ABSTRACT

The tremendous growth in electronic equipments demands innovative solutions to the thermal management challenges. Nearly 80-90% of input given to the electronic devices is converted into heat and hence thermal management is becoming increasingly critical to the electronics industries. Maintaining the junction temperature at an acceptable level is a great challenge to the thermal engineers. In the present high powered electronic devices, air-cooled heat sinks are were short falling in attaining the cooling demands. Hence, in the recent years, numerous techniques for cooling such electronic devices have been studied broadly and employed in several thermal management systems. The present survey attempts to study the technological importance and recent developments in cooling systems for electronic devices for enhancement of its performance by increasing surface roughness through surface modification techniques.

Most of the earlier studies on heat sinks with pin-fins have considered the individual geometry compared with other types of fin geometry, materials and fin arrangement. They did not include any surface modification for the whole heat sink in their study. The recent pioneering advancement in nano technology paves the way to further enhance the heat transfer in pin-fin heat sinks, through various types of nano-coatings. Though there are research studies on the use of a grit blasted surface to enhance the heat transfer in selective applications in the recent years, the concept was not attempted for heat sinks to enhance the heat transfer. Hence the major objectives of the present research were to investigate the heat transfer performance enhancement of the nano-coated and grit blasted surface heat sinks compared to the bare heat sink under natural and forced convection conditions thereby achieving higher heat transfer or reducing the material requirement.
An aluminum pin-fin heat sink was identified, which is used in the existing high-end computers due to its large requirement and potential for the performance enhancement through surface modification techniques. The Electron Beam (EB) evaporation technique which is one type of Physical Vapour Deposition (PVD) is used for nano-coating. DC Box-type vacuum coating machine procured from Hind High Vacuum, Bangalore, India was used for the coating. Three different high thermal conductivity materials (Cu, Ag, Al) were chosen and these materials in nano powder form with an average size of 500 to 800 nm with 99% purity, procured from, Nano labs, Jamshedpur were chosen for coating. Pneumatically operated air assisted blasting machine with steel grit balls with hardness of 45 HRC, size of 0.4 mm dia and at a pressure of 4 bar was used for grit blasting. An experimental setup was constructed in the present work to study the heat transfer characteristics of the un-coated and surface modified heat sinks under natural and forced convection conditions.

The characteristics of the surface treated samples compared to the untreated sample surface observed from the present study and the performance evaluation of the heat sink with and without surface treatment under natural and forced convection conditions are presented.

The SEM image depicts uniformity in the distribution of the coating along the surface with the nanoparticles with spherical shape covering the entire surface. The cross-sectional SEM images of all the three nano coated heat sinks show that the thickness of the coated surface varies in the range of 400 to 550 nm and further indicates that the thickness increases with grain size which causes increased surface roughness. The EDAX spectrum indicates that the weight percentage of coating material is about 15 to 25% of the base material and also the presence of carbon and oxygen traces that have been developed due to the interaction between surfaces with atmosphere.
Among the surfaces, the highest surface roughness was observed for the grit blasted heat sink with the surface roughness size of 1.168 µm and aluminum nano-coated heat sink surfaces with a roughness size of 0.872 µm which is the highest among the coated surfaces. The X-ray diffraction patterns of all the samples show the highly crystalline nature of the material with preferred orientation. Aluminum coated sample has the maximum crystalline size of 64 nm with cubic crystalline structure.

One more important observation made from the present results is that the increase in temperature at the base of the heat sink is uniformly very fast till 60°C and further increase in the temperature is very slow till 70°C for all the sample cases and also at all surrounding temperature conditions. This could be the reason for designing most of the commercial heat sinks to withstand a temperature upto 70°C. Further it is understood from the present results that the temperature driving potential had a predominant effect compared to the convective heat transfer coefficient particularly during the natural convection situations. Hence the heat sink designed for particular ambient conditions (say 25°C) leads to failure of the entire system / device due to poor dissipation of heat through the heat sink when the system is exposed in a region at higher surrounding temperature. In most of the hot countries, when the electronics systems with heat sinks are exposed to very high ambient temperature during summer, there is a possibility of failure of the device. Hence, the use of surface treated heat sinks is recommended in many electronic systems/devices without changing the other design aspects and compactness for use in hot countries.

The major conclusions from the present heat transfer studies are

- The treated surfaces increase the surface roughness and disturb the thermal boundary layer which in turn increases the surface
convection heat transfer co-efficient. The increased roughness also enhances the exposed heat transfer surface area. The said effects are higher in the aluminum coated heat sink than the other surface treated cases as there is a good mechanical bonding established between the aluminum heat sink and the aluminum coating due to similar material.

- In the case of natural convection, the treated surfaces play a vital role only when there is sufficient temperature driving potential i.e. at lower surrounding temperature whereas in the case of forced convection, as the driving potential exists at all temperatures due to induced flow, the percentage performance enhancement is high at both the extreme temperature conditions considered. However, the higher temperature difference further enhances the performance improvement.

- There was no temperature variation in the upper one-fourth height of the fin in all the surface treated heat sinks. Hence it is inferred that the fin height could be reduced by 25% in the case of the nano-coated heat sink for achieving the equivalent heat transfer performance.

- During the transient heat transfer process, the increase in ‘h’ value also helps in increasing the ‘ΔT’ value and this cascading effect leads to much higher percentage enhancement in heat transfer than the percentage enhancement in ‘h’ value. The empirical values of the heat transfer coefficient ‘h’ given in the present work have a lot of practical importance while designing heat sinks for a given application with surface treatment.

- The heating and cooling of the heat sink showed a contradictory effect in the performance enhancement due to nano-coating,
with variation in surrounding temperature of the heat sink. During the heating of the heat sink, the nano-coating showed enhanced performance with decrease in surrounding temperature particularly in the case of natural convection whereas during the cooling of the heat sink the nano-coating showed increased performance with increase in surrounding temperature.