EE236: Experiment No. 3
I-V and C-V Characteristics of Solar Cell

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February 12, 2022

1 Overview of the experiment

1.1 Aim of the experiment

Aim of this experiment is to analyze the forward bias I-V and C-V characteristics of Solar Cell. How to use solar cell as a power source.
To calculate the Fill Factor using I-V plot and also doping concentration as well as built-in potential of solar cell using the C-V plot.

1.2 Methods

Firstly, I read and understood the background theory of Solar Cell. Then, I wrote the netlist for simulation model and simulated forward bias solar cell for various values of light generated current (I_L) and plotted I_d vs V_d graphs using dc analysis. Then, I simulated the solar cell as power source configuration, plotted I-V and P-V plots and calculated the Fill Factor. Finally, I simulated Circuit given in Part 4 to plot the C-V characteristics of solar cell.

2 Design

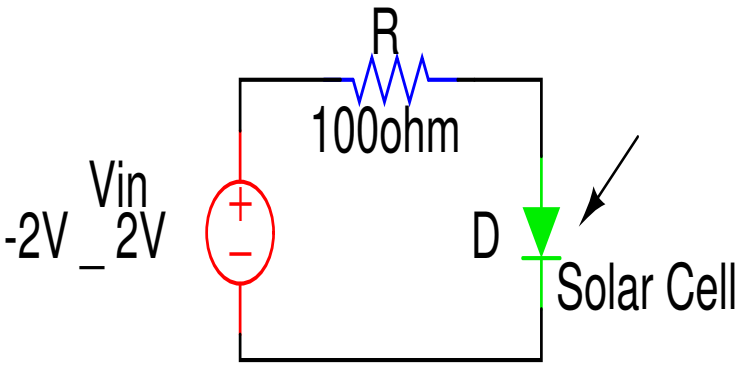

Fig 1. : I-V Characteristics of Solar Cell

The circuit in Fig. 1 is for the I-V characteristics simulation of Solar Cell. I did DC analysis for input voltage from -2V to 2V. The Solar Cell is forward biased. I simulated the circuit for 3 different values of light generated current I_L namely 0A, 8mA and 10mA.

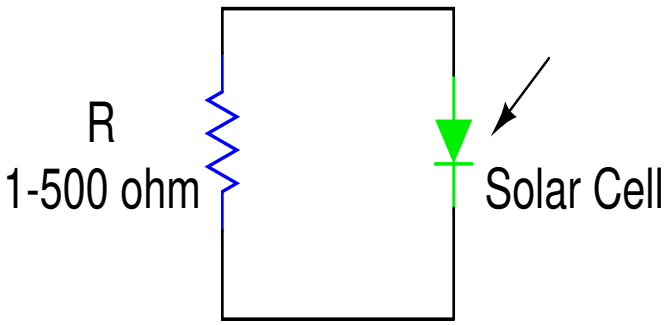

Fig 2. : I-V Characteristics of Solar Cell as a power source

This circuit represents I-V Characteristics of Solar Cell as a power source. I did a DC analysis for resistance from 1 Ω to 500 Ω. Then, I measured the I-V characteristics of the circuit for 8mA and 10mA light generated current. V_{OC} is the rightmost point on the I-V curve whereas I_CS is the leftmost point on the curve. Lastly, I plotted P-V graph and calculated the Fill Factor using the following formula.

$$\text{Fill Factor (FF)} = I_{MP} * V_{MP}/(I_{SC} * V_{OC}) \tag{1}$$

[where, V_{MP} is the voltage at which the power P reaches maximum and I_{MP} the current at the maximum power point.]

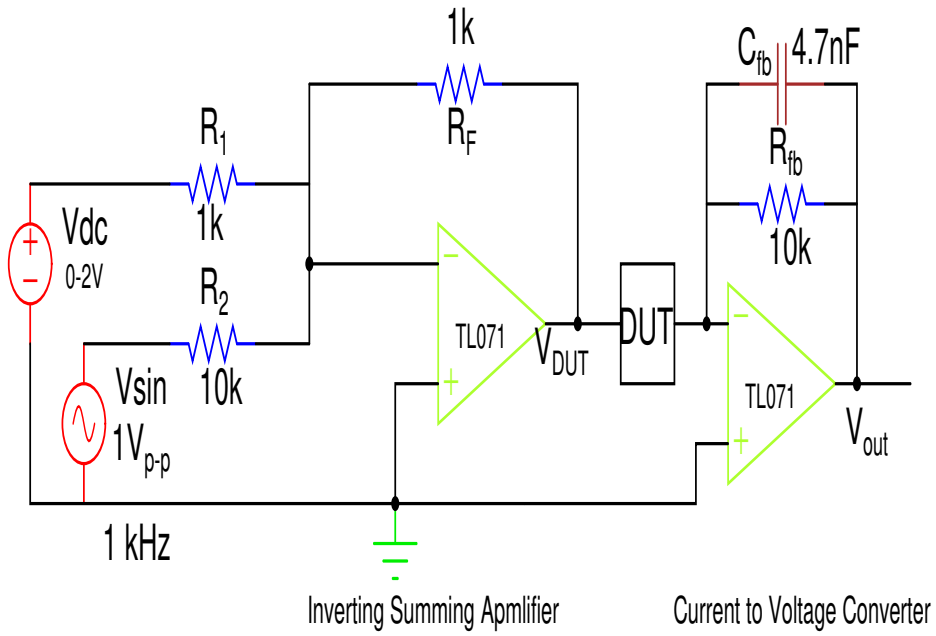

Fig. 3 : C-V Characteristics of Solar Cell

The circuit in Fig. 3 is for the C-V characteristics simulation of Solar Cell. I did DC analysis for input voltage from 0V to 2V.
Then, I plotted C_{DUT} vs V_d graph using the given equation,

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

Finally, I plotted $\frac{1}{C^2}$ vs V_{DUT} graph using the given equation to find the values of Doping Density N_D (in terms of atoms/cm3) and Built in Voltage Vbi.

$$\frac{1}{C^2} = \frac{2}{q\epsilon N_D}(V_{bi} - V_R) \tag{3}$$

[where C is normalised junction capacitance = C_{DUT}/Area
consider Area = 1um x 1um (Hypothetical value)

V_R is Reverse diode voltage (= VDUT) and
$\epsilon = \epsilon_0 * \epsilon_{Si}$ (ϵ_{Si} =11.68)]

3 Simulation results

3.1 Code snippets

3.1.1 I-C Characteristics of Solar Cell :

```
Mayur Ware | 19D070070
*EE236 | Lab 3
*I-V Characteristics of Solar Cell
*Including Solar cell model file
.include Solar_Cell.txt
*Netlist
Vin In GND dc 0.01
Vx 1 2 dc 0
R1 In 1 100
X1 2 GND solar_cell IL_val=8e-3
*DC Analysis
.dc Vin 0.01 2 0.01
.control
run
set color0 = white
set color1 = black
set color2 = blue
set color3 = red
set xbrushwidth = 2
*Id vs Vd plot
plot I(Vx) vs V(2)
plot log(I(Vx)) vs V(2)
.endc
.end
```

3.1.2 Solar Cell as a power source :

```
Mayur Ware | 19D070070 *EE236 | Lab 3
*Voc and Isc measurement
*Including Solar cell model file
.include Solar_Cell.txt
```

```
*Netlist
Vx 1 2 dc 0
R1 0 1 100
X1 2 0 solar_cell IL_val=8e-3
*DC Analysis
.dc R1 1 500 0.01
.control
run
set color0 = white
set color1 = black
set color2 = blue
set color3 = red
set xbrushwidth = 2
plot I(Vx) vs V(2)
plot V(1)*I(Vx) vs V(2)
.endc
.end
```

3.1.3 Voltage Doubler :

```
Mayur Ware | 19D070070
*EE236 | Lab 3
*Including Model files
.include TL071.cir
.include Solar_Cell.txt
*Netlist
R1 1 3 10k
R2 2 3 1k
Rf 3 4 1k
Rfb 5 Out 10k
Cfb 5 Out 4.7n
X1 0 3 a b 4 TL071
X2 0 5 c d Out TL071
X3 4 5 solar_cell IL_val = 0e-3
*Voltages
Vdc 0 2 dc 0.01
Vsin 0 1 sin(0 1 1k 0 0)
Va 0 a dc 15
Vb 0 b dc -15
Vc 0 c dc 15
```

```
Vd 0 d dc -15
*DC Analysis
.dc Vdc 0 2 0.01
*Control Commands
.control
run
set color0 = white
set color1 = black
set color2 = blue
set color3 = red
set xbrushwidth = 2
let Cfb = 4.7n
let Rfb = 10k
let alpha = sqrt(1 + (1/(2*3.14*1000*Rfb*Cfb)2))
let Cdut = abs(((V(Out))*Cfb*alpha)/(V(4)))
plot Cdut vs V(2)
let ep = 8.85e-12*11.68
let q = 1.6e-19
let A = 16e-4
let C = Cdut/A
let y = C(-2)
plot y vs V(4)
.endc
.end
```

3.2 Simulation results

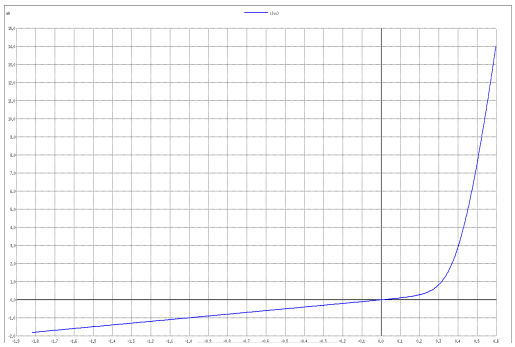

Fig. 4: I-V Characteristics of Solar Cell $I_L = 0A$

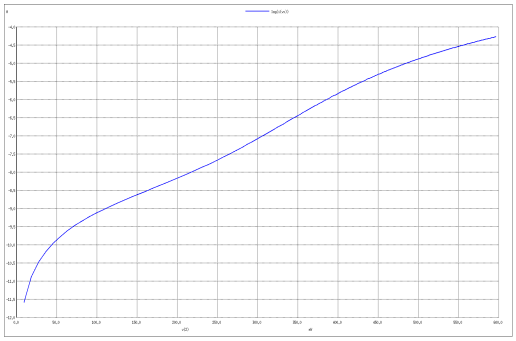

Fig. 5 : $\log(I_d)$ vs V_d for Solar Cell with $I_L = 0A$

Eta value for $I_L = 0A$ is 3.4803.

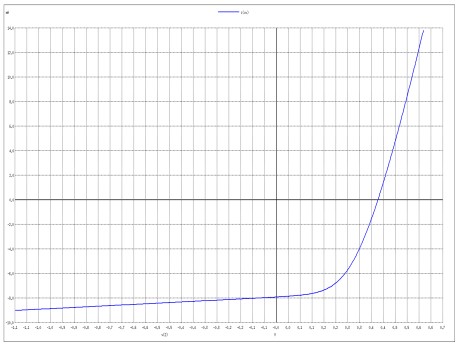

Fig. 6 : I-V Characteristics of Solar Cell $I_L = 8mA$

We can see that the graph is similar to the graph for $I_L = 0A$ but just shifted by 8mA in the negative y-axis.
Eta value for $I_L = 8mA$ is 6.8557.

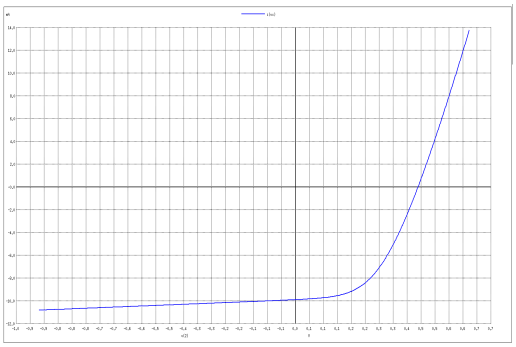

Fig. 6 : I-V Characteristics of Solar Cell I_L = 8mA

We can see that the graph is similar to the graph for I_L = 10mA but just shifted by 10mA in the negative y-axis.
Eta value for I_L = 10mA is 8.0169.

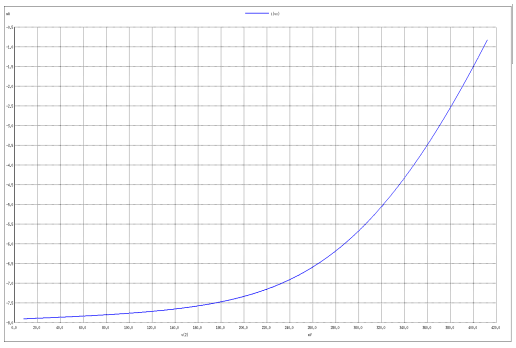

Fig. 7 : I-V Characteristics for Solar Cell as a power source

Graph of I-V Characteristics for Solar Cell as a power source is parabolic. The leftmost point on the curve is the short circuit condition (approx) as the voltage is approaching 0. Similarly, rightmost point on the curve is the open circuit condition (approx) as the current is approaching 0.
The experimental values are,

$$I_{SC} = -7.9mA$$

$$V_{OC} = 0.412V$$

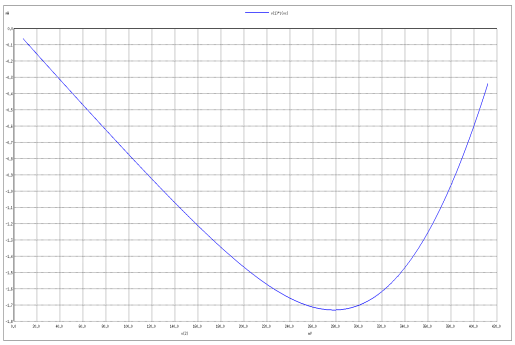

Fig. 8 : P-V Characteristics for Solar Cell as a power source

Graph of P-V Characteristics for Solar Cell as a power source first decreases almost linearly with the voltage and then increases. Power values are negative here as the circuit is emitting power. The lowest point on the graph has the maximum power emission.
Maximum power is product of I_{MP} and V_{MP} which is -1.7mW.

$$\begin{aligned}\text{Fill Factor (FF)} &= I_{MP} * V_{MP}/(I_{SC} * V_{OC}) \\ &= \frac{-1.7mW}{-7.9 * 0.412W} \\ &= \frac{1.7}{3.2} \\ &= 0.5312\end{aligned}$$

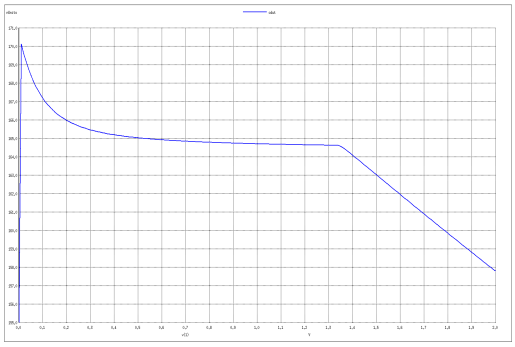

Fig. 9 : C-V characteristics of Solar Cell

Graph of C-V Characteristics of Solar Cell first increases sharply to it's maximum value, then decreases almost exponentially and eventually becomes linear.
Maximum value of C_{DUT} is 170.2 nF.

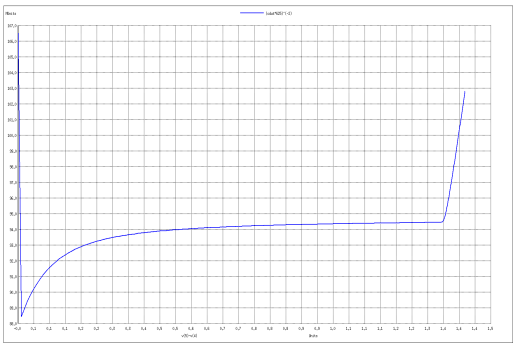

Fig. 7 : $\frac{1}{C^2}$ vs V graph of Solar Cell

$\frac{1}{C^2}$ vs V graph of Solar Cell is exactly opposite to the Graph of C-V Characteristics of Solar Cell. Minimum value of $1{\overline{C}}^2$ is 88.5 M F${\overline{m}}^2$.
Values of Doping Density N_D and Built in Voltage V_{bi} using the slope of straight line part of the graph are 6.98*10^{20} $\frac{atoms}{cm^3}$ and 0.63V respectively.

4 Experimental results

This section is not applicable for this experiment.

5 Experiment completion status

I have completed all sections as well as exercises in this lab.

6 Questions for reflection

This section is not applicable for this experiment.

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