EE 236: Experiment No. 3
I-V and C-V Characteristics of Solar Cell

Vinamra Baghel, 190010070

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1 Overview of the experiment

1.1 Aim of the experiment

The following were the aims of the experiment:

- To plot and measure the I-V characteristics of a solar cell under different illumination levels and find the *fill factor*.
- To plot and measure the I-V characteristics of a solar cell and estimate its *doping concentration* and *built-in potential*.

1.2 Methods

The method overview includes constructing circuit netlists according to the given circuits in the handout for each part, simulating them using *dc* analysis and calculating required parameters for all parts. The first two parts required us to plot the I-V Characteristics of a solar cell while the second part also required us to plot the Power-voltage characteristics. Third part included calculation of *fill factor* whereas the fourth part dealt completely with simulation and calculations related to diode capacitance in reverse bias.

2 Design

2.1 Part 1

The netlist for each of the three cases, described below, included a dedicated 100Ω resistor, and the solar cell with the input voltage common for the three parallel sub-circuits and was written according to the following circuit.
The three cases were based on different levels of illumination:

- Dark. $IL = 0$.
- Light generated current, $IL = 8$ mA.
- $IL = 10$ mA.

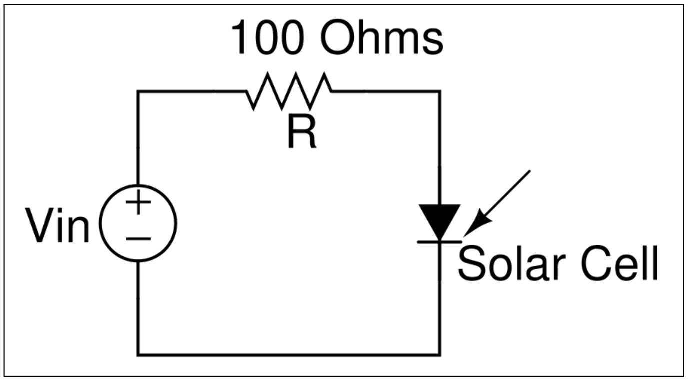


Figure 1: The I-V Characterization Circuit

DC analysis was performed by varying V_{in} from -2V to 2V in steps of 0.01V to obtain the I-V characteristics. The ideality factor, η, was found using the following equation:

$$\frac{ln(I_{D2}) - ln(I_{D1})}{V_{D2} - V_{D1}} = \frac{1}{\eta V_T}$$

2.2 Part 2

In this part, the solar cell was used as the power source. The illumination level was chosen as $IL = 10$ mA. The netlist is simple with just the solar cell and load resistor.

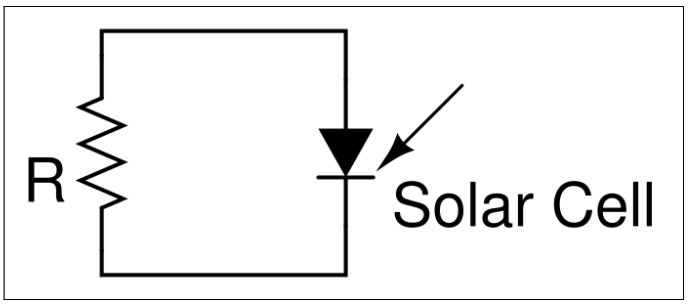


Figure 2: I-V Characterization Circuit

DC analysis was performed by varying the load resistance from 1 to 500 Ω in steps of 0.1 Ω. $I_D - V_D$ and $P_R - V_D$ characteristics were plotted, where $P_R = I_R * V_R$. The short-circuit current, I_{SC}, and open-circuit voltage, V_{OC}, were obtained from the former graph.

2.3 Part 3

Max-power current and voltage, I_{MP} and V_{MP} respectively, were obtained from the graphs in the previous part. The fill-factor, FF was obtained according to the relation:

$$FF = \frac{I_{MP} * V_{MP}}{I_{SC} * V_{OC}}$$

2.4 Part 4

The netlist was written according to the following circuit diagram. Here, the *device under test, DUT* is the solar cell. The solar cell is kept under no illumination ($IL = 0$ mA).

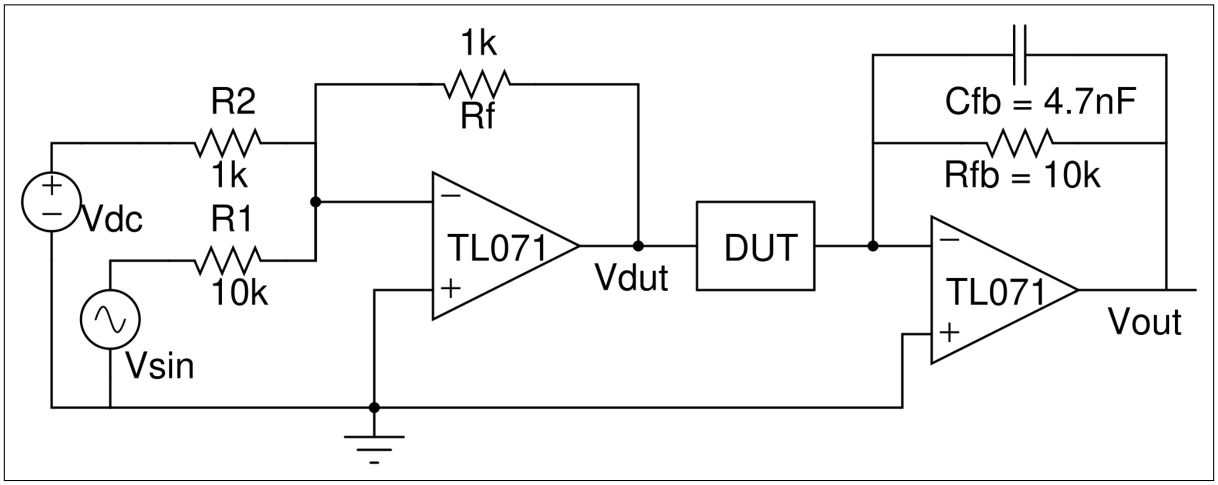


Figure 3: The Circuit

DC analysis was performed by varying V_{in} from 0 to 2V in steps of 0.01V to obtain the plot of junction capacitance, C_{DUT}, as varied against input dc voltage V_{DC}, and the $\frac{1}{C^2}$ vs V_{DUT} characteristics, where C is the normalized junction capacitance $= C_{DUT}/Area$.
The first plot of C_{DUT} was based on the equation:

$$\left|\frac{V_{out}}{V_{DUT}}\right| = \frac{C_{DUT}}{C_{fb}} \frac{1}{\sqrt{1 + \frac{1}{(\omega R_{fb} C_{fb})^2}}}$$

The second plot, that of $1/C^2$ vs V_{DUT} was plotted directly by taking area as 16 cm^2. Its linear region was used to find the Doping Density, N_D, and Built in Voltage, V_{bi}, according to the following equation:

$$\frac{1}{C^2} = \frac{2}{q\epsilon_0\epsilon_{Si}N_D}(V_{bi} - V_R)$$

where, $\epsilon_{Si} = 11.68$.

3 Simulation results

3.1 Code snippets

3.1.1 Part 1

```
Vinamra Baghel 190010070 IV Characteristics Part 1
.include Solar_Cell.txt

*Netlist
r1 in out1 100
X1 1 gnd solar_cell IL_val = 0
Vd1 out1 1 0
r2 in out2 100
X2 2 gnd solar_cell IL_val = 8e-3
Vd2 out2 2 0
r3 in out3 100
X3 3 gnd solar_cell IL_val = 10e-3
Vd3 out3 3 0
Vin in gnd 0

*Analysis
.dc Vin -2 2 0.01
.control
run
set color0 = white
set color1 = black
set color2 = red
set color3 = blue
set color4 = green
set xbrushwidth = 2
plot I(Vd1) vs V(1) I(Vd2) vs V(2) I(Vd3) vs V(3)
meas dc i11 find I(Vd1) when V(1) = 500m
meas dc i21 find I(Vd2) when V(2) = 500m
meas dc i31 find I(Vd3) when V(3) = 500m
meas dc i12 find I(Vd1) when V(1) = 450m
meas dc i22 find I(Vd2) when V(2) = 450m
meas dc i32 find I(Vd3) when V(3) = 450m
let il11 = log(abs(i11))
let il21 = log(abs(i21 + 8m))
let il31 = log(abs(i31 + 10m))
let il12 = log(abs(i12))
let il22 = log(abs(i22 + 8m))
let il32 = log(abs(i32 + 10m))
let e1 = 50m/(26m*(il11-il12))
let e2 = 50m/(26m*(il21-il22))
let e3 = 50m/(26m*(il31-il32))
print e1 e2 e3
.endc
.end
```

3.1.2 Part 2

```
Vinamra Baghel 190010070 IV Characteristics Part 2
.include Solar_Cell.txt

*Netlist
r1 2 1 1
X1 1 gnd solar_cell IL_val = 8e-3
Vd1 2 gnd 0

*Analysis
.dc r1 1 500 0.1

.control
run
set color0 = white
set color1 = black
set color2 = red
set xbrushwidth = 2

plot I(Vd1) vs V(1)
let Vr = V(2)-V(1)
plot I(Vd1)*Vr vs V(1)
plot I(Vd1)*Vr vs I(Vd1)
.endc
.end
```

3.1.3 Part 4

```
Vinamra Baghel 190010070 Part 4
.include TL071_1.cir
.include Solar_Cell.txt

*Netlist
X1 gnd n1 pp nn dut1 TL071
X2 gnd dut2 pp nn out TL071
X3 dut1 dut2 solar_cell IL_val = 0
r1 in1 n1 10k
r2 in2 n1 1k
rf n1 dut1 1k
rfb dut2 out 10k
cfb dut2 out 4.7n
Vpp pp gnd 15
Vnn nn gnd -15
Vdc in2 gnd 2
Vsin in1 gnd sin(0 0.5 1k 0 0 0)

*Analysis
.dc Vdc 0 2 0.01

```

```
.control
run
set color0 = white
set color1 = black
set color2 = red
set color3 = blue
set xbrushwidth = 2
plot abs(V(out)/(V(dut2)-V(dut1)))*4.7n*3.530844 vs V(in2)
let C_dut = abs(V(out)/(V(dut2)-V(dut1)))*4.7n*3.530844
let area = 100u
let C_norm = C_dut/area
plot 1/C_norm^2 vs V(dut1)-V(dut2)
.endc
.end
```

3.2 Simulation results

3.2.1 Part 1

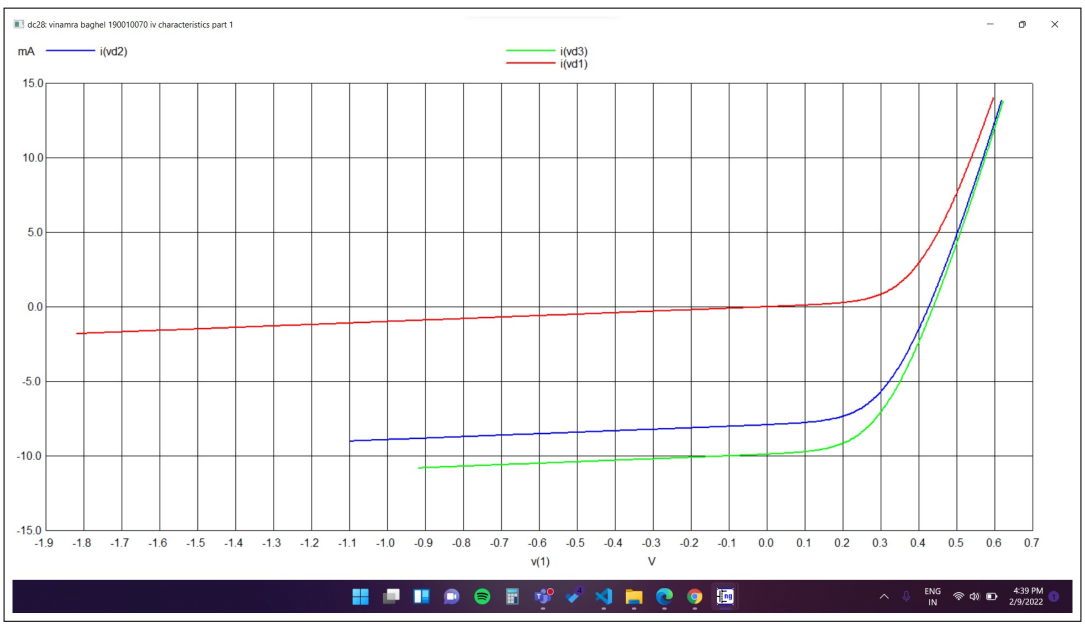
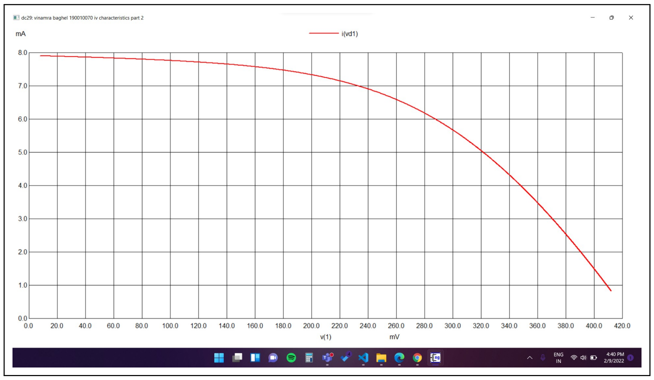


Figure 4: I-V Characteristics

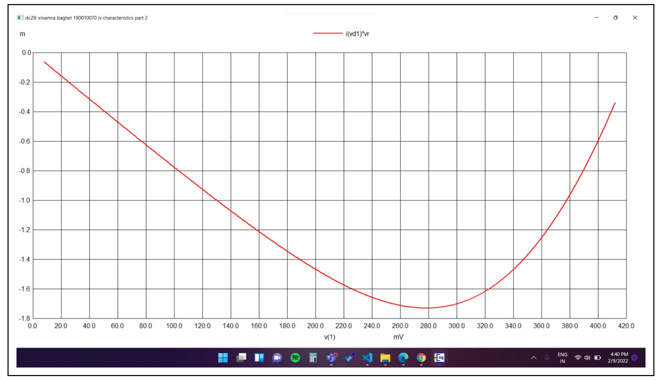
Shown above were the I-V characteristics obtained for the solar cell in the three different illumination levels. Index:

- **Red:** Dark ($IL = 0$ mA)
- **Blue:** $IL = 8$ mA
- **Green:** $IL = 10$ mA

3.2.2 Part 2



(a) $I_D - V_D$ characteristics



(b) $P_R - V_D$ characteristics

Figure 5: Plots of Part 2

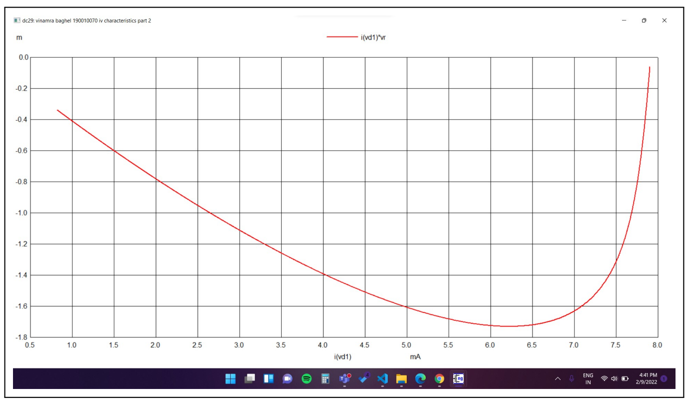


Figure 6: $P_R - I_D$ characteristics

Above are characteristic plots obtained for the given circuit in Part 2. The first plot was used to obtain I_{SC} and V_{OC}. The second and third plots were used to obtain V_{MP} and I_{MP} respectively.

3.2.3 Part 4

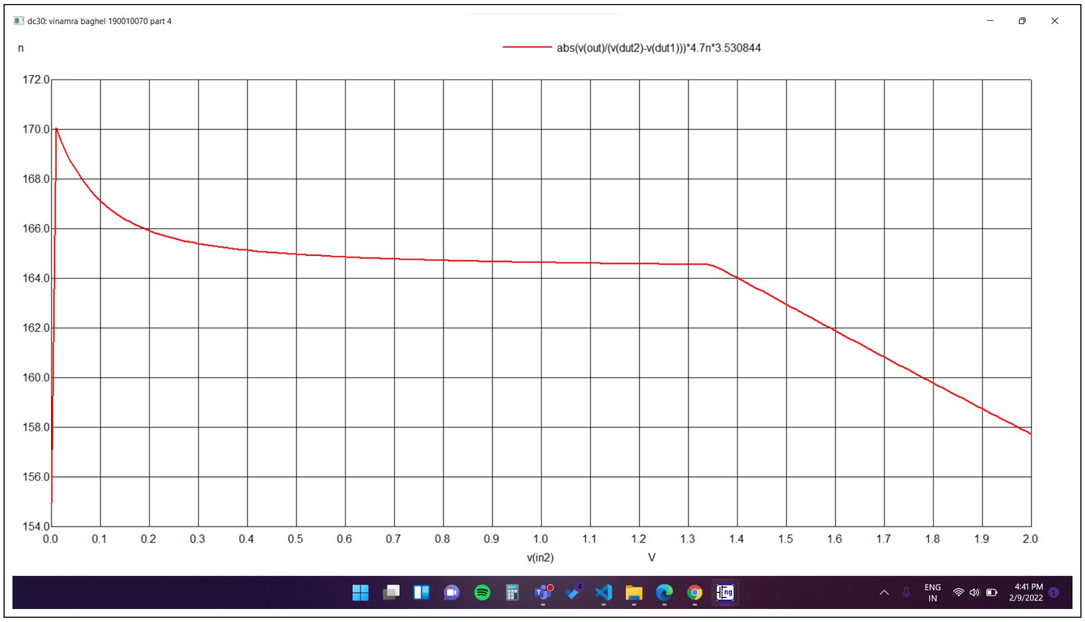


Figure 7: C_{DUT} vs V_{DC}

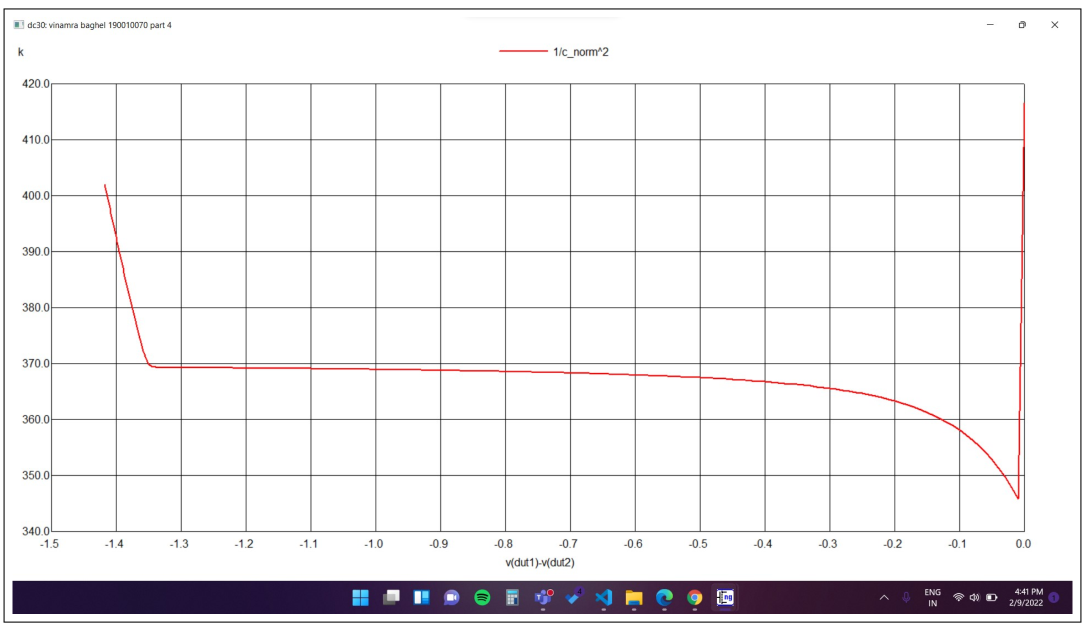


Figure 8: $1/C^2$ vs V_{DUT}

Above are plots for Part 4. Explanation for both has been written in the Design section. The linear part of the second plot was used to find the Doping Density and Built-in Voltage.

4 Experimental results

The following ideality factor, η values were obtained for the solar cell under different illumination levels:

Illumination Level (in mA)	**Ideality Factor (η)** (in V^{-1})
0	**4.502**
8	**6.318**
10	**6.839**

The maximum power point, short-circuit and open circuit values were obtained as:

- $V_{MP} = 278.55$ mV
- $I_{MP} = 6.23$ mA
- $I_{SC} = 7.92$ mA
- $V_{OC} = 420$ mV

The Fill Factor was found to be, $FF = \mathbf{0.522}$.
Equation of the linear region of 2nd plot of part 4 is:

$$y = -552791.59756771x\text{–}380967.38529574$$

Hence, Doping Density, $\mathbf{N_D = 8.541 \times 10^{17} cm^{-3}}$, and Built-in Voltage, $\mathbf{V_{bi} = 1.451V}$.

5 Experiment completion status

I could complete all the parts of the lab. There was no hardware involvement as it was all simulation based. The results were shown to the TA and then submitted.