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Light-heat conversion and thermal conductivity enhancement of PEG/SiO_2 composite PCM by in situ Ti_4O_7 doping

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A R T I C L E I N F O

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A B S T R A C T

To improve the energy utilization efficiency of solar energy, $Ti_4O_7/PEG/SiO_2$ form-stable phase change material (PCM) with characters of light-heat conversion and thermal conductivity enhancement was developed by in-situ doping titanium black (Ti_4O_7) through acid and alkali catalytic sol-gel method. The structure and properties of PCM were investigated by SEM, FT-IR, XRD, DSC, TG, coefficient of thermal conductivity and thermal conversion testing, etc. The results showed that the $Ti_4O_7/PEG/SiO_2$ could effectively absorb UV–visible light of solar radiation, simultaneously, the light energy was translated into thermal energy which was storied by PCM. Furthermore, the composite PCM exhibited good thermal stability below 360 °C, excellent shape-stabilized effect and high thermal conductivity. The $Ti_4O_7/PEG/SiO_2$ as novel thermal storage material can usefully enhance the utilization efficiency of solar energy.

1. Introduction

Global warming and energy shortage have become important issues facing humanity today [1]. Thus, new energy sources and highly efficient energy-storage technologies need to be developed urgently [2–8]. In a variety of new energy sources, solar energy is a type of renewable energy with many advantages, such as large amount of resources, availability, no transport, and absence of environmental pollution. Therefore, the conversion, storage and application of solar energy have been widely concerned [9,10]. However, solar energy is discrete and discontinuous. Thus, the development of energy-storage materials for storing solar energy to improve its utilization efficiency has become an important research topic in recent years [9–13].

Conversion of solar energy to heat energy is an important mode of solar energy utilization. Heat storage is typically categorized into three types: sensible thermal energy storage, phase-change energy storage, and chemical reaction energy storage. In particular, the development of shape-stabilized phase change materials (PCMs [3,14–17]) for storing solar thermal energy is considered to have highly promising applications due to their high phase change latent heat. What is more, there is no leakage phenomenon during the phase change process [18–21]. However, 45% of the total solar energy with wavelength from 350 to 800 nm cannot be absorbed and transfered to thermal energy easily by traditional PCMs [22,23]. Therefore, developing novel solar energy conversion and storage materials is highly promising to improve utilization efficiency of solar energy.

In previous studies, we synthesized novel visible light-driven organic PCMs by integrating dye molecules into a poly(ethylene glycol) (PEG) matrix to absorb visible light and convert it into heat [24–26]. However, capturing and converting full-band solar irradiation are extremely difficult because the dye selectively absorbs visible light. At the same time, low thermal conductivity of organic PCMs leads to lower heat storage and release rate. Accordingly, the present study aimed to capture and convert full-band solar irradiation as well as improve the heat storage and release rate. Low-cost and nontoxic titanium black (Ti_4O_7), which has high thermal conductivity, broad range of UV–vis light absorbance, and good light-thermal conversion capability [27], was introduced into a PCM system to obtain novel $Ti_4O_7/PEG/SiO_2$ composite capable of full-band light-driven reversible phase transition. The novel form-stable $Ti_4O_7/PEG/SiO_2$ PCM was synthesized by a simple ultrasound-assisted sol–gel method through in situ Ti_4O_7 doping (Fig. 1). Ti_4O_7 in the $Ti_4O_7/PEG/SiO_2$ composite could effectively absorb UV–visible light of solar radiation and translate it into thermal energy. At the same time, Ti_4O_7 could also be used as the thermal conductivity enhancement agent because of its high thermal conductivity. The heat energy from the light-to-heat conversion was quickly stored by PEG through phase transition. The composite excellently maintained its shape stability during the process of reversible phase transition owing to the supporting effects of inorganic SiO_2 net. Thus, the novel sunlight-driven $Ti_4O_7/PEG/SiO_2$ composite can be useful for highly efficient solar radiation applications.

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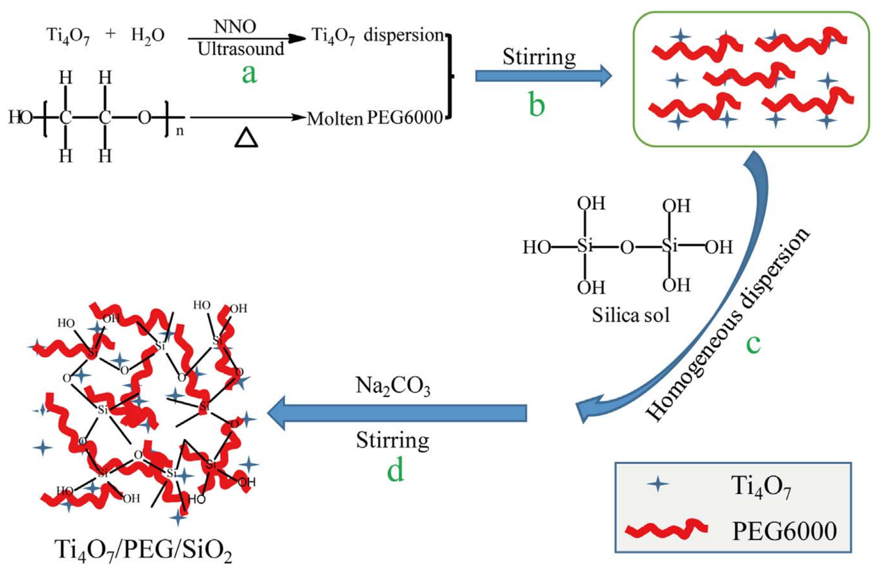

Fig. 1. Synthesis scheme of $Ti_4O_7/PEG/SiO_2$ composite PCM.

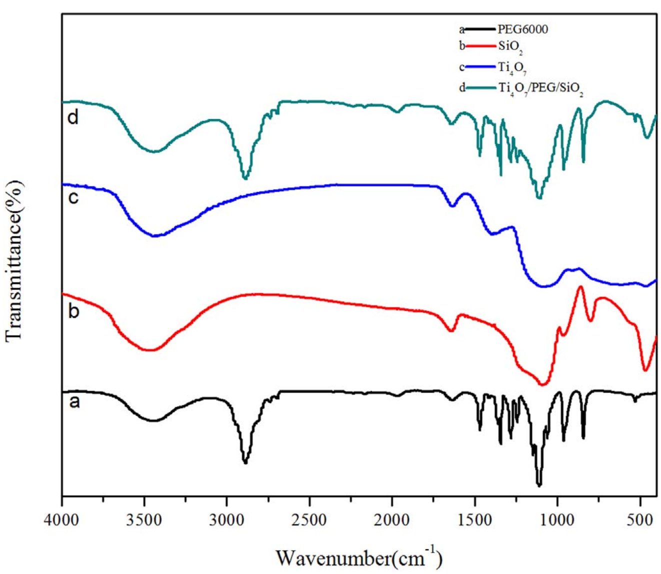

Fig. 2. FT-IR spectra of SiO_2, PEG6000, Ti_4O_7 and PCM.

2. Experiments

2.1. Materials

All of the chemicals used in the experiments were of analytical grade. PEG6000 was purchased from Sinopharm Chemical Agent Company (Shanghai, PR China). Tetraethyl orthosilicate (TEOS) used in the experiments was obtained from the Tianjin Damao Chemical Agent Company (Tianjin, PR China). Ti_4O_7 was supplied by Beijing Huanqiu jin xin international company Co. Ltd.

2.2. Preparation of hybrid PCMs with enhanced thermal conductivity

2.2.1. Dispersion of Ti_4O_7

In a sanding tube, 3 g Ti_4O_7 and 1.2 g dispersant NNO were mixed. Then, the gully sanding point was inserted into two-thirds of the tube. Last, 3 mL deionized water was added. The mixture was allowed to undergo sanding for 3 h. Thereafter, the resulting Ti_4O_7 powder was collected by removing water in vacuum.

2.2.2. Preparation of $Ti_4O_7/PEG/SiO_2$

In a round-bottom flask, 10.70 g TEOS (as precursor) and 9.00 g distilled water were mixed, and the resulting solution was stirred at room temperature for 5 min. Then, 0.5 M HCl was added to adjust the pH to 1–2. After 30 min, the solution became a clear liquor. Subsequently, the sol of silicon was obtained.

Different qualities of Ti_4O_7 powder were added into different beakers, and different qualities of deionized water were used to disperse the powder under ultrasound conditions. After 30 min, 17 g melting PEG6000 were added to the Ti_4O_7 dispersion, and the mixture was intensively agitated on a stirrer. Thereafter, prepared silicon sol was cautiously added drop by drop under high-speed stirring. A few

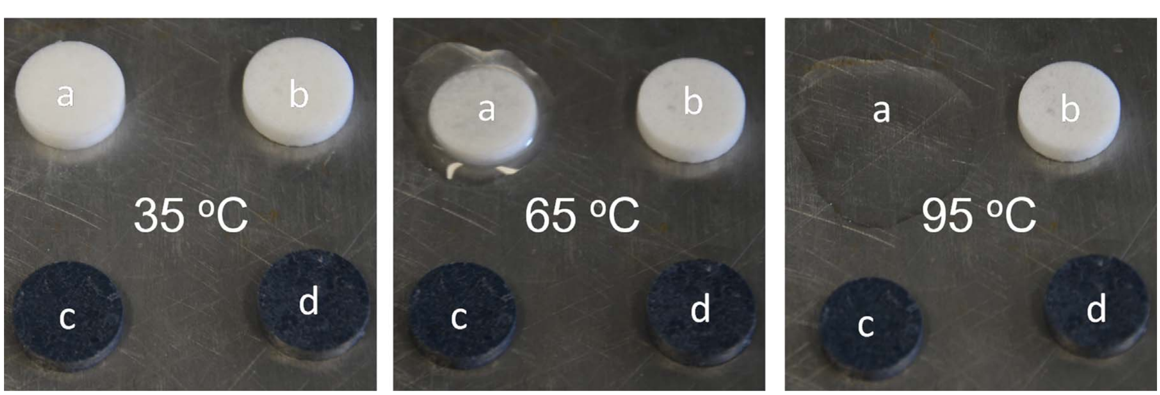

Fig. 3. Heating test of (a) PEG (b) PEG/SiO_2 (c) Ti_4O_7(1%)/PEG/SiO_2 and (d) Ti_4O_7(3%)/ PEG/SiO_2 on the hot plate.