ELEC 4700
Assignment 3

Evan Morhart, 100973017

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1 Monte-Carlo Without Bottle-Neck

1.1 Electric Field Through Sample

Applying a voltage of 0.1 V across the x-dimension of the silicon sample will induce an electric field in the sample. Given that the electric field is the gradient of voltage applied through the sample, and that the electric field is assumed to be constant through the sample, the electric field can be found simply as

$$\vec{E} = \frac{dV}{dx} = \frac{0.1V}{200nm} = 500\frac{kV}{m}\hat{i} \tag{1}$$

1.2 Force on Electron

The force on an electron due to the electric field found in the previous section is

$$\vec{F} = qE = (1.602 * 10^{-19}C)(500\frac{kV}{m}) = 8.01 * 10^{-14}N\hat{i} \tag{2}$$

1.3 Electron Acceleration

The acceleration due to the force from the electric field can be calculated using Newton's Laws of motion using the effective mass of the electron as follows

$$a = \frac{F}{m} = \frac{8.01 * 10^{-14}N}{(0.26)9.10938356 * 10^{-31}kg} = 3.382 * 10^{17}\frac{m}{s^2} \tag{3}$$

The trajectories for electrons travelling through the silicon sample with an electric field can be found in Figure 1.

1.4 Electron Drift Velocity

The drift current density of electrons in a material is described using Eq. (4).

$$\vec{J} = qn\mu_n\vec{E} \tag{4}$$

Where q is the fundamental charge, n is the number of electrons, μ_n is the mobility of the charge carriers (in this case electrons), and $\vec{E}$ is the electric field in the system. The product of the mobility and the system's electric field is also the velocity of a charge carrier in the system. Given that the current system only has an electric field in the X-direction and that that field is constant, the current density as a function of the particle velocity is

$$\vec{J} = qn\vec{V} \tag{5}$$

A plot of the drift current as a function of time in the silicon sample can be found in Figure 2.

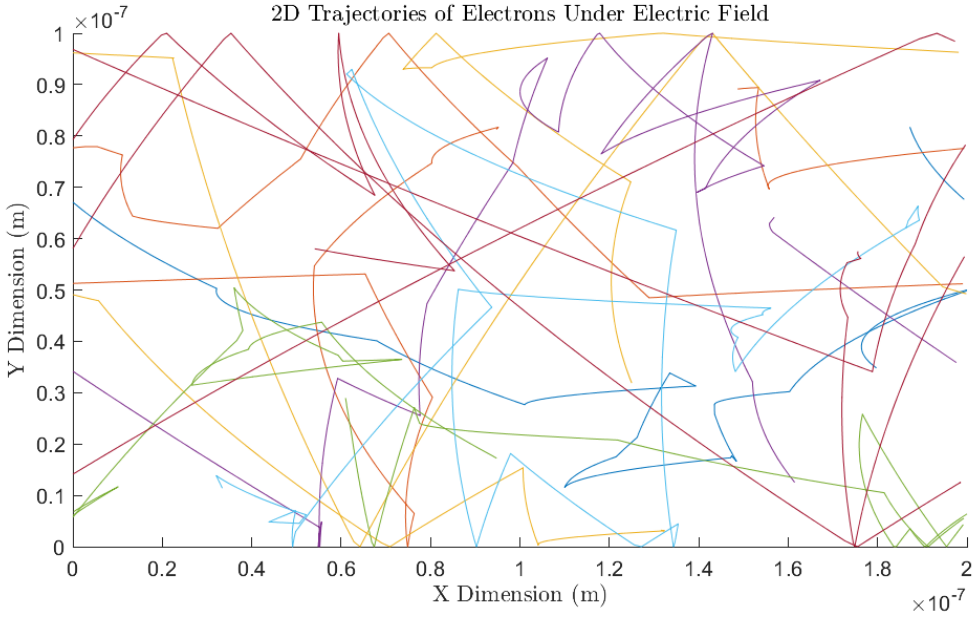

Figure 1: Simulated 2D electron trajectory of 7 electrons travelling through a silicon sample. Simulated to experience both scattering and acceleration due to an electric field. The voltage applied was increased to 0.2 V to exaggerate trajectory curvature.

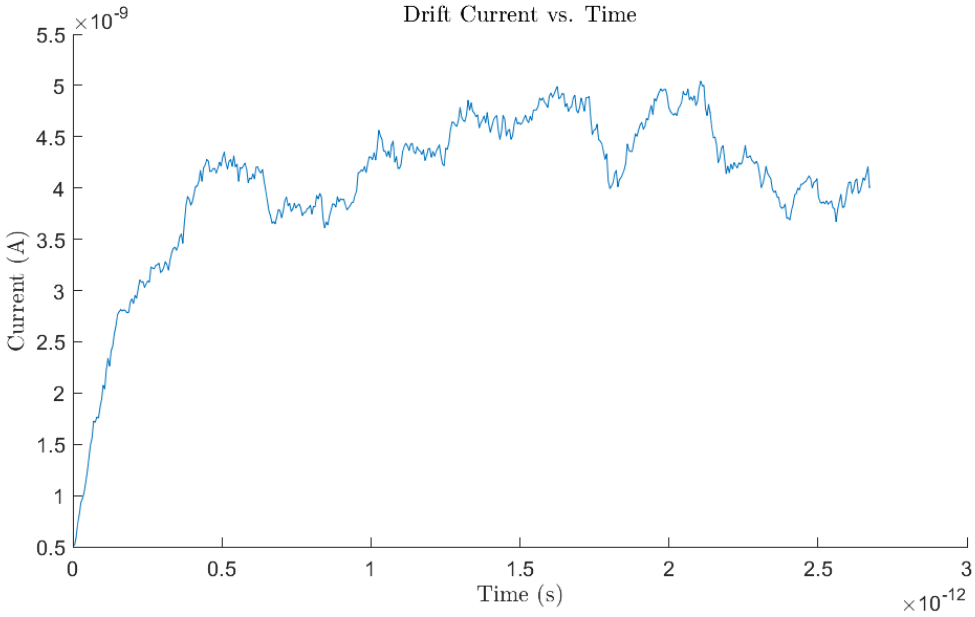

Figure 2: Drift current vs. time for a simulated silicon sample, for 500 electrons, 500 cycles. 0.2 V Applied across X-axis.

It is interesting to note that early cycles of the simulation show a gradually increasing drift current before it levels out and remains relatively constant for the remaining cycles. This is likely due to the random assignment of velocities at the initialization of the simulation. This random assignment means that the velocities essentially cancel, leaving no overall current. As the field begins to accelerate particles in the X direction, the overall average velocity changes according to the applied electric field.

1.5 Electron Mapping

The electron density map in this simulated system can be found in Figure 3.

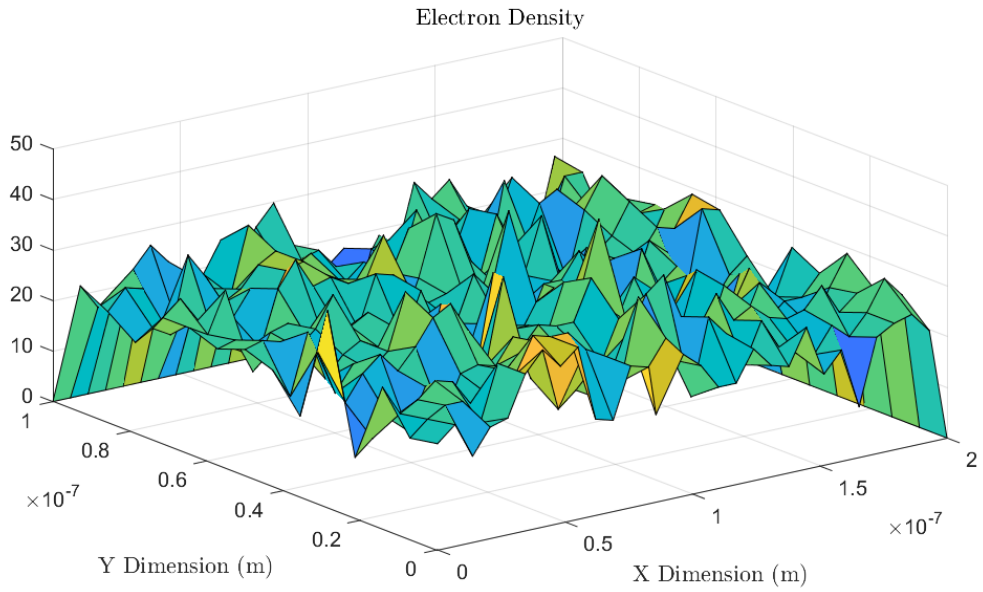

Figure 3: Electron Density of 10,000 electrons after 100 cycles.

The electron density in the system is fairly evenly distributed across the entire sample. This is likely due to the periodic x boundaries causing electrons travelling through one side to appear at the other. This would likely not be the case if the boundaries were set up to reflect or hold the electrons, like in the case of a plate on a parallel plate capacitor. The temperature density for the same simulated system can be found in Figure 4.

2 Finite Difference Method

Using the finite difference method developed in assignment 2, the potential for the bottleneck system laid out from assignment 1 was solved with 0.2 V applied across the X dimension. This solution can be found in Figure 5

The gradient of this solution was taken as the electric field, in the same manner as assignment 2. The plot of the electric field can be found in Figure 6.

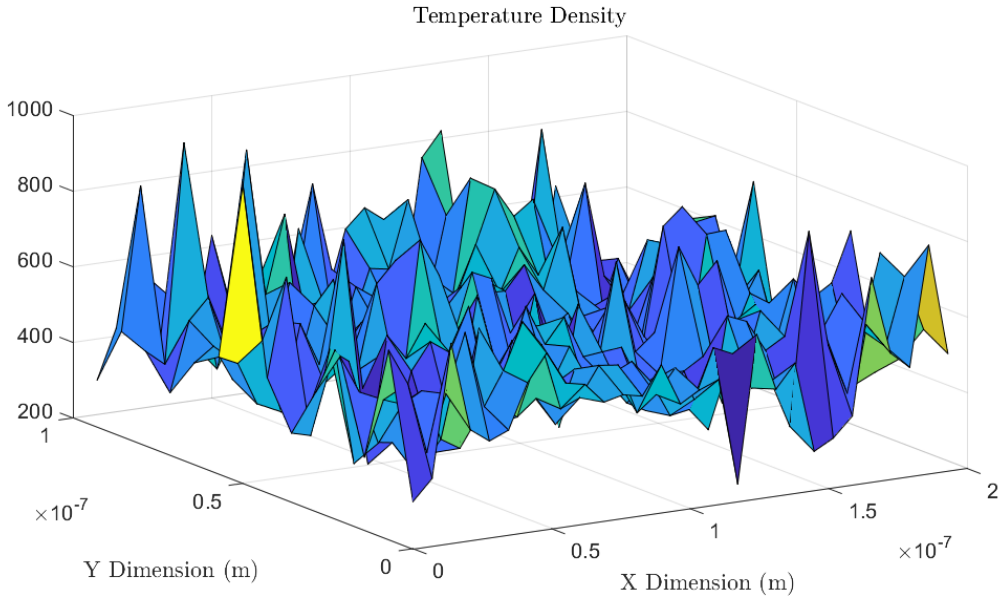

Figure 4: Temperature Density of 10,000 electrons after 100 cycles.

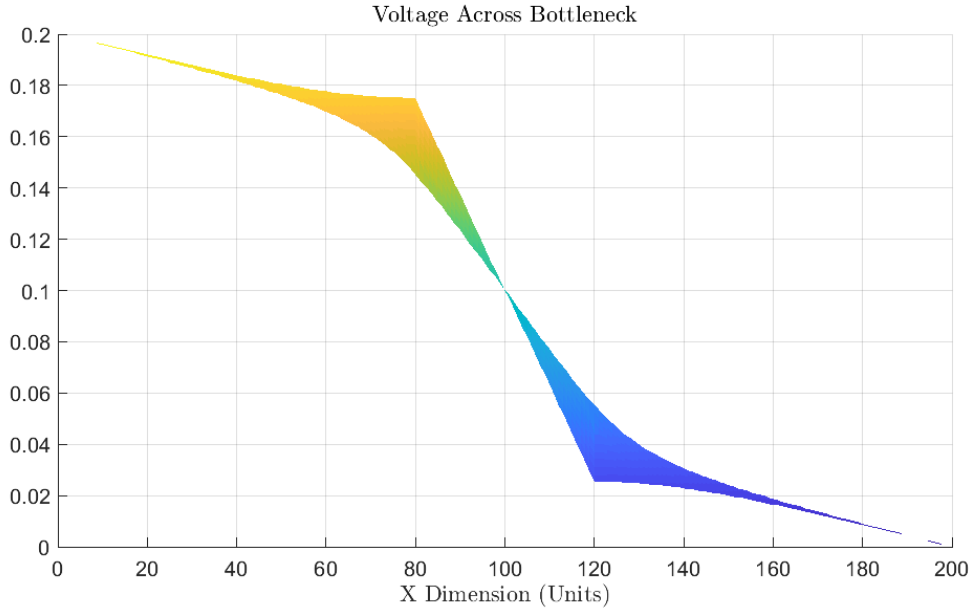

Figure 5: Cross-section of potential in assignment 1 bottle neck system solved using finite difference method. High resistivity regions are those with higher slopes, smoother slope is low resistivity bottleneck.

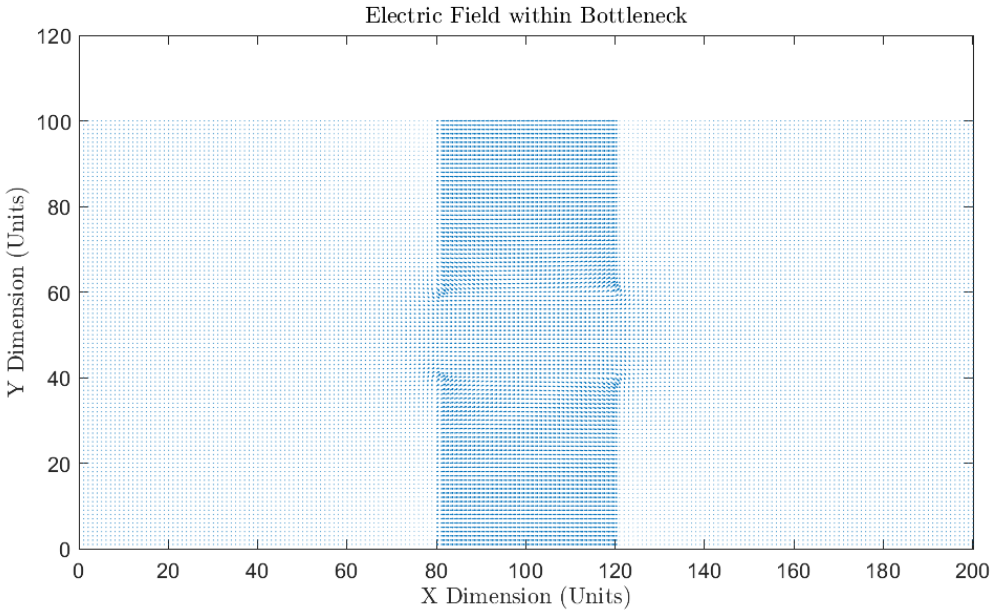

Figure 6: Electric field in the bottleneck region as set out in assignment 1. Note the higher electric field presence within the bottleneck.

3 Simulation Coupling

The simulated electron trajectories of 7 of 1000 electrons over 1000 time steps can be found in Figure 7.

The electron density at the end of 5000 time steps can be found in Figure 8.

The increased field inside the bottle neck region means that electrons travelling through the region will be accelerated through, spending less time on average within the bottleneck. As the electric field is also constant for the length of the simulation, electrons are accelerated out of the region if they happen to re-enter from the positive X-side. This means that electrons are force to stay in the same region. This creates a behaviour similar to a capacitor when the X-boundaries are made to not be periodic like in this example.

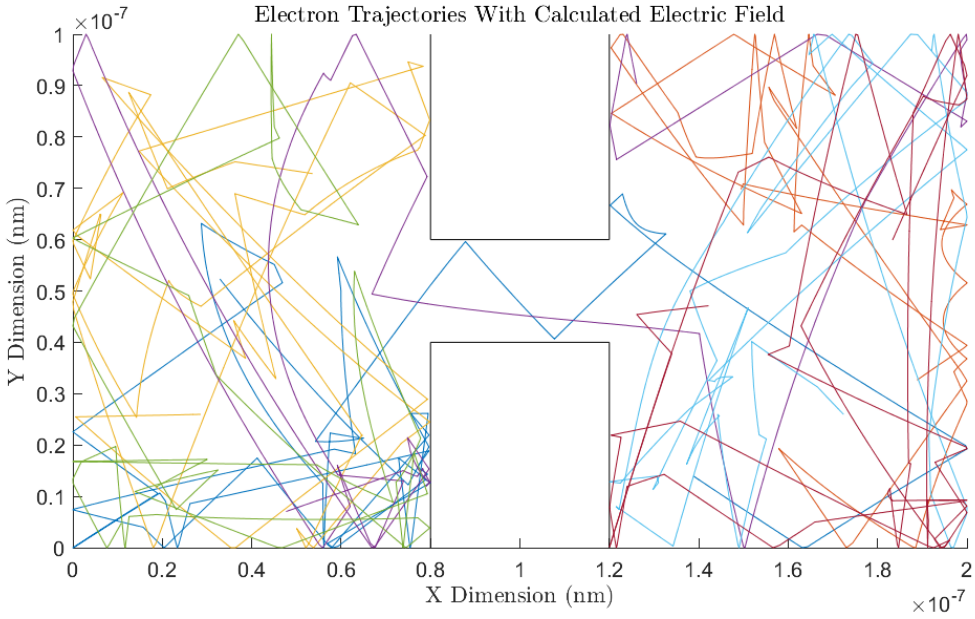

Figure 7: Simulated trajectories of 7 electrons in silicon sample with forbidden regions. 0.8 V applied across X dimension. 1000 time steps.

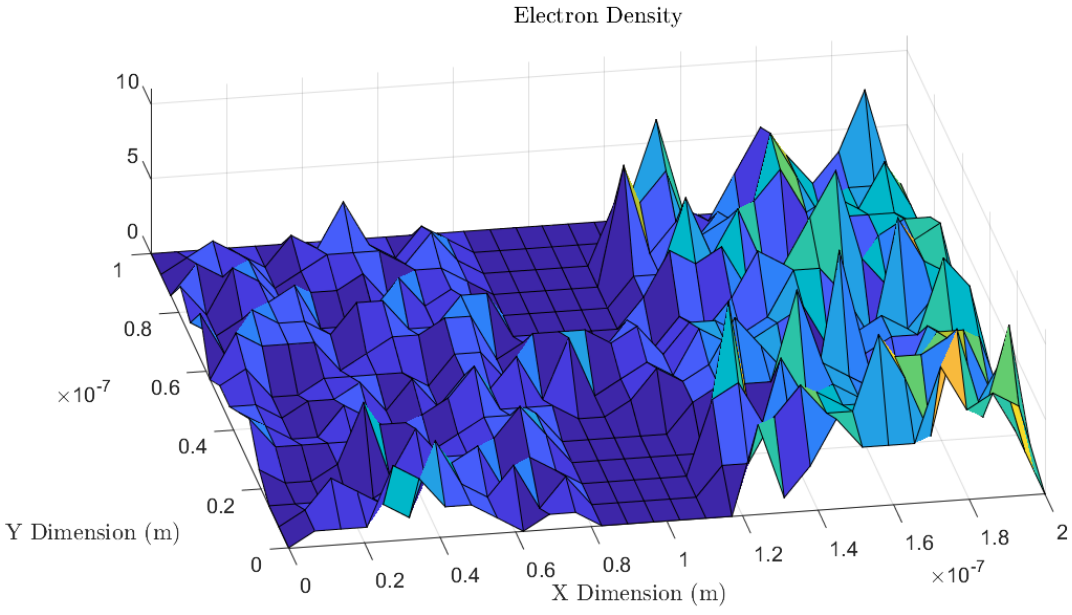

Figure 8: Electron density after 1000 time steps of system containing 1000 electrons.