CARLETON UNIVERSITY

DEPARTMENT OF ELECTRONICS

ELEC 4700 A

Assignment 3

Author:
Denis SHLEIFMAN
101001778

Professor:
Tom SMY

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Contents

1 Introduction

In this assignment, the bottle neck simulation from assignment 1 was revisited, with the addition of acceleration from the electric fields simulated in assignment 2.

2 Question 1

For this question, the particle simulator from assignment 1 was modified. This modification included the addition of a voltage drop across the box. This voltage was used to add an acceleration onto the particles. To simplify the simulation, the electric field was assumed constant across the box. The sections below show the results of this change to the simulator.

2.1 Question 1a

The equation that relates voltage to electric field is shown below in Equation 1.

$$\vec{E} = -\frac{dV}{dx} \tag{1}$$

If there is a voltage drop of $\Delta V = 0.1\,\mathrm{V}$ across the x axis and the length of the box is $\Delta x = 200\,\mathrm{nm}$, the resulting electric field (as per Equation 1) is $\vec{E} = 0.5\,\frac{V}{\mu\mathrm{m}}$.

2.2 Question 1b

The electric force equation is shown below in Equation 2.

$$\vec{F} = q\vec{E} \tag{2}$$

Where q is the charged particle. In this case the particle is an electron therefore $q = -1.602 \cdot 10^{-19}\,\mathrm{C}$. Note that the charge is negative because electrons are negatively charged. Using the electric field calculated in Section 2.1 with the charge of the electron yields a force on each electron of $\vec{F} = -80.11\,\mathrm{fN}$.

2.3 Question 1c

The equation for the acceleration on each particle is shown in Equation 3.

$$\vec{a} = \frac{\vec{F}}{m} \tag{3}$$

The particles used in this case are electrons. The effective mass of the electron in this case is $m_{eff} = 2.368 \cdot 10^{-31} kg$. The resulting acceleration per particle is $a = -3.382 \cdot 10^{-17} \, \frac{\mathrm{m}}{\mathrm{s}^2}$.

Applying this acceleration to each individual particle, and re-running the particle simulation from assignment 1 yields Figure 1 below.

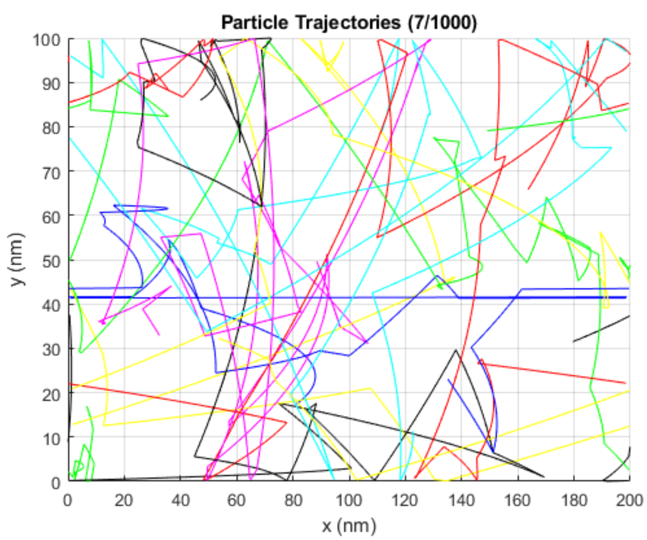

Figure 1: Constant E Field Particle Traces

As seen in the plot above, the constant acceleration has added a curvature into the particle trajectories. This is as expected.

2.4 Question 1d

The relationship between the electron drift current density and the average carrier velocity is shown below in Equation 4.

$$J_x = env_{dx} \tag{4}$$

Where J_x is the drift current in the x direction, e is the elementary charge, n is the electron concentration and v_{dx} is the electron velocity drift velocity in the x direction.

The simulation was used to produce a plot of the current versus time. The electron concentration was assumed to be $10^{15}\,\text{cm}^{-2}$. The resulting plot is shown in Figure 2 below.

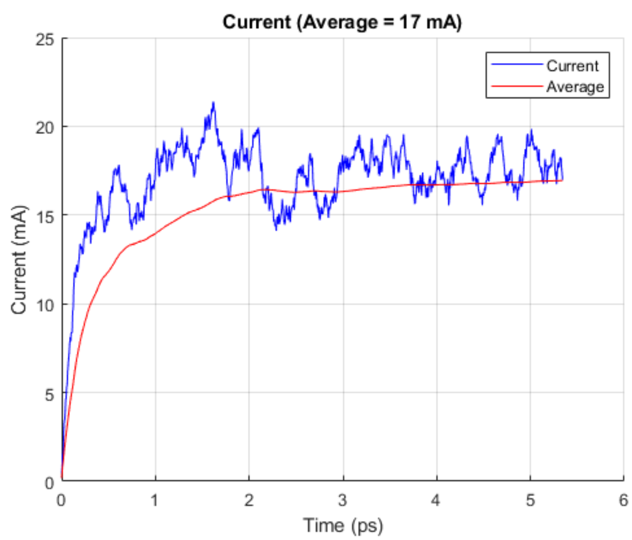

Figure 2: Constant E Field Transient Current Plot

The average current after the end of the simulation is 17 mA. Over time the current increases and the stabilizes. This is to do with the fact that the velocity increases due to the applied voltage, however it is limited by the scattering of the particles, that reduces the velocity. After some time, these effect balance causing a stabilization of the current.

2.5 Question 1e

After the simulation is complete, the average particle and temperature distribution was generated. These plots are shown in Figure 3 and Figure 4 below.

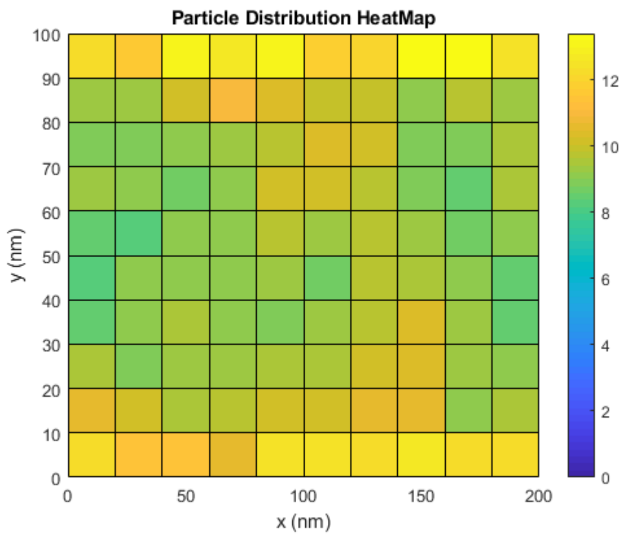

Figure 3: Constant E Field Particle Distribution

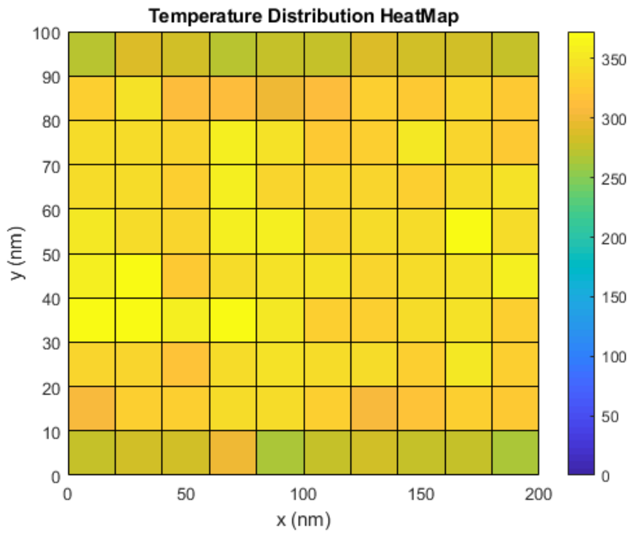

Figure 4: Constant E Field Temperature Distribution

As seen in the plots above, there tends to be more particles near the top and bottom edges however the particles in away from the edges tend to be hotter.

3 Question 2

For this section the code from assignment 2 was used to calculate the voltage and electric field (with the bottleneck) across the region. The results are in the sections below.

3.1 Question 2a

The voltage across the board is shown in Figure 5 below.

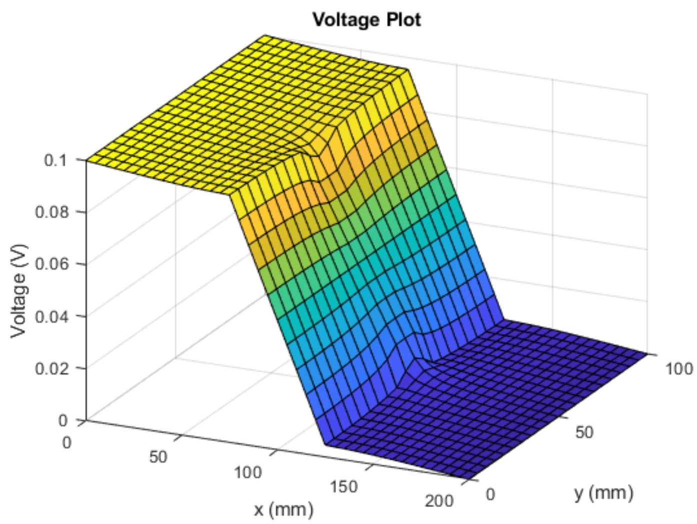

Figure 5: Potential Across the Board

3.2 Question 2b

The electric field across the board is shown in Figure 6 below.

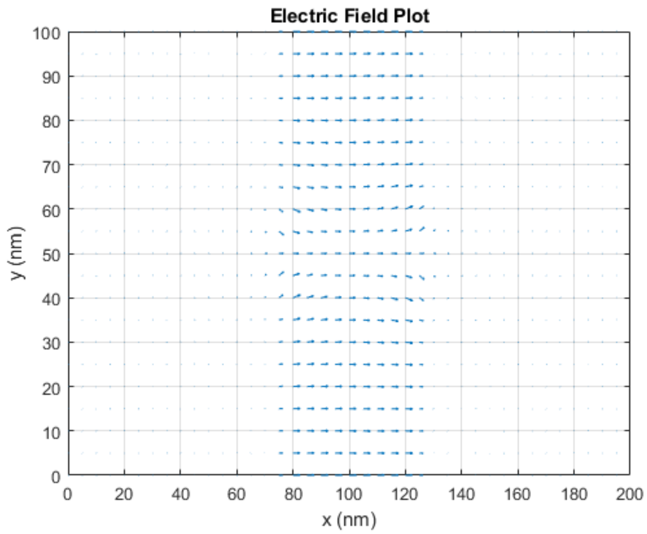

Figure 6: Electric Field Across the Board

4 Question 3

In this section the electric field generated in Section 3 was combined with the particle simulator from Section 2. The bottle neck boundary conditions from question 1 were also added.

4.1 Question 3a

The resulting particle trajectories from this simulation are shown in Figure 7.

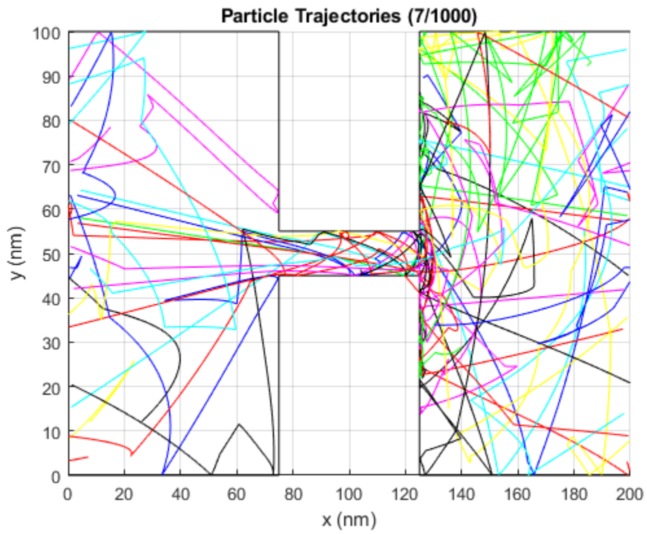

Figure 7: Non-Constant E Field Particle Trajectories

As seen in the figure above, the particles seem to bunch up on the right side. This is because the acceleration on the particles causes them to over time move left. These particles then wrap around and get stuck at the bottle neck.

4.2 Question 3b

After running the simulation for 1000 iterations (with a 0.8V potential difference across x), the particle and temperature distributions are found to be as shown in Figure 8 and 9 respectively.

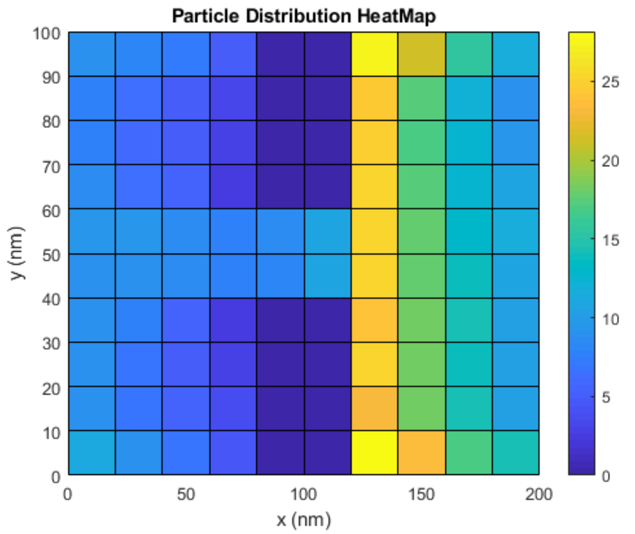

Figure 8: Non-Constant E Field Particle Distribution

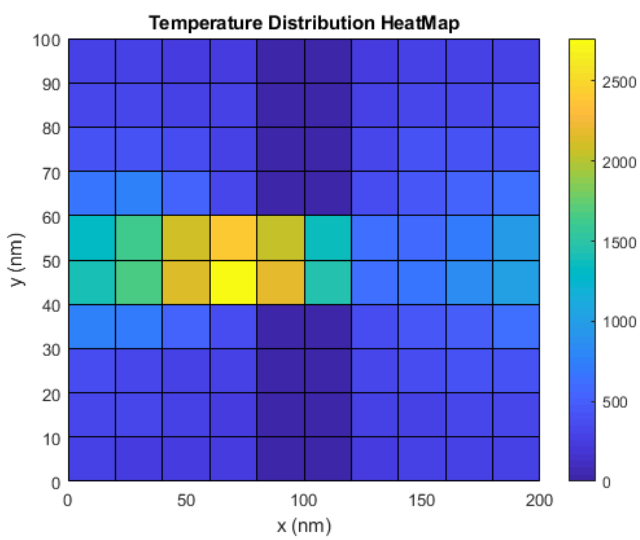

Figure 9: Non-Constant E Field Temperature Distribution

As seen in the plots above, the particles seem to congregate near the right edge of the bottle-neck. This is most probable because the acceleration is changing the direction of movement of all the particles to move left across the board. These particles then wrap around and most of them hit this boundary of the bottle neck. The particles that hit the boundary will bounce off, however, the acceleration will cause them to return eventually and hit again.

The temperature of the plot is greatest on the left side of the bottle neck. This means that the particles are moving the fastest in this region. This is most likely because as seen in Figure 6, the electric field is highest across the bottle neck. The higher electric field means that the acceleration across this region will be highest. This means that particles that end up going through the bottleneck will in general be accelerated very quickly and will exit the bottle neck at very fast speeds. These higher speeds mean that the temperature in these regions will be higher.

4.3 Question 3c

A method of improving this simulation is to better implement the collisions between particles. One method of implementing this is to check when individual particles collide. Though this method would be the most accurate, this method is very computationally intensive. A simpler method is to calculate the actual mean free path based on the density of the particles across the board. This value can be used to determine the probability of a particle scattering.

Another method of improving this simulation is to account for jerk. Currently, in the simulation, the initial acceleration of each particle is calculated by interpolating the electric field at each point where a particle exists. This initial acceleration is considered to be constant across the iteration, and recalculated for each new iteration. This does not account for jerk. For most of the locations across the board this does not matter much as the change in the acceleration is not very large. The only locations where it may matter is at the entrance and exit of the bottle-neck. At these locations the jerk is the largest.

References

[1] *Society for Neuroscience, Ottawa Chapter* [Online] Available FTP: http://cdn.sfn-ottawa.ca Directory: images/misc File: cu-logo-vertical.png?1415290081