The University of Windsor

ELEC2250: Physical Electronics

Summer 2020

Lab Six

Equilibrium p-n Junction Analysis

Friday, July 24, 2020

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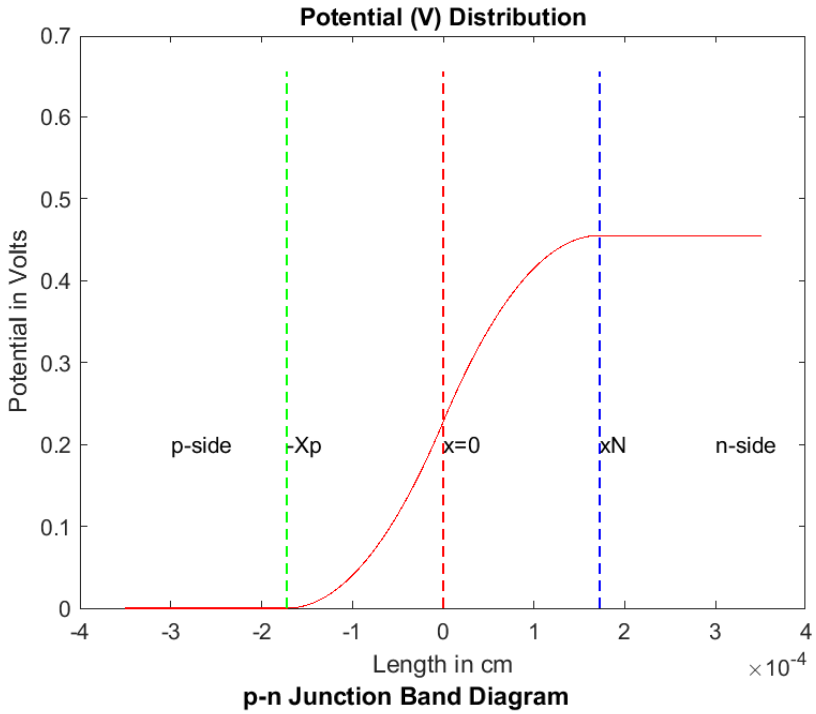
Lab Tasks Part 3: *Code can be found in "Task 3" folder of the attached zip file*

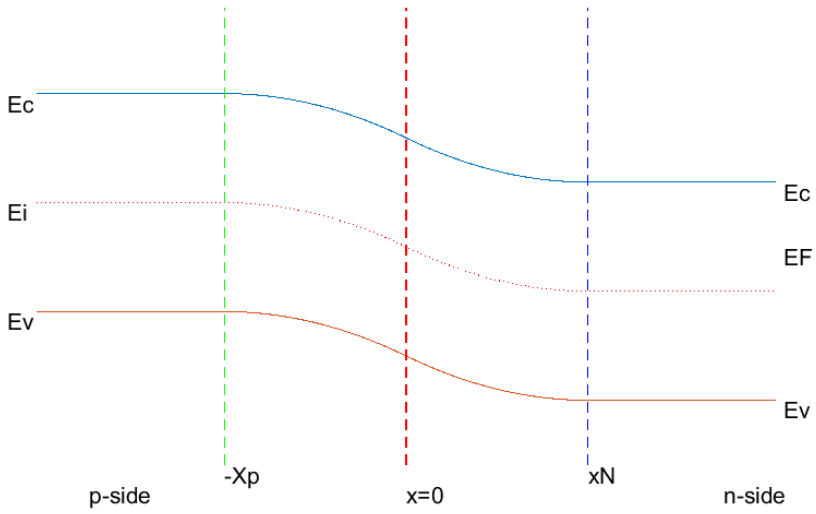
a) Input Values

NA = 1e14

ND = 1e14

Output





NA =

1.0000e+14

ND =

1.0000e+14

V0 =

0.4552

xN =

1.7226e-04

xP =

1.7226e-04

W =

3.4453e-04

Emax =

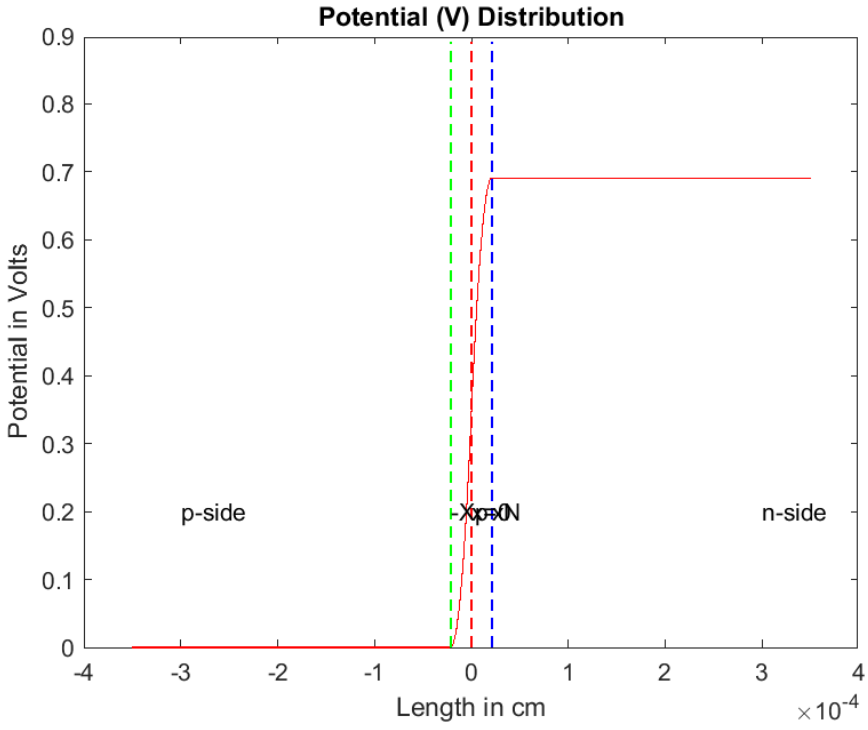
-2.6426e+03

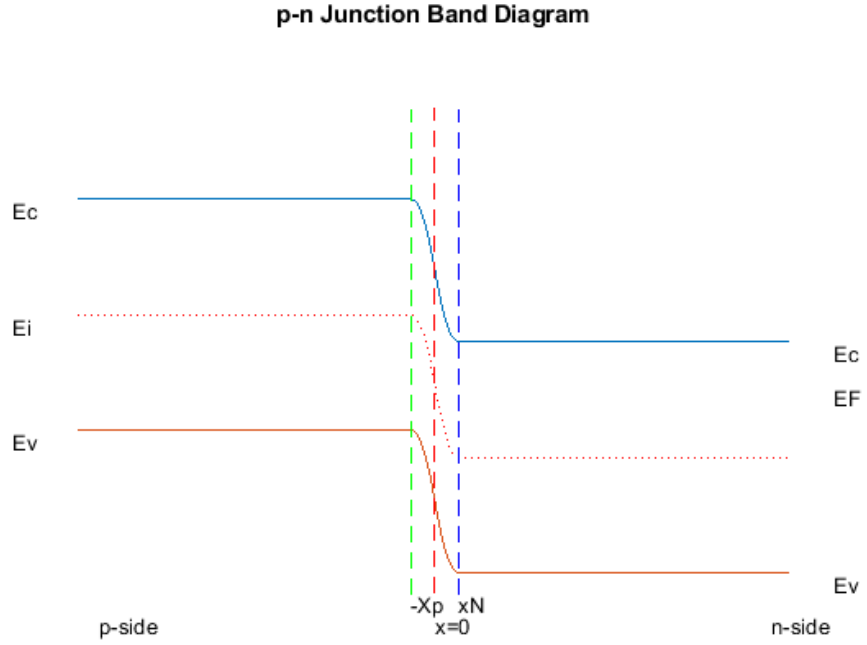
Input Values

NA = 1e16

ND = 1e16

Output





NA =

1.0000e+16

ND =

1.0000e+16

V0 =

0.6933

xN =

2.1259e-05

xP =

2.1259e-05

W =

4.2519e-05

Emax =

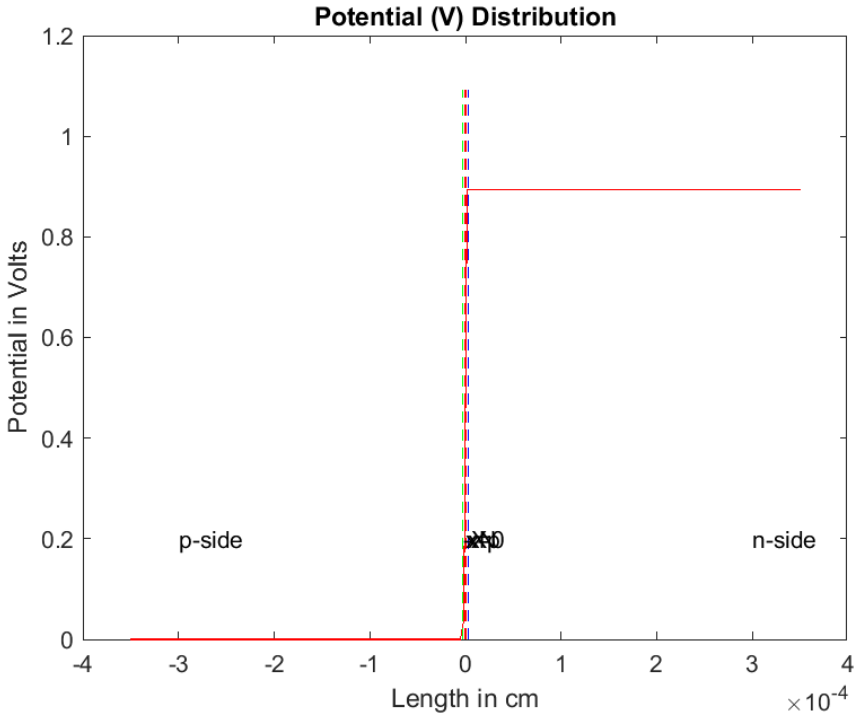
-3.2613e+04

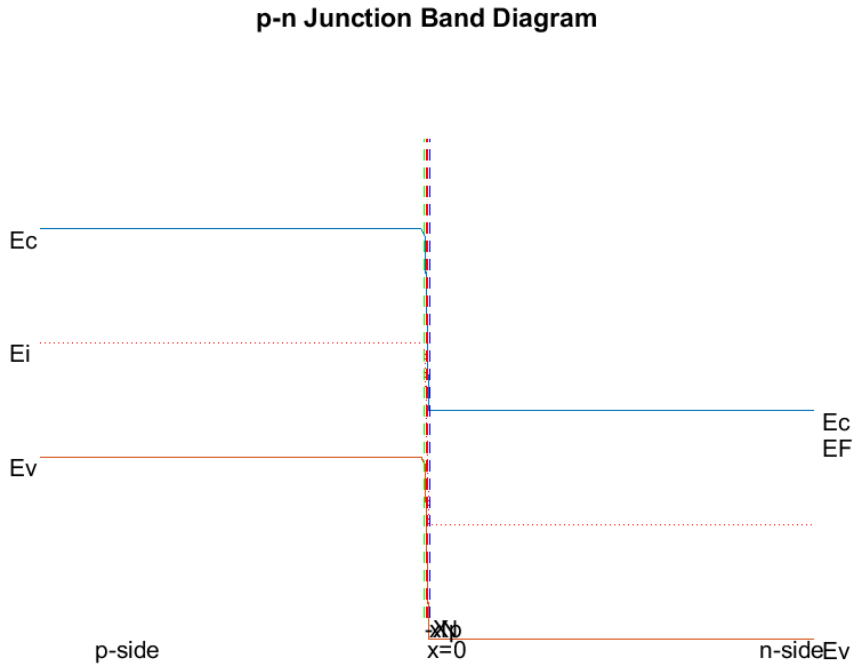
Input Values

NA = 1e18

ND = 1e18

Output





NA =

1.0000e+18

ND =

1.0000e+18

V0 =

0.9314

xN =

2.4641e-06

xP =

2.4641e-06

W =

4.9282e-06

Emax =

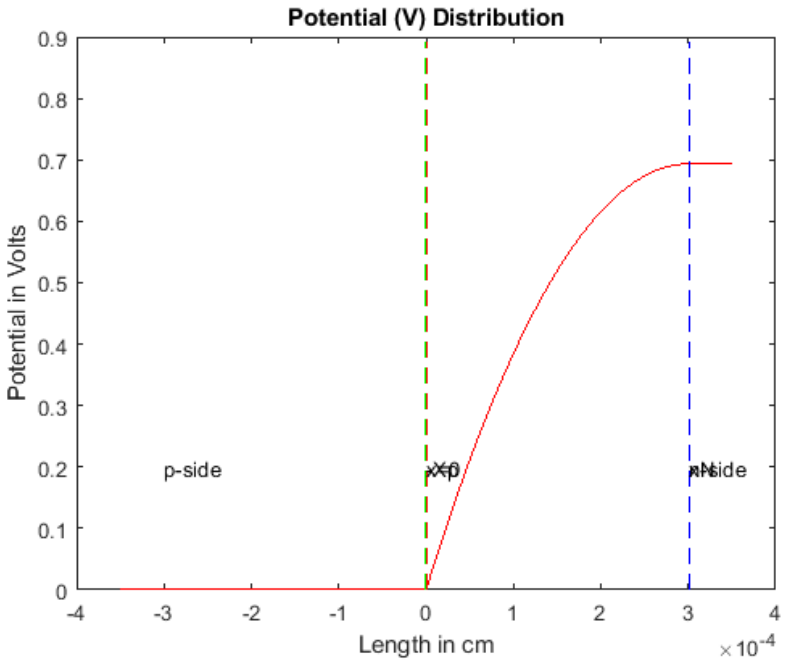
-3.7800e+05

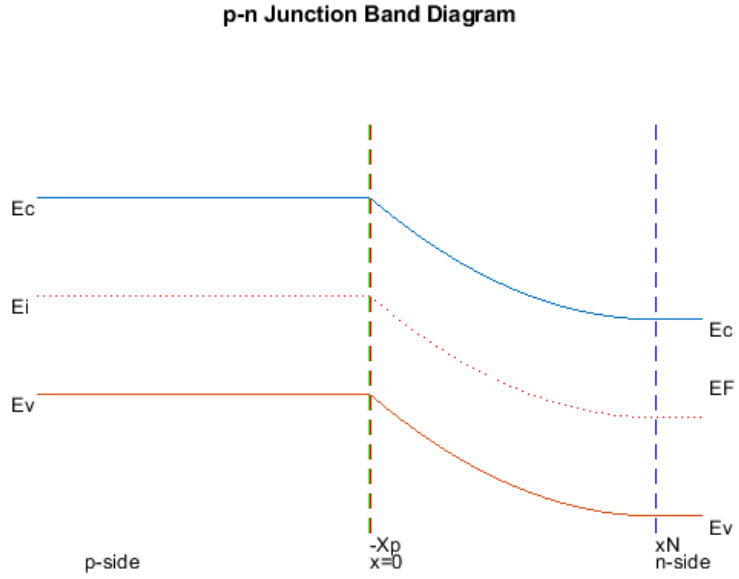
b) Input Values (p-side concentration > n-side concentration)

NA = 1e18

ND = 1e14

Output





NA =

1.0000e+18

ND =

1.0000e+14

V0 =

0.6933

xN =

3.0064e-04

xP =

3.0064e-08

W =

3.0067e-04

Emax =

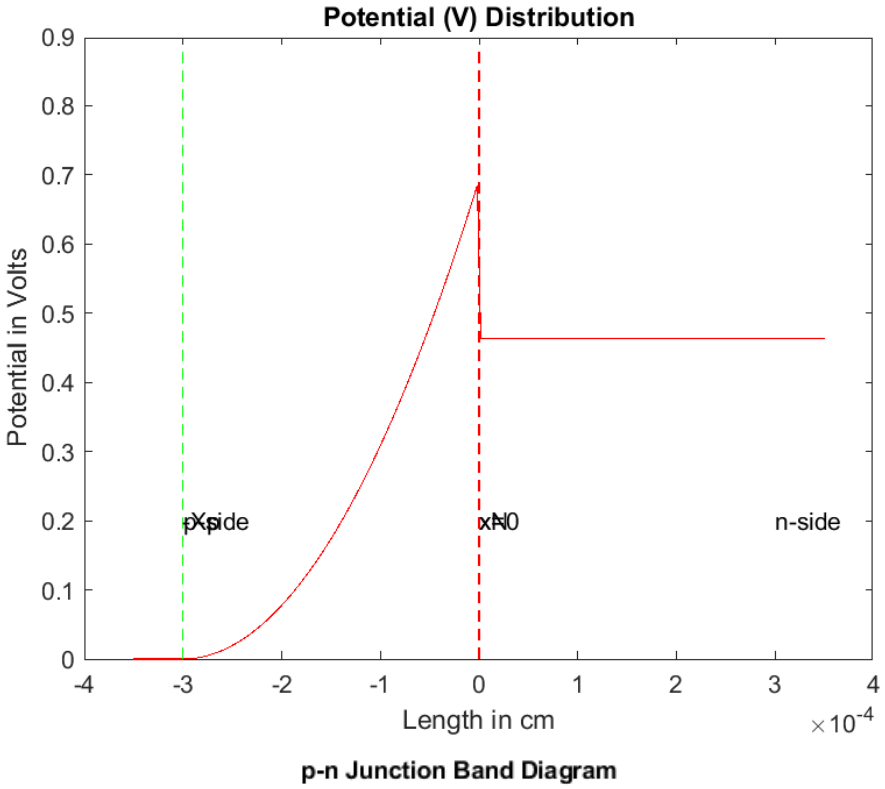
-4.6119e+03

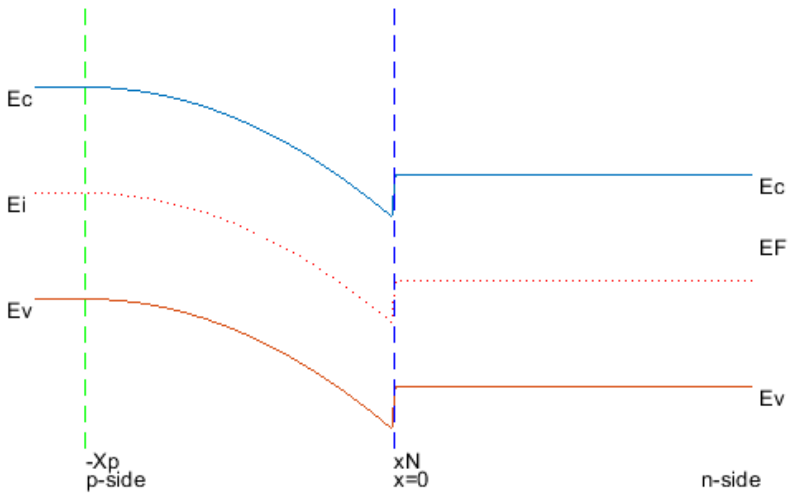
c) Input Values (p-side concentration < n-side concentration)

NA = 1e14

ND = 1e18

Output





NA =

1.0000e+14

ND =

1.0000e+18

V0 =

0.6933

xN =

3.0064e-08

xP =

3.0064e-04

W =

3.0067e-04

Emax =

-4.6119e+03

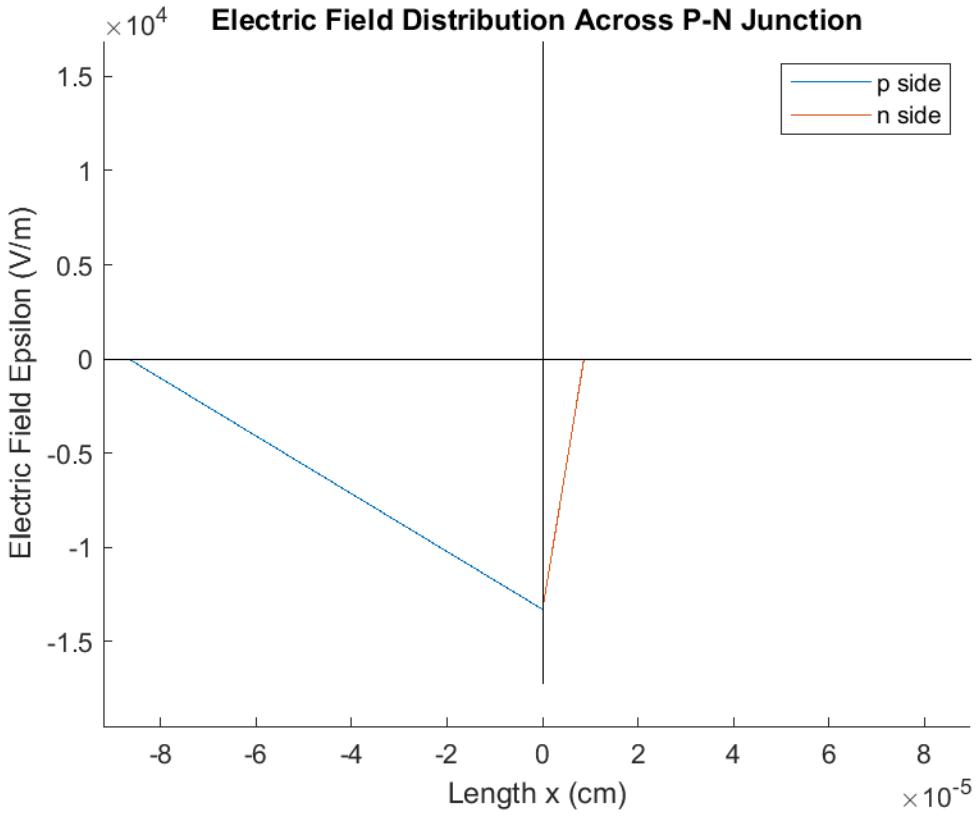
Lab Tasks Part 4: *Code can be found in "Task 4" folder of the attached zip file*

Input Values:

NA = 1e15

ND = 1e16

Output



NA = 1.0000e+15

ND = 1.0000e+16

V0 = 0.6338

xN = 8.6672e-06

xP = 8.6672e-05

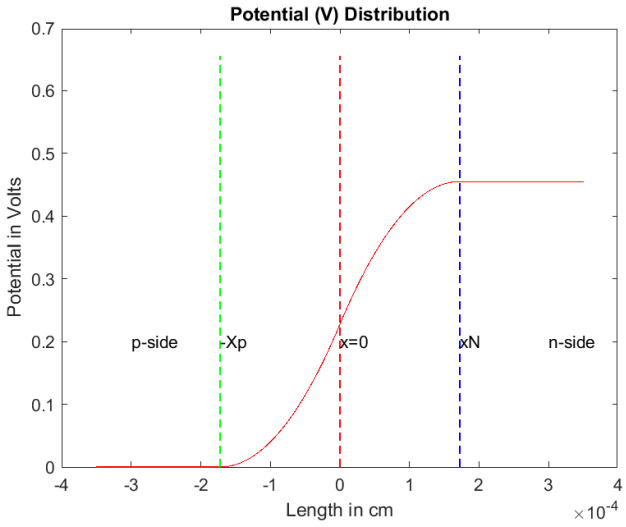
W = 9.5339e-05

Emax = -1.3296e+04

Lab Report Section

1) *Code and images can be found in "Task 3" folder of the attached zip file*

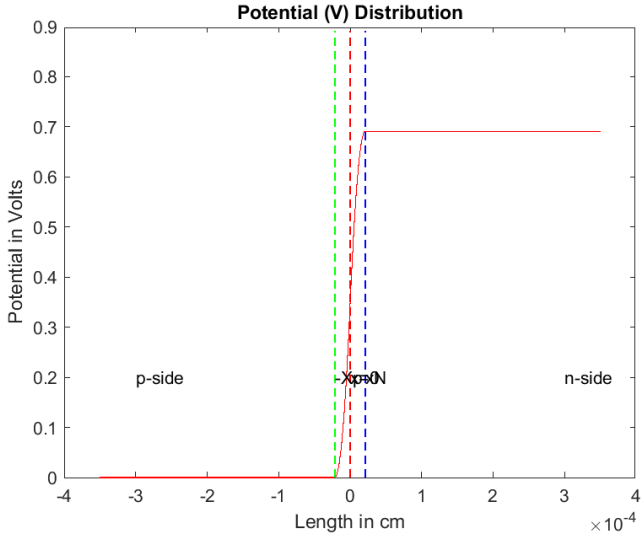
To observe the change in width, we will use the doping concentration value of 1E14/cm^3 as our reference point as seen below:




```
W =

    3.4453e-04
```

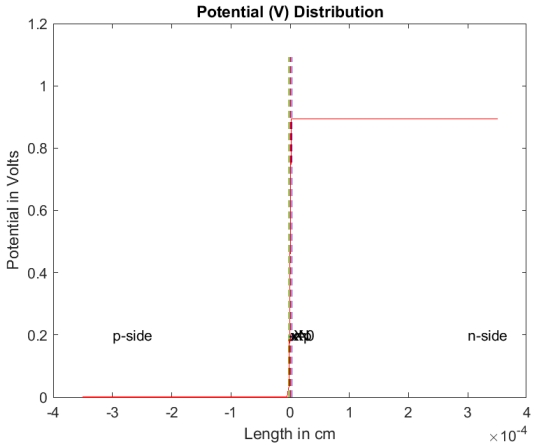
Now we will increase the doping concentration to Na=Nd=1E16/cm^3




```
W =

    4.2519e-05
```

Now we will further increase the concentration to Na=Nd=1E18/cm^3



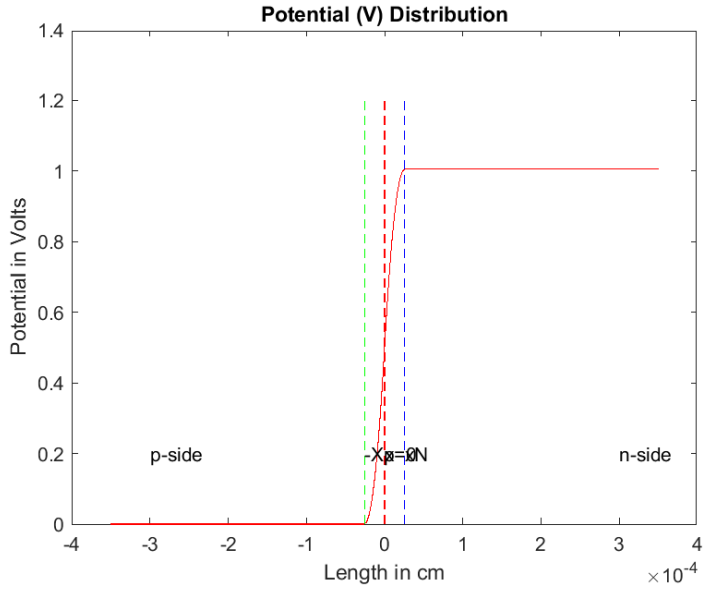

```
W =

    4.9282e-06
```

After comparing the three results, we can say that SCR width decreases when we increase the doping concentrations.

2) *Code and images can be found in respective "Lab Report Questions 1-13" folder*

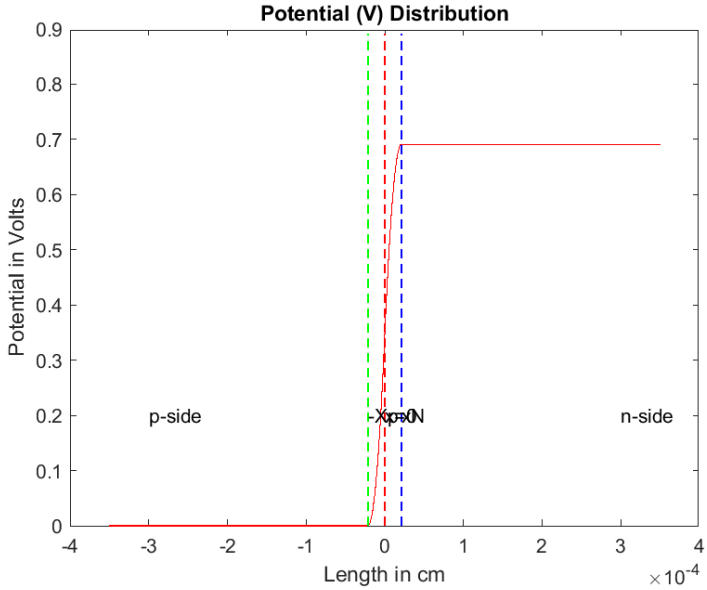
Using a doping concentration of Na=Nd=1E16/cm^3 at T=100K as our reference:




```
W =

    5.1221e-05
```

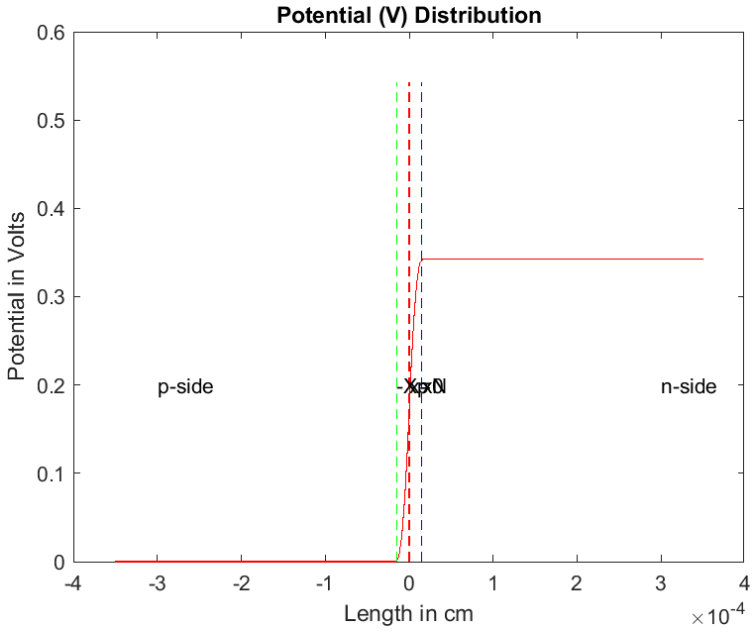
Now we will increase the temperature to 300K and see how the width changes




```
W =

    4.2519e-05
```

Now we will further increase the temperature to 500K and observe how the width changes



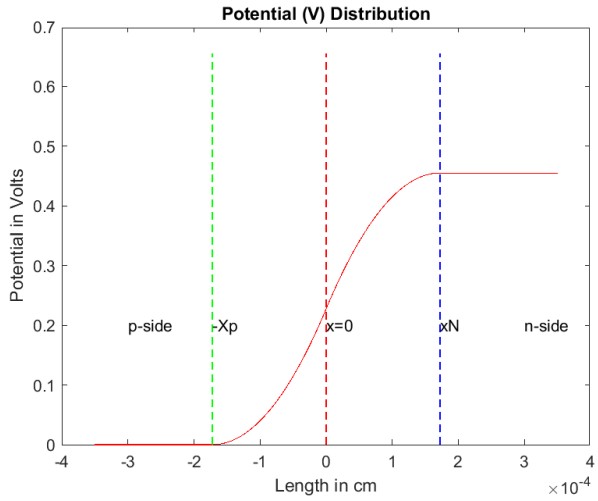

```
W =

   2.9899e-05
```

We can conclude that when we keep doping concentrations the same but change the temperature, SCR width decreases with time. This can be attributed to the intrinsic carrier value also increases with temperature which is inversely proportional to the width.

3) *Code and images can be found in "Task 3" folder of the attached zip file*

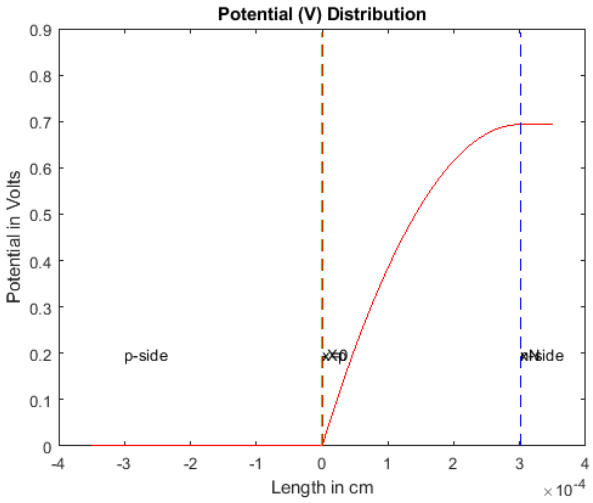
To observe how the p-side SCR penetration changes when we increase its doping concentration, we will use Na=Nd=1E14/cm^3 as our reference:




```
xP =

   1.7226e-04
```

Now we will increase the p-side doping concentration to Na=1E18/cm^3



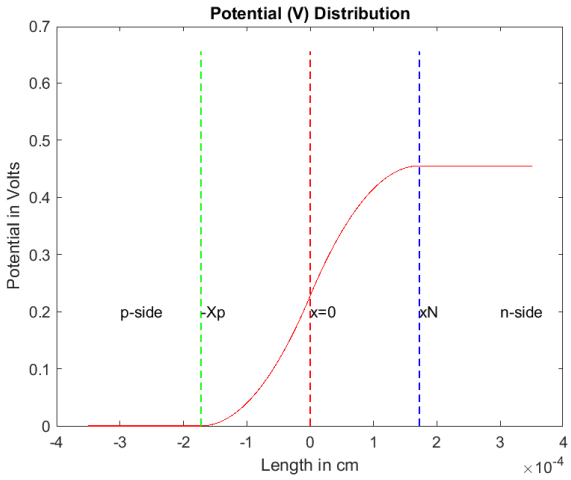

```
xP =

   3.0064e-08
```

It can be observed that as we increased the doping concentration, the p-side SCR penetration decreases.

4) *Code and images can be found in "Task 3" folder of the attached zip file*

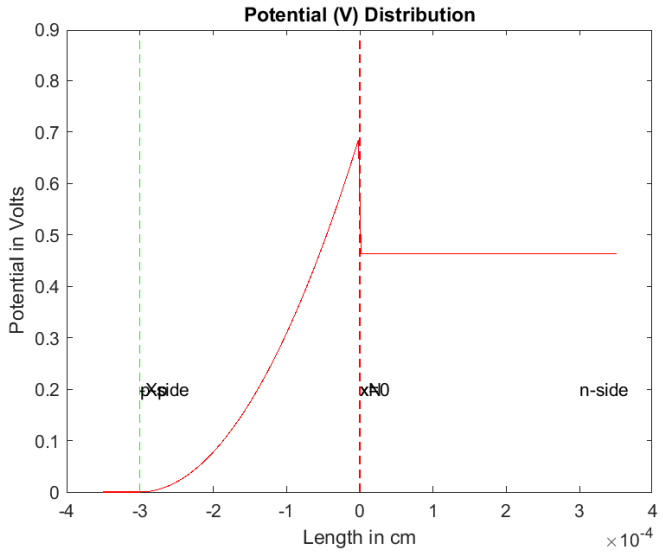
To observe how the n-side SCR penetration changes when we increase its doping concentration, we will use Na=Nd=1E14/cm^3 as our reference:




```
xN =

   1.7226e-04
```

Now we will increase the n-side doping concentration to Nd=1E18/cm^3



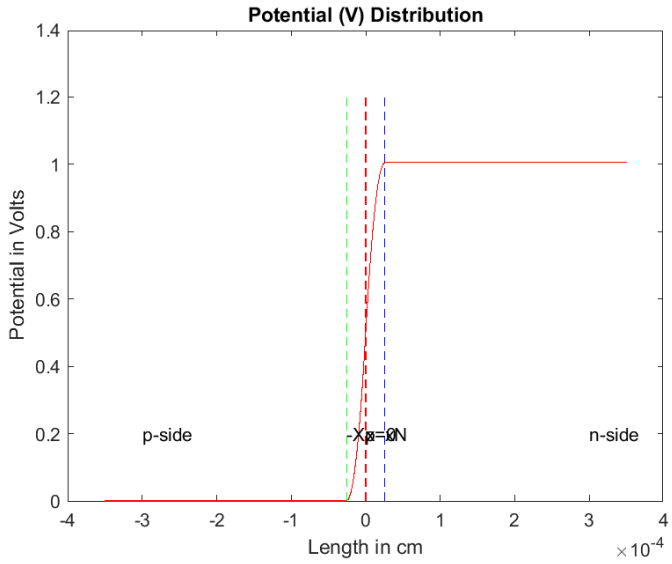

```
xN =

   3.0064e-08
```

It can be observed that as we increased the doping concentration, the n-side SCR penetration decreases.

5) *Code and images can be found in respective "Lab Report Questions 1-13" folder*

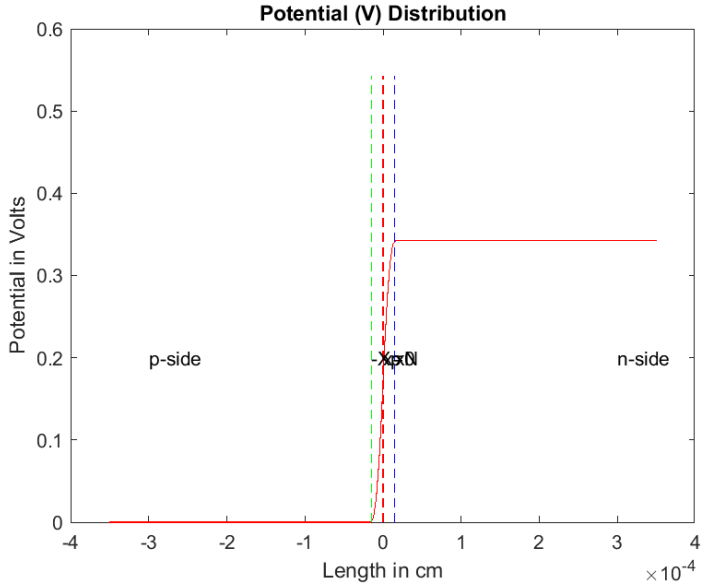
Using a doping concentration of Na=Nd=1E16/cm^3 at T=100K as our reference:




```
xP =

   2.5611e-05
```

Now we will further increase the temperature to 500K and observe how the width changes



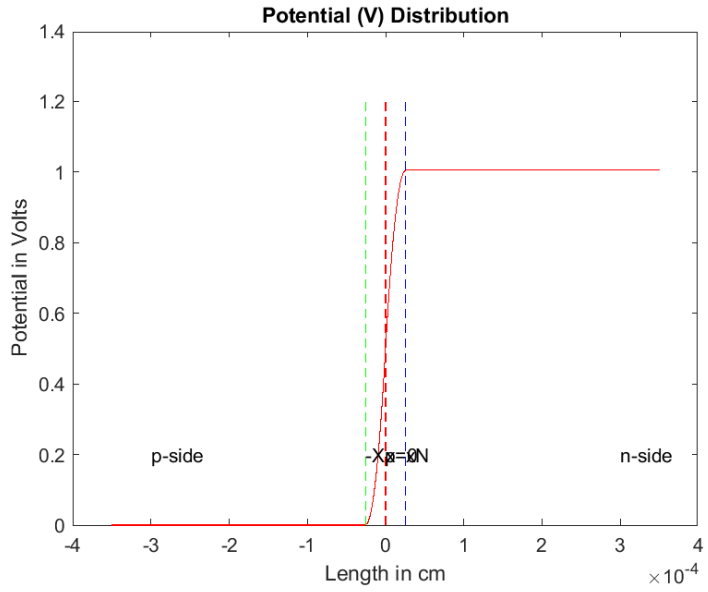

```
xP =

   1.4950e-05
```

We can conclude that when we keep doping concentrations the same but increase the temperature, the p-side SCR penetration decreases.

6) *Code and images can be found in respective "Lab Report Questions 1-13" folder*

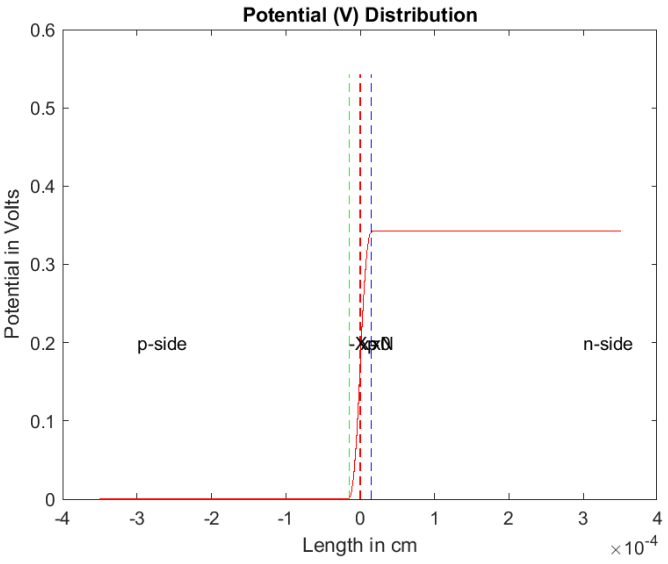
Using a doping concentration of Na=Nd=1E16/cm^3 at T=100K as our reference:




```
xN =

    2.5611e-05
```

Now we will further increase the temperature to 500K and observe how the width changes



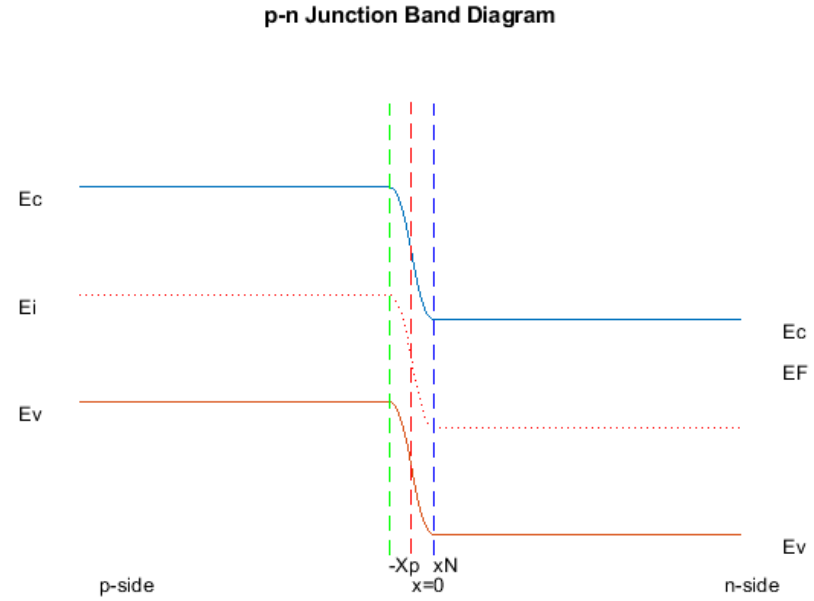

```
xN =

    1.4950e-05
```

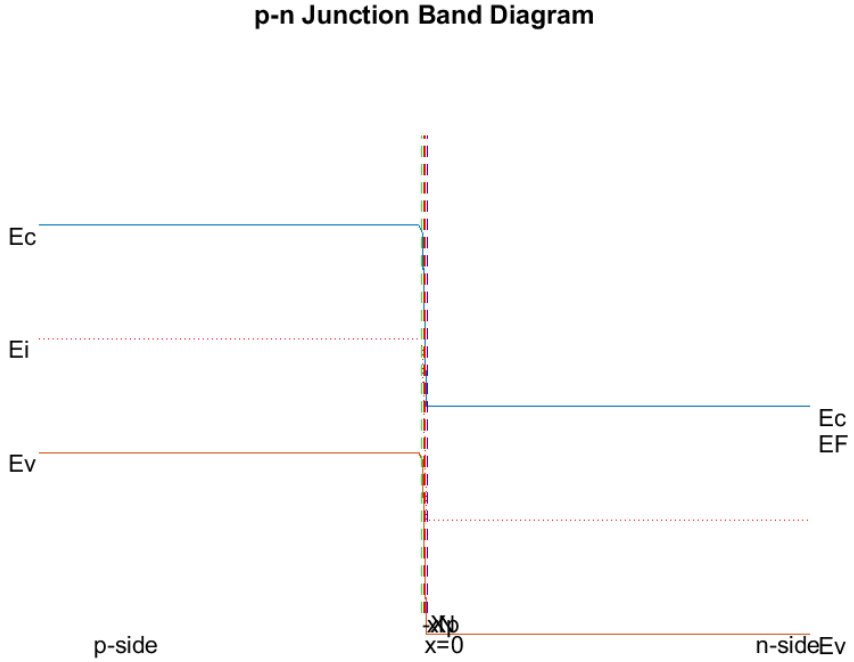
We can conclude that when we keep doping concentrations the same but increase the temperature, the n-side SCR penetration decreases.

7) *Code and images can be found in respective "Lab Report Questions 1-13" folder*

To observe the band bending amount across the SCR as doping increases, we will first use the concentration value of 1E16/cm3 as our reference point as seen below:



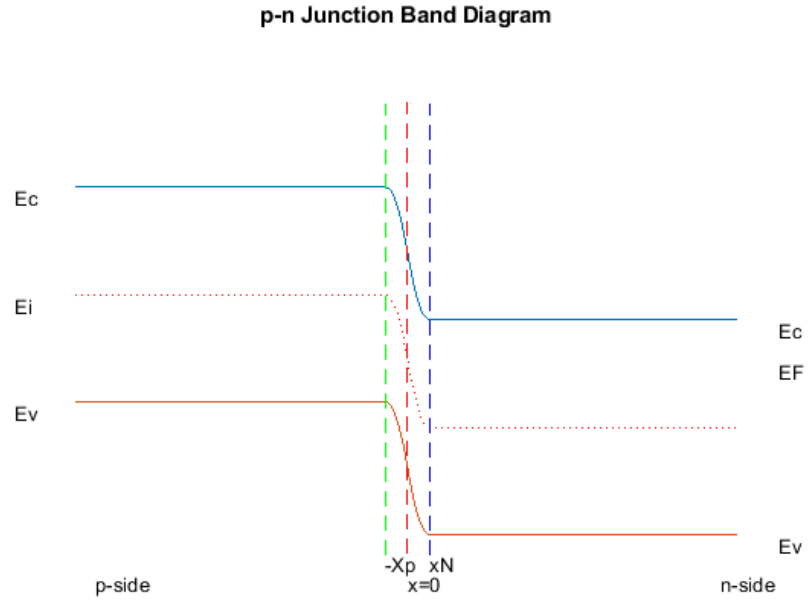
Now we will increase the concentration to Na=Nd=1E18/cm^3



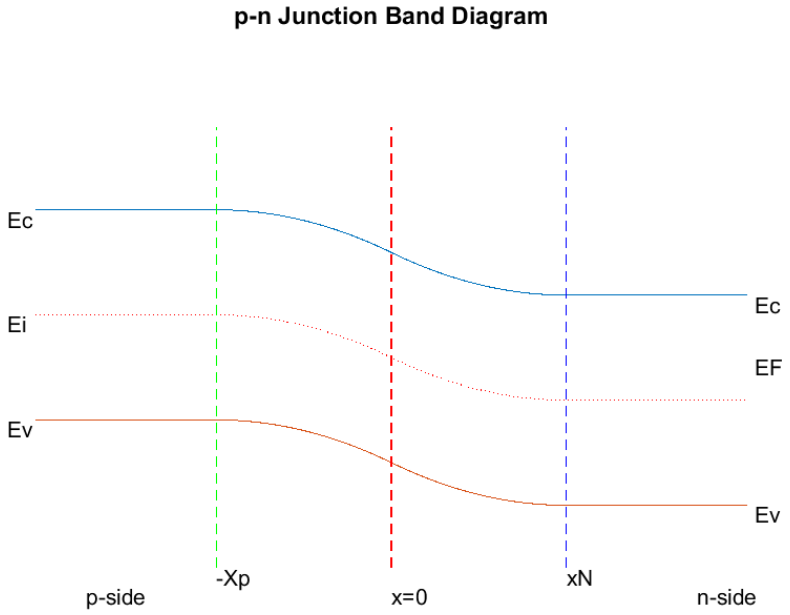
We can observe that increasing the doping concentration increases the band bending amount across the SCR. Moreover, the SCR p and n side penetrations become smaller and the band is bent at a much steeper angle.

8) *Code and images can be found in respective "Lab Report Questions 1-13" folder*

To observe the band bending amount across the SCR as doping decreases, we will first use the concentration value of 1E16/cm3 as our reference point as seen below:



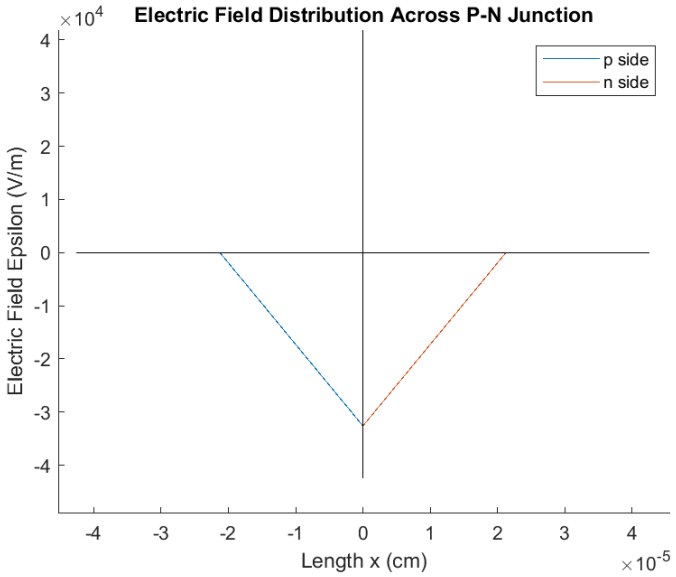
Now we will decrease the concentration to Na=Nd=1E14/cm^3



We can observe that decreasing the doping concentration decreased the band bending amount across the SCR. Moreover, the SCR p and n side penetrations become larger and the band is bent at a much more horizontal and less steep angle.

9) *Code and images can be found in respective "Lab Report Questions 1-13" folder*

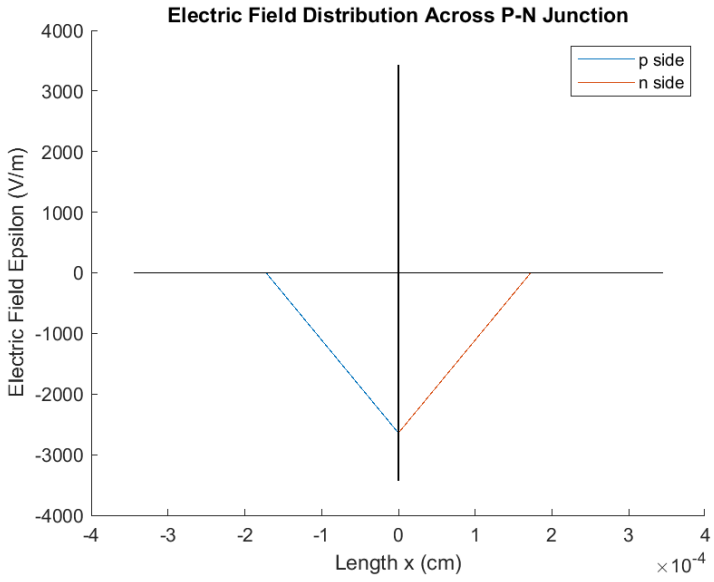
To observe how the maximum electric field value changes as doping concentrations increase or decrease, we will use concentration values of Na=Nd=1E16/cm^3 as our reference as seen below:




```
Emax =

  -3.2613e+04
```

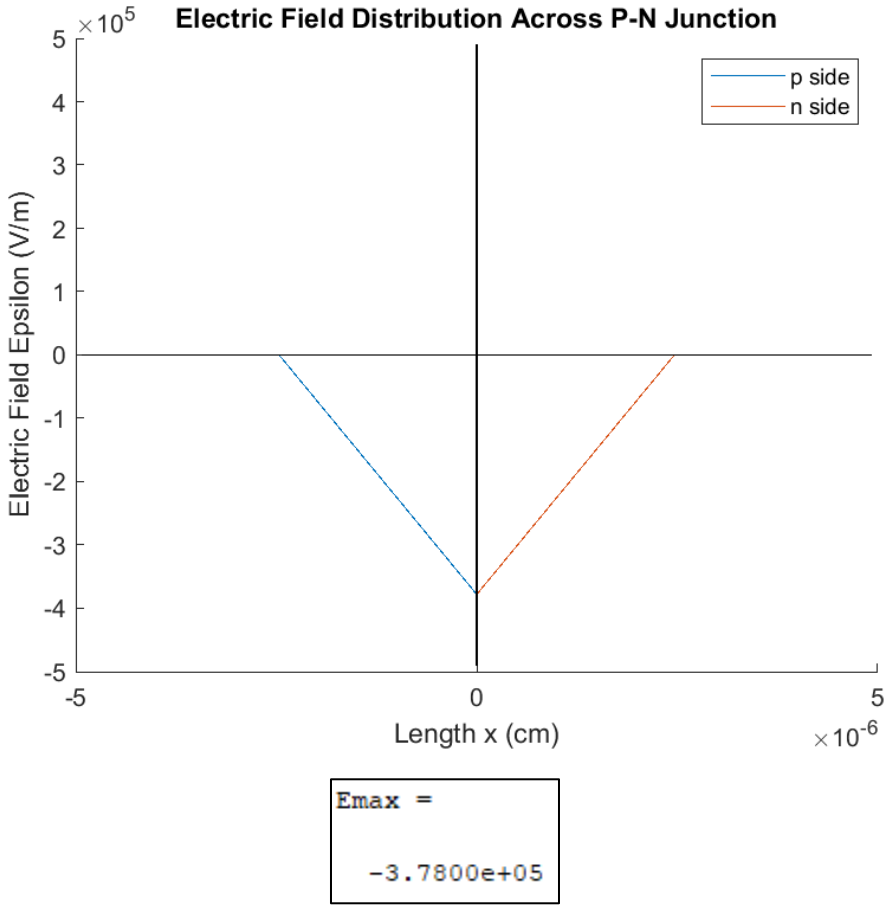
Now we will decrease the concentration to Na=Nd=1E14/cm^3




```
Emax =

  -2.6426e+03
```

Now we will increase the concentration to Na=Nd=1E18/cm^3



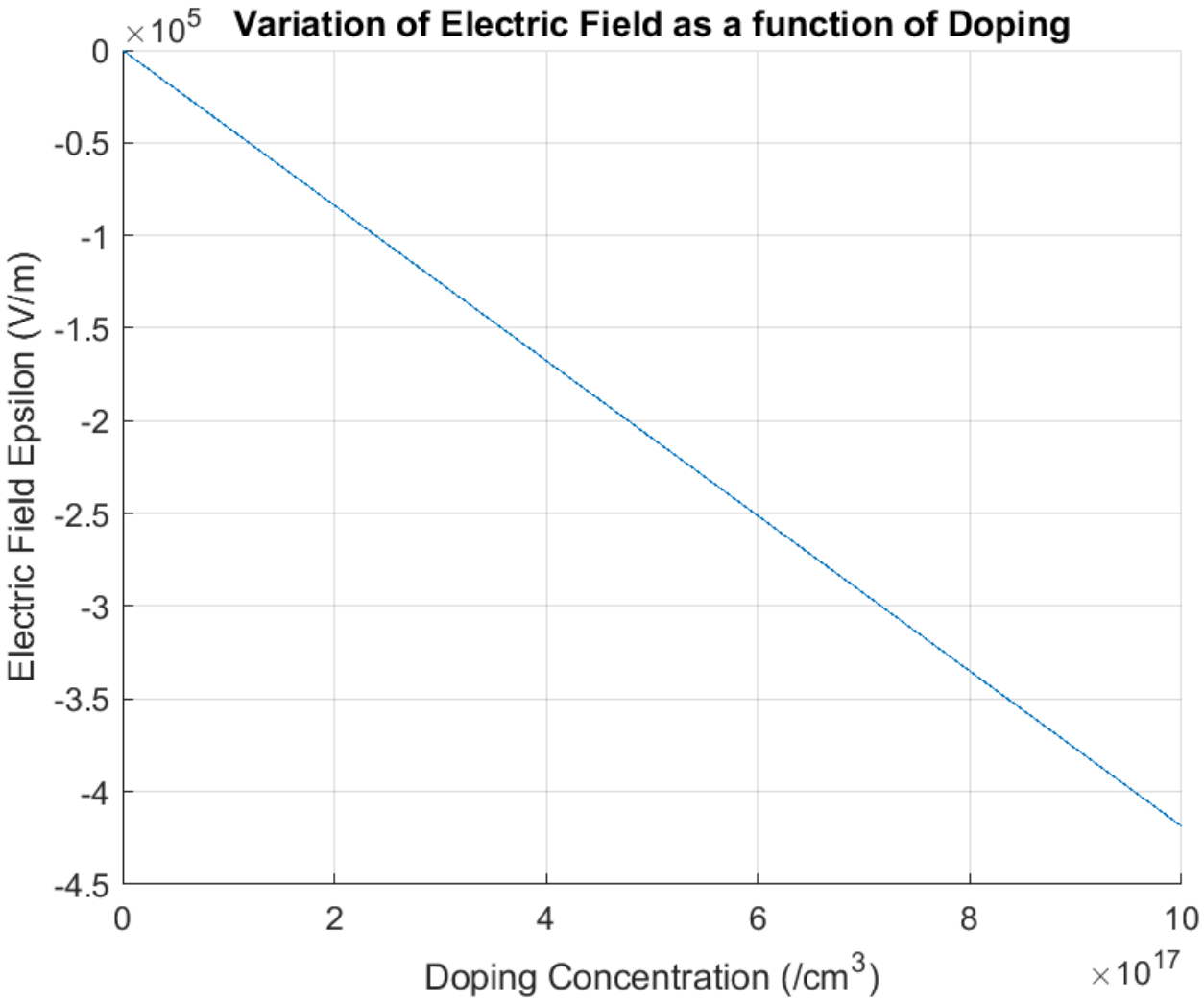

```
Emax =

  -3.7800e+05
```

After analyzing our results and comparing our maximum electric fields with our control variable. We can say that the maximum electric field increases when doping concentrations decrease and the maximum electric field decrease when doping concentrations increase.

10) *Code and images can be found in respective "Lab Report Questions 1-13" folder*

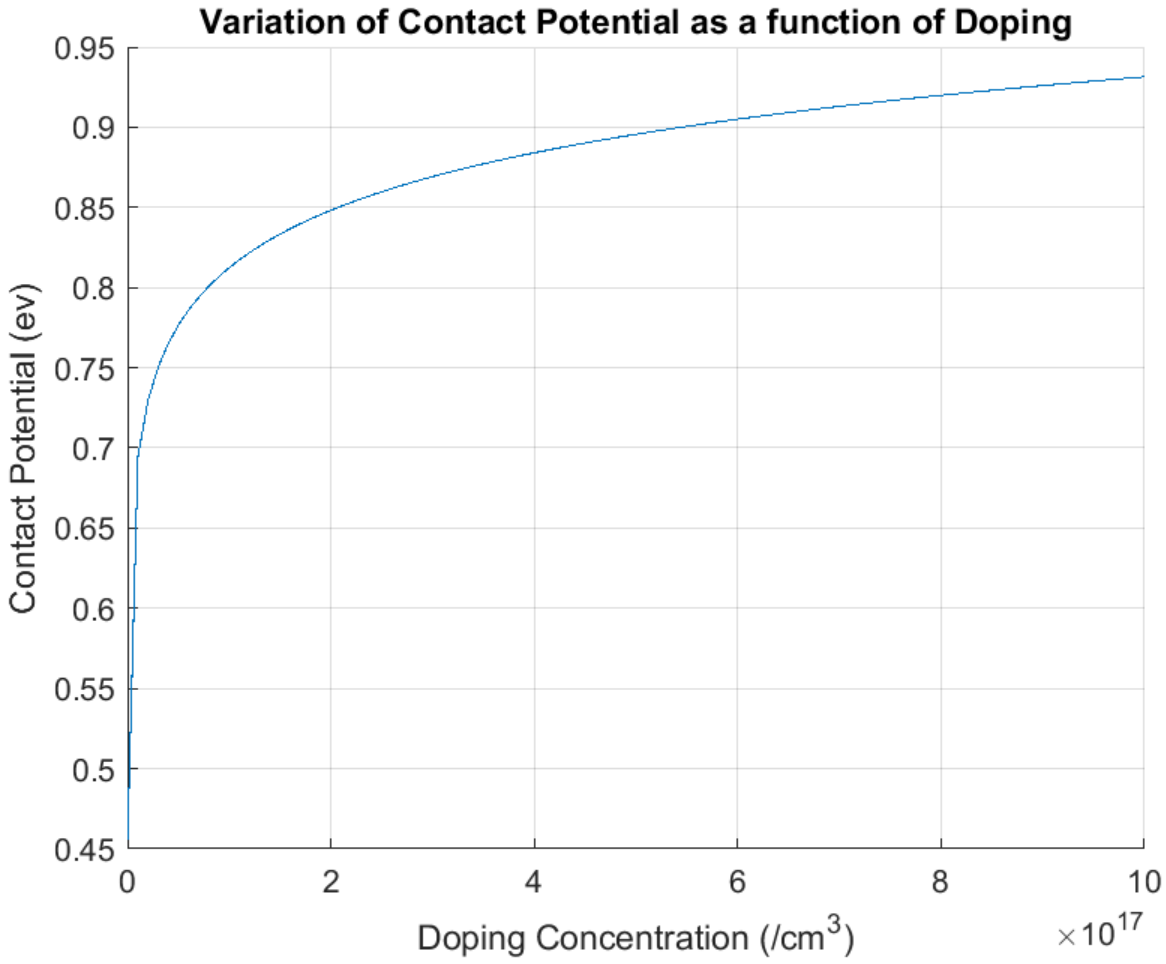
To observe the variation of the electric field as a function of doping, we must consider a location to measure the electric field from in the p-n junction. The best position to do this is at Emax or when x = 0. From that position we will vary the doping concentrations of Na and Nd to achieve the plot you see below:



After observing the graph, we can see a negative linear relationship between the doping concentration and the electric field. Hence, we can say that as the doping concentration increases, the electric field decreases.

11) *Code and images can be found in respective "Lab Report Questions 1-13" folder*

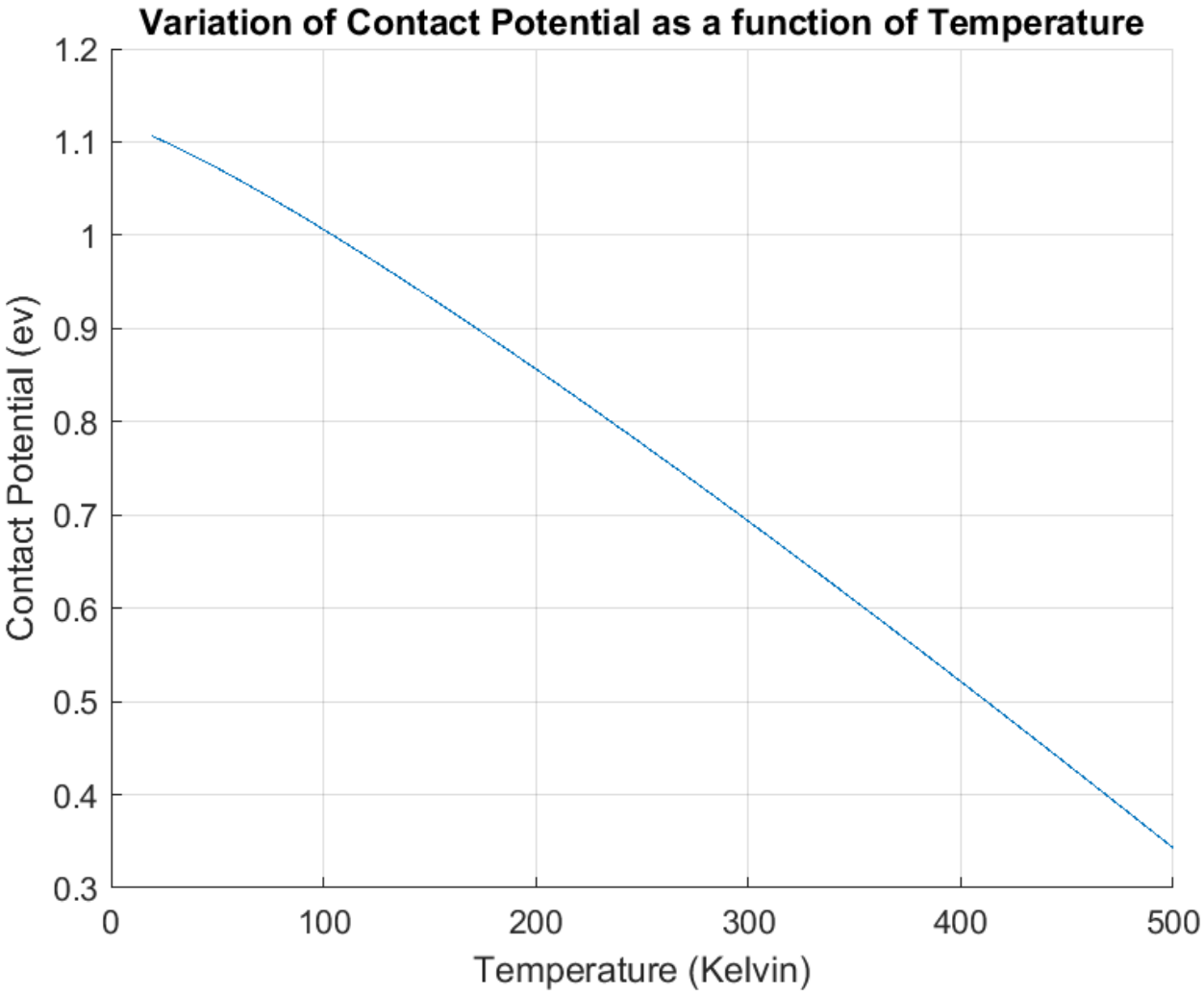
To observe the variation of contact potential as a function of doping, we will vary the doping concentrations of Na and Nd to achieve the plot you see below:



From our plot above, it is observed that as the doping concentration increase, the contact potential also increases logarithmically.

12) *Code and images can be found in respective "Lab Report Questions 1-13" folder*

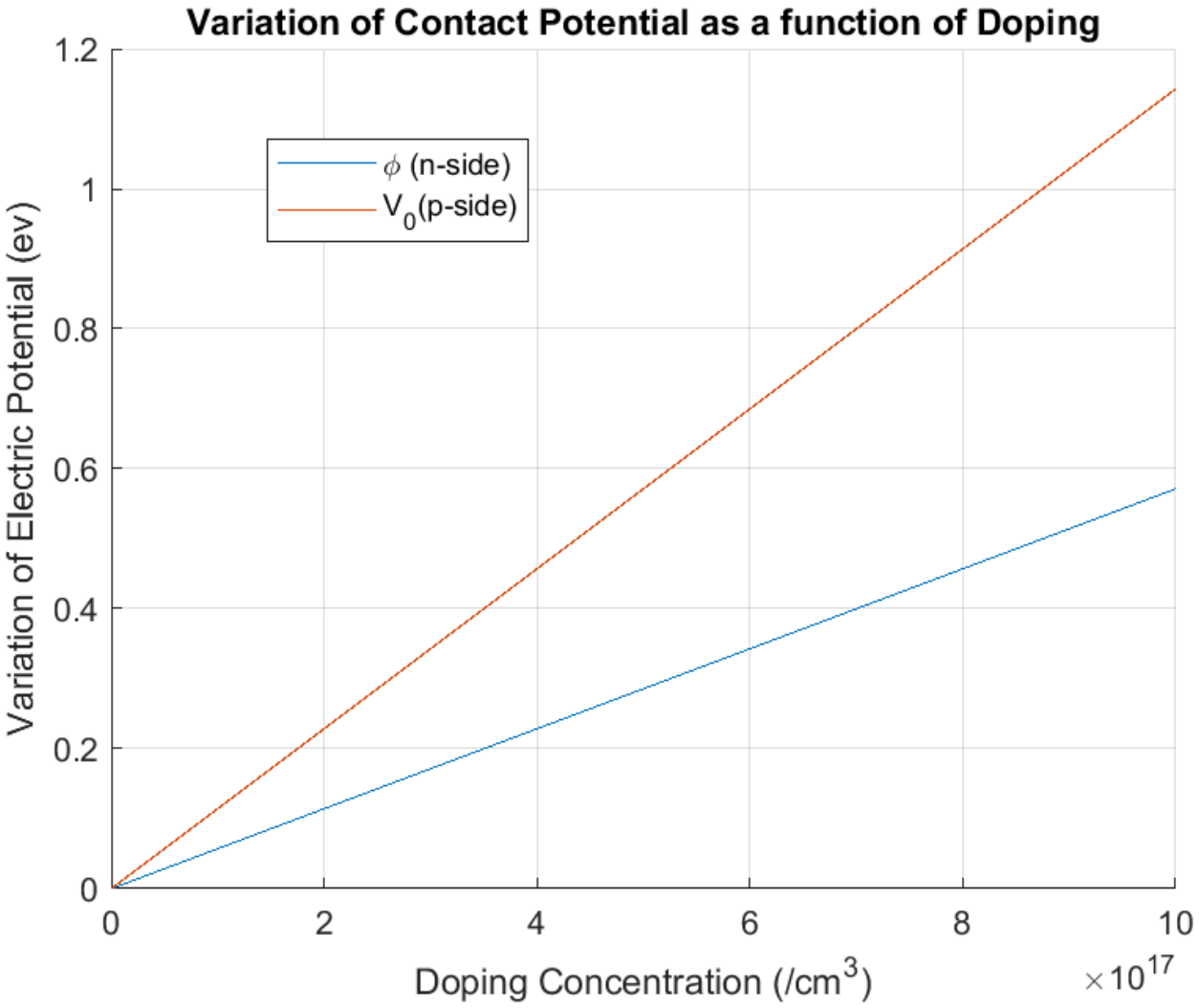
To observe the variation of contact potential as a function of temperature, we will vary the temperature to achieve the plot you see below:



From our plot above, it is observed that as the temperature increase, the contact potential decreases.

13) *Code and images can be found in respective "Lab Report Questions 1-13" folder*

To observe the variation of electric potential as a function of doping, we will vary the doping concentration to achieve the plot you see below:



From our plot above, it is observed that as the doping concentration increases, our n-side and p-side electric potential also increases. Moreover, the p-side electric potential grows faster than the n-side electric potential.

Discussion

Throughout this lab, we varied doping concentrations and temperatures to observe changes in SCR width, n & p-side SCR penetration, band bending, electric fields, contact potential, and electric potential. We discovered that the SCR width, n-side SCR penetration, and p-side SCR penetration decreased with an increase in temperature and decreased when we are increased doping concentrations. Additionally, the band bending amount across the SCR increased when we increased doping and decreased when we decreased doping.

By observing our electric field plots found above, we found that when we increased the doping concentrations, our electric field becomes more negative(decreasing) while becoming less negative when decreasing doping concentrations(increasing). After plotting the electric field as a function of doping, we found that as the doping increased, the electric field decreased linearly. Graphing the contact potential as a function of doping displayed logarithmic growth as doping increased. Graphing contact potential as a function of temperature displayed that increasing the temperature decreased the contact potential to a near-linear trend. We did this by assuming our p-n junction was ideal and solving for varying intrinsic carrier values. Finally, we observe that the variation in electric potential as a function of doping increased linearly; the p-side increased with greater amplitude than the n-side.

All supporting graphs/figures are found above. All of the figures and code for this lab are put in a zip file in their respective folders.