Evaluation and Enhancement of Thermal Transport Characteristics of Metal Matrix Composites and Contact Interfaces

G.V Krishna Reddy, H. S. Monohar N. Chikkanna, B. Umamaheswar Goud

Abstract - In this work, effort has been made in the evaluation and enhancement of thermal transport characteristics of metal matrix composites and contact interfaces. The thermal management systems are important in today's faster growing industrial needs which are demanding the high end processors with highest speed and reliability of performance. The thermal management systems are used for applications like central processing unit (CPU) cooling, cooling of electronics circuit boards, cooling of mechanical and automobile systems like engine cooling. However, this work focuses on thermal management systems related to CPU cooling. In this work, initially, the importance and motivation behind the evaluation of the thermal characteristics for the MMC's as well as TIMs. Thermal contact resistance in heat transfer applications are presented with examples. The heat transfer phenomenon at the interfaces is detailed with the classification based on contact criteria. The development of new MMC's was detailed along with the different compositions of the MMCs. For this, initially, baseline materials were explained in detail along their thermal properties. Six MMC's have been proposed with varying compositions of aluminum and silicon carbide. Aluminum was varied in percentage composition from 25% to 35% . The MMC's were evaluated for the properties like thermal conductivity, specific heat, thermal diffusivity, CTE, density and Young's modulus. Also, the variation of these properties with respect to temperature is evaluated. Finally recommendations are given for the MMC's based on the required property criteria of the heat source material. As a second approach, the thermal contact resistance models were developed. A measurement system for contact resistances has been established by performing measurements on the known properties of the greases. Application of thermal greases is given in detail. The measurement system was established by conducting the experiments.

Key words: Heat sink, Aluminum, silicon carbide, Thermal grease, Thermal interface material, contact interface.

I.INTRODUCTION

One of the challenges the industry facing today is the rate of heat dissipation from the micro electronics systems. The higher and the fast heat removed, the better it is. However, there is a challenging situation that exists when the heat is removed from the electronic components. Generally, the heat sink is attached directly to the heat generating device so that heat is removed fast and device can be always kept cool.

However, the requirement in such case is the selection of material for the heat sink. The coefficient of thermal expansion (CTE) of the heat sink material must be close enough to that of the semiconductor device.

Most of the electronic devices like microprocessors are made out of silicon or its alloys. Hence the CTE of heat sink materials to be chosen should be close enough to that of silicon. This enables both the materials to expand by similar rates so that one can eliminate the fracture in the devices arising due to the differential thermal expansions. However, by choosing the heat sink materials with low CTE, there is a possibility that those materials can have the low thermal conductivities so that heat is not removed at a faster rate. This is conflicting situation where if one needs higher heat dissipation, it will result in device fractures or if one needs to protect the electronic device, it will be at the cost of higher heat dissipation. In generally highly conducting materials like copper or aluminum are chosen for manufacturing the heat sinks.

One can use interfacial materials which has got high thermal conductivity to increase the heat dissipation rate. But, there is a possibility that the high conducting pastes can short the built in electronic circuitry of the microprocessor or IC at the surface.

Hence it is required to develop solutions for increasing the heat transfer by developing new materials which has good thermal conductivity and good CTE. Mechanical properties that can be tailored include stiffness, strength, density, and thermal properties are thermal conductivity, specific heat and coefficient of thermal expansion. The physical property that can be designed to suit the design requirement is density.

In this research work, the thermal characteristics are studied in order to come out with a means to enhance the thermal characteristics of MMCs evaluated for a wide range of compositions of the MMCs and effect of the
Composition on the thermal properties is.

II.DEVELOPMENT OF NEW MMC'S

One of the challenges the industry facing today is the rate of heat dissipation from the micro electronic systems. The higher and the fast heat removed, the better it is. However, there is a challenging situation that exists when the heat is removed from the electronic components. Usually, the heat sink is attached directly to the heat generating device so that heat is removed fast and device can be always kept cold. However, the requirement in such case is the selection of material for the heat sink. The coefficient of thermal expansion (CTE) of the heat sink material should be close enough to that of the electronic device.

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Hence the CTE of heat sink materials to be chosen should be close enough to that of silicon. This enables both the materials to expand by similar rates so that one can eliminate the fracture in the devices arising due to the differential thermal expansions. However, by choosing the heat sink materials with low CTE, there is a possibility that those materials can have the low thermal conduct ivies so that heat is not removed at a fast rate. This is conflicting situation where if one needs higher heat dissipation, it will result in device fractures or if one needs to protect the electronic device, it will be at the cost of higher heat dissipation.

Usually highly conducting materials like copper or aluminum are chosen for manufacturing the heat sinks. Their CTE are very high compared to that of Silicon devices. One popular technique is to use the interfacial materials between the silicon device and the heat sink. The interfacial materials compensate for the differential thermal expansion so that the stresses induced at the interface are reduced. There is also one drawback here again, as the interfacial materials act as a thermal barrier between the heat source and the heat sinks, thereby reducing the heat transfer rate. The advantage provided by the high conducting materials is lost when the thermal interfacial materials are used.

One can use interfacial materials which has got high thermal conductivity to increase the heat dissipation rate. But, there is a possibility that the high conducting pastes can short the built in electronic circuitry of the microprocessor or IC at the surface.

Hence it is required to develop solutions for

I. Increasing the heat transfer.
II. Reducing the possibility of shorting of the circuitry
III. Developing the new material which has good thermal conductivity and good CTE.

A. Baseline Materials:

Materials which are known for this kind of applications are:

- Fe-Ni alloys : It has got compatible CTE but offers low thermal conductivity
- Kovar: It has got compatible CTE but offers low thermal conductivity
- Cu-W alloys: It has got compatible CTE and Thermal conductivity, but has high density due to which the weight of the heat sink become high which cannot be sustained by the electronic devices like microprocessors or ICs. Moreover, the manufacturing and production cost of these metals are high.
- Cu-Mo alloys: It has got compatible CTE and Thermal conductivity, but has high density due to which the weight of the heat sink become high which cannot be sustained by the electronic devices like microprocessors or ICs. Moreover, the manufacturing and production cost of these metals are high.

Table 1: List of heat sink materials and essential properties

Material	Thermal Conductivity (W/mK)	CTE (ppm/C)	Density (gm/cc)
Silicon	124	2.49	2.3
Copper	385	16.4	7.76
Aluminum	240	24	2.7
SiC	210	2.7	3.2
Fe-Ni	13.2	9.8	8.25
Kovar	17.3	4.9	8.36
Cu-W	190	7	16
Cu-Mo	180	7	10

Since silicon is the material of the devices, the thermal conductivity of the chosen material should be above 124 W/m-K and the CTE must be very close to 2.49 ppm/C and the density should be close to 2.3 gm/cc. By looking at the other materials listed in Table 1 all materials except Fe-Ni and Kovar have thermal conductivities higher than Si. Of these materials, copper has the CTE very high compared to Si and hence cannot be chosen as heat sink materials due to the reasons listed above. So is the case with aluminum. Of the three remaining materials, SiC, Cu-W and Cu-Mo have CTE and density properties close to Si. Cu-W and Cu-Mo are not feasible again due to the reasons listed above. SiC may be chosen for this purpose. However, there are again cost, manufacturing and production issues with SiC. It is not easily moldable to required shapes and most of SiC parts are made using powder compaction.

The alternative all the problems is a composite with Aluminum as the matrix embedded with SiC particle to reduce the CTE from 24 to the values close enough to Si.

B. Proposed Materials:

In this work, three different compositions are Aluminum and SiC are used for producing the specimens to determine the properties. The composition is varied by

Table 2: Designation of the specimen composition and volume fractions

Designation	Aluminum	SiC
15Al-85SiC	15%	85%
25Al-75SiC	25%	75%
35Al-65SiC	35%	65%

III.EXPERIMENTAL RESULTS

For composition, the five specimens are tested for the following properties.

- Thermal Properties
  - Thermal Conductivity
  - Specific Heat
  - Coefficient of thermal expansion (CTE)
- Mechanical property
  - Young's Modulus
- Physical Property
  - Mass Density

Table 3: Properties of 25Al-75SiC

25Al-75SiC	Thermal Properties			Mechanical Property	Physical Property
	Thermal Conductivity (W/m K)	Specific Heat (J/g K)	CTE (ppm/C)	Young's Modulus (GPa)	Density (gm/cc)
Specimen 1	142	0.75	7.1	203	3.1
Specimen 1	142	0.75	7.1	203	3.1
Specimen 2	148	0.6	6.7	198	3
Specimen 3	149	0.65	6.7	205	3.1

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Specimen 4	**148**	**0.72**	**7**	**208**	**3.1**
Specimen 5	**153**	**0.7**	**7.1**	**210**	**3.2**
Mean	**148**	**0.684**	**6.92**	**204.8**	**3.1**

Table 3 shows the measured values of the properties of the new MMC 25Al-75SiC. The mean values of thermal conductivity is 148 W/m-K, specific heat is 0.684 J/g-K, CTE is 6.92 ppm/C, Young's modulus is 204.8 GPa and density is 3.1. The thermal conductivity of the 25Al-75SiC is well above to that of Si which is a desirable property. Whereas CTE of the 25Al-75SiC is higher than that of Si, it is close enough. The density of the 25Al-75SiC is also slightly higher, but much lesser than Cu-W and Cu-Mo.

Table 4: Properties of 30Al-70SiC

30Al-70SiC	Thermal Properties			Mechanical Property	Physical Property
	Thermal Conductivity (W/m K)	Specific Heat (J/g-K)	CTE (ppm /C)	Young's Modulus (GPa)	Density (gm./cc)
Specimen 1	175	0.75	7.68	208	3
Specimen 2	175	0.74	7.6	201	3.1
Specimen 3	178	0.71	7.59	203	3.1
Specimen 4	184	0.71	7.65	202	2.9
Specimen 5	181	0.72	7.68	210	3.2
Mean	178.6	0.726	7.64	204.8	3.06

Table 4 shows the measured values of the properties of the new MMC 30Al-70SiC. The mean values of thermal conductivity is 178.6 W/m-K, specific heat is 0.726 J/g-K, CTE is 7.64 ppm/C, Young's modulus is 204.8 GPa and density is 3.06. The thermal conductivity of the 30Al-70SiC is well above to that of Si and 25Al-75SiC which is a desirable property. Whereas CTE of the 30Al-70SiC is higher than that of Si, it is close enough to 25Al-75SiC. The density of the 30Al-70SiC is also slightly higher than Si and close to 25Al-75SiC, but much lesser than Cu-W and Cu-Mo. Hence 30Al-70SiC may be chosen over25Al-75SiC since the Young's modulus is same as that of 25Al-75SiC, due to which the induced stress levels are same for the same geometry and temperature difference.

Table .5: Properties of 35Al-65SiC

35Al-65 SiC	Thermal Properties			Mechanical Property	Physical Property
	Thermal Conductivity(W/m K)	Specific Heat (J/g-K)	CTE (ppm/C)	Young's Modulus (GPa)	Density (gm/cc)
Specimen 1	181	0.73	8.73	185	3.03
Specimen 2	182	0.75	8.9	191	3.02
Specimen 3	181	0.72	8.6	189	2.95
Specimen 4	176	0.7	8.8	188	2.98
Specimen 5	178	0.76	8.9	189	3
Mean	179.6	0.732	8.786	188.4	2.996

Table.5 shows the measured values of the properties of the new MMC 35Al-65SiC. The mean values of thermal conductivity is 179.6 W/m K, specific heat is 0.732 J/g K, CTE is 8.786 ppm/C, Young's modulus is 188.4GPa and density is 2.996 gm/cc. The thermal conductivity of the 35Al-65SiC is well above to that of Si and 25Al-75SiC and close to too 30Al-70SiC which is a desirable property. Where as CTE of the 35Al-65SiC is higher than that of Si, 25Al-75SiC and 30Al-70SiC. The density of the 35Al-65SiC is also slightly higher than Si and close to 25Al-75SiC and 30Al-70SiC, but much lesser than Cu-W and Cu-Mo.

Table.6 Thermal conductivity for different temperature

Thermal Conductivity (W/m k)	25°C	50°C	75°C	100°C	125°C	150°C
25Al-75SiC	148	151	155	159.5	161.1	164
30Al-70SiC	178.6	182	186.5	188	192.5	194
35Al-65SiC	179.6	181	184.5	186.3	189.1	192

Fig. 1: Variation of thermal conductivity with respect to temperature

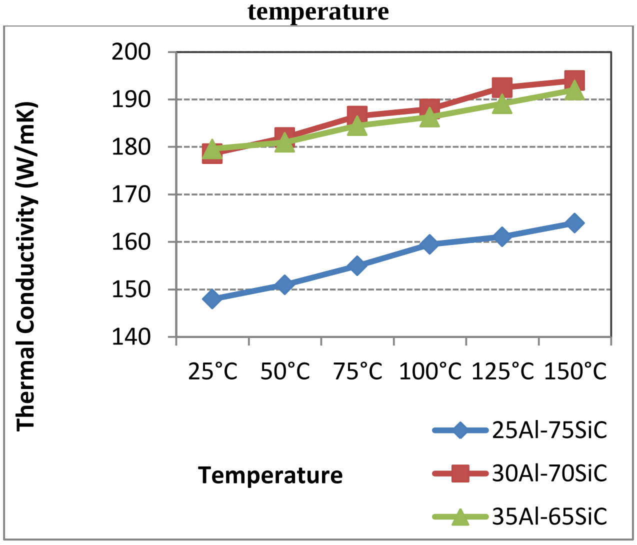

Table.6 & Fig.1 shows the variation of thermal conductivity with respect to temperature. Due to practical limitations of the measurement facilities, the properties are not measured beyond 150°C. From the Fig. 4.6 it can be observed that the thermal conductivity of the MMCs increased with the temperature. When operating at temperatures up to 150°C, one can choose 30Al-70SiC if the thermal conductivity is a criteria for selection, since it performs well at all temperatures except near room temperature.

Table 7: Variation of CTE with respect to temperature

CTE (ppm/C)	25° C	50° C	75° C	100° C	125° C	150° C
25Al-75SiC	6.9	7.2	7.5	7.7	7.9	8.2
30Al-70SiC	7.6	7.8	8.1	8.3	8.6	8.9
35Al-65SiC	8.7	9	9.2	9.5	9.8	10.1

Figure 2: Variation of CTE with respect to Temperature

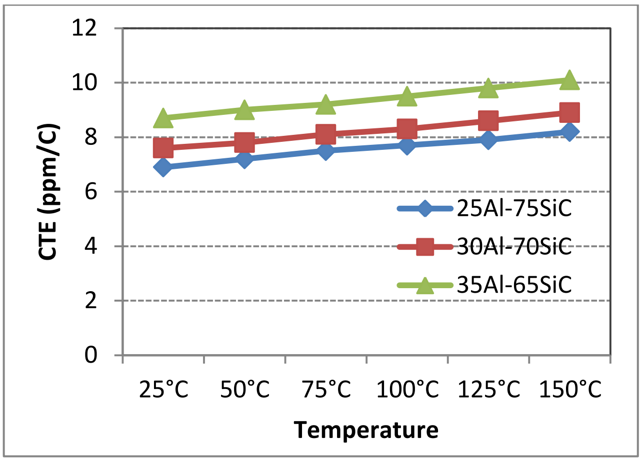

Table 7 & Fig.2 show the variation of CTE with respect to temperature. Due to practical limitations of the measurement facilities, the properties are not measured beyond 150°C. From the Fig. 4.7 it can be observed that the CTE of the MMCs increased with the temperature almost linearly, 25Al-72SiC, 30Al-70SiC and 35Al65SiC. When operating at temperatures up to 150°C, one can choose 25Al-75SiC if the CTE is criteria for selection, since it performs well at all temperatures.

Table 8: Variation of specific heat with respect to temperature

Specific Heat (J/g-K)	25°C	50°C	75°C	100°C	125°C	150°C
25Al-75SiC	0.684	0.714	0.745	0.77	0.804	0.834
30Al-70SiC	0.726	0.751	0.784	0.812	0.843	0.879
35Al-65SiC	0.732	0.774	0.803	0.834	0.8673	0.88

Figure 3: Variation of Specific Heat with respect to Temperature

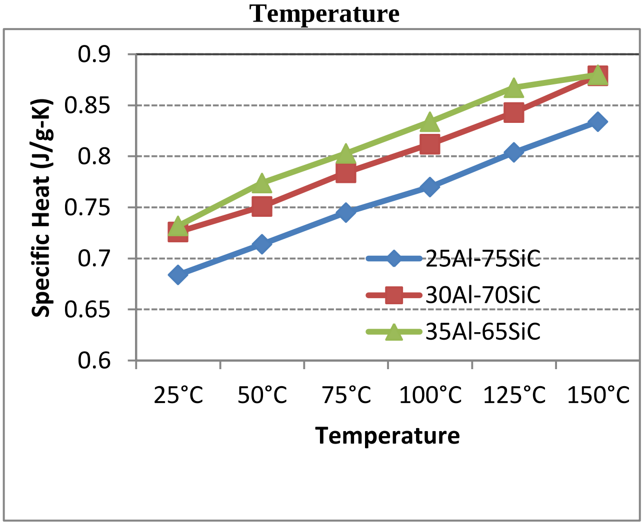

Table 8 & Fig.3 shows the variation of specific heat of MMC's with respect to temperature. Due to practical limitations of the measurement facilities, the properties are not measured beyond 150°C. From the Fig. 4.8 it can be observed that the specific heat of the MMCs increased with the temperature almost linearly. The specific heat profiles of 45Al-55SiC, 55Al-45SiC and 55Al-45SiC are very closely spaced to each other in terms of the specific heat at room temperature as well as at all other temperatures up to 150°C.

Similarly, one can group the other three MMC's, namely, 25Al-72SiC, 30Al-70SiC and 35Al65SiC. When operating at temperatures up to 150°C, one can choose 65Al-35SiC if the specific heat is a criteria for selection, since it performs well at all temperatures.

IV.EXPERIMENTAL VALIDATION OF PROPERTIES OF THERMAL GREASE USED IN THERMAL MANAGEMENT:

Experimentations were carried to find out the thermal contact resistance for different varieties of interstitial materials and form. A copper and aluminum plate of size 125mm x 125mm x 4mm are taken for experimentation. The copper plate is connected to heat source and maintained at a constant temperature of 200C. Whereas, the aluminum plate is maintained at a constant temperature of 100C. The interstitial materials are placed between the copper and aluminum plates. The thickness of the interstitial material at the interface is maintained by applying pressure and using standard shim to maintain a definite thickness.
Table 5 shows the types different interstitial materials and forms used along with their thermal conductivities.

Table 9: Interstitial materials and forms vs. thermal conductivities

Interstitial Material and Form	Thermal Conductivity in W/mK
G 641 Silicone grease Type I	0.83
G 641 Silicone grease Type II	1.7
G 641 Silicone grease Type III	2
G 641 Silicone grease Type IV	3
G 641 Silicone grease Type V	5
DC 340 (Dow Corning) Silicone grease with metallic oxide powder	0.42
P 12 (Wacker) Silicone grease with metal powder	0.81

Figure 4: Experimental Evaluation of Thermal Contact Resistance of Type I, Type II and Type III in 1e^{-6}

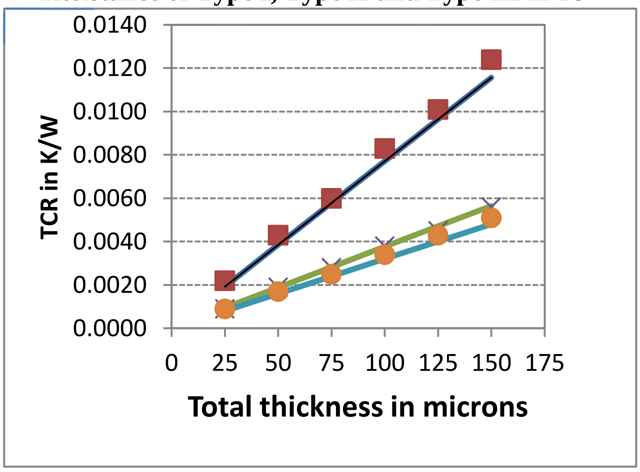

Fig 4. shows the experimental evaluation of the thermal contact resistance for three types of greases namely, G 641 Silicone grease Type I, Type II and Type III. The experimental results compare very well with the theoretical prediction. The variation of the difference in the data is not too much and the difference can be attributed to the variations in the experimental set up versus the theoretical assumptions.

The relation between the thermal contact resistance and the experimental values are linear in nature.

Fig.5: Experimental evaluation of thermal contact resistance of Type IV, Type V and DC 340

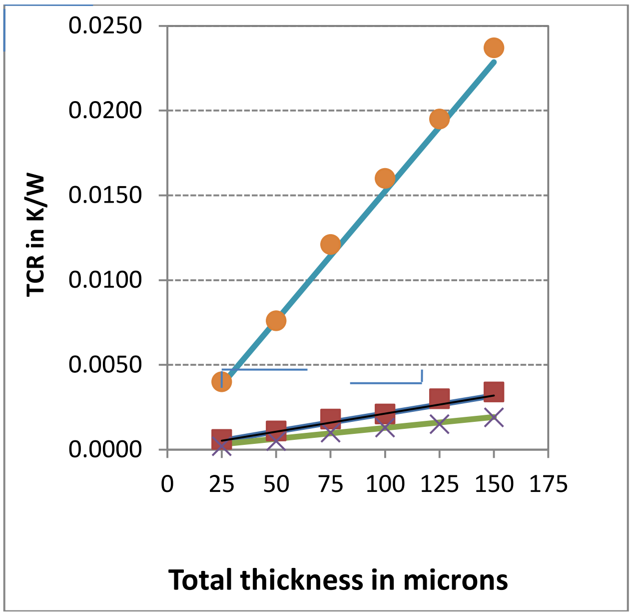

Figure. 5. shows the experimental evaluation of the thermal contact resistance for three types of greases namely, G 641 Silicone grease Type IV, Type V and DC 340. The experimental results compare very well with the theoretical prediction. The relation between the thermal contact resistance and the thickness of interstitial material are linear in nature. The contact resistance is least in the grease Type V grease among the three greases compared for the given conditions.

V.CONTACT RESISTANCE MODELS FOR BETTER THERMAL MANAGEMENT

Experimentations were carried to find out the thermal contact resistance for different varieties of interstitial materials and combinations. An intel processor and an aluminum heat sink 37.5 mm x 37.5 mm are considered for experimentation. The processor maximum temperature at the center point of the top surface is 51C at 30W and 71C at 110 W of power rating. The temperatures of the processor at the other power ratings can be calculated based on linear interpolation and is experimentally verified. The thickness of the interstitial material at the interface between the processor and the heat sink is maintained by applying pressure and using standard shim to maintain a definite thickness.

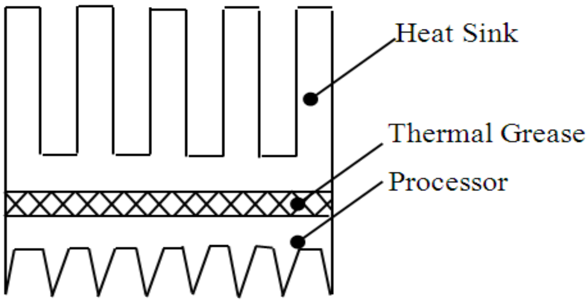

Figure 6: Heat sink and processor with low or high conducting thermal grease as adhesive

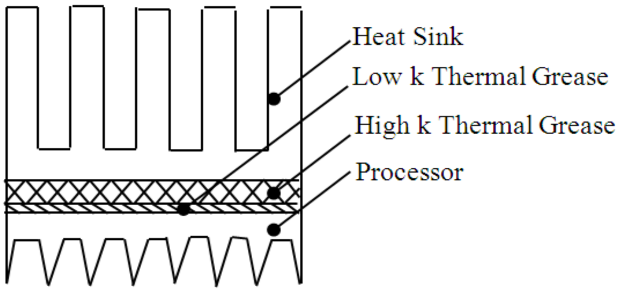

Figure 7: Heat sink and processor with low and high conducting thermal grease as adhesives

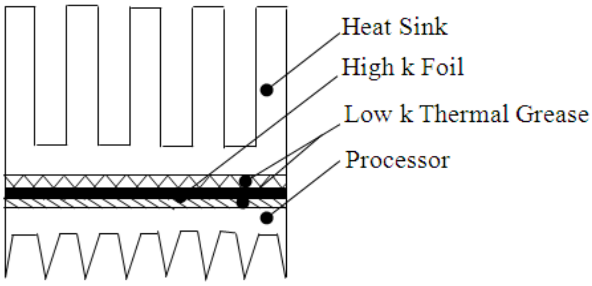

Figure 8: Heat sink and processor with low conducting thermal grease as adhesives and highly conducting foil in between

In this experimentation, three models are tested, which are given as follows.

1. Heat sink and processor with low or high conducting thermal grease as adhesive (PGH: Processor-Grease-Heat sink)
2. Heat sink and processor with low and high conducting thermal grease as adhesives (PG1G2H: Processor-Grease-Grease-Heat sink)
3. Heat sink and processor with low conducting thermal grease as adhesives and highly conducting foil in between (PG1FG2H: Processor-Grease-Foil-Grease-Heat sink)

In the PGH model, grease can be a high conducting grease or low conducting grease. The advantage of low conducting grease is that it does not short the internal circuitry of the processor at the interface and hence the life of the processor is high. Some of the examples of the greases that can be treated as low conducting greases are listed in table 1. The ratings are only a recommendation and do not have any engineering proof for this naming convention. Low conducting grease should have

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a thermal conductivity as close as possible to that of the processor top surface. From the list of greases that were collected for the experimentation, the greases with thermal conductivity less than 1 W/mK are considered as "Low", between 1 and 3W/mK as "Medium" and above 3W/mK as "High".

VI.EXPERIMENTAL RESULTS

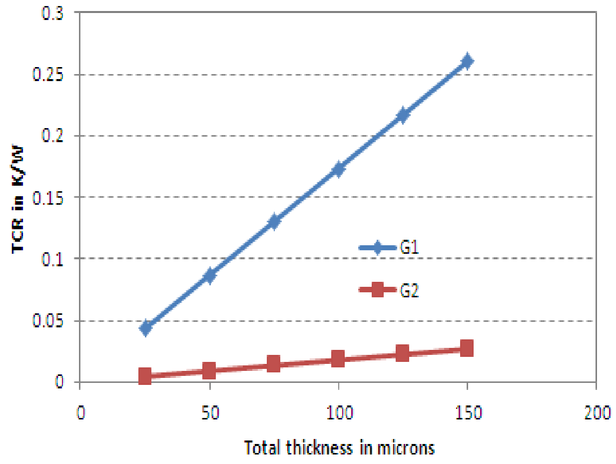

Figure 9: Experimental Evaluation of Thermal Contact Resistance for Model PG1H, PG2H

Fig. 9 shows the experimental evaluation of the thermal contact resistance for two types of greases namely, Silicone grease based on polydimethylsiloxanic oil, with metallic oxide powder (G1) and Furon C695 Graphite foil coated on one side with acrylic adhesives (G2).

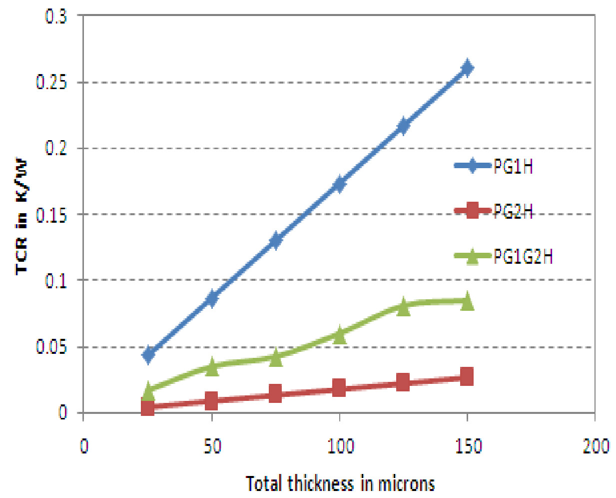

Figure 10: Experimental Evaluation of Thermal Contact Resistance for Model PG1H, PG2H and PG1G2H

Fig. 10 shows the experimental evaluation of the thermal contact resistance for double layer of greases. The first layer G1 is 25% of the total thickness and the layer G2 is of 75%. The G1 and G2 are Silicone grease based on polydimethylsiloxanic oil with metallic oxide powder and Furon C695 Graphite foil coated on one side with acrylic adhesives respectively. The results show that with the addition of a highly conducting layer above the low conducting layer, the thermal contact resistance drops there by increasing the heat flow.

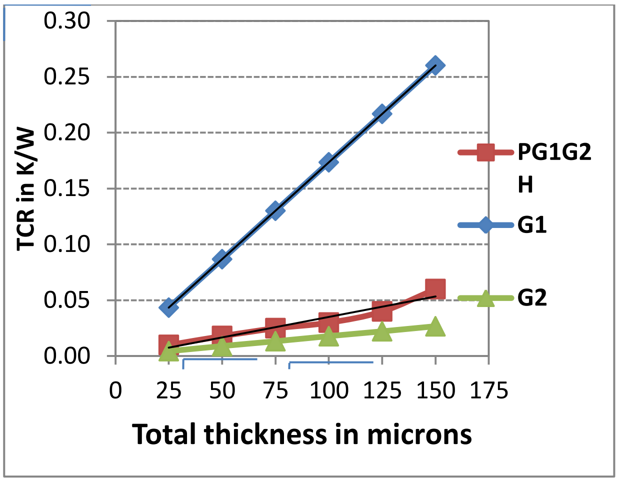

Figure 11: Experimental Evaluation of Thermal Contact Resistance for Model PG1H, PG2H and PG1G2H

Fig. 11. shows the experimental evaluation of the thermal contact resistance for double layer of greases. The first layer G1 is 25% of the total thickness and the layer G2 is of 75%. The G1 and G2 are Silicone grease based on polydimethylsiloxanic oil with metallic oxide powder and Furon C695 Graphite foil coated on one side with acrylic adhesives respectively. The results show that with the addition of a highly conducting layer above the low conducting layer, the thermal contact resistance drops there by increasing the heat flow.

VII.CONCLUSION

After review of the literatures available, it has been observed that there is not enough research work has been done to enhance the heat transfer by studying the effects of improving both the materials of heat sinks as well as the contact resistance models. In this study work, to improve the designs of the TCR models, the thermal characteristics are evaluated for a wide range of compositions of the MMC's as well as thermal interfacial materials. The effect of the composition on the thermal properties is studied in order to come out with a means to enhance the transport characteristics of heat sinks.The experimental evaluation of the thermal characteristics of different composition of new MMC's developed in this work. The summary of the properties of the new MMCs developed are presented. The study indicates that the MMC 35Al-65SiC has a very good thermal conductivity and 25Al-75SiC has the least CTE, One has to choose the composition based on the requirement. For example, for the heat sink applications, one can choose 30Al-70SiC because it has good thermal conductivity and CTE both. The variation of thermal conductivity for different compositions. The specific heat capacity increases with increased in the volume percentage of the aluminum from 25 to 35. However, the relationship is not linear. It is observed that by increasing the percentage of aluminum content the specific heat of MMC increases. Overall, the thermal properties are evaluated for MMCs and based on the section criteria, the composition of the MMCs can be chosen for the best performance.

The measurement systems for measuring the thermal contact resistance were validated and the thermal contact resistance of the thermal greases was validated with respect to the theoretical values. Experimentations were conducted for each set of three materials. The thermal contact resistance compared three sets of materials and found least one for each set, the measured values of thermal contact resistance compares very well with the theoretical prediction.

New contact resistance models were developed and the measurement systems which are validated in Chapter 5 were used to measure the contact resistances. Three different types of models are verified in this work, namely, PGH, PG1G2H and PG1FG2H. In the PGH model, grease G is high conducting grease or low conducting grease. It is proved experimentally that by adding additional highly conducting layers the thermal resistance drops. Also it is verified that by reducing the thickness of the layer next to the processor, the thermal conductance improves.

The purpose of enhancement in the characteristics of the thermal management systems are achieved by two means, namely,

- Development of new MMC's for heat sinks to match closely with the required properties of the heat source
- Development of new thermal contact resistance models to overcome the short comings of the thermal management systems being used without thermal grease/pastes.

The thermal management consists of three components, namely, heat source (CPU), heat sink, and interstitial materials to fill the gap between heat source and heat sink. To enhance the performance of the thermal management system, design of CPU cannot be altered by the user as its design and performance is decided by the manufacturer of the CPU. The user can only modify the designs of heat sink and the interstitial elements to enhance the overall performance. In this research work, effort is made towards this goal.

Thermal management system is by developing new thermal resistance models. Three thermal resistance models are developed namely, PGH, Pg1G2H and PG1FG2H. P stands for Processor, G stands for grease and F and H stands for foil and heat sink respectively.

It is concluded that the models PGH with Al-Foil, PGH with G2 and PG1FG2H has the lower temperatures at the heat sink interface for a heat removal of 110W. G1 grease has lower thermal conductivity and G2 has higher thermal conductivity than G1. But as mentioned before the interfacial material which is adjacent and in touch with the CPU must have the lowest thermal conductivity to avoid the shorting on electronics on the CPU. Hence the model PG1FG2H is treated as the best case for this application.

REFERENCES

1. Fletcher L S. A review of thermal control materials for metallic junctions. J Spacecraft Rocket, 1972, 9: 849-850
2. Kraus A D, Bar-Cohen A. Thermal analysis and control electronic equipment. New-York: McGraw-Hill, 1983
3. D.R. Tenny, G.F. Sykes, and D.E. Bowles, "Composite Materials for Space Structures," Proc. Third European Symp. Spacecraft Materials in Space Environment, ESA SP-232 (Noordwijk, Netherlands: European Space Agency, October 1985), pp. 9–21.
4. Madhusudana C V, Fletcher L S. Contact heat transfer-The last decade. AIAA J, 1986, 24(3): 510-523
5. S.P. Rawal and M.S. Misra, "Dimensional Stability of Cast Gr-Mg Composites," 19th International SAMPE Conference (Covina, CA: SAMPE, October 1987), pp. 134–147.
6. D.M. Goddard, P.D. Burke, and D.E. Kizer, "Continuous Graphite Fiber MMC's," Engineered Materials Handbook, Vol. 1 (Materials Park, OH: ASM, 1987), p. 867.
7. C. Thaw et al., "Metal Matrix Composites for Microwave Packaging Components," Electronic Packaging and Production (August 1987), pp. 27–29.
8. M.E. Buck and R.J. Suplinskas, "Continuous Boron Fiber MMC's," Engineered Metal Handbook, Vol. 1 (Materials Park, OH: ASM, 1987), pp. 851–857.
9. Fletcher L S. A review for thermal enhancement techniques for electronic systems, IEEE T Component Hybrid ManufTechnol, 1990, 13(4): 1012-1021
10. Madhusudana C V. Thermal Contact Conductance. New York: Springer-Verlag, 1996
11. Lambert M A, Fletcher L S. Review of models for thermal contact conductance of metals. J. Thermo physics Heat Transf, 1997, 11(2): 129- 140
12. Yovanovich M M. Conduction and thermal contact resistances (conductances). In: Rohsenow W M, Harnett J P, Cho Y I, eds. Handbook of Heat Transfer. Chapter 3. New York: McGraw Hill, 1998
13. Yovanovich M M, Antonetti V W. Application of thermal contact resistance theory to electronic packages. In: Bar-Cohen A, Kraus A D, eds. Advances in Thermal Modeling of Electronic Components and Systems. New York: Hemisphere Publishing, 1998
14. Fletcher L S. Recent developments in contact conductance heat transfer. Transa ASME J heat transf, 1988, 110: 1059-1070
15. M.A. Occhionero, R.A. Hay, R.W. Adams, K.P. Fennessy, Aluminium silicon carbide (AlSiC) for cost-effective thermal management and functional microelectric packaging design solutions 12th European Microelectronics and packaging Conference, June 7e9 1999, pp. S10-S04.
16. Occhionero, M.A.; Hay, R.A.; Adams, R.W. and K.P. Fennessy, Aluminium silicon carbide (AlSiC) for cost-effective thermal management and functional micro electric packaging design solutions 12th European Microelectronics and packaging Conference, June 7e9 1999, pp. S10-S04.
17. Hecht, R. L., Dinwiddie, R. B., and Porter, W. D., Predicted Influence of Materials' Thermal Properties on Disc Brake Roughness Due to Thermoelastic Instability". Proc. of TMS Fall Meeting, 1999.
18. D.B. Miracle and B. Maruyama, "Metal Matrix Composites for Space Systems: Current Uses and Future Opportunities," Proc. National Space and Missile Materials Symp., ed. M. Stropki (Dayton, OH: Anteon Corp., 2000).
19. Ogando, J. Thermally conductive plastic beat the heat Available at. http://www.designnews.com/article/165Thermally_conductive_plastics_beat_the_heat.php (2001).
20. J. Miller, Thermally conductive polymers delete the heat Available at http://machinedesign.com/article/thermally-conductive-polymers-delete-the-heat-0503 (2001)
21. J. Ogando, Thermally conductive plastic beat the heat Available at. http://www.designnews.com/article/165-Thermally_conductive_plastics_beat_the_heat.php (2001).
22. Lambert M A, Fletcher L S. Thermal contact conductance of non-flat, rough, metallic coated metals. Trans ASME J Heat Transf, 2002, 124: 405- 412
23. A. Mortensen, C. SanMarchi, H.P. Degischer, Glossary of terms specific to metal matrix composites, MMC-Assess Thematic Network (2002) Available at.
24. Technologies Research Corporation, USA, Aluminium metal matrix composites technology roadmap Available at. http://www.almmc.com/AlMMCRoadmapMay2002.pdf (2002)
25. Myers, B.A., Cooling issues for automotive electronics, electronics Cooling (2003) issue:August2003, available at.www.electronics-cooling.com
26. Yovanovich M M, Marotha E. Thermal spreading and contact resistance. In: Bejan A, Kraus A D, eds. Heat Transfer Handbook. Chapter 4. New York: Wiley, 2003
27. J.M. Molina, M. Rheme, J. Carron, L. Weber, Thermal conductivity of aluminium matrix composites reinforced with mixtures of diamond and SiC particles, ScriptaMaterialia 58 (2007) 393-396.
28. Chander, A. Thermal management in electronic components e canpolymersreplace metals or ceramics? Available at.http://www.slideshare.net/ (2008)(accessed 04.02.10).

29. Chander, A. Thermal management in electronic components e can polymers replace metals or ceramics Available at. http://www.slideshare.net/ (2008).
30. R. Prieto, J.M. Molina, J. Narciso, E. Louis, Fabrication and properties of graphite flakes/metal composites for thermal management applications, ScriptaMaterialia 59 (2008) 11-14.
31. A. Chander, Thermal management in electronic components e can polymers replace metals or ceramics Available at. http://www.slideshare.net/ (2008).
32. MMC Metal Matrix Cast Composites, METGRAFTM products data sheet availableat. http://www.mmccinc.com (2009)
33. Myers, B.A.; Eesley, G. and Ihms, D., electronics cooling in the automotive environment, electronics Cooling (2010) issue: April 2010, Available at. www.electronics-cooling.com
34. Cola, B.A, Carbon nanotubes as high performance thermal interface materials, Electronics cooling (2010) issue: April 2010, Available at. www.electronicscooling.com

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