

# Preparation of Enhanced Thermal Conductive Phase Change Material and Its Application in Thermal Control of Solar Cells

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**Abstract.** The enhanced conductive lauric acid (LA) phase change material was prepared with expanded graphite, aluminum powder and carbon fiber as the thermal conductive filler and its thermal properties were tested and analyzed. The results show that expanded graphite, aluminum powder and carbon fiber thermal filler in LA phase change material does not greatly influence LA phase change temperature. The phase change temperature of the LA phase change material is between 45 °C -45.9 °C when the mass fraction of thermal conductive filler is 2%, 5%, 10% and 20% and the LA / EG composite phase change material has a low "leakage" threshold. The thermal conductivity reached 1.478 W/m·K when the EG mass fraction reached 30%. In addition, thermal control system of solar cells was designed using LA / EG phase change material as the thermal control material, and the experimental research on optimal configuration of solar cells and phase change material was carried out. The results show that phase change material has obvious control effect on solar cell temperature, reducing the temperature by 7 °C.

## 1. Preface

With the continuous reduction of traditional petrochemical energy reserves and the environmental pollution caused by the use of petrochemical energy, the development and utilization of clean and renewable energy sources have become one national strategy in various countries in the world. Solar energy is widely distributed, pollution-free and hugely reserved, which is the best clean renewable energy. Moreover, it is extensively studied and applied in solar thermal utilization and photovoltaic power generation aspects. As we all know, in photovoltaic power generation, only 5-15% solar energy is converted to electric energy, more than 80% solar energy is absorbed by solar cells and converted to heat, resulting in solar cell temperature rise. For crystalline silicon solar cells, the conversion efficiency will drop by 0.45% every time temperature increases by 1 °C [1]. Therefore, to strengthen the temperature control of solar cells is of great significance for improving the output of photovoltaic power generation system [2-5]. The use of phase change thermal storage technology to achieve solar cell temperature control has been studied. For example: Hausler et al. designed the PV / PCM system with integrated PV module and PCM glass box[6]. Hasan et al. designed thermal management systems using phase change material, by which, solar cell temperature maximally decreased by 18 °C in 30min and decreased by 10 °C in 5h under the condition of 1000W/m<sup>2</sup> [7].

Maiti et al. controlled the operating temperature of the solar cell using a paraffin phase change material with a melting range of 56-58 °C. In the room, the solar cell temperature could be maintained within 65-68 °C in 3h under 2300W/m<sup>2</sup> irradiance; in the open air, the solar cell temperature could be reduced from 78 °C to 62 °C, and solar cell output power increased by 55% under natural conditions [8]. These results show that the use of phase change thermal storage technology is effective for solar cell temperature control. However, the application of phase change materials in solar cell thermal control systems is still in its infancy [9-10]. Such questions as optimal configuration of phase change materials and solar cells, heat balance model of PV / PCM system and the influence of enhanced thermal conductive phase change material on thermoelectric properties of solar cells have yet to be further studied. In this paper, by studying thermal properties of lauric acid composite phase change material filled with aluminum, carbon fiber and expanded graphite, experimental study was carried out on the influence of thermal conductive lauric acid composite phase change material mass and solar cell area ratio on solar cell temperature control characteristics.

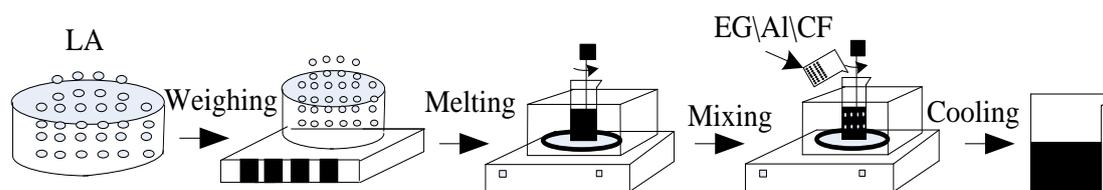
## 2. Preparation of composite phase change energy storage material

### 2.1. Material

Lauric acid (LA, chemical purity, melting point 44 °C), Sinopharm Chemical Reagent Company; expanded graphite (EG, 99% carbon content, 80 mesh, expansion factor at 300mL / g), provided by Qingdao Jinrilai Graphite Co.,Ltd (Al, content ≥ 99%), Tianjin Zhiyuan Chemical Reagent Co., Ltd.; carbon fiber (CF, also called milled carbon fiber, 325 mesh / kg), domestic; CP153 electronic balance, OHAUS Instrument (Changzhou) Co.,Ltd ; DF-101Scollector the rmostaticheating magnetic stirrer, GongyiKehua Equipment Co., Ltd.; ZK82J-type electric vacuum oven, Shanghai Experimental Instrument Factory Co., Ltd.; BEDS200 differential scanning calorimetry; DRL-III-type thermal flow conductometer, Xiangtan Xiang Instrument Co., Ltd..

### 2.2. Preparation

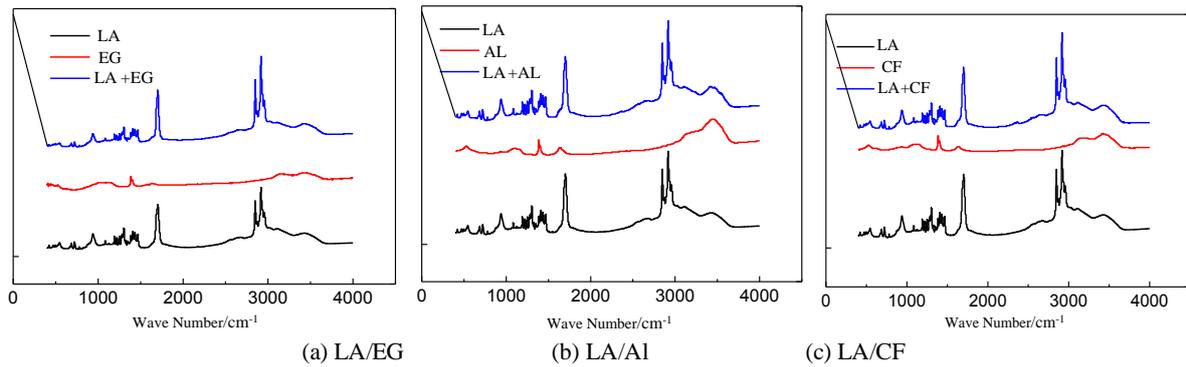
LA/EG, LA/Al and LA /CF phase change composites were prepared by thermostatic water bath heating method. A certain amount of lauric acid was weighed and added to a beaker. The beaker was placed in a 60 °C collector thermostatic heating magnetic stirrer and heated to melt. Expanded graphite or aluminum powder or carbon fiber was added in proportion, heated for 20 minutes while stirring so that it was fully mixed. Then, the beaker was placed in a vacuum drying oven at 50 °C to be dried to constant weight. The preparation process is shown in Figure 1.



**Figure 1.** Preparation process of composite phase change energy storage material.

## 3. Composite phase change material testing

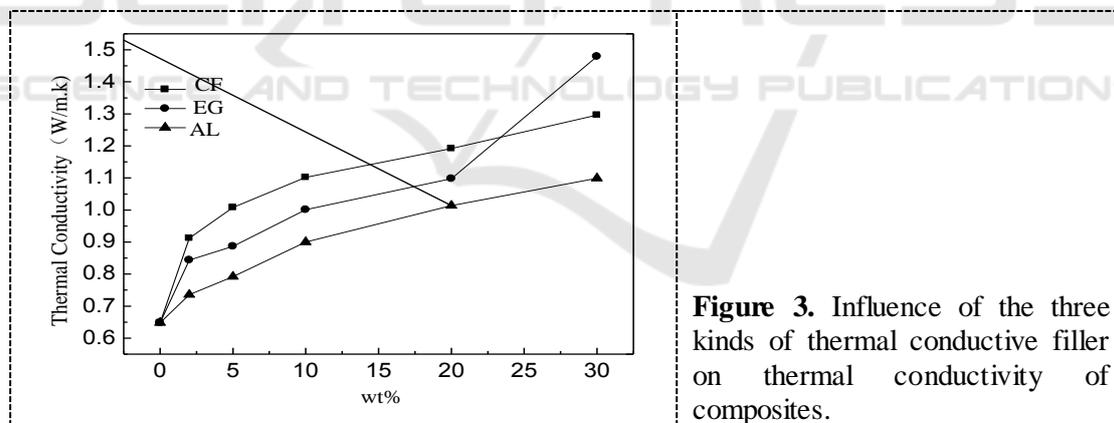
3.1. *Physical and chemical properties and characterization of composite phase change material.* The FT-IR chart of lauric acid, expanded graphite, aluminum powder, carbon fiber, lauric acid / expanded graphite, lauric acid / aluminum powder and lauric acid / carbon fiber phase change composite material are shown in Figure 2.



**Figure 2.** FT-IR chart of enhanced thermal conductive lauric acid phase change material.

It can be seen from the Figure that LA / EG, LA / Al, LA / CF phase change materials have stretching vibration absorption peaks of methyl and methylene CH bonds at 2950  $\text{cm}^{-1}$  and 2850  $\text{cm}^{-1}$ ; the absorption peak at 1460 $\text{cm}^{-1}$  is characteristic peak of -CO- in carboxylic acid, the absorption peak at 1700 $\text{cm}^{-1}$  is the stretching vibration peak of C = O. The positions of infrared spectrum characteristic peaks of LA / EG, LA / Al, LA / CF phase change material is basically consistent with that of lauric acid, indicating that the physical and chemical properties of lauric acid phase change material are not changed after thermal conductive filler is filled in lauric acid, which ensures phase change property and thermal storage capacity of lauric acid phase change body in the enhanced thermal conductive phase change material.

### 3.2. Thermal characteristic testing and analysis of composite phase change material

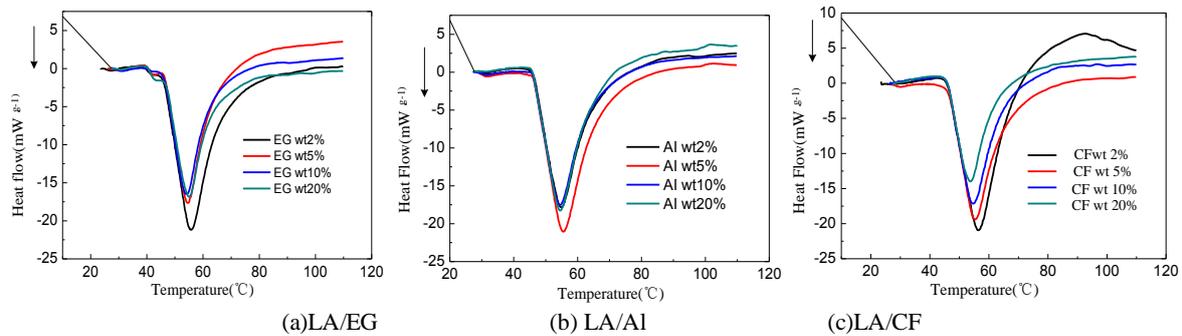


**Figure 3.** Influence of the three kinds of thermal conductive filler on thermal conductivity of composites.

**3.2.1. Thermal conductivity characteristics of the material.** Thermal conductivity of LA / EG, LA / Al and LA / CF composite phase change energy storage materials with different proportions were measured by DRL-III heat flow conductometer. In order to meet the requirements of DRL-III heat flow conductometer for shape and size of the test sample, a test sample of cylindrical composite phase change material with a thickness of 5 mm and a diameter of 30 mm was prepared and the test results are shown in Figure 3. It can be seen from Figure 3 that carbon fiber has a great effect on the increase of thermal conductivity of composite materials when lauric acid is filled with aluminum powder, carbon fiber and expanded graphite thermal conductive filler if the filler mass fraction is less than 20%. The thermal conductivity of LA / EG composites increases sharply when the filler mass fraction is beyond 20%. The thermal conductivity of composite phase change material

reaches 1.478 W/k·m when the mass fraction of expanded graphite reaches 30%, indicating that LA / EG composite phase change material has a lower "leakage" threshold.

**3.2.2. Phase change temperature and enthalpy characteristics of the material.** The melting point and phase change enthalpy of LA / EG, LA / Al and LA / CF composite phase change energy storage materials in different proportions were measured by BEDS200 differential scanning calorimetry. The results are shown in Figure 4 (a) (b) (c).

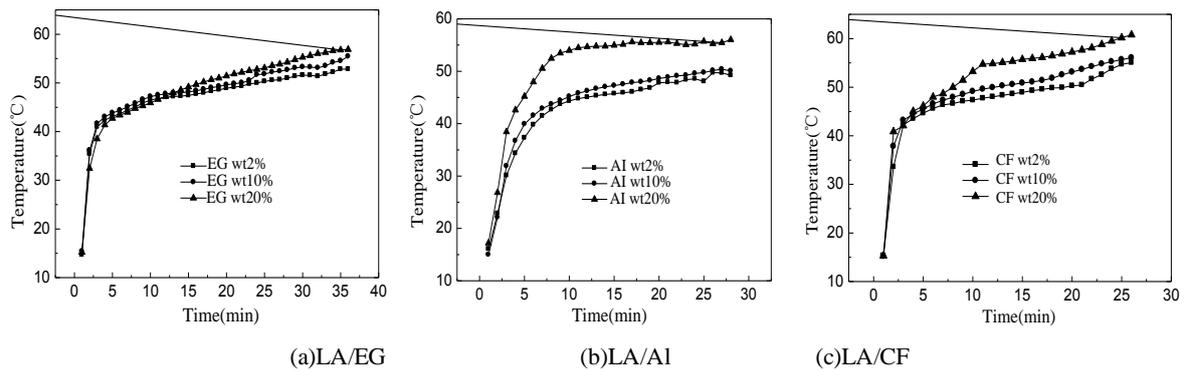


**Figure 4.** DSC chart of the three kinds of composite phase change materials.

It can be seen from the Figure that the phase change temperatures of the phase change materials are 45 °C, 45.5 °C, 45.6 °C and 45.4 °C respectively when the mass fraction of Al is 2%, 5%, 10% and 20% in the LA / Al phase change material. The phase change temperatures of phase change material are 45.5 °C, 45.5 °C, 45.8 °C and 45.9 °C respectively when the mass fractions of EG are 2%, 5%, 10% and 20% in LA / EG phase change material. The phase change temperatures of phase change material are 45 °C, 45.2 °C, 45.2 °C and 45.1 °C when the mass fractions of carbon fiber are 2%, 5%, 10% and 20% respectively in LA / CF phase change material. The phase change temperature of lauric acid is not affected by the filling of expanded graphite, aluminum powder and carbon fiber thermal conductive filler in LA phase change material. However, the phase change enthalpy decreases as the increasing proportion of thermal conductive filler.

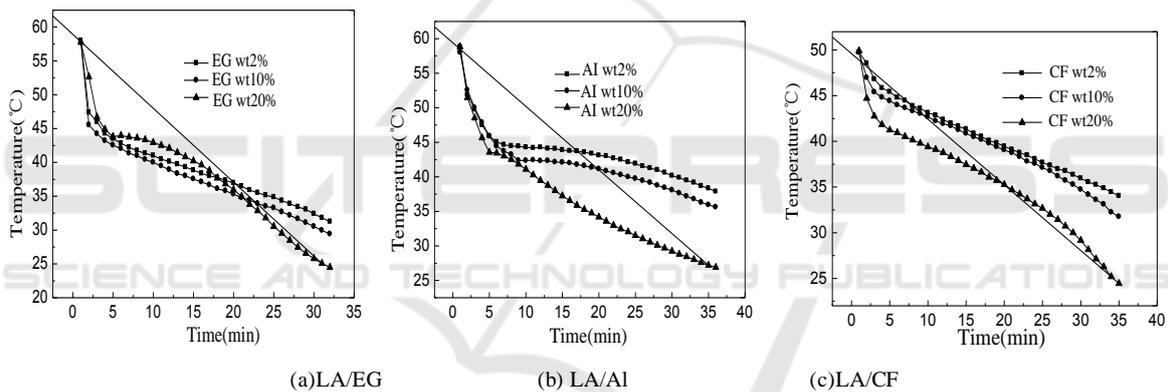
**3.2.3. Material heat storage and heat release characteristics.** For testing and analysis of melting process (heat storage) of lauric acid / expanded graphite, lauric acid / aluminum powder and lauric acid / carbon fiber composite phase change energy storage material, 10g of different composite phase change materials were respectively put in a 50ml conical flask, and pt100 platinum was electronically embedded in the composite material. Using water bath heating method, the conical flask was heated in a thermostatic water bath at 70 °C until the phase change material completely melted. In the heating process, the temperature change characteristics of the composite phase change material were recorded with Altay multi-channel data acquisition system, as shown in Figure 5.

From the melting characteristic curves of LA / EG, LA / Al and LA / CF composite phase change materials, it can be seen that the time required for the phase change material to reach the saturation temperature varies with the increase of the proportion of thermal conductive filler. The required time decreases with the increase in proportion of thermal conductive filler. It is mainly because the heat transfer rate of melting process is increased with the increase of thermal conductive filler ratio, decrease of composite phase change material enthalpy and increase of heat conductivity.



**Figure 5.** Melting characteristics of the three composite phase change materials.

For testing and analysis of coagulation (exothermic) characteristics of composite phase change material, a conical flask loaded with fully melted composite phase change material was placed in the ambient temperature for cooling. Meanwhile, the temperature change characteristics of the composite phase change material were recorded with Altay multi-channel data acquisition system, as shown in Figure 6.



**Figure 6.** Coagulation characteristics of the three kinds of composite phase change materials.

From the coagulation characteristic curves of LA / EG, LA / Al and LA / CF composite phase change materials, it can be seen that there is a phase change temperature near 45 °C during the drop of the curve. With the increase of the proportion of thermal conductive filler, phase change time gradually decreases. In addition, temperature of composite phase change material decreases fast, which is mainly because the increase of thermal filler proportion and the increase of thermal conductivity of composite phase change material accelerate heat transfer rate of phase change material.

#### 4. The application of phase change material in photovoltaic thermal control system

The PV / PCM thermal control test system was designed by using EG / LA composite phase change material with EG mass fraction at 10% to study optimal thermoelectric characteristic of solar cell with different phase change materials. In the design, EG / LA composite phase change material was respectively loaded in aluminum boxes with a volume of 0.48L (h = 2cm), 0.64L (h = 3cm), 0.8L (h = 4cm), 0.96L (h = 5 cm) and 1.12L (h=6cm). The five aluminum boxes were respectively attached to the back surface of the solar cell module having an area of 210 mm × 90 mm with consistent VI

characteristic by using thermal conductive silica gel. A test system was set up based on Altay multi-channel data acquisition card, which comprises:Pt100 platinum resistor, temperature transmitter, BT-2 radiation general table, computer and the like for measurement of solar cell surface temperature, temperature of phase change material in the aluminum box, output voltage and current of solar cell, solar irradiance and ambient temperature, respectively.

On March 31, 2017 and April 1, 2017, the thermal and electrical characteristics of the designed PV / PCM thermal control test system were experimentally tested. The results are shown in Figure 7 and Figure 8.

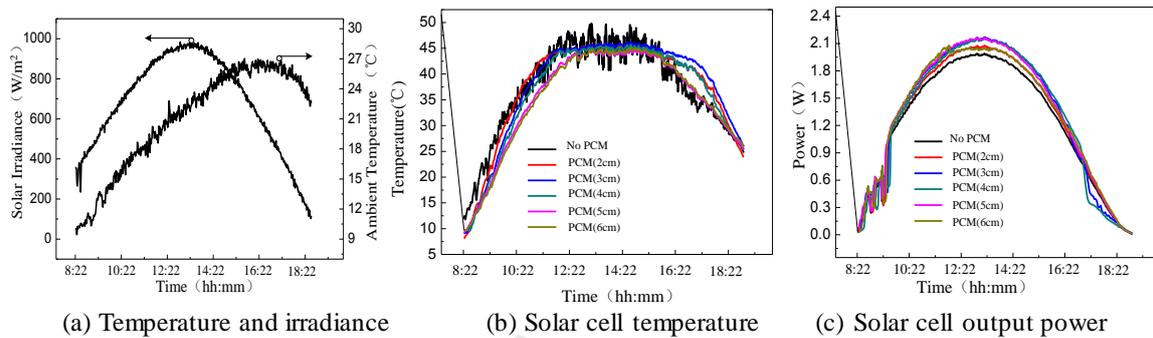


Figure 7. Test performance of solar cell thermal control system (2017.3.31).

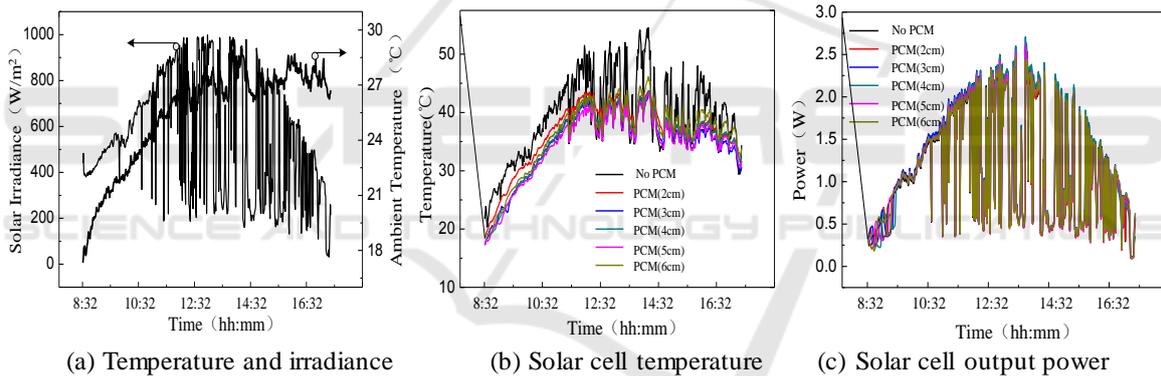


Figure 8. Test performance of solar cell thermal control system (2017.4.1).

The experimental results were statistically analyzed, with the statistical data shown in Table 1,2.

Table 1. Statistical table of solar cell system thermoelectric characteristics data (2017.3.31).

Parameter name	Aluminum box V=0.48L (h=2cm)	Aluminum box V=0.64L (h=3cm)	Aluminum box V=0.8L (h=4cm)	Aluminum box V=0.96L (h=4cm)	Aluminum box V=1.12L (h=5cm)	Without phase change material
Statistical time (hh:mm)	11:00-15:00					
Average solar irradiance	672.485(W/m <sup>2</sup> )					
The maximum solar cell temperature	42.17 °C	43.01 °C	40.68 °C	39.92 °C	39.24 °C	46.07 °C
The average solar cell power	0.985W	0.999W	1.025W	1.055W	1.054W	1.034W
The Maximum Power	2.559W	2.696W	2.645W	2.634W	2.592W	2.575W

**Table 2.** Statistical table of solar cell system thermoelectric characteristics data (2017.4.1).

Parameter name	Aluminum box V=0.48L (h=2cm)	Aluminum box V=0.64L (h=3cm)	Aluminum box V=0.8L (h=4cm)	Aluminum box V=0.96L (h=4cm)	Aluminum box V=1.12L (h=5cm)	Without phase change material
Statistical time (hh:mm)	11:00-15:00					
Average solar irradiance	834.59(W/m <sup>2</sup> )					
The maximum solar cell temperature	46.05 °C	46.24 °C	45.70 °C	44.7 °C	45.22 °C	49.8 °C
The average solar cell power	1.297W	1.336W	1.318W	1.355W	1.328W	1.247W
The Maximum Power	2.078W	2.170W	2.160W	2.164W	2.079W	1.991W

From the experimental results, it can be seen that phase change material exerts obvious effect on solar cell temperature control. By adding phase change temperature control system to the solar cell, the temperature of the solar cell decreased. The temperature control effect was more obvious with the increase in thermal control material mass. For example, on March 31, 2017, the maximum solar cell temperature decreased by 7 °C. On April 1, 2017, the maximum solar cell temperature decreased by about 5 °C. At the same time, solar cell output power increased in varying degrees after the use of phase change material. For example, on March 31, by taking advantage of heat dissipation of phase change material, the maximum solar cell output power increased by 0.121W, nearly 4.6%. In addition, in the PV / PCM system, the effective thermal control of phase change material concerns external weather conditions such as solar irradiance, ambient temperature. For example, on April 1, solar irradiance was high, the maximum ambient temperature was 28.5 °C, the phase change material required for effective temperature control of solar cell (area: 210mm × 90mm) was 0.96L; on March 31, the solar irradiance was low, the maximum ambient temperature was 23.5 °C, the phase change material required for effective temperature control of solar cell (area: 210mm × 90mm) was only 0.80L. The experimental results provide experimental basis for the optimization design of PV / PCM thermal control system.

## 5. Conclusions

The phase change temperature of lauric acid was stable and not greatly affected by the filling of expanded graphite, aluminum powder and carbon fiber thermal conductive filler in LA phase change material. Among the prepared LA / EG, LA / Al, LA / CF composite phase change materials, LA / EG composite phase change material has a low "leakage" threshold, and the thermal conductivity reached 1.478W/m·K when EG mass fraction reached 30%. For the PV / PCM thermal control system designed by LA / EG composite phase change material, in natural environment, phase change material has a significant effect on solar cells temperature control. During the test, with the addition of phase change material, the maximum solar cell temperature decreased by about 7 °C and the maximum cell output power also increased. In PV / PCM system, effective thermal control of phase change material is greatly influenced by external weather conditions such as solar irradiance and ambient temperature. The experimental results provide experimental basis for the optimization design of PV / PCM thermal control system.

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