

COMPARATIVE THERMAL PERFORMANCE EVALUATION OF GRAPHITE/EPOXY FIN HEAT SINKS

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ABSTRACT

Heat sinks constructed from natural graphite/epoxy composites are a high performance, lightweight alternative to traditional copper and aluminum designs. For applications where the heat source is the same size as the heat sink, laminated graphite/epoxy heat sinks have been shown to perform equivalently to copper heat sinks at a 75% lower weight. However, when the heat source is smaller than the heat sink, laminated graphite/epoxy heat sinks perform poorly. For this situation, a hybrid graphite epoxy heat sink has been developed. This hybrid construction incorporates graphite/epoxy fins bonded to a copper base. This paper examines the thermal performance of this heat sink and includes both computer models and experimental results. The effects of fin material and bonding techniques on thermal performance were examined. An optimized hybrid heatsink was found to have a thermal performance nearly equivalent to that of a copper heat sink combined with a 40% reduction in weight.

KEY WORDS: heat sink, graphite, epoxy, aluminum, copper

NOMENCLATURE

L_B = Length of heat sink base, fin direction (mm)
 W_B = Width of heat sink base (mm)
 H_B = Height of heat sink base (mm)
 H_S = Height of spacers (mm)
 H_F = Exposed height of fins (mm)
 t_F = Thickness of fins (mm)
 t_S = Spacing between fins (mm)
 N = Number of fins
 T_{HC} = Temperature at the center of the heat sink base ($^{\circ}\text{C}$)
 T_{AMB} = Ambient air temperature ($^{\circ}\text{C}$)
 Q = Heat flow (W)
 V = Air velocity at entrance to heat sink (m/s)
 R_{θ} = Thermal resistance of the heat sink ($^{\circ}\text{C}/\text{W}$)
 $R_{\theta C}$ = Thermal resistance of a soldered, all copper heat sink ($^{\circ}\text{C}/\text{W}$)
 ΔR_{θ} = Change in thermal resistance of a given heat sink relative to the soldered, all copper heat sink ($^{\circ}\text{C}/\text{W}$)

INTRODUCTION

Heat sinks constructed from natural graphite/epoxy composites are a high performance, lightweight alternative to traditional copper and aluminum designs. The high in-plane thermal conductivity of natural graphite/epoxy composite

materials (370 W/mK) compared to copper (387 W/mK) and aluminum (167 W/mK) make graphite/epoxy a potential substitute for traditional copper and aluminum fin materials. Laminated fin graphite/epoxy heat sinks have been manufactured and tested with large multi-chip modules. The thermal performance of this graphite/epoxy heat sink has been shown to be equivalent to that of all copper heat sinks when the area of the heat source is equal to that of the base of the heat sink. However, performance problems with graphite/epoxy heat sinks have been encountered when area of the heat source is much smaller than the base area of the heat sink.

To overcome this problem, a hybrid heat sink, composed of graphite/epoxy fins bonded to an copper base has been developed. The design of this hybrid heat sink is compared to that of a laminated graphite/epoxy heat sink in Fig. 1. The laminated heat sink is made from graphite/epoxy fins and spacers that are fused together. The hybrid heat sink is fabricated with graphite/epoxy fins that are inserted and bonded into slots cut into a copper base. The height of the copper base, H_B , is the same as the height of the spacers, H_S , used in the laminated heat sink. The number of fins, N , the fin thickness, t_F , the fin spacing, t_S , and the exposed fin height, H_F , are identical in both designs.

The graphite/epoxy material is highly anisotropic, with a thermal conductivity of 387 W/mK in the along the a and b axes and 7 W/mK along the c axis. As shown in Fig. 1, in both constructions, the a and b axes are aligned with the height and length of the fin and the c axis with the fin thickness.

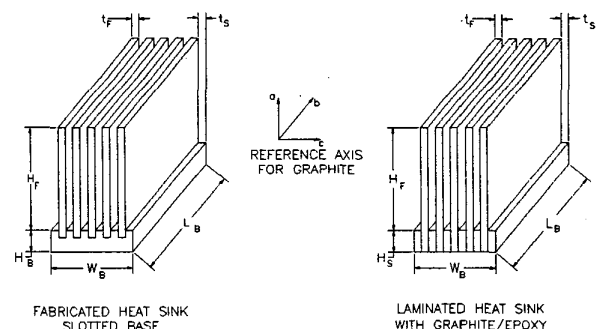


Figure 1. Comparison of hybrid and laminated graphite/epoxy heat sinks.

For this hybrid heat sink to be successful, the bonding methods used to attach the fins to the metal base must minimize thermal resistance losses between the base and fins. This paper investigates various attachment methods used to bond graphite fins into a copper base and compares the performance of hybrid graphite/epoxy heat sinks with equivalent aluminum and copper heat sinks.

PUBLISHED LITERATURE

Various approaches to improve heat sink performance have been described in recent literature. These primarily involve alterations of heat sink geometry. Heat sinks made with fluted and wavy fins were evaluated by Sikka et al.[1] Pin fin heat sinks designed using optimization techniques were tested by Zapach et al.[2] A heat sink design incorporating thin, high aspect ratio fins that radiate at various angles from the base was presented by Tavassoli.[3] Serrated plate fins were analyzed by Shwaish et al.[4] Three dimensional woven mesh heat sinks were fabricated and tested by Wirtz et al.[5] Further work with this approach was performed by Li et al, who formed wire mesh into screen fins.[6]

Changes in the materials used to fabricate heat sinks are less frequently reported. Heat sinks fabricated from copper or aluminum fins combined with copper or aluminum bases were examined by Zaghlol et al.[7] The all copper heat sink was found to have a 28.7% reduction in thermal resistance as compared to the all aluminum heat sink. Loh examined alternatives to the brazing process used to make folded fin heat sinks that included soldering and adhesive bonding.[8]

The first published work on natural graphite composite materials for thermal management applications was by Norley et al.[9] Material properties were reported for laminated plates made from natural graphite/epoxy composite molding compounds. While demonstrating that a combination of lightweight and high in-plane thermal conductivity was achievable in natural graphite/epoxy materials, the thermal conductivity values were only a modest improvement over aluminum alloys. Improvements in graphite/epoxy material properties were demonstrated by Norley and Chen.[10] In-plane thermal conductivity values similar to copper were reported at only 22% of copper's weight. The manufacture of high performance heat sinks using this graphite/epoxy material was described by Marotta et al.[11] In this work a bonded fin graphite/epoxy heat sink was built to cool a multi-chip module. The thermal performance of the heat sink was comparable to a copper heat sink of like geometry at only 21-25% of the copper weight. Chen et al report reported that a deficiency of this type of heat sink is that it can only conduct heat effectively in two directions and hence is only effective when the heat source is the same size as the heat sink base.[12]

ANALYTICAL MODEL

Heat Sink Description

A heat sink typical of those used in server applications was chosen to examine the situation where the heat source is

significantly smaller than the heat sink base. A drawing of this heat sink is shown in Fig. 2 and dimensions are as follows.

$$\begin{aligned} L_B &= 114.3 \text{ mm} & W_B &= 98.0 \text{ mm} & H_B &= 7.6 \text{ mm} \\ H_F &= 30.6 \text{ mm} & t_F &= 0.5 \text{ mm} & t_S &= 2.0 \text{ mm} \\ N &= 46 \end{aligned}$$

This heat sink is mounted against a CPU chip in a server module. The CPU chip generates a maximum of 89 watts of heat and has an exposed surface with dimensions of 37 mm x 37 mm. The heat sink is enclosed in an aluminum shroud that fits flush to the top of the fins and is pinned to the base. In situ measurements indicate that the airflow to the heat sink varies from 2-3 m/sec.

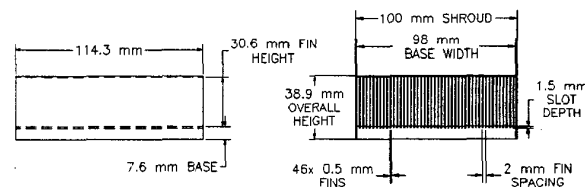


Figure 2. Dimensions of the heat sink used in this study.

CFD Modeling

Computation fluid dynamics (CFD) models were created for four versions of this heat sink, with each version made from different material. The four heat sinks modeled are as follows:

- laminated graphite/epoxy,
- all aluminum,
- all copper and
- a hybrid heat sink with graphite/epoxy fins in a copper base.

Properties of the materials that were used in the model are given in Table 1. Note that the aluminum and copper materials are isotropic while the graphite epoxy material is highly anisotropic. The thermal joints between fins and spacers and fins and bases of all four heat sinks were assumed to be perfect, with no interface temperature losses. The shroud was not included in the model since it is only pinned to the base. Heat source and airflow parameters similar to those of the server application were modeled, as shown in Table 2. The CFD software used was ICEPACK Ver. 4.1 by Fluent Inc.

Table 1. Heat Sink Material Properties used in CFD Model

Property	Units	Direction	Graphite Epoxy	Aluminum	Copper
Density	g/cm ³		1.94	2.70	8.89
Thermal Conductivity	W/mK	a,b	370	167	387
Thermal Conductivity	W/mK	c	6.5	167	387
Specific Heat Capacity	J/kgK		846	896	385

Table 2. Heat Source and Air Flow Parameters used in CFD Model

Property	Value
Wattage	89 W
W_H	37 mm
L_H	37 mm
Air Velocity	1.5, 2.25, 3 m/s
Air Inlet Temperature	25 °C

The CFD model was used to compute the temperature at the center of the base of the heat sink, T_{HC} . This temperature was then used to compute the thermal resistance, R_θ , of the heat sink from the ambient air temperature, T_{AMB} , and the heat flow rate, Q , using,

$$R_\theta = \frac{T_{HC} - T_{AMB}}{Q} \quad (1)$$

Results of the CFD model are summarized in Fig. 3, which shows the thermal resistance of each heat sink as a function of air velocity. As shown, the thermal resistance of the laminated graphite/epoxy heat sink is twice as high as that of the all-copper heat sink. However, the performance of the hybrid graphite/epoxy fin copper base heat sink is very similar to that of the all copper heat sink.

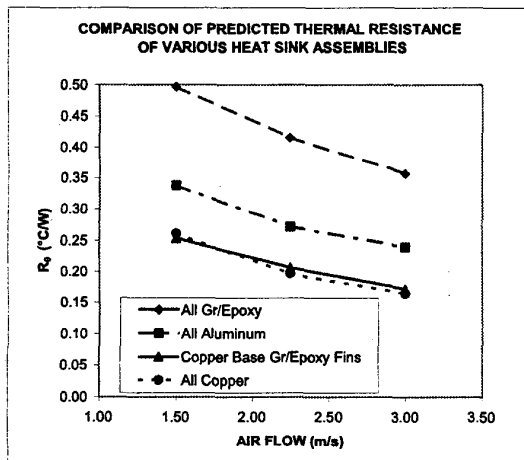


Figure 3. Predicted performance of various heat sinks from CFD model.

The reason for the extremely poor performance of the laminated graphite/epoxy heat sink can be seen by examining a three-dimensional map of the temperature distribution in this heat sink, Fig. 4. As shown, heat is not being spread evenly across the width of the heat sink; only those fins located immediately adjacent to the heat source are hot. This is caused by the low thermal conductivity of the graphite/epoxy material across the thickness of the fins and spacers. Heat is poorly transmitted across the width of the base and fins located some distance away from the heat source remain at temperatures

close to ambient. Thus, no more than about half of the fins are being efficiently used to extract heat.

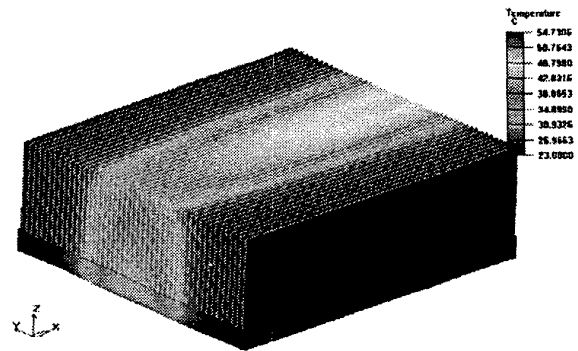


Figure 4. Temperature distribution in the laminated graphite/epoxy heat sink.

The temperature distribution in the hybrid graphite/epoxy fin copper base heat sink, shown in Fig. 5, is dramatically better. Here all the fins are at a more uniformly high temperature and they are all being used to efficiently extract heat from the source. The isotropic copper base acts to spread the heat to the anisotropic fins. In the thin graphite/epoxy fin, the low thermal conductivity across the thickness of the fins has little effect on the overall performance of the heat sink.

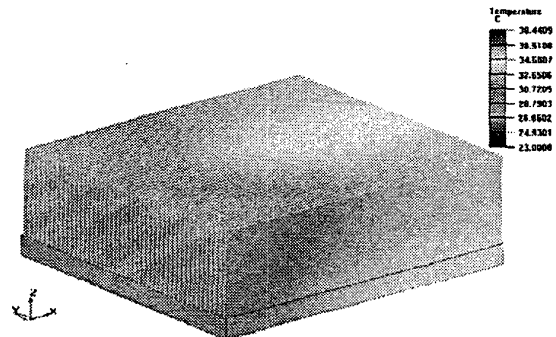


Figure 5. Temperature distribution in the graphite/epoxy fin copper base heat sink. Perfect thermal joint between fin and base assumed.

For situations where there is a single heat source that is significantly smaller than the heat sink base, the CFD model shows that a hybrid heat sink in which graphite/epoxy fins are bonded into a copper base can be as efficient as an all copper heat sink. However, for this to happen, the bonding methods used to attach the fins to the metal base must minimize thermal resistance losses between the base and fins. The next portion of this paper will investigate various attachment methods used to bond graphite/epoxy fins to the copper base and compare the performance of these heat sinks with equivalent aluminum and copper heat sinks.

EXPERIMENTAL

Heat Sink Materials

Test heat sinks were manufactured to the dimensions shown in Fig. 2 using a variety of materials. Properties of these materials are given in Table 3. Various iterations of aluminum and copper bases were manufactured with aluminum, copper and graphite/epoxy fins. The aluminum alloy used was 6061 in a T6 heat treatment and the copper alloy was CDA 110 in a H01 temper. The graphite/epoxy material is a composite formed from natural graphite and epoxy resin. The main features of the graphite/epoxy material are its low density, 1.94 g/cm³, and its anisotropic thermal conductivity, 370 W/mK in the plane of the fins and 6.5 W/mK through the thickness of the fins.

Table 3. Typical Properties of Aluminum, Copper and Graphite/Epoxy Materials used in Heat Sinks

Property	Units	Direction	Graphite/Epoxy	Aluminum 6061 T6	Copper C110 H01
Density	g/cm ³		1.94	2.70	8.89
Thermal Conductivity	W/mK	a,b	370	167	387
Thermal Conductivity	W/mK	c	6.5		
Specific Heat Capacity	J/kgK		846	896	385
Coefficient of Thermal Expansion (30-100 °C)	10 ⁻⁶ m/m/°C	a,b	-0.8	23.6	17.0
Coefficient of Thermal Expansion (30-100 °C)	10 ⁻⁶ m/m/°C	c	53		
Flexural Strength	MPa	In-Plane	70	276 (YS)	205 (YS)
Interlaminar Shear Strength	MPa		3.4		
Young's Modulus	GPa	In-Plane	42	69	115

These materials were used in combination to manufacture the heat sinks. Fins were attached to the base by milling slots into the base, inserting the fins and bonding them to the base. The slots in the base were 0.62 mm wide and 1.5 mm deep. Three different methods were used to bond the fins to the base. These consisted of a lead tin solder, a standard industrial epoxy (Loctite M-31CL Hysol®), and a thermally conducting epoxy (Lord Thermoset 340). Six heat sinks were manufactured using these attachment methods, as summarized in Table 4.

Table 4. Summary of Heat Sinks Manufactured

Heat Sink Number	Base Material	Fin Material	Fin Attachment Method	Weight (g)
1	Aluminum 6061 T6	Aluminum 6061 T6	Epoxy Loctite M-31CL Hysol®	457
2	Copper CDA 110 H01	Graphite/Epoxy	Epoxy Loctite M-31CL Hysol®	852
3	Copper CDA 110 H01	Graphite/Epoxy	Thermally Conducting Epoxy Lord Thermoset 340	850
4	Copper CDA 110 H01	Graphite/Epoxy	Solder	891
5	Copper CDA 110 H01	Copper CDA 110 H01	Epoxy Loctite M-31CL Hysol®	1428
6	Copper CDA 110 H01	Copper CDA 110 H01	Solder	1417

Wind Tunnel

Thermal resistance measurements were obtained using a horizontal wind tunnel. This wind tunnel utilizes a computer-controlled blower and heat source to ensure constant air velocity and heat flow through the sink during testing. The wind tunnel, shown in Fig. 6, has an overall length of 360 cm and consists of several sections: a blower, a flow straightener, a calibrated orifice, a converging inlet, a test section and a diverging outlet. The flow straightener incorporates both honeycomb meshes and wire grids to generate a uniform planar air flow. The volumetric airflow rate through the wind tunnel is controlled by a PID control loop that utilizes the pressure differential across the calibrated orifice as the feedback variable.

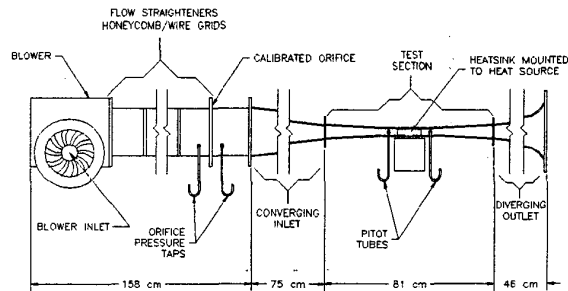


Figure 6. Wind tunnel used for heat sink thermal resistance measurements.

Heat Source

The heat sink is heated by the heat source shown in Fig. 7. The heat source consists of a 300 Watt electric heating element clamped around an aluminum heat riser. This assembly is encased in an insulated housing that minimizes heat loss and ensures one-dimensional heat flow along the heat riser. Heat is transferred from the heating element into the heat riser, where it propagates up and is transferred out, through a thermal interface, into the heat sink. The cross section of the heat riser

can be altered to accommodate different size heat sinks. In these tests, the cross section measured 37 mm x 37 mm, the same size as the CPU chip.

A set of five Resistance Temperature Detectors (RTDs), spaced at 12.7 mm intervals along the length of the riser, were used to measure the temperature gradient in the riser. The heat flow into the heat sink, Q , was calculated from this temperature gradient and the thermal conductivity of the heat riser.

The heat riser was made from 6063 aluminum. The thermal conductivity of the riser was determined independently using an Anter Model 10C thermal impedance tester. Heat flow was monitored and maintained constant using a PID control loop to control the electrical power to the heaters.

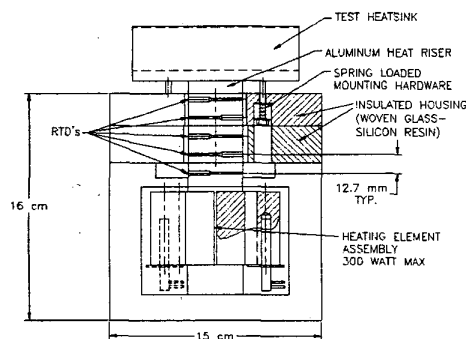


Figure 7. Schematic of heater assembly used to control wattage to heat sink.

Test Section

The test section, shown in Fig. 8, consists of a constant cross section central duct located between a tapered inlet and outlet. The constant cross section duct is 33.8 mm high and 104 mm wide. It is closely matched to the outside dimensions of the heat sink shroud so that the shroud fits tightly against the walls of the duct and no air is allowed to bypass the heat sink. The duct is designed so that the top of the heat sink base is flush with the lower inside wall of the duct. Two Pitot tubes are installed along the centerline of the test section. One was located 55.5 mm upstream of the sink while the other was located 30 mm downstream. A thermocouple was mounted on each Pitot tube and the tip of each thermocouple was exposed to the airflow. The upstream thermocouple was used to measure air inlet temperature to the heat sink. All tests were run with an air inlet temperature of approximately 23 °C. Air velocity in the test section was varied from 0.9 to 3.2 m/s.

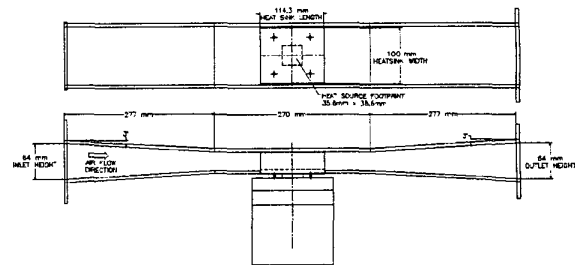


Figure 8. Test section with heat sink.

The heat sink was bolted to the composite housing of the heat source using four threaded holes in the bottom of the heat sink. A compression spring was used on each bolt to apply a uniform load and the contact pressure between the heat sink and heat source was adjusted to 140 kPa. A graphite thermal interface material, HiTherm™ 005, was used between the bottom of the heat sink and the end of the heat riser. Two thermocouples were attached to the bottom of the heat sink, one in the center and one in an outside corner.

Instrumentation

Air velocity was measured using the pressure differential across the calibrated orifice. This orifice was previously calibrated to determine the relationship between pressure drop and air flow rate. The pressure differential was measured using an Alta Labs PX-010 Differential Pressure Transducer. The RTDs used in the heat riser were Omega RTD-3-1PT100KN25 15-36T and all thermocouples used were Type J, 32 gage.

Pressure and temperature data was acquired using an Agilent 34907A Data Acquisition/Switch Unit equipped with an Agilent 34901A 20 Channel Multiplexer card. This data was used in an Agilent VEE program that incorporated PID control loops to control airflow and wattage. Airflow was controlled by an Agilent 34907A Multifunction Module controlling a variable frequency drive on the blower. Wattage was controlled using an Agilent 6655A 120VDC power supply to control to the electric heater. All measurements were made after airflow and heat flow had stabilized and are the average of ten readings taken over a five-minute period.

RESULTS AND DISCUSSION

Thermal Resistance

The measured thermal resistance, R_{0M} of each heat sink was calculated using EQ (1) and the temperature measured at the center of the base of the heat sink, T_B , the ambient air temperature, T_{AMB} , and the measured heat flow, Q . The error present in the measurements is estimated as follows:

$$\begin{aligned} \text{air velocity - standard deviation} &= 0.03 \text{ m/s,} \\ \text{wattage - standard deviation} &= 0.18 \text{ W,} \\ R_{0M} - \text{standard deviation} &= 0.0005 \text{ }^{\circ}\text{C/W} \end{aligned}$$

A plot of measured and predicted thermal resistance versus air velocity for the all copper heat sink with the soldered fins is shown in Fig. 9. At low velocities, the agreement between the CFD model and the experiment is excellent, but as air velocity

increases, the measured versus predicted thermal resistance increases. At 3 m/s, this increase is approximately 2%. This behavior is likely due to the thermal resistance of the solder bond between the fins and base. At low flow rates, where heat sink thermal resistance is high, the contribution of the solder to the overall thermal resistance is not apparent. As the airflow rate increases and the thermal resistance of the heat sink drops, the contribution of the solder bond to the total thermal resistance of the heat sink becomes more significant.

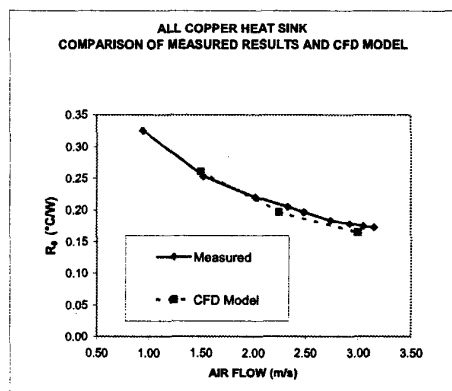


Figure 9. Thermal resistance versus air velocity for the all copper heat sink.

The measured thermal resistance of the all copper soldered heat sink is compared to that of the aluminum heat sink and the hybrid heat sink with soldered graphite/epoxy fins in Fig. 10. As shown, the all copper-soldered heat sink has the lowest thermal resistance, followed by the hybrid graphite/epoxy-heat sink and then by the aluminum heat sink. As the chart demonstrates, differences in thermal resistance among heat sinks are small compared to overall thermal resistance. This suggests that differences between the various heat sinks can be carefully examined by plotting the change in thermal resistance of each heat sink relative to that of the all copper soldered heat sink. Using the all copper soldered heat sink as a standard, the effect of materials and adhesion techniques in the other heat sinks can be easily evaluated.

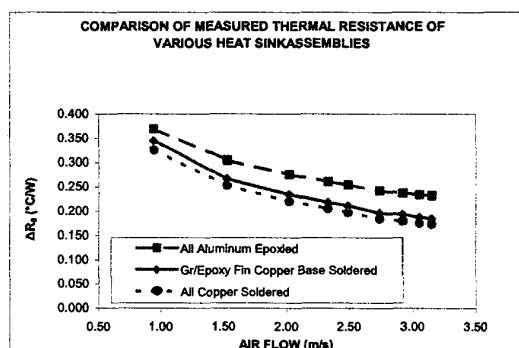


Figure 10. Thermal resistance versus air velocity for the various heat sink assemblies.

The difference in the thermal resistance of a given heat sink compared to the copper heat sink, ΔR_{θ} , can be computed as a function of air velocity, V , from the equation,

$$\Delta R_{\theta}(V) = R_{\theta}(V) - R_{\theta c}(V) \quad (2)$$

Using this approach, the performance of the aluminum heat sink and the hybrid heat sink with graphite/epoxy fins soldered to the copper base are compared to that of the all copper soldered heat sink in Figure 11. At an air velocity of 3.0 m/s, the all copper heat sink has a thermal resistance that is 0.059 °C/W lower than the all aluminum heat sink. Thus, the all copper heat sink has a thermal resistance approximately 33% lower than that of the all aluminum heat sink but is nearly 3 times its weight.

Most dramatic is the improvement in thermal resistance of the graphite/epoxy heat sink compared to the aluminum heat sink, this being due to the higher thermal conductivity of the graphite/epoxy fins and copper base. Note that the change in thermal resistance of the graphite/epoxy heat sink is only slightly dependant on airflow. Averaging data for this heat sink across the range of air velocity shows that this hybrid graphite/epoxy heat sink has a thermal resistance that is only 0.014 °C/W higher than the all copper heat sink. As shown in Table 4, this hybrid graphite/epoxy-finned heat sink weighs 891 grams, compared to 457 grams for the all aluminum heat sink and 1417 grams of the all copper heat sink.

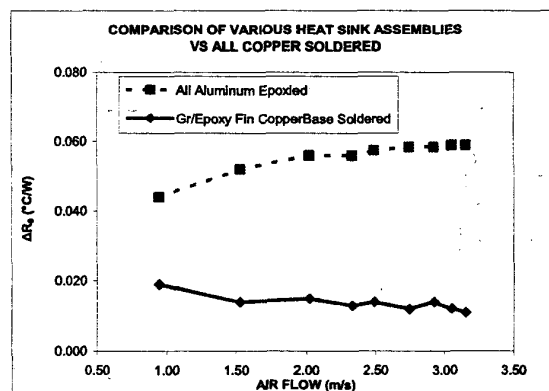


Figure 11. Change in thermal resistance of various heat sink assemblies versus an all copper soldered heat sink.

This technique is used to evaluate the effect of graphite/epoxy versus copper fins in Fig. 12. As shown, the graphite/epoxy fins have a slightly higher thermal resistance than the copper fins, regardless of whether the fins are soldered or bonded with standard epoxy. Overall, the soldered fins perform better than the epoxied fins, but this effect is very slight. Note that this change in thermal resistance is only slightly dependant on airflow rate. Data from both sets of curves can be averaged together to obtain a value for the difference in thermal resistance that can be attributed to the substitution of graphite fins for copper fins. As shown in Table 5, on average the use

of graphite/epoxy fins in place of copper fins resulted in an increase in thermal resistance of 0.013 °C/W. At an air velocity of 3 m/s, this is an increase of 7%.

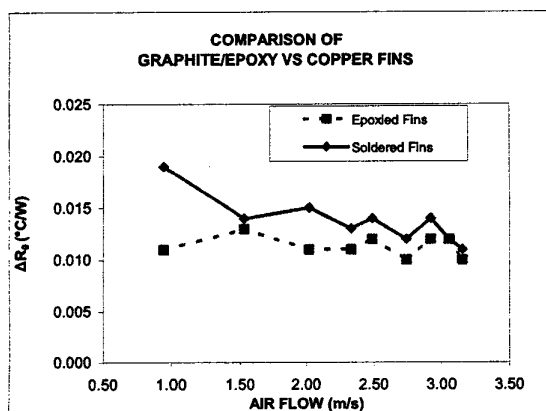


Figure 12. Change in thermal resistance of graphite versus copper fins.

The effect of adhesive bonding techniques versus soldering is shown in Fig. 13. Here, the change in thermal resistance of the standard industrial epoxy adhesive and thermally conductive epoxy are compared to that of soldering, using graphite epoxy fins in the copper base. As expected, the thermally conductive epoxy had a lower thermal resistance than the standard epoxy. Again, this change in thermal resistance is essentially independent of airflow rate so that individual curves can be averaged to obtain a value that can be attributed to each adhesive. These results are also shown in Table 5. On average, the use of standard industrial epoxy to secure the graphite/epoxy fins increased thermal resistance by 0.018 °C/W relative to soldering, while the thermally conductive epoxy increased thermal resistance by only 0.002 °C/W.

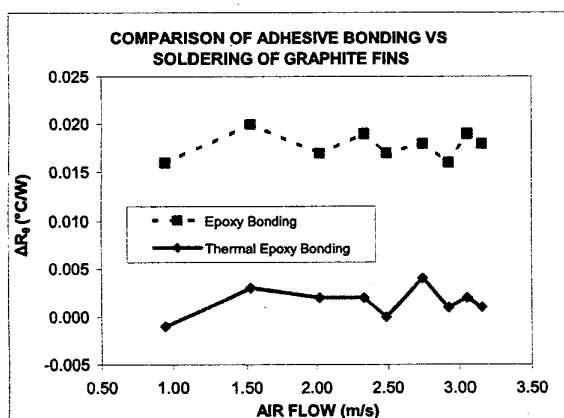


Figure 13. Change in thermal resistance of various adhesives versus solder bonding.

Thus, at an airflow rate of 3 m/s, the use of a thermal epoxy in place of solder increased thermal resistance by only 1%. This very slight decrease in thermal performance more than compensates for manufacturing difficulties encountered when soldering epoxy/graphite fins to the copper base. These problems include the distortion of the fins that can result from the relatively low glass transition temperature, 130 °C, of the graphite/epoxy material compared to typical soldering temperatures of 180 °C.

Table 5. Summary of the Effects of Fin Materials and Bonding Methods on the Change in Thermal Resistance

Comparison	ΔR_0 (°C/W)	
	Average	Standard Deviation
Graphite vs Copper Fins	0.013	0.002
Epoxy Bonding vs Soldering	0.018	0.001
Thermal Epoxy Bonding vs Soldering	0.002	0.002

The improvement in performance of the thermal epoxy compared to the standard epoxy is due to the higher thermal conductivity (1.5 W/mK versus 0.2 W/mK) of the thermally conductive epoxy. A photomicrograph of the thermally conductive epoxy interface, Fig. 14, shows that the average gap between the base of the fin and bottom of the slot is ~ 100 μm and the gap between the sides of the fin and sides of the slot is ~ 60 μm. The thermally conductive epoxy has filled these gaps, with very few air pockets apparent. This photomicrograph also shows that the epoxy forms a small fillet between the fin and the top of the copper base.

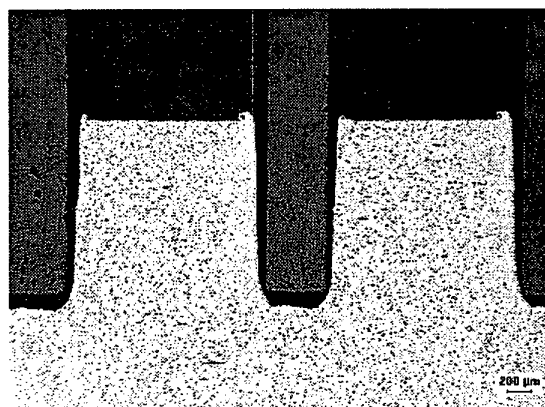


Figure 14. Bonding of graphite/epoxy fins into a copper base using thermally conductive epoxy.

The hybrid heat sink made with graphite/epoxy fins bonded to a copper base with a thermally conducting epoxy adhesive offers the best combination of weight, thermal performance and ease of manufacture. The thermal performance of this heat sink is compared to that of the all copper soldered heat sink in Fig. 15. On average, this heat sink has a thermal resistance

that is only 0.015 °C/W higher than that of the all copper heat sink. At an airflow rate of 3 m/s, this is an increase in thermal resistance of only 9%. The weight of this heat sink is 350 grams, which is 40% lower than the copper heat sink.

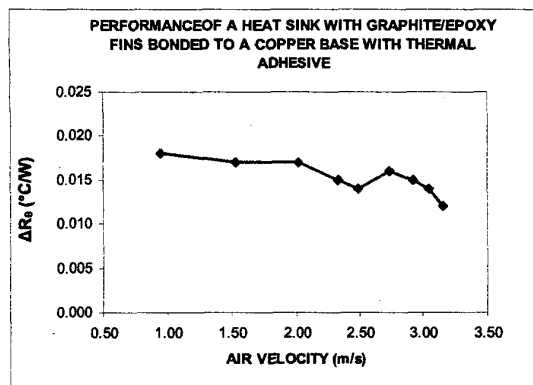


Figure 15. Change in thermal resistance of a hybrid heat sink with graphite/epoxy fins bonded to a copper base using a thermally conducting epoxy adhesive.

CONCLUSIONS

Performance problems with laminated graphite/epoxy heat sinks have been encountered when the area of the heat source is much smaller than the base area of the heat sink. To overcome this problem, a hybrid heat sink, composed of graphite/epoxy fins bonded to a copper base was developed.

The performance of this design was examined using a heat sink typical of those found in server applications. A CFD model of this heat sink was created. This model showed that thermal resistance of a laminated graphite/epoxy heat sink was twice as high as that of the all copper heat sink. The model also showed that the performance of the hybrid graphite/epoxy fin copper base heat sink was very similar to that of the all copper heat sink.

To confirm this result and to determine the effects of fin materials and attachment methods, a number of different heat sinks were manufactured and tested to determine their thermal performance. As predicted by the CFD model, it was found that the best performance was obtained from a soldered all copper heat sink. The performance of a variety of hybrid graphite/epoxy heat sinks was compared to this copper heat sink. A hybrid heat sink made with graphite/epoxy fins bonded to a copper base with a thermally conducting epoxy adhesive was found to have the best combination of weight, thermal performance and ease of manufacture. On average, this heat sink had a thermal resistance that is only 0.015 °C/W higher than that of the all copper heat sink and its weight was 40% lower than the all copper heat sink. The increase thermal resistance was attributed to the increased thermal resistance of the graphite/epoxy versus copper fins (0.013 °C/W) and of the thermal epoxy adhesive versus solder (0.002°C/W).

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HiTherm™ is a trademark of AET Inc.

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