

Carleton University

ELEC 4700 A

Assignment- 1: Monte-Carlo Modeling of Electron Transport

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ELECTRON MODELLING

The primary part of the assignment involves modelling a group of electrons as particles inside of silicon.

The thermal velocity of the particles is given by the following equation, where the temperature is assumed to be $T = 300\text{K}$, the effective mass of the electrons is given as $m_n = 0.26m_0$, and the nominal size of the modelled region is given as $200\text{ nm} \times 100\text{ nm}$:

$$V_{th} = \sqrt{\frac{2kT}{m_n}} = \sqrt{\frac{2kT}{0.26m_0}} = 1.8702 \times 10^5 \text{ m/s.} \quad (1)$$

The mean free path of the electrons is given by the following equation, where the mean time between collisions is given as $\tau_{mn} = 0.2\text{ ps}$, meaning the mean free path of the electrons (the average amount of time they can travel without a collision) is given by:

$$MFP = V_{th} \cdot \tau_{mn} = 0.37404 \text{ ns} \quad (2)$$

The particles were generated with a random initial position and direction, with a fixed velocity given by V_{th} . There were three plots that were generated, including a plot of the individual particles' trajectories, an animated plot of the particles' trajectories within the region, and a plot of the current temperature within the region caused by the particles. This can be seen below:

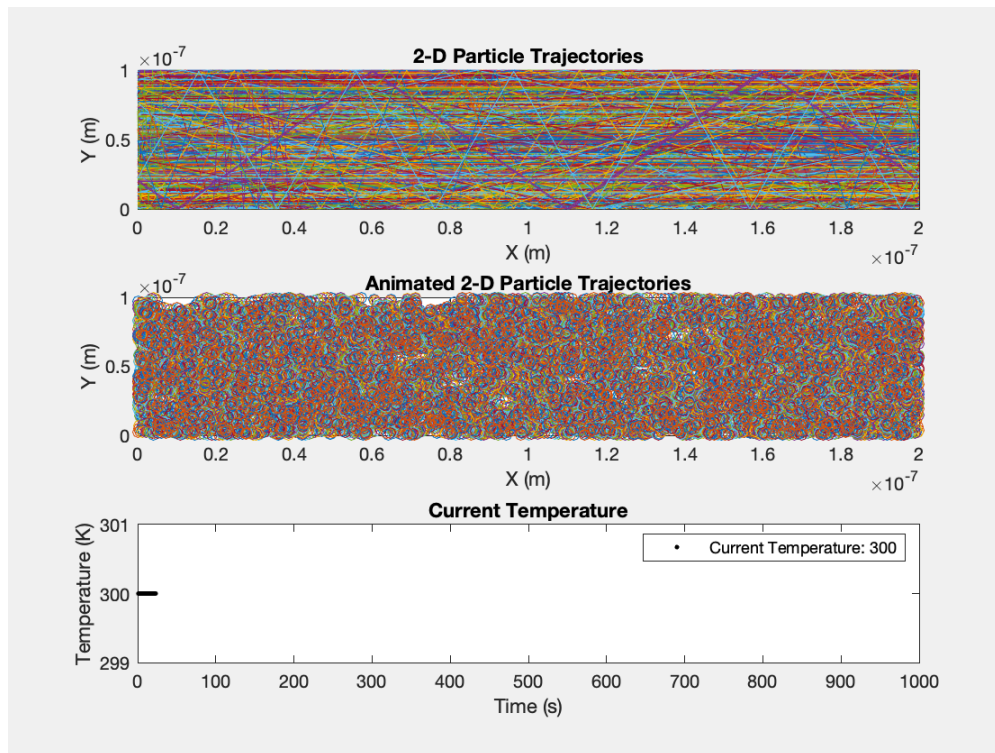


Figure 1. Plot of Model of Particles in Silicon

As can be seen in Figure 1 above, the temperature stays constant at 300K throughout the simulation. This is because since the velocity of each particle is given as a constant thermal velocity, there will not be any change in temperature.

COLLISIONS WITH MEAN FREE PATH

The secondary part of the assignment involves using a Maxwell-Boltzmann distribution for the simulated particles, with their average velocity being equal to the thermal velocity at 300K. A histogram for the particle velocity for 1000 particles can be seen below:

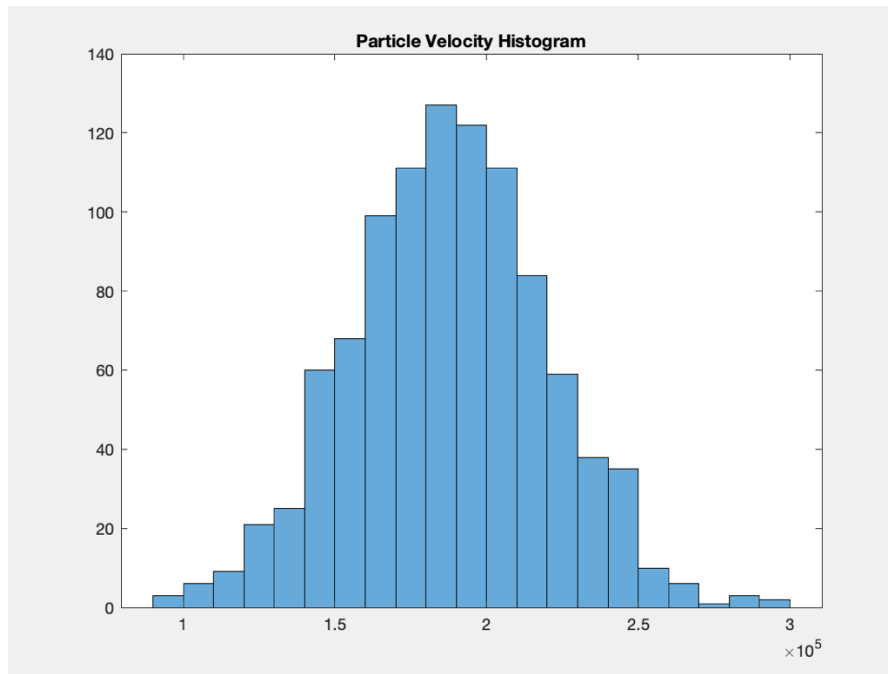


Figure 2. Maxwell-Boltzmann Distribution for Particle Velocity

Moreover, the simulation incorporated the ability for every particle to be given a probability to scatter and therefore, have the capacity to be assigned a new random velocity. The scattering probability was given by:

$$P_{scat} = 1 - e^{-\frac{dt}{\tau_{mn}}} \quad (3)$$

The particles were once again generated with a random initial position and direction. There were three plots that were generated, including a plot of the individual particles' trajectories, an animated plot of the scattered particles' trajectories within the region, and a plot of the current temperature within the region caused by the particles. This can be seen below:

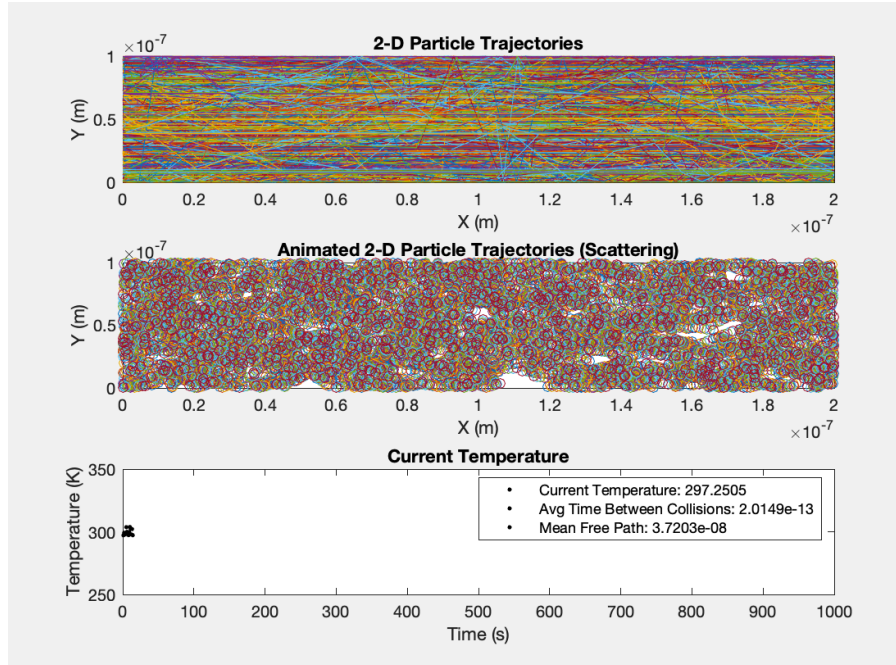


Figure 3. Plot of Model of Scattered Particles

As seen in Figure 3 above, the temperature does not remain at a constant 300K anymore; however, it fluctuates around 300K, approximately 5 degrees higher and lower. This is because the thermal velocities are being averaged at 300K using uniform distribution. This indicates that there are particles with lower thermal velocities will have lower temperatures, and vice-versa. Moreover, the mean time between collisions and mean free path remained constant over time at approximately 2.0149×10^{-13} s, and 3.7203×10^{-8} s respectively.

ENHANCEMENTS

The last part of the assignment involves adding some extra features to the simulation, including adding boundaries in the shape of two small boxes added to the middle of the region. The same parameters that were used in the second part of the assignment were used in this simulation; however, the two box boundaries were added for the particles to interact with. This can be seen below:

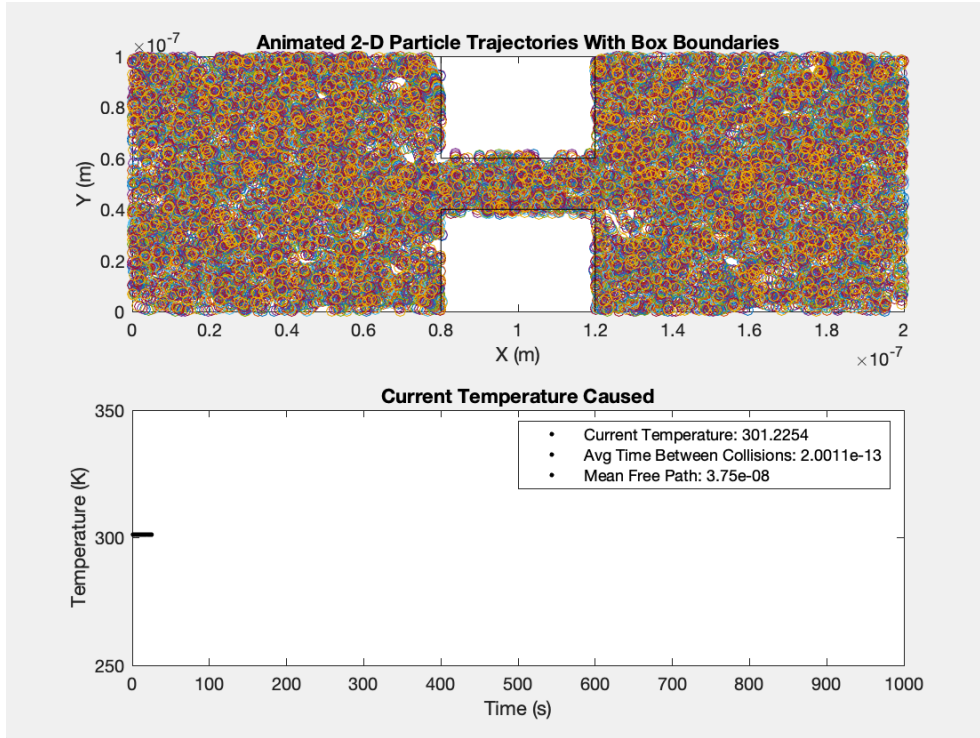


Figure 4. Plot of Model of Scattering Particles with Box Boundaries

The resulting electron density map and electron temperature map from the simulation in Figure 4 can be seen below:

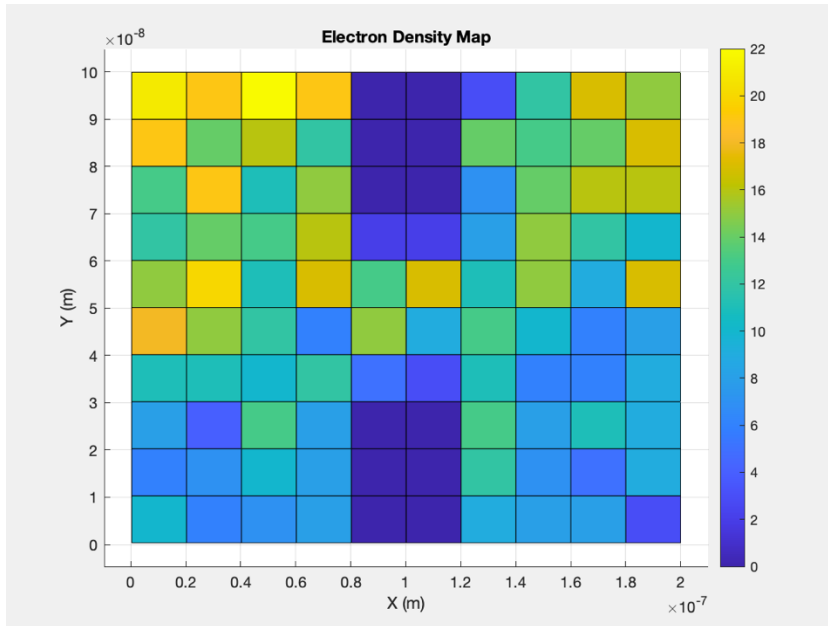


Figure 5. Electron Density Map

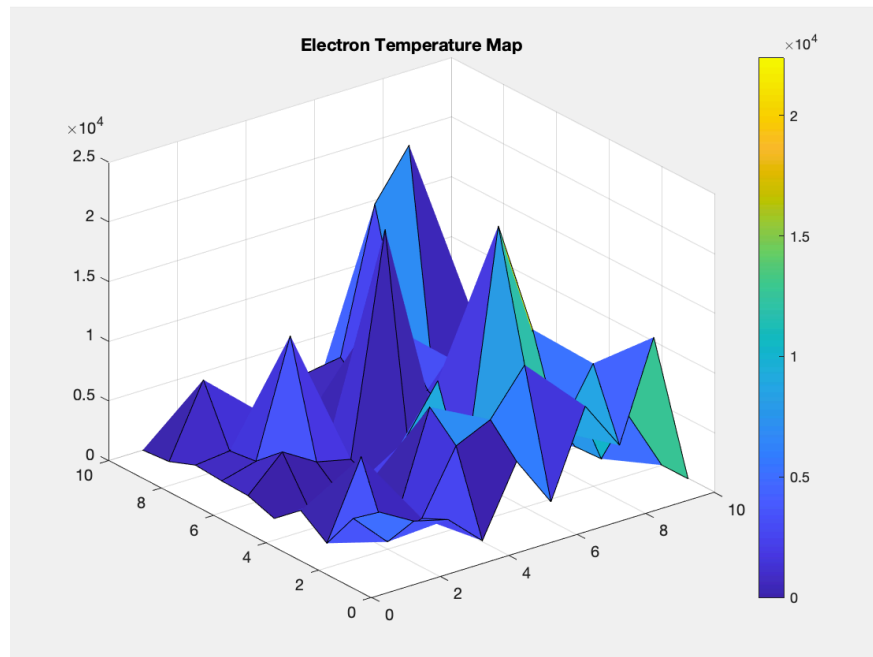


Figure 6. Electron Temperature Map