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# Fabrication of shape-stable composite phase change materials based on lauric acid and graphene/graphene oxide complex aerogels for enhancement of thermal energy storage and electrical conduction

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ABSTRACT

This paper reported the fabrication and performance of shape-stable composite phase change materials (PCMs) based on lauric acid (LA) and graphene/graphene oxide (GO) complex aerogels for enhancement of thermal energy storage and electrical conduction. The graphene/GO complex aerogels were prepared through a reduction reaction and freeze-drying technology, and then LA was incorporated into the complex aerogels *via* vacuum-assisted impregnation. The complex aerogels and their composites were characterized by scanning electron microscopy, X-ray powder diffraction and *Fourier*-transform infrared spectroscopy. These LA/complex aerogel composites not only exhibited high electrical conductivity but also achieved high phase-change enthalpies more than 198 J/g, high heat-charging and discharging efficiency more than 90%, excellent cyclic stability, good phase-change reversibility and good shape stability. The crystallization kinetic study demonstrated that the aerogel framework could generate a heterogeneous nucleation effect on the crystallization of LA and therefore improved the crystallization rate of LA under both nonisothermal and isothermal conditions.

## 1. Introduction

As the society and economy develop rapidly, human beings have to face a series of global challenges such as global warming, greenhouse gas emissions, climate change, environmental pollution and fossil energy shortage [1]. Sustainable development has become a worldwide tendency. The exploitation of renewable and green energy and the improvement of energy efficiency are considered as two important means to avoid an overdependence on fossil energy resources, which can effectively reduce the environmental pollution and carbon emissions [2]. As a new type of recyclable energy-storage materials, phase change materials (PCMs) can store huge amounts of latent heat from the outside or interior of a system through phase transitions and then release it controllably at an almost constant temperature according to the thermal energy demand [3]. PCMs can well bridge the gap between the availability and use of thermal energy, and therefore the thermal energy-storage technology by use of PCMs becomes an ecological energy-save pathway to improve energy efficiency and reduce energy consumption effectively [4]. PCMs have been recognized as a new type of the most important green energy materials in recent decades, and they have achieved broad applications in industrial and domestic fields such as thermal energy harvesting and storage, heat recovery and reuse, waste energy-saving buildings, concentrated solar energy systems, heat-pump systems, thermal management systems for Li-ion battery cells, photovoltaic-thermoelectric systems, pharmaceutical refrigeration, telecom shelters in tropical regions, smart fibers and textiles with a thermoregulatory function, thermal comfort in vehicles, cooling or thermal protection of electronic devices, etc. [5,6].

The utilization of PCMs for thermal energy-storage and thermal management systems has witnessed a series of handicaps resulting from the solid-liquid phase transitions when conducting latent heat storage and release [7]. Especially in the liquid state, PCMs are hard to be handled and easy to leak out or diffuse into the other materials. The use of bulk PCMs also have to suffer from low thermal conduction, high supper cooling, poor heat transfer and slow thermal response to ambient temperature [8]. In this case, the designs of special latent heat devices or heat exchange surfaces for PCMs are necessary in traditional applications. This not only increases the thermal resistance between the PCMs and environment but also improves the relevant expense of practical use of PCMs [9]. Such a drawback has been resolved by microencapsulation of PCMs into various polymeric or inorganic shells through physical and chemical methods [10]. Numerous studies

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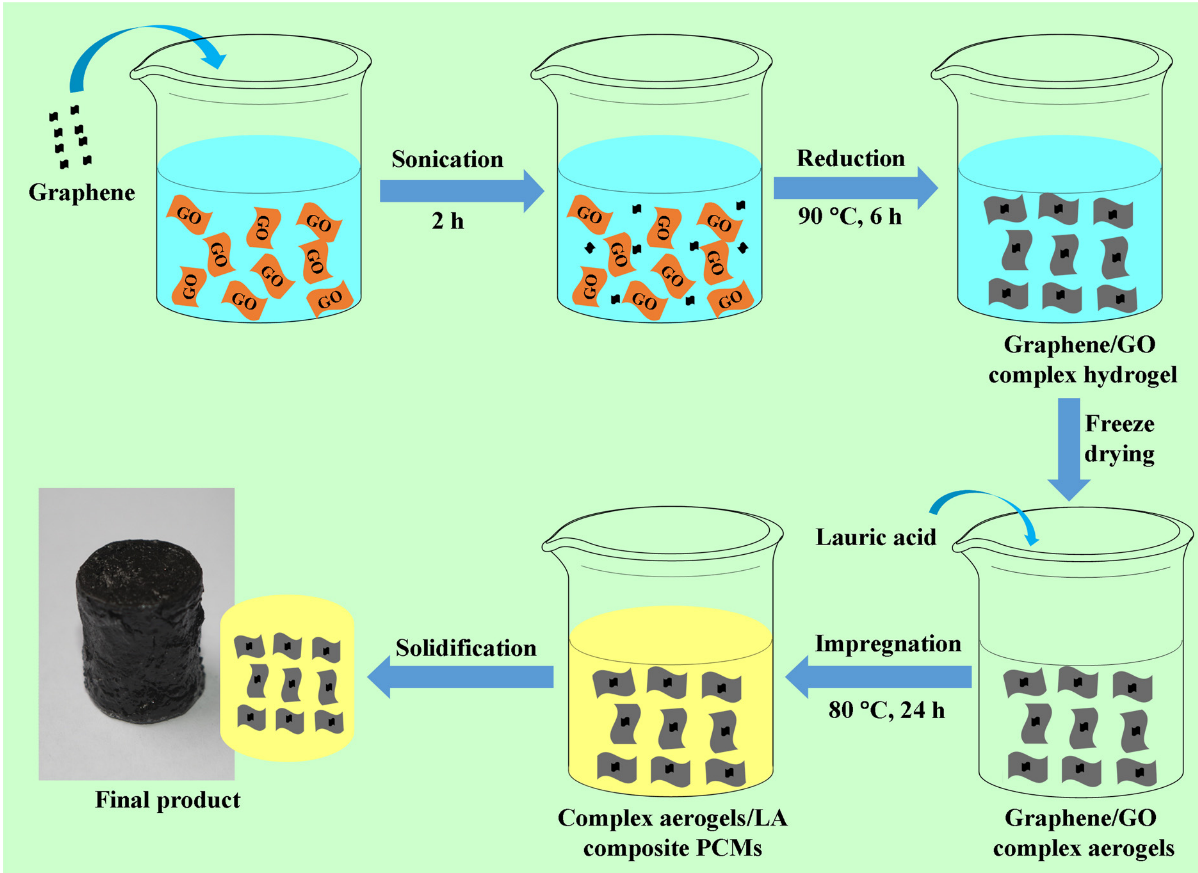


**Fig. 1.** Scheme for the formation process of LA/aerogels composites as shape-stable composite PCMs.

demonstrated that various organic or inorganic materials such as melamine-formaldehyde resin [11], polyurea-formaldehyde resin [12], polyurethane [13], poly(methyl methacrylate) [14], poly(butyl acrylate) [15], polystyrene [16], $SiO_2$ [17], $CaCO_3$ [18], $ZrO_2$ [19], ZnO [20], $TiO_2$ [21] and $Cu_2O$ [22] could well serve as shell materials for microencapsulation of organic PCMs like paraffin waxes, fatty acids, alcohols and glycols. The formation of these shell materials not only can well protect PCMs from leakage and diffusion during the solid-liquid phase-change processes but also can enhance their thermal performance and latent heat-storage capability effectively. Nevertheless, the utilities of these microencapsulation techniques are not so facile and sometimes are expensive for the applications of PCMs. On the other hand, the combination of organic PCMs with some inorganic fillers, porous materials or framework materials not only can provide a shape stability for PCMs but also can enhance their thermal conductivity and thermal performance [23]. This methodology is reasonably facile, safe and cheap, thus making it acceptable for most of PCMs in various applicable areas. A literature survey demonstrated that a number of inorganic substances could be used as supporting materials for preparation of shape-stable composite PCMs through a simple physical route [24]. Lv et al. [25], Konuklu and Ersoy [26], Sari et al. [27], Xu and Li [28], Li et al. [29] and Zhang et al. [30] reported the preparations and thermal performance of paraffins/kaolin, fatty acids/xonotlite, fatty acid/sperlite, paraffins/diatomite, paraffins/bentonite and fatty acids/vermiculite composites as shape-stable PCMs, respectively, and they found that the shape stability, thermal conductivity, and thermal stability of the resulting composite PCMs were improved significantly. Moreover, some of multiporous inorganic materials like active carbon, carbon nanotubes, silica molecular sieves, expanded graphite and graphene oxide aerogel (GOA) are reported as good candidates as supporting materials to prepare shape-stable PCMs. Qian et al. [31] reported the use of single-walled carbon nanotubes for enhancement of shape stabilization and heat transfer of a poly(ethylene glycol) (PEG) PCM. Feng et al. [32] reported an extensive investigation on the PEG-based composite PCMs with active carbon and mesoporous silica (SBA–15 and MCM–41) for shape stabilization. Xu et al. [33] prepared the mannitol/expanded graphite composite PCM through a vacuum absorbing method, and they found that both the shape stability and heat transfer of the composite PCM were remarkably enhanced. Ye et al. [34] reported the utilization of GOA as a supporting material to load paraffin and found that the resulting composite PCM achieved a good shape stability and high thermal conductivity. Tang et al. [35] investigated the effect of oxidation degree on the thermal performance of PEG/GOA composite PCMs and found that the efficient photo-to-thermal energy conversion and storage could be realized by tuning the oxidation level of graphene oxide in the aerogel. Yang et al. [36] reported the preparation and thermal energy-storage performance of a PEG-based shape-stable PCM by use of gas/cellulose composite as a supporting material and found that a good shape stability and high thermal conductivity were achieved for the resulting composite PCM. All of these work indicated that the multiporous inorganic materials could well supported the molten PCMs within their nanostructural frameworks, thus effectively preventing them from leakage and diffusion in the liquid state. As a result, a good shape stability could be maintained for PCMs. Moreover, the multiporous inorganic frameworks also provided an effective thermal conduction channel for PCMs, and therefore the thermal conductivity and heat transfer rate of composite PCMs were enhanced significantly.

In the present work, we designed and fabricated a type of shape-stabilized composite PCMs by incorporating lauric acid (LA) into highly conductive graphene/GO complex aerogels. The obtained composite PCM was expected to gain a good shape stability and good electrical