On the Suitability of Phase Change Material (PCM) for Thermal Management of Electronic Components

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Abstract

Objectives: To review the suitability of Phase Change Material (PCM) for the thermal management of electronic components.

Methods/analysis: Day by day, physical world has been changing to digital world by involving electronic components such as computers, digital meters, smart phones, high sensitive sensors, high precision devices etc. One of the important issues pertaining to smooth running of electronic components is their thermal management. Electronic components generate heat during operation and this heat has to be driven out to safeguard the equipment. Researchers have proposed various methods such as heat sinks, nano-fluids, micro-channels etc to reduce and dissipate heat from the components. The requirement for the usage of miniaturization of electronic components has further increased the complexity to effectively dissipate the heat from the confined space of these electronic components. Various techniques provide their own set of benefits and trade-offs for thermal management of electronics to reduce operating temperatures, dissipate excess heat and long-term reliability. The present study aims to address the usage of PCMs with their advantages and disadvantages for the thermal management of electronic components. Findings: PCM based heat sinks can be an alternative technique for effective dissipation of heat and maintain safer temperature range for the electronic devices. Novelty/improvement: The study provides an insight about the applicability of PCM especially for the thermal management of electronic components such as computer processors, IC boards etc. to maintain with in maximum allowable temperature range. Based on the study it can be suggested that the usage of PCM can satisfy the present demand of cooling system.

Keywords: Electronic Components, Heat Dissipation, Heat Sink, Phase Change Materials, Thermal Management

1. Introduction

In the present world, electronic components play a vital role in human lives. Electronic devices are being used for circuit support and protection, power dissipation and signal distribution etc. Electronic devices such as micro-processors, Integrated Circuit (IC) boards, transistors, resistors, batteries etc. generate heat. The heat generated by high configuration systems is more. The reliability and efficiency of the system are based on the reliability of electronics. Electronic components work due to the passage of electric current through a resistance which in turn results in heat generation. Also, high thermal stress due to temperature variations in solder joints mounted on circuit boards lead to failure. The present day requirement of miniaturization of electronic components further increases the complexity to effectively dissipate the heat load.

The failure rate of electronic equipment’s increase exponentially with temperature. Based on US Air Force survey it was mentioned that more than 55% of electronic goods fail due to temperature issues. A 1˚C decrease in temperature of electronics may lower 4% failure rate and about 10-20˚C increase in temperature may increase the failure rate by 100%. In order to prevent electronic components from overheating the maximum permissible temperatures range is 85 to 120˚C. Therefore, thermal management has become most significant criteria in the design and operation of the electronic components.

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2. Techniques for Cooling of Electronic Components

Cooling techniques for electronic components can be broadly classified into two categories i.e. i) Active cooling and ii) Passive cooling. In active cooling, external aid is required to run the cooling system. Active cooling is mechanically assisted, independent on working conditions and easily controllable. By using active cooling, the main advantage is that desired temperature of the component can be controlled independently to that of surroundings. Various types of active cooling techniques are used to dissipate heat from the electronic components such as fan-assisted cooling, spray cooling, jet-impingement cooling, micro-channel based single and multi-phase cooling etc. In spite of their effective heat removal capacity, active cooling technologies may not be preferred due to issues such as maintenance, noise and vibrations etc. Some of these problems can be avoided by using passive cooling techniques. In passive cooling heat transfer/dissipation is not assisted by any external means. Passive cooling system is noise free and has low maintenance when compared to that of active cooling techniques. The passive cooling system has less heat dissipation capacity compared to active cooling systems even though passive cooling systems are preferred because of low cost, no parasitic power, quiet operation and reliability. Different passive cooling techniques are preferred for thermal management of electronic components such as heat sinks, heat pipes, heat spreaders, PCMs etc.

In most of electronic components, heat is extracted from the device by placing heat sinks over on it. The general pattern of heat sink is a metal device with number of fins. The arrangement of fins is the reason for effective heat transfer of thermal energy to the surroundings. The effectiveness of a heat sink material is directly proportional to its thermal conductivity. The heat transfer by using heat sinks results free convection. Heat pipe is also widely used passive cooling technique, by structure it is a sealed tube with interior wall structure (wick) made of a highly conductive material. In Heat pipe, wick structure produces capillary effect for liquid transportation consequently heat transportation between two ends. In mobile applications, heat spreading materials is being used for heat dissipation and to increase the heat dissipation capacity the number of layers should be increased which is limited due to space constraint.

Practically passive cooling technique is more promising option for thermal management of electronic components than active cooling but it has less heat dissipation capacity. In passive cooling such trade-offs can be overcome by integrating heat sinks and heat pipes with PCMs. Therefore PCM technology can be considered as an attractive solution for thermal management in challenging applications.

3. Description about PCMs

The material which undergoes phase change by transmission of heat, these materials are said to be PCMs. PCMs change its phase at constant temperature. When temperature reaches to melting temperature, PCMs transform from one state to other. PCMs can be broadly classified as solid-solid, solid-liquid, solid-gas, liquid-gas PCMs. Practically solid-gas, liquid-gas are not preferred due to large volume changes and required additional energy to compress. Therefore, solid-liquid and solid-solid PCMs can be considered for the thermal management of electronic components. In solid-liquid PCMs, once the melting temperature is attained the thermal energy extracted from the electronic component changes its phase from solid to liquid. In the case of solid-solid PCM, the material is transformed from one crystalline structure to the other. The PCM extracts the heat from the electronic component and once the melting temperature is attained the phase change take place and regains back to its original shape after dissipating heat to the surroundings.

4. Desirable Properties of a PCM

The suitability of a PCM for the thermal management depends on several desirable properties. Table 1. provides various desirable properties of a PCM.

5. Classifications of PCMs

PCMs are mainly classified as organic, inorganic and eutectics. The classification of PCMs along with their characteristics, advantages, disadvantages and methods for improvement are presented in Table 2.

Due to the attractive feature of effective dissipation of heat, Kandasamy et al. investigated the thermal management of electronic devices operated at power range 6-12W by using PCMs. They concluded as PCM is suitable solution for thermal management of electronic
components operated at higher input power on basis of successful experimentation on cooling of a printed circuit board. Rajesh and Balaji carried out experiments using PCM-heat sinks with different combinations and observed superior enhancement in operating time and performance at various operating temperatures and power levels.

6. The Possible Options of PCMs for Thermal Management of Electronic Components

For the thermal management of electronic components, PCM can be a promising option because there is no need of external aid and due to its compatibility in size. Also,

| Table 1. Desirable properties of PCM |
|-------------------------------------|
| **Thermal Properties** | **Physical Properties** | **Kinetic Properties** | **Chemical Properties** | **Economical Properties** |
| Melting temperature should be in the desired operating range | Small volume change on phase transformation | No/little supercooling | Long-term chemical stability | Abundant Easily Available |
| High latent heat of fusion per unit mass | Low vapour pressure at the operating temperature | Sufficient crystallization rate | Compatibility with materials of construction | Low cost |
| High specific heat is required | Favourable phase equilibrium | Congruent melting of the PCM | Non-toxic | Recyclability |
| High thermal conductivity in both solid and liquid phases | High density | Non-flammable | Non-explosive for safety | |
| Thermal stability | |

| Table 2. Classification of PCMs along with their characteristics, advantages, disadvantages and methods for improvement |
|----------------------------------|
| **Classification** | **Characteristic Descriptions** | **Advantages** | **Disadvantages** | **Methods for Improvement** |
| Organic-Paraffin's and Non-Paraffin's | Saturated hydro carbons. The general empirical formula is Acid/esters, high aliphatic hydrocarbon, or salts, alcohols, aromatic hydrocarbons, aromatic ketone, lactam | Physical and chemical stability Cycling stability Good thermal behaviour Adjustable transition zone Non-corrosive Low or no sub-cooling | Low thermal conductivity Low density Low phase change enthalpy Low melting point Highly volatile Flammable More volume change | High thermal conductivity additives Fire retardant additives |
| Inorganic-Salt hydrates and Metallic's | Typical crystalline solids of general formula AB.n Molten salt, metal or alloy, crystalline hydrates | Higher energy storage density Higher thermal conductivity Non-flammable Inexpensive | Sub-cooling Phase segregation Corrosive Incongruent melting point Lack of cycling stability | Mixed with nucleating and thickening agents Thin layer arranged horizontally Mechanical stir. Shape stabilized PCM |
| Eutectic | Eutectics are mixture of inorganic (mostly hydrated salts) and/or organics They have a single melting temperature | Sharp melting temperature (could be used to deliver the desired melting temperature required) Volumetric thermal storage density slightly above organic compounds No segregation and congruent phase change | Limited data are available on their thermo physical properties Some fatty eutectics have a quite strong odour and therefore they are not recommended | Cannot comment due to the availability of limited data |
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PCMs dissipate heat from electronic components at constant temperature by which the rise in temperature can be effectively restricted. Number of options is possible based on temperature requirement, physical confinements, environmental conditions, cost and compatibility requirement. Several PCMs are available in the open market with phase change temperatures between 30°C and 70°C. By using PCMs, product failures and assembly failures can be reduced which can further lead to improve in productivity.

The major problem with PCMs is their low thermal conductivity. This problem can be alleviated by adding of high thermal conductivity materials (i.e. Thermal conductivity enhancers), nano particles, metallic foam matrix and metallic fins etc.\(^{14,15}\), encapsulation etc.

7. Conclusion

The study provides an insight of heat dissipation in electronic components and challenges associated with thermal management of electronic devices. Due to the capability of dissipating larger amount of heat at constant temperature, PCMs can be considered as an attractive option for the thermal management of electronic components. According to literature, PCMs are gaining widespread acceptance by several researchers to dissipate heat from the electronic components. It is expected that PCMs can play a pivotal role in the future cooling techniques due to its attractive features such as noise free, long-term reliability and effective dissipation of heat. Based on above study, it can be concluded that PCMs can be a suitable option for thermal management of electronic components.

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