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Research Paper

An experimental study of enhanced heat sinks for thermal management using n-eicosane as phase change material

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HIGHLIGHTS

- 2 mm thick pin-fin heat sink dissipates the heat more uniformly and keeps the base temperature lower.
- The latent heat phase duration decreases with increasing of input heat flux.
- 2 mm thick pin-fin heat sink contributes larger enhancement in operation time against all input heat levels.
- Enhancement ratio of about 4.0 is gained for SPTs of 45 °C in case of a 2 mm thick pin-fin heat sink.
- It is revealed that higher thermal performance is achieved for $\psi = 1.00$.

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ABSTRACT

This study experimentally explores the thermal performance enhancement of portable electronics; based on the n-eicosane used as a phase change material (PCM) filled pin-fin heat sinks. A constant heat flux ranging from 0.79 kW/m^2 to 3.17 kW/m^2 is applied at the base of heat sink. Comparison was carried out with and without n-eicosane for finned and un-finned heat sinks. Four configurations of pin-fin heat sinks are tested at four different volumetric fractions of n-eicosane including no fin heat sink to quantify the effectiveness of pin-fins for cooling of electronics. Pin-fins of constant volume fraction (9% to the total volume of heat sink) are used as thermal conductivity enhancers (TCEs) within PCM as the PCM has very low thermal conductivity to dissipate heat. TCEs are made of aluminum. Pin-fin heat sinks of fin thickness of 1 mm, 2 mm and 3 mm, are investigated to examine the effect of fin thickness, amount of n-eicosane and input heat flux for three different critical set point temperatures (SPTs). The findings indicated that inclusion of n-eicosane in pin-fin heat sink had viable performance to keep the temperature of mobile devices in comfortable zone. At lower heat inputs steady state operating conditions, uniform charging of PCM takes longer duration, and more phase duration of latent heat is achieved. Enhancement ratios revealed that 2 mm thick pin-fin heat sink had the maximum thermal performance for reliable performance of electronic package.

1. Introduction

Thermal management techniques for portable hand-held electronic devices rely on the combination of material and heat transfer methods to stabilize the component temperature at desired level. As an example the latest model of mobile phones have smaller dimensions and packaged with additional features such as cameras (with video recording and playback facility), digital music player and full web browsing. With advance features of electrical portable devices, dissipation of generated heat has become the major issue, which not only causes the deterioration in performance, failure of critical components but also causes discomfort to the end user of device.

Forced convention cooling, using fans can enhance the heat transfer rate but fans are generally bulky, thus not suitable for

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Nomenclature

TM	thermal management
TCE	thermal conductivity enhancer
SPT	set point temperature
T	thermocouples inside the PCM
W	thermocouples inside the side walls
H	thermocouples inside the base
PCM	phase change material
V_S	total volume of heat sink
V_f	total volume of fins
t_{cr}	time to reach for a critical temperature
G	thermal conductance
Q	heat transferred
ΔT	temperature difference
T_{max}	maximum temperature after charging phase
T_{amb}	temperature at ambient condition.
q	heat flux
$\boldsymbol{c}$	specific heat
$\boldsymbol{T_m}$	melting temperature of PCM

Greek symbols

γ	volume fraction of the TCE
ψ	volumetric fraction of PCM
υ_{PCM}	volume of PCM
ξ	enhancement ratio at TCE
ε	enhancement ratio at PCM
β	thermal capacity
κ_{PCM}	thermal conductivity of PCM
λ	latent heat
ρ_{PCM}	density of PCM

the cooling of many portable hand-held electric devices.[1–3] This is reason that traditional approach may not be feasible for newer electronic devices because of size, power consumption, weight, aesthetic constraints, and reliability. For example, bulky and noisy fans are not suitable for the cooling of hand-held devices (mobile phones, mini laptops) [4–6].

Suitable selection of PCM is based on the high heat of fusion and melting temperature for various applications. PCM melts and solidifies at a certain temperature and has the ability of storing and releasing a large amount of energy. During the phase change from solid to liquid heat is absorbed and heat is released when the liquid solidifies. The cooling process of electronic devices using PCMs can be classified into three phases. In phase 1, heat released from the electronic device is absorbed which gradually increase the temperature of solid PCM to its melting point. In phase 2, melting of PCM starts at a constant temperature. During this phase latent heat is absorbed without the variation of temperature and there might be a small change in volume ($< 10\%$) during the solid to liquid phase transition. In phase 3, temperature of liquid rises again [7].

Current applications of PCMs are; solar thermal application [8,9], air-conditioning systems [10], passive heating of buildings [11–13], textile industry [14], desalination [15], refrigeration [16], electronics cooling [17,18], batteries [19],heat pipes [20]. and space-crafts [21].

PCMs usually have the low thermal conductivity which is a disadvantage of PCMs prolonging charging (melting) and discharging (solidification) duration of PCM. To increase the thermal conductivity of PCMs, various configurations of extended surfaces of high thermal conductivity material can be arranged in conjunction with PCMs. Different geometries of high thermal conductivity material e.g. *pin-fin*, plate-fin, etc. are manufactured inside the heat sinks. These geometries made of aluminum or copper are usually called thermal conductivity enhancers (TCEs). Many studies are reported on *pin-fin* and *plate-fin* heat sinks. For PCM based *plate-fin* heat sinks, Tan and his co-authors [17,22–24] comprehensively studied the cooling of portable hand-held mobile devices. Heat storage unit (HSU) with no fin, 3 fins and 6 fins was filled with *n-eicosane*. Effect of orientations, charging and discharging cycles for steady and unsteady heat mode for 3–5 W were explored. Numerical simulation had also been carried out for eight different cases. The results showed that a plate-fin PCM based heat sink had an effective capability to keep the temperature below the critical temperature of HSU, a 50 °C temperature was recorded after 2hr. Further it was found that a heat sink was more suitable for the thermal management of mobile phones under intermittent moderate usage conditions. Shatikian et al. [25,26] studied numerically the cooling of mobile devices for plate-fin heat sink filled with PCM at constant heat flux. Unsteady and two-dimensional simulation was carried out and Nusselt number (Nu), melt fraction vs. Fourier number (Fo), Reynolds number (Re), fin parameters and Stefan number (Ste) were presented for internal fins heat sink. They concluded that Rayleigh number has significant effects on thermal performance.

Yang and his co-workers [27,28] contributed numerical scheme for cooling of mobile electronic device for multi fins PCM based plate-fin heat sinks. Power levels of 2–4 W were applied for no fin, 3 fins, and 6 fins heat sink filled with *n-eicosane*. Developed numerical model was validated with experimental studies and maximum error of 10.2% was found. Furthermore, Effect of orientations (at horizontal, slanted, and vertical) were explored numerically against charging and discharging modes. It was found that 6 number of plate-fins heat sink had best performance in comparison of other finned heat sinks and orientations had limited effects on heat dissipation rate. A comprehensive study on passive cooling of electronics was presented both numerically and experimentally for plate-fin PCM based heat sinks by Hosseinizadeh et al. [29]. Different parameters were explored such as effect of power levels, number of fins, height of fins, and thickness of fins. The findings indicated that number of fin and height had significant effects against the thickness of a plate-fin PCM filled heat sinks. Fan et al. [30] experimentally investigated the thermos-physical properties of two PCMs having different melting temperature with no fin and plate-fin heat sinks. It was concluded that a PCM having higher melting temperature was favored to prolong the operation time of electronics in comparison of low melting temperature PCM. An optimization of cross plate fin PCM based heat sink was reported using ANN-GA by Baby and Balaji [31,32]. Different volume fractions of TCEs of 0%, 9%, 15%, and 21% in a plate-fin heat sink were tested with different mass fractions of PCM filled in each configuration of heat sink. A heat sink of 15% of TCE having fin thickness 1.42 mm showed maximum thermal performance and enhancement ratio of 15 was reported at 7 W. Further, optimized heat sink was used for the thermal performance of electric devices using constant and intermittent heat fluxes and lower base temperature was achieved even at higher input powers. To explore the effect of different plate-fin configurations and different types of PCMs having different thermo physical properties and melting temperature, an experimental study was presented by Mahmoud et al. [33]. Authors conducted study on parallel fins and cross fins cavities, results were compared to honey comb structure. It was