Department of Electronics

ELEC 4700

Assignment 3

Monte-Carlo / Finite Difference Method

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1. *Introduction*

The third assignment of the semester involves the application of principles and concepts associated with Monte Carlo modelling of electrons and Finite Difference Method where the two simulators were coupled in order to understand the operation of device accompanied by extraction of parameters. The assignment comprises of 3 modules each requiring the application of the two techniques learned in the assignments 1 and 2 to solve the problems.

The calculations, code and atomistic simulations required for this assignment were completed with the aid of MATLAB. The report discusses the techniques applied and results obtained after the completion of the assignment.

2. *Results and Discussion*

The assignment consisted of 3 sections requiring MATLAB programming for each. The sections covered in the assignment are:

- Modification of the Monte -Carlo simulator from assignment 1
- Modification of the Finite Difference Method to determine the electric field to be applied to the Monte -Carlo conditions
- Coupling of Simulators for analysis of the device parameter extraction.

The results obtained for each part have been discussed in this report.

1. Modification of The Monte – Carlo Simulator

The first segment of the assignment involved the determination of the electric field on the electrons of a rectangular region of dimensions L x W with a voltage of 0.1 V being applied in the x-direction. The electric field was calculated to be 5 V/nm. The Force on the electrons can be calculated using the formula:

$$F = E \times C$$

where C is $-1.60217662 \times 10^{-19}$ Coulombs.
The Force was calculated to be 8×10^{-14} N.
The acceleration can be calculated using the formula:

$$a = F/m$$

where m = 9.10938356e-31*0.26
Therefore, the acceleration was calculated to be -33.3 nm/s.

The obtained value of acceleration was utilized to revise the velocity of the electrons at each time step. The code was also modified to allow the electrons to respond to the static electric field in the x and y directions. The plot shown in Figure 1 was obtained when the modifications were made.

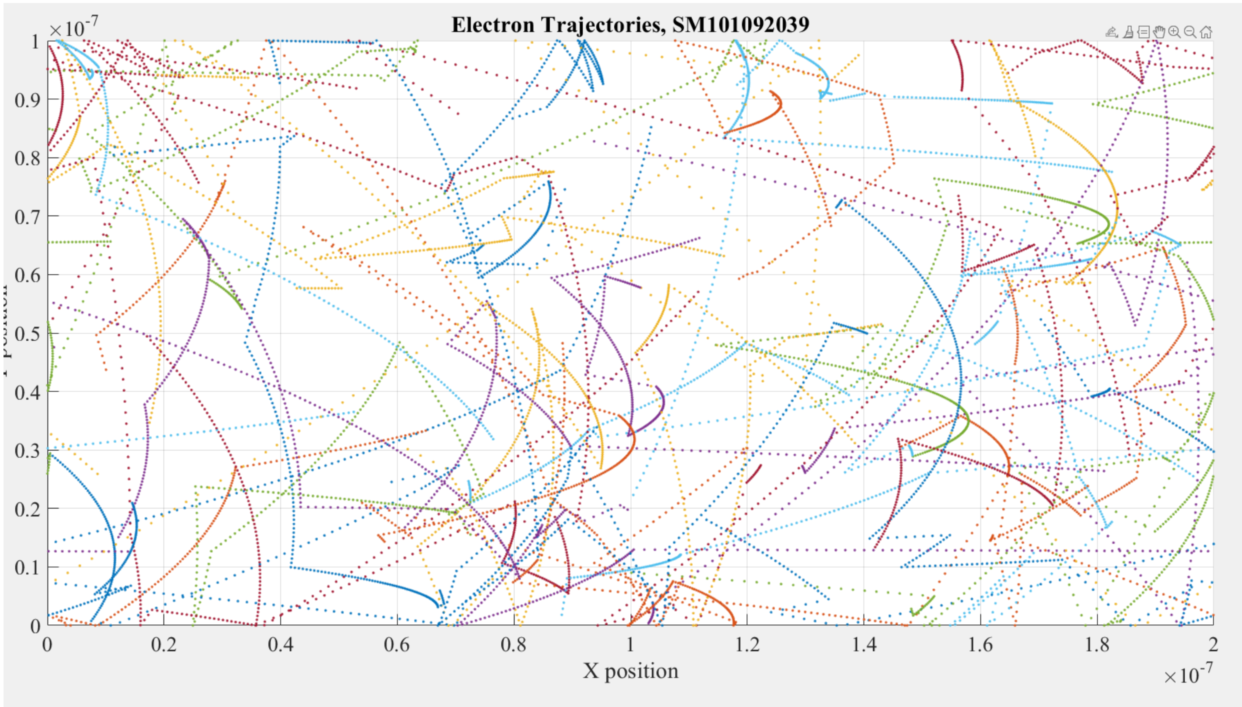

Figure 1: Plot of Electron Trajectories

The relationship between the electron drift current and average carrier velocity is given by the equation:

$$J = qnV$$

where is J is the current density and V is the average velocity of the electrons. The relationship was utilized to generate a plot of variation of current over time. The plot shown in Figure 2 depicts the variation of current with time.

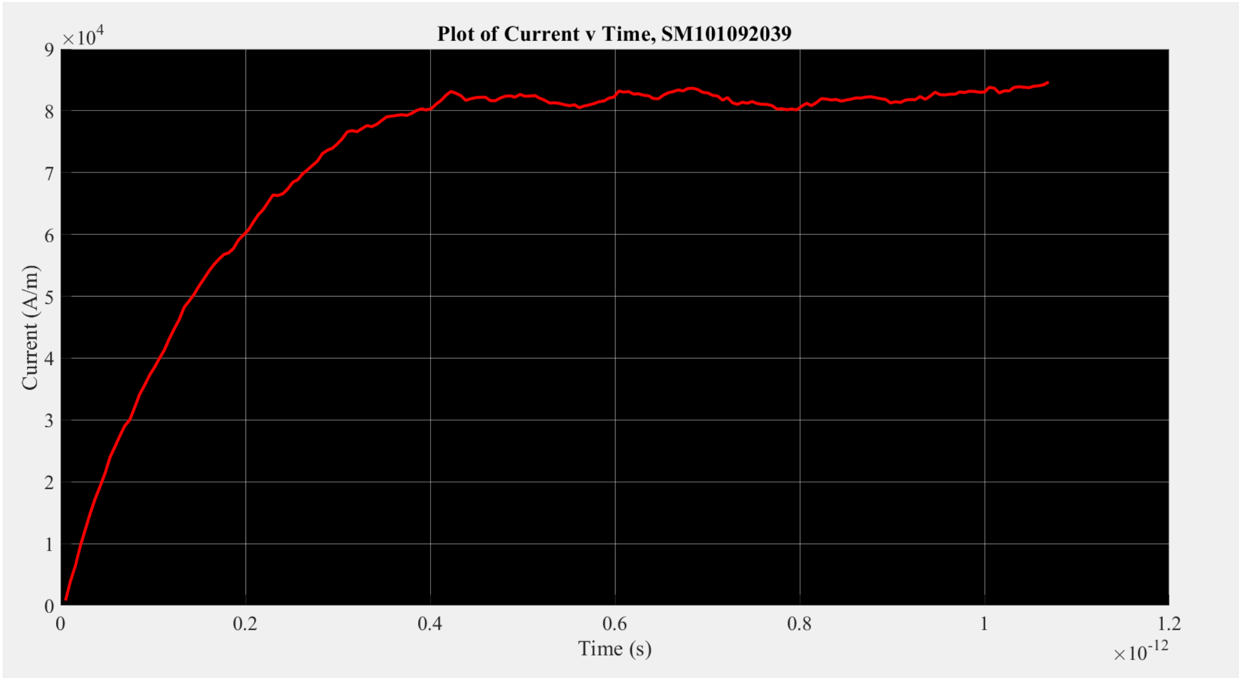

Figure 2: Plot of Variation of Current Over Time

From the plot shown in Figure 2, it can be observed that the current density varies directly with the passage of time. It can also be concluded that the changes in current are directly proportional to the changes in the velocity.

The density and temperature map of the electrons was also generated. The plots shown in figure 3 and 4 depict the density and temperature maps, respectively.

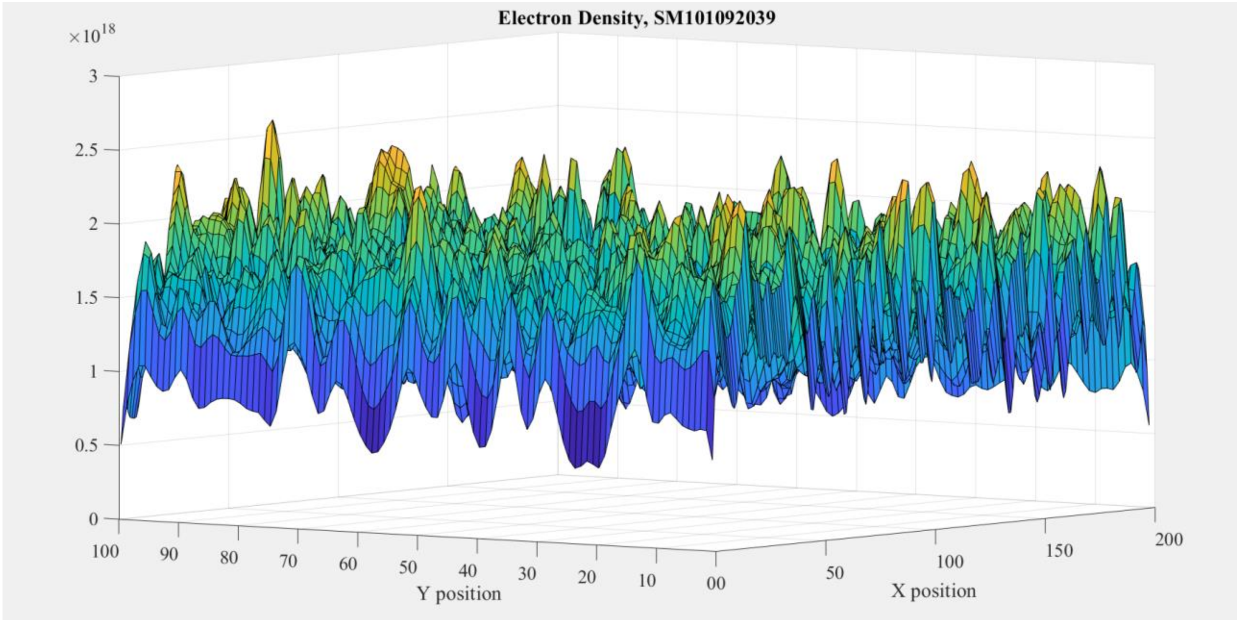

Figure 3: Electron Density Map with V_x = 0.1V.

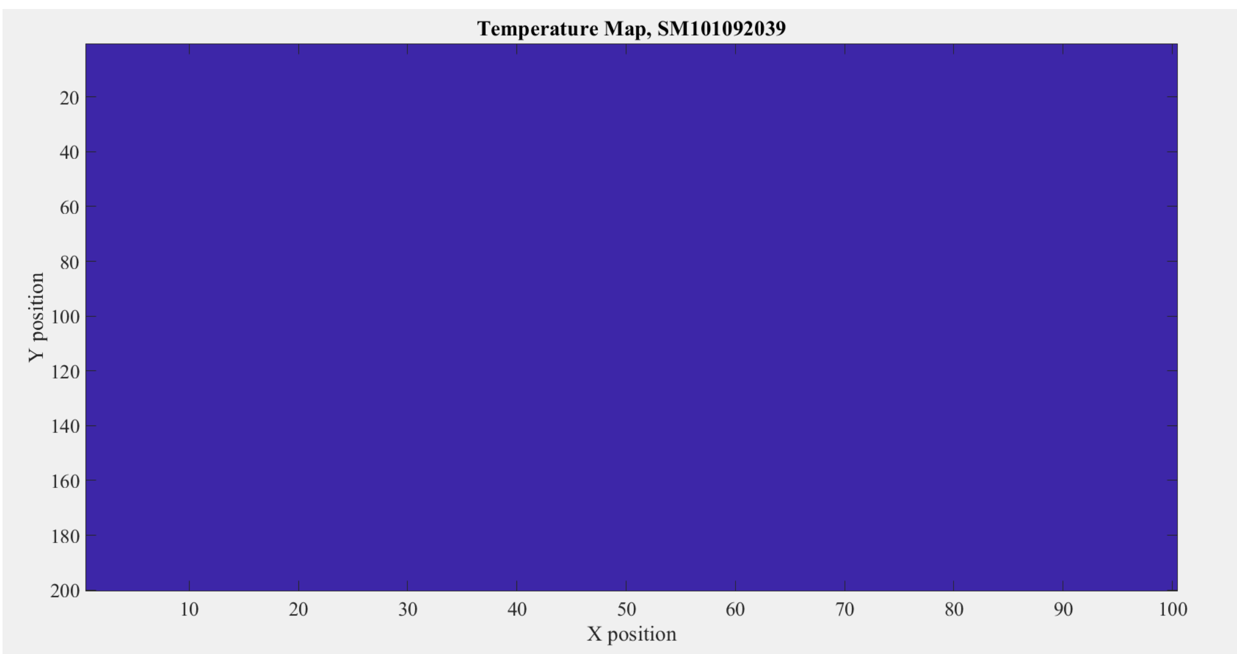

Figure 4: Temperature Map with V_x = 0.1V.

The analysis of the data obtained in this section allowed the determination of the electric field, force, acceleration, and the current variation over time. It was observed that the velocity of the particles changes with the change in the electric field as a stronger field led to an increase in the velocity.

2. <u>Application of Finite Difference Method</u>

The second segment of the assignment involved utilization and modification of the finite difference method code developed for assignment 2. The technique was utilized to solve for electric field and the resultant value was to be applied to the Monte-Carlo setup for simulation.

The calculated potential was plotted and the figure 5 depicts the potential of the bottle neck solved through the Finite Difference method.

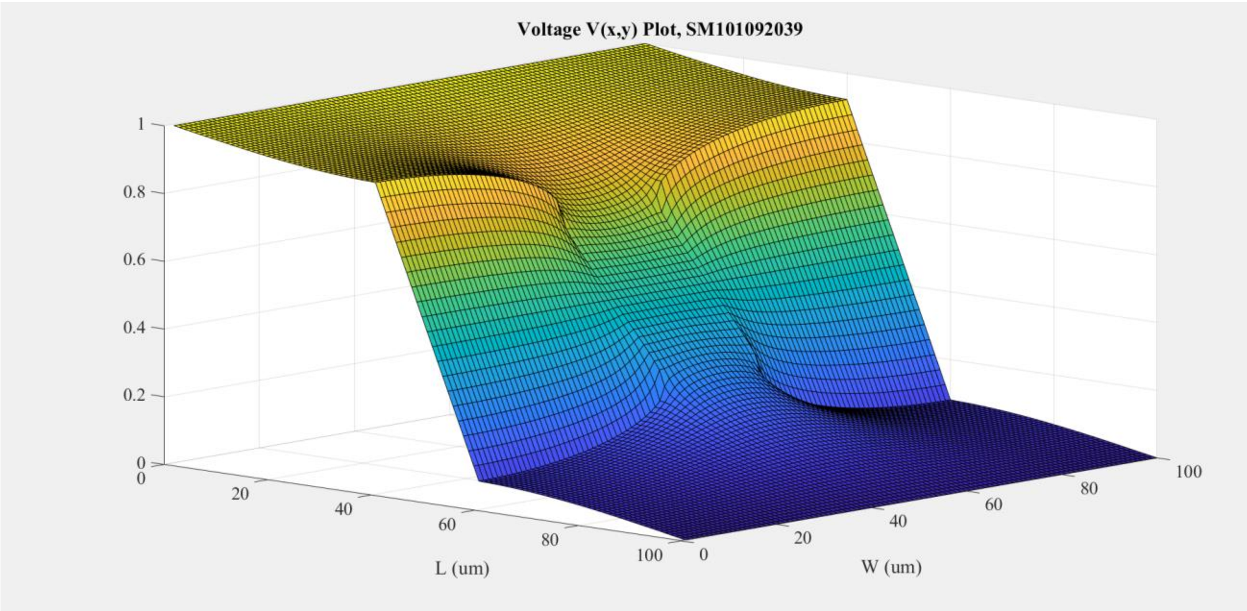

Figure 5: Voltage Plot with bottle neck regions.

The electric field in the region was calculated and plotted. The graph shown in Figure 6 depicts the electric field of the region with bottle neck structures.

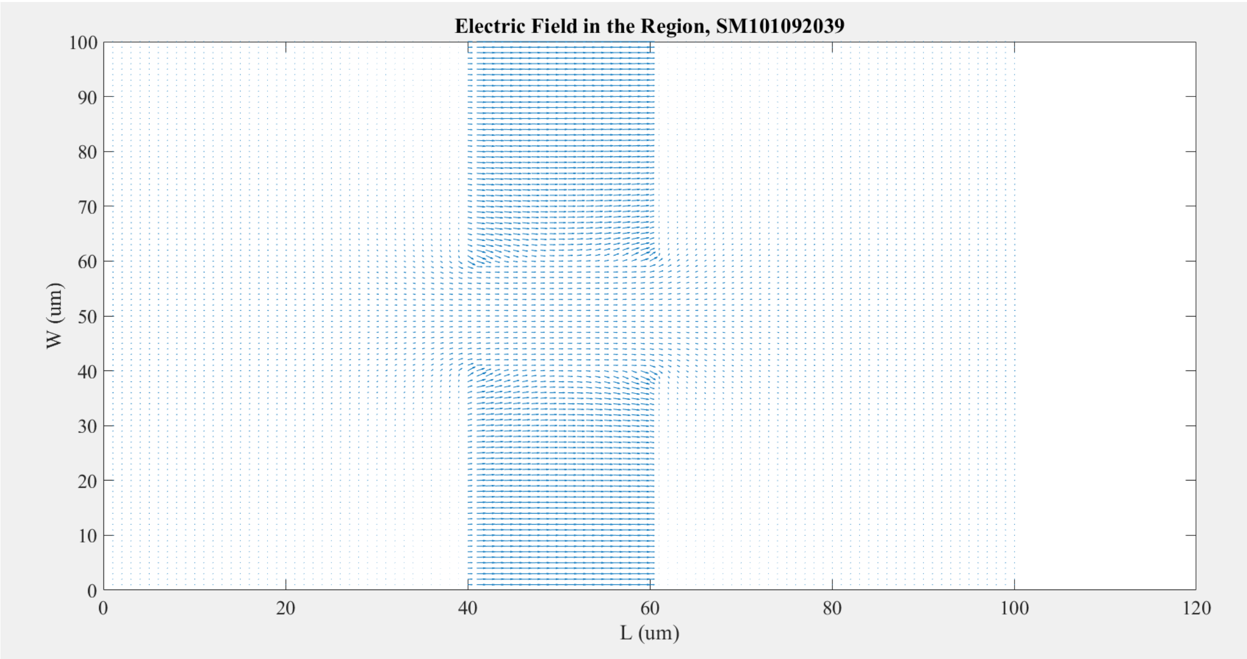

Figure 6: Current Density Plot of the region.

The obtained parameters were then applied to the Monte -Carlo Simulator. The electric field determined for the bottle neck through the Finite Difference method was then applied and the plot shown in Figure 7 was obtained.

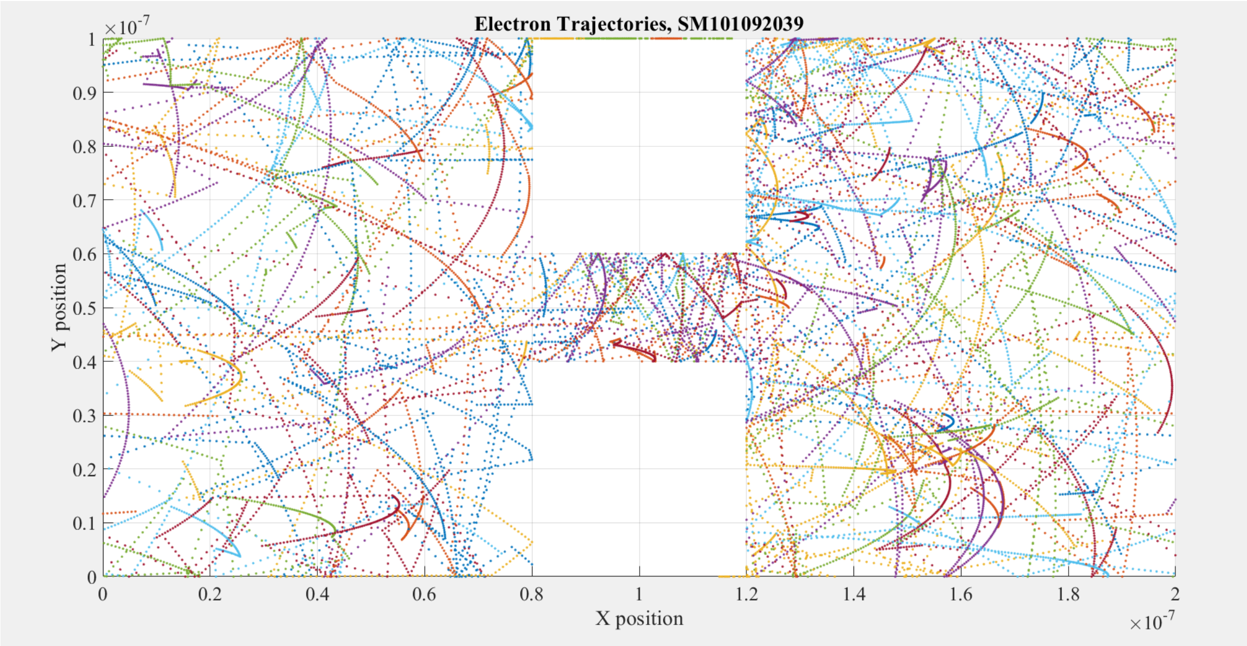

Figure 7: Electron Trajectories with Bottle neck regions.

From the plot shown in Figure 7, it can be observed. that the particles experience higher acceleration within the bottle neck. This is due to the presence a of a greater electric field within the bottle necks which tends to quickly force the electrons out of the region. A higher concentration of electrons be observed around the the region within higher potential on the right side.

3. <u>Coupling of the Simulators</u>

The final module of the assignment the coupling of the two simulators to analyze the device and extract simple parameters. The first two modules involved fine tuning and configuration of the two simulators for coupling which would be utilized for testing the device's operational parameters.

The density map for the device generated and the behavior at 0.8 V was analyzed. The plot shown in Figure 8 density plot of when a voltage of 0.8 V was applied.

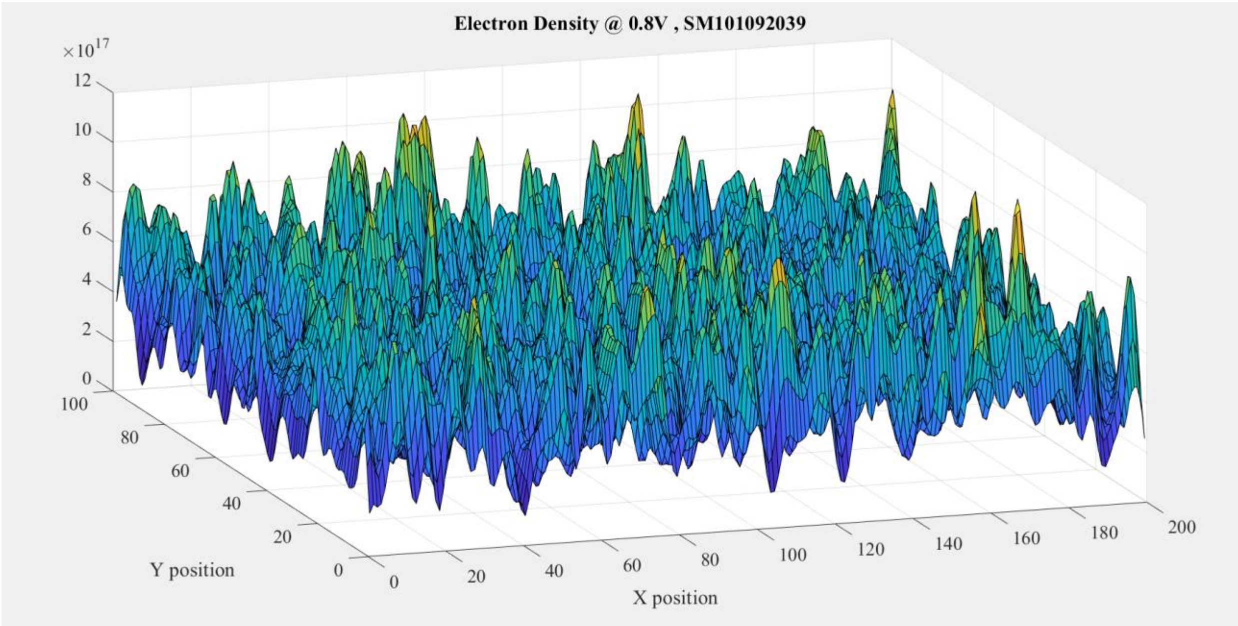

Figure 8: Density map at 0.8 V.

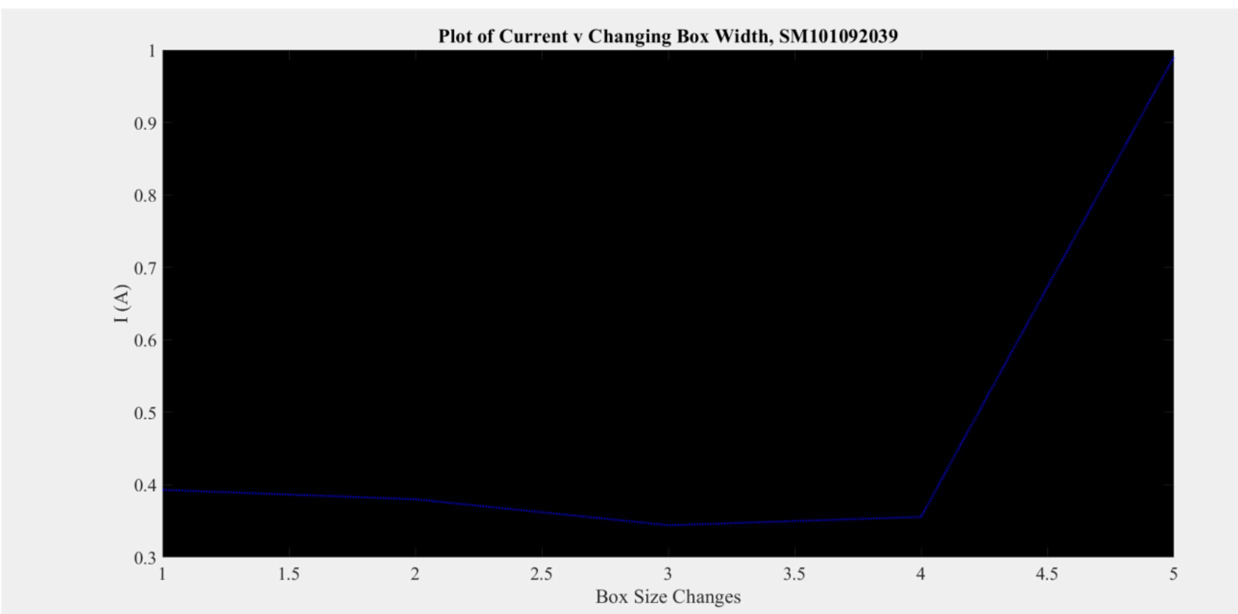

Figure 9: Plot of Current versus Varying Box Sizes.

Finally. The variation of current with respect to the changing bottle neck parameters was also studied. The plot shown in Figure 9 depicts the variation of current in the region when the bottle neck widths are subject to a change.

From the plot shown in Figure 10, it can be observed that the as the width of the bottle necks increases the current tends to experience a sharp increase after a certain a value. This could be accounted due to the fact that as the width increase, the electric field increases which in turn increases the acceleration of a higher concentration of electrons through the region.

3. Conclusion

The primary objective of the assignment was to combine the Monte -Carlo techniques with the Finite Difference method. The coupling of the two simulators provided an infrastructure for the analysis of the device and the extraction of associated parameters. The assignment provided a great opportunity to experiment and understand the application of Finite Difference Method to generate an electric field for the Monte-Carlo Simulations. The code was assembled, and a separate file has been prepared which will be attached with the report and submitted on GitHub as well as CuLearn.