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Designing of long wavelength cut thin film filter for temperature reduction of concentrator photovoltaic

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Abstract. This paper presents a comparison of three-dimensional simulation for concentrator photovoltaic module using two types of multi-junction solar cell. Each had its own range of spectral response and based on that range a thin film filter was developed for each case to reflect the unused spectral of the solar spectrum and allowed the desired spectrum to reach the solar cell. The thin film was deposited on a secondary optical element that was used to homogenize the irradiance distribution on the solar cell. A thermal simulation was conducted to compare the resulted decrease in cell temperature due to the use of the thin film for each case.

1 Introduction

Concentrator photovoltaic (CPV) system is considered one of the most promising technologies in the field of solar energy which have received an increasing attention in R&D in recent years [1]. A CPV system utilizes the inexpensive optical elements, such as Fresnel lenses to concentrate sunlight into a small-size III-V multi-junction solar cell [2]. Multi-junction solar cells are influenced by their operating temperature. Decreasing solar cell temperature can have great impact on the open circuit voltage, maximum power point and efficiency of the multi-junction cell. In this paper we propose a Fresnel lens optical concentration system with concentration ratio of 1322 times.

The optical systems concentrate solar irradiance on two types of solar cells. Each has its own spectral response range, the first cell is InGaP/InGaAs/Ge triple junction solar cell with high spectral response in the range from 400 nm to 1700 nm [3], and the other is InGaP/GaAs/InGaAs triple junction solar cell with high spectral response in the range from 400 nm to 1100 nm [4]. We used thin film filter to utilize the part of solar spectrum which is beneficial to the solar cell while reflecting the rest of the long wavelength spectrum which will result in reduce of the cell temperature.

2 Optical model

Ray-trace calculation was conducted for the optical system using commercial optical simulation software ZEMAX. The optical system consists of typical flat Fresnel lens as primary optical element with dimensions of 200 mm × 200 mm as incident ray area (focal length = 420 mm), and secondary optical element (homogenizer).

Figure 1 shows the schematic diagram of the CPV optical structure. The homogenizer (14 mm×14 mm as entry aperture area, 5.5 mm×5.5 mm as exit aperture area, and 40 mm in height) was set at the focal point of the Fresnel lens. The used thin film was deposited at the entry aperture of the homogenizer, and the resulted intensity distribution of the concentrated light was analysed. The distance between Fresnel lens and solar cell was 460 mm. the geometrical concentration ratio for this system was 1,322 times.

The spectral irradiance using ray trace simulation was AM1.5 (total power: 900 W/m^2). Ray trace was carried out in the wave length from 300 to 2500 nm to show the effect of the thin film on the overall performance of the system.

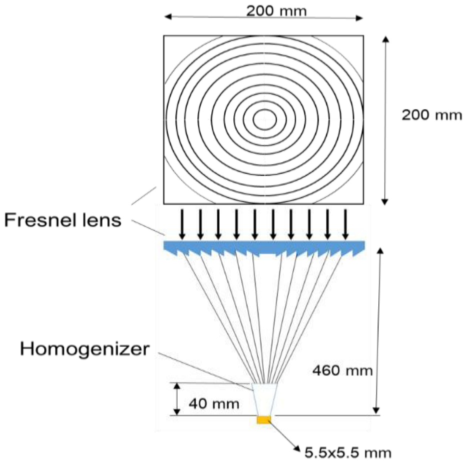

Figure 1. Schematic Diagram of the CPV optical structure.

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3 Thin film Design

For designing the thin film there is different traditional optimization method wildly accepted and used, nevertheless most used optimization technique for thin film are greatly affected by the initial structure of the used film, which may cause a local convergence, Tikhonravov et al. [5,6] has developed a powerful optimization method called Needle optimization technique. The two materials in the filter are H which has the high refractive index (in our case TiO_2), while L has the low refractive index material (in our case SiO_2).

Using needle optimizing and TFcalc (commercial thin film design software), we developed two filters; the first filter was used for the InGaP/InGaAs/Ge triple junction solar cell concentrator module and it only allowed the spectrum in the range from 400 to 1700 nm to be transmitted onto the solar cell while reflecting the rest of the long wavelength spectrum. The resulted structure consisted of 65 layers and had a thickness of 3490.4 nm. It’s expressed as follow:

S 731.37L 4.15H 36.04L 5.42H 22.65L 7.46H 17.42L 9.99H 12.16L 16.17H 11.12L 111.53H 14.33L 20.22H 20.39L 10.89H 42.16L 6.5H 254.28L 6.41H 39.05L 9.16H 18.17L 20.3H 13.99L 130.37H 15.79L 25.23H 42.99L 10.24H 250.9L 8.42H 44.82L 23.89H 15.7L 137.42H 15.15L 23.01H 43.1L 8.07H 260.08L 8.52H 41.91L 24.87H 14.18L 130.73H 14L 16.6H 15.96L 7.22H 40L 4.06H 274.14L 5.24H 32.43L 7.28H 14.9L 19.55H 6.57L 135.53H 14.98L 14.43H 25.97L 11.64H 93.2L A,

where S is the substrate in this case it’s BK7 and A stands for air.

As for the thin film used for the InGaP/GaAs/InGaAs triple junction solar cell it transmitted the spectrum in the range from 400 to 1100 nm and reflected the rest of the long wavelength spectrum. It’s expressed as:

S 6.61H 38.65L 12.67H 22.3L 14.71H 22.05L 12.98H 29.1L 9.05H 50.39L 2.82H 452.84L 9.08H 38.66L 25.18H 12.45L 133.25H 7.69L 22.55H 30.71L 9.82H 230.37L 7.52H 49.58L 17.06H 27.69L 25.03H 18.8L 31.87H 9.84L 150.55H 6.26L 23.86H 32.29L 11.67H 215.82L 15.27H 26.04L 117.25H 15.75L 17.37H 33.9L 5.67H 488.99L 6.05H 25.1L 12.21H 14.93L 110.92H 26.71L 13.4H 198.49L 11.95H 22.79L 107.25H 25.24L 15.31H 212.5L 9.62H 19.36L 10.88H 12.95L 112.5H 11.72L 16.24H 15.77L 8.43H 34.97L 3.96H 212.15L 40.78L 7.27H 36.94L 12.97H 20.45L 18.94H 15.28L 24.33H 13.48L 22.01H 19.22L 12.64H 38.5L 7.59H 225.9L 6.98H 39.31L 11.67H 45.42L 12.05H 106.47L A

This thin film consisted of 91 layers with total thickness of 4551.6 nm.

Figure 2 shows the transmittance for the two thin films.

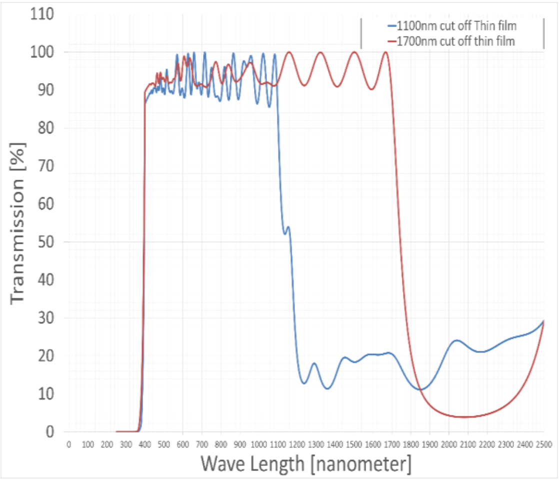

Figure 2. Thin film transmittance curve as a function of wavelength.

4 Heat Transfer module of CPV module

Heat transfer simulation for the CPV module was carried out using COMSOL Multiphysics. Figure 3 shows the geometry model developed for the calculating of heat transfer in the CPV module. The receiver consisted of homogenizer, III V solar cell, a solder, a copper electrode, insulation materials and aluminium stage which was mounted on the aluminium chassis.

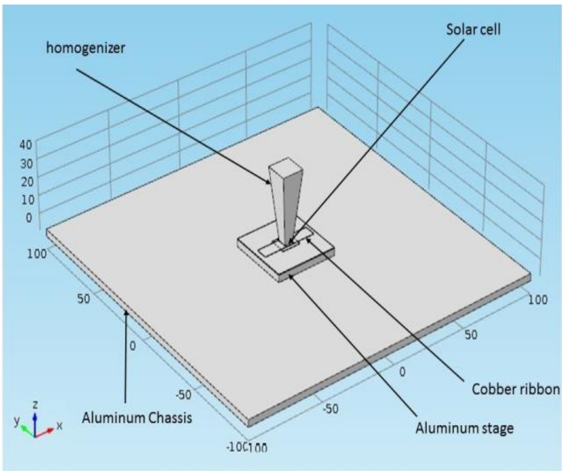

Figure 3. Simple geometry module for the heat transfer simulation.

I.Antón et al. [7] reported that the cell temperature (T_{cell}) could be related to the module temperature (temperature at the back surface of CPV module) through:

$$T_{cell}=T_{module}+R_{th\_cell\_heatsink}\times P \quad , \tag{1}$$

where T_{module} (K) is module temperature at back surface, $R_{th\_cell\_heatsink}$ (K/W) is thermal resistance between the cell and the back chassis or heat sink core, and P (W) is the heat power, respectively. The heat Power was related to the direct normal irradiance (DNI) through:

$$P=DNI\times A_{cell}\times C\times \eta_{op}\times(1-\eta) \quad , \qquad (2)$$

where A_{cell} is the solar cell area, (C) is the concentration ratio, η_{op} is the optical efficiency, and η is the electrical efficiency. A_{cell} was fixed to 5.5×5.5 mm^2. The initial temperature was 300 K.

5 Results and discussion

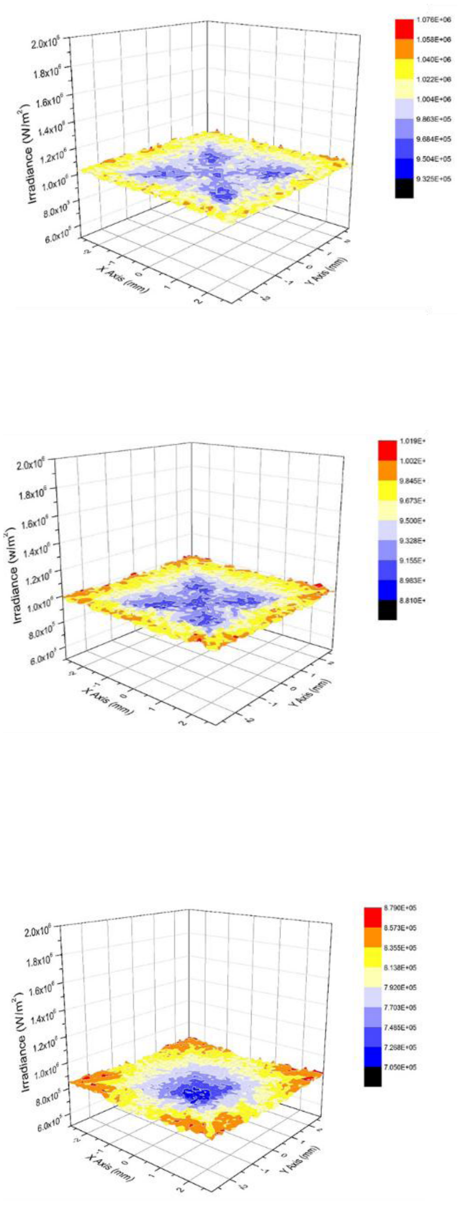

Figure 4. Calculated irradiance distribution on the solar cell.

Using ray-trace simulation we analysed the irradiance distribution on the solar cell for three cases; a)No thin film on the homogenizer face, b)1700 nm cutoff wavelength thin film, and c)1100 nm cutoff wavelength thin Film. Figure 4 shows the irradiance distribution on the solar cell for these three cases. The results showed good irradiance uniformity due to the use of homogenizer in all three cases.

Heat transfer simulation for the CPV module was carried out using COMSOL Multiphysics. The receiver consisted of homogenizer, III-V solar cell, a solder, a copper electrode, insulation materials and aluminium stage mounted on the aluminium chassis. Figure 5 shows the temperature distribution on the solar cell for each case. The results of thermal simulation for the three cases showed that the highest temperature was observed for the case of no thin film (118.7°C), while the temperature dropped to 114.5°C in the case of 1700 nm cutoff wavelength thin film with total drop of about 4°C in temperature.

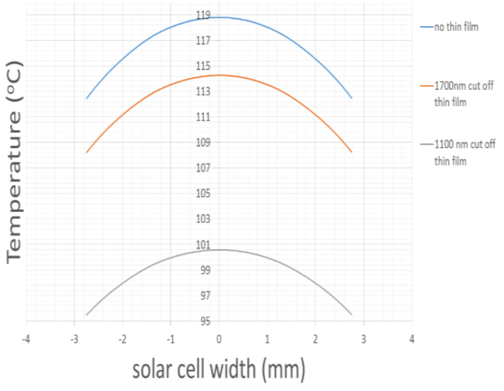

Figure 5. Temperature gradient on the solar cell surface.

The best thermal performance was achieved by the 1100 nm cutoff wavelength thin film case where the temperature decreased by 18.2°C to 100.5°C. The use of the thin film will have great effect on the solar cell performances.

6 Conclusion

Optical and thermal simulation have been conducted to an optical system with two types of multi junction solar cell and thin film that allows only the spectrum in which the solar cell has the highest response to pass through. Results showed great increase in the thermal performance of the InGaP/GaAs/InGaAs triple junction with decrease in total temperature by about 18.2oC from the no thin film case. The use of the thin film will have great effect on the solar cell performances.

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