The University of Windsor

ELEC2250: Physical Electronics

Summer 2020

Lab Four

Resistivity and Mobility

Friday, July 10, 2020

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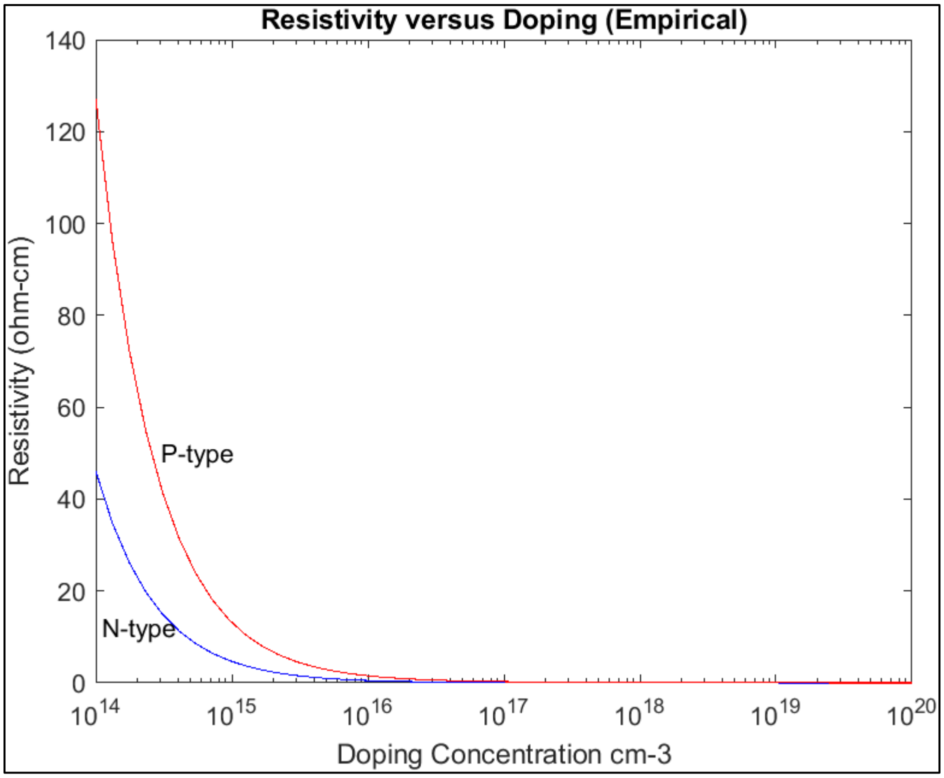
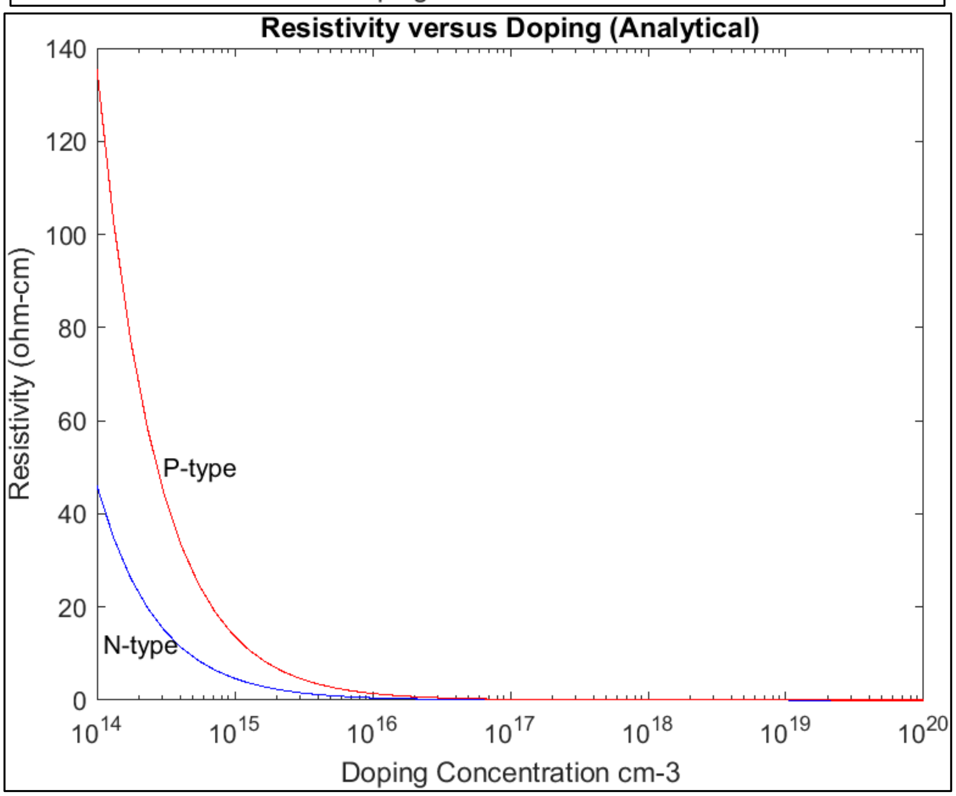
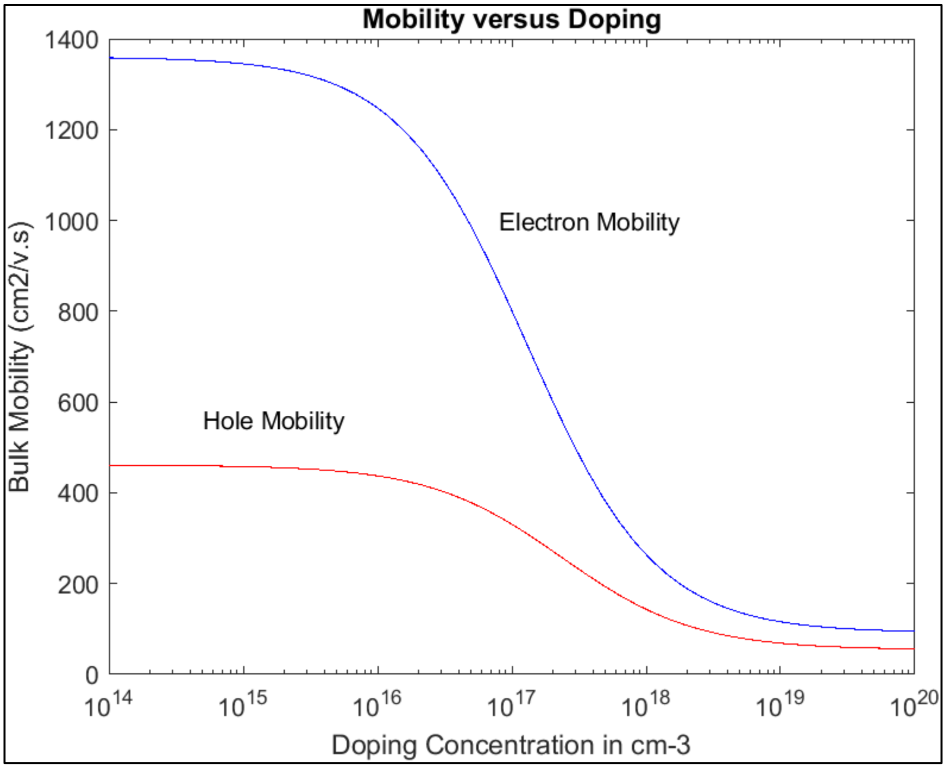
Part 1



Resistivity versus Doping (Empirical)
Resistivity (ohm-cm)
140
120
100
80
60
40
20
0
P-type
N-type
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
Doping Concentration cm-3

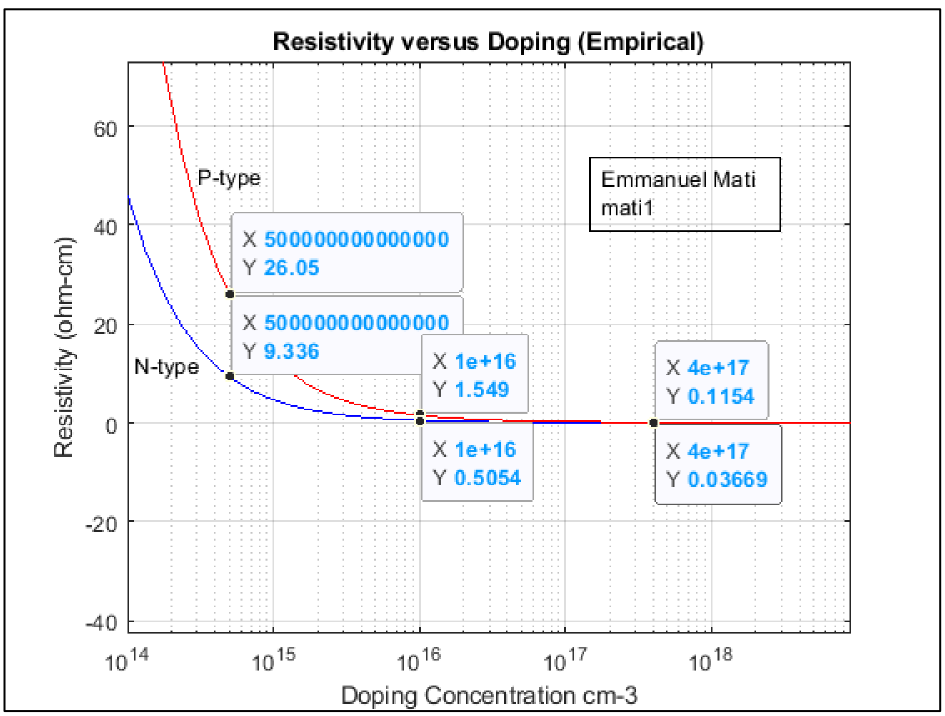


Resistivity versus Doping (Analytical)
Resistivity (ohm-cm)
140
120
100
80
60
40
20
0
P-type
N-type
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
Doping Concentration cm-3

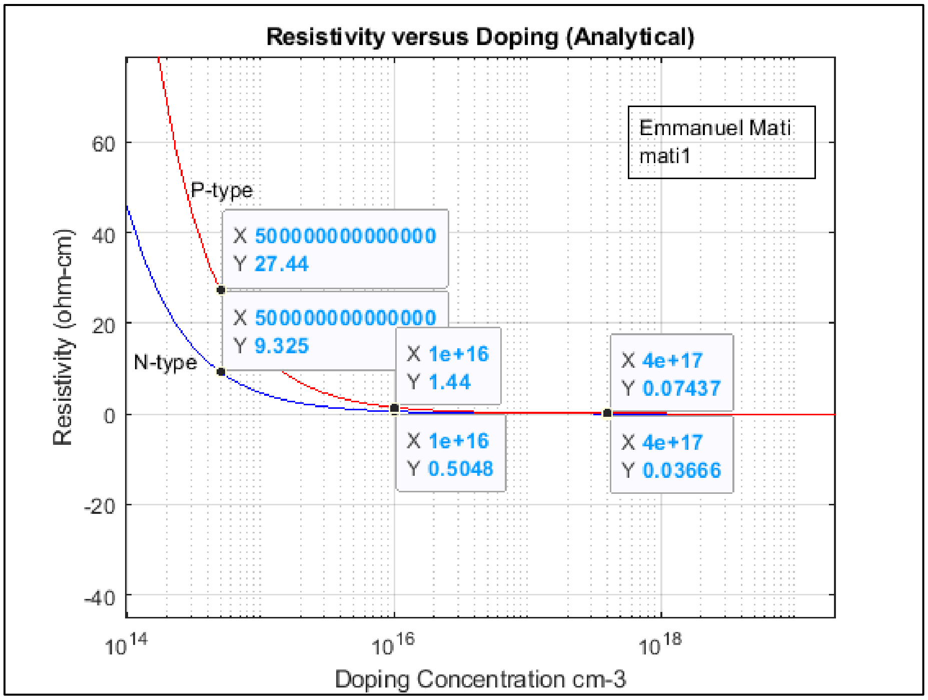


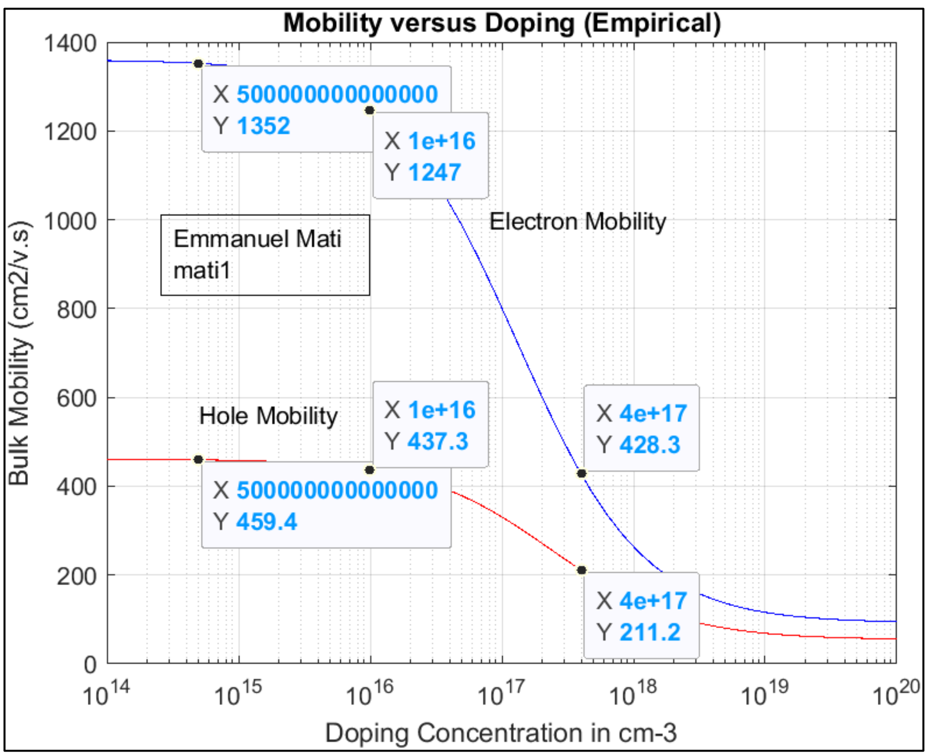
Mobility versus Doping
Bulk Mobility (cm2/v.s)
Electron Mobility
Hole Mobility
Doping Concentration in cm-3

Part 2

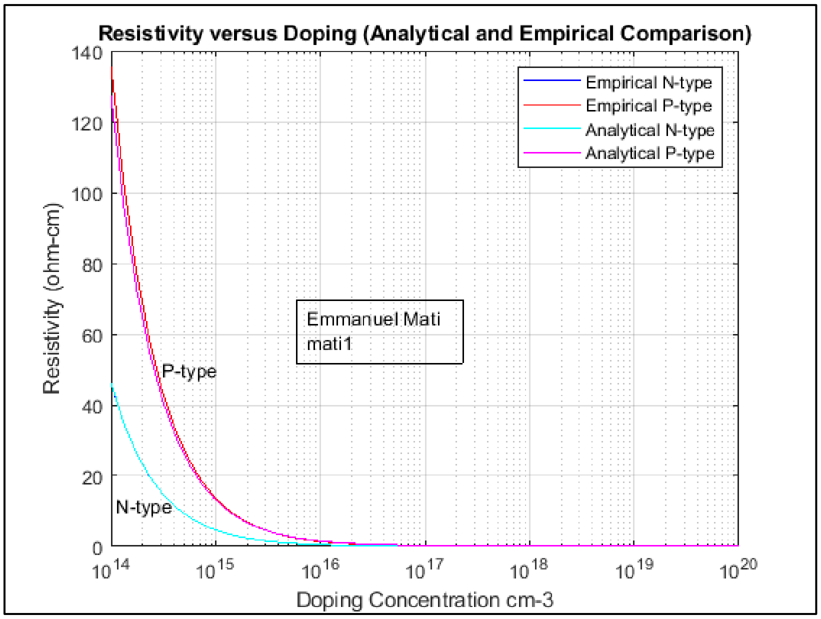


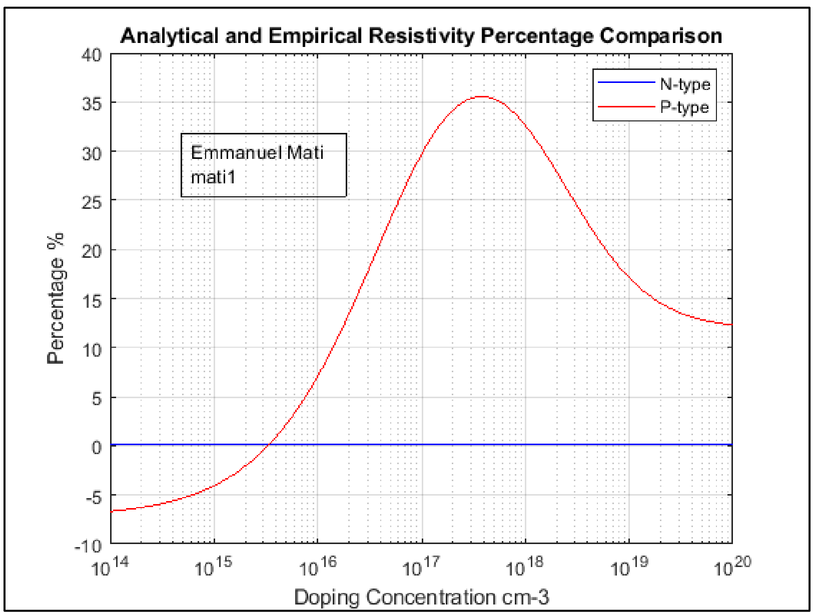
Resistivity versus Doping (Empirical)
Resistivity (ohm-cm)
P-type
N-type
Emmanuel Mati
mati1
X 500000000000000
Y 26.05
X 500000000000000
Y 9.336
X 1e+16
Y 1.549
X 1e+16
Y 0.5054
X 4e+17
Y 0.1154
X 4e+17
Y 0.03669
Doping Concentration cm-3


Resistivity versus Doping (Analytical)
Emmanuel Mati
mati1
P-type
N-type
X 500000000000000
Y 27.44
X 500000000000000
Y 9.325
X 1e+16
Y 1.44
X 1e+16
Y 0.5048
X 4e+17
Y 0.07437
X 4e+17
Y 0.03666
Resistivity (ohm-cm)
Doping Concentration cm-3


Mobility versus Doping (Empirical)
X 500000000000000
Y 1352
X 1e+16
Y 1247
Electron Mobility
Emmanuel Mati
mati1
Hole Mobility
X 1e+16
Y 437.3
X 4e+17
Y 428.3
X 500000000000000
Y 459.4
X 4e+17
Y 211.2
Bulk Mobility (cm2/v.s)
Doping Concentration in cm-3

Part 3





Command Window

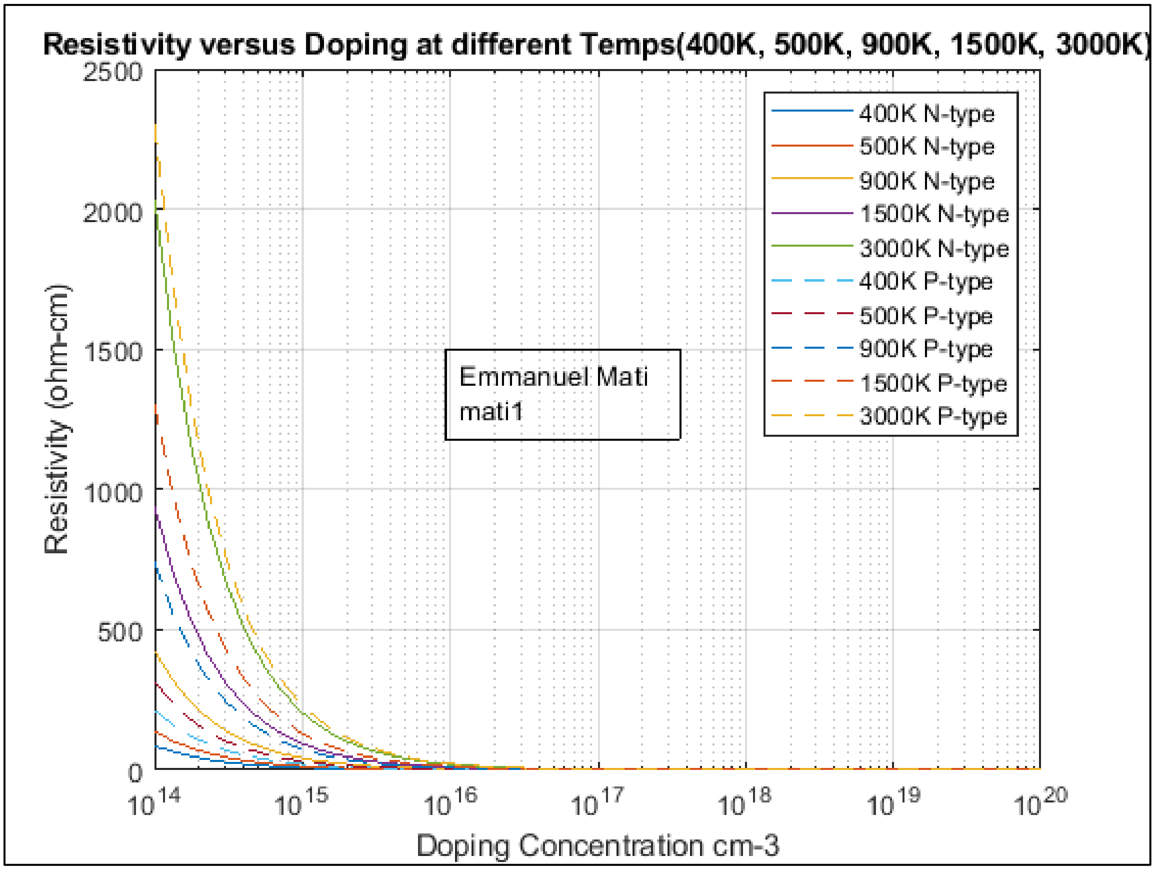
```
Empirical and Analytical concentration comparison percentages = (1 - (analytical/empirical)) * 100%

Using the values obtained in question 2, the N-type empirical values
are greater than the analytical values for doping concentrations of 5e14, 1e16, 4e17 by:
 0.117823%
 0.118718%
 0.081766%
respectively

Using the values obtained in question 2, the P-type empirical values
are greater than the analytical values for doping concentrations of 5e14, 1e16, 4e17 by:
 -5.335893%
 7.036798%
 35.554593%
respectively
>>
```

Code used to compare the empirical and analytical graphs

```
%Comparison Code
figure
%Graph Comparison
semilogx(N,rhon,'b',N,rhop,'r',N,rn,'c',N,rp,'m')
title('Resistivity versus Doping (Analytical and Empirical Comparison)')
ylabel('Resistivity (ohm-cm)')
xlabel('Doping Concentration cm-3')
grid on;
text(1.1e14,12,'N-type')
text(3.0e14,50,'P-type')
legend('Empirical N-type','Empirical P-type','Analytical N-type','Analytical
P-type')

%Displaying the formula that was used to compare the graphs
disp('Empirical and Analytical concentration comparison percentages = (1 -
(analytical/empirical)) * 100%');

%Percentage Comparison Code
figure
%Graph Comparison using the percentage values
xx = (1- rhon./rn)*100;
yy = (1- rhop./rp)*100;
semilogx(N,xx,'b', N, yy, 'r')
title('Analytical and Empirical Resistivity Percentage Comparison')
ylabel('Percentage %')
xlabel('Doping Concentration cm-3')
grid on;
legend('N-type','P-type')

%Comparing specific n-type points from question 2
e1 = (1-(9.325/9.336))*100;
e2 = (1-(0.5048/0.5054))*100;
e3 = (1-(0.03666/0.03669))*100;
fprintf('\nUsing the values obtained in question 2, the N-type empirical
values \nare greater than the analytical values for doping concentrations of
5e14, 1e16, 4e17 by:\n %f%% \n %f%% \n %f%%\nrespectively\n',e1, e2, e3)

%Comparing specific p-types points from question 2
a1 = (1-(27.44/26.05))*100;
a2 = (1-(1.44/1.549))*100;
a3 = (1-(0.07437/0.1154))*100;
fprintf('\nUsing the values obtained in question 2, the P-type empirical
values \nare greater than the analytical values for doping concentrations of
5e14, 1e16, 4e17 by:\n %f%% \n %f%% \n %f%%\nrespectively\n',a1, a2, a3)
```

The code directly above was used to compare the graphs in 3 different ways. The first way was by using the graph titled "Resistivity versus Doping (Analytical and Empirical Comparison)" to overlap the empirical and analytical plots which give a better perspective on how closely related the different functions were to one another. From that graph, we can see that the n-type values are very closely related and visually speaking, look identical while the empirical p-type plot seems to have slightly larger resistivities than the analytical p-type plot. The second way and arguably the best way we can see how different the empirical and analytical plots are was by plotting the percentage of how close the analytical values are to the empirical. The equation used is as follows (1 - (analytical/empirical)) * 100%). Using this equation and observing the graph, we can see that as the doping concentration increases, the difference in p-type resistivity in the empirical and analytical plots grows greater when using the empirical values as a reference. Meanwhile, the n-type resistivities remain essentially the same regardless of the doping concentrations. Lastly, we compared the data points we marked in question two which can be seen in the command window. In doing so we can see that the n-type values are nearly identical while the p-type empirical values grow greater than the analytical values. While using the empirical plot as a reference, we see that the empirical p-type plot becomes as much as ~35% than that of the analytical plot.

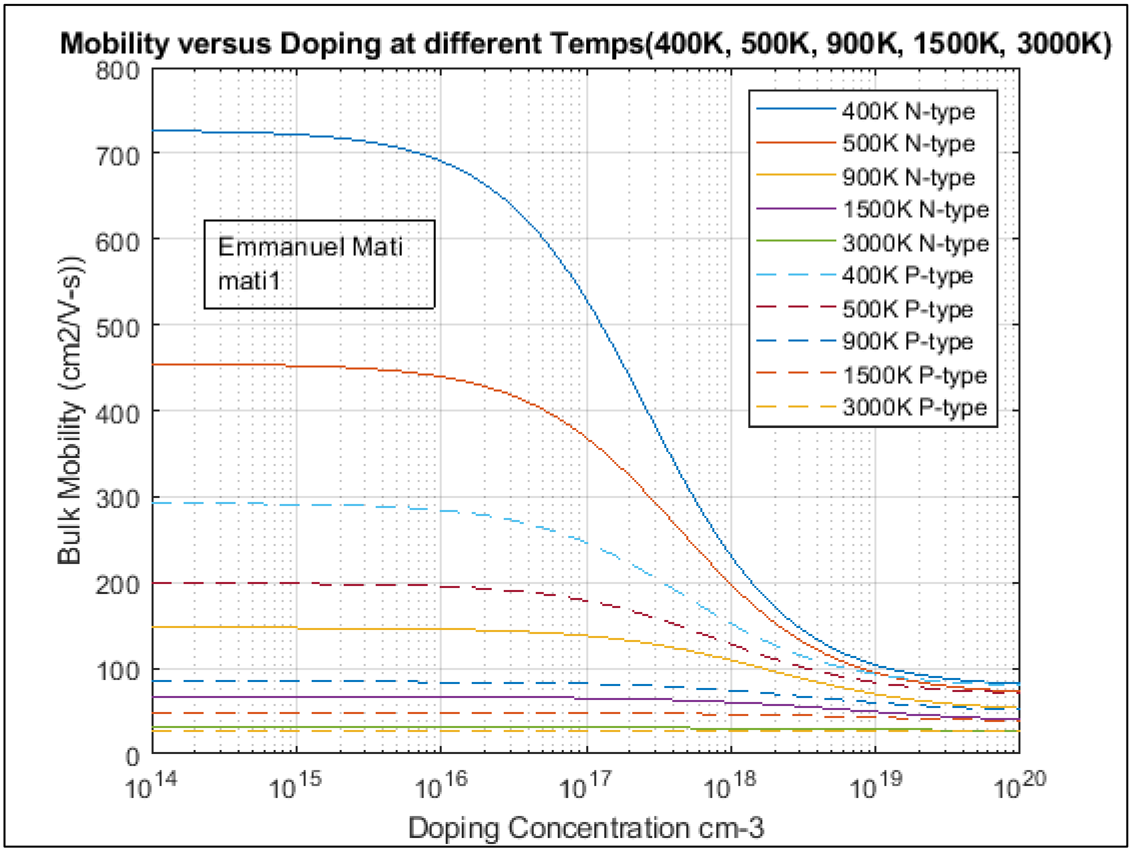
Part 4



Modified code can be found in attached MATLAB file

After modifying the code to plot the resistivity graphs for 5 different temperatures in the same window, it can be observed that resistivity at lower doping concentrations is increased at higher temperatures. At lower temperatures, the resistivity remains low and the separation between n-type and p-type plots of the same temperature becomes greater. Interestingly enough, both p-type and n-type plots eventually reach zero resistivity once the doping concentrations reach a value of around $10^{15}cm^{-3}$ to $10^{16}cm^{-3}$.

Part 5



Modified code can be found in attached MATLAB file

After modifying the code to plot the mobility graphs for 5 different temperatures in the same window, it can be observed that mobility at lower temperatures is increased. This is especially true at lower doping levels. Moreover, it can be said that the gap between the n-type and p-type mobilities decreases at higher temperatures while increasing at lower temperatures. This can especially be noticed when looking at the 400K n-type and p-type values where the n-type values are significantly greater than their p-type counterparts at lower doping concentrations. Interestingly enough, all of the mobilities begin to converge at very high doping levels regardless of temperature.

Part 6

Summary

To summarize our observations above, we can say that at higher temperatures, resistivity increases and mobility decreases. From observing the graphs, we can say that once doping concentrations reach high levels, both n-type and p-type mobility and resistivity concentrations converge to zero. To best observe the behaviour of semiconductors, it is recommended to observe them at lower doping levels as their behaviours are more amplified and noticeable. From observing the differences between the empirical and analytical resistivity percentage comparison graphs, we can say that the n-type values are nearly identical and that both are acceptable to use. The same cannot be said about the p-type values as the analytical and empirical values had moments where their separation was too great for the empirical results to be relied upon.

Conclusion

To conclude, we can say that using the empirical and analytical equations is acceptable if we are concerned with fining the n-type resistivity values. The same cannot be said about the p-type values as they had large differences in resistivity as shown in part 3 where we compared their percentages. Thus, it is better to use the analytical values for analyzing p-type resistivity. We can also conclude that increasing temperature will mean the semiconductors have higher resistivity at similar doping concentrations. Inversely, at lower temperatures, semiconductors have more mobility when comparing them at the same doping concentrations. It is also important to note that at higher doping levels the mobility and resistivity concentrations converge to zero and diverge at lower doping concentrations.