

Electrical Energy Harvesting from Thermal Energy with Converged Infrared Light

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Abstract. Photovoltaics (PV) cell is a common energy harvester that had been used to harvest solar energy and convert it into electrical energy. However, the vast energy from the spectrum of sunlight is not fully harvested. Therefore, thermoelectric (TE) module that harvest electrical energy from heat is being proposed in this paper. Generally, the part of the sunlight spectrum that induce heat is in the spectrum band of infrared (IR). For the experimental set-up in this paper, infrared (IR) light bulb was being used to simulate the IR spectrum band of the sunlight. In order to maximize the heat energy collection, a convex lens was being used to converge the IR light and therefore focused the heat on an aluminium sheet and heat sink which was placed on top of the hot side of the TE module. The distance between convex lens and IR light bulb is varying in between 10cm and 55cm and the reading was taken at an interval of 5cm. Firstly, the temperature of the IR light and converged IR light were recorded and plotted in graph. The graph showed that the temperature of the converged IR light bulb is higher than the IR light bulb. Lastly, the voltage and power output of the TE module with different heat source was compared. The output voltage and power of the TE module increased inverse proportional to the distance between IR light bulb and TE module.

1. Introduction

Sunlight has a wide spectrum which covers ultraviolet at one extreme to infrared light at the other extreme and in between is the visible light. The solar irradiation on earth are 5% UV, 43% visible and 52% Infrared. In term of wavelength, ultraviolet is in between $0.2\mu - 0.39\mu\text{m}$, visible is in between $0.39\mu - 0.78\mu\text{m}$, whereas infrared is in between $0.78\mu - 100\mu\text{m}$ [4]. The photon energy of the spectrum is inversely proportional to the wavelength. Infrared has lowest photon energy compare to ultraviolet and visible light and therefore is insufficient to break through the bandgap of the photovoltaics cell. This mean that the vast energy of sunlight is not fully utilized by PV cell to generate electrical power.

TE module is suggested to be used for harvesting heat energy from sunlight and convert into useful electrical power. In this paper, an experiment set-up an Infrared light bulb is being used to simulate the sunlight.

TE module is popular for generating electrical energy from industries and machinery which produce relative high heat energy. Toshihiko and Hiroaki proposed heat pipes as heat source for TE module, so electrical energy can be produced from the heat that dissipates from heat pipes [5]. The TE module they used was attached to the heat pipes, and heat sink was used to cold down the cold surface of the TE module. The temperature gradient that they achieved was at 50°C . The output voltage per temperature gradient was about $0.00656\text{v}/^{\circ}\text{C}$. In another study, Lauri and Matti suggested to used automotive internal combustion engines as heat source [6]. The temperature gradient of combustion engine can achieve up to 200°C which generated $0.0376\text{V}/^{\circ}\text{C}$. On the other hand, Jie Chen considered gamma radiation as heat source and heat sink as cold surface to generate electrical energy [7]. By



using gamma radiation, the temperature gradient that he can produce was at about 120°C hence achieved a performance of 0.0508V/°C. In addition, Rajeh and Kiran discovered that chimney from industrial plant was suitable for TE module to generate electrical energy [8]. From their paper, the highest temperature gradient is they can produce was at about 85°C and the output voltage is 0.0198V/°C.

2. Thermoelectric Module (TE module)

The fundamental process of thermoelectric module is based on the Seebeck effect, named by Thomas Seebeck in 1821. The Seebeck effect is the generation of electricity within two dissimilar metals and these metals placed in two different temperature, thus it will generate voltage output. Therefore, it usually used as thermometer and its call thermocouples. However, the dissimilar metal can be improved with semiconductors because semiconductors have higher Seebeck coefficients, so they are more suitable to be used for generating electrical power compared to metal [1,3]. Figure 1 shows the P-N junction that built up TE module. It connected electrically in series and thermally in parallel. Besides, ceramic plate is used to sandwich the N pairs of thermocouple. Using ceramic plates because it is good in heat conduction and resistive of electricity [2].

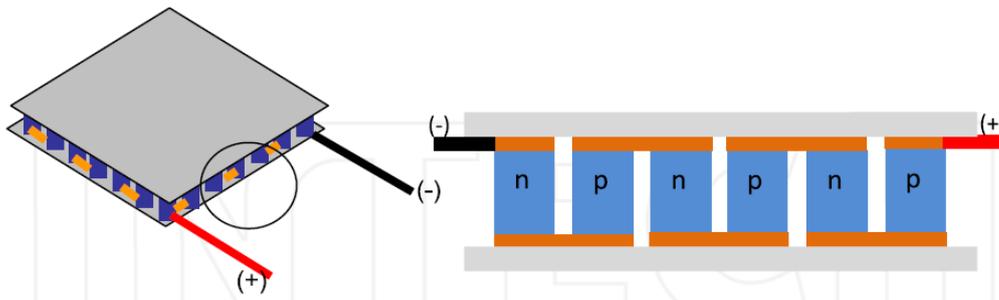


Figure 1. Thermoelectric module [2].

According to the Seebeck effect, the excess of electron will flow from hot junction to cold junction in n-type material. In p-type material, the holes of electron will flow from cold junction toward hot junction. Therefore, this flow produce the current flow of the TE module[1]. In addition, the Seebeck coefficient, α , is defined as the change in voltage per degree of temperature gradient [1,3]:

$$\alpha = \frac{dV}{dT} \text{ volts/K} \quad (1)$$

Seebeck coefficient also included in voltage V_s produces from a TE module while it is applied temperature gradient which is T_h as hot temperature and T_c as cold temperature [2]:

$$V_s = \alpha(T_h - T_c) \quad (2)$$

3. Sunlight spectrum and PV cell

Table 1 shows the bandgap of variety type of solar cell and Table 2 shows the solar irradiation, wavelength and photon energy of spectrum sunlight. Polycrystalline silicon solar cell is most common used nowadays. In addition, the bandgap required is about 1.1eV which means most of the infrared light from sunlight cannot breakthrough the bandgap and generate the electricity. Therefore, sunlight is not fully utilized by using solar cell as energy harvester

Table 1. Bandgap of material used for manufacture solar cell [4]

Solar Cell Material	Bandgap (eV)
Cadmium Telluride (CdTe)	~1.58
Gallium Diselenide (CIGS)	~1.38
Polycrystalline Silicon	1.1
Germanium	0.477

Table 2. Solar irradiation, Wavelength and Photon energy of spectrum sunlight [4]

Spectrum Sunlight	Solar Irradiation (%)	Wavelength (μm)	Photon Energy (eV)
Ultraviolet	5	0.2 – 0.39	6.2 – 3.2
Violet			
Blue			
Green	43	0.39 – 0.78	3.2 – 1.59
Yellow			
Orange			
Red			
Infrared	52	0.78 - 100	1.59 – 0.0124

4. Experimental Set-up

There are three experiments carried out in this paper. All of the experiments were using IR light bulb as the heat source to simulate the heat energy from sunlight. Besides, the convex lenses were used to converge the IR light to focus the heat.

First of all, the temperature of radiated IR light bulb and converged IR light bulb was measured by using thermometer and compared in graph. In order to dissipate the heat evenly, aluminium sheet or heat sink was place on hot surface of TE module. Besides, heat sink was place on the cold surface of the TE module, so the temperature gradient of the TE module can be maintained. Figure 2 shows illustration of these three experiment. Figure 2 (a) shows measuring temperature of radiated IR light and converged IR light, Figure 2 (b) shows converged IR light on TE module with aluminium sheet on top and Figure 2 (c) shows converged IR light on TE module with heat sink on top.

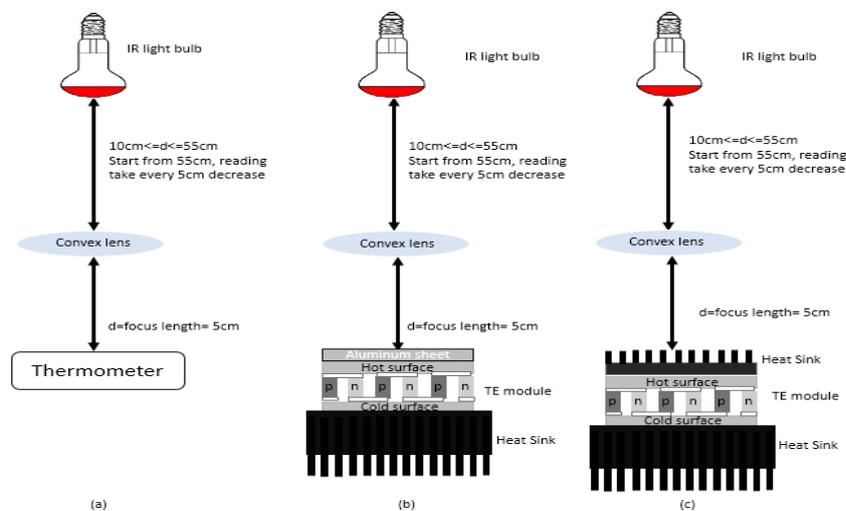


Figure 2. Illustration of (a) measuring temperature of radiated IR light and converged IR light (b) Converged IR light on TE module with aluminium sheet on top (c) Converged IR light on TE module with heat sink on top.

Figure 3 shows the experiment set-up in lab. The focus length of convex lens was fixed as 5cm. In addition, the distances between IR light bulb and convex lens are 55cm, the voltage and current output were taken every 5cm IR light bulb near to convex lens.

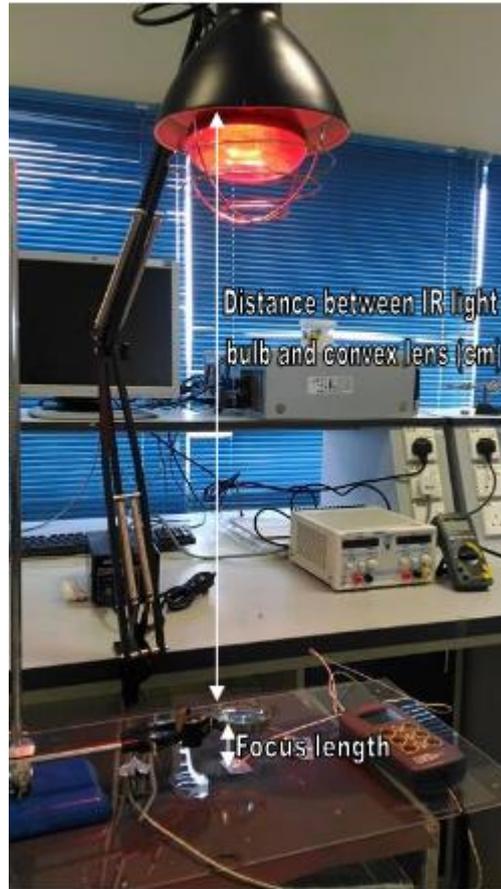


Figure 3. Using IR light bulb as experimental set-up

Figure 4 shows the first lab experiment which is being used to measure the temperature from IR light bulb. Two temperatures were taken in the experiment, which are IR light and converged IR light. One of the thermocouple was placed on the bottom of convex, another thermocouple was placed outside the focus area of a convex lens. After that, both of the temperature readings were plotted in graph and compared.

Next, the converged IR light were used as a heat source for TE module to generate an electrical energy from the heat energy. Firstly, an aluminium sheet with a dimension of 8cm length and 8cm width was put on the top of TE module. This was followed by placing a 19cm in diameter and 9cm height heat sink to replace the aluminium sheet.

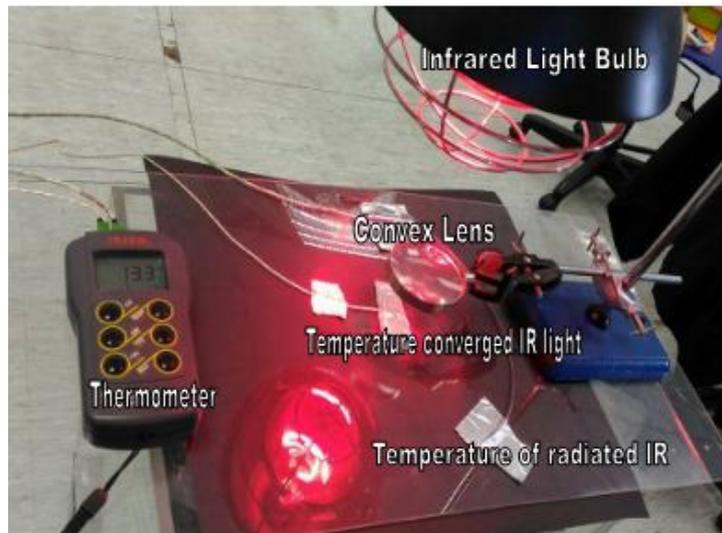


Figure 4. Measuring temperature of radiated IR light and converged IR light

Figure 5 shows the experimental set-up of converged IR light on the aluminium sheet. TE module that used in the paper is from Laird Technology UltraTEC series. The TE module was placed between the aluminium sheet and heat sink, so that the aluminium sheet can dissipate the heat on TE module evenly. Besides, the heat sink can release the heat from the TE module to maintain the cold surface of the TE module. Additionally, an aluminium foil with PE foam was used to reflect and resist the heat energy from IR light radiate to heat sink.

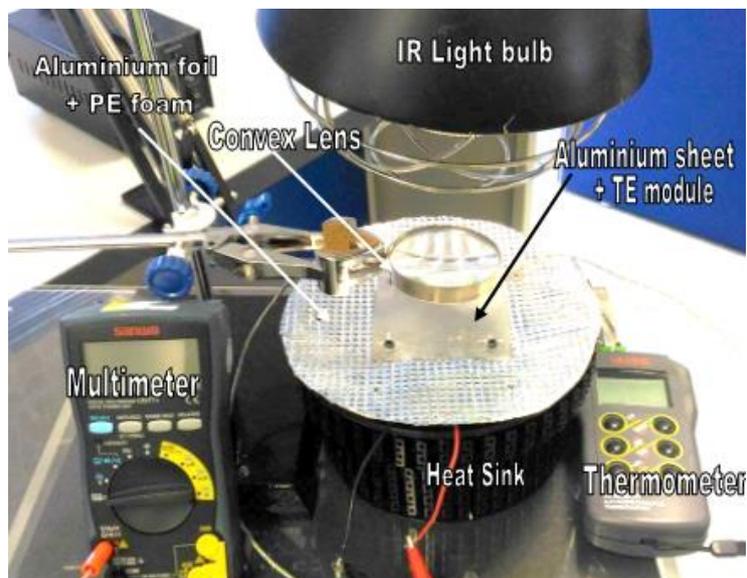


Figure 5. Converged IR light is focused on aluminium plate.

Figure 6 shows the experimental set-up of converged IR light on heat sink. The TE module was placed between two heat sinks, the small heat sink has the same function with aluminium sheet in former experimental set-up which is heat dissipation on TE module uniformly. Lastly, the voltage output and power of the TE module in different experimental set-up is plotted and compared.

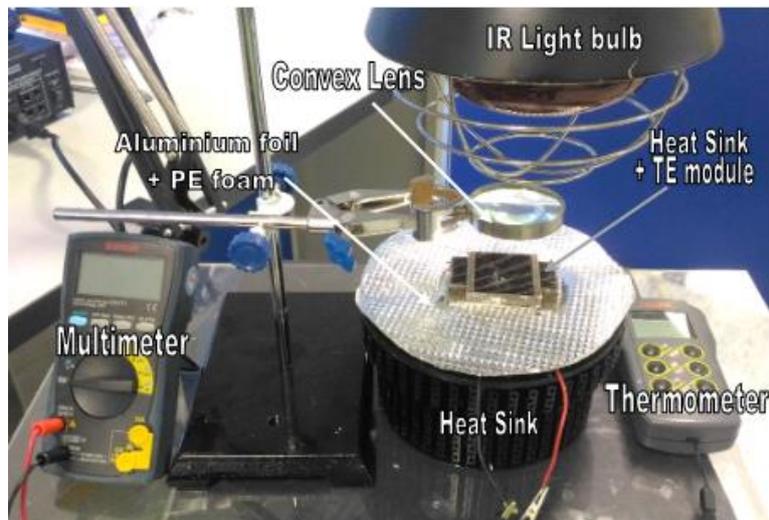


Figure 6. Converged IR light is focused on heat sink

5. Result and Discussion

Figure 7 shows temperature of the IR temperature, the converged IR temperature, and the temperature different at different distance between IR light bulb and convex lens. From the graph above, it shows that the temperature between IR light and converged IR light have not much different from 55cm until 40cm. However, temperature changed dramatically from 45cm until 10cm. There is a 1.3°C temperature gain from the converged IR light when the distance between the IR light bulb and the convex lens is at 40cm. Moreover, the temperature different between the IR light and the converged IR light is 30.9°C when the distance is at 10cm. Therefore, it shows that the convex lens has the potential to double up the temperature that was produce by the IR light bulb. It clearly shows that a convex len is suitable to be used for focusing IR light for better heat energy production from the same heat source.

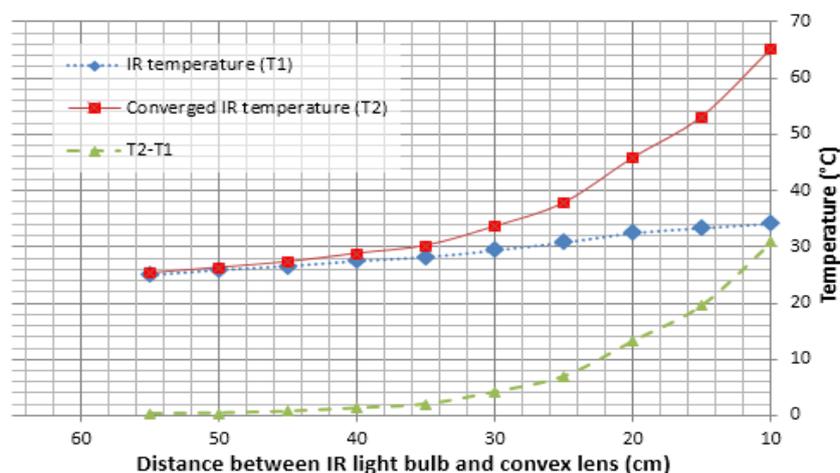


Figure 7. Temperature ($^{\circ}\text{C}$) versus distance between IR light bulb and convex lens (cm).

Figure 8 shows the voltage output of TE module while different temperature gradient was applied on it. Besides, there are two different materials that was put on top of TE module, which are a aluminium sheet and a heat sink. When the distance between IR light bulb and convex lens is at 10cm, the temperature of the aluminium plate and the heat sink obtained the highest temperature which are at 10.7°C and 12.05°C respectively. Although the highest temperature showed a different of only about 1°C, but the outputs voltage have a significant different between them. When the distance between IR light bulb and convex lens is at 10cm, the output voltage of TE module with aluminium plate on top is 0.1059V while the voltage output of the TE module with the heat sink on top is 0.341V. From Figure 7, the increment of the voltage per temperature of the TE module with aluminium plate and heat sink are 0.00978V/°C and 0.0286V/°C respectively. It is about a factor of 3 times different between these two different experimental set-ups.

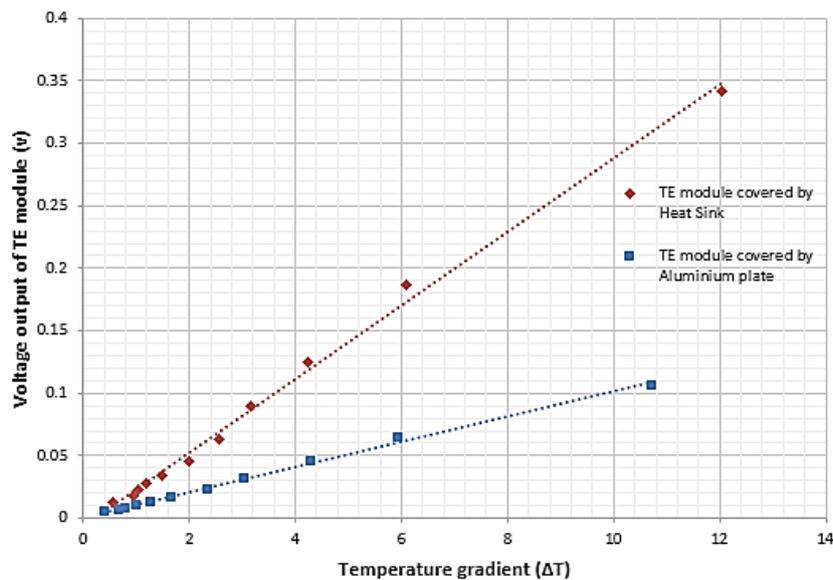


Figure 8. Voltage output of TE module from variance temperature gradient.

Figure 9 compares the power output of TE module from different perspective, including variance resistor load, variance distance between IR light bulb with convex lens, and different material cover TE module. The power increase from origin until peak power, the peak power output occurs between 80 Ω and 140 Ω resistor load.

There are three different distances between IR light bulb and convex lens included in output power measuring which are 30cm, 35cm, and 40cm. The temperature applied on the TE module increased, while the distance, d between the IR light bulb and the convex lens decreased. In comparison to the same material that used to cover TE module, the power output is at its highest when distance is at 30cm. When aluminium was used to cover the TE module, the peak power that can be obtained is about 1.23 μ W at separation distance of 30cm. Besides, the peak power is 0.6 μ W and 0.31 μ W when the distance is at 35cm and 40cm respectively. This scenario is same when the TE module covered by the heat sink, the highest power is obtained when the distance is at 30cm. The peak power when distance equal to 30cm is about two times of the peak power when distance is at 35cm.

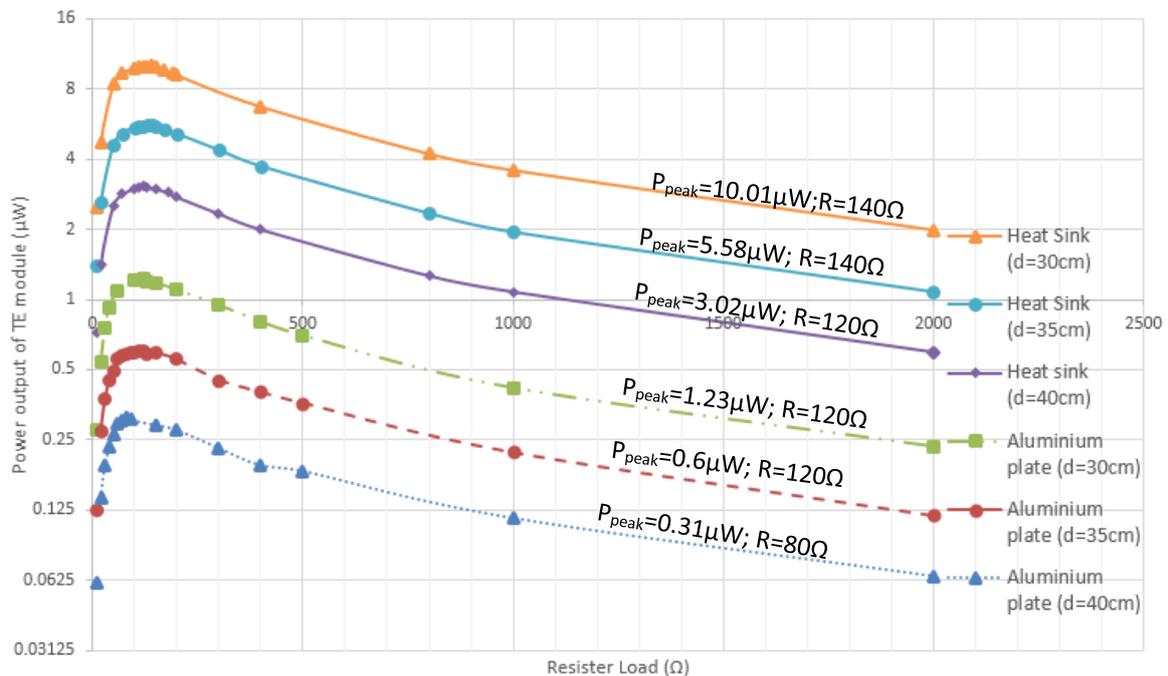


Figure 9. Power output of TE module from variance resistor load

According to Figure 8, the power output of using heat sink to cover the TE module is at its higher than using the aluminium plate to cover it. When using the same distance between IR light bulb and convex lens, the power output of using heat sink as the cover is 8 to 10 times higher than that using aluminium plate as the cover. Therefore, it can be concluded that the heat sink is more suitable to be used as the cover to dissipate the heat onto the TE module uniformly.

6. Conclusion

The above results showed that, the heat energy collection is greater for a converged IR light than a radiated IR light. Therefore, it can be applied to produce higher temperature to act on a TE module and hence generating more electrical energy. According to the voltage output and power output of the TE module, a heat sink is more suitable to be used as a cover of a TE module instead of using an aluminium plate as a cover. Since, a TE module can produce more voltage and power output when using heat sink as a cover. Therefore, using a converged IR light as heat source generation of electrical energy from the sunlight as a potential heat source for TE module.

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