High Performance Graphene Enhanced Thermal Interface Technology for Electronics Cooling Applications

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ABSTRACT

The rapid growth of information technology continues to increase power density and integration levels in electronics devices, leading to an increase in greater heat dissipation, lower performance, and shorter operating life. Thus, the development of new Thermal Interface Materials (TIM) with substantially high thermal conductivity is essential for various device cooling applications. This paper focuses on the development of a new high-performance thermally conductive graphene enhanced TIM (GT-TIM) via chemical cross-linking of vertically aligned graphene and silicone polymer. The effect of vertical alignment on the thermal performance of the new GT-TIM has been evaluated and further potential use in various application areas has been proposed. Advantageously, GT-TIM offers a very low thermal contact resistance at the same time very high elasticity, recovery degree and very high reliability as compared to the state-of-the-art TIM materials available in the market.

INTRODUCTION

There is an increasing demand for efficient thermal dissipation materials with high thermal conductivity, and high elasticity to be used in electronics cooling applications such as 5G wireless modules, high-power CPUs/GPUs, data servers, gaming modules, LEDs, and Opto-modules.[1-2] To handle the needs, the industry uses whatever the market can offer and takes higher repair costs, with lower/limited performance to survive and wait for better TIMs to be developed. This indicates that the electronics industry constantly seeks new TIM products to solve thermal management issues.

A variety of thermal interface materials (TIM) (adhesives, liquid metals, greases, pastes, gels, pads, and encapsulates) are available in the market, depending on their application and power requirements.[1] The composition of most TIMs comprises two parts: base material and filler material. Base materials are silicones, polyurethanes, acrylics, and filler materials including metal powders (silver, aluminium, copper etc) and other non-metallic fillers (carbon black, graphite, graphene, aluminium oxide, silicon oxide etc), which directly affect the thermal conductivity of the final product.[3]

Over the past decade, graphene is considered as a promising material for industrial application in the fields of chemistry, materials science, and engineering.[4-5] Graphene enhanced products have received much attention lately and are promising materials for various industrial applications. Graphene enhanced TIM reported so far is made via traditional approaches using mixing and casting of graphene powder with a suitable polymer matrix. Because of the high thermal contact resistance derived from the weak coupling between the graphene skeleton and the polymer matrix, the random arrangement of graphene sheets and polymer resins seriously reduces the thermal conductivity of the graphene-composite-based TIMs.[6]
Some researchers have focused on improving the thermal conductivity using an aligned form of graphene.[6] However, to construct TIMs with excellent thermal conductivity, graphene sheets with high in-plane thermal conductivity need to be put together and assembled such that they are ordered in the vertical direction so that the intrinsic thermal properties of graphene can be fully extended and used. However, the arrangement and assembly strategies of graphene sheets are very complicated and often end with the poor performance of the final graphene-based TIM. So, careful molecular engineering of graphene layer alignment is required, which plays a decisive role in transmitting the thermal properties of the graphene microstructure to the macroscopic graphene assembled materials.

To our best knowledge, no research publications are available on the vertically aligned graphene and silicone-based TIM that offer as high thermal conductivity as GT-TIM. In this publication, a graphene assembled film and the silicone polymer matrix were chemically cross-linked to get GT-TIM and it was characterized via the ASTM 5470 method for the thermal performance. Reliability tests were also carried out to examine GT-TIM stability and thermal performance under different environmental conditions.

EXPERIMENTAL METHODS

Preparation of graphene assembled film and GT-TIM and thermal characterization: The GT-TIM was produced using multiple process steps. A well-dispersed Graphene Oxide (GO) suspension was made by shear mixing. The GO film

(GOF) with a certain thickness was prepared by drying the GO suspension. Afterward, the GOFs were annealed to get GFs with micro-gasbag foam-like structures[7]. GT-TIM was produced via vertical alignment with GF, followed by immersion in a silicone polymer. After that, GF and silicone polymer mixture were cured between 100 and 120^{0}Cto complete the curing process.

The bulk through-plane thermal conductivity of GT-TIMs was measured by Laser Flash (LFA 447 instrument).[8] Contact thermal resistance and effective thermal conductivity of GT-TIMs were measured using steady-state measurements according to ASTM D5470-17.[9] A thermal testing platform was built to show the superior thermal conductivity of the GT-TIMs at the through-plane and in-plane directions.

Reliability testing: A set of customized test rigs was designed and ~~a~~ 1 mm thick, 3x3 cm^2 sized GT-TIM test samples were used. GT-TIM pad was compressed to 30% and further subjected to three different industry standard reliability tests i.e., thermal aging (at 120ºC), temperature cycling (between –40ºC and +125ºC), and damp heat (at 85ºC, 85% RH). The thermal contact resistance was measured sequentially during each test to monitor changes from the triplicate of test specimens. Detailed reliability characterization testing has been reported in a recent publication.[10]

RESULTS AND DISCUSSION

***Structure of GT-TIM*:** The operation and lifetime of a circuit board largely determine the type of TIM and application technique. The new graphene enhanced TIM contains vertically oriented graphene fillers and a silicone polymer matrix, via structural control technology, to combine these two materials effectively. GT-TIM can offer a through-plane thermal conductivity of up to 100 W/m.K.[11] Figure 1 shows an image of a GT-TIM, revealing the vertically oriented graphene creating a pathway to the other side of GT-TIM.

To apply the TIM, it should be sandwiched between the heating element and the heat sink to boost heat transfer efficiency.

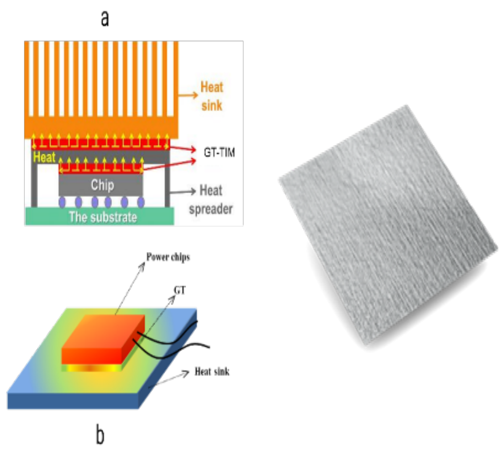

Figure 1.GT-TIM thermal interface materials for electronics and power module cooling.

GT-TIM offers reusability while maintaining the high thermal conductivity of vertically oriented graphene and is a proven technology in thermal burn-in and other industrial electronics cooling applications as compared to general-purpose grease.

Thermal performance. As compared to thermal conductive adhesives, non-curing thermal grease materials, and other forms of low thermal conductive thermal pads and tapes, the graphene enhanced TIM (GT-TIM) can offer up to 100 times better bulk thermal conductivity, 2–5 times better effective thermal conductivity and 2–5 times lower than effective thermal resistance compared to the current commercial products (Table 1).[3,11]

Table 1: Commercial TIMs and typical properties vs. GT-TIM measured with ASTM 5470 standard.

Type	Thermal conductivity (W/m.K)	BLT (um)	Thermal interface resistance (Km^2/W)	Pump-out effect	Stress absorption	Reusable
Thermal grease	0.4-4	20-150	10-200	Yes	Well	No
Thermal pad	0.8-3	200-1000	100-300	No	Well	Yes
Thermal gel	2-5	75-250	40-80	No	Medium	No
Thermally conductive adhesive	1-2	50-200	15-100	No	Medium	No
Solder	20-80	25-200	<5	No	Poorly	No
GT-TIM	50-100	150-300	5-10	No	Outstanding	Yes

From Table 1, it is observed that GT-TIM shows almost comparable thermal performance to pure indium solder bonding. In addition, the GT-TIM has more advantages than indium solder bonding, including lightweight (density=0.4-0.6 g/cm^3), good maintainability, and ease of use. The resulting GT-TIM thus opens new opportunities for addressing large heat dissipation issues in form factor driven electronics and other high power-driven systems.

In addition, GT-TIM can also be re-used with ultra-long-lasting performance as compared to thermal paste and other competitor products available in the market. Interestingly, GT-TIM offers extremely low thermal contact resistance value compared to other non-metal-based TIM products available from the commercial market. Figure 2 shows GT-TIM effective thermal resistance vs applied pressure. GT-TIM offers very high flexibility, softness, extreme compressibility, reusability, and recovery compared to the competitor products from the market.[3]

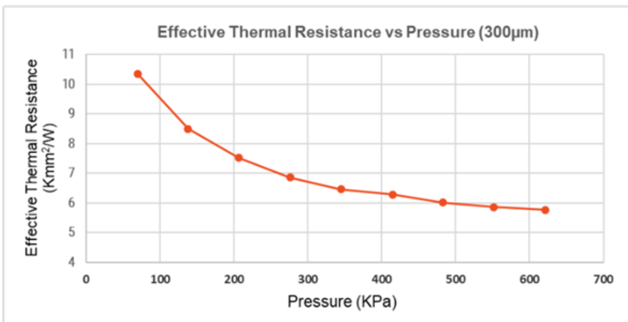

Figure 2. GT-TIM effective thermal resistance vs applied pressure.

Applications. GT-TIM is currently qualified in many potential cooling applications such as 5G, gaming, crypto mining and data server, CPU/GPU modules because of its long-lasting life compared to the commercial thermal paste. It also offers a very high compressibility, high recovery, and sustainable manufacturing processes because of high automation degree. Thus, the GT-TIM offers a very interesting energy efficient thermal management solution and saves energy up to 30% compared to commercial thermal paste.

A. 5G wireless module cooling: 5G wireless technology offers enhanced mobile broadband, ultra-reliable low-latency communication, and massive machine-type-communications, which enable the growth of artificial intelligence and the Internet of Things technologies. However, development and verification of an efficient ultra-high cooling materials and technology are still in an infancy stage.

Use of graphene assembled materials for ICT 5G wireless product cooling application is a great interest for telecom industry.

Figure 3 shows the percentage of the change in thermal resistance from pristine rigs to current conditioning time and total thermal interface resistance plotted against conditioning time for the damp heat specimens according to the telecom reliability testing requirements. The reliability tests of graphene-enhanced thermal pads have shown a very stable thermal performance over time, showing that GT-TIM is very stable in different environmental conditions.[10] It was also confirmed that thermal resistance levels did not worsen. GT-TIM surpasses in terms of reusability under harsh temperature conditions and is expected to become the main component in 5G electronics device cooling and related power module cooling applications.

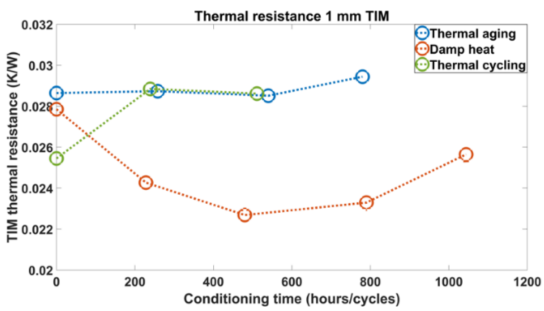

Figure 3. Reliability Characterization of GT-TIM.

B. Thermal Burn-In/Test Equipment: Recently, the GT-TIM were successfully used in thermal burn-in and IC thermal testing equipment applications. Figure 4 shows an assessment of the thermal performance of GT-TIM in thermal burn-in testing with very reliable performance compared to the existing TIM used in the testing applications.

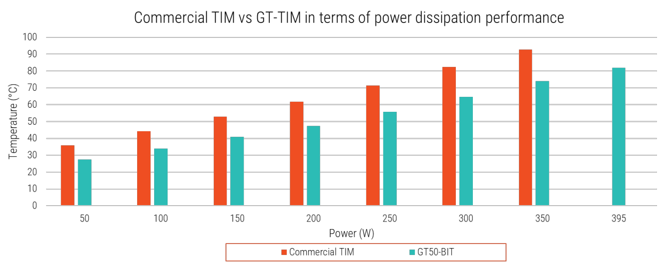

Figure 4. Assessment of Thermal performance in Thermal Burn-In Test (GT-50).

C. CPU, GPU, and Gaming hardware Cooling: Power dissipation of central processing units (CPUs) and graphics processing units (GPUs) are often very high. The GT-TIM can dissipate heat from the modules efficiently compared to the thermal paste. Figure 5 shows that they are also highly effective in cooling of CPUs. It can offer over 10 degrees low operation temperature for gaming as compared to conventional TIM product.

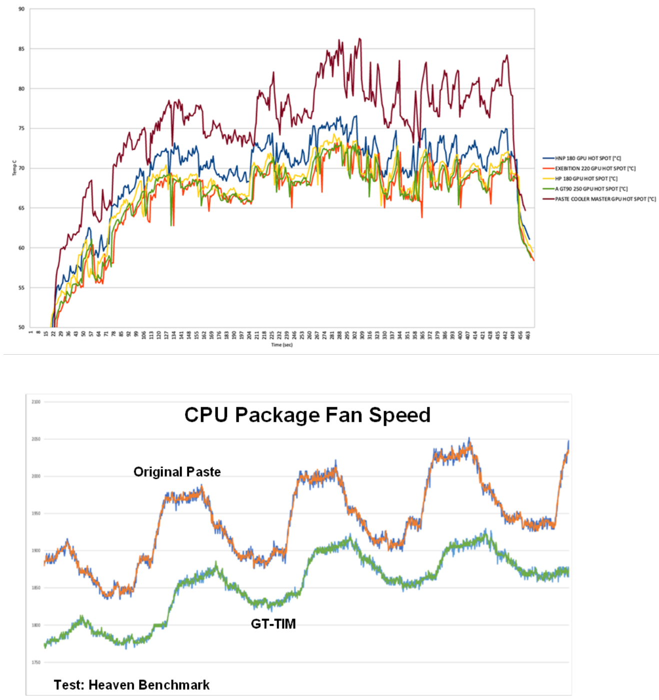

Figure 5. GT-TIM can offer more than 10°C lower operation temperature for gaming compared with commercial paste.

CONCLUSIONS

In summary, a lightweight, compressible, and highly thermal conductive GT-TIM has been developed as a combined thermal interface material and heat-spreading material for both through-plane and in-plane thermal management applications. The high thermal conductivity and high compressibility effectively fill the voids between the heating device and the cooling device to achieve low thermal contact resistance and outperform commercial materials. The resulting GT-TIM thus opens new opportunities for addressing large heat dissipation issues in form-factor driven electronics and other high power-driven systems. GT-TIM can successfully be implemented in a 5G wireless technology cooling, thermal burn-in tester and IC thermal testing equipment, and GPU/CPU cooling as a replacement for thermal grease currently being used by many electronics manufactures. In conclusion, GT-TIM offers long-lasting cooling performance, cost-effectiveness, energy saving, easy use and is chemically stable for a long period as compared to thermal grease materials.

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11. https://smarthightech.com/ and GT-TIM is a trademark registered product of Smart High Tech.