FLEXIBLE NANOCOMPOSITE THERMAL INTERFACE MATEIRALS

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Introduction

Thermal interface materials (TIM) are commonly used to improve the heat transport from a silicon device to a heat sink in an electronic system. Several conductive additives have been successfully incorporated as fillers to improve the thermal conductivity of commonly used thermal grease **[1 - 3]**. However, the improvement in thermal grease thermal conductivity does not address the problems of squeeze out, pump out, dry out and inconsistent application. Research has also been done to develop high thermal conductivity polyethylene for this type of application **[4]**. This paper describes research efforts on fabricating and assessing the thermal performance of silicone rubber sheets filled with carbon nanotubes (CNT) **[5]** and carbon nanofibers (CNF) **[6]** for use as a new flexible TIM material.

Materials

Flexible silicone rubber sheets (Poly-dimethylsiloxane, MW 3500g/mol) were processed with CNT filler (20 wt% and 30 wt%, 20 - 30 nm diameter), and with CNF filler (30 wt% and 40 wt% , 100 - 150 nm diameter). This material has the ability to be compliant to surfaces under contact pressure and to enhance the interface thermal conductance. A photograph of a flexible sheet processed at the Eaton Innovation Center is shown in **Fig 1**.

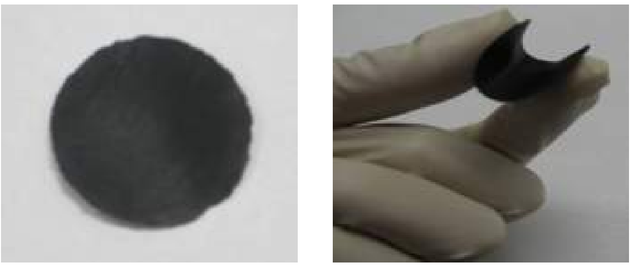

Fig. 1: Flexible nanocomposite TIM sheet

Material Characterization

SEM micrographs of 20 wt% CNT and 30 wt% CNF are shown in **Fig. 2a & 2b**. It is clear that the CNT filler is insufficient to provide a continuous thermal path and the silicone rubber matrix is dominant. However, the CNF filler appears to be better connected and has a better opportunity for attaining good thermal conductance.

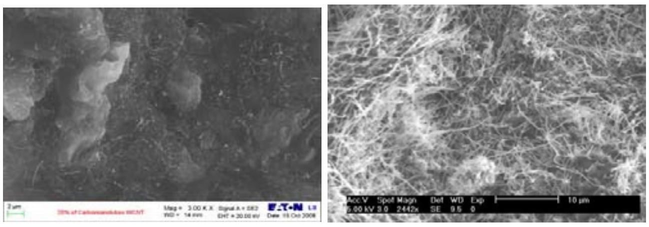

Fig. 2: SEM image of silicone rubber sheets:
(a) 20 wt% CNT filler, and (b) 30 wt% CNF filler.

Thermal conductivity measurements were performed on the Eaton in-house processed samples using a hot disk transient plane source (TPS) machine. The thickness (0.20 mm) of the samples was sufficient to perform through thickness measurements. The commercially available samples (0.05 - 0.10 mm thick), were too thin and we were able to perform only the in-plane thermal conductivity measurements. The results are summarized in **Fig.3**.

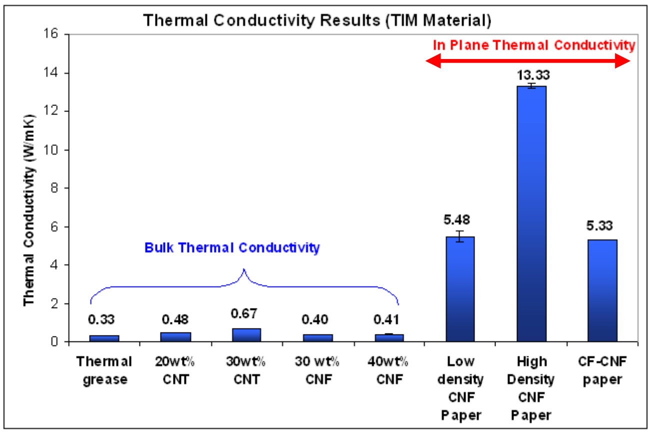

Fig. 3: Measured thermal conductivity for TIM samples

All of the Eaton in-house samples out perform the bulk thermal conductivity of the thermal grease. The best result was for the 30 wt% CNT filler, which shows a two fold increase (0.67 W/m°K) over thermal grease (0.33 W/m°K). Also, the silicone with the CNT filler out performs the bulk thermal conductivity with the CNF filler, even with a reduced CNT filler content. Therefore, it is likely that the bulk thermal conductivity is governed by the interface between the CNT and the silicone matrix, rather than by the CNT to CNT (or CNF to CNF) thermal connection.

The in-plane thermal conductivity results for the commercial TIM material are an order of magnitude higher than the bulk thermal conductivity of the Eaton in-house samples. However, the in-plane thermal conductivity is not directly useful information, because the typical TIM applications require high values for through plane (bulk) thermal conductivity.

It should be noted that the overall thermal conductance (including the contact interface on each side of the TIM sheet) needs to be further evaluated when these materials are used as media sandwiched between two surfaces.

Computational Model and Analysis

Analytical simulations were completed for an electronic assembly in which an SCR is mounted on an aluminum heat sink (**Fig. 4**), with a TIM at the interface. The objective was to evaluate the effects on the SCR junction temperature by using a higher thermal conductivity TIM material. A finite element analysis and a simplified thermal network analysis **[7]** were conducted to determine the thermal performance of various TIM materials. The difference in the results between the FEA and thermal network simulations was less than 7.7%. It was assumed that there is no thermal resistance at both TIM interfaces at the aluminum heat sink and at the SCR.

The simulation results (**Fig. 5**) show that increasing the TIM thermal conductivity to from 0.30 to 13.33 W/m-°C, results in a very large reduction in the junction temperature rise (56°C). Any additional increase of the TIM material thermal conductivity or reduction of the TIM thickness has a minimal effect on the SCR junction temperature rise.

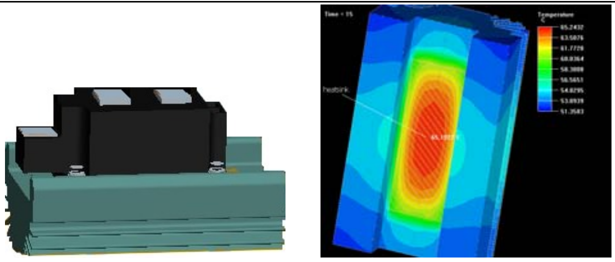

Fig. 4: (a) SCR mounted on an aluminum heat sink. (b) FEA result showing heat sink temperatures.

Conclusions

TIM materials made from silicone rubber with CNT and CNF filler were evaluated for thermal conductivity. The maximum bulk thermal conductivity was achieved with a 30 wt% CNT filler, which provided a 2 times improvement in thermal conductivity over thermal grease. Also, it was found that commercially available CNF sheets have a very large in-plane thermal conductivity. Thermal simulations show that a 40X increase in thermal conductivity results in a very large reduction in the SCR junction temperature rise. It was also shown that additional increases in TIM thermal conductivity have no significant effect on the SCR junction temperature rise. Future work will evaluate the overall thermal conductance (including the contact interface on each side of the TIM sheet).

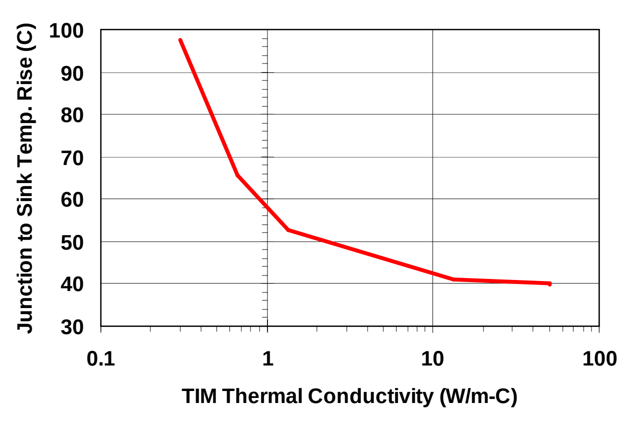

Fig. 5: Simulation results - SCR junction temperature rise with enhanced thermal conductivity TIM.

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