PVSEC19 November 9-13, 2009

An optical simulation algorithm based on ray tracing technique for light absorption in thin film solar cells

*Seok-Joo Byun[1,3], Seok Yong Byun[1], Jangkyo Lee[1], Jae Wan Kim[1], Taek Sung Lee[2], Won Mok Kim[2], Young Kyu Park[3], Kyuman Cho[3]

[1]INSIDEOPTICS Co. LTD
172 Gongreung2-dong, Nowon-gu, Seoul 139-743, Korea
[2]Thin Film Materials Research Center, Korea Institute of Science and Technology
39-1 Hawolgok-dong, Sungbuk-gu, Seoul 136-791, Korea
[3]Department of Physics and Interdisciplinary Program of Integrated Biotechnology, Sogang University
1 Sinsoo-dong, Mapo-ku, Seoul 121-742, Korea

*e-mail : sjbyun@insideoptics.com

Introduction

Last couple of decades has observed a vast improvement in thin film solar cell efficiency.
Unlike bulk Si solar cells, thin film solar cells have limited thickness of active layer, thereby limiting the light absorption efficiency. Therefore, obtainment of rough surface whether it is formed naturally during thin film processing or textured intentionally is one of the most powerful techniques in increasing cell efficiency by increasing light path length inside active medium. Estimating and determining the exact amount of light absorption in component layers comprising thin films solar cells is of utmost importance in studying the cell efficiency in relation with the cell structure and the optical characteristics of materials. However, in most of the previous optical simulation studies, the estimation of light absorption in individual layer was limited to the case of totally flat surface and interfaces, and usual simulation steps were composed of calculating the reflectance of individual layer and determining the energy absorbed by combining the absorption coefficient and the incoming light energy which was determined from the calculated reflectance. In other words, previous simulation utilized a coherent 2x2 characteristic matrix method combined with weighting factor from the characteristics of bidirectional scattering distribution function (BSDF). Unfortunately, this kind of approximated method can not guarantee the accuracy in the case that random optical paths, which will remove the interference effect, are generated by rough surfaces or other optical geometry distorting light path. Furthermore, the calculated results will provide only relative ratios of absorption inside the component layers, and will have difficulty in exact estimation of absorbed solar energy. Recently, an optical modeling based on ray tracing was proposed [6]. But this method is only an indirect method in that it gave total absorption inside solar cell system by obtaining the total reflectance and transmittance without considering interferences.
In this paper, we introduce a direct calculation method which can overcome the inevitable inaccuracy observed in approximated method. This method is based on Monte-Carlo ray tracing techniques, and is capable of calculating the optical absorption energy directly by separating the light passing through medium into the coherent part and the incoherent part in the course of non-sequential ray tracing throughout the whole region of solar cell structure. Therefore, this method can provide direct calculation of accurate amount of absorbed energy in the individual layer regardless of coherent and/or incoherent light inside the medium.

● Perfectly Flat Coherent Structure

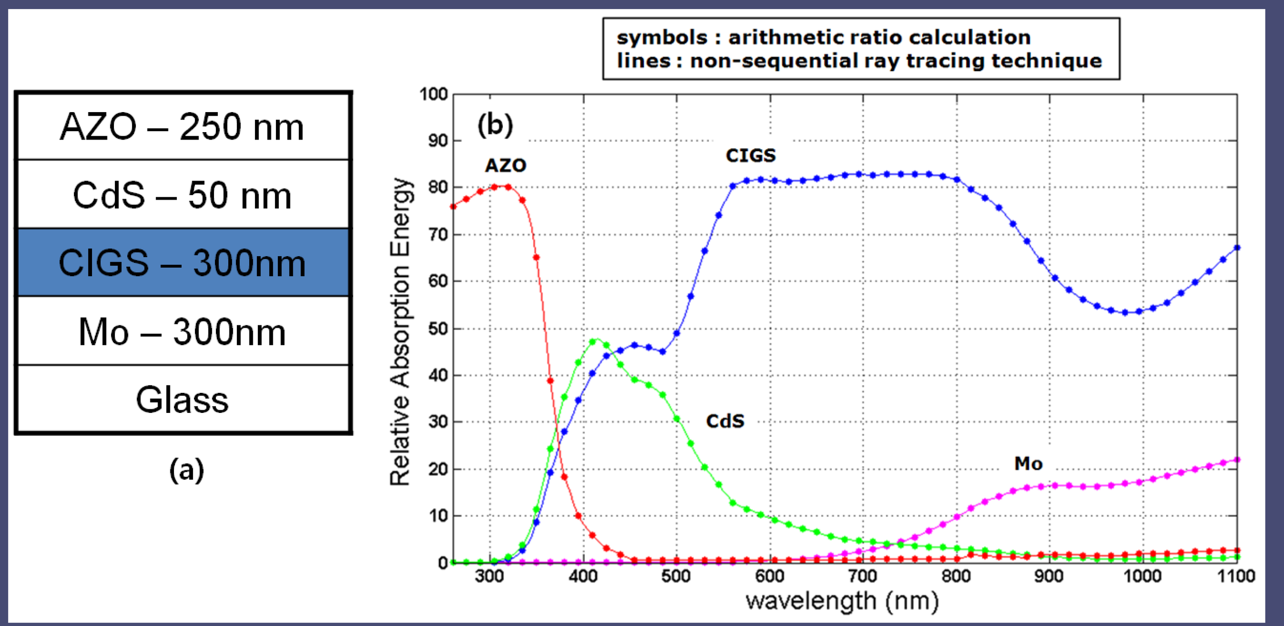

Fig. 1. (a) Schematics of tested solar cell structure,
(b) spectra of absorption ratios determined from arithmetic ratio calculation (symbols) and non-sequential ray tracing technique (lines)

Simulation Algorithm & Simulation Results

Coherent region

$$[M]=\begin{bmatrix}\cos\delta & i\dfrac{\sin\delta}{Y_f}\\ iY_f\sin\delta & \cos\delta\end{bmatrix}$$

$$\text{phase differnce: }\ \delta=\frac{2\pi}{\lambda}Nd\cos\theta,\ \ \text{admittance: }\ Y_f=\frac{H_f}{E_f}$$

Incoherent region

$$\Phi(x,\lambda)=\Phi^0(0,\lambda)\exp(-\alpha(\lambda)x)\qquad \Phi^0(\lambda)=P(\lambda)\frac{\lambda}{hc}$$

$$\Phi_{Absorption}(\lambda)=\sum_{n=1}^{n=\text{traced ray numbers}}\Phi_{Absorption}(n,\lambda)$$

All system region

- ✓ Snell's Law by complex IOR
- ✓ Fresnel Equations with complex IOR
- ✓ BSDF
- ✓ Coating Information (ex: anti-reflection)

● Coherence & Incoherent Results

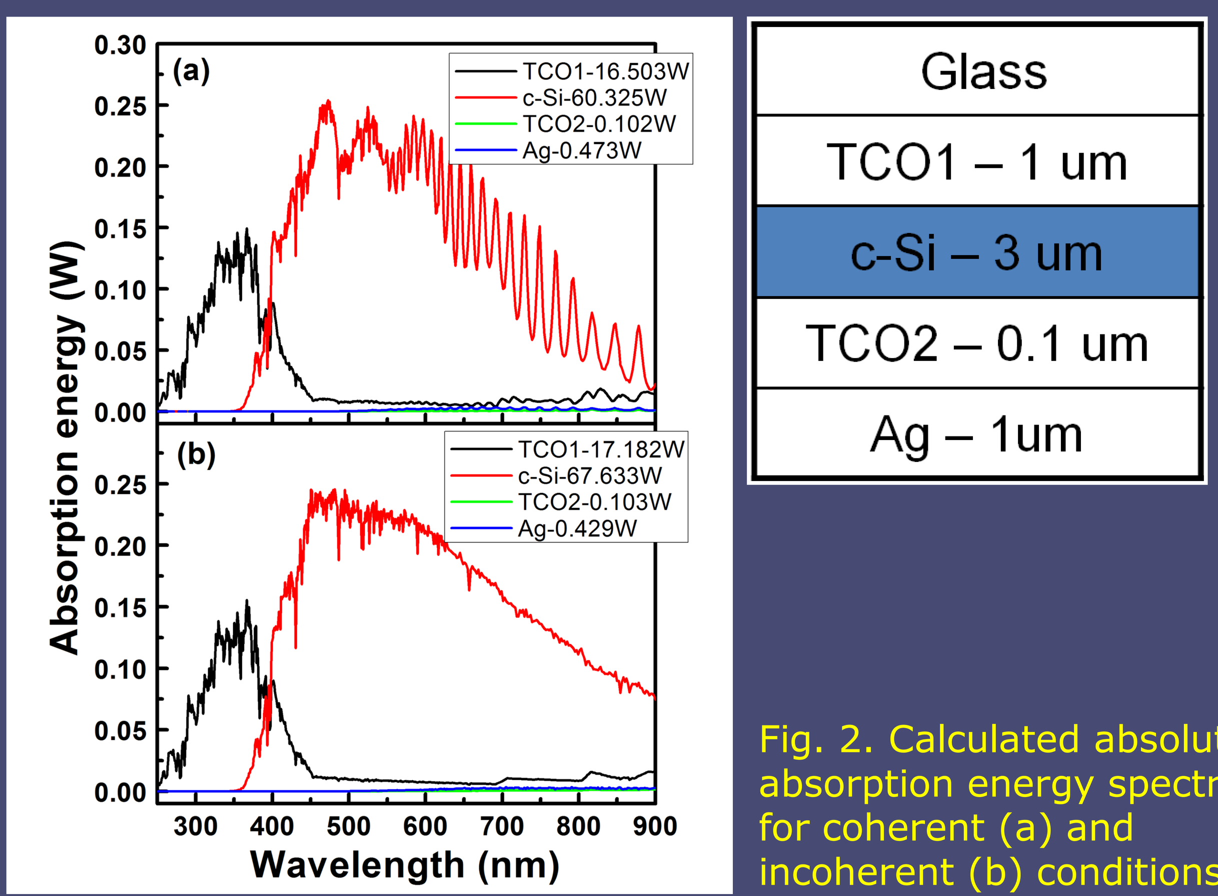

Fig. 2. Calculated absolute absorption energy spectra for coherent (a) and incoherent (b) conditions.

● Coherent multi layers on Complex Structure

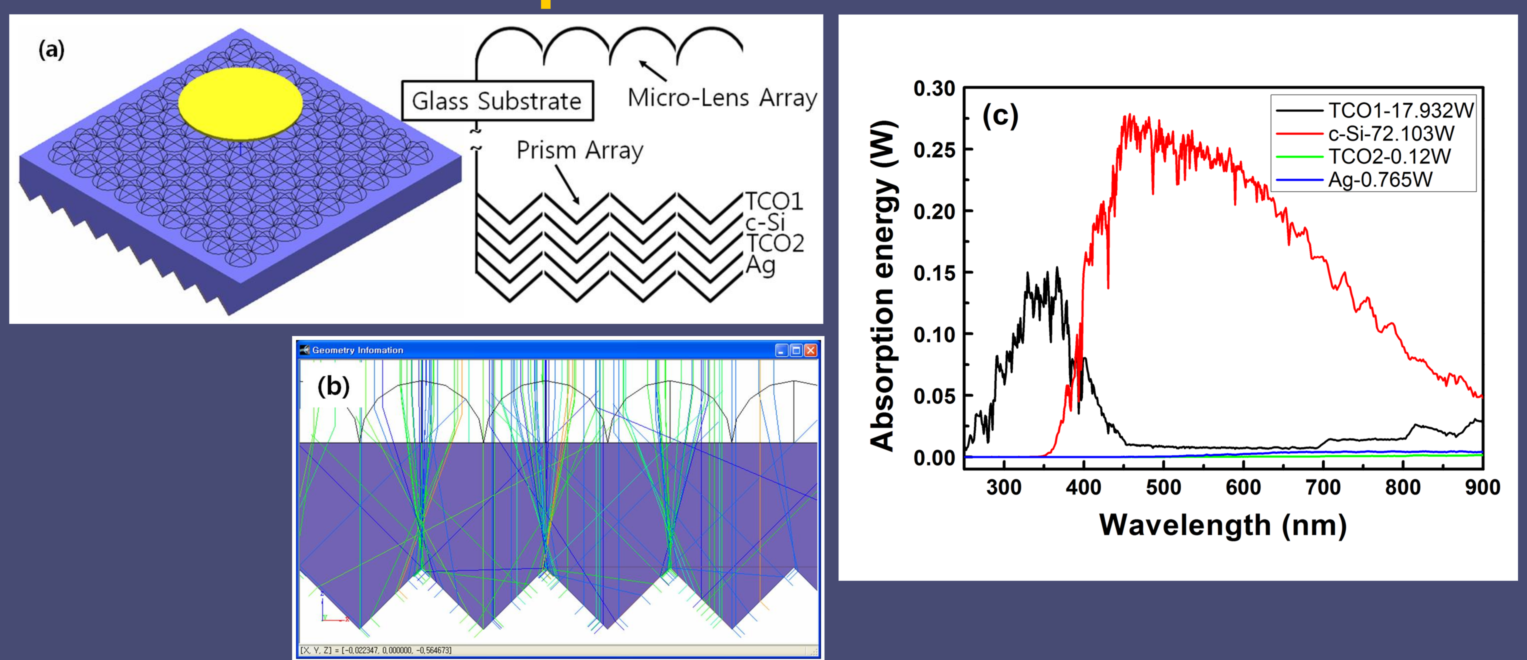

Fig. 3. (a) Schematics and perspective view of simulation system,
(b) Example ray path inside simulation system, and
(c) calculated absolute absorption energy spectra by combining coherent and incoherent ray conditions.

Conclusions

● Comparison of Conventional Method and New Simulation Algorithm

Optical Simulation Issues	Conventional Method	New Simulation Algorithm
Total Reflected Energy	Yes [relative ratio output]	Yes
Total Transmitted Energy	Yes [relative ratio output]	Yes
Total Absorption Energy	Yes [relative ratio output]	Yes
Individual Layer's Absorption Energy	Yes [relative ratio output]	Yes
Coherent Multi Layer	Yes [Only Flat Case]	Yes
Textured Multi Layer	Yes [Using Approximation]	Yes
Incoherent Multi Layer	No	Yes
Multi Layer on rough surface	No	Yes
Multi Layer in CPV [random direction]	No	Yes
Real Scale System	No	Yes-possible

● Summary

- ➢ A new method for calculating the absolute absorption energy by using non-sequential ray tracing technique was introduced.
- ➢ Through comparison of simple coherent case with conventional arithmetic ratio calculation, the validity of algorithm was verified.
- ➢ The benefit and effectiveness of new method were clarified via calculation of the absolute absorption energy in the individual layer of solar cell structure with rough surface of BSDF characteristics.
- ➢ New algorithm could yield more accurate and direct estimation of the absorption energy than the conventional method whose calculation algorithm is limited to the use of BSDF angular profile in the form of weighting factor while assuming flat surface.
- ➢ Lastly, the new algorithm was applied for the calculation of absolute absorption spectra of complex system similar to concentrator photovoltaic system, and was proved to be very effective in analyzing complex geometry which necessitates the combination of coherent and incoherent calculation.

RayWiz™ insideoptics KIST Korea Institute of Science and Technology SOGANG UNIVERSITY