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Design and Analysis of Thin Film Silicon Solar Cells Using FDTD Method

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Abstract

Silicon based solar cells are having weak absorption of light and hence, needs light trapping mechanism for the enhancement of solar cell performance. This paper explores the designing of thin film solar cells based on distributed Bragg reflector (DBR) and diffraction grating using FDTD method. Three DBR pairs with 0.8 µm center wavelength were found to be good choice for better performance of solar cells. A relative enhancement in short-circuit current is observed for 5, 10 and 20 µm cell thicknesses respectively which corresponds to an enhanced absorption in the wavelength 450-1100 nm. Use of three binary layer based grating yields enhanced quantum efficiency as comparison to single layer grating based solar cell.

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Keywords: Photonic crystals; solar cells; absorption; diffraction grating

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1. Introduction

Silicon based devices are inexpensive due to compatible existing fabrication technology and availability of silicon in earth crust. Since many decades silicon has been the primary choice of semiconductor industries and recommended for thin film based solar cells with a better efficiency and low cost of fabrication. Thin film based solar cells have some advantages e.g. needs less amount of material, allows material with shorter carrier diffusion length, low energy consumption for device fabrication and light-weight. However, thin film silicon solar cells have disadvantage of weak absorption of long wavelength spectrum due to indirect band gap of silicon which limits their overall efficiency. Hence, light trapping mechanism is essential for the enhancement of incident light absorption. Conventionally, light trapping is based on geometrical optics which prolongs photon path length by the way of scattering from front textured surface and reflecting from bottom aluminum reflector. The purpose of light trapping

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is to prevent the entered photons into the solar cell with the probability to absorb within the active region. This requirement can be fulfilled by two mechanisms: one is diffraction or scattering which can change the direction of incident photons so that as much as of photons can propagate at higher angles with prolonged path length within the cell while second is coupling of incident photons provided with the guided mode in the active region of solar cell with a confinement of light. In simple words, once the incident photons entered into the device their mean residing time in active region must be long enough and they are absorbed before escaping the device. Various design concepts of efficient light trapping structures have been explored and discussed for better performance of silicon based solar cell [1-8].

This paper explores the designing of thin film solar cells based on silicon using FullWAVE commercial available simulation tool. In section second, theory and design approach is presented while results are discussed in section third. Finally, paper is concluded in section fourth.

2. Theory & Design Approach

To achieve high efficiency from solar cells, an incident light must have minimum reflection and be absorbed in the crystalline silicon layer (c-Si). But practically the light is partly reflected from the front layer of anti-reflection coating. In addition, a long wavelength light range will not be absorbed by the solar cell due to weak absorption limitation of the silicon solar cells. The characteristics equation of short-cicuit current can be expressed as:

$$J_{SC} = \frac{e}{hc}\int_{\lambda_1}^{\lambda_2} \lambda A(\lambda) \frac{dI}{d\lambda} d\lambda \qquad (1)$$

where λ_1 & λ_2 - the range of incident solar spectrum, c- the speed of light, A(λ) - the absorption in active silicon region and I- the incident solar cell spectrum in the units of $Wm^{-2}nm^{-1}$.
The short circuit current calculated from above equation contributes to the calculation of efficiency as:

$$\eta = (J_{sc} \times V_{oc} \times FF)/P_{in} \qquad (2)$$

where Voc – the open circuit voltage which can be obtained when the current through solar cell equals to zero and FF - the fill factor which is defined as the ratio of maximum power that can be derived from solar device to the product of short circuit current and open circuit voltage which can be expressed as:

$$FF = (Jmp \times Vmp)/(Jsc \times Vsc) \qquad (3)$$

Three parameters such as open circuit voltage, fill factor and efficiency are the main to study the characteristics of any solar cell.

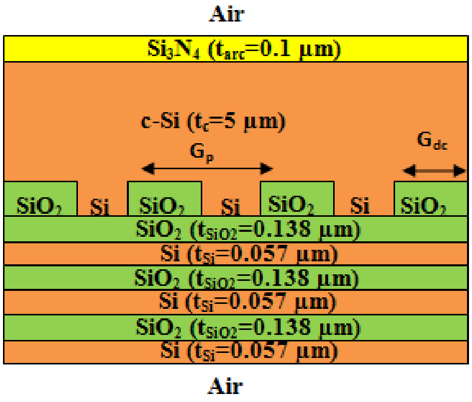

Fig. 1. Schematic diagram of designed solar cell based on DBR and diffraction grating.

Fig.1 shows a designed solar device with 5 µm cell thickness with physical location of their constituent layers. It comprises of an anti-reflection coating layer of silicon nitride, crystalline silicon layer, a distributed Bragg reflector (DBR) and diffraction grating. DBR works as one-dimensional photonic crystal with center wavelength 0.8 µm and composed of periodic layers of silicon and silicon dioxide with their refractive index 3.5 and 1.46 and thickness 0.057 µm and 0.138 µm respectively. The diffraction grating made of silicon dioxide is embedded into active silicon region in a periodic manner.

3. Results and Discussion

Fig. 2 shows absorption in active region of solar cell as a function of incident solar spectrum for different cell thicknesses. Here, we have observed an enhancement in absorption with the use of three binary layer grating for 5, 10 and 20 µm cell thicknesses respectively. The plotted absorption curves are observed to be optimal in the wavelength range of 450-1100 nm whereas overlapping of absorption curve is noticed in wavelength range 650-780 nm.

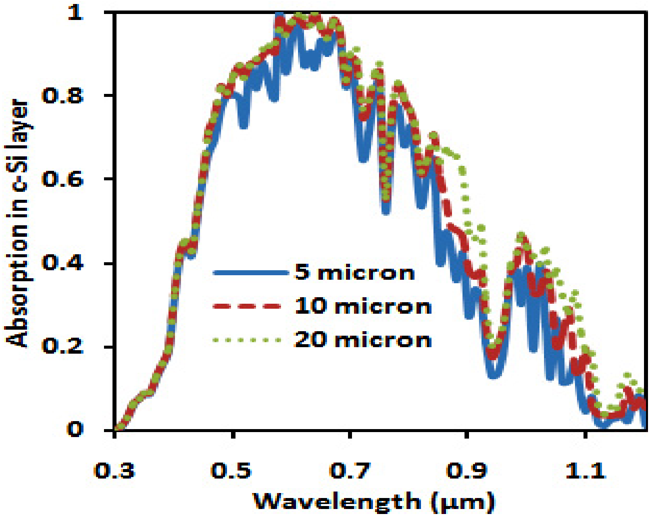

Fig. 2. Absorption in active silicon region in accordance to incident solar spectrum.

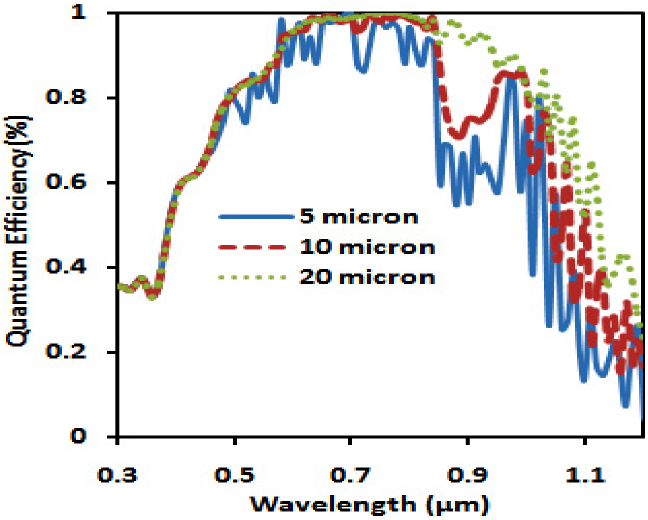

Fig. 3. Quantum efficiency in accordance to incident solar spectrum.

Fig. 3 depicts quantum efficiency as function of incident solar spectrum. As can be seen, it shows better performance of binary grating based solar devices and observed maximum in the wavelength range 580-850 nm. Our designing shows enhanced efficiency in red and infrared region of solar light which make this an efficient trapping of light. Depending of these designs, we have plotted fig. 4 as comparison of cell efficinecy of three solar cells. The highest achieved efficiency is ~ 23 % of the solar cell with 20 µm cell thickness.

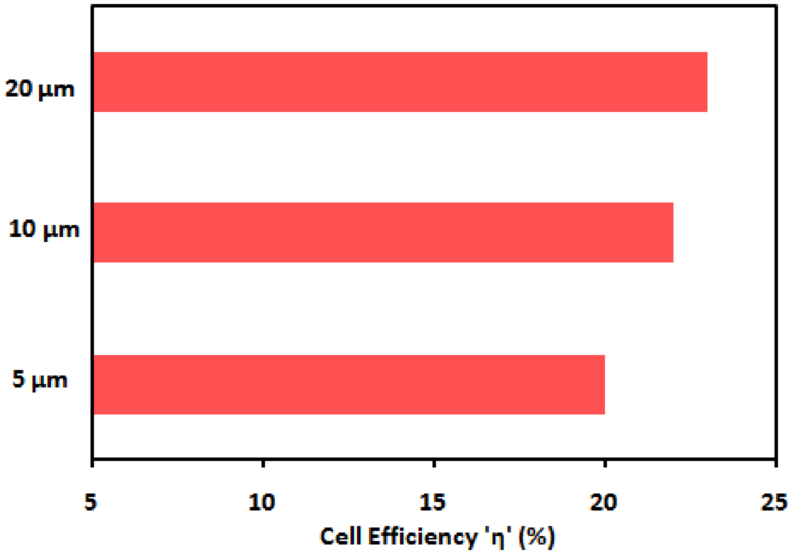

Fig.4. Comparison of cell efficiency of three designed solar cells of 5, 10 and 20 µm respectively.

Further, we have plotted J-V characteristics of solar cells in fig. 5 for different cell thicknesses 5, 10 and 20 µm respectively. The short-circuit current was found to be increased with respect to cell thicknesses and it was 34.6 mA/cm^2 for cell thickness 20 µm.

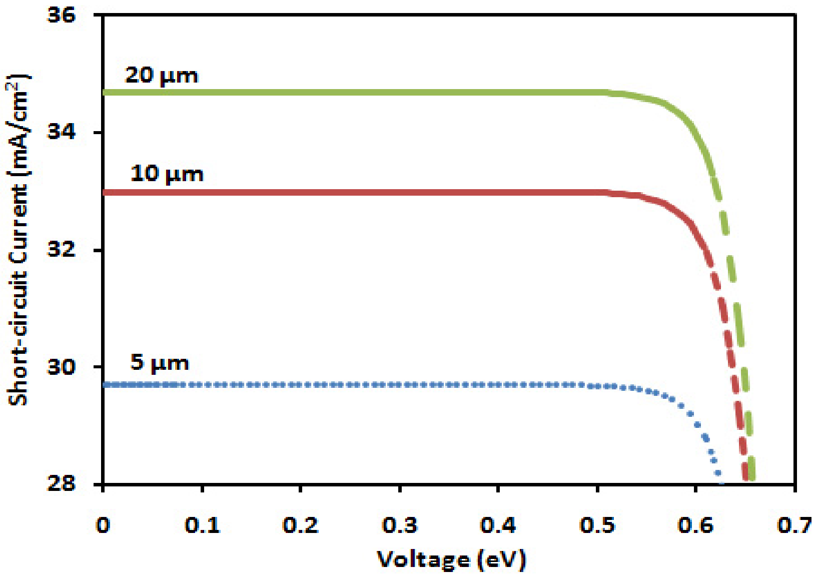

Fig. 5. Short-circuit current of solar cells based on DBR and diffraction grating.

Bilayer grating based solar cell design not only gives broadband absorption but also efficeint guidng of light in si-active layer. In our previous work, we had observed a significant enhancement in absorption and quantum efficiency with a maximum cell efficiency upto 24 % from 50 µm cell thickness [9]. Grating parameters such as grating width, grating period and duty cycle were found to be important in order to trap and guide light efficiently in active region. In another work, use of a metal layer in combination a DBR as a part of back reflector has shown a better performance with minimum requirement of DBR pairs. This design with optimized parametrical value has achieved a relative enhancement in short-circuit current ~ 68 % due to enhanced absorption of light in UV and infrared part of solar spectrum [10].

Table 1

Solar cell structure	Short-circuit current (mA/cm^2)	Efficiency (%)	Relative Enhanced Efficiency (%)
Reference Designed 5 µm cell thickness (ARC only)	21.3	14	-
Designed 5 µm cell thickness (ARC+DBR+GRA)	30.2	20	42.8
Designed 10 µm cell thickness (ARC+DBR+GRA)	33.1	21.7	57.1
Designed 20 µm cell thickness (ARC+DBR+GRA)	35.47	23.3	64.2

Table 1 summarizes the performance of designed solar cells of different cell thicknesses with reference solar cell. With comparison to reference solar cell of 14 % efficiency, we have achieved 42.8, 57.1 and 64.2 % relative enhanced efficiency for three bilayer grating while it was 28.5, 35.7 and 50 % for single layer grating based solar cells of 5, 10 and 20 µm thicknesses respectively.

4. Conclusions

We have presented a design of thin film solar cells using FDTD method. We have observed that three DBR pairs with 0.8 µm center wavelength was good choice for optimal performance of solar cell. We have compared the cell efficiency of single and double grating layer based solar cells and observed an enhancement in later one. A relative enhancement in short-circuit current is observed i.e. 29.6, 32.9 and 34.6 mA/cm^2 of 5, 10 and 20 µm cell thicknesses which indicate the enhanced absorption in the wavelength 450-1100 nm. Finally, binary grating based solor cell designing is more efficient for light trapping which yields maximum quantum efficiency.

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