Integrating solar cells simulation software in an Undergraduate Engineering Class

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Abstract

Numerical simulation of a photovoltaic (PV) devices is an essential method to find the optimum parameters of a viable model and to test the effects of the physical parameters on its performance. Solar Cell Capacitance Simulator (SCAPS) is a one- dimensional solar cell simulation program that has been developed by many researchers at the Department of Electronics and Information Systems (ELIS) of the University of Gent, Belgium. This user-friendly software can be used in teaching engineering undergraduate students about numerical simulations of photovoltaics. This paper will introduce the SCAPS software and outline a tutorial which introduces photovoltaic simulations to undergraduate students in an optoelectronics course. The paper will also provide examples on the ways the software can be used to enhance the learning experience for the students on topics related to solar cells design such as generating and interpreting the current -voltage plots and calculating the efficiency of different types of solar cells.

Keywords

SCAPS, Solar cell simulation, SCAPS tutorial

Introduction

Numerical simulation of a photovoltaic (PV) device is an essential method to find the optimum parameters of a viable model and to test the effects of the physical parameters on its performance. This article introduces the solar cell simulation software SCAPS.

Solar Cell Capacitance Simulator (SCAPS) is a one- dimensional solar cell simulation program that has been developed by many researchers at the Department of Electronics and Information Systems (ELIS) of the University of Gent, Belgium. SCAPS was originally designed for the cell structures of the CuInSe2 and the CdTe family but owing to the improvements on several extensions, this simulator can be used as a general polycrystalline thin- film device simulator for modelling CIS, CGS, CIGS based solar cells [1] in addition to crystalline solar cells (Si and GaAs family) and amorphous cells (a-Si and micromorphous Si) [2].

SCAPS

SCAPS is a windows program and few of its main features are listed below [1, 3]:

- Up to seven semiconductor layers can be added to the device
- Almost all physical parameters can be graded in a new window if required
- Ability to estimate steady- state band diagram, recombination profile and carrier transport

- Options for variable voltage bias, temperature and illumination
- Can calculate concentrations, and currents at a given working point, J- V, C-V, C-f and Q-V characteristics, AC characteristics, spectral response
- Can also simulate IB solar cells by modifying the absorption coefficient of the absorber layers
- Ability to calculate single and batch values
- Ability to output and export final and intermediate values, graphs and other important data

This paper will focus on a tutorial to design a silicon solar cell using SCAPS version 3.3.0.3. The schematic of the solar cell is shown in figure 1.

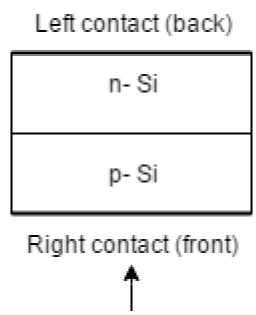

Figure 1: Schematic of silicon solar cell with the arrow indicating the direction of light.

The steps below outline the procedure of building the solar cell and generating the bandgap diagrams and the current-voltage curves of the solar cell.

SCAPS opens with a very intuitive "Action Panel" page which can be seen above in Figure 2. A solar cell can be designed by following the steps mentioned below:

1) Set problem

   Users have to first click on "Set problem" button (orange button towards the left of the screen) to define the cell layers. Upon clicking on the button, the "Solar Cell Definition Panel" opens up as shown in Figure 3.

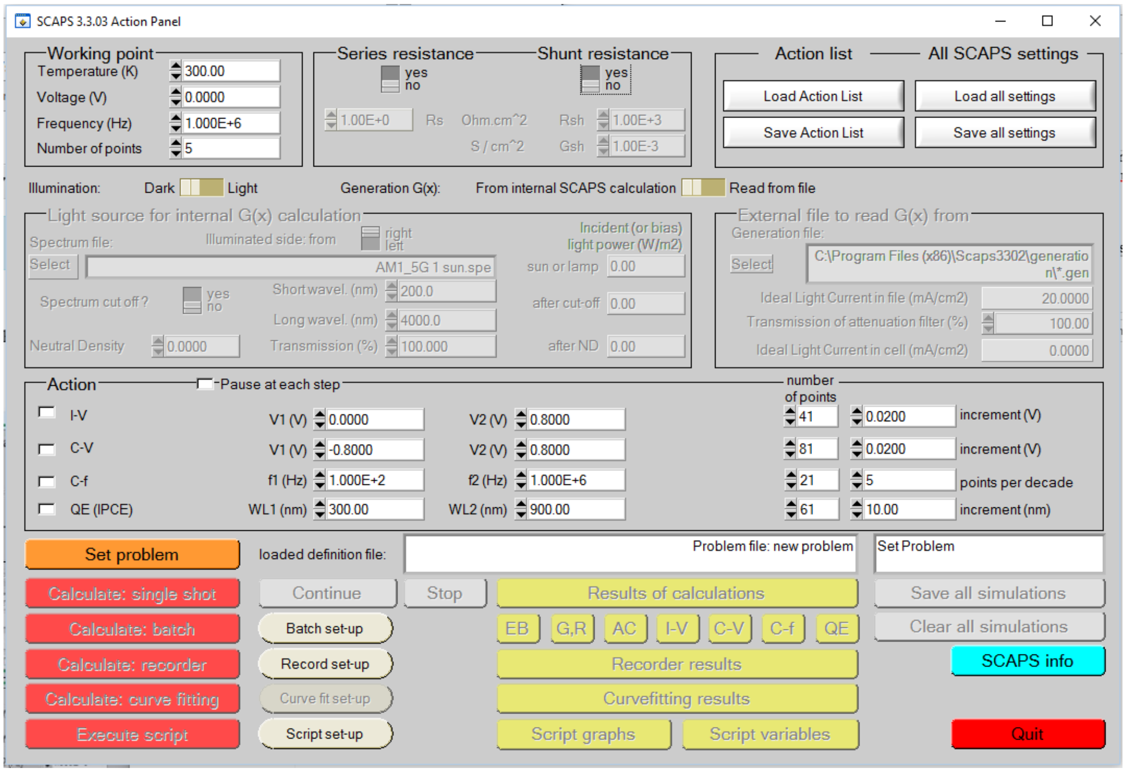

Figure 2: Action Panel of SCAPS 3.3.0.3.

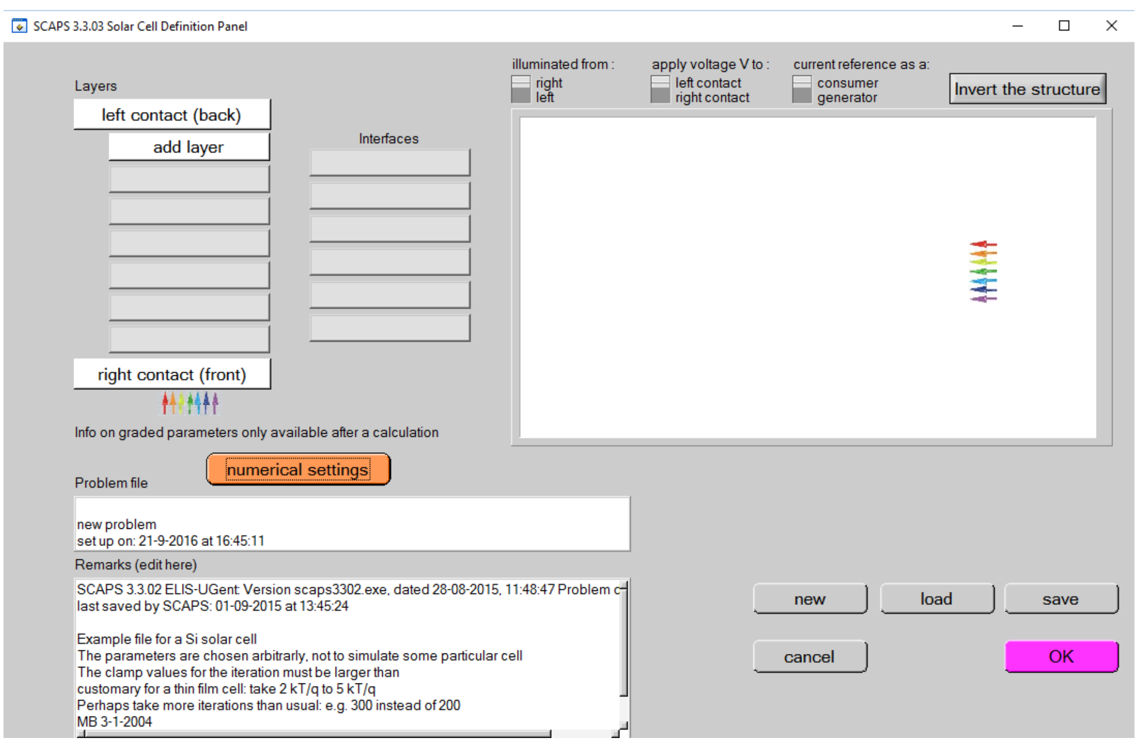

Figure 3: Solar Cell Definition Panel

2) Add layers

While on the Solar Cell Definition Panel, the user can either work with and modify a pre-defined cell design on the SCAPS library by clicking on the "load" button towards the bottom of the screen or users can also create a new design by adding layers and editing the left and right contacts.

For this problem, we will create our own design by clicking on the "add layer" button under the Layers section towards top left. The "Layer Properties Panel" lets the users set various parameters like thickness, bandgap, electron affinity, dielectric permittivity, CB and VB effective density of states, electron and hole thermal velocity, electron and hole mobility and donor and acceptor density. Apart from these basic parameters, users can also modify the absorption model, recombination model and add a defect to a layer. A screenshot of the Layer Properties Panel screen is shown below in Figure 4.

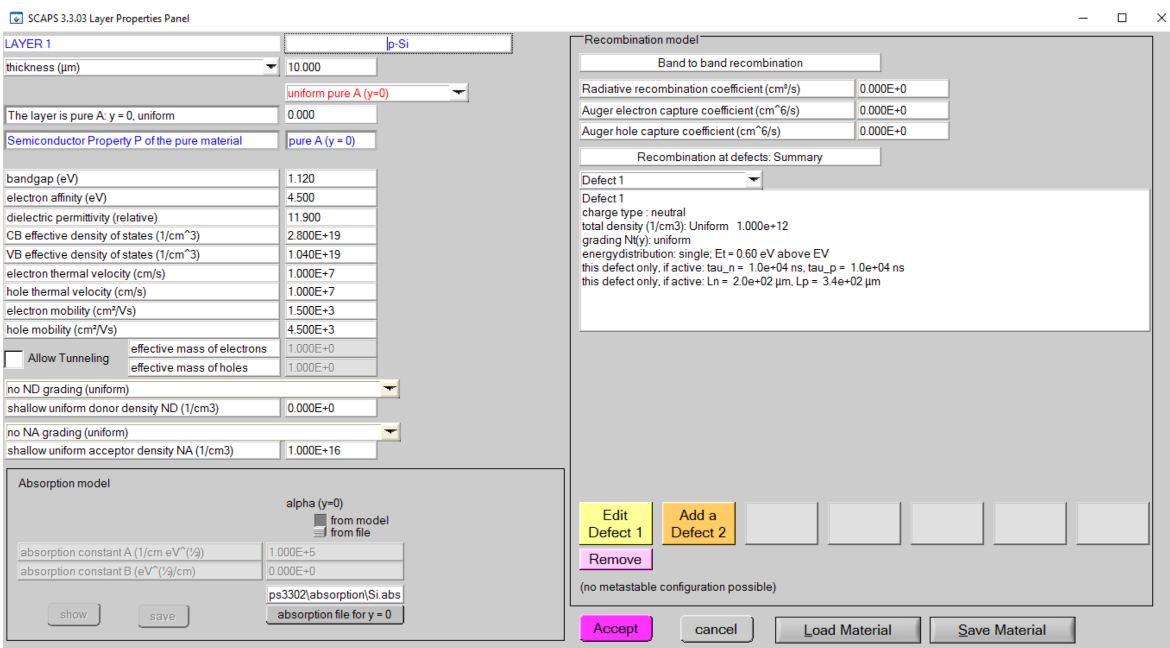

Figure 4: Layer Properties Panel

3) Modify contacts

Apart from adding the layers with desired physical parameters, the users can also modify the left and right contacts by editing the surface recombination velocity for both electrons and holes and adding the metal work function for the material of the contact. Users can also select the flat band option instead of adding a metal work function value. For the flat band calculations, the layer adjacent to the contact is considered; depending upon whether it is n-type or p-type or intrinsic type layers, and SCAPS automatically calculates the metal work function [4].

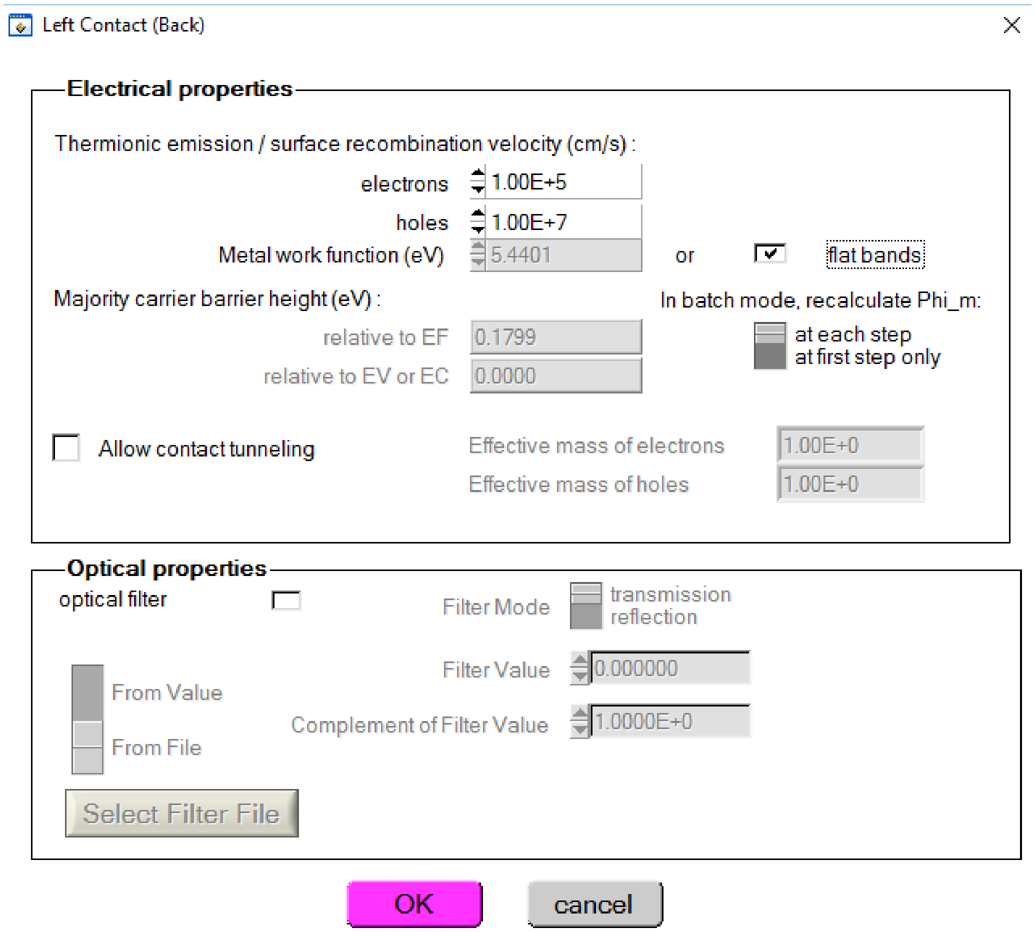

Figure 5: Window to edit electrical and optical properties for a contact.

4) Verify directions

Once the layers and contacts have been modified, the user should verify the direction of illumination and voltage application and set the current reference as consumer or generator. These options are towards the top right of the screen as shown in Figure 6.

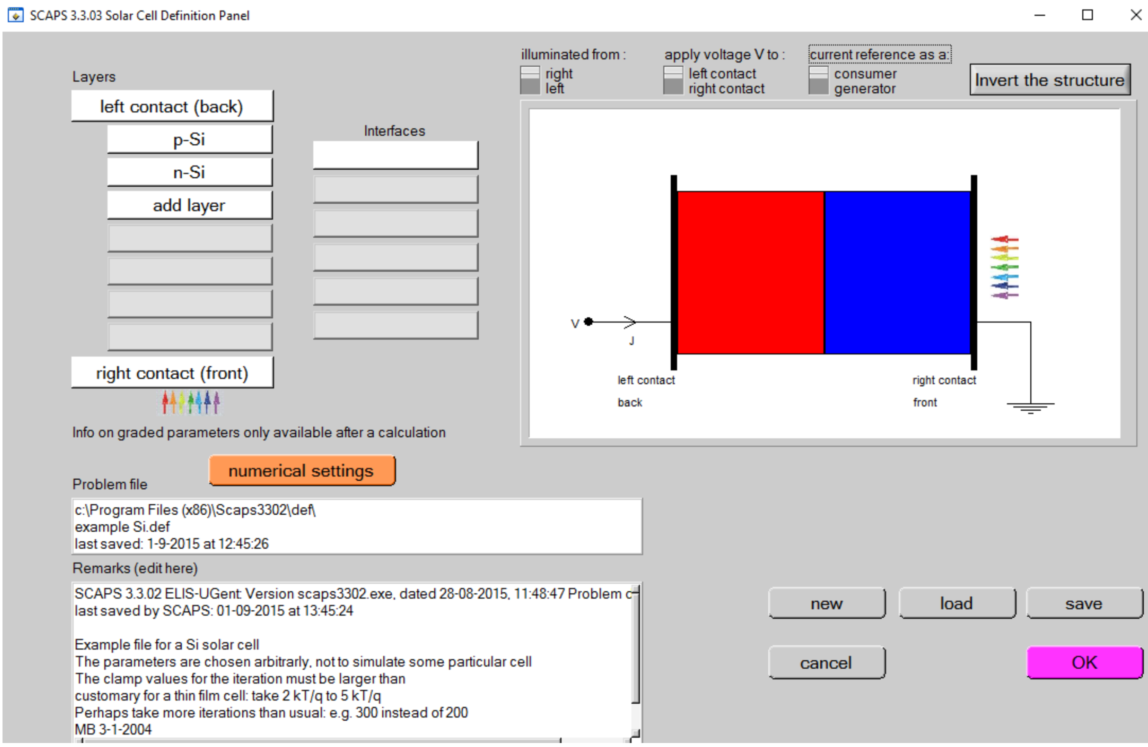

Figure 6: Solar Cell Definition Panel for Si solar cell.

5) Save .def file

After every detail of the solar cell design has been verified, users should save the file as a .def file and click on OK to go back to the SCAPS Action Panel.

6) Set working point

Once the solar cell design has been loaded on SCAPS using the Set Problem button, the users need to set the working point by setting the desired temperature, voltage, frequency, resistance and number of points.

The users can also edit the series and shunt resistance and modify the illumination settings after changing it from dark to light.

7) Select Action

After all the settings have been modified, the users need to select what they intend on calculating by clicking on the corresponding options and setting up the range under the Action tab which is in the center of the Action Panel window.

8) Calculate

To start the calculation, users have to click on one of the “Calculate” options colored in red under the Set Problem button. Since only one file has been loaded for this problem, the “single shot” option was selected. Upon clicking the button, Energy Bands Panel window open up with the band diagram, carrier density, current density and occupation probability of deep defects for electrons graph plots as shown in Figure 7 below.

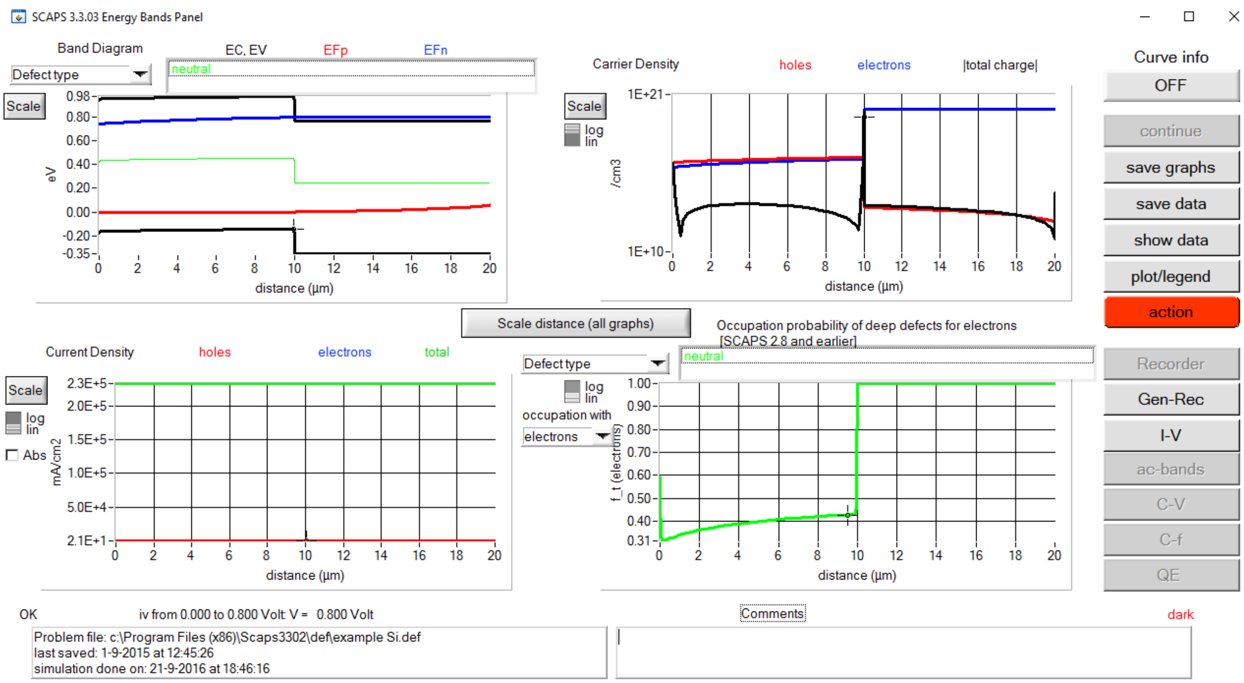

Figure 7: Screenshot of Energy Bands Panel window for the Si cell design.

9) Results of Calculations

Users can either click on options (Gen- Rec, I-V) from the right side of the Energy Bands Panel window or exit the window to click on options under the “Results of Calculations” button in yellow on the Action Panel window. Clicking on the I-V option opens the I- V panel. Users can also save graphs and export out of SCAPS as shown in figure 8 as JPEG, PNG or BMP files.

10) The user can also chose to simulate the performance of the solar cell under illumination by clicking “Light” on the action panel. The program will then output an I-V curve under illumination which the user can use to calculate the efficiency of the solar cell. Figure 9 shows the I-V curve of the solar cell under illumination.

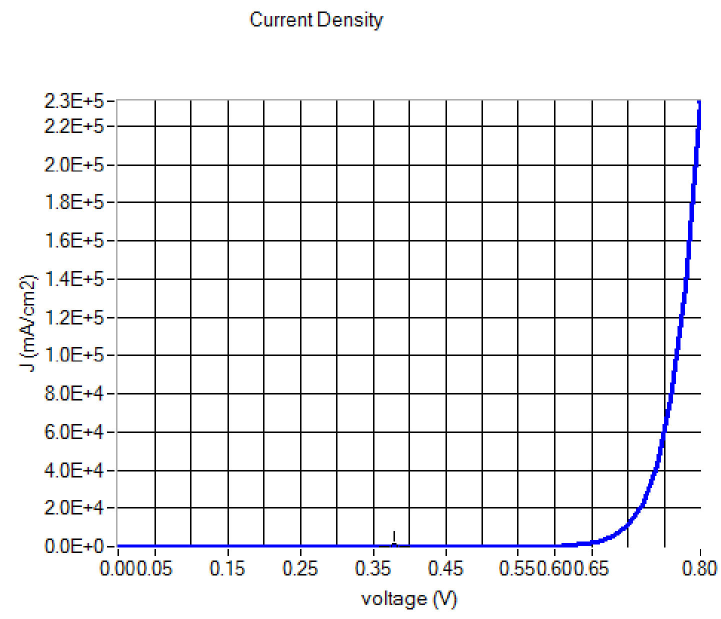

Figure 8: I-V curve of the solar cell under darkness exported from SCAPS.

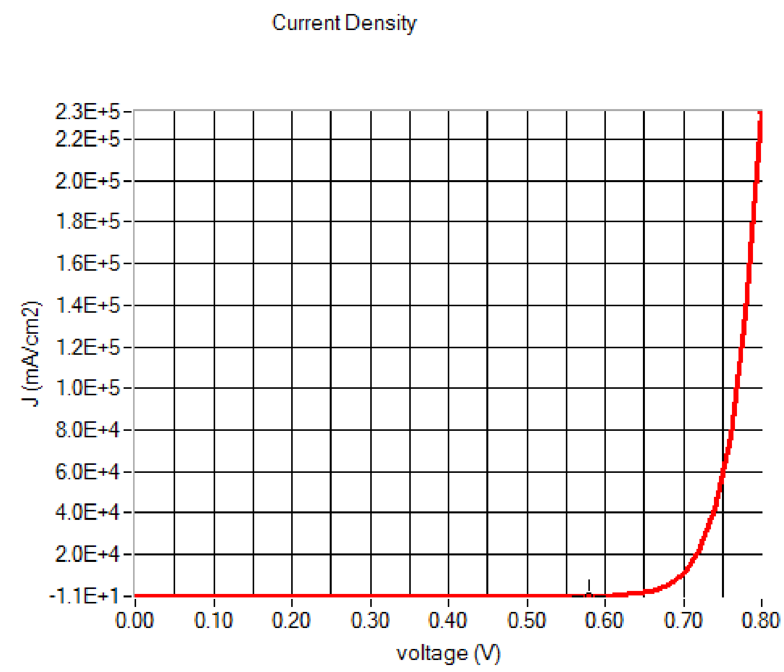

Figure 9: I-V curve of the solar cell under illumination exported from SCAPS.

Calculating efficiency

In order to calculate the efficiency of the solar cells the user can find the I-V curve under illumination and obtain from the curve the following parameters which are all shown in figure 9.

- V_{oc}: is the open circuit voltage. It is the point at which the output current of the solar cell is equal to 0.

- I_{sc}: is the short circuit current. It is the point at which the output voltage of the solar cell is 0.

- I_{mp}: is the maximum output current. This parameter corresponds to a current value where the solar cell is providing the maximum output power.

- V_{mp}: is the maximum output voltage. This parameter corresponds to a voltage value where the solar cell is providing the maximum output power.

- P_{max}: is the maximum output power which is V_{mp}*I_{mp}.

- P_{in}: is the input power of the solar cell. Under 1 sun this value is estimated at $1KW/m^2$.

Once the above parameters are extracted, the efficiency of the solar cell can be calculated using equation 1:

$$\boldsymbol{efficiency = \frac{I_{mp}V_{mp}}{P_{in}}}$$

Equation 1: Efficiency of a solar cell.

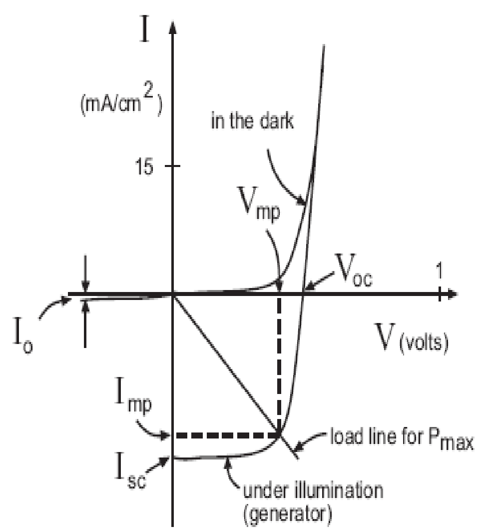

Figure 9: Parameters for calculating the efficiency of the solar cell

Undergraduate Implementation

This tutorial can be used in an undergraduate engineering course that focuses on electronics. It is suggested that the student taking the course have taken prerequisite courses in introductory physics or circuits' theory. The tutorial can be used as an exercise in a lab where students have to design a solar cell and calculate its efficiency. It gives students an insight on building a p-n junction and using the p-n junction to extract power.

Conclusion

Simulation tools are a major tool that is used to design solar cells. Through simulations students can exercise the theory of the functionality of solar cells devices. SCAPS is a user friendly software that can be used for educational purposes and for research purposes as well. This paper outlines a procedure that will allow the student to build a p-n junction, add contacts and simulate the bandgap energy diagram and the I-V curve of a silicon solar cell.

References

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2 Marc Burgelman, Koen Decock, Alex Niemegeers, Johan Verschraegen, Stefaan Degrave, SCAPS Manual February 2016, February 17 2016, page 7

3 Marc Burgelman, Koen Decock, SCAPS 3.0 An introduction, page 3

4 Alex Niemegeers, Marc Burgelman, Koen Decock, Johan Verschraegen, Stefaan Degrave SCAPS manual, Version: 20 May 2014, page 17

Bibliographical Information

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Dr. Amal Kabalan is currently an assistant professor in the Electrical and Computer Engineering Department at Bucknell University. She studied properties of semiconducting materials for photovoltaics applications at Harvard University. She completed her dissertation at Villanova University where she worked on the application of quantum wells in solar cell. Her research focuses on integrating nanotechnology structures in electronic devices. Currently she is working on improving the efficiency of solar cells. She is also interested in humanitarian technology. She is working on developing solar backpacks for students who lack access to electric power around the world.

Sam Roy

Sam Roy is pursuing his Master's degree in Electrical Engineering at Bucknell University. He is currently working under the supervision of Dr. Amal Kabalan on simulating and designing efficient solar cells. As an undergraduate, Sam has experience of working on low- energy powered electrical devices. Sam is also interested in gaining more knowledge on sustainable and renewable energy sources.