Addendum: Modular Heat Sinks for Desktop Computers and Other Electronics

James W. Klett and Michael Trammell

I. INTRODUCTION

THE evaporative cooling technique described in this paper is uniquely suited to systems where the chip or actual electronic device can be bonded directly to the graphite foam and then immersed in the cooling fluid. It is desired, however, to adapt this technology to stand alone and aftermarket heat sinks for desktop computers and electronic devices. This would be suitable for either OEM or aftermarket heat sinks if the thermal resistance can be similar to the state of the art aluminum and copper finned heat sinks.

Current state-of-the-art heat sinks are finned aluminum with a copper spreader of some sort (see Fig. 1). The copper spreads the heat as much as possible without sacrificing weight. The aluminum reduces mass, while maintaining heat transfer. Typical heat sinks, such as the TI-V707TN by Thermal-Integration[1] are mounted to the top of the chip package and a standard commercial fan is used to force air over the fins at up to 5500 rpm. This speed is the limit due to noise problems, rather than the physical limits of the fan. At these speeds, the best thermal resistance reported for this heat sink is around 0.44 °C/W. In addition, weight of these heat sinks is a concern, as during shipping, the heat sink is creating a large moment arm that can vibrate and crack the motherboard. Hence, if the evaporative cooling technique can be applied to this modular heat sink design and result in either a reduction in weight or thermal resistance (or both), the product would be useful.

II. DESIGN OF MODULAR EVAPORATIVE COOLING HEAT SINK

The design of the heat sink was simple (Fig. 2), and comprised of an aluminum housing, foam bonded to the base of housing, and a condenser lid. The foam was bonded to the base of the aluminum housing with the MRi process. The condenser lid was then bonded to the housing creating an internal cavity. A heater was attached to the bottom surface of the base with thermal grease and held in place by small drops of epoxy at two corners. A flat microthermocouple was also placed between the heater and the base, in the thermal grease. A commercial cooling fan, TR2-M2, used in an aftermarket heat sink by Thermaltake, was used to supply the air over the condenser lid at a fan speed of 5600 rpm. After assembly, the Fluroinert FC-87 was backfilled into the evacuated chamber, boiled to de-air the system, and then sealed. Tests were conducted by incrementally increasing power to the heater and recording the internal vapor temperature, the interface temperature, and the heater temperature.

Fig. 1. Typical state-of-the-art computer heat sink: TI-V707TN by Thermal-Integration.

III. TEST PROCEDURES AND RESULTS

Two identical heat sinks (labeled Base A and B) were fabricated to provide duplicate baseline data. Results (see Fig. 3) show that the bases are nearly identical, with Base A performing slightly better. This is most likely an artifact of the foam properties.

Using the internal vapor temperature and the heater temperature, the thermal resistance to boiling and the overall thermal resistance can be calculated as a function of power input. As can be seen in Fig. 4, the internal resistance decreases between 1 and 20 W input, most likely the point at which nucleate boiling is starting to occur, and then levels out to a uniform thermal resistance of nearly 0.08 °C/W (nearly identical to the thermal resistance found in the paper). However, it can also be noted that the overall resistance is significantly larger, nearly 0.31 °C/W (better than the 0.358 °C/W reported for the Sunflower). Clearly, the thermal resistances other than the boiling are a large part of the overall resistance. These resistances,

Manuscript received August 22, 2004. This work was supported by the National Security Agency and the Missile Defense Agency under Contracts 1651-S563-A1 and 2347-S534-A1, respectively.

The authors are with Metals and Ceramics Division, Oak Ridge National Laboratory, Oak Ridge, TN, 37831 USA (e-mail: klettjw@ornl.gov).

Digital Object Identifier 10.1109/TDMR.2004.836731

---

[1] [Online.] Available: http://www.dansdata.com/coolercomp_p9.htm#mcxp4. 2003.

1530-4388/$20.00 © 2004 IEEE

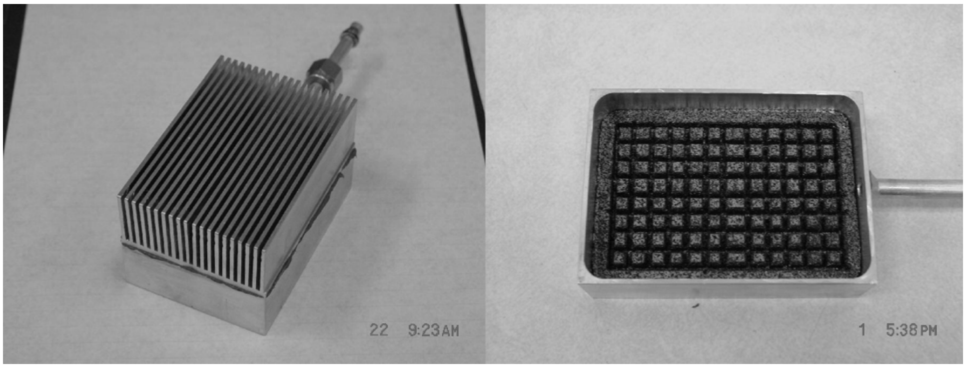

Fig. 2. Modular heat sink design.

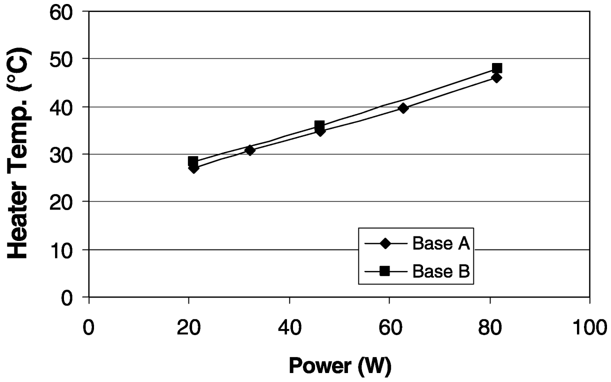

Fig. 3. Performance of baseline heat sinks.

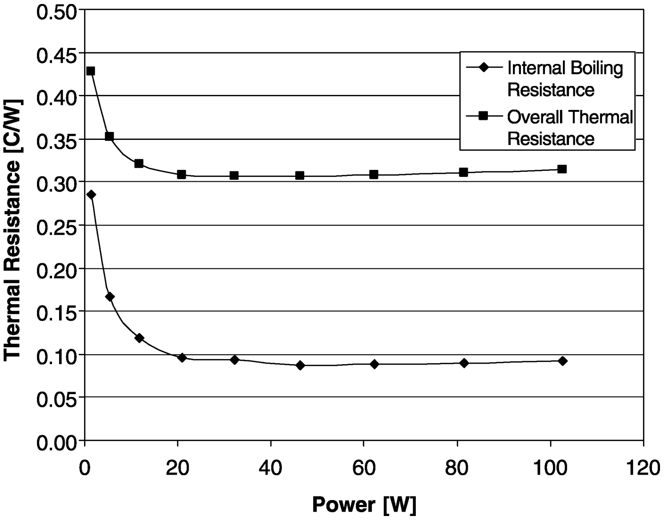

Fig. 4. Internal and overall thermal resistances in modular heat sinks.

condensation, conduction, and convection, were not optimized or even considered in the original design.

The foam in heat sink Base A was then machined into a slotted pattern, similar to Chip 4 in the paper, and then characterized (Fig. 5). Unfortunately, the boiling performance decreased slightly, but the overall performance did not change appreciably. It was noticed that purging the air from the system was difficult with this heat sink design, and perhaps the system was not completely de-aired during testing.

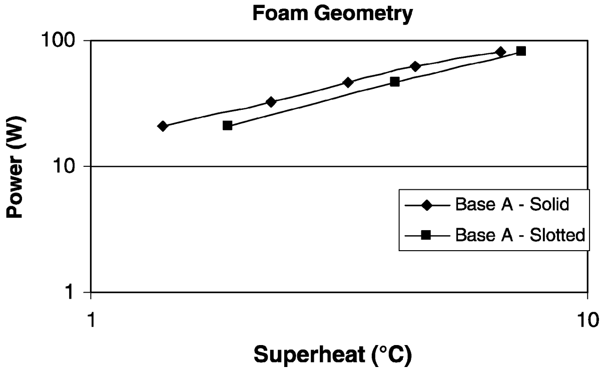

Fig. 5. Effects of slotting the foam in the modular heat sink.

The data from these tests revealed a relatively high thermal resistance in the finned condenser. Clearly, a new design which aims to increase the surface area for condensation, reduces the conduction path length, and increases the surface area for convection would be ideal in reducing the overall resistance. To address this, a new condenser was designed utilizing a thin wall conduction path concept. This is achieved with a rectangular array of holes drilled in the underside of a slotted external pattern (Fig. 6). The decrease in wall thickness provided less thermal resistance from the vapor chamber to the external cooling medium, as well as an increased surface area for condensation. However, the external surface area for convection decreased with this concept, a concern as the air side thermal resistance is typically the largest.

Fig. 7 shows the results with the slotted Base A and the new condenser lid and indicate that the internal performance of the system increased slightly (lower super heat). This indicates that the temperature of the vapor is closer to the temperature of the cooling air. However, the overall performance of the heat sink (see Fig. 8) did not change significantly, indicating that while the condensation and conduction thermal resistances may have decreased, the convective resistance likely increased.

IV. CONCLUSION

Clearly, it has been shown that the passive evaporative cooling technique can be applied to modular aftermarket finned heat sinks. However, the performance was only moderately better, 30%, than the standard designs (0.31 versus 0.44 °C/W). It is evident that the thermal resistances of condensation, conduction,

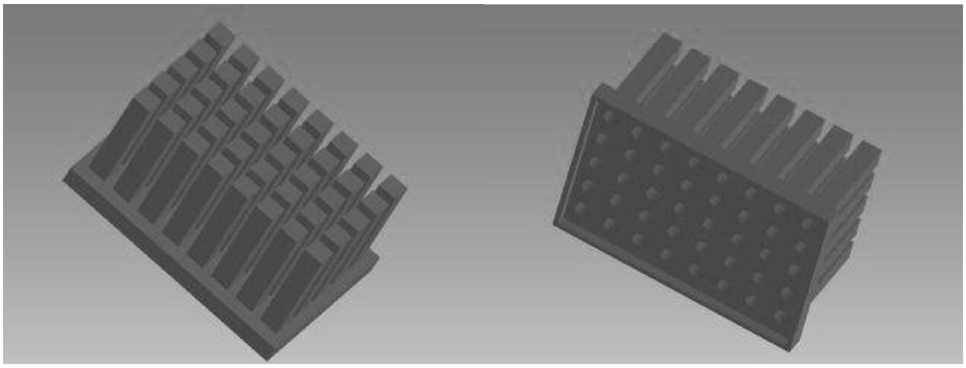

Fig. 6. Schematic of new “drilled” condenser design to reduce thermal resistances.

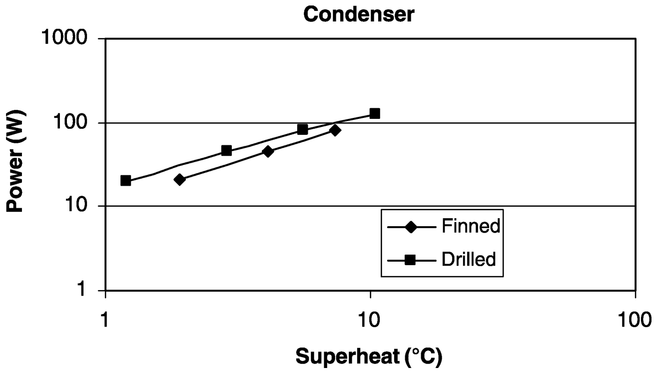

Fig. 7. Internal boiling performance of system with new condenser lid.

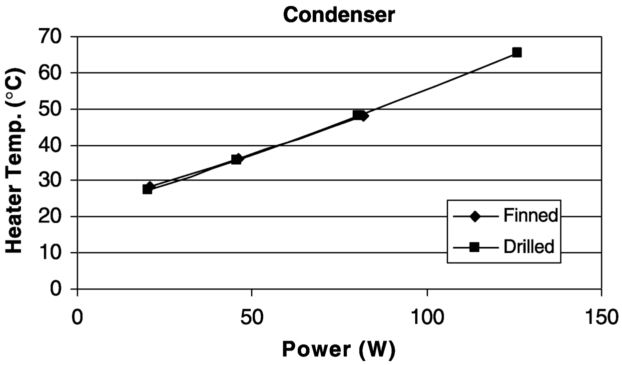

Fig. 8. Overall performance of system with new lid.

and convection need to be optimized to reduce the overall resistance. By redesigning the condenser, the surface area for condensation of the vapor can be increased, while also increasing the external surface area of the fins. Perhaps metallic or graphitic foam would be well suited here. Using a foam, however, may reduce the release of the condensed liquid back to the pool, and a small pore-size foam may not be suitable. Although, better designs where the conduction pathway is as short as possible, might make improve performance. However, these new designs need to be optimized with respect to increasing the external surface area for convection. An ideal design would be similar to the first concept of a finned heat sink, but with hollow fins filled with and aluminum foam. This would provide increased external surface area, an enhanced conduction path, and an enhanced condensation area. However, while such a heat sink may be easily fabricated in a casting process, machining a prototype would be very expensive.