

Research Article

Study of Phase Change Materials Applied to CPV Receivers

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There are lots of factors which can directly affect output efficiency of photovoltaic device. One of them is high temperature which would cause adverse effect to solar cell. When solar cell is operated in high temperature, the cell's output efficiency will become low. Therefore, improving thermal spreading of solar cell is an important issue. In this study, we focused on finding new materials to enhance the thermal disspreading and keep the temperature of solar cell as low as possible. The new materials are different from conventional metal ones; they are called "phase change materials (PCMs)" which are mainly applied to green buildings. We chose two kinds of PSMs to study their thermal disspreading ability and to compare them with traditional aluminum material. These two kinds of PCMs are wax and lauric acid. We made three aluminum-based cuboids as heat sinking units and two of them were designed with hollow space to fill in the PCMs. We applied electric forward bias on solar cells to simulate the heat contributed from the concentrated sunlight. Then we observed the thermal distribution of these three kinds of thermal spreading materials. Two levels of forward biases were chosen to test the samples and analyze the experiment results.

1. Introduction

In the development of concentrating photovoltaic (CPV) technology, heat dissipation is always an important issue that affects the output efficiency of CPV module or receiver. The output power of solar cell is inversely proportional to its operating temperature. The lower temperature solar cell is the higher power it can produce [1]. Currently, the most popular thermal-dissipation structure is aluminum-extruded heat sink with varied shapes, which maximizes the thermal-dissipating surface area to the air. It will increase the efficiency of passive thermal convection and keep the temperature of CPV receivers as low as possible. In this paper, we used different approaches and materials to achieve the new thermal-dissipation path. These materials are called phase change materials (PCMs) which have been applied to thermal storage and green building technology for a long time [2]. Some PCMs with low melting point ($40^{\circ}\text{C}\sim 60^{\circ}\text{C}$) and high latent heat (over 150 J/g) have good ability to reduce room temperature fluctuation as used in the sandwich wall of the buildings.

In this study, some PCMs were used to keep solar cell at a proper temperature for a period of time, making solar module

have better power conversion efficiency. This temperature depends on the melting point of applied PCMs. As a result, the temperature of solar cell could be controlled at an expected value. Therefore, it is important to choose suitable PCMs to perform this experiment.

2. The Thermal Function of Phase Change Materials

There are three kinds of thermal spreading modes in heat transfer mechanism: conduction, convection, and radiation. These are also the core concepts of designing heat sinks. The most common material of heat sink is aluminum due to its high thermal conductive coefficient (167 W/mK) and easy-shaping characteristic. Here we embedded the PCMs into the aluminum heat sink. These materials were expected to add extra heat capacity of the original heat spreading system. The extra heat capacity comes from its high latent heat value that could keep temperature at a specific melting point for a long time and restart to heat up again until PCMs melting into liquid state entirely.

In this paper, two PCMs were used, which were paraffin wax and lauric acid. The properties of these PCMs are listed in

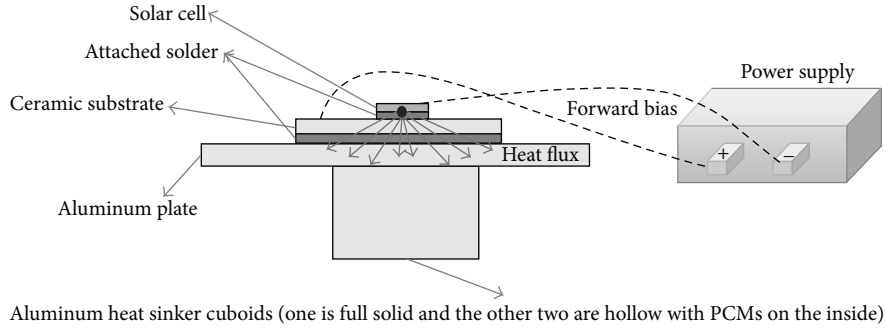


FIGURE 1: Sketch of experiments with solar cell applied forward bias as a heat source center.

TABLE 1: The individual characteristics of the three experimental materials [3, 4].

Material	Aluminum	Paraffin wax	Lauric acid
Density (g/cm^3)	2.7	0.9	0.88
Specific heat (solid) ($\text{J}/\text{g}\cdot\text{K}$)	0.91	2.9	2.4
Specific heat (liquid) ($\text{J}/\text{g}\cdot\text{K}$)		2.13	2.0
Latent heat of melting (J/g)	321	189	182
Melting point ($^{\circ}\text{C}$)	660	49	42
Thermal conductivity (solid state) ($\text{W}/\text{m}\cdot\text{k}$)	167	0.21	0.15
Thermal conductivity (liquid state) ($\text{W}/\text{m}\cdot\text{k}$)		0.167	0.148

Table 1 in comparison with aluminum. The melting points of paraffin wax and lauric acid are 49°C and 42°C , respectively. These melting points are at the lower margin of the CPV operating temperature. But there are also some thermal spreading issues of PCMs. First of all, these PCMs often have low thermal conductivity and high thermal resistance comparing with aluminum. Another issue is that the PCMs cannot contact directly with solar cell since there are some interface materials and circuit board between them. It will affect heat absorption efficiency of PCMs. In this study, some samples were fabricated to verify these issues.

3. Experimental Parameters and Conditions

For our thermal spreading and dissipating experiment, we designed a modified structure from our original CPV receiver, as shown in Figure 1. The test receiver had several components and was packaged by SMT. First of all, the backsides of the solar cells were connected with the gold contact electrode pads of the ceramic substrates by solder. We joined the topsides of the dies and the circuit of the ceramic substrates with wire bonding. The backsides of the ceramic substrates were integrated in the topside of the aluminum plate to form the primary part of CPV receiver. Finally three aluminum cuboids were fixed on the backside of the CPV receiver and located at bottom center of each solar cell. We fabricated two different types of the cuboids, shown in Figure 2, to execute our PCMs thermal-dissipation

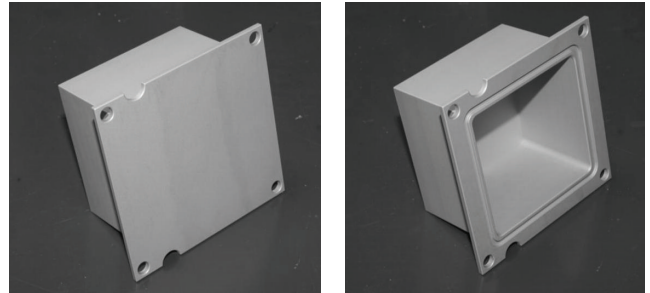


FIGURE 2: The two types of the aluminum heat sinker cuboids for the thermal spreading experiment.

experimental analysis. One type of the cuboids was a solid aluminum bulk as reference sample. Another type was a hollow cuboid which would fill with PCM as test sample. Furthermore, two kinds of PCMs were filled into the hollow cuboids, which were paraffin wax and lauric acid. All of them were attached directly onto the backside of the aluminum plate of CPV receiver. Therefore, there were three different samples in the CPV receiver and the solar cells of each sample were connected in series.

For establishing a stable and equal heat source, we used a power supply to bias the solar cells with a 4A or 6A forward current continuously in the laboratory for 100 minutes instead of irradiating by unstable outdoor sunlight. When the solar cells were in forward bias, they would become LED-like devices and consume the input electric power into heat and light. During this process, we observed the temperature change and distribution of these three samples on the topside of the CPV receiver by thermal image instrument. The room temperature and humidity were controlled by the air conditioner.

4. Result and Discussion

The first experimental condition was that the CPV receiver was biased continuously by fixed-value 6A forward current in 100 minutes to observe the thermal spreading pattern. After the experiment, the thermal-equilibrium temperatures of the solar cells of these three samples were 71.9°C for lauric acid, 71.6°C for aluminum bulk, and 73.5°C for paraffin wax, respectively, as shown in Figure 3. These temperature values

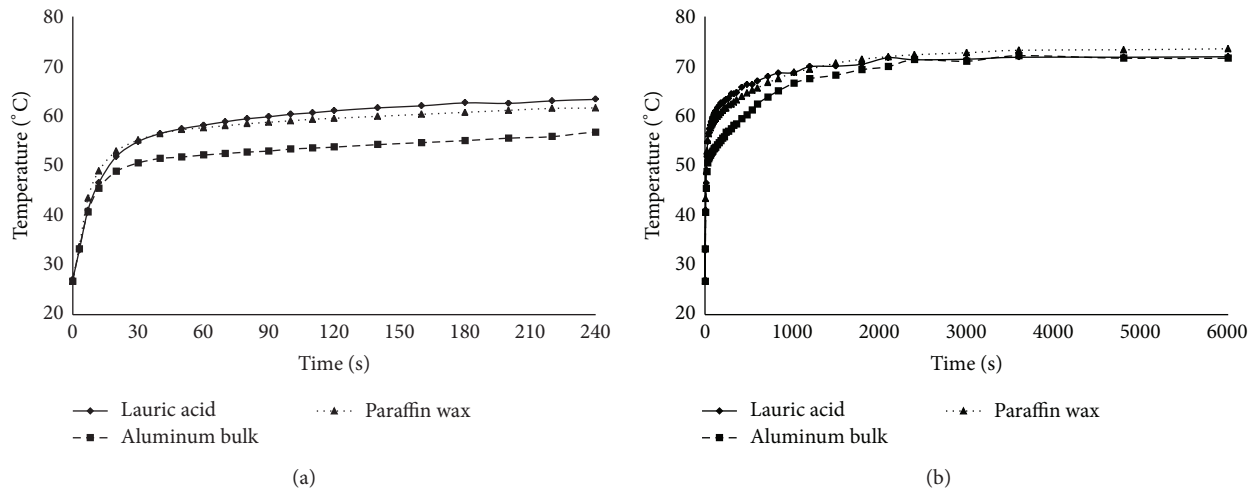


FIGURE 3: (a) The first two-minute and (b) the 100-minute temperature variations of the solar cells of the three experimental samples under 6A forward current injection.

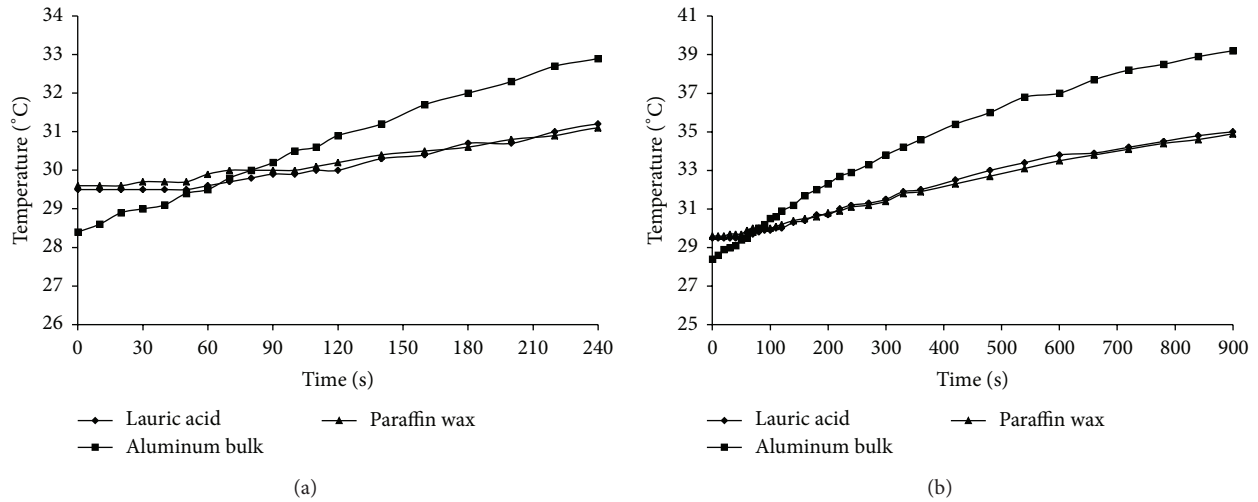


FIGURE 4: (a) The first two-minute and (b) the fifteen-minute bottom temperature values of the three cuboids measured by IR image instrument.

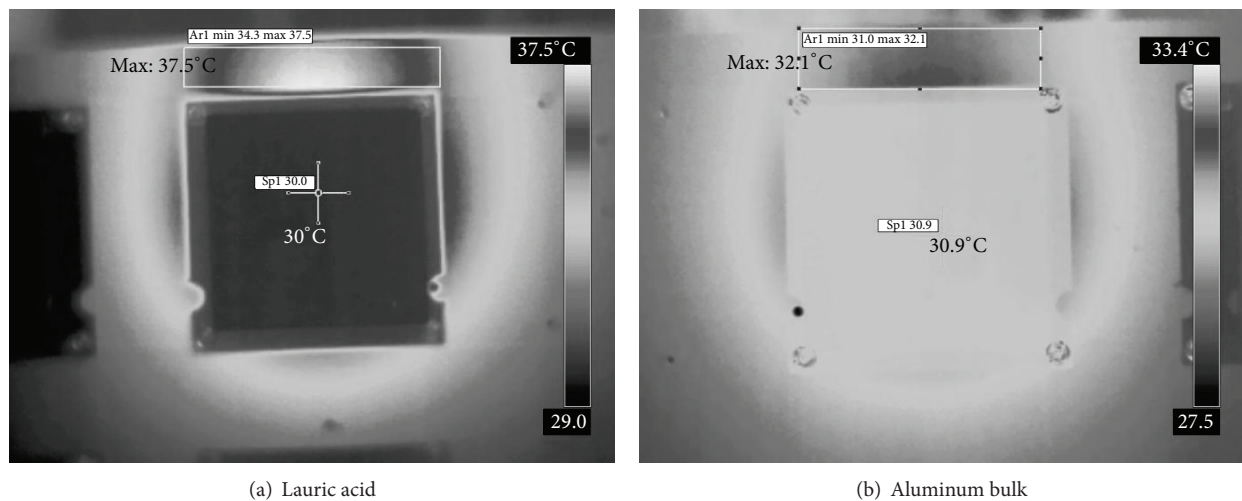


FIGURE 5: The thermal images of the test samples which were heated two minutes ((a) is lauric acid and (b) is aluminum bulk).

were quite close to the outdoor operating temperature of solar cell in the sunny summer. The result showed that the entire thermal spreading and dissipating efficiency of these three samples were quite close, too.

Another focus of observation was the different temperature-rising curves of the three samples during the first two minutes of heating. For the sample with the aluminum bulk, temperature rising rate of its solar cell was the lowest. This was because aluminum bulk had most outstanding thermal conductive efficiency of all samples. The quantity of heat which was transferred quickly from the solar cell to the bottom of the aluminum bulk was more than the PCMs samples. Then there was the highest temperature value on the backside of the sample with aluminum bulk in first two and entire fifteen minutes, as shown in Figures 4(a) and 4(b), respectively. In another view, the comparison of two thermal images which is backsides of the samples with aluminum bulk and lauric acid was shown in Figure 5. When the CPV receiver was heat by forward current in two minutes, the temperature in the plate region of the lauric acid sample was 37.5°C (maximum value) and 30°C in the bottom of the cuboid. The different between the two measured points was 7.5°C. For the sample with aluminum bulk, the different value was only 1.2°C. Further the 3D temperature distribution in the zone of the each PCMs sample was more wide range and higher than the aluminum bulk sample after being biased two minutes, as shown in Figure 6. The heat was transferred less efficiently downward to the cuboids due to the lower thermal conductivity of the PCMs and the thermal crowding in the nearby region of the solar cells caused temperature increase more quickly.

In addition the thermal spreading and dissipating experimental result showed another phenomenon that the solar cell did not keep in a specific temperature point which was equal to melting point of lauric acid or paraffin wax. It was also due to large thermal conductive different among aluminum and PCMs. In the CPV receiver structure here, the PCMs were surrounded by aluminum and did not touch the solar cells directly. There were too many interface materials to have good heat absorption efficiency for the PCMs. When the heat absorption of the PCMs was less efficient than the heat generation from power supply, it caused that the temperature value of the solar cell would be higher than the melting point of the PCM. Although the temperature value of the solar cell was not entirely controlled in our default method, effect of the PCM still happened in the cuboid of the CPV receiver backside. The temperature values of the samples in the CPV backside were close to the melting points of the two PCMs and the thermal equilibrium was also shown in Figure 7. The Sp3 point was 43°C and Sp4 was 43.3°C; furthermore, these temperature values were very close to the melting points of the lauric acid and paraffin wax, respectively. The PCMs were in touch directly with the whole inner surface of the cuboids, so the thermal transference and absorption would have more efficiency and immediacy than the heat flow from the solar cells to the PCMs. The outcome was that the temperature difference from cuboid to PCMs was smaller than from solar cell to PCMs. If the CPV system operates in the field, the lower backside temperature of the CPV module

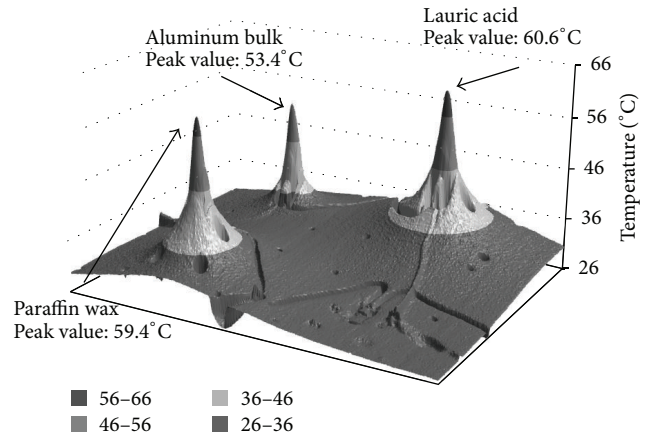


FIGURE 6: Highest temperature value and 3D thermal distribution of each test sample on CPV receiver topside in first two minutes of forward biasing.

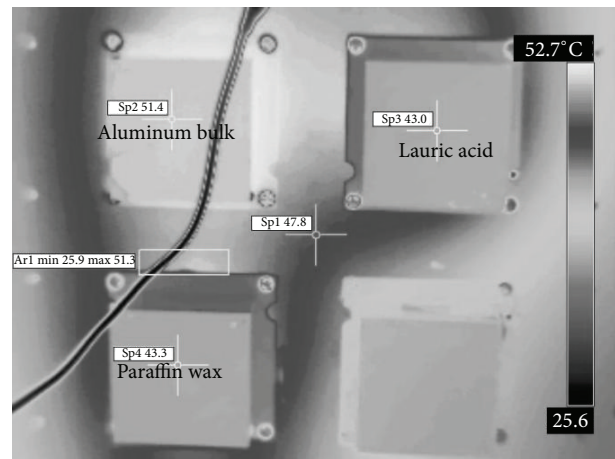


FIGURE 7: The highest temperature values of the three bottoms of the cuboids measured after heating in 100 minutes.

will have more superior protection for system operators and maintenance staffs. It still had benefit for the development of the CPV technology to strengthen workplace safety.

We tested another experimental parameter for observation of lower thermal spreading situation. The 4A forward current which was given by power supply was injected into the three test samples continuously for 100 minutes and the result was shown in Figures 8(a) and 8(b). In the lower input power case, the three thermal-equilibrium temperature values of the samples were, respectively, 56°C for lauric acid, 55.9°C for aluminum bulk, and 56.8°C for paraffin wax. The difference of the temperature-rising curves was closer than the previous experiment. Because the input power was lower, the thermal accumulation was less. Therefore, the main thermal spreading and dissipating mechanism was the same with 6A current injection case. From the results of these two experimental parameters, we could find that the quantity of the input power did not influence distinctly

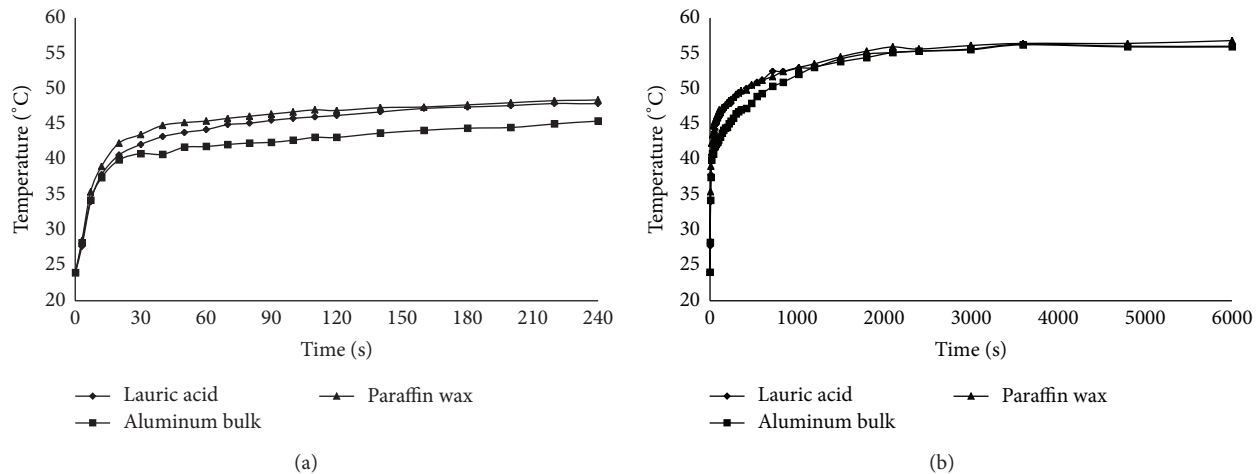


FIGURE 8: (a) The first two-minute and (b) the 100-minute temperature variations of the solar cells of the three experimental samples under 4A forward current injection.

the heating-rising trend and the difference of the thermal-equilibrium temperature values in the CPV receiver. The behavior patterns and mechanisms of the 4A and 6A current injections were quite the same.

5. Conclusion

We tried to develop innovative thermal sinking method to decrease the operating temperature of the solar cells in the CPV receiver. However the PCMs were not an effective improvement for the heat sinking of these solar cells. The shape of this experimental sample was cuboid, and then we would try to fabricate other shapes to test more conditions in the future. Although there were the similar temperature values of the solar cells of the test samples for all materials in the thermal equilibrium by heating, it had improved the backside temperature of the CPV receiver indeed. This experiment is the beginning application of the PCMs in the CPV field and it has still many unexplored questions to be found and solved.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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