Fabrication and Simulating Solar Cell Devices using Silvaco TCAD Tools

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Abstract

Solar cells are p-i-n photodiodes, which are operated under forward bias. The intention is to convert the incoming optical power into electrical power with maximum efficiency.

In this paper we are going to design a solar cell and simulation of solar cell using the Silvaco TCAD tools.

Silvaco TCAD refers to Technology Computer-Aided Design. This means that computer simulations are used to develop and optimize semiconductor processing technologies and devices. As TCAD simulations solve fundamental, physical partial differential equations, such as Poisson, Diffusion and Transport equations in a semiconductor device. This deep physical approach gives TCAD simulation predictive accuracy. It is therefore possible to substitute TCAD simulations for costly and time-consuming test wafer runs when developing and characterizing a new semiconductor device or technology.

Keywords- photodiode, Silvaco TCAD Tools.

1. INTRODUCTION

Silvaco TCAD offers complete and well integrated simulation software for all aspects of solar cell technology. CAD modules required for Solar Cell simulation include: S-Pisces, Blaze, Luminous, TFT, Device3D, Luminous3D and TFT3D [1]. The TCAD Driven CAD approach provides the most accurate models to device engineers. Silvaco is the one-stop vendor for all companies interested in advanced Solar Cell technology simulation Solutions.

2. TCAD MODULES FOR SOLAR CELL TECHNOLOGY SIMULATION

Brief descriptions of the TCAD modules that can be used for solar cell technology simulation are listed below. For more details of these modules, please visit the Silvaco TCAD products.

S-Pisces is an advanced 2D device simulator for silicon based technologies that incorporates both drift-diffusion and energy balance transport equations. Large selections of physical models are available for solar cell simulation which includes surface/bulk mobility, recombination, impact ionization and tunneling models.

Blaze simulates 2D solar cell devices fabricated using advanced materials. It includes a library of binary, ternary and quaternary semiconductors. Blaze has built-in models for simulating state-of-the-art multi-junction solar cell devices.Device3D is a 3D device simulator for silicon and other material based technologies. The DC, AC and time domain Characteristics of a wide variety of silicon, III-V, II-VI and IV-IV devices are analyzed.

Luminous and Luminous3D are advanced 2D and 3D simulator specially designed to model light absorption and photo generation in non-planar Solar Cell devices. Exact solutions for general optical sources are obtained using geometric ray tracing. This feature enables Luminous and Luminous3D to account for arbitrary topologies, internal and external reflections and refractions, polarization dependencies and dispersion. Luminous and Luminous3D also allows optical transfer matrix method analysis for coherence effects in layered devices. The beam propagation method may be used to simulate coherence effects and diffraction.

TFT and TFT3D are advanced 2D and 3D device technology simulators equipped with the physical models and specialized numerical techniques required to simulate Spectral Response of a Solar Cell. Amorphous or polycrystalline devices including thin film transistors. TFT and TFT3D can be used with Luminous and Luminous3D to simulate thin film solar cells made from amorphous silicon. Spectral, DC and transient responses can be extracted.

3. SIMULATING OF SOLAR CELL CHARACTERISTICS

Here, we will discuss the various aspects of solar cell characteristics that can be simulated by Silvaco TCADTools. Typical characteristics include collection efficiency, spectral response, open circuit voltage, VOC and short Circuit current ISC. The simulated spectral response of a solar cell using the luminous module. This

figure1 is obtained by varying the incident wavelength of a light source to extract the solar cell's spectral response.

From this figure 1, the green curve is the equivalent current from the light source; the red curve is the available photo current generated by the light within the solar cell device and the blue curve is the actual terminal current. Collection efficiency including the effects of reflection can be calculated by the ratio of these quantities.

It is possible to study the details of photo generation of carriers in the solar cell device during light illumination. This is very useful for simulation of multi-junction devices. Contour plot of photo generation rate in a simple thin film amorphous silicon solar cell. Note that in this figure, the device has an opaque metal contact in the center of the structure. Once photo generation rates are obtained, terminal currents can be evaluated to determine the quantum efficiency of the solar cell. One useful feature of the luminous module is ray tracing. This feature enables the analysis of more advanced solar cells designs. Besides studying the photo generation rates due to a normal incident light beam, the photo generation rates due to an angled light beam can also be studied. The photo generation in a silicon solar cell when light impinges on the cell which has pyramids on the surface. From this figure, it can be seen that the light path inside the semiconductor is diverted from its original path due to the pyramid surface. This causes the contour of the photo generation rates to be a saw-tooth shape as shown in the right hand photo generation Rate from Angled Light Beam. Photo generation Contours in Amorphous Silicon Once the photo generation rates are obtained by the Luminous module, ATLAS will then be able to simulate the terminal currents to obtain the IV characteristics. The IV characteristics of an amorphous silicon solar cell under AM0 illumination. In this figure, ISC is the short circuit current and VOC is the open circuit voltage. The ISC is extracted from the curve when the voltage is zero. On the other hand, the VOC can be extracted from the IV curve when the current is zero. Also, the maximum current, Im and maximum voltage, Vm, can be obtained from the maximum power rectangle as indicated in the figure. By changing the illumination power of the light beam, we can obtain a series of IV characteristics as a function of the illumination power can be obtained.. From this figure, it can be seen that the short circuit current increase linearly with the increase of light power, where the open circuit voltage begins to saturate with the increase of light power.

4. CONCLUSION

In conclusion, Silvaco TCAD tools provide a complete solution for researchers interested in solar cell technology. It enables researchers to study the electrical properties of solar cells under illumination in both Two- and Three dimensional domains. The simulated properties include IV characteristics, spectral response, quantum efficiency, photo generation rates, potential distribution, etc. In addition, the software is also capable of simulating amorphous silicon solar cell devices and large area solar cells with texture surfaces. Silvaco is the one-stop vendor for all companies interested in advanced solar cell technology simulation solutions.

5. References

"ATLAS User's Manual ", Silvaco, Santa Clara, California, USA.

 Silvaco ATLAS website: http :/www.silvaco.com/ products/device_simulation/atlas.html

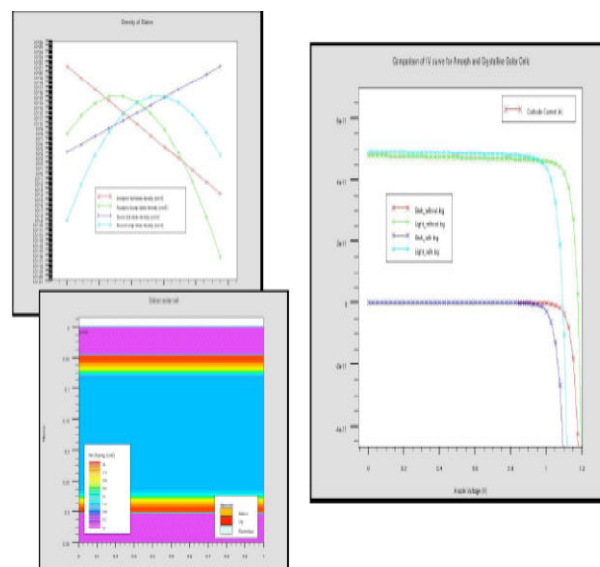"ATHENA User's Manual ", Silvaco, Santa Clara, California, USA.

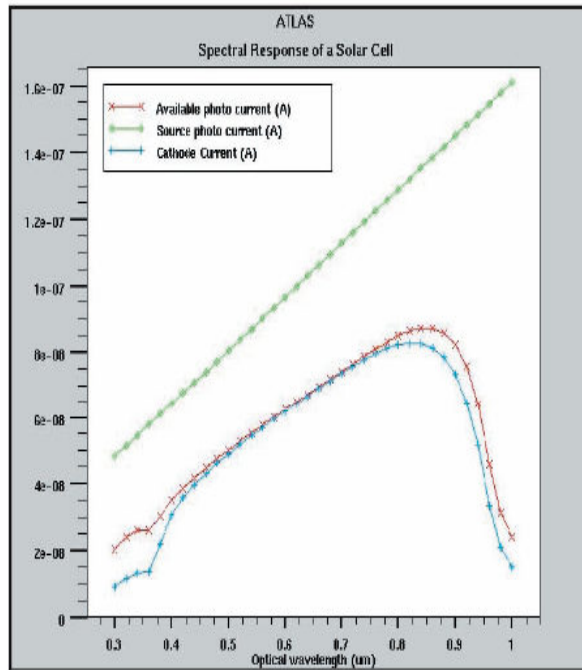**Figure 1: Si based solar cell Fabrication and Simulation Result**

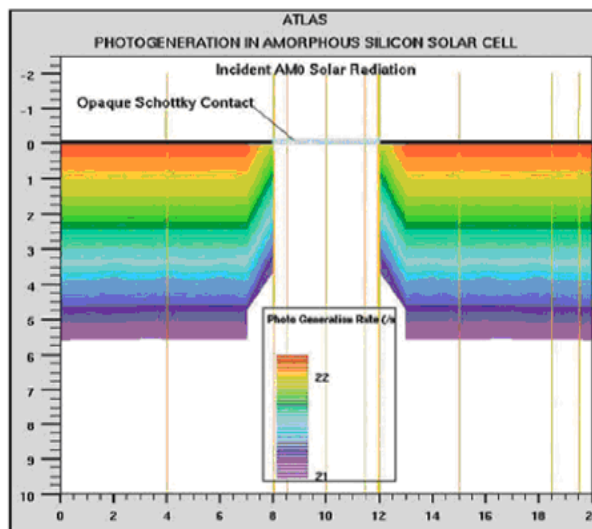**Figure 2: Spectral Response of a Solar Cell**

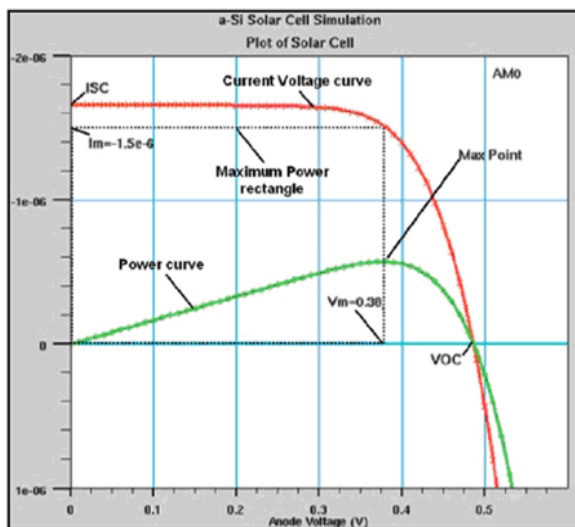**Figure 3: Photo generation Contours in Amorphous Silicon Solar Cell Device**

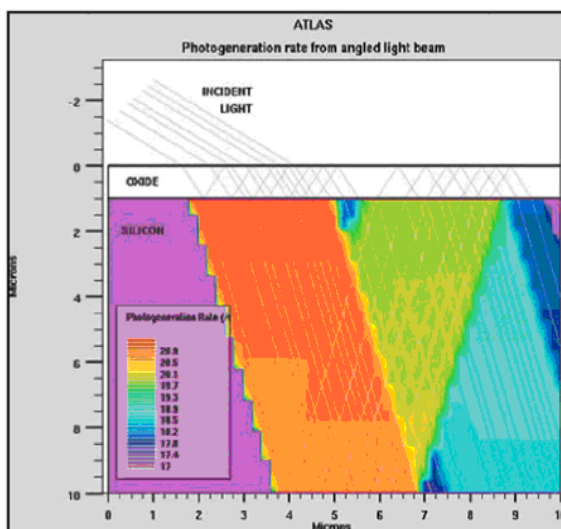**Figure 4: Current Voltage Characteristics of Amorphous Silicon Solar Cell Device**

Figure 5: Photo generation Rate from Angled Light Beam