ELEC 4700 Assignment 1

Monte-Carlo Modeling of Electron Transport

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Purpose:

The purpose of this assignment is to get familiar with performing Monte-Carlo simulations using Matlab. In this assignment, the Monte-Carlo method is used to simulate electrons inside a semidconductor crystal.

Theory:

The thermal voltage v_{th} can be written in the following way, where $k_B = 1.3806x10^{-23}\ m^2kg\ s^{-2}K^{-1}$ is the Boltzmann constant, T is the temperature in Kelvin, and m is the rest mass of an electron.

$$v_{th} = \sqrt{\frac{k_B T}{m}}$$

$$v_{th} = \sqrt{\frac{(1.3806x10^{-23}) * (300)}{0.26x9.109x10^{-31}}}$$

$$v_{th} = 1.3224x10^5\ m/s$$

If the mean time between collisions is $\tau_{mn} = 0.2ps$, the mean free path (MFP) is:

$$MFP = v_{th} * \tau_{mn}\ \ m$$

$$MFP = 1.3224x10^5 * 0.2x10^{-12}\ m$$

$$MFP = \ 26.45x10\ nm$$

Simulation:

A toy was written in Matlab to model electrons in a silicon mass. Boundary conditions were placed on particles of random positions all carrying the same velocity v_{th}. The angle of travel for these electrons was chosen randomly.

Once a particle reaches a horizontal boundary, the particle is transferred to the opposite side of the silicon block, so that no mass is lost horizontally. The vertical boundary condition bounces the particles back in the opposite vertical direction.

The following equation is used to calculate the semiconductor temperature during the simulation.

$$T = \frac{\bar{v} \cdot m}{k_b}$$

The Monte-Carlo simulation traces the paths of the electrons as shown below in Figure 1. The calculated temperature is plotted against time as shown in

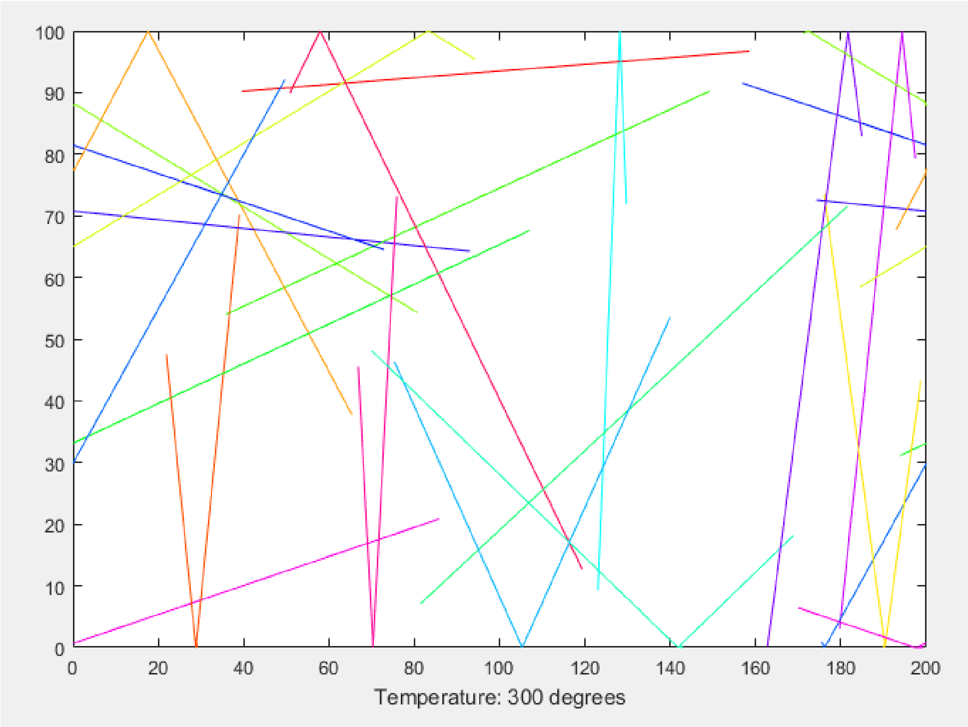

Figure 1—Traced paths of the simulated electrons inside the silicon material

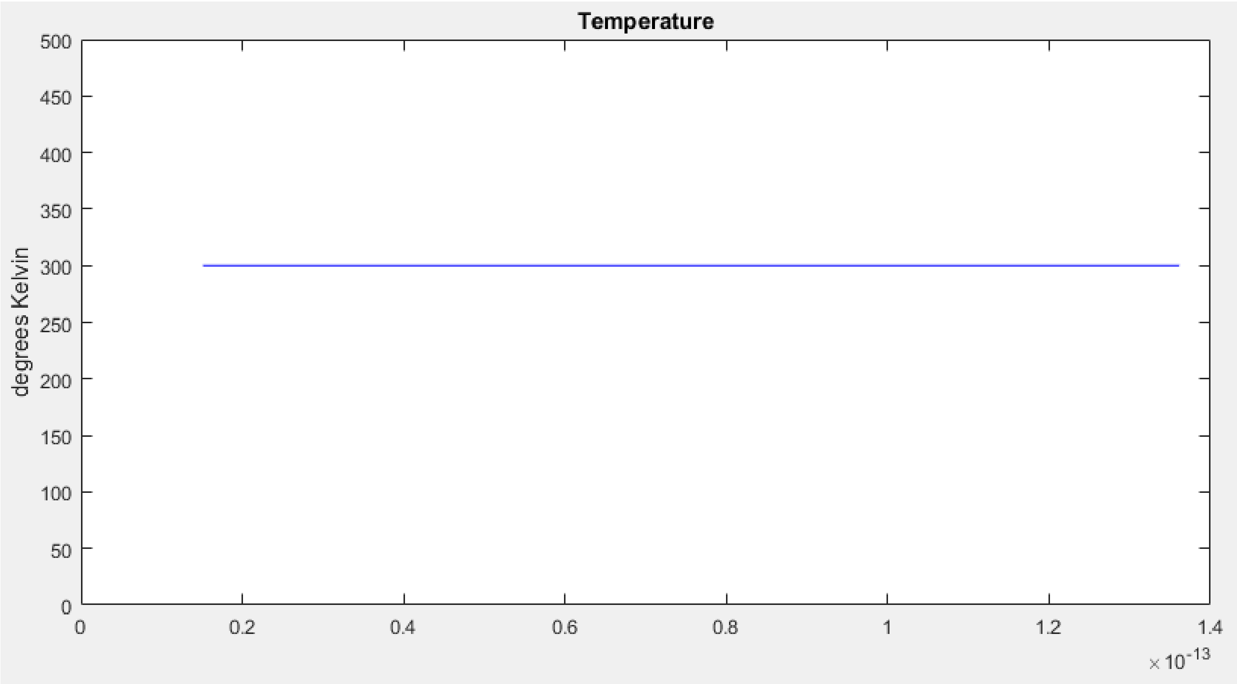

Figure 2—Temperature of the simulated silicon material plotted against time

For part 2 of the assignment, the electrons are given an initial velocity assigned randomly using a Boltzmann distribution centered about v_{th}. The electrons are also given the opportunity to scatter with a probability of:

$$P_{scat} = 1 - e^{-\frac{dt}{\tau_{mn}}}$$

The traced paths of the scattered electrons are shown below in Figure 3.

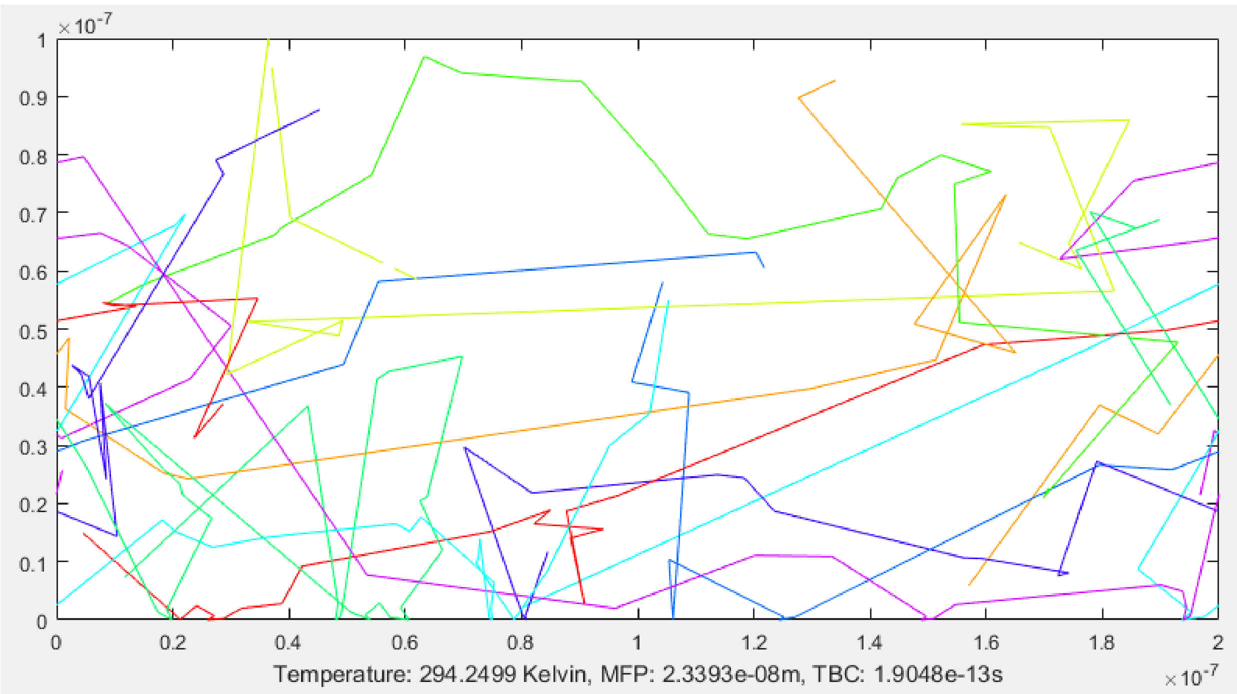

Figure 3—Scattered electrons with their paths traced

The x-label of Figure 3 shows the updating calculations of the Mean Free Path (MFP) and the Time Between Collisions (TBC). Due to the rolling mean nature of these values, they slowly approach their statistically favorable values as more time passes.

Due to the Boltzmann distribution of electron velocities, the temperature of the material now fluctuates as seen in Figure 4. A histogram showing the distribution of these velocities is shown below in Figure 5.

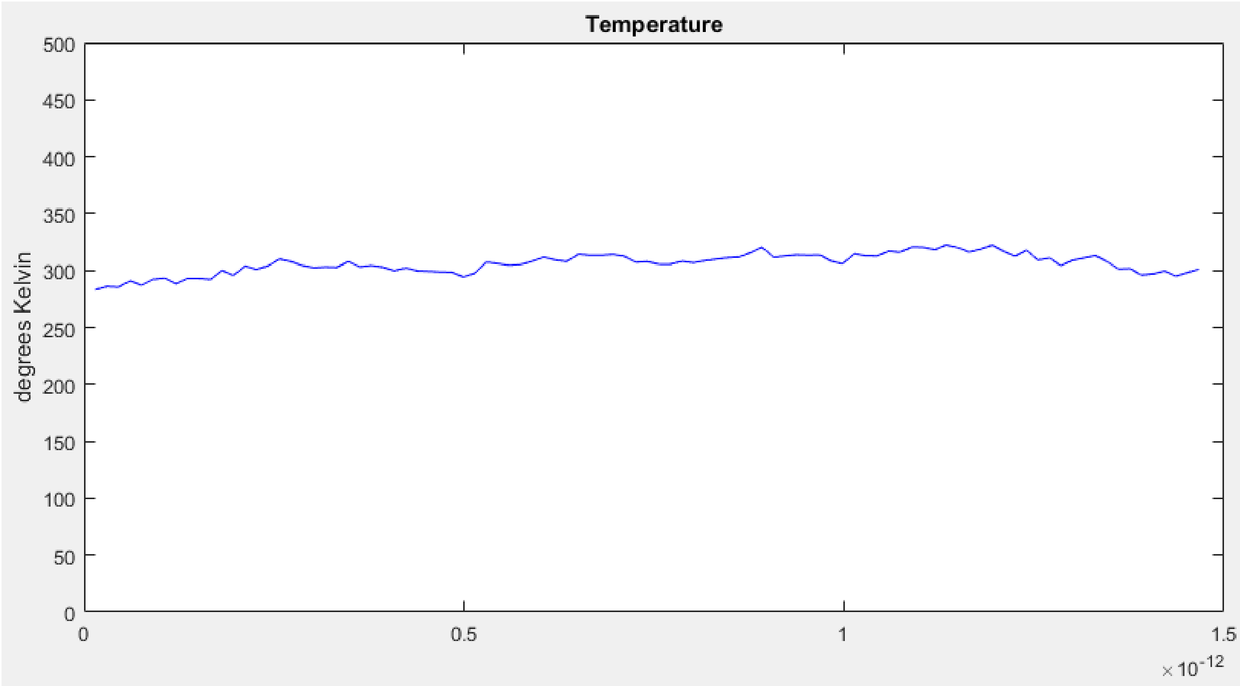

Figure 4—Simulated silicon material temperature fluctuations due to distributed electron velocities

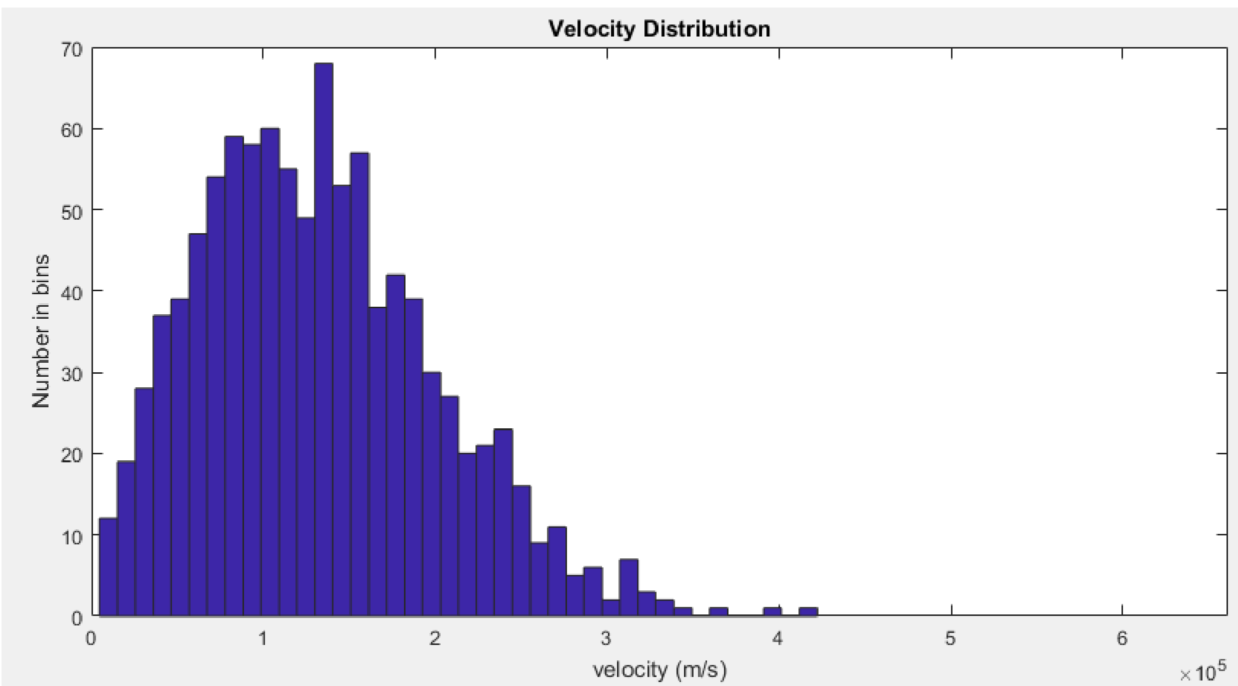

Figure 5—Updated histogram of electron velocities

In part 3 of the assignment, the first step was to add a “bottle neck” boundary. I was not successful in creating boundaries that would deflect the electrons horizontally, though the vertical box boundaries would keep the electrons out.

The trick to the horizontal deflection is to add 90 ° to the electron velocity angle, but unfortunately there were too many kinks in my code to work out the rest of the assignment.

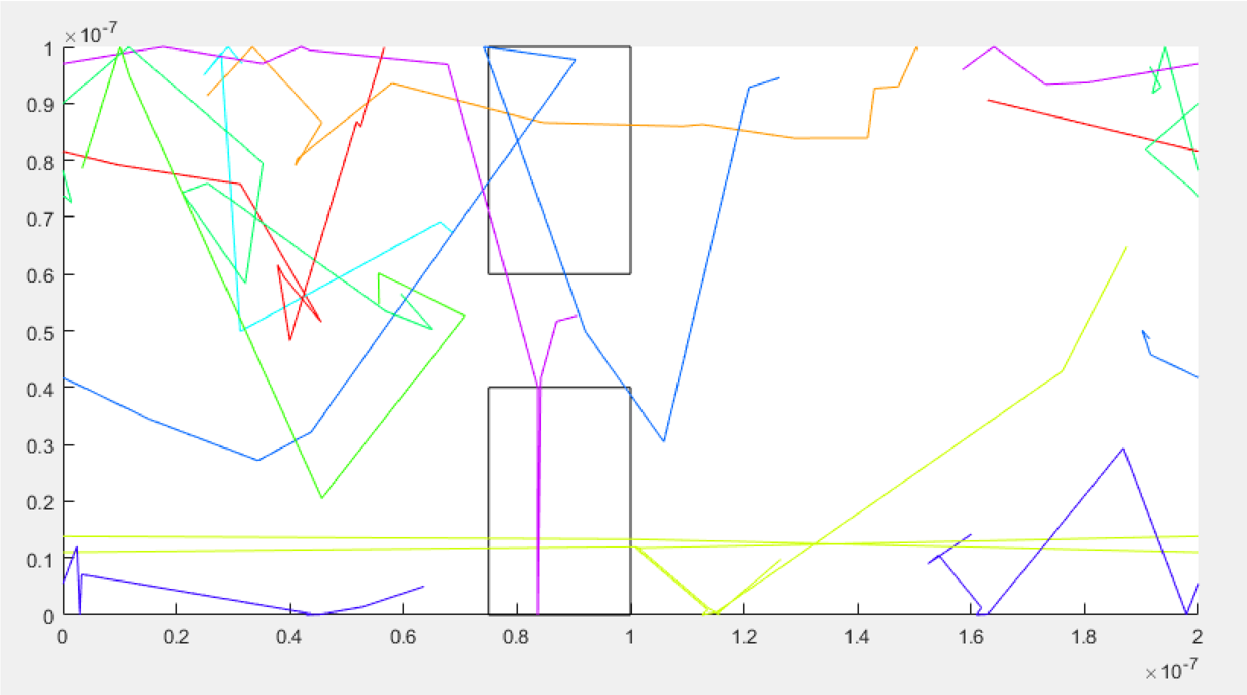

Figure 6—Bottle neck barrier unsuccessfully preventing horizontal pass through but maintaining vertical control (see pink line)