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Effectiveness of PCM Heat Sink for Cyclic Load Conditions in High Ambient Conditions

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Abstract: In hot ambient conditions of desert thermal management system provided with electronics equipments becomes insufficient, leads to under performance or failure. In this study passive thermal management technique using Phase Change Material (PCM) is demonstrated for cyclic power (load) conditions in hot desert like field condition. A PCM heat sink has been designed and fabricated and its thermal performance was evaluated on a simulated heat load in hot environment. The results are compared with a same size conventional aluminum heat sink. Results indicate that because of latent heat absorbing property of PCM, source temperature increase slowly with PCM heat sink than the aluminum heat sink for the same ambient and power conditions.

INTRODUCTION:

The heat withdrawal capacity of the conventional heat sinks greatly depends upon the ambient temperature, as ambient goes high the gradient between the fin and ambient reduce and cause the lower heat transfer. This in turn increases the device temperature and some time cross the safe operational limit. During desert military operations and field trials number of electronic gadgets is used or fitted on the vehicles, have to work under high ambient temperature. The efficiency of existing cooling system (heat withdrawal system) of electronic equipments gets affected by high ambient temperature, causing their underperformance, malfunctioning or failure during their operation.

Wallace T. Anderson[1] address this problem that high temperature operation not only reduces the performance of electronic devices, but also greatly shortens their lifetime. The problem of dependency of cooling systems, attached with electronic gadgets, on ambient temperature has been address by application of PCM in heat sink for thermal management. PCM works on absorption of latent heat and absorbs a significant amount of heat at its melting point irrespective of the ambient amount of heat because of melting of PCM and reduce the rate of temperature rise of the source temperature. Different publication has reported that use of the PCM with heat sinks can maintain devices temperature within operational limit [1-3].

Amy S yoo Yoo D at al.[4] studied the thermal performance of plate fin and pin fin PCM incorporated heat sinks under periodic power inputs and published that using PCM heat sinks the cooling fan operate less period of time than conventional heat sink.

Bellettre et al. [5] applied a organic PCM for cooling of an auto synchronous electric motor stator. A sensitivity analysis for PCM properties was performed, which showed that thermal performance improved with increasing thermal conductivity and latent heat of melting of the PCM, and with decreasing melting point.

Fleischer et al.[6] analyzed the performance of PCM with an embedded light weight carbon fiber heat sink to improve the thermal performance.

Dong-won Yoo et al.[7] reported the incorporation of phase change materials in heat sink resulted in energy saving in the range of 5.4 to 12.4% due to less exercise of the fan integrated with PCM heat sink. Study reported that inclusion of PCM also provides the possibility of size reduction of thermal management devices like heat sinks.

In this study, PCM incorporated heat sink performance was studied for its thermal behavior in cyclic operations i.e. periodic power ON-OFF condition. The metal eutectic PCM absorbs and release heat during pulse On and Off period as shown in fig 1.

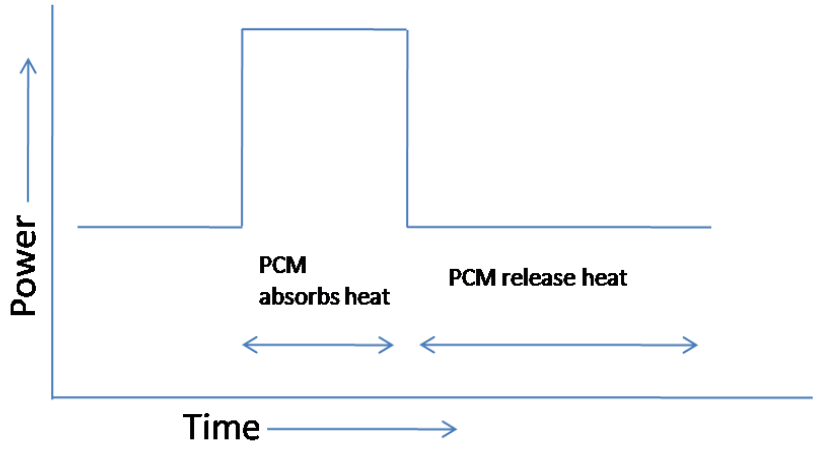

Fig 1 PCM behavior during cyclic load condition

MATERIALS AND METHODS:

Phase Change Materials (PCM) metal eutectic are prepared by solid solutionising of multiple low melting metals like Bi, Sn, Pb, cd, In. The melting point of metal eutectic PCM can be tailored by changing the composition of metals. In this study experiments were performed using metal eutectic PCM having composition of (Bi: 50%, Sn: 12.5%, Pb:25%, cd:12.5%) and melting point: 72.0"C. For the experiment purpose a PCM incorporated sink of size (114 * 34* 16 mm) is fabricated. The surface area of fin and sink for dissipating heat is 100 sq cm and contact area to extract heat from heat generating surface is 114 * 34 mm. Metal eutectic PCM quantity used in sink is 350gms. Typically conventional heat sink of this size is attached with solid state power amplifier used in micro wave transmitting system. PCM heat sink was fabricated by customized the fin size as shown in fig 1(a) and 1(b).

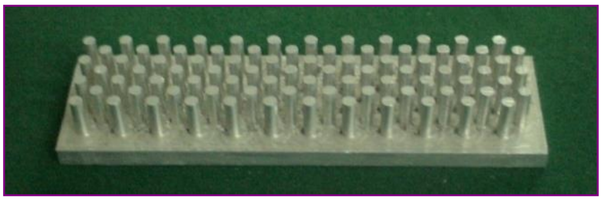

Fig 1: (a) PCM Heat sink (b) Reference Aluminum heat sink for Solid state Power Amplifier

During fabrication of PCM sink cavity for PCM housing is formed and PCM metal eutectic filled in the cavity. The total surface area for dissipating heat is kept constant by increasing the number of fins on PCM sink. Both the sinks were evaluated in similar ambient temperature condition for their thermal performance by examine the rate of rise of source temperature and maximum source temperature during the pulse period (power on period). A climatic test chamber was used to provide similar ambient conditions to test set up during evaluation.

Experiment Set up: A experimental set has been assembled to studied the effectiveness of the PCM heat sink in high ambient temperature conditions with pulse power input. This set up is integration of heating source, sensor, power supply etc as shown in fig 2.

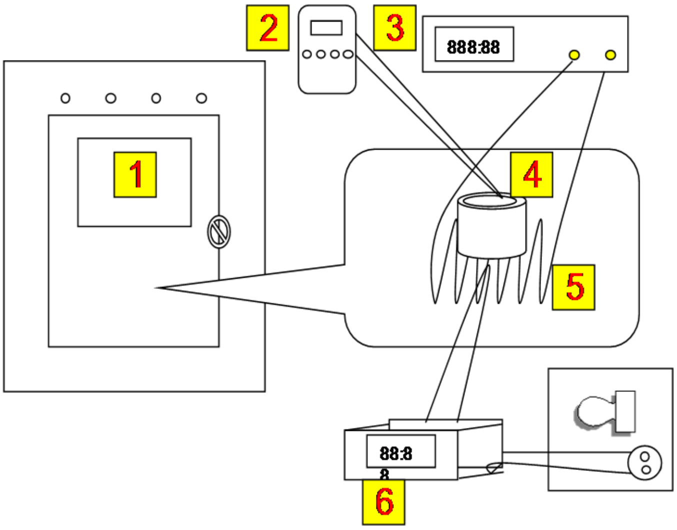

Fig - 2 Schematic of Experimental Set up for PCM HWS and reference heat sink

Environmental (Climatic) Chamber [1]: A climatic test chamber, CME make, has been used to provide the uniform ambient temperature to the test setup i.e. PCM heat sink and conventional heat sink. The temperature range that can be simulated inside the chamber is from -30ºc to 120ºc.

Heat simulation source [5]: Heat simulation source has been developed using Nichrome (80% nickel and 20% chromium) metal heating ribbon of required width and thickness. The heating element selected on the basis of power (heating) output requirement and size of heating source. Heat sources of 20, 40 & 60 watt capacity is designed and fabricated for our testing purpose.

Sensor and Display [2,3,6]:For temperature monitoring during testing and evaluation of PCM heat sink and conventional heat sink different temperature sensors and indicators are used.

A) For monitoring of heater source temperature a PT-100 sensor is used. This sensor is inserted in between the mica layer (just above the heating filament) and the copper plate (used for uniform distribution of the temperature). The two output control leads of the sensors are extended by using the thin wires of the cooper, to take out the connection to display unit of the PT-100 sensor. The range of this display is -50˚C to 400˚C.

B) For monitoring of heat sink temperature inside the climatic chamber digital thermo meter of Euro lab make are used. The probe of this thermometer is fixed on the heat sink fins and the display is set on the desk outside the chamber to monitor the temperature. The range of the thermometer is -50˚C to 200˚C..

Method of evaluation: To study the PCM effectiveness in heat sink and for comparison of rate of rise of source temperature and maximum source temperature during the pulse period (power on mode) following steps are performed:

- Experiment setup installed inside the climatic test chamber with conventional heat sink mounted on the heater.
- After attaining the required ambient temperature i. e. 50˚C, pulse power is applied to the heater with 20 watt input power level and collected data for the source temperature. Pulse cycle period set at 50 minutes (18 minutes ON and 32 minutes OFF). Data has been collected for three successive cycles.
- Replace the conventional sink by PCM sink and repeat the process of pulse for three cycles.
- Plot the data for source temperature with time for both the sink.
- Repeat the process for other set of ambient and power input level.

RESULT AND DISCUSSION:

(A) Ambient temperature 50˚C and I/P power 20watt: Thermal performance of conventional and PCM heat sinks in term of source temperature with time is shown in fig 3. The experiment data are collected for three successive cycle of input power (20 watt), whereas one cycle period was selected of 50 minutes (18 minutes on, 32 minutes off). Curve indicates that at high ambient temperature source temperature increases sharply with conventional sink, whereas, with PCM sink it increases up to PCM melting point i.e. 72˚C, thereafter melting of PCM slow down the sharp increase of source temperature. During melting PCM absorbs the heat generated by heater by transforming its phase from solid to liquid and slow down the rate of rise of source temperature. Curve also indicates that with the conventional sink during pulse ON period, source temperature touches the 100˚C, whereas, it remains well below (near 80˚C) with PCM sink. Hence, for cyclic load (electric power) condition PCM sink not only increase the safe working time of electronic devices but also increase reliability by reduces the operating working temperature.

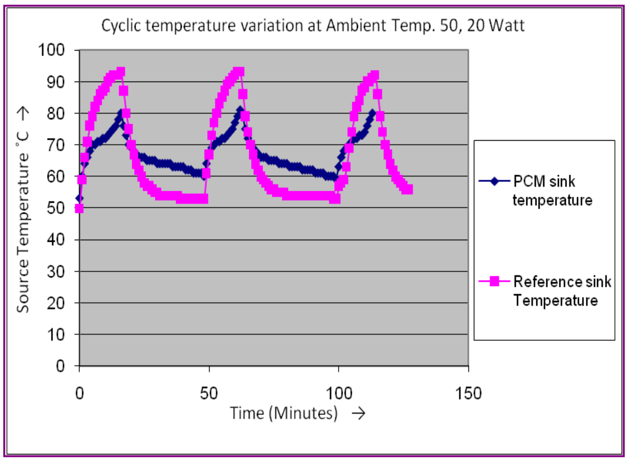

Fig - 3 Source temperature data for conventional and PCM sink for three cycle at ambient 50˚C

(B) Ambient temperature 55˚C and I/P power 18watt: Another experiment with increase pulse ON time to provide proper time to melt PCM completely, also adjust the power ON time so that conventional sink temperature remains below safe temperature. Cycle period set as previous at 50 minutes (28 minutes ON, 22 minutes OFF). Other two parameters ambient temperature and input power are fixed 55˚C and 18watt respectively. The thermal performance of conventional and PCM heat sinks in term of source temperature with time is shown in fig 4 for three successive cycles of input power.

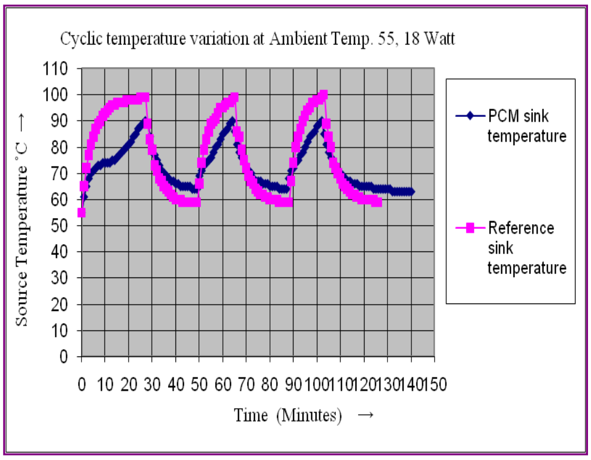

Fig - 4 Source temperature data for conventional and PCM sink for three cycle at ambient 55˚C

Result indicate that by increasing the pulse ON period gives the proper time to PCM for melting and steady state source temperature remain 10˚C to 20˚C below using PCM sink than the conventional sink. It reduces the temperature stress on the heat generating device and gives it extra time before to reach the safe working temperature. Arrhenius equation states that with every 10˚C increase in temperature, rate constant becomes almost double[10]. Means the failure rate of component become almost double for every 10˚C increase in device temperature.

$$\ln k = \ln A - Ea / R\,T$$

Where, $k \rightarrow$ Rate constant, $Ea \rightarrow$ Activation energy

$A \rightarrow$ Constant, $T \rightarrow$ Temperature

$R \rightarrow$ Gas constant

Hence, if PCM sink reduces the source temperature 10˚C, the rate constant (reaction rate) becomes half or we can say the thermal reliability of the device becomes double.

CONCLUSION:

The following conclusions were reached based on the experimental results:

- PCM metal eutectics are good heat absorbing metal at low temperature range (within 100˚C) and PCM heat sinks can improve the thermal performance of heat generating devices or systems affected by high ambient temperature conditions.
- In high ambient temperature conditions, electronic devices / component operated in cyclic mode with customized PCM heat sinks can maintain the device or system temperature well below than the conventional sink. This increase the electronic system reliability as well as life.
- PCM heat sinks are passive heat sinks like conventional heat sinks and can be used in system subjected to occasionally heat spikes or segmented heat load.
- Time to arrest the temperature at lower value can be adjusted by regulating the PCM quantity in heat sink.

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