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Research paper

Thermal conductivity enhancement of lauric acid phase change nanocomposite with graphene nanoplatelets

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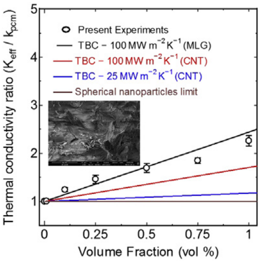
HIGHLIGHTS

- Thermal conductivity of lauric acid with graphene nano inclusions were measured.
- Inclusion of 1 vol% of graphene enhances the thermal conductivity by 230%.
- Model calculations show graphene performs superiorly than other nano materials.
- Phase change enthalpy and melting temperature remains unaltered at 1 vol% loading.

GRAPHICAL ABSTRACT



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ABSTRACT

In this work, we prepared lauric acid based phase change nanocomposites with chemically functionalized graphene nanoplatelets and measured its thermal conductivity using transient hot wire method. We show that inclusion of graphene nanoplatelets increases the thermal conductivity of phase change material by 230% at a loading of 1 vol%. Comparing the experimental results with the model calculations based on the effective medium theory suggests that graphene based nanocomposites outperforms those with carbon nanotubes or metal nanoparticles reported in the literature. High thermal conductivity, high aspect ratio and low thermal interface resistance at the graphene – host matrix interface makes it the most suitable nano filler candidate to enhance the thermal conductivity of low conductive materials. Differential scanning calorimetry study of the nanocomposites show that the phase change enthalpy and the melting temperature remains similar to that of pristine material, which makes graphene a promising candidate for thermal energy storage applications.

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1. Introduction

Thermal energy storage using phase change materials (PCM) are often employed in waste heat recovery and solar energy storage [1,2]. Thermal energy storage is also an attractive way to cool micro-electronic devices during peak loads [3]. At present, many PCMs which can be classified as inorganic, organic and their mixtures have been used for this purpose due to its large latent heat storage capabilities and wide range of melting temperatures [4,5]. Inorganic PCMs possess higher latent heat storage capabilities when compared to organic PCMs however their applications are rather limited due to high super cooling. Among organic PCMs, fatty acids and their eutectic mixtures are considered promising for

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Nomenclature

d	diameter, m
l	length, m
T	temperature, °C
t	time, s
q	heat flux per unit of length, W m^{-1}
k	thermal conductivity, W m^{-1} K^{-1}
k_{eff}	effective thermal conductivity, W m^{-1} K^{-1}
k_{pcm}	phase change material thermal conductivity, W m^{-1} K^{-1}
k_{MLG}	thermal conductivity graphene nanoplatelets
k_{ii}^{c}	equivalent thermal conductivity along the symmetric axis, W m^{-1} K^{-1}
k_{11}^{c}	equivalent thermal conductivity along the transverse direction, W m^{-1} K^{-1}
k_{33}^{c}	equivalent thermal conductivity along the longitudinal direction, W m^{-1} K^{-1}
k_p	thermal conductivity of spheroid, W m^{-1} K^{-1}
L_{ii}	geometric shape factor of ellipsoidal particle along symmetric axis
L_{11}	geometric shape factor of ellipsoidal particle along transverse direction
L_{33}	geometric shape factor of ellipsoidal particle along longitudinal direction
a	aspect ratio length to diameter
R	thermal boundary resistance, m^2 K W^{-1}
ϕ	volume fraction
ΔH_{fus}	phase change enthalpy, J kg^{-1}

storage applications due to its excellent properties such as high phase change enthalpy, non-toxicity, low vapour pressure, little or no super cooling, good thermal and chemical stability, wide range of melting point and low cost [6].

The rate of energy storage and release of PCMs is directly proportional to its thermal conductivity. Fatty acids based PCMs like other organic materials possess low thermal conductivity, which remains a great challenge for practical applications. Recently this has led to increasing interests in the use of high conductive nano inclusions to enhance the thermal conductivity of such PCMs [7]. High conductive nanoparticles such as Ni, Al_2O_3, TiO_2 [8–12], silver nanowires [13] or carbon nanoadditives such as nanofibers [14], carbon nanotubes (CNT) [15–18] and graphite nanoplatelets [19–23] have also been used for enhancing the thermal conductivity of PCMs.

Utilization of metallic nanoparticles would decrease the energy storage capabilities of the PCMs. Carbon based nanoadditives have shown tremendous potential to enhance the thermal conductivity of organic PCMs due to its high thermal conductivity. Carbon nanotubes (CNT), a one-dimensional allotrope of carbon is widely used for this purpose. Wang et al. [15,16] reported a thermal conductivity enhancement of 51% at a loading of 1 wt % for chemically modified CNTs dispersed in palmitic acid. Cui et al. [17] investigated the effect of carbon nanofibers and CNTs in soy wax based nanocomposites. They reported a significant improvement in thermal conductivity upon nano inclusions. However, they showed that CNTs performed poorly compared to carbon nano fibers which is in direct contradiction to the results of Wang et al. [15,16]. Recent thermal conductivity measurements of graphene nanosheets, a two-dimensional allotrope of carbon shows a much higher thermal conductivity than CNTs [19]. Hence it is anticipated that the use of graphene will significantly enhance the thermal conductivity of organic fatty acids based PCMs, the latter being of significant interest for energy storage applications. Yavari et al. [19] utilized graphene nanosheets and reported a thermal conductivity enhancement by a factor of ~1.8 for fatty acid based ester nanocomposites at a loading of 1 vol %. Similar thermal conductivity enhancement was reported for paraffin/graphene nanoplatelets based nanocomposites in the literature [19–23].

Based on the previous studies, it is evident that many high conductive nanomaterials were utilized to enhance the thermal conductivity of organic PCMs. However, it still remains unclear in selecting the appropriate material and dimensionality of nano inclusion to enhance the thermal transport of organic PCMs without affecting the energy storage capability. In this work, using an organic fatty acid based phase change material we show remarkable enhancement in thermal conductivity by a factor of approximately ~2.3 using chemically functionalized graphene loading of 1 vol %. Besides, we compare the experimental results with model calculations based on effective medium theory for nano inclusions of different dimensionalities considering the role of interfacial thermal transport into account. Based on model calculations, we show that planar structure, high thermal conductivity and low Kapitza resistance between graphene-host matrix interface make graphene nanoplatelets a promising nano filler candidate. Furthermore, this material offers better thermal performance to enhance the thermal properties of organic materials than carbon nanotubes or other nanoparticles reported in the literature. Moreover, differential scanning calorimetry investigations show that the energy storage capability and the phase transition temperature of the PCMs remain unaltered at small loadings which makes graphene a promising filler candidate for thermal energy storage applications.

2. Materials and methods

2.1. Material characterization and sample preparation

The phase change material used in the present work is *n*-Dodecanoic acid (Lauric acid, $C_{12}H_{24}O_2$) with a melting temperature of ~44 °C and with an excellent phase transition enthalpy of ~180 kJ/kg. Liquid phase exfoliated multilayer graphene nanoplatelets (MLG) were purchased from XG Sciences with an average thickness of 5–10 nm (Grade M, Mean particle diameter of 15 µm, Density 2.2 g/cm^3). A scanning electron microscopy image (SEM,

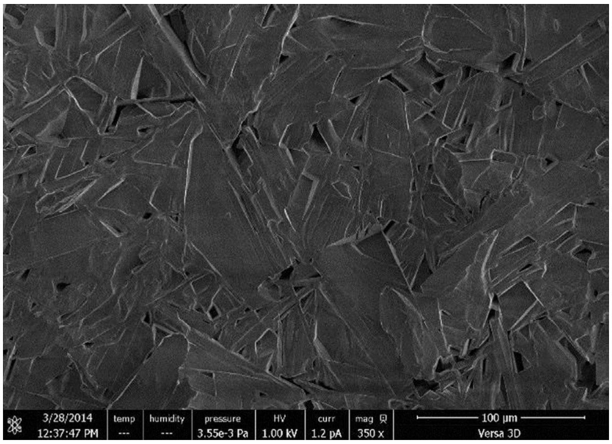

Fig. 1. SEM visualization of pristine lauric acid.

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