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Research Paper

Improving thermal management of electronic apparatus with paraffin (PA)/expanded graphite (EG)/graphene (GN) composite material

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HIGHLIGHTS

- A novel PA-EG-GA composite PCM.
- The proposed new material has better thermal properties.
- Tests examined the heat transfer properties of the new material.
- An experiment for simulative electronic chips.
- The new material has better thermal management capacity.

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ABSTRACT

This study introduced a novel PA-EG-GN composite phase change material (PCM) with better thermos-physical properties to help dissipate heat in electronic apparatus. Both the X-ray diffractometer and Fourier transformation infrared spectra patterns show that the composite PCM is the pure physical combination of no chemical interactions. Raman spectroscopy results suggest that the structural symmetry of the GN decreases with vibration increases. Results from Scanning Electron Microscopy show that GN can improve the compatibility with the mixture of PA and EG. Differential scanning calorimetry curves indicate that the composite PA-EG-GN has a lower latent heat than that of pure PA and PA-EG. The weight-loss ratios of the PA-EG and PA-EG-GN are roughly equivalent to the mass ratio of PA in the composite PCMs. The thermal conductivity of the PA-EG-GN is evidently higher than PA-EG and shows a strong linear relationship with the compress density. To verify these conclusions, an experiment was conducted to compare the thermal management capabilities of the PA-EG composites and the PA-EG-GN composites with several simulative chips. Both the surface peak temperature and the apparent heat transfer coefficient of chips were measured. The final results confirmed that the PA-EG-GN has a better performance than regular PA-EG composites.

1. Introduction

In the informational era, there are two emerging trends in electronics development. One is faster computational performance and the other is higher chip integration level [1–3]. Both trends lead to higher heat flux that generated by the electronics, which is the major challenge for the electronics industry [4]. Traditional cooling methods, such as natural and single-phase forced convection, are not efficient in the next generation of electronic chips due to their high heat fluxes [5]. Thus, researchers proposed many new technologies for the electronic apparatus cooling, such as heat pipes [6], energy selective electron devices [7,8], thermoelectric cooler [9,10], and etc.

Apart from aforementioned technologies, phase change materials (PCM) attract increasing attention, given its simplicity, high reliability, and low power consumption [11,12]. Besides, the large latent heat of PCM can also be utilized to maintain the temperature of the electronic apparatus within a stable range, which ensures a safer work environment [13]. Therefore, PCM for active and passive electronic cooling apparatus has been intensively investigated in recent years. For example, Wang et al. [14] discussed the influence of properties of paraffin and porosity of metal on heat dissipation and optimized the performance of phase change thermal control apparatus. Kandasamy et al.

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[15] analyzed the influences of component direction, input power, and cool-heat cycle time on the thermal management of electronic apparatus. Baby et al. [16] reported that utilizing fins in the heat sinks that encapsulated with PCM could drastically enhance the performance of electronic devices. Gharbi et al. [17] found that the alliance of the PCM and well-space fins could effectively control the temperature of the electronic devices in an appropriate range. Wu et al. [18] concluded that phase change material board performs better than natural cold air cooling for electronics. Jaworski et al. [19] designed a new heat spreader filled with PCM which could improve the cooling effect on the electronic devices. Samimi et al. [20] simulated the thermal management performance of the battery cell using the carbon fiber-PCM composites. They reported that the utilization of the composite PCM with higher mass fraction carbon fibers contributed to an even temperature distribution within the battery cell.

Although PCM has been proven effective in controlling the temperature of electronic apparatus, the low thermal conductivity of PCM is still the largest barrier to its wider application. To overcome this limitation, researchers have developed many methods to create the composite PCM with high thermal conductivity, such as embedding dispersing metallic particles into pure PCMs [21–23], blending PCMs with nanoparticles [24,25], and adding carbon materials into pure PCMs [26,27]. Among these approaches, using carbon materials cannot only effectively reduce the weight and cost of the energy storage systems, but also be naturally compatible with PCMs [28]. EG is one of the most popular carbon materials, which is intensively utilized to improve the thermal conductivity of PCMs, such as $LiNO_3$-KCl-$NaNO_3$ [29], $LiNO_3$-KCl [30], stearic acid [31], polyethylene glycol [32], and palmitic-stearic acid eutectic salts [33]. Previous studies [28,34,35] show that adding the EG can effectively enhance the thermal conductivity of PA. Another typical carbon material is GN, which is also widely applied to enhance the thermal conductivity of PCMs, such as palmitic-stearic acid [36], palmitic acid-polypyrrole [37], and lauric acid [38]. However, few studies reported about integrating both GN and PA-EG to further enhance the thermal conductivity of the PCMs. In the meantime, the thermal conductivity of PA-EG could be improved with the increase of EG, but the latent heat of PA-EG also would decline dramatically. Thus, only little nanoscale GN with superior thermal conductivity easily absorbed into the holes of EG could enhance greatly the thermal conductivity of PA in the holes of EG and decrease the storage capability decline rate.

In this paper, the novel composite PA-EG-GN was proposed and prepared to improve the thermal conductivity of the PCMs. To examine the thermal-physical properties of the new composite, the pure PA, PA-EG, and PA-EG-GN were compared and analyzed. The X-ray Diffraction (XRD) was used to characterize the crystalline phases of the PCMs. The Fourier Transform Infrared Spectroscopy (FTIR) spectra of the PCMs was recorded by the KBr disk method. The Raman spectrometer was used to observe the Raman spectroscopy patterns of EG and GN. Atomic Force Microscopy (AFM) was used to observe the shape of GN. The Scanning Electron Microscope (SEM) was used to observe the microstructures of the PCMs. The thermogravimetric analysis (TGA) was conducted with a thermal analyzer. The Differential Scanning Calorimetry (DSC) was used to measure the phase change temperatures and latent heat of the PCMs. The thermal constant analyzer was used to measure the thermal conductivity of the PCMs. Also, a validation experiment on simulative electronic chips was conducted to compare the thermal performance using the PA-EG-GN with that using the PA-EG.

2. Methodology and experiment design

2.1. Preparation of the composite PCM

The proposed composite PCM composes of base organic PCM and inorganic supporting materials. PA (Shanghai Huayong paraffin Co., Ltd, China) with appropriate phase change temperature (melting point from 48 °C to 50 °C) was chosen as the base organic PCM. EG was selected as the inorganic supporting material for the paraffin phase change material. EG can be produced through expansion treatment of the raw expandable graphite (average particle size: 500 μm, expansion ratio: 300 ml/g, from Qingdao Hengsheng Graphite Co., Ltd) in a microwave oven (Midea Inc, China) with a power of 800 W for 30–40 s. The EG was used to absorb a mass of the mixture of the PA and GN. Table 1 shows the physical properties of the graphene nanoplatelets (Zhuhai Lingxi New Material Technology Co., Ltd, China).

Table 1
Physical properties of GN.

Parameters	Value
Diameter	5–15 μm
Thickness	1–5 nm
Carbo Content	> 99 wt%
Density	0.5 g/cm^3
Thermal Conductivity	~5000 W/(m·K)
Specific Surface Area	100 m^2/g

The material composition process includes three steps. Firstly, the PA was melted by water bath heating at 80 °C. Then, the GN was put into the liquid paraffin with a roll mixer to ensure mixing uniformity. Finally, the EG was dissolved in the liquid. After natural cooling, the new PA-EG-GN composite material can be acquired. Based on the conclusion of a previous study [35], the maximum amount of paraffin (melting point from 48 °C to 50 °C) can be absorbed by EG is about 85.6 wt%. Thus, the PA-EG composites with a fixed EG mass fraction of 80% were chosen in this study to prevent the paraffin leakage. To investigate the relationship between the mass fraction of GN and the thermal-physical properties of the composite PCM, a series of the composite PCM samples with different GN mass fractions were prepared. Table 2 shows the mass fractions of composite samples.

2.2. Characterization

Crystalline phases of EG, GN, PA, and PA-EG-GN composite PCM were characterized by an X-ray diffractometer (XRD, D8 Advance, Bruker, German) with Cu-Kα irradiation (k = 1.5406 Å) accelerating voltage and 40 mA currents. Fourier transformation infrared (FT-IR) spectra of EG, GN, PA and PA-GN-EG composite PCM were recorded between 400 and 4000 cm^{-1} on a spectrometer (Tensor 27, Bruke, Germany) using the KBr disk method.

Raman spectroscopy patterns of EG and GN were obtained by using the Raman spectrometer (LabRAM Aramis, HJY Inc., France). The excitation line at 632.8 nm was emitted by the AR ion laser. The laser power and scanning time of this ion laser were respectively 20 mW and 20, and then when it normally works. The shape of GN, especially the thickness, was observed by using the Atomic Force Microscopy (Veeco Multimode, America).

The microstructures of EG, GN, PA-EG, and PA-EG-GN were observed using a scanning electron microscope (SEM) (S3700N, Hitachi Lnc., JNP). The phase change temperatures and latent heat of PA, PA-EG and PA-EG-GN were measured by a differential scanning calorimeter (DSC 214 Polyma, NETZSCH, Germany) under a nitrogen atmosphere from 10 to 80 °C. The sample mass was controlled in the range of 5–10 mg and the heating/cooling rate was set at 2 °C/min. Furthermore, the sample of PA-EG-GN was placed in a high and low temperature heat

Table 2
Mass fractions of composite samples.

Sample Name	Mass Fraction of PA-EG Composite	Mass Fraction of GN
PA-EG	PA: EG = 80%: 20%	PA-EG:GN = 1: 0.0%
PA-EG-GN	PA: EG = 80%: 20%	PA-EG:GN = 1: 5.0%

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