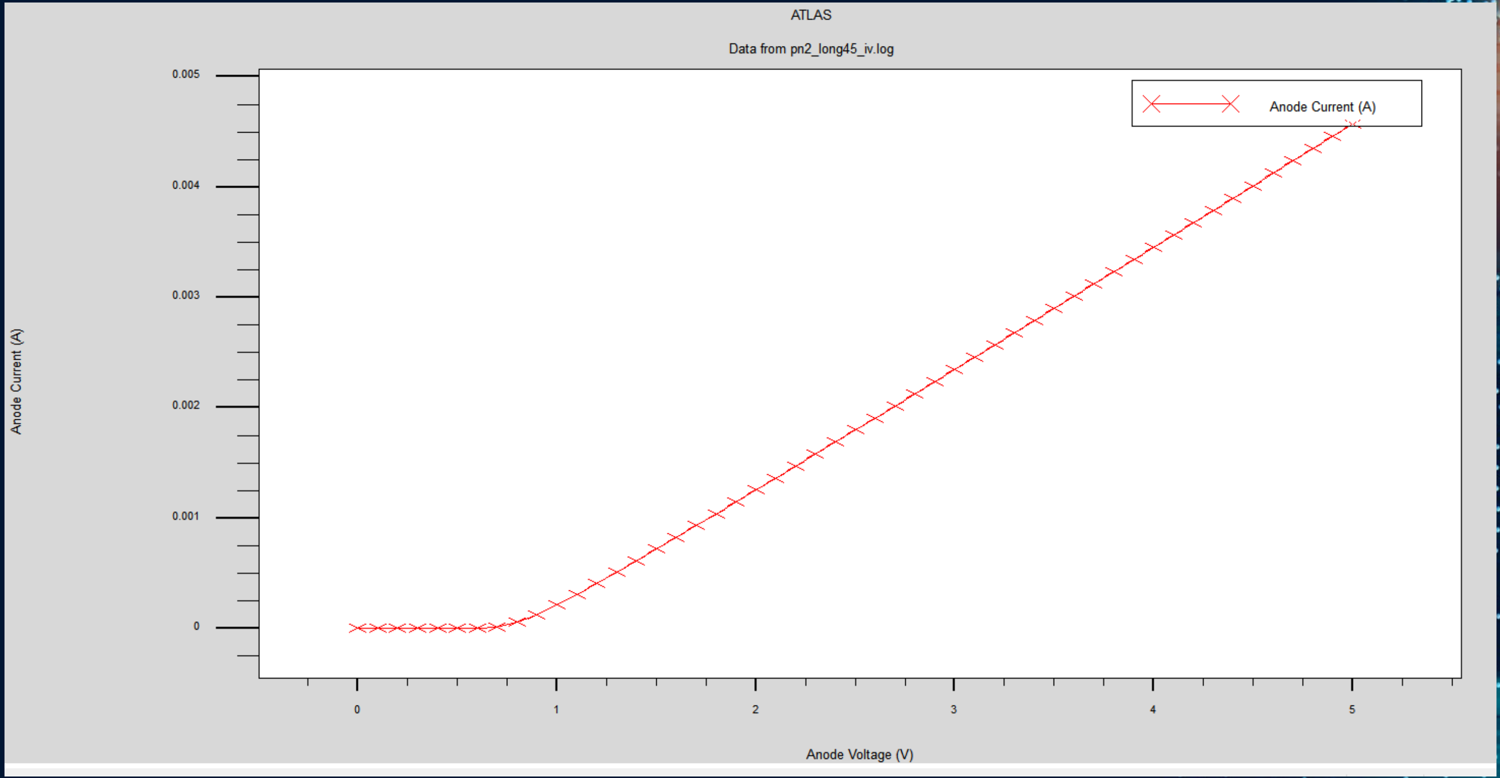
Part 1: P-N Junction

Assume that we are designing a long silicon diode with step junction and doping concentrations of 10^{19} $Atom.cm^{-3}$ for phosphorous and 10^{19} $Atom.cm^{-3}$ for boron

1. Draw electron and hole concentrations (mark depletion regions), electric potential (fermi level), 4 current components (drift and diffusion for both carrier types) and doping concentrations for zero bias, forward bias and reverse bias.

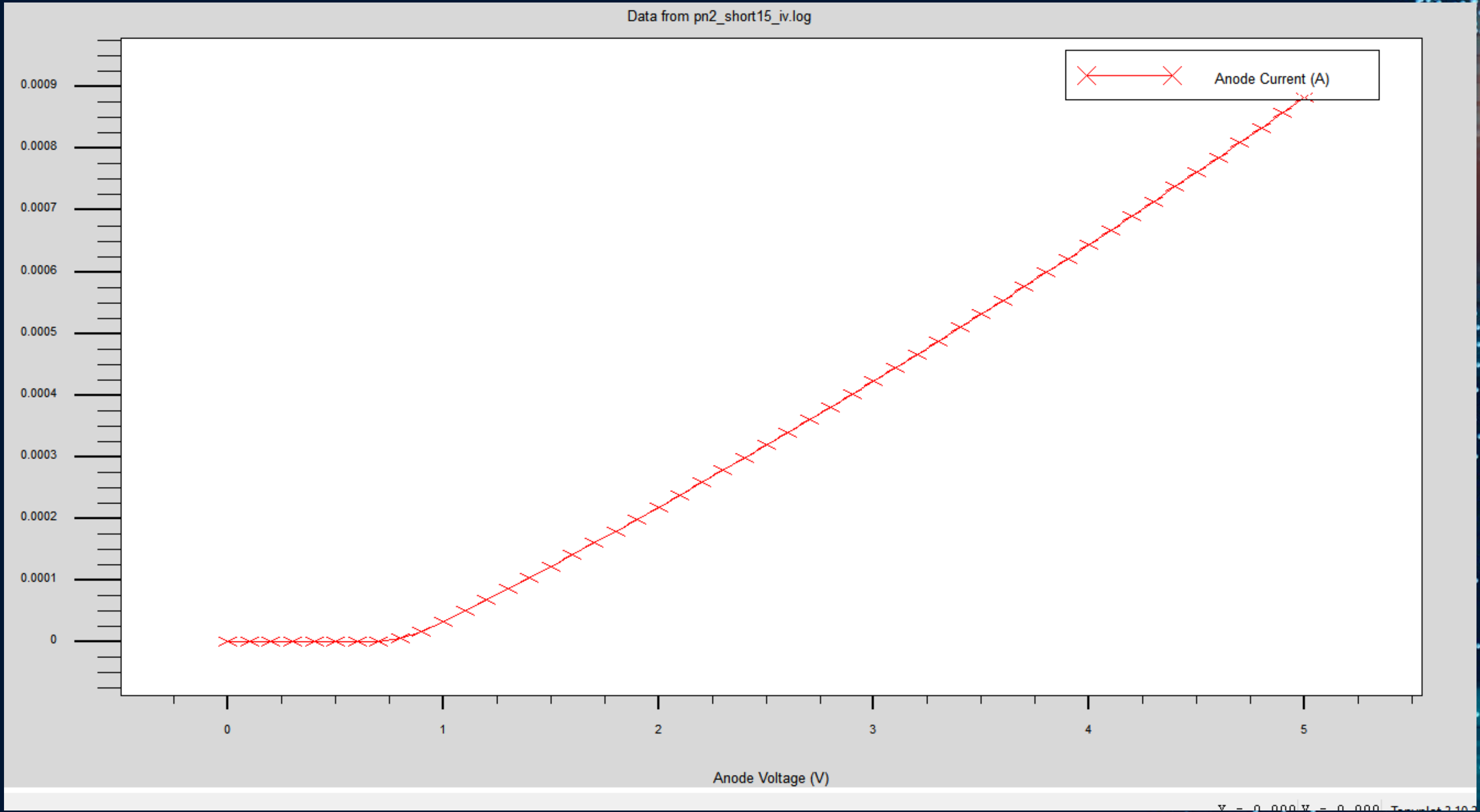
2. Using the information above, make a short diode and a long diode and compare their I-V characteristics.

Long diode



ATLAS
Data from pn2_long45_iv.log
Anode Current (A)
0.005
0.004
0.003
0.002
0.001
0
Anode Current (A)
0
1
2
3
4
5
Anode Voltage (V)

Short diode



Data from pn2_short15_iv.log
Anode Current (A)
0.0009
0.0008
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
0
1
2
3
4
5
Anode Voltage (V)

Part 1: P-N Junction

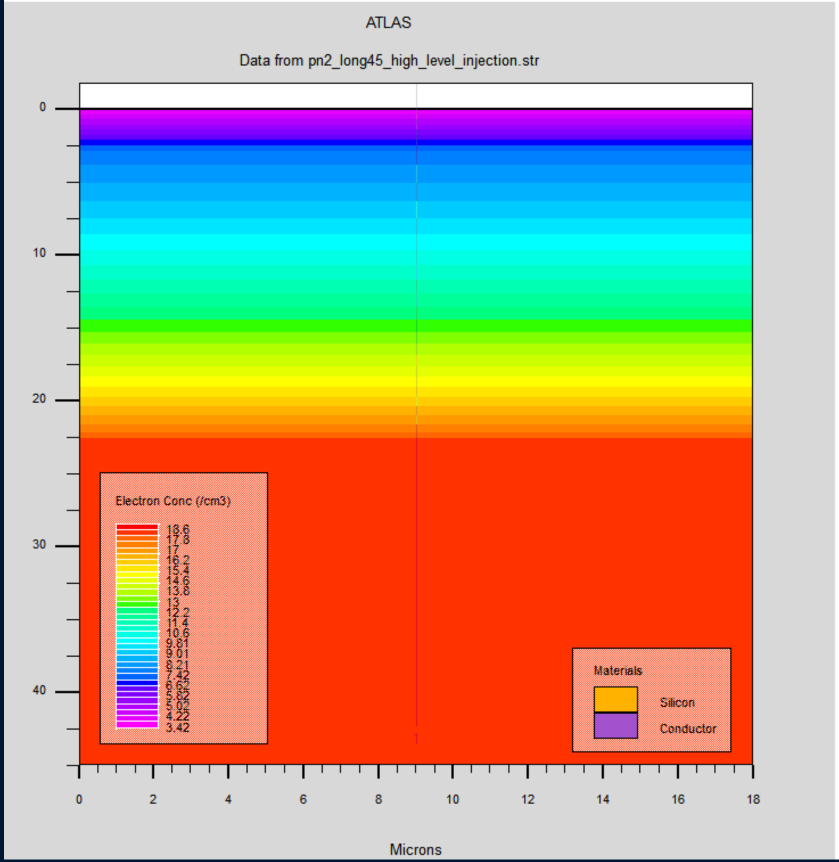
Assume that we are designing a long silicon diode with step junction and doping concentrations of 10^{19} $Atom.cm^{-3}$ for phosphorous and 10^{19} $Atom.cm^{-3}$ for boron

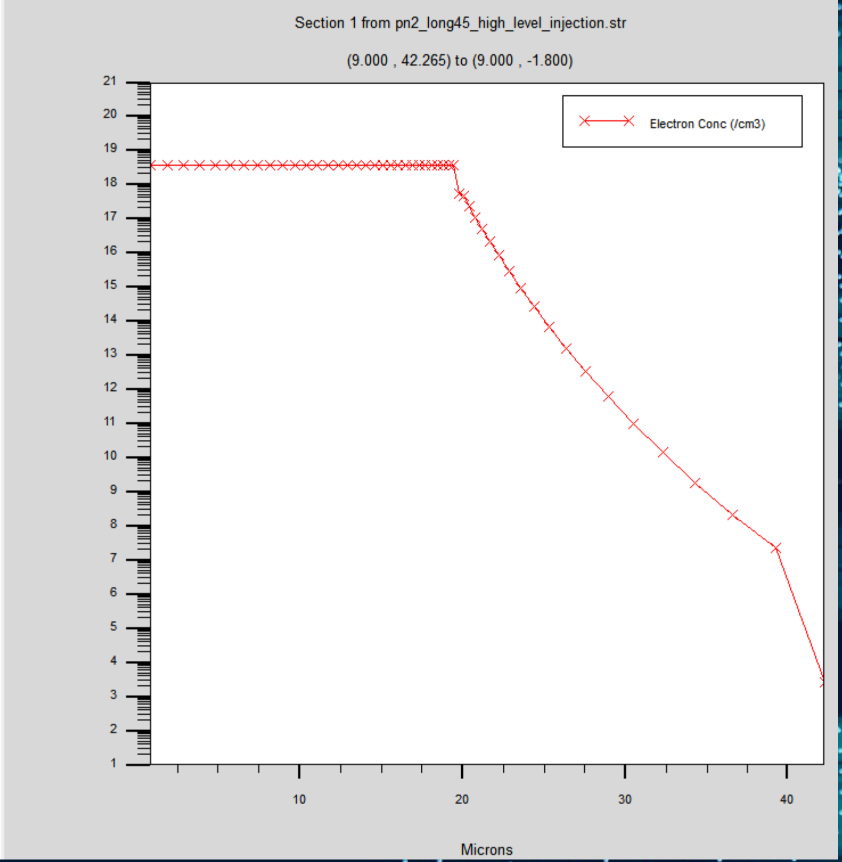
1. Draw electron and hole concentrations (mark depletion regions), electric potential (fermi level), 4 current components (drift and diffusion for both carrier types) and doping concentrations for zero bias, forward bias and reverse bias.

2. Using the information above, make a short diode and a long diode and compare their I-V characteristics.

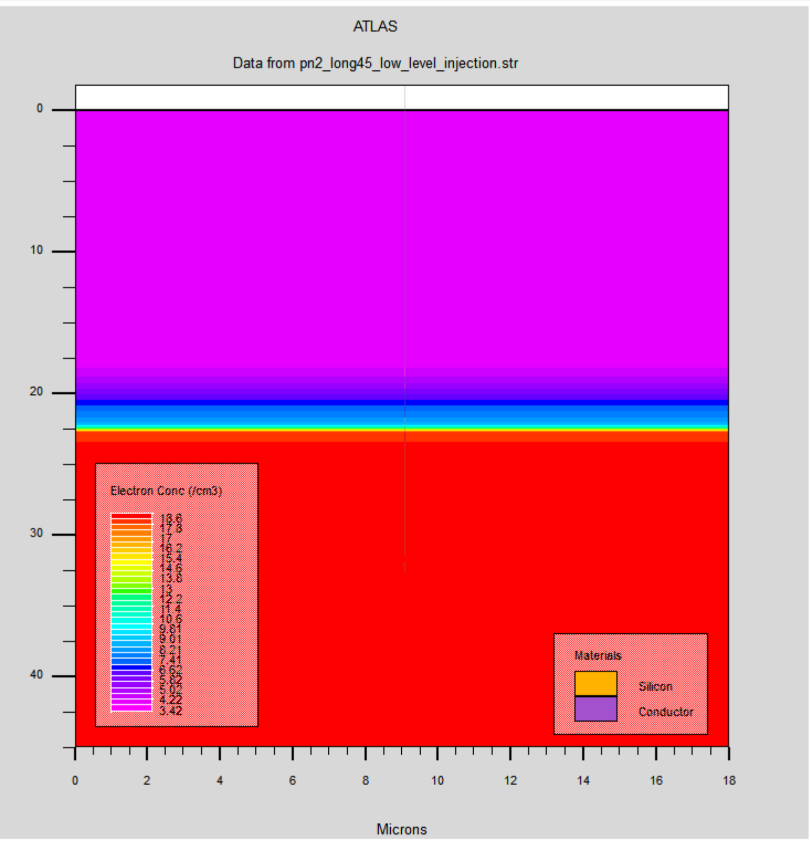
3. For the long diode and short diode, draw the current components in low-level injection and high level injection.

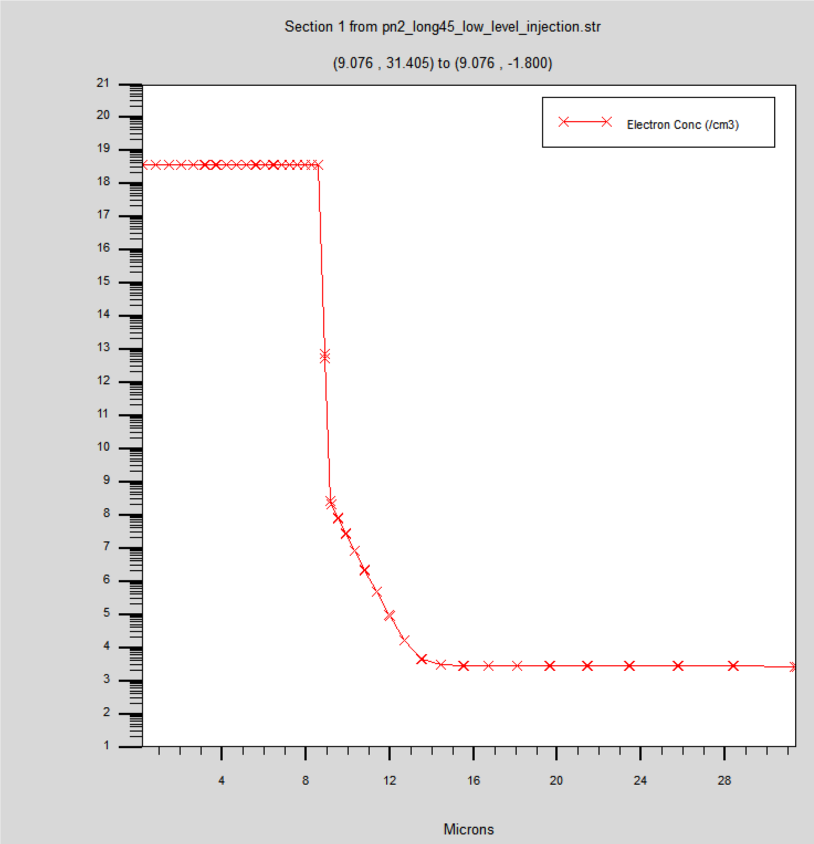
Electron Conc. In High-Level Injection in Long Diode ($V_{forward}$ = 3v)



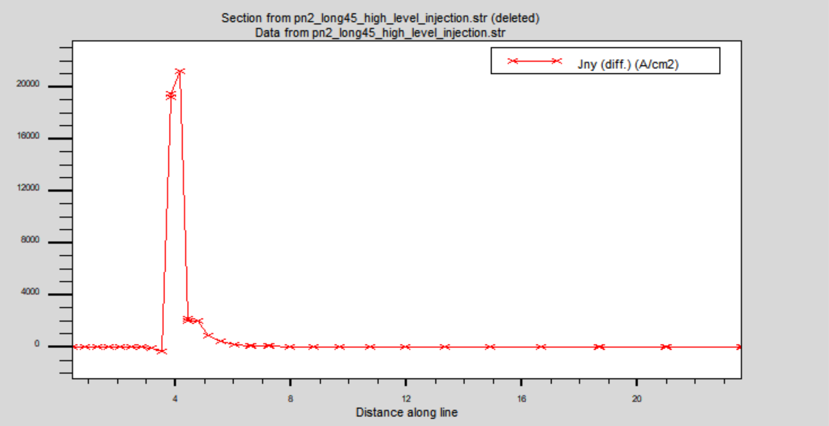


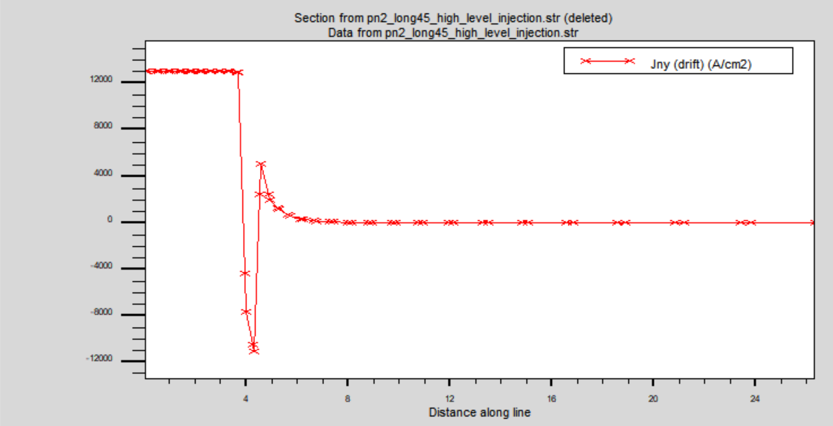
Electron Conc. In Low-Level Injection in Long Diode ($V_{forward}$ = 0.3v)

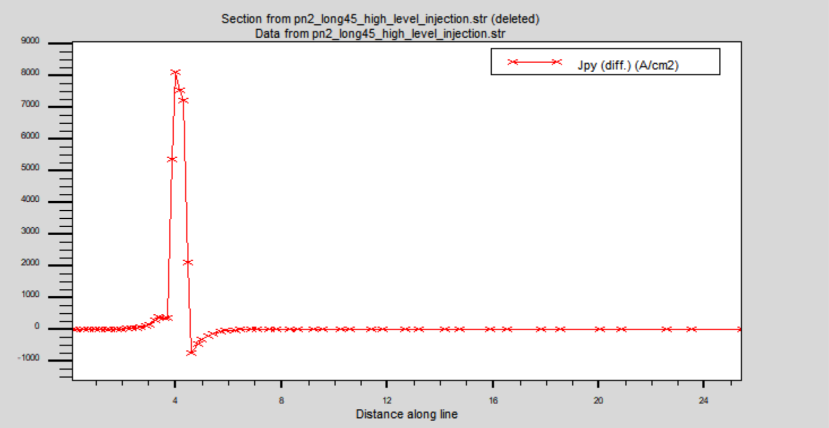


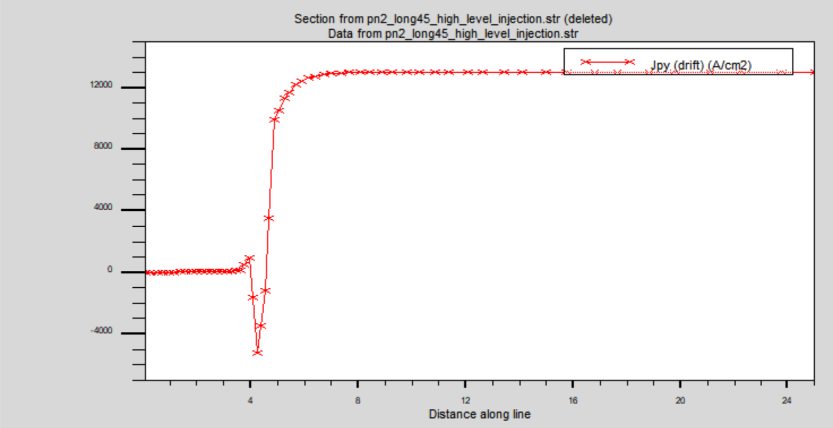


High level injection in Long Diode : (all 4 components of current)



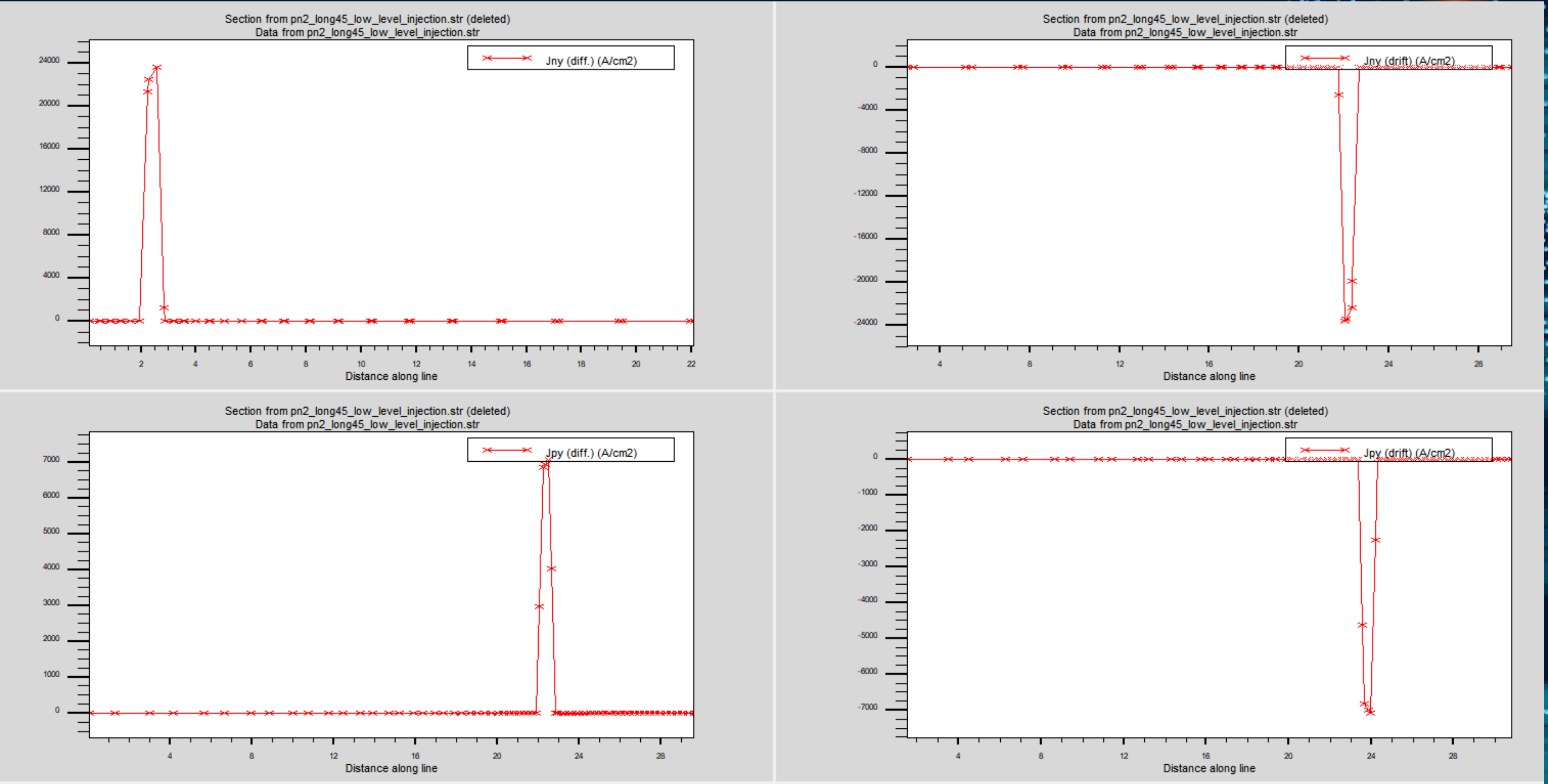






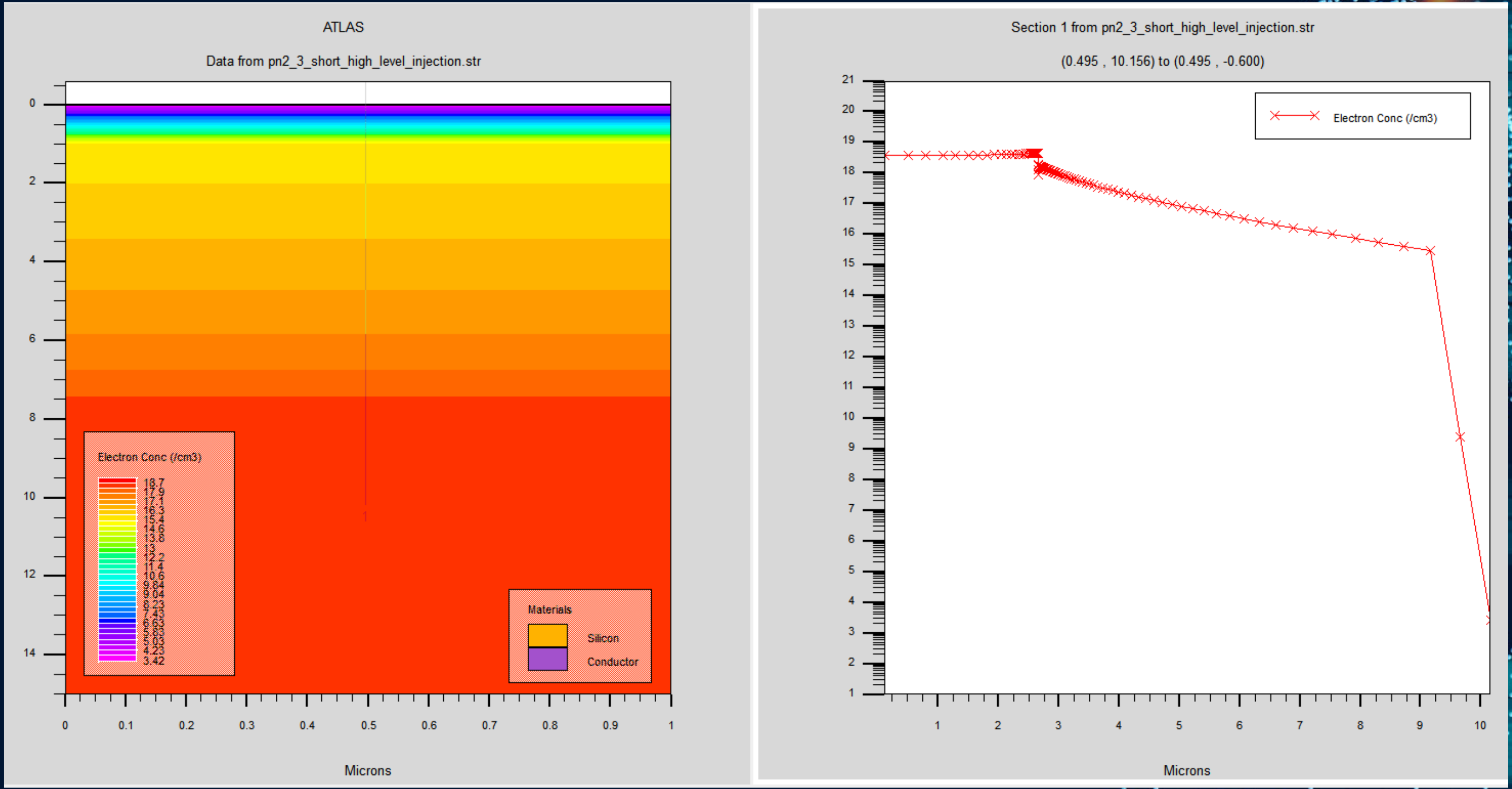
The x component of the current is negligible!

Low level injection in Long Diode : (all 4 components of current)

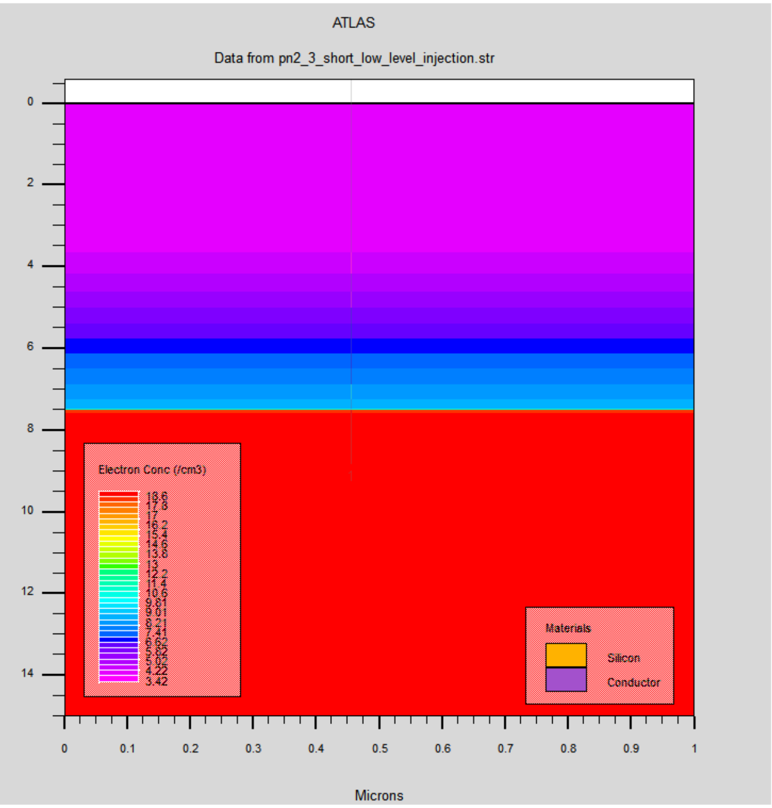


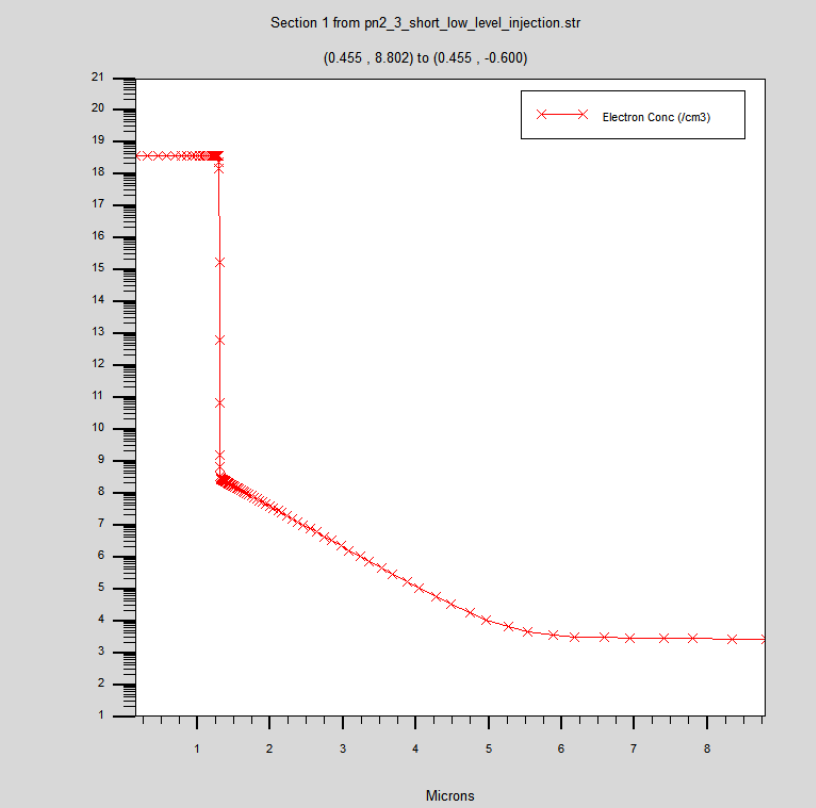
The x component of the current is negligible!

Electron Conc. In High-Level Injection in Short Diode ($V_{forward}$ = 3v)

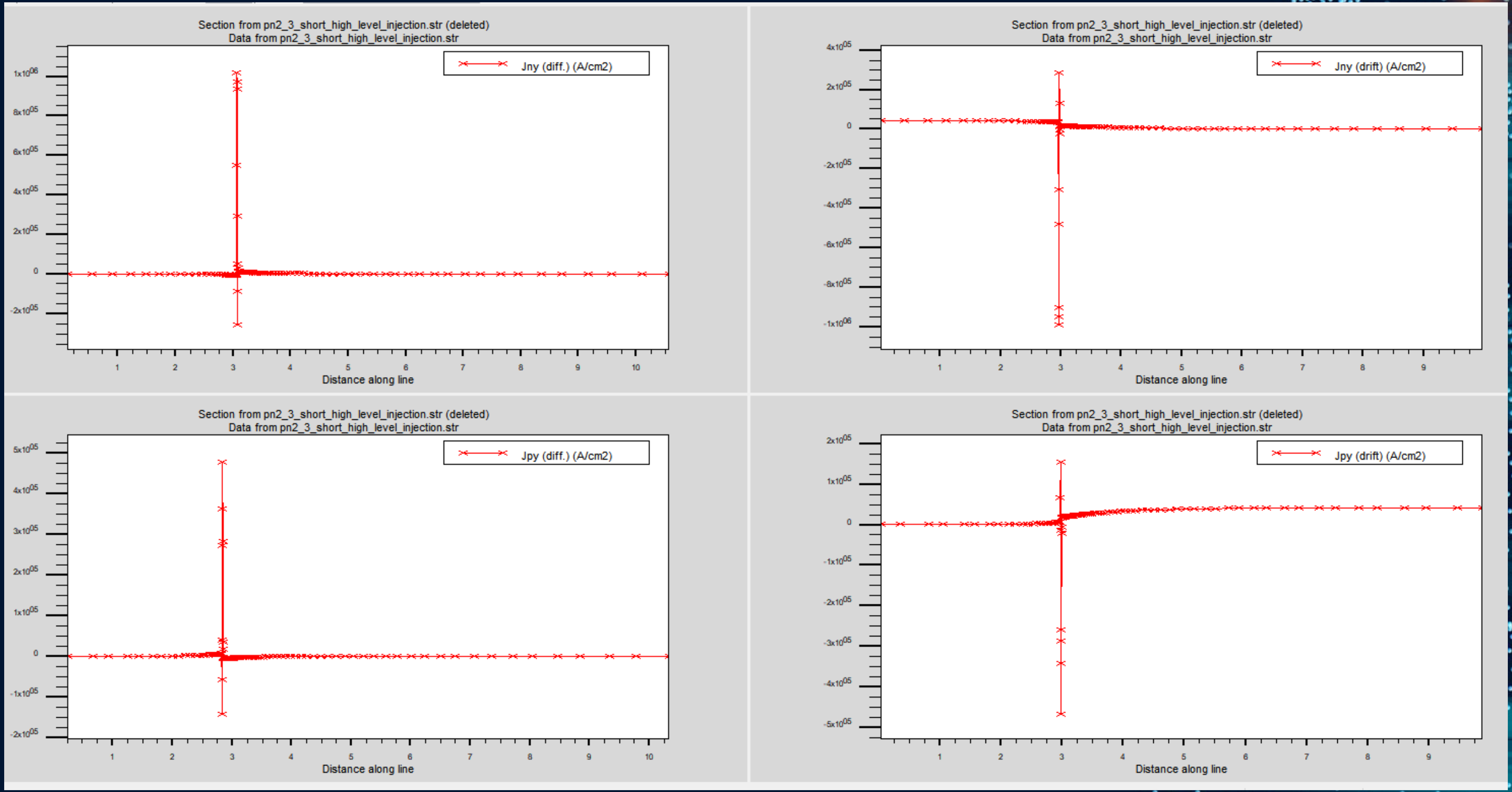


Electron Conc. In Low-Level Injection in Short Diode ($V_{forward}$ = 0.3v)



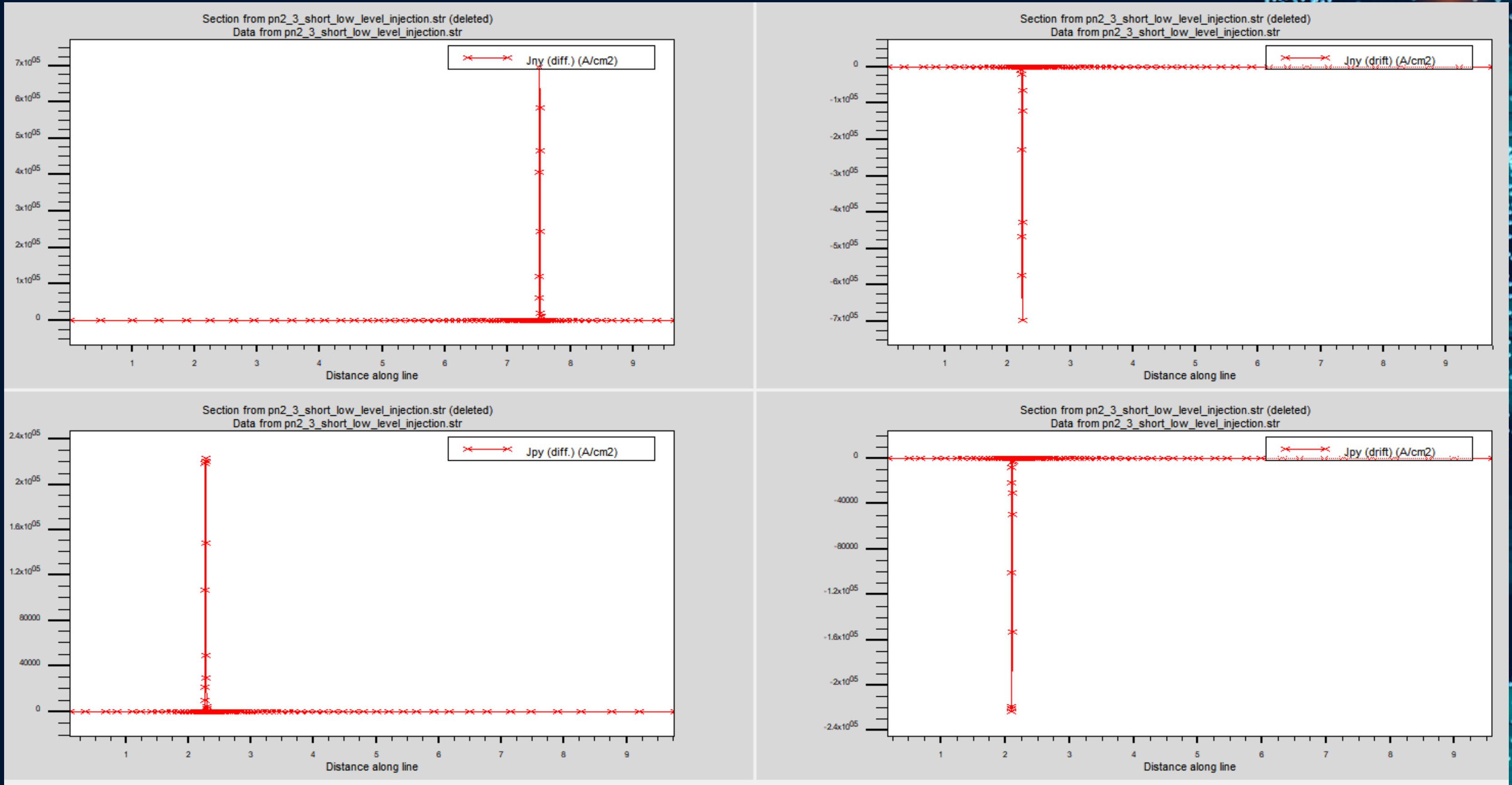


High level injection in Short Diode : (all 4 components of current)



The x component of the current is negligible!

Low level injection in Short Diode : (all 4 components of current)



The x component of the current is negligible!

Part 1: P-N Junction

Assume that we are designing a long silicon diode with step junction and doping concentrations of 10^{19} $Atom.cm^{-3}$ for phosphorous and 10^{19} $Atom.cm^{-3}$ for boron

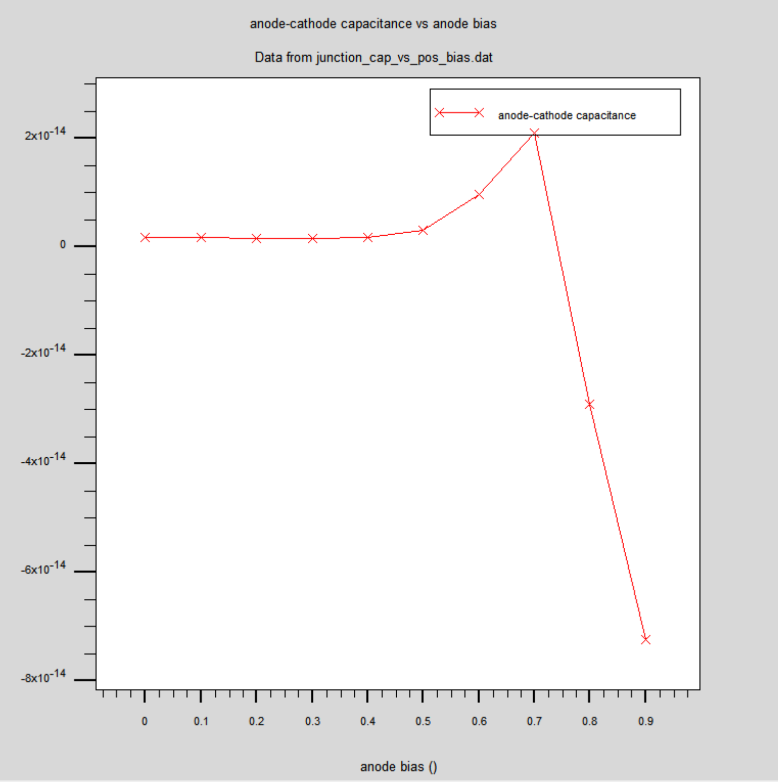
1. Draw electron and hole concentrations (mark depletion regions), electric potential (fermi level), 4 current components (drift and diffusion for both carrier types) and doping concentrations for zero bias, forward bias and reverse bias.

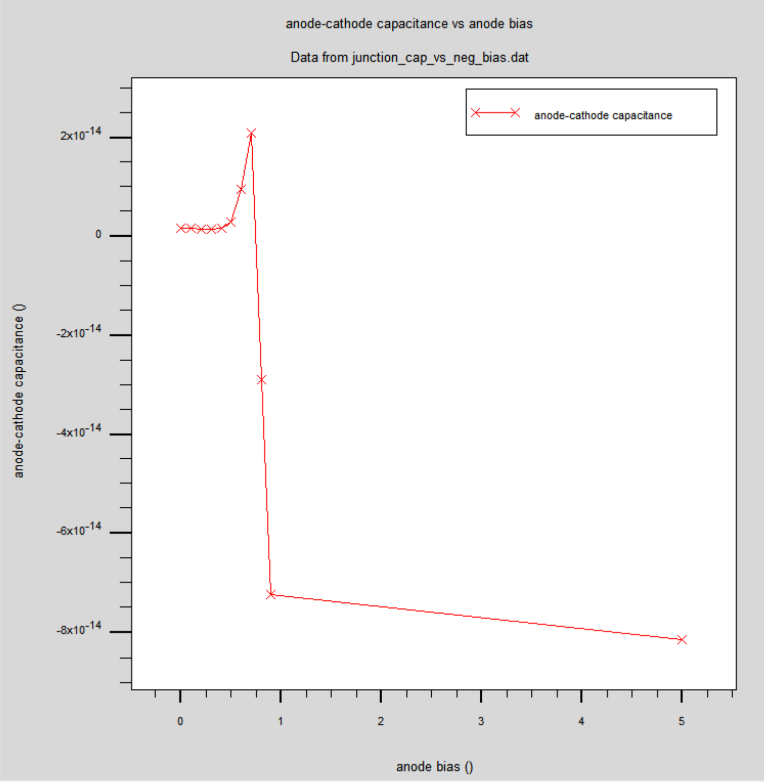
2. Using the information above, make a short diode and a long diode and compare their I-V characteristics.

3. For the long diode and short diode, draw the current components in low-level injection and high level injection.

4. Extract the junction capacitance and storage capacitance for long channel diode. Sweep the bias from forward to reverse and report the change in both capacitances.

Junction Capacitance vs Negative and Positive DC bias





Part 1: P-N Junction

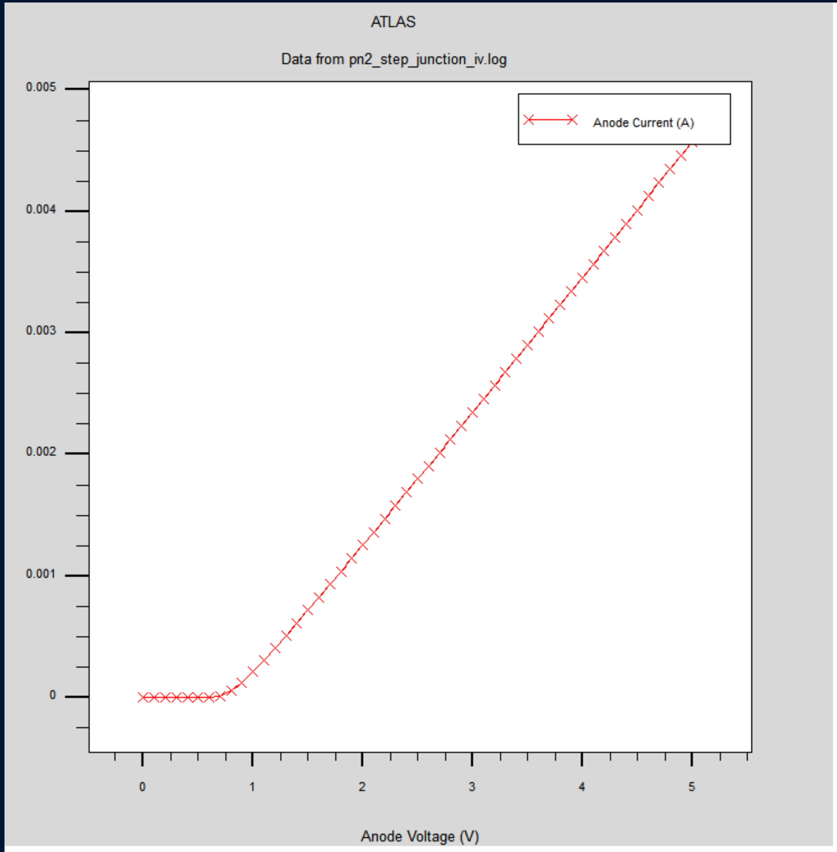
3. For the long diode and short diode, draw the current components in low-level injection and high level injection.

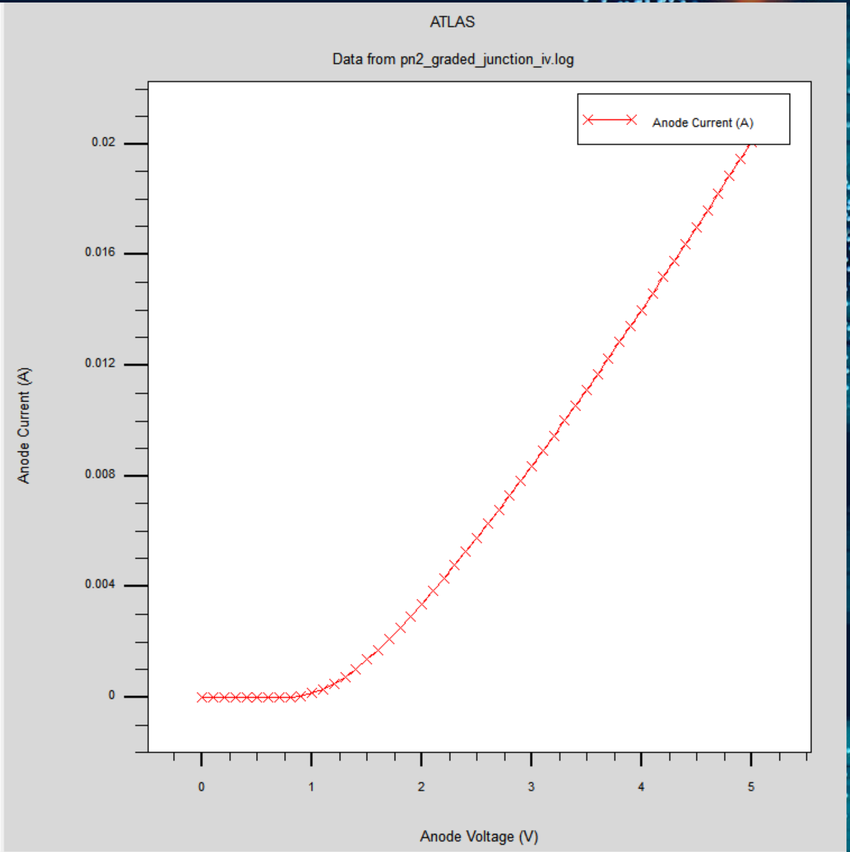
4. Extract the junction capacitance and storage capacitance for long channel diode. Sweep the bias from forward to reverse and report the change in both capacitances.

4. Change your junction from step to graded and compare their I-V characteristics. Then, compare doping concentrations fermi levels and junction and storage capacitance in both of them.

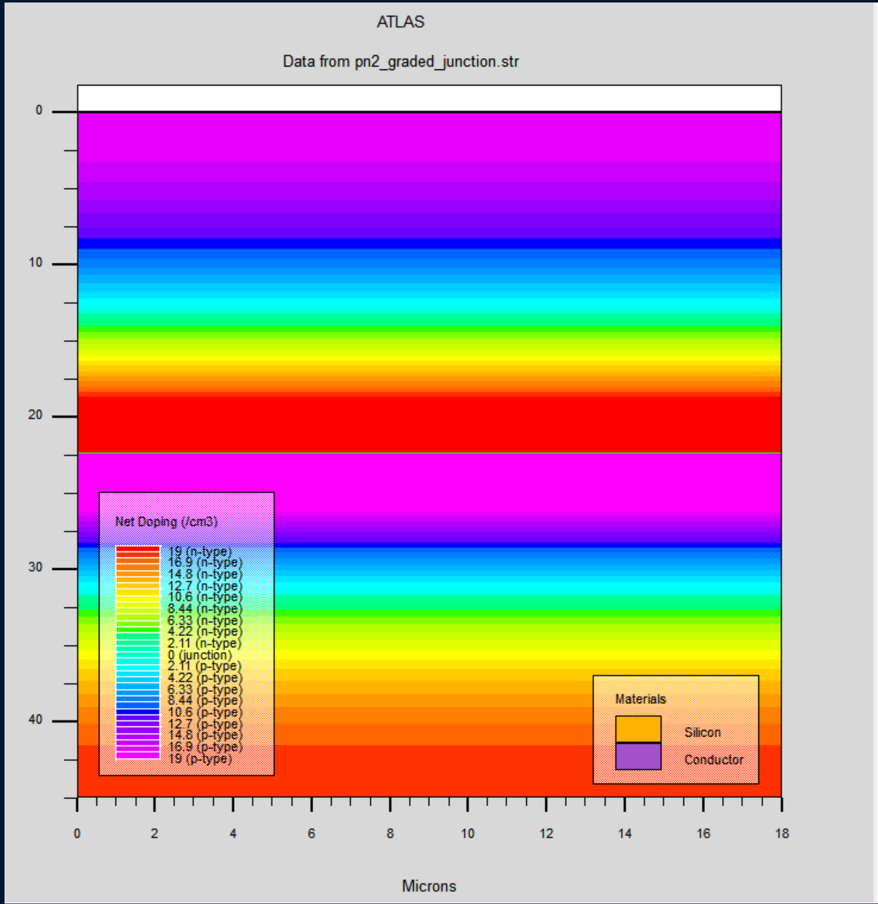
```
# Graded Doping Concentration
doping gaussian p.type conc=1e19 peak=0.0 junc=22.5 char=2
doping gaussian n.type conc=1e19 peak=45.0 junc=22.5 char=2
```

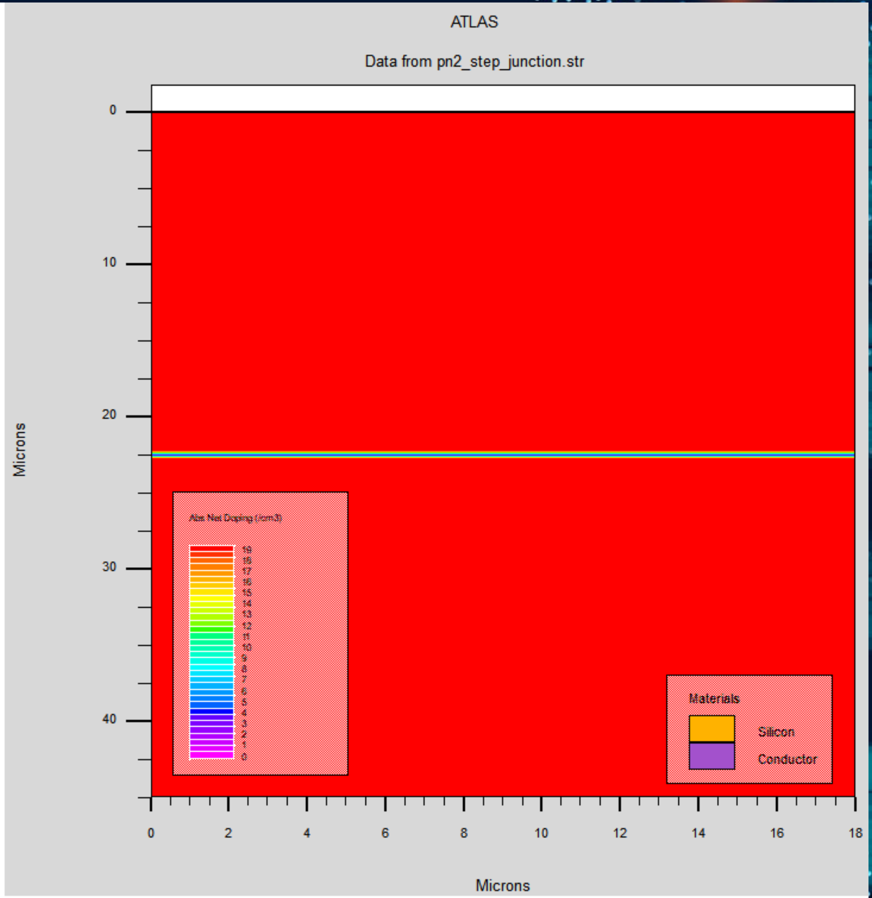
I-V Characteristics comparison in Step and Graded junction



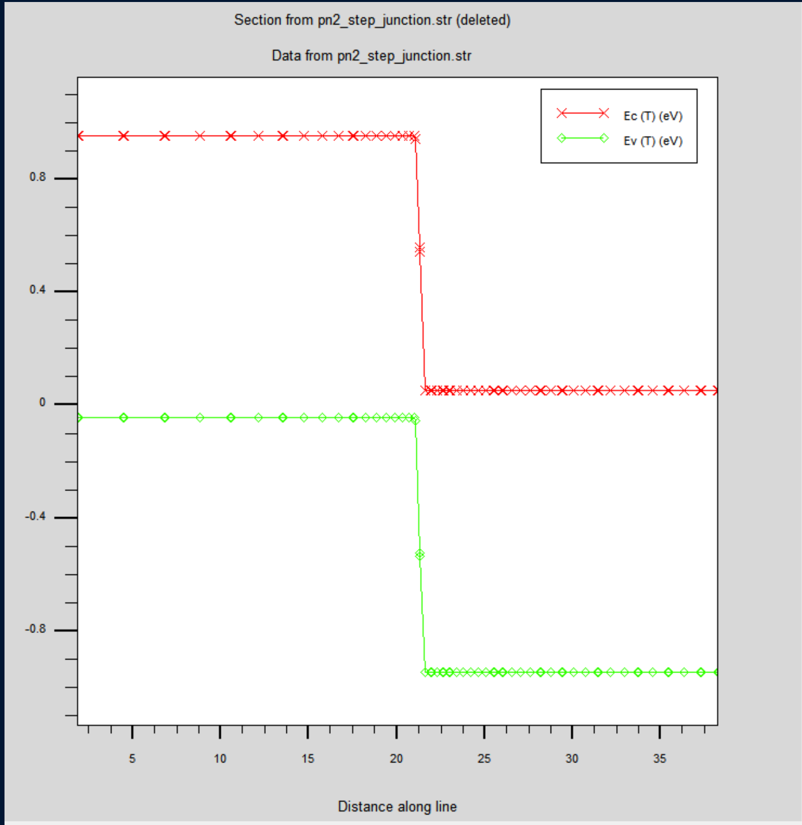


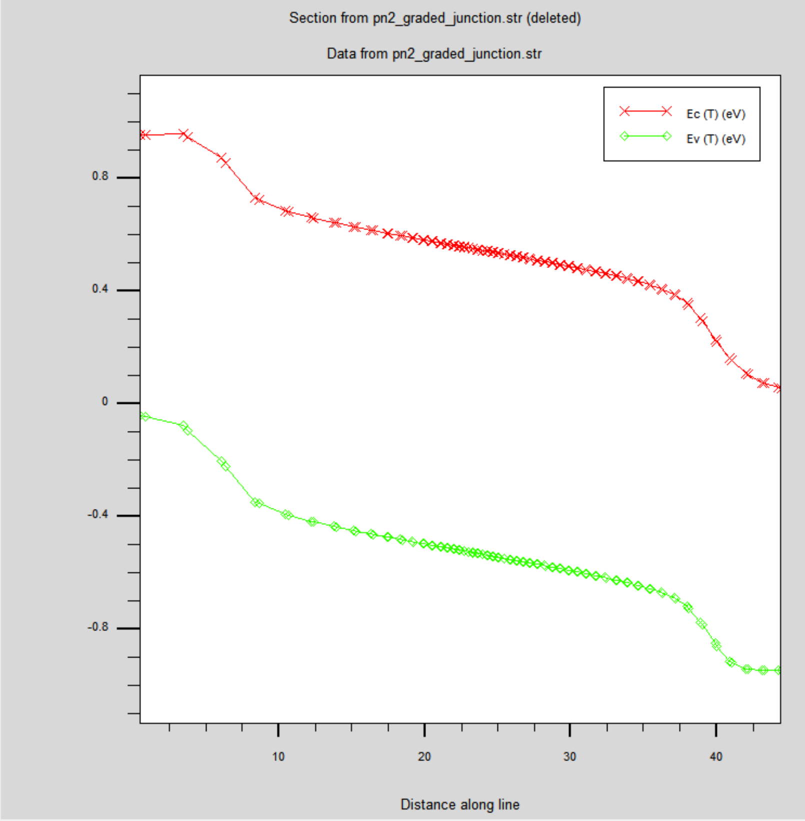
Doping Concentrations comparison in Step and Graded junction





Ec and Ev comparison in Step and Graded junction



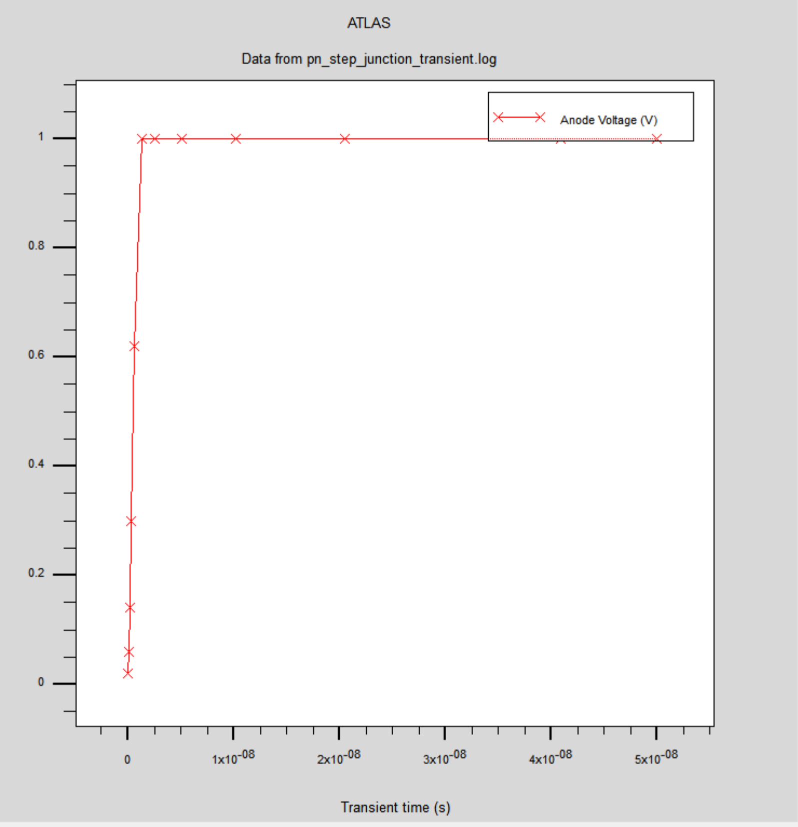


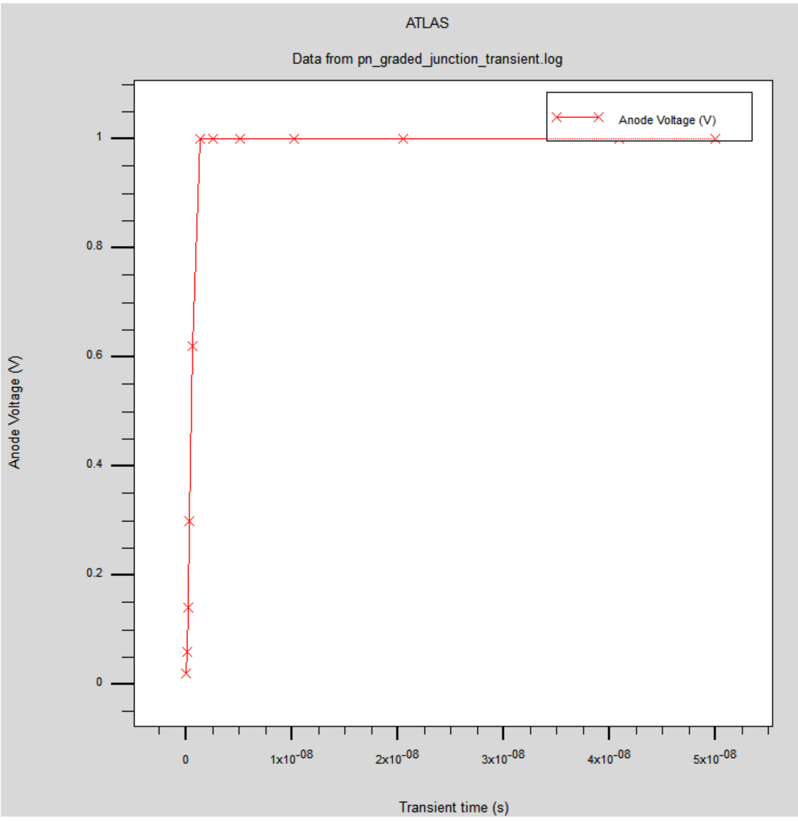
Part 1: P-N Junction

4. Change your junction from step to graded and compare their I-V characteristics. Then, compare doping concentrations fermi levels and junction and storage capacitance in both of them.

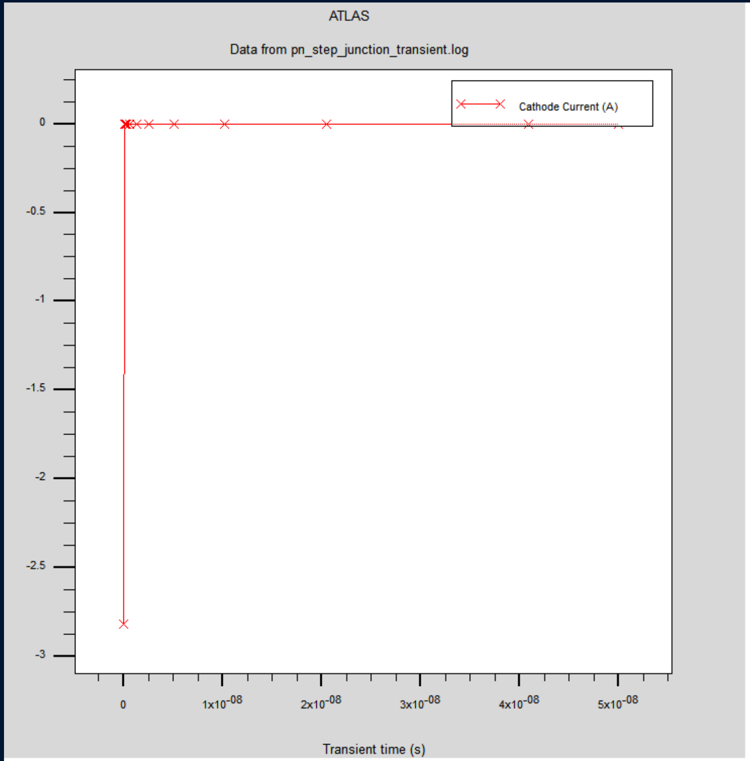
5. Simulate the transient response of long channel and short channel diodes with both graded and step junctions. Compare their switching speeds when turning on and off. (The on switching time is when the current reaches 90% of the its maximum amount.)

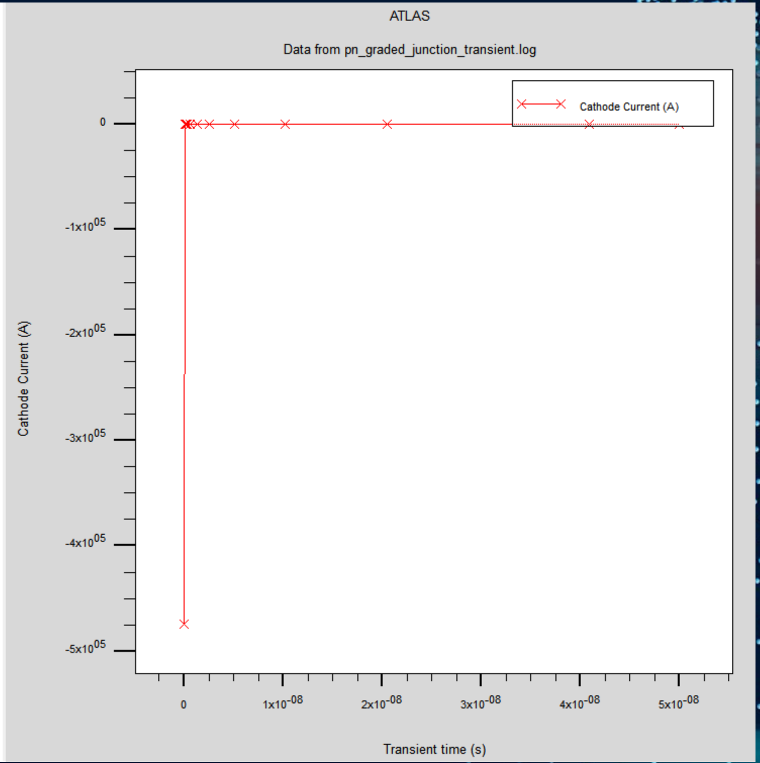
Transient Step input for Step and Graded junction





Transient current output for Step and Graded junction





Unfortunately I couldn’t obtain correct results for the output current though.

Part 1: P-N Junction

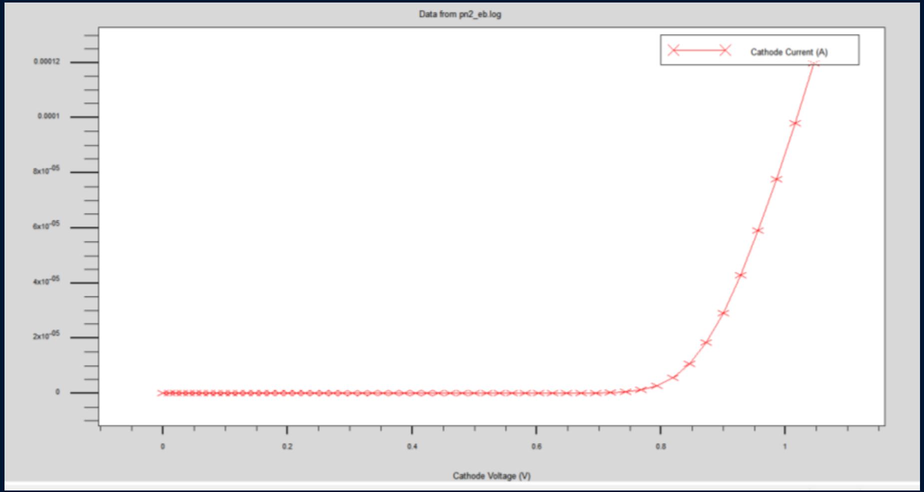
4. Change your junction from step to graded and compare their I-V characteristics. Then, compare doping concentrations fermi levels and junction and storage capacitance in both of them.

5. Simulate the transient response of long channel and short channel diodes with both graded and step junctions. Compare their switching speeds when turning on and off. (The on switching time is when the current reaches 90% of the its maximum amount.)

7. Find the breakdown voltage of the step-junction diode given above using the function and simulation and compare the results.

Curvetracing to find the breakdown voltage of the P-N

```
curvetrace end.val=1e-4 contr.name=cathode curr.cont mincur=1e-3 nextst.ratio=1.02 step.init=0.01
log outf=pn2_eb.log
solve curvetrace

tonyplot pn2_eb.log

quit
```



Unfortunately my code didn't converge for other doping profiles and I couldn't fix the problem….

References

1. ATLAS User's Manual
2. nanoHUB.org (Introduction to Silvaco ATLAS)
3. Youtube video : https://youtu.be/qmTRw6YTbCU (EXPLORING PN JUNCTION DIODES with Silvaco TCAD Simulation: Compare Si, Ge, GaAs, and GaN Diodes!)
4. Youtube video: https://youtu.be/soMdqRkgVo8 (Silvaco TCAD BREAKDOWN CURRENT SIMULATION for pn Junction Diode and MOSFET!)
5. Atlas Device Simulation Toturial by Maria Concetta Allia
6. Silvaco Website hints on visualizing Drift and Diffusion Current Densities
7. Silvaco document on Laser Diode Simulation
8. Research Gate website forum