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Research Article

Reuse of the Reflective Light and the Recycle Heat Energy in Concentrated Photovoltaic System

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A complex solar unit with microcrystalline silicon solar cells placed around the centered GaAs triple junction solar cell has been proposed and carried out. With the same illumination area and intensity, the total resultant power shows that the excess microcrystalline silicon solar cells increase the total output power by 13.2% by absorbing the reflective light from the surface of optical collimators. Furthermore, reusing the residual heat energy generated from the above-mentioned mechanism helps to increase the output power by around 14.1%. This mechanism provides a simple method to enhance the utility rate of concentrated photovoltaic (CPV) system. Such concept can be further applied to the aerospace industry and the development of more efficient CPV solar energy applications.

1. Introduction

In recent years, enhancing the output efficiency and reducing production cost have been the major core focus for studying solar cells. Many studies concerning the method of improving solar cell efficiency have been released. By modifying different cell structure types [1–5], changing material [6–8], textured cell surface or light receiving interface [9–14] and dye-coated cell surface [15, 16] are several examples of improving solar cell efficiency. Nevertheless, the use of solar condenser for increasing solar power output is one of the most novel approaches being focused at present, and related research papers have also been published [17–19].

The concentrated photovoltaic (CPV) system employs sunlight concentrated onto GaAs-related solar-cell surfaces for the purpose of high electrical power production. CPV systems are less expensive to build, because the concentration mechanism allows for the production of a much smaller chip size of solar cell than the nonconcentrated one.

The CPV unit with optical rod prism is a well-known configuration which concentrates sunlight from Fresnel lens via rod prism itself onto the GaAs solar cell top surface to generate electricity. Optical rod prism is mainly made of aluminum and coated with silver-nickel mirror like films. Most of the light will be guided to the chip surface of a GaAs solar cell, through the lens and the prism, but still some reflective light is scattered when sunlight illuminates on their polished surface. Due to the structure of optical rod prism which allows only part of the sunlight to illuminate again to the GaAs solar cell (the other part of the reflective light spreads outward), thus resulting in limited output power. Therefore, in this study, we aim at generating more electrical power by placing microcrystalline silicon solar cells cells around the CPV unit.

In addition, light concentrating on the surface of optical rod prism and solar cells of a concentrated photovoltaic system also create heat simultaneously, which warms the prism and cells. If the above-mentioned extra reflected light

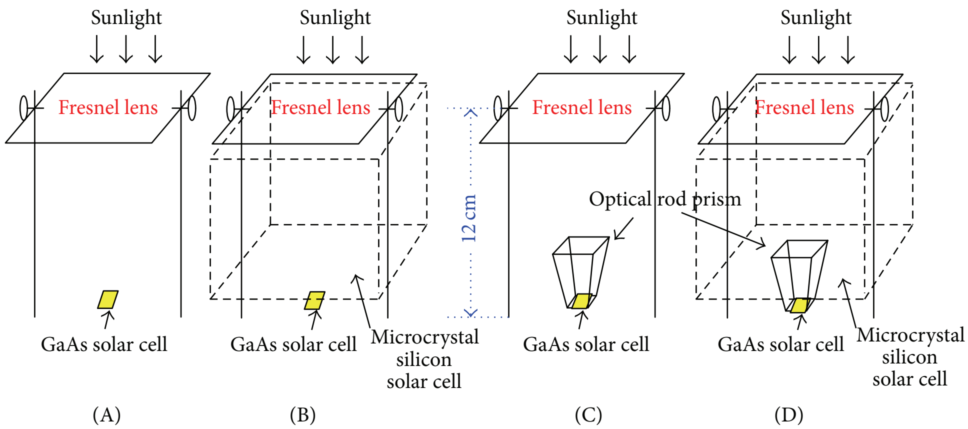


FIGURE 1: Four different mechanisms are used in this research work.

and heat energy can be reused together, it is then possible to further increase the output power of CPV solar cells. Therefore, in the last part of this study, in addition to the microcrystalline silicon solar cells are placed around CPV solar cells. Meanwhile, thermoelectric generating modules are installed at the back of optical rod prism and solar cells, respectively. By pivoting such a characteristic, it is expected to provide a simple method to an improved CPV output power, the utility rate of light under the same illuminated area and light intensity without extra considering costs, which ultimately enhances the total conversion rate with limited resources. In the other way, due to the flexibility of organic solar cell [20, 21], the proposed CPV system may adopt the single-layered organic photovoltaic cell in its side walls.

2. Experiment

Figure 1 shows the schematic structures of this research. Mechanism (A) is a concentrated photovoltaic system with GaAs solar cell only. Mechanism (B) is a concentrated photovoltaic system with GaAs solar cell and microcrystalline silicon solar cells around CPV. Mechanism (C) is a concentrated photovoltaic system with GaAs cell and an optical rod prism. Mechanism (D) is a concentrated photovoltaic system with GaAs cell, an optical rod prism, and four place microcrystalline silicon solar cells placed around CPV. Furthermore, in the last part of this work, a configuration with an installation thermoelectric device at the back of the optical rod prism and GaAs solar cell is assembled and characterized.

Among the mechanisms mentioned above, GaAs cell used was a triple-junctions solar cell manufactured by Visual Photonics Epitaxy (cell size: 5.7 mm × 6.8 mm, the measure output voltage and current at A.M 1.5 G and room temperature 25°C were showed, resp., in Table 1). The research also used a thin plastic Fresnel lens concentrator (size: 90 mm × 135 mm, thickness: 0.3 mm, material: PVC, focus: 120 mm, power-magnifying: 3x) within the concentrator mechanism (B&D). The Microcrystalline silicon solar cell was manufactured by PowerFilm Solar and the maxima output power of the solar was 5 Watts (0.3 A/15.4 V) with a size of

TABLE 1: The output property of GaAs solar cells.

Solar cell	Output current (mA)	Output voltage (V)
GaAs	2.54	2.30

120 mm × 120 mm. The thermoelectric device adopted here is a 5-layer structure. The solar simulator used as a light source was controlled at A.M. 1.5 G with room temperature 25°C. After analyzing and measuring the output characteristics of the mechanisms mentioned above, the best configuration (mechanism) is detailed in the following section.

We have repeated our measurement several times for each case to confirm the data collected in the study, and only the best values are given in the correspondent tables. The error of measured values in this study does not exceed ±0.5%.

3. Results and Discussion

3.1. Reuse the Reflection Light. By combining optical rod prism with CPV solar cell and surrounding them with microcrystalline silicon solar cells, it is found that the output power can be increased effectively. The results in Table 2 shows that microcrystalline silicon solar cells in mechanism (D) generate excess output current of 3.98 mA at an output voltage of 10.72 V. Therefore, with comparison to the present mechanism (C), the total output power of mechanism (D) has increased 13.2% (shown in Figure 2) under the same illumination area and intensity. In addition, with comparison to mechanism (A) in output characteristics, mechanism (B) is able to improve the output power by a value of 16.2 mW. All these results show that the extra microcrystalline silicon solar cells are able to absorb the reflected light from the surface of an optical rod prism. With such a characteristic, mechanisms (B) and (D) are both proven to be able to generate extra output power easily than those of conventional CPV cells without extra side-wall silicon cells.

For the purpose of further understanding the out-put power enhancement contribution from each correspondent reflective surface of the rod prism, we try to block the incident light to the individual surface of the prim and measure

Table 2: The output property of the four different mechanisms.

Mechanism	GaAs solar cell			Microcrystal silicon solar cell		
	Output current (mA)	Output voltage (V)	Output power (mW)	Output current (mA)	Output voltage (V)	Output power (mW)
(A)	90.00	2.52	226.80		None	
(B)	90.15	2.52	227.18	1.80	8.53	16.20
(C)	141.00	2.55	359.55		None	
(D)	142.85	2.55	364.27	3.98	10.72	42.67

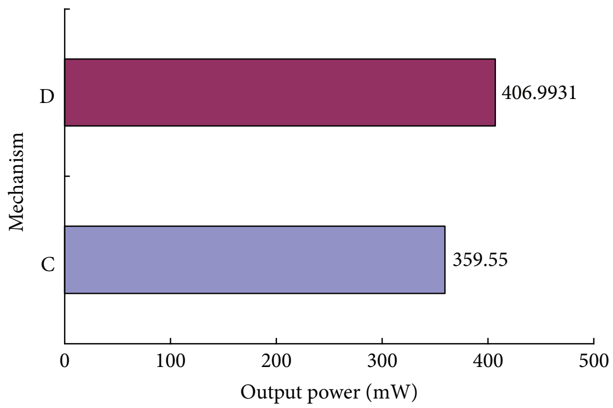


Figure 2: The output power of mechnism (B) and mechainsm (D).

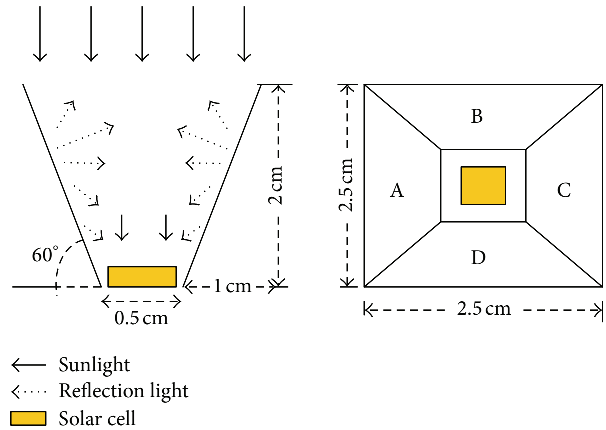


Figure 3: Schematic diagram of the optical rod prism in this research work and Table 3.

the output power variation of the mechanism (D). Table 3 shows the output characteristics of the microcrystal side-wall silicon solar cell of mechanism (D) based on different masking conditions (the given code number for each side is shown in Figure 3). Without reflective light of the optical rod prism, microcrystal silicon solar cell merely produces 1.83 mA and 8.62 V. Of course, there is a little difference between this date shown in Table 2 and mechanism (B). However, remember that the rod prism is present here, which has its four reflective surface blocked. When none, one, two, or three side masking are present, the output current and voltage of microcrystalline silicon solar cell are 3.98 mA 10.72 V, 2.93 mA 9.99 V, 2.25 mA 9.24 V, and 2.18 mA 9.16 V, respectively. The largest case, giving 2.15 mA and 2.10 V difference than the ones which the optical rod prism with four sides masked. This experiment verified that the microcrystalline side-wall silicon solar cell may further increase power output due to the reflective light from various sides of the rod prism surface.

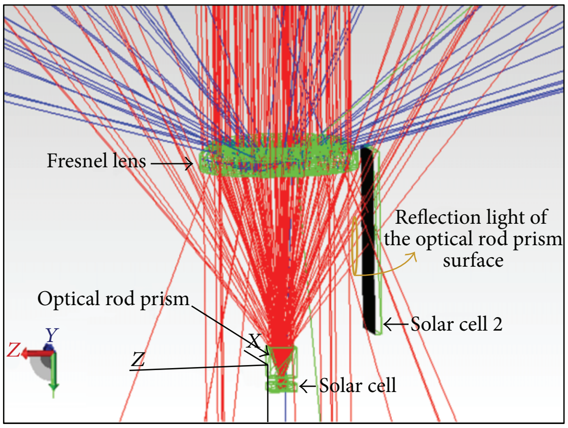
Meanwhile, in this study, the result derived from the software TRACEPRO is adopted to simulate light trace in mechanism (D) and shown in Figure 4(a). As observed from this figure, the light propagation reflecting from the surface of optical rod prism does shine on the side-wall silicon solar cells (microcrystalline silicon solar cells). The correspondent intensity distribution of the reflected light on the side wall silicon solar cell is shown in Figure 4(b). The simulated figure suggests that the reflected light mostly concentrates on the upper central part of the microcrystalline silicon solar cells. The results also show that each side of the cell is able to receive 6% of the light reflecting from the surface of optical rod prism and the CPV GaAs cell. Theoretically, we can calculate the reasonable enhancement by totally 24% of injected light reflected from the optical rod prism and multiple by microcrystalline silicon solar cell's efficiency of 12%, an absolutely 3% output power enhancement is expected. With respect to the GaAs triple junction solar cell adopted in this study, under 3 sun illumination, 25% efficiency, a relative output power enhancement of 12% is obtained. In the future, the side-wall solar cells can be replaced with single crystal silicon wafer with an efficiency of 20% (or other flexible organic solar cells), then an absolute 4.8% cell efficiency enhancement is expected.

3.2. Reuse the Recycle Heat Energy. It has been discussed that reusing the heat energy generated by the light concentrated on both optical rod prism and GaAs solar cell can also contribute to the increase of extra output powers of a CPV system. The correlation between temperature rising on the two thermoelectric generating modules and concentrated sunlight illuminating time is shown in Figure 5. As shown in Figure 6 and Table 4, the thermoelectric generating modules placed at the back of optical rod prism and at the bottom of the GaAs solar cell are measured to generate extra output power at the correspondent current voltage values of 6.7 mA/0.11 V and 11.98 mA/0.21 V, respectively.

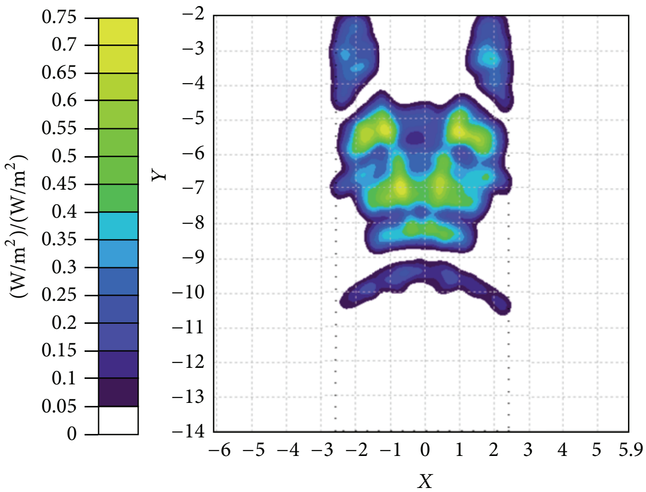
Based on the above measurement, the final CPV mechanism combining both reflected light capture with heat

TABLE 3: The output power of the microcrystal side-wall silicon solar cell of Mechanism (D) under the different masking conditions.

Masking area	Microcrystal silicon solar cell		
	Output current (mA)	Output voltage (V)	Output power (mW)
No	3.98	10.72	42.67
A	2.93	9.99	29.27
A, B	2.25	9.24	20.79
A, B, C	2.18	9.16	19.97
A, B, C, D	1.83	8.62	15.77

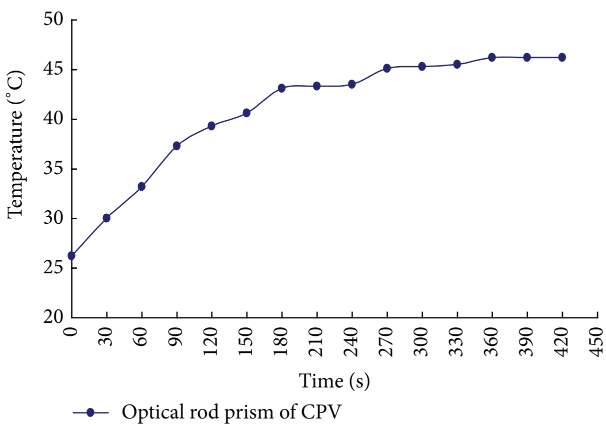


(a)

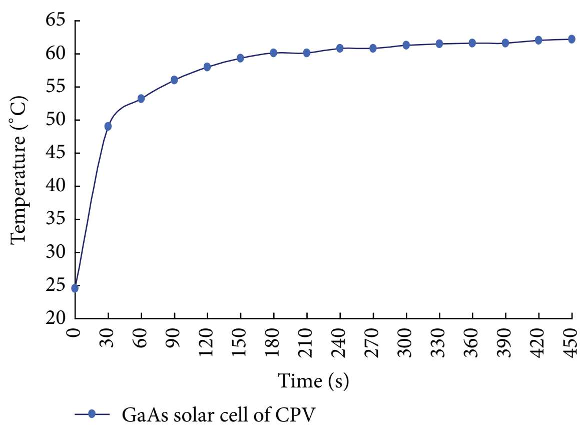


(b)

FIGURE 4: The simulation result derived from the software TRACEPRO which is used to simulate the light trace in mechanism (D).



(a)



(b)

FIGURE 5: (a) The temperature of the back side of the optical rod prism with time. (b) The temperature of Back side of GaAs solar cell with time.

energy reuse. As shown in Figure 7, there have been successful attempts in supplying extra output power of 14.1% (50.61 mW) by applying proper side-wall cells installation, thermal voltage modules attachment and individual output circuit design, which is with comparison to the traditional CPV cell configuration.

4. Conclusions

This study has provided and demonstrated a possible way to further enhance the output power of CPV solar cell system by the reuse of both the reflected light from the rod prism surface the residual heat generated by the light concentrator. We have

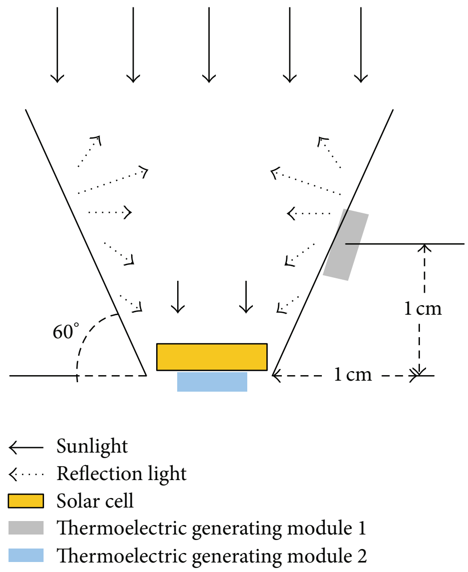


Figure 6: Schematic diagram of the thermoelectric generating modules placed at the backside of the optical rod prism and the bottom side of the GaAs solar cell in this research.

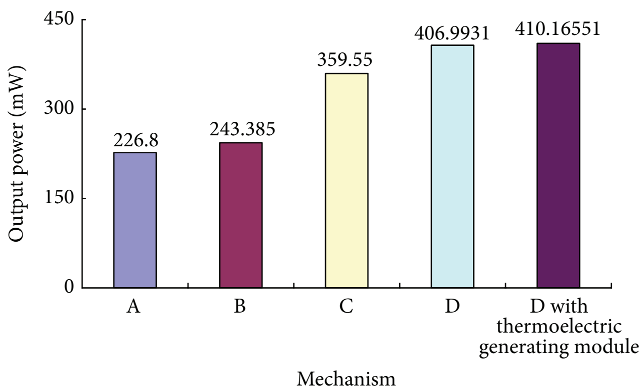


Figure 7: The output power comparason of mechnismsproposed in this reaserch.

Table 4: The output energy of the correspondent thermoelectric generating module 1 and 2.

Thermoelectric generating module	Output current (mA)	Output voltage (V)	Output power (mW)
1, back side of the rod prism	6.76	0.11	0.72
2, bottom side of the GaAs cell	11.98	0.21	2.46

detailed how reflected light from the surface of the optical rod prism and affected the output power of the additional side wall of a solar cell (microcrystal silicon solar cell). As a result, a 13.2% output power enhancement is obtained under the same illumination conditions. Furthermore, in this work, we have also explored the feasibility of the extra power generation by heat energy reusing. The heat reusing results show that an excess output power of 3.3 mW can be generated. Therefore, by appropriating cell installation, residual heat reusing and individual output circuit designing, a relative enhancement of the CPV output power by a value of 14.1% (equal to an ideal absolute solar cell efficiency enhancement of 4%) is reported and is considered to be a simpler way for improving the utilization of sunlight under the same illumination condition.

Conflict of Interests

The author report no financial or other conflict of interests relevant to the subject of this paper.

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