



(RESEARCH ARTICLE)



Exploring optical properties of solar cells by programming and modeling

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Abstract

One of the main factors influencing the efficiency of solar cells is their optical properties. So, most light is reflecting back and transmit through solar cell. This leads to a decrease in the efficiency. We know that the refractive index of silicon is 3-4 depending on the wavelength of light, and the refractive index of air is about 1. This causes to reflect 34 percentages of the incident light. To reduce the amount of reflected light, the surface of the solar cell should be covered with an anti-reflection layer. It is important to determine the conditions of the types and thicknesses of the material covering the surface of the solar cell. Semiconductor devices modeling has become very popular. Because the results obtained through modeling are very close to the experimental results. In this study, we also modeled the solar cell with and without an anti-reflective layer using the Sentaurus TCAD software package and presented the results obtained. A new program was developed using the C # programming language, and a library was developed to help new researchers study the optical properties of solar cells directly for that program, and a number of results were obtained.

Keywords: TMM; Solar cell; Anti-reflective coating; C#, TCAD

1. Introduction

Today, renewable energy sources are widely used. Of these, the amount of energy extracted from the solar cells is significant. Solar elements of various constructions are produced. Of course, the efficiency of solar cells is not very high. That is, the efficiency of silicon-based solar cells does not theoretically exceed 29% [1]. This is definitely for a simple silicon based solar element. We can change this value if we improve its optical properties. To improve the optical properties of the solar cell, a texture is formed on its surface [2] or covered with an anti-reflective layer. We have discussed below the optical properties of solar cells which are simple silicon bases solar cells and covered with antireflective layers.

PC1D, DESSIS, SCAPS programs are used for one-dimensional modeling in the study of solar cells [3]. Silvaco TCAD, Sentaurus TCAD and COMSOL programs are popular for 2D and 3D modeling [4].

Using direct programming languages to study solar cells also gives good results. Among the programming languages, Python has a library for modeling solar cells, which is open source and free. But since we mostly use the C # programming language, we tried to create a full program instead of using the library. Because there are not enough libraries in this programming language to study solar elements.

Theory.

To better understand the transfer matrix method, let's do a theoretical analysis. To do this, we use Fresnel formulas. And we create matrices to make the calculation easier.

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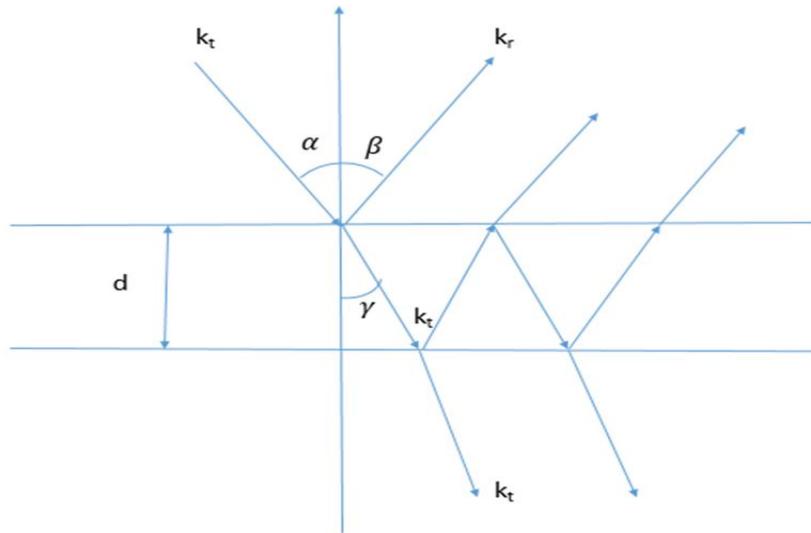


Figure1 Transmission and reflection of light in layer

$$M^\perp = \begin{pmatrix} M_{11}^\perp & M_{12}^\perp \\ M_{21}^\perp & M_{22}^\perp \end{pmatrix} \quad (1)$$

$$\begin{cases} r_{um}^\perp = \frac{M_{21}^\perp}{M_{11}^\perp} \\ t_{um}^\perp = \frac{1}{M_{11}^\perp} \end{cases} \quad (2)$$

For parallel

$$\begin{bmatrix} E_i^\parallel \\ E_2^\parallel \end{bmatrix} = M^\parallel \begin{bmatrix} E_t^\parallel \\ 0 \end{bmatrix} \quad (3)$$

$$M^\parallel = \begin{pmatrix} M_{01}^\parallel & M_{12}^\parallel \\ M_{21}^\parallel & M_{22}^\parallel \end{pmatrix} \quad (4)$$

$$\begin{cases} r_{um}^\parallel = \frac{M_{21}^\parallel}{M_{11}^\parallel} \\ t_{um}^\parallel = \frac{1}{M_{11}^\parallel} \end{cases} \quad (5)$$

Total reflection coefficient,

$$R_{um} = \frac{(r_{um}^\parallel)^2 + (r_{um}^\perp)^2}{2} \quad (6)$$

Total transmission coefficient,

$$T_{um} = \frac{n_3 \cos \gamma_3}{n_0 \cos \alpha} \left(\frac{(t_{um}^\perp)^2 + (t_{um}^\parallel)^2}{2} \right) \quad (7)$$

We know that, sum of transmission, reflection and absorption coefficients is equal to one. So we can find absorption coefficient by reflection and transmission coefficients [5-8].

$$A_{um} = 1 - R_{um} - T_{um} \quad (8)$$

Nowadays, it is popular to cover the surface of solar elements with several antireflective layers. This begs the question, what should be the refractive index of the m-layer? If we analyze above equation, we can find dependency among refractive index of layers [9].

$$n_m = n_{sup} \left(\frac{M+1-m}{M+1} \right) \left(\frac{m}{M+1} \right) n_{sub} \quad (9)$$

Here:

M- number of layers

m - position of layer which is found refractive index.

2. Material and methods

The Sentaurus TCAD software package consists of 17 main and 5 additional tools. We mainly use 4 instruments to model solar elements. They are Senaturus Structure Editor (SDE), Sentaurus Device (SDevice), Sentaurus Visual (SVisual) and Senaturus Workbench (SWB).

SDE was used to create a 2D geometric model of the solar element. In addition, the generated geometric model is given the amount of praise for the type of material and the concentration of the input. Once the geometric model of the solar cell is fully formed, it is meshed for discrete calculations. We can see it in Figure 2.

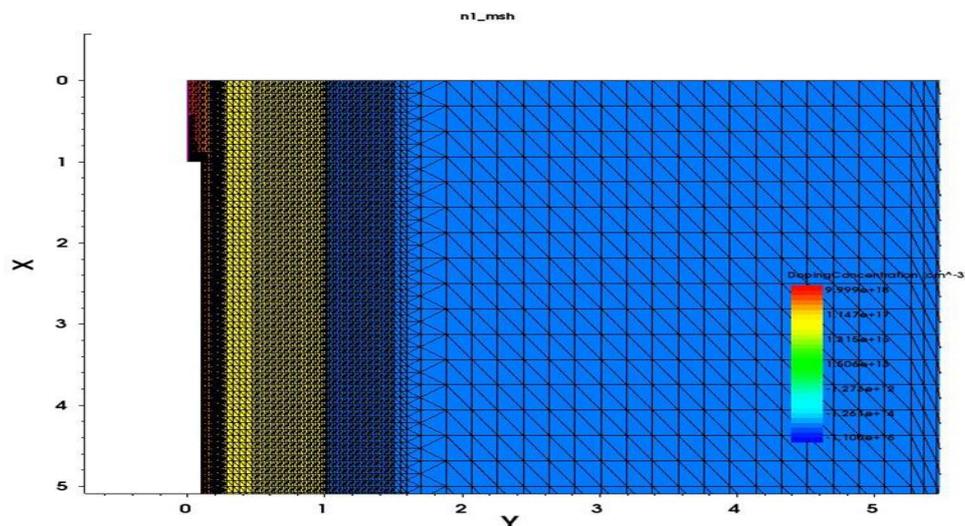


Figure 2 Geometrical model of solar cells which was created by SDE

The solar cell generated by the Sdevice is exposed to various light rays and its optical properties are calculated using the Transfer Matrix method (TMM). There is also the Ray Tracing method. But TMM was used to model the optical properties of solar cells.

We visualized and graphed the results obtained through Svisual. The advantage of this is high quality and the ability to obtain interrelated graphs of all defined parameters.

SWB has the ability to conduct virtual experiments, that is, connect the rest of the instruments. During the experiment, we want to change the parameters and get results. For example, when we determine that the volt-ampere characteristic of a solar cell depends on its temperature, we change the temperature. Similarly, we can obtain different experimental results by changing the parameters using SWB. In our model, we determined the optical properties of a solar cell at different thicknesses of SiO₂ coated with a solar cell.

C # is an object-oriented programming language developed by Microsoft. Creating applications for the Windows operating environment is easy with C #. That is, a compilation language. We implement our theories and statistical calculations developed during our research through this programming language. The aim is to create a database of the results of the research and to develop libraries that will be used in the new research of the solar cell field for the programming language. Also, a new library in C # programming language was created to determine the optical properties of these solar cells and the results were obtained.

3. Results and discussion

Based on the above theory, a program called "suntulip-1" was developed. In this program, the optical properties of a silicon-based solar cell with a single antireflective layer were determined (Figure 3). SiO₂ is selected as an anti-reflective layer. Its thickness is 75 nm. The thickness of the substrate is 200 μm. There, we can see the highest absorption is in visible light diapasons. It is about 66 percentages. Beside, we find optical properties of silicon solar cells with perovskite Cs₁₇Br₁₇ (Figure 4). If we compare the two values, the optical properties of the perovskite-coated silicon-based solar cell would be better. That is, its light absorption coefficient would be better than that of a silicon-based solar cell coated with SiO₂.

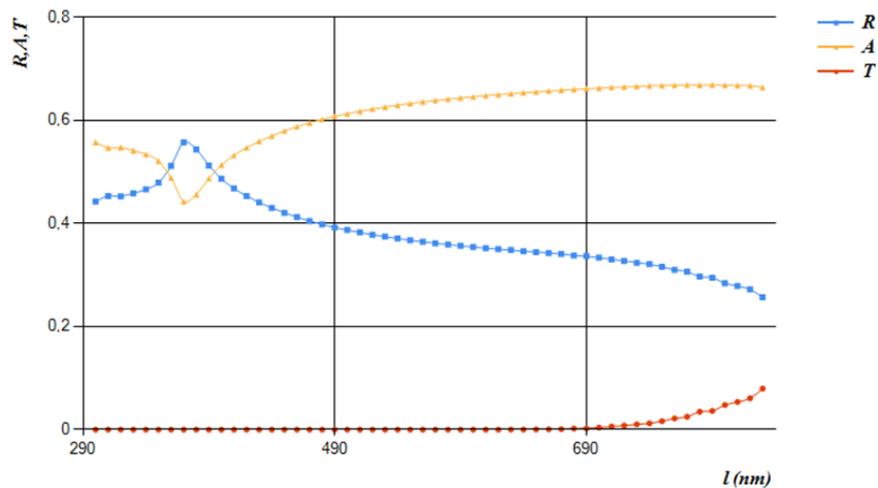


Figure 3 Reflection, absorption and transmission coefficients of silicon bases solar cells with SiO₂ antireflective layer.

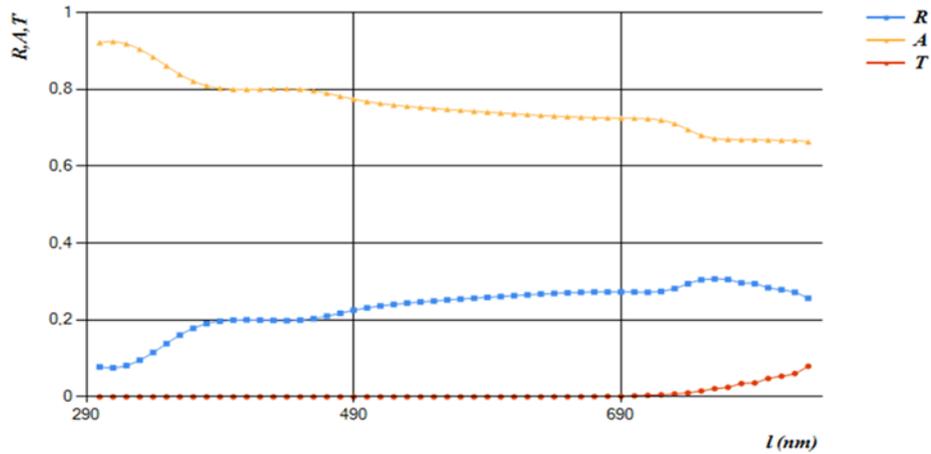


Figure 4 Reflection, absorption and transmission coefficients of silicon based solar cells with perovskite $CS_{17}Br_{17}$ antireflective layer.

Using the SDevice, the transfer matrix method determined that the absorption and reflection factors of a solar cell coated and uncoated with an anti-reflective layer of SiO_2 of different thicknesses depend on the wavelength. The return factor of an uncoated solar cell coated with 75, 100, 125, and 150 nm thick SiO_2 was at least 100 nm. The greatest value of absorption was at this thickness. The average reflectance of an uncoated solar cell was 0.4, while that of a 100 nm thick coating was reduced to 0.05. Absorption increased from 0.6 to 0.95.

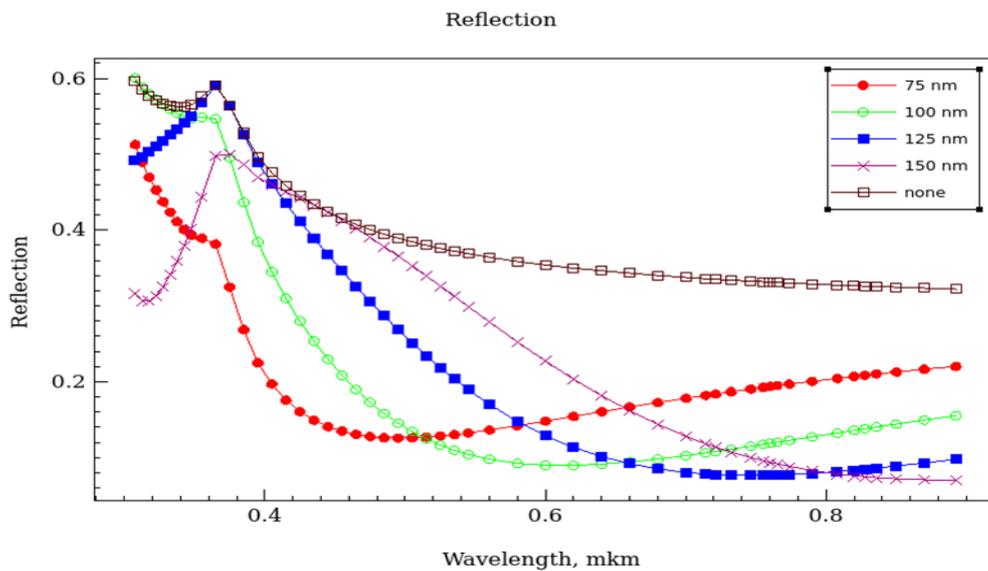


Figure 5 Wavelength dependent reflection factor of solar cell.

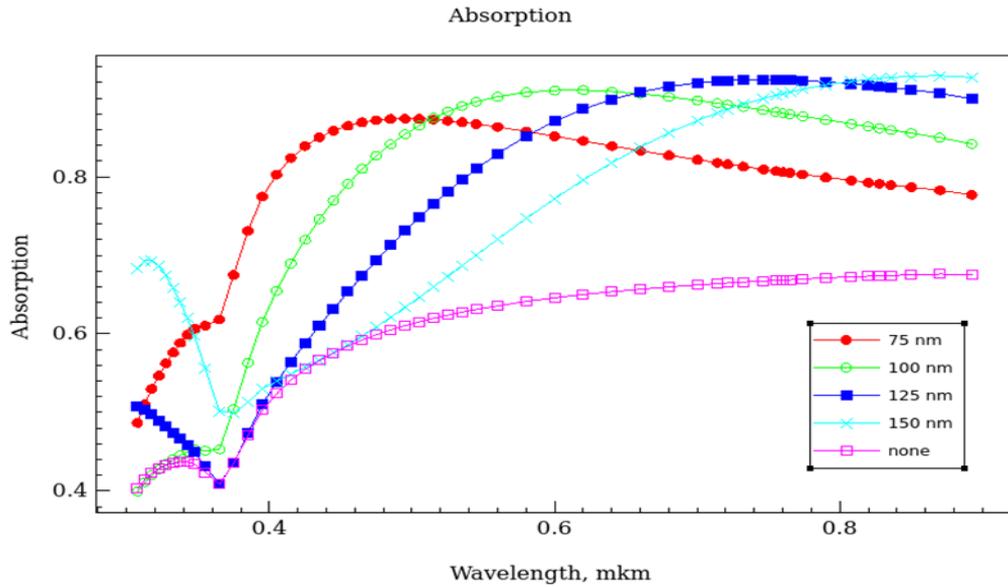


Figure 6 Wavelength dependent absorption factor of solar cell.

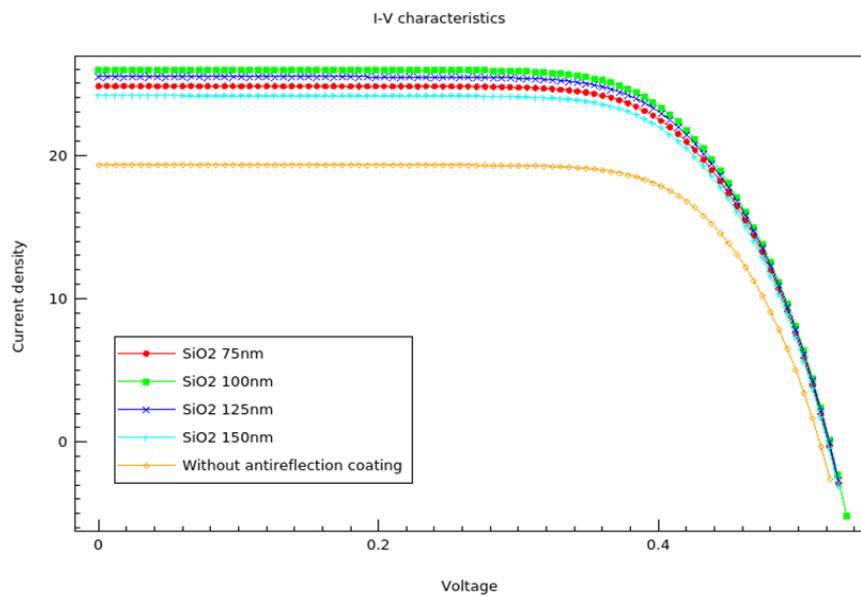


Figure 7 Volt-ampere characteristic of a solar cell at different thicknesses of a solar cell coated with a layer of anti-reflective SiO₂ light.

The volt-ampere characteristics of optically coated and uncoated solar cells were studied using the Sentaurus TCAD software package. In this case, the effect of the thickness of the optical layer on the efficiency of the solar cell was studied. The thickness of type n of the solar cell was 1 μm and the thickness of type p was 200 μm . The width was 1000 μm . The input concentration of type P was $1\text{e}15\text{ cm}^{-3}$ and that of type n was $1\text{e}17\text{ cm}^{-3}$. Light source AM1.5. As shown in Figure 3, the best result is at a thickness of 100 nm of SiO₂. In some publications, a thickness of 75 nm is taken as the optical layer in the nominal state [10-12]. However, the efficiency of a solar cell coated with an optical layer is much higher than that of a solar cell without an optical layer. We have also conducted experiments in this area. According to the experimental results, the efficiency of a silicon-based solar cell not coated with an optical layer is 13.6%, while that of a solar cell coated with an anti-reflective jump is 19.6%. The model we created also shows that the efficiency of a solar cell coated with SiO₂ at a thickness of 100 nm is 1.3 times higher than that of a normal solar cell. This ensures that the model is compatible with the experience.

4. Conclusion

Finally, I have to say for calculating optical properties of solar cells we can use transfer matrix method. With this method we can find out which substance we will cover the solar cell with which will have better optical properties. By improving the optical properties of solar cells, we can increase its efficiency. We can even increase the efficiency of thin-based solar cells by equating them with the efficiency of classical solar cells. In this way, we will achieve economic success. We will reduce the cost of solar cells. We can test the best of the results obtained through theory and application in practice and even apply them to production.

It is useful to use TCAD programs to increase the efficiency of the research work and reduce the time spent. We can also conclude from the results obtained by Sentaurus TCAD that it is expedient to cover the surface of the solar cell with SiO₂ with a thickness of 100 nm.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

To the best of our knowledge, the named authors have no conflict of interest, financial or otherwise.

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