Group No:

Experiment-01

Study of Diode Characteristics

CSE251 - Electronic Devices and Circuits Lab

Objective

1. To become familiar with a silicon p-n junction diode and understand its operation
2. To study the current-voltage i.e. I-V characteristics of silicon p-n junction diodes

Equipments

1. p-n junction diode (1N4007) - $\times 1$
2. Resistor (1kΩ) - $\times 1$
3. DC power suply
4. Breadboard
5. Wire
6. Digital multimeter

Background Theory

Diode is a semiconductor device that allows current flow only in one direction, from p to n or anode to cathode. The schematic diagram, diode notation and circuit symbol are shown in Figure-1. Diodes are usually marked with a dot or a bar appearing on the cathode side. This mark helps identify the diode terminals.

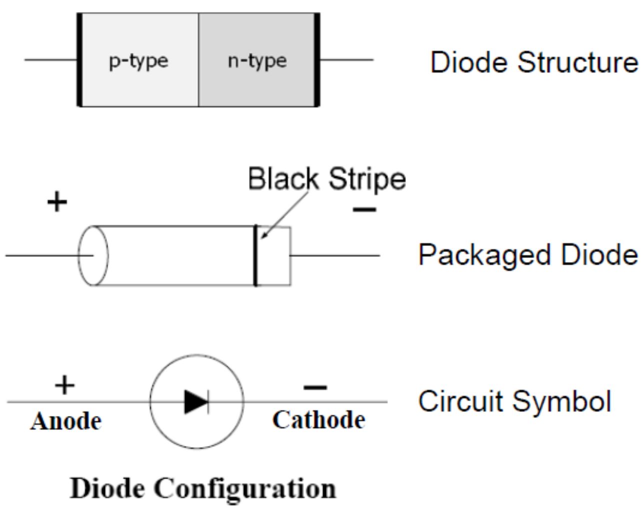

Figure 1: Diode structure and circuit symbol

Diodes have small impedance to current flow in one direction (forward-biased) and large impedance in the reverse-biased mode. When diodes fail they either short-circuit (pass current in both directions – i.e. low resistance in both directions) or open-circuit (do not pass current at all).

Ideal Diode Characteristics

Ideally, we want a diode to behave like an electronic valve. That is, it should allow any amount of current in one direction, while blocking all the currents in the opposite direction. This behavior can be characterize using the current and voltage relation between the diode (or for any electronic device) – which is also known as the IV characteristics of the device.

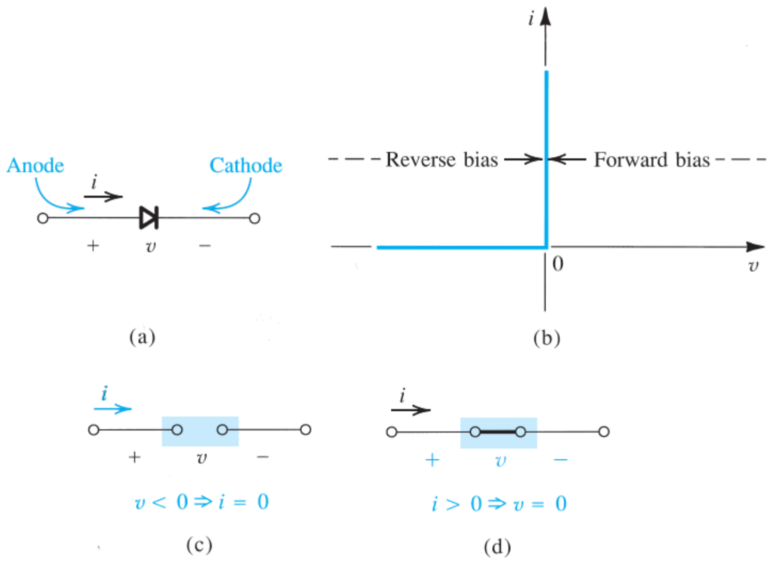

Figure 2: IV Characteristics of an ideal diode

Real Diode Characteristics

Real diodes are made of semiconductor materials, which have highly non-linear IV characteristics. However, under certain conditions and approximations, the real diode behaves like an ideal diode. For a real diode, the current I_D when a voltage V_D is applied across it is given by:

$$I_D = I_S \left(\exp\left(\frac{V_D}{nV_T} \right) - 1 \right)$$

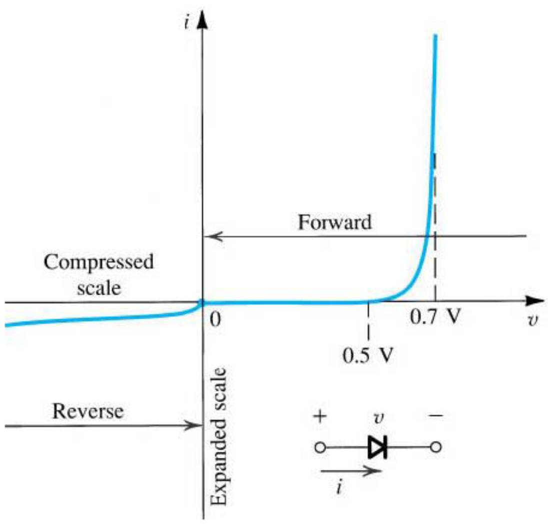

Figure 3: IV Characteristics of a Real Diode

Here,

- I_S is called the reverse saturation current
- n is called the diode ideality factor, and it has a value between 1 and 2
- V_T is called the thermal voltage, which has a value of 25 mV at 27°C

However, there are 2 special cases:

- When $V_D >> nV_T$: in this case, e^{V_D/nV_T} will be much higher that 1, and hence we can ignore 1. Therefore, $I_D \approx I_S\ exp(V_D/nV_T)$
- When $V_D < 0$: in this case, e^{V_D/nV_T} will be negligible compared to 1, and hence we can ignore the exp() term. Therefore, $I_D \approx -I_S$

Diode Resistance

As the diode IV characteristic is not linear, it will have different resistances at different points on the curve. A dynamic or AC resistance for the diode is defined as,

$$r_d = \frac{dv}{di} \approx \frac{nV_T}{I_D}$$

The static or DC resistance at any point is defined as, $R_D = V_D/I_D$

Diode Specification

There are many specifications for each type of diode, the most important two are:

1. Peak inverse Voltage (PIV): maximum voltages the diode can tolerate in reverse direction.
2. Maximum Forward Current (I_F) the maximum current the diode can conduct in forward biased condition without exceeding the safe limit.

Look at the data sheet of a diode provided at the last page to get familiar with some of the diode specifications.

Diodes are widely used in applications such as mixers, detectors, protection circuits. In this experiment you will investigate its I-V characteristics.

IV Characteristics

I-V characteristic defines the relationship between the current flow, I and the voltage across two terminals, V of an electronic device or element. It is a tool for understanding the operation of the circuit. The Current-Voltage (I-V) characteristics are found by evaluating the response of a device/element under different conditions. The behavior of a device depends on the applied excitation and can change if the excitation changes. For example, a device may act as an "open circuit" under certain input conditions and as "current source" in another. A diode acts as an open circuit below a specific threshold voltage and acts differently after that.

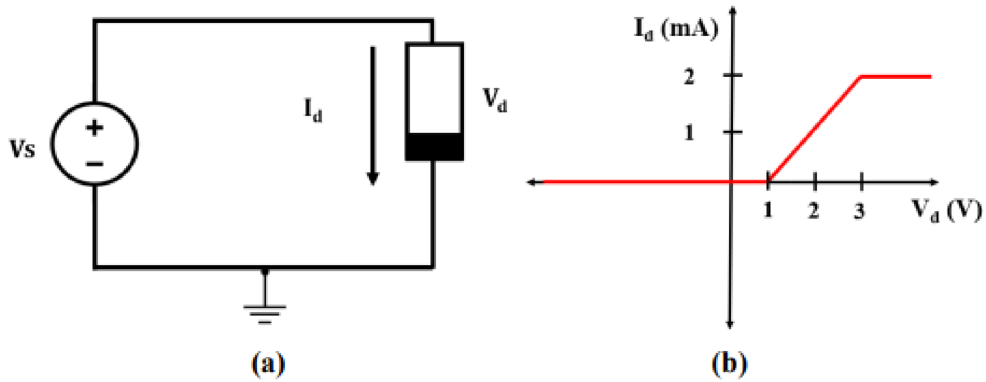

Figure 4: (a) A circuit with a voltage source, (b) I-V characteristic of the device

A simple circuit with a voltage source and an electronic device is shown in the figure above. The voltage source acts as an excitation medium for the device. Varying the voltage source would result in change in the current flow, I_d across the device. By plotting this current with respect to the voltage across the device, V_d, the I-V characteristics of this device can be determined.
I-V characteristics gives us the idea of the behaviour of a device which is enough information for us to know about a device.

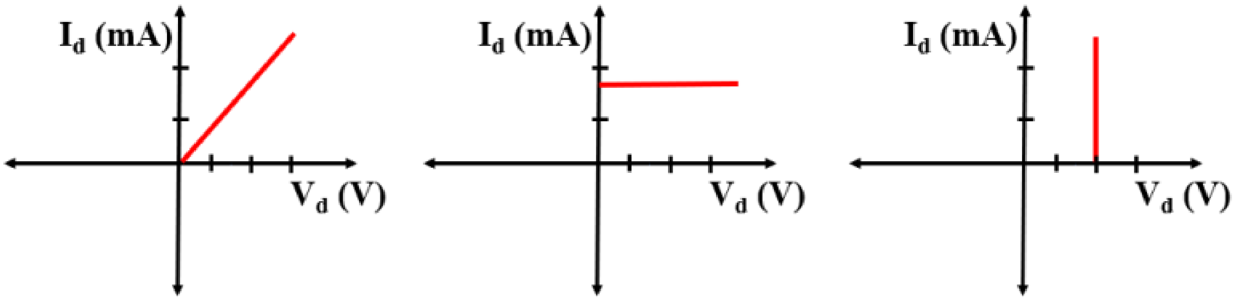

Figure 5: I-V curves of some linear elements

Depending on the I-V characteristics, the electronic devices can be divided into two categories: (1) Linear (2) Non-linear.
If the current through the element is a linear function of the applied voltage across it, it is a linear device. If the current through the element is a nonlinear function of the applied voltage across it, it is a non-linear device.

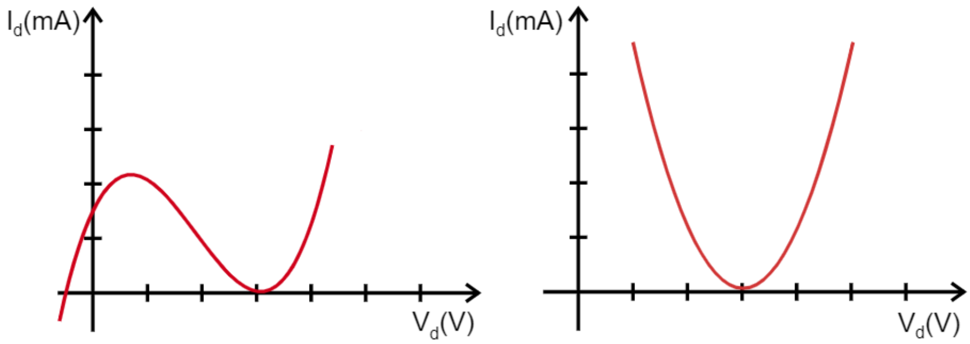

Figure 6: I-V curves of some non-linear elements

In this experiment, we will study the I-V characteristics of diodes. We will observe that, diodes exhibit non-linear I-V characteristics.

Task-01: Data Collection

In this task, we will build a circuit that will enable us to collect required data to observe the characteristics of a diode. We will vary the source voltage of the circuit which will eventually change the voltage and current across the diode. This data of voltage and current will be used to plot the IV graph of the diode.

Experimental Design

The following figure shows the circuit required for this experiment.

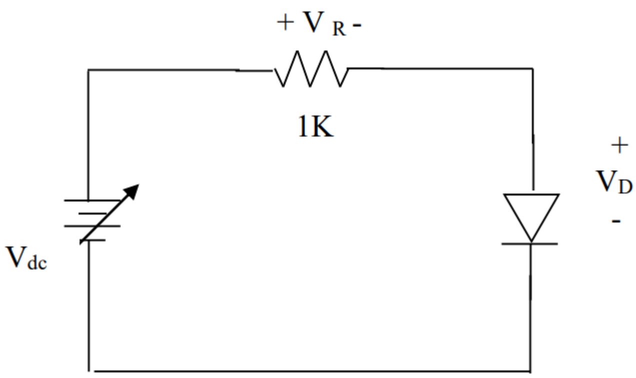

Figure 7: Circuit diagram for finding out the diode IV Characteristics

Procedure

1. Measure resistance accurately using a digital multimeter.
2. Construct the circuit as shown in Figure 7. Vary input voltage V_{dc} from 0v to 14v and measure V_R and V_D. Increase V_{dc} in 0.1v steps for 0v to 1v, and then in 1v steps for 1v to 14v.
3. For each value of V_{dc}, also calculate the diode current using $I_R = V_R$.
4. Plot diode IV characteristics of the diode for different readings obtained.
5. Calculate the diode ideality factor n and the reverse saturation current I_S, using the diode equation assuming $V_D >> V_T$.
6. Calculate the static and dynamic resistances for $I_D = 4$, 8 and 12 mA.

Data Table

$R = 1k\Omega$ (measure the accurate resistance using the digital multi-meter)

Supply Voltage, V_{DC} (v)	Diode Voltage, V_D (v)	Voltage across the Resistor, V_R (v)	Diode Current, $I_D = I_R = V_R/R$ (mA)
0			
0.1			
0.2			
0.3			
0.4			
0.5			
0.6			
0.7			
0.8			
0.9			
1			
2			
4			
6			
8			
10			
12			
13			
14			

Calculation

Determining Ideality Factor, n

Let, $\alpha = \frac{1}{nV_T}$

Take any two data from the table: $I_{D1} = I_S \exp(\alpha V_{D1})$ and $I_{D2} = I_S \exp(\alpha V_{D2})$

Taking ratio of I_{D1} and I_{D2},

$$\Rightarrow \frac{I_{D1}}{I_{D2}} = \exp(\alpha(V_{D1} - V_{D2}))$$

$$\Rightarrow \alpha = \frac{\ln\left(\frac{I_{D1}}{I_{D2}}\right)}{V_{D1} - V_{D2}} = \frac{1}{nV_T} \qquad \Rightarrow n = \frac{1}{\alpha V_T}$$

Determining Static (R_D) and Dynamic (r_D) Resistance

$$R_D = V_D/I_D$$

$$r_D \approx \frac{nV_T}{I_D}$$

Task-02: Plotting and Calculations

In this task, we will use the data that were collected in the previous task and plot the IV graph of the diode using Google Sheets.

1. Create a Google Spreadsheet by visiting `https://docs.google.com/spreadsheets`
2. Fill in the spreadsheet with the data that you've collected in the lab (refer to your lab sheet). Select both the columns of V_D and I_D (to select a column, click on the column head, e.g., "B". Then hold CTRL while clicking the second column, e.g., "D", to select both columns).

A	B	C	D
VDC	Vd (V)	Vr (V)	Id = Ir (mA)
0	0	0	0
0.1	0.1	0	0
0.2	0.2	0	0
0.3	0.3	0	0
0.4	0.392	0.008	0.004
0.5	0.443	0.057	0.0285
0.6	0.465	0.135	0.0675
0.7	0.478	0.222	0.111
0.8	0.487	0.313	0.1565
0.9	0.494	0.406	0.203
1	0.499	0.501	0.2505
2	0.527	1.473	0.7365
3	0.54	2.46	1.23
4	0.549	3.451	1.7255
5	0.555	4.445	2.2225
6	0.56	5.44	2.72
7	0.565	6.435	3.2175
8	0.569	7.431	3.7155
9	0.572	8.428	4.214
10	0.575	9.425	4.7125
11	0.577	10.423	5.2115
12	0.58	11.42	5.71
13	0.582	12.418	6.209
14	0.584	13.416	6.708
15	0.586	14.414	7.207

3. Select Insert $\longrightarrow$ Chart. You should be getting a graph that looks like the following diagram.

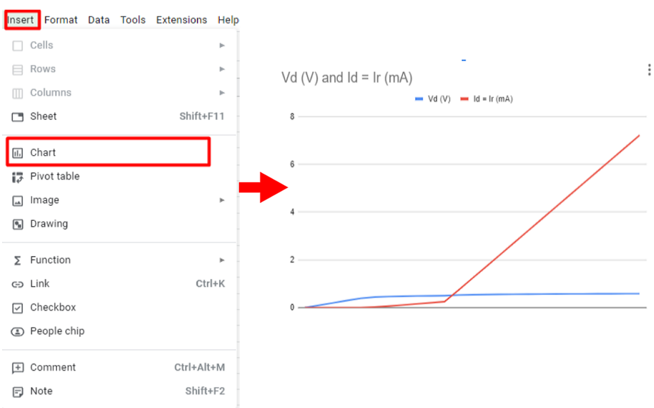

Figure 8: Step-3

4. A Chart Editor section should pop up at the right side of your screen. If it does not show up, then double click on the graph. Go the setup section in the chart editor and change the “Chart type” to “Scatter chart”. Your graph should be changed into a scatter plot as shown below.

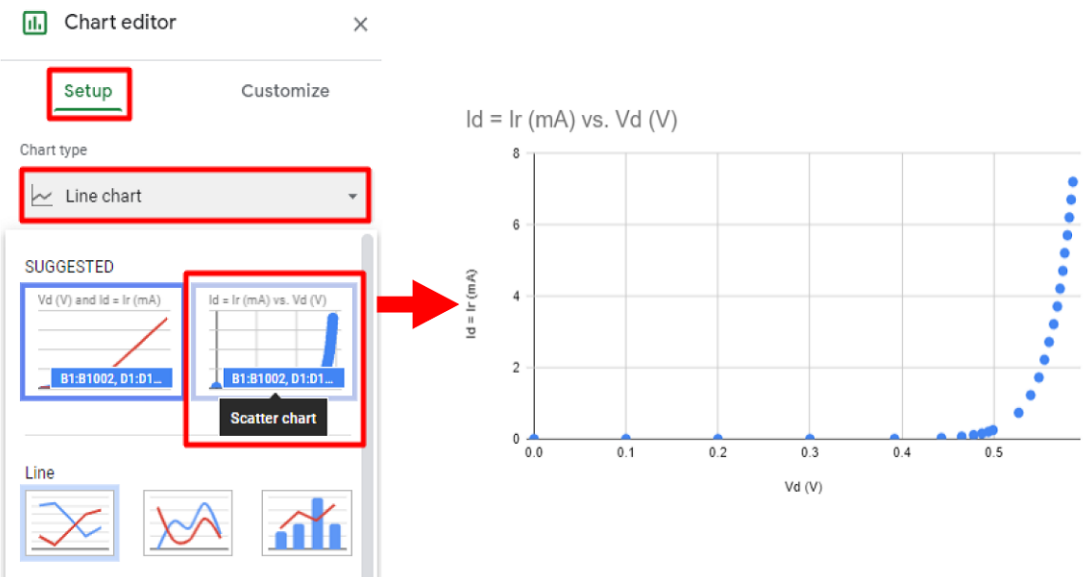

Figure 9: Step-4

5. Chart Editor ⟶ Customize ⟶ Series ⟶ Check the Trendline box ⟶ Change the type of trendline to “Exponential” ⟶ Change the “Label” to “Use Equation”. You may also change the line color, line opacity and line thickness according to your preference.

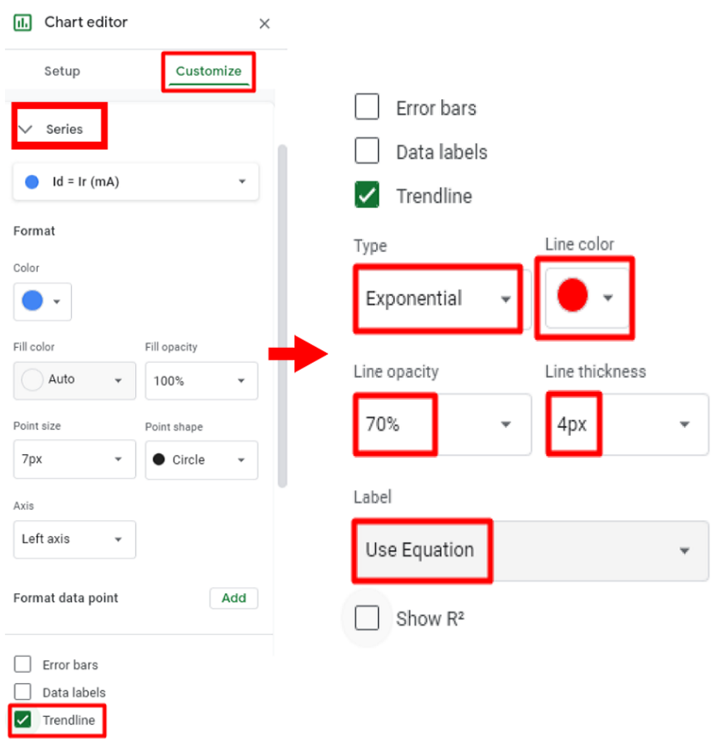

Figure 10: Step-5

6. Your graph should now look like the following figure. The equation at the top of the graph defines the trendline, which basically represents the equation of I_D as a function of V_D (x-axis).

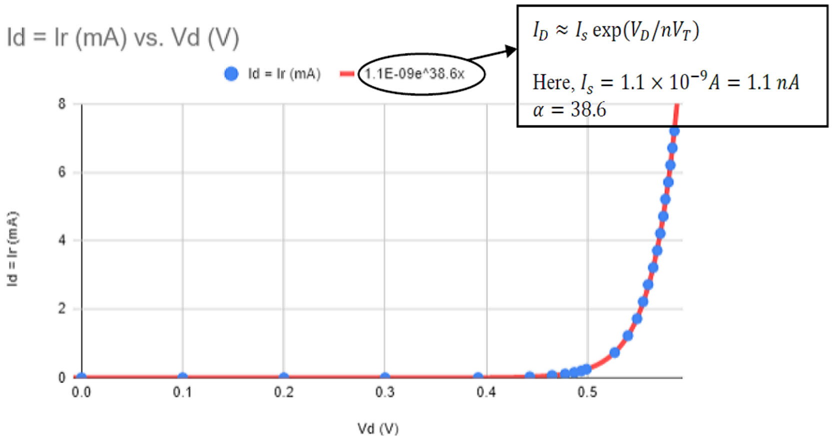

Figure 11: Step-6

7. Find I_S, α and ideality factor n from the equation and write the parameter values on the spreadsheet as the following table.

Calculation from graph	
Is	
n	

Figure 12: Step-7

Note: This is a sample data collected from a simulation. Your data may not match with this one.

Task-03: Simulation

In this task, we will simulate the experiment in LTspice and verify the results that were obtained in Hardware lab. Follow the following steps for the simulation:

1. Create a new schematic file in LTspice. Go to File → Save as. Rename the file as "diodeIV.asc" and save it in a suitable location of your hard drive.

2. Select View → check the Show Grid option for better visibility of the interface.

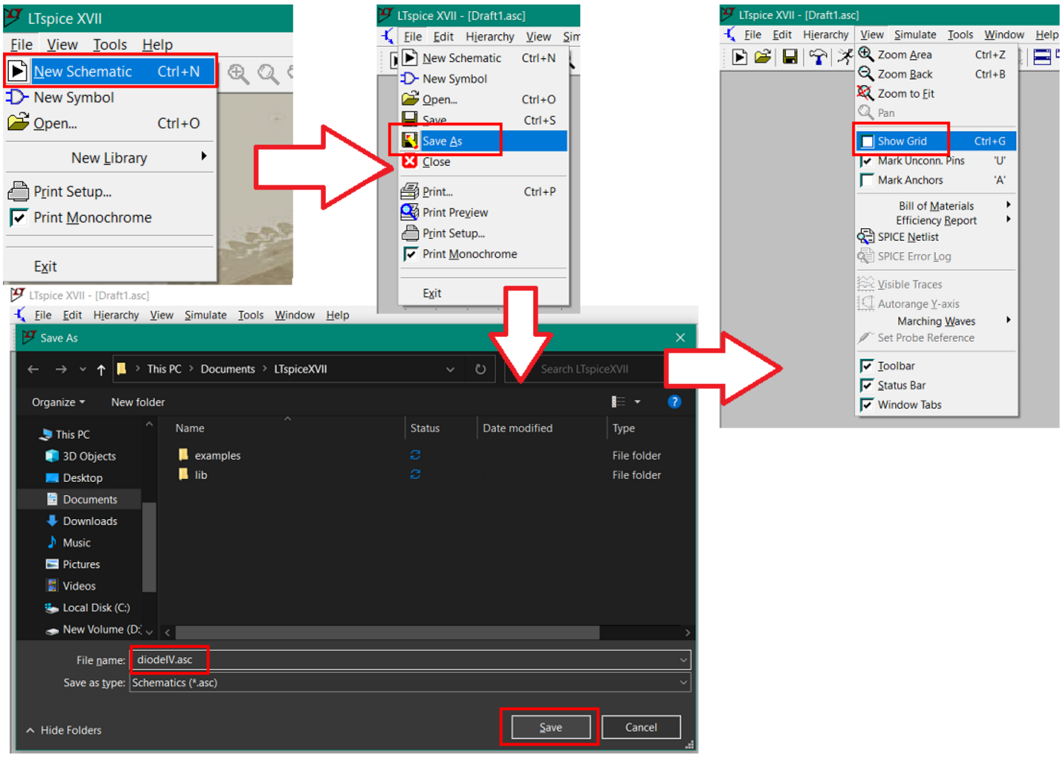

Figure 13: Step-1 and 2

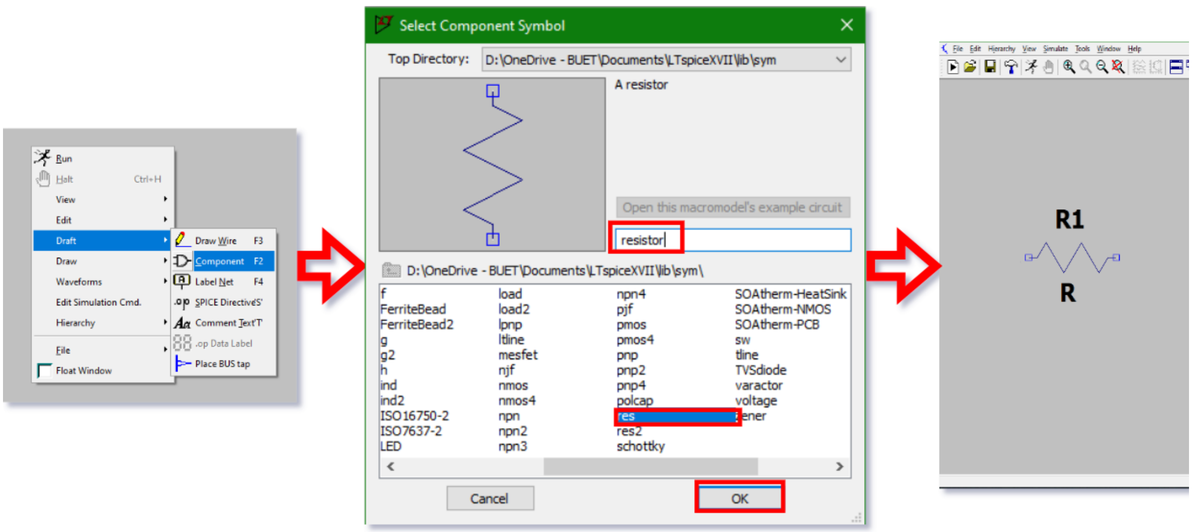

Figure 14: Step-3

3. Insert a resistor from component library. Right-click on blank space → Draft → Component. A Select Component Symbol window will open. Type the keyword for a component to be inserted. For this case, type 'resistor' → select the component → click OK → Press *ctrl + r* to rotate the resistor → place the diode in a blank space → Press ESC to get rid of the resistor.

4. Insert a diode. Type 'diode' in the Select Component Symbol window and place it in a blank space just like the resistor.

5. Type 'voltage' in the Select Component Symbol window to insert a voltage source and place it in a blank space. The schematic will look like the following figure.

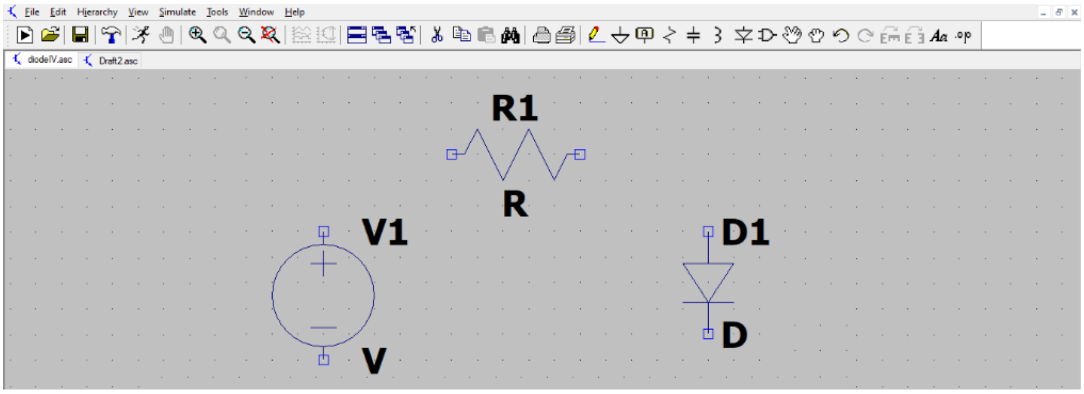

Figure 15: After Step-4 and 5

6. Now we need to connect the components using wire. Right-click on blank space → Draft → Draw Wire Or, Press F3. The cursor will change into a crosshair i.e. similar to '+' sign as shown in the following figure.

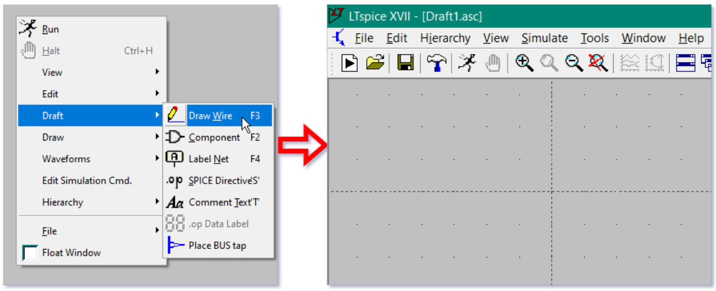

Figure 16: After Step-6

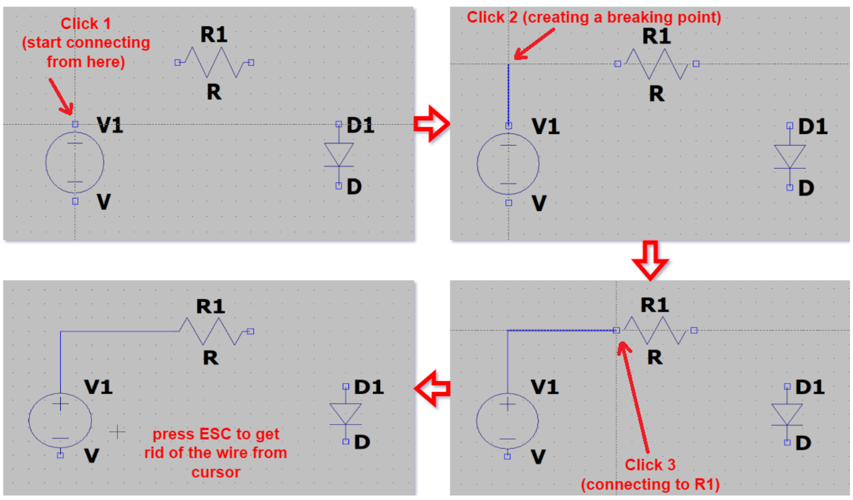

Figure 17: After Step-7 and 8

7. Click on one of the terminals (small squares attached to a component) to start connecting. For example, Figure-17 shows the steps to connect the voltage source to the resistor R1.

8. Press ESC to get rid of the wire from cursor.

9. In this way, wire all of the components together.
10. Now, place a ground in the circuit. Press ‘g’ in your keyboard → place the ground in a blank place → connect it to the circuit using wire as described previously. The circuit will look like the following figure.

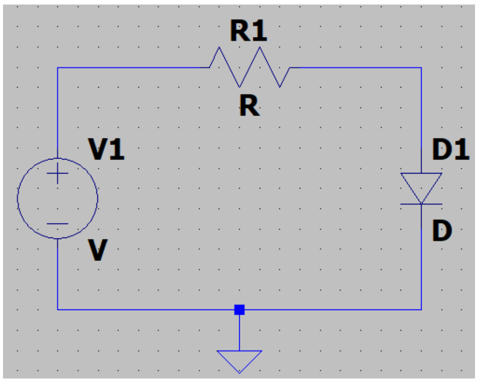

Figure 18: After Step-9 and 10

11. Now we need to set the value of the components. To set the resistance of a particular resistor (for example R1), hover the cursor on the resistor. The cursor will change into a hand. Right click on it. It will open up a new window for different specs of the resistor R1. Type 1k for Resistance [Ω]. Leave the other fields as it is and Click OK. This will set R1 as 1 kΩ.

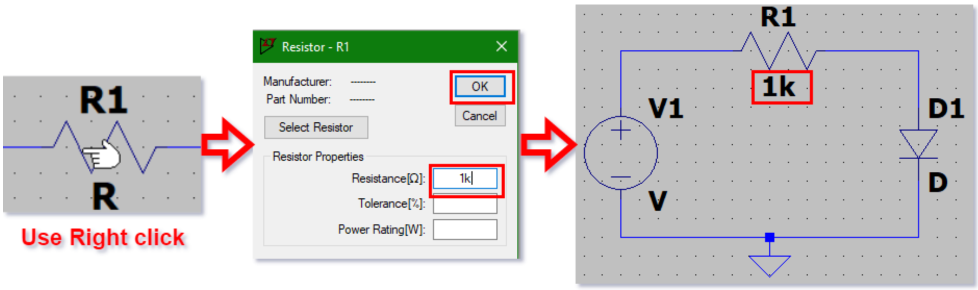

Figure 19: After Step-11

12. Now Right-click on the diode to open the property window. Pick New Diode → Select 1N4148 by looking in the Part No. → Click OK.

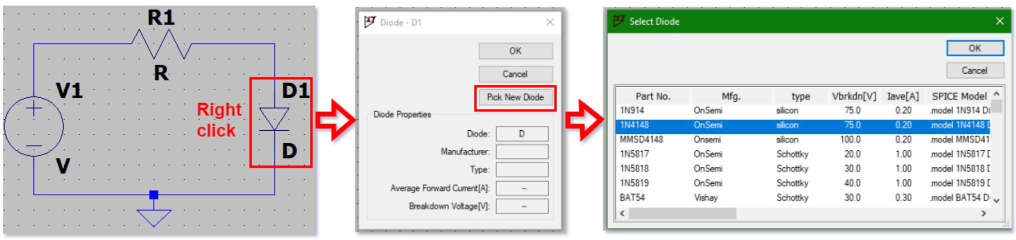

Figure 20: Step-12

13. To simulate the I-V characteristics of the diode, we need to vary the voltage applied to the circuit. Before that, we need to set an arbitrary value for the voltage. To do this, hover the cursor over it → right click. This will open a setting window for the voltage source. Type ‘5’ in the DC Value [V] field and Click OK. This will set the voltage source as 5 V DC.
14. Labelling nodes: We will now label the circuit nodes. This helps in keeping track of voltages. To label a node, Right-click on blank space → Draft → Label Net Or, Press F4. A Net Name window will open. Type ‘Vd’ in the box and click OK. Place the label Vd as shown in Figure-22. Then Vd denotes the potential difference between across the diode. The node variables are case-insensitive.

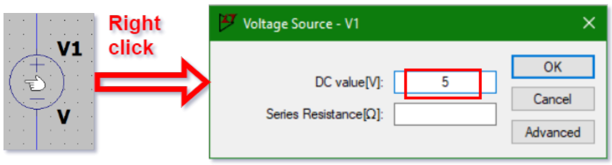

Figure 21: Step-13

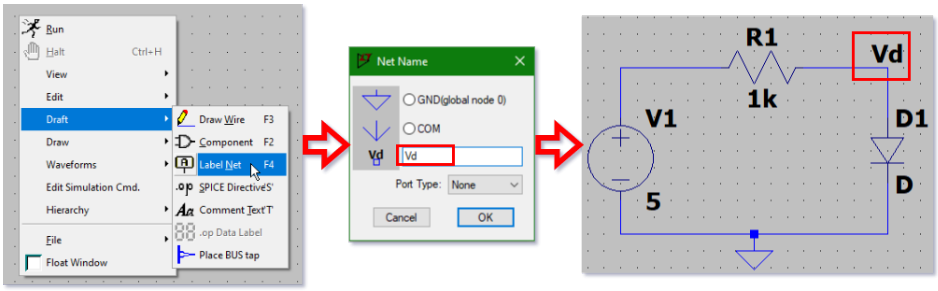

Figure 22: Step-14

15. Running the simulation: Now we are all set to run the circuit to observe the I-V characteristics of the diode. Right-click on blank space → 'Edit Simulation Cmd.' which opens the 'Edit Simulation Command' window.

16. In the Edit Simulation Command window, go to the 'DC sweep' tab. In the '1st source' tab write 'V1' in the 'Name of 1st source to sweep' field. Select the 'Type of sweep' as 'Linear'. Fill up the following fields as 'Start value' = 0, 'Stop value' = 10, 'Increment' = 0.001 and Click OK. Place the command anywhere within the grey interface. The input voltage (V1) is linearly varied from 0 V to 10 V with an increment of 0.001 V.

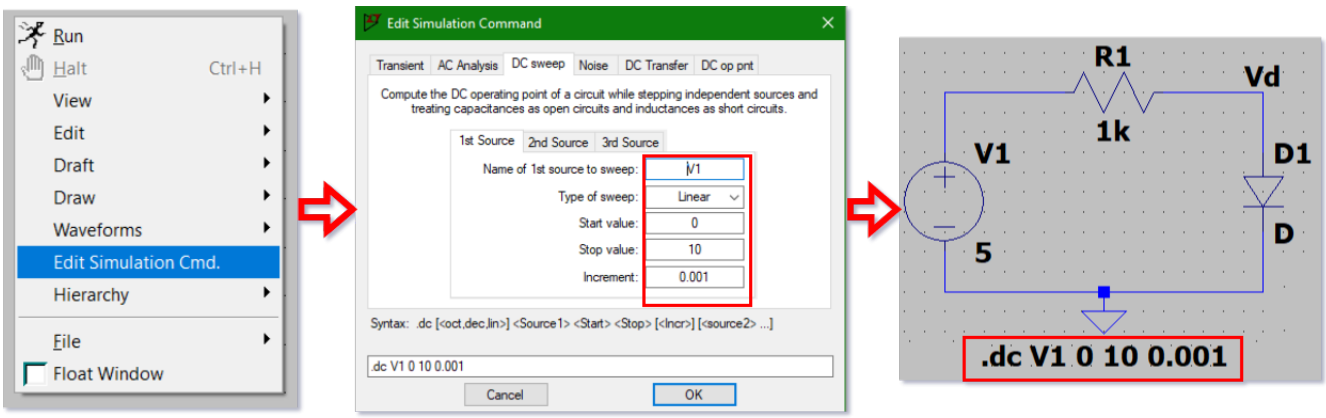

Figure 23: Step-15 and 16

17. To run the simulation, Right-click on blank space → Run. This opens a plot window (diodeIV.raw).

18. To plot the current through the diode, Right click on the black area → Add Traces. This will open a window where all the node voltages and the elemental currents are listed. Select I(D1) or I(R1) or I(V1) and then Click OK. You will get a plot like Figure-24. Note that this is not the I-V curve for the diode. The varying source voltage is plotted in the horizontal axis. We have to plot I(D1) vs Vd.

19. Alternately, a voltage or current can be plotted by selecting first the circuit window and hovering the cursor over any node to view the voltage at that node or over any element to view the current flowing through that element. Left clicking will plot the particular current/voltage.

20. To plot the diode voltage along the horizontal axis, hover the cursor over the horizontal axis. The cursor changes into a ruler. Use the Right click. It will open a property window for the axis. Write 'V(Vd)' in the 'Quantity Plotted' field and Click OK. Right click on the plot → View → Check the Grid. This is the I-V characteristics of diode which can be seen in Figure-25.

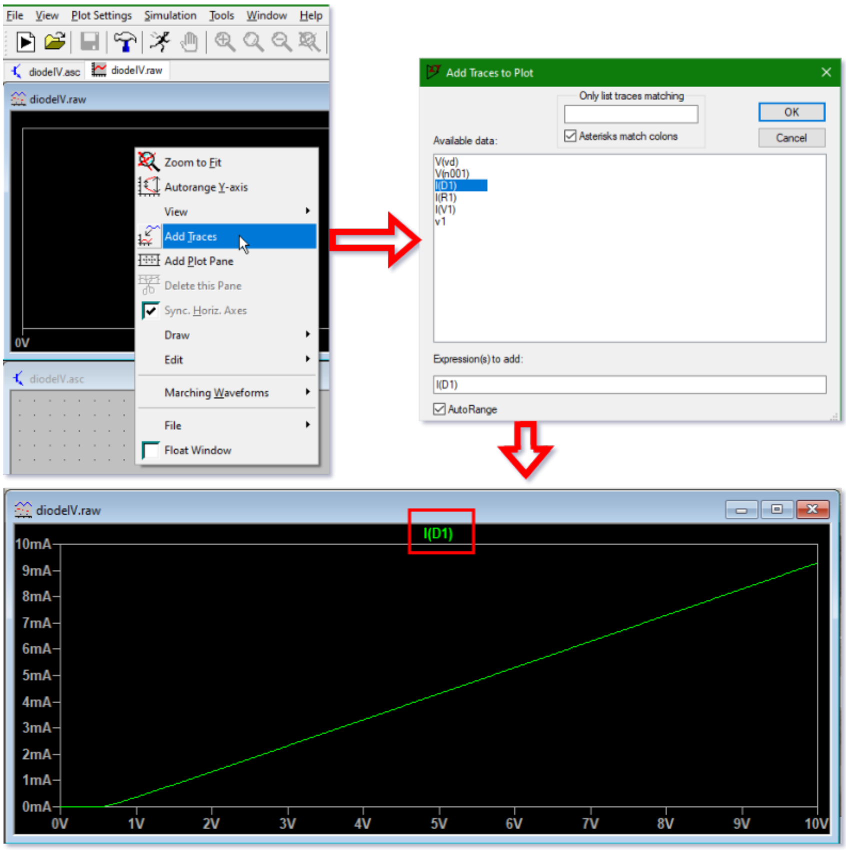

Figure 24: Step-17 and 18

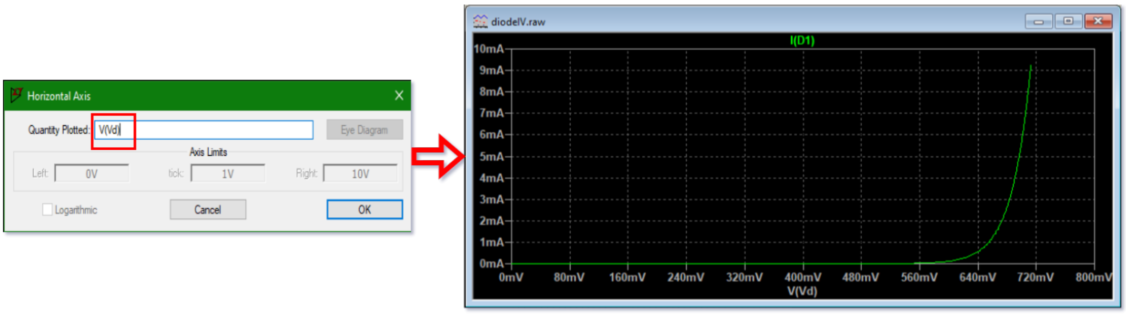

Figure 25: Step-20

21. To see values at different positions in a plot, Left-click on the label of the trace. This enables the data cursor. Click and drag the cursor. The attached window shows the cursor coordinates which can be seen in Figure-26.

22. To mark a data point, Right click on the plot → Draw → Cursor Position. The colour of the data point indicator can be changed by right-clicking on it. Figure-27 demonstrates the data point marking.

23. The plots can be saved for future use and analysis by selecting the plot window → File → Save Plot Settings As → Name.plt.

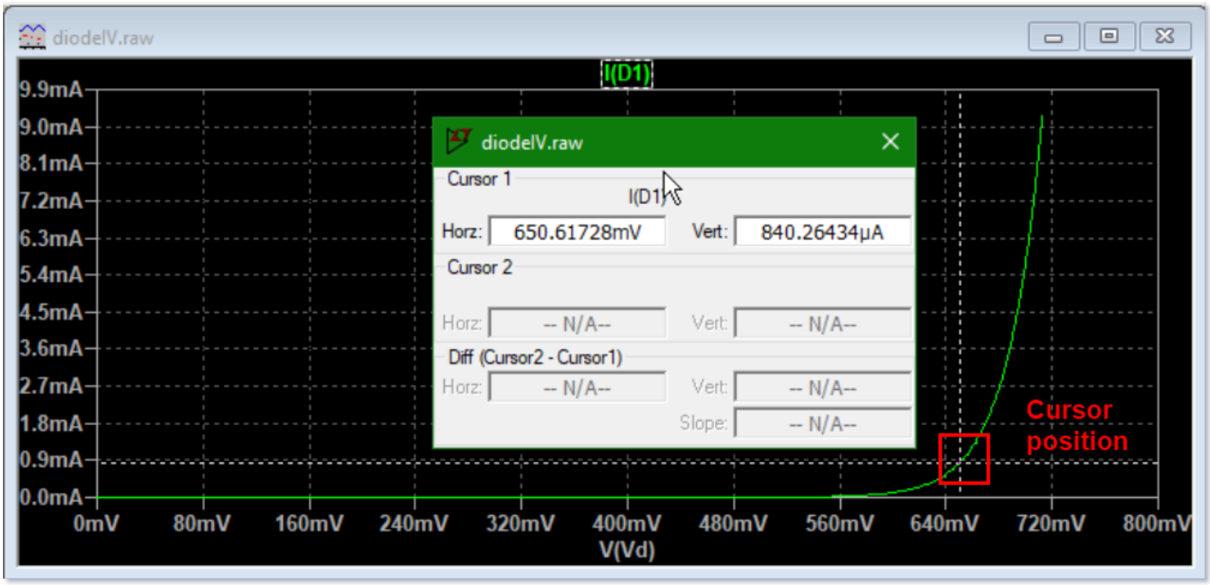

Figure 26: Step-21

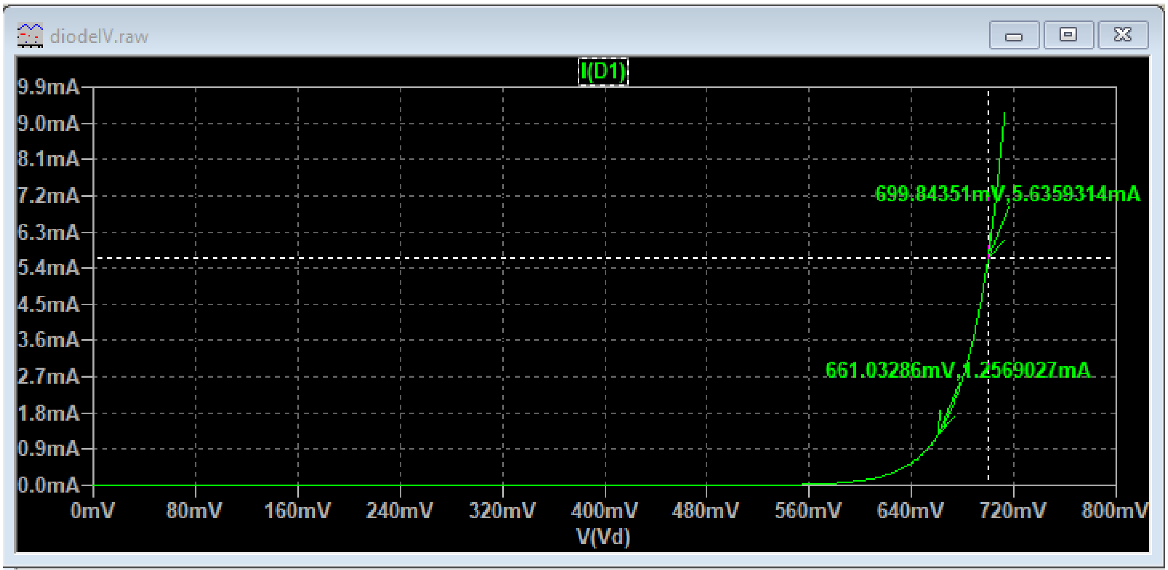

Figure 27: Step-22

Task-04: REPORT

1. Cover page [include course code, course title, name, student ID, group, semester, date of performance, date of submission]
2. Circuit Diagram
3. Signed data sheet and calculation
4. Graph from Task-02 and calculated parameters (I_S and n) from the graph
5. Simulate the circuit in LTspice with R = [2 + (last 2-digits of your ID / 10)] $k\Omega$. Attach the IV graph in the report. Do you see any change in the graph? Explain
6. Discussion