Plan for tutorial:

NOTE: anything before **'4 Simulation using Aquarius'** will not be included in the user manual, its just for this word document.

- Screenshot all steps taken
- Could offer a brief explanation on zooming out and navigating around the screen (not sure if this is overkill)
- I could put in my data from python as a .csv file so people who use the tutorial can compare the data they made?
- Base tutorial off each screenshot.
- In some of the path files for the images, NOTE, the underscores have been changed to dashes to agree with the kebab-case.

Key:

- ### means an image is going to be placed here
- #word# means the word will be put in box in the user manual the → indicate separate boxes, these # will be removed later. Note some of them already have a box since they were copy and pasted onto this word document so there may be examples in this document where the hashtags have not been implemented. This was done so as not to lose track.
- #brief description, means it's something I'm going to add.

DAVIDS PART OF THE USER MANUAL

4.1.1 Lauch Editor

- Lauch the device editor as explained in the Resistor example.

4.1.2 Define Device Geometry

- Directly below the menu bar, left-click the square

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- Position the cursor on the canvas to draw a rectangular shape:
  - Left-click to start drawing.
  - Left-click again to finish the shape.

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- After drawing the rectangle, the **Exact Coordinates** dialog will open automatically:
    - Set the First Vertex to `(-0.1, 0)`.
    - Set the Second Vertex to `(0.1, 1)`.
    - Click `OK` to confirm.

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- The **Region Properties** dialog will then open:
    - Set the Region Material to `Silicon (Si)`;
    - Set the Acceptor Doping to `1E+16`
    - Click `OK` to confirm.

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- Repeat process again but changing the colour of the region and this time with the following parameters:
    - Set the First Vertex to `(-0.1, 0.1)`.
    - Set the Second Vertex to `(1, 2)`.
    - Set Donner concentration to 1E+16.
    - Select a colour of choice for the N region. It is better to have it set as a different region to the P region for differentiability.
        - Note: the two regions should be neatly on top of each other.

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4.1.3 Define Device Contacts

As it was done in the Resistor example, define the contacts on either end of the diode, keeping the same labels the same as in the resistor example.

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4.1.4 Defining Mesh Construction Lines

As it was done in the simple resistor example, an initial grid is defined. Here the mesh will be slightly different as we are simulating a PN diode which is slightly more complex than a resistor. In this example of a PN diode, It is necessary to have a horizontal mesh should be graded in such a way that the spacing between the lines increases towards the depletion region at the centre of the diode. This is because the centre of the diode is a point of interest.

- In the menu Menu Bar select #Mesh → Define Mesh Construction Grid#. The **Mesh Construction Grid** window will open.
- In the **Mesh Construction Grid** window click #Add#.
- The **Mesh Grid Lines** window will open. Set the below properties:
    - Set the **Orientation** to #Horizontal#.
    - Set the **Interval** to #Graded#.
    - Set the **Coordinates** of the box that will contain the mesh line to:
        - X1 = -0.1
        - X2 = 0.1
        - Y1 = 1
        - Y2 = 0
    - Set the **Spacing Between Lines** top to 0.005 microns and bottom to 0.05
- Click OK
- Repeat the above steps setting **Coordinates** of the box that will contain the mesh line to:
        - X1 = -0.1
        - X2 = 0.1
        - Y1 = 2
        - Y2 = 1
    - Then set the **Spacing Between Lines** #top# to #0.05# microns and #bottom# to #0.005#

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- As was done in the Resistor example, generate the Finite Element Mesh.

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4.1.6. Defining Variables

Considering the equations shown in the parameters section, variables need to be set to agree with tis example. The **minority lifetime** and the **carrier mobility** need to be set here for the electrons and holes.

- If the Finite element mesh is still active, go to the toolbar at the top of the window, select #Mesh → Exit Mesh#
- In the menu bar, select #Model_→ Material Library#. The **Material Library** window will open.

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- Select the material you wish to use, here select #Si# (silicon). On the right-hand side of the **Material Library** window, select #Edit Material#, the **Si Material Properties** window will open.

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First, we will change the value for **carrier mobility**:

  - Go to the toolbar of the **Si Material Properties** window and select #Mobility#.
  - Find the variable names #Mu_0_p# and set it to #450# cm2/Vs. This will change the charge mobility for the holes.
  - Repeat the same process for #Mu_0_n# but set the value to #1000# cm2/Vs. This will change the charge mobility for the electrons.

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Now we will change the values for the minority lifetime:

  - Go to the toolbar of the **Si Material Properties** window and select #Recombination#.
  - Under the #Shockley Read Hall (SRH) and Traps# section, find the #SRH_TAU_p# variable, second to top, and change the value to #1E-5# seconds. This will change the minority carrier lifetime for the holes.
  - Repeat the same process for #SRH_TAU_n# using the same value. This will change the minority carrier lifetime for the electrons.

- Press #OK#

- As it was done in the **Resistor** example, save the device and specify the filename (e.g pn_junction_diode.sdm).

4.2 Steady State Simulation:

We will now use the diode in a simple steady state example as was done for the Resistor example with a few changes.

4.2.1 Adding Circuit Components:

- Follow the same steps as in section 4.2.1 in the Resistor example for the device created in this example.

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- Set the voltage range for the diode to:
    -
    - `Start Voltage (V) = 0`
    - `End Voltage (V) = 1`
    - `Step (V) = 0.002`

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- The simulated circuit should look similar to the one In the Resistor Example:

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- Next run the simulation as in section 4.2.2 of the Resistor, the simulation may take slightly longer since there are more voltage steps.
- If you want to export the data, when the **Simulation Status** window opens, click #Export log#. The data will be saved as a .txt file.

###insert image of clicking exporting log ?

4.3 Simulation Results

- Repeat steps in section 4.3 in the resistor accept using the diode that has just been made.
- The IV graph produced in the **Results Visualiser** will look different than the one produced from the resistor. It will not be linear.
- For this graph, it is often useful to log scale the graph. This can be done by ticking the box labelled #Log Scaling#.

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4.3.1 Analysing Results

#Put example calculation of saturation current and then an example of ideal diode equation?

5 Conclusion

This example displays how a PN junction diode that is uniformly doped in the P and N region respectively can be modelled and simulated in the Aquarius TCAD environment. The current-voltage graph can be verified from the analytical model bellow:

###insert python IV graph

#should I say it was done on python?

- Note: the graphs were implemented using a logarithmic scale

As we can see, **Aquarius Simulation Result** deviates off from agreeing with the **Ideal Diode Equation.** This deviation is a result of the fact that the Aquarius model considers the series resistance across the diode. This means the resistance across the

P region, N region and the depletion region between those two regions is considered in the Aquarius simulation. Using Ohm’s law, as seen in the Resistor example, we see that the higher the voltage, the higher the resistance. This resistance increase causes the drop gradient of the IV graph since the gradient is the reciprocal of the resistance.

#Not sure what to write about the slight offset at the start of the graph.