Effect of bonding pressure on thermal performance of graphene-enhanced thermal interface materials for immersion cooling applications

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Abstract

Graphene, due to its exceptional mechanical, optical, electrical, physical and thermal properties, has attracted strong interest for both fundamental studies and real applications. Among all these properties, the extraordinary high thermal conductivity makes graphene an ideal cooling material for power devices and systems. In mean time, rapid growth of information and AI technology continues to push power density and integration level in electronics devices, leading to an increase in greater heat dissipation causing lower performance, and shorter operating life. In this paper, the technology of a new graphene-enhanced thermal interface material (GT-TIM) manufacturing process is described. The effect of bonding pressures on thermal performance of the GT-TIM with different thicknesses is presented. The immersion test up to 1-month in immersion condition was carried out. The results show that the GT-TIM can be exposed to very high bonding pressure without delamination, well beyond normally used bonding pressure regions and extremely low thermal resistance in the range of 4-5 Kmm2/W at 40 psi (276kPa) at a thickness of 0,2 mm. In a typical biocompatible coolant environment, the thermal performance is basically intact after one month´s exposure.

It is thus concluded that that this class of the novel GT-TIM has very interesting feature that can potentially be used for many large power cooling applications, especially for immersion cooling.

Introduction

The continuous performance drive in applications such as datacom, Artificial Intelligence (AI) and autonomous driving etc has led to an increased demand on miniaturization and integration of electronics devices used in the electronics system. Systems-in-Package (SIP) is a typical way for the future integration. The heat developed due to the operations in such a SIP can reach over 1200 W for an AI system in a typical chiplet integrated module. This has been identified to be one of the most critical bottlenecks that blocks further development of the electronics systems [1]. Thermal interface material (TIM) is generally used to fill the gaps between the heatsink and heat-generating components, as seen in Figure 1. Today, typical TIM used is thermal paste, thermal gel and phase change material due to their ability to achieve thin bond-line thickness and large power conversion/absorption capability. But these materials such generally from pumping out, ageing out phenomena for long time use. Their durability and reliability for high power applications are very limited.

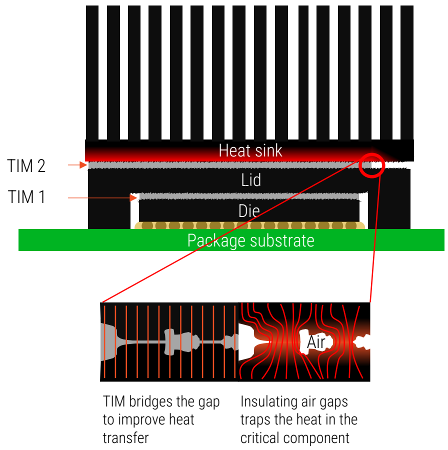

Figure 1. Heat transfer of using TIM in an electronics module.

Graphene is considered as one of the most promising candidates for thermal management owing to its excellent thermal conductivity and mechanical stability [2-3]. In this paper, we report a novel graphene-enhanced TIM in terms of the compression performance for immersion cooling applications.

Experimental

Graphene-assembled film used in this study is produced using modified Hummer's method to exfoliate graphene-oxide (GO) from graphite [4]. The GO suspension obtained from the exfoliation step is homogenized by high mixing and centrifugation. Subsequently, the GO suspension is cast to form a GO film. The GO film is then post-processed by high temperature annealing to remove oxides followed by a mechanical pressing step to remove interlayer voids. The resulting graphene-assembled film has very high thermal conductivity and flexibility. Previously, thermal conductivity data up to 3826 W/mK has been measured on 1 μm thick graphene-assembled films that were produced with this method [5].

After this, a polymeric and elastomeric material is mixed with the graphene-assembled film. A graphene-enhanced TIM is thus developed and produced with a vertically aligned structure embedded in a polymer matrix. A schematic drawing of the heat dissipation path in such a structure is shown in Figure 2.

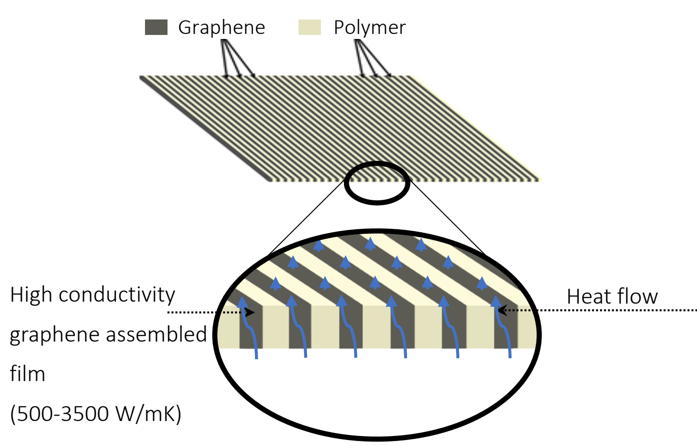

Figure 2. Schematic drawing of the concept of the graphene-enhanced TIM (thermal pad).

Figure 3 shows a photograph of the graphene-enhanced TIM (a thermal pad).

Figure 3. Photograph of a graphene-enhanced TIM (a thermal pad).

To study the effect of bonding pressure, the pressure is varied up to 100 psi for a thickness range between 0,2 and 1,5 mm of the pad. The thermal performance is measured according to the ASTM-5470 after 15 minutes relaxation and stabilization time. A power of 80W is used during the measurement.

The immersion cooling is carried out using a pad with a size of 68x68x0,15 and 68x68x0,2 mm by immersing the pad into a biodegradable coolant media from DOW: EcoSmooth Universal Fluid 1100 up to 1-month on a hotplate at 80^0C assisted by mechanical shaking. Shaking was done daily with more than 10 min per day.

The sample´s thermal performance was checked according to ASTM 5470-standard. The compressibility and recovery degree were also studied using a mechanical tester from Instron.

Results

The thermal resistance vs bonding pressure for different thicknesses for GT70, GT70PRO and GT90PRO is shown in Figure 4 to 6.

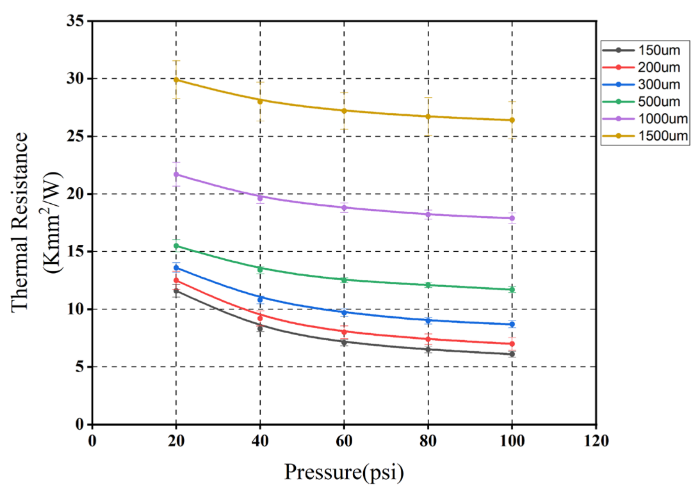

Figure 4. GT70 thermal resistance vs. bonding pressure curve.

The pads produced in this way have a bulk thermal conductivity performance up to 90 W/mK in Z-direction and can offer a contact resistance down to 5.0 Kmm2/W) at 0,2 mm thickness and at 40 psi (276kPa) compression pressure with excellent recovery and compressibility. Figure 4 to 6 also show that for soft pads such as in GT70PRO case, the thermal resistance does not drop less compared to the hard pads in the lower pressure bonding region up to 40 psi (276kPa). At higher bonding pressure, the thermal resistance is not significantly influenced by the bonding pressure.

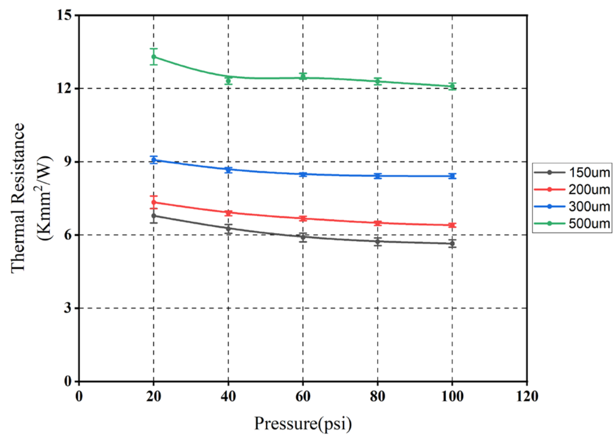

Figure 5. GT70PRO thermal resistance vs. bonding pressure curve.

The lowest thermal resistance is achieved with GT90PRO of the samples above for the same thickness.

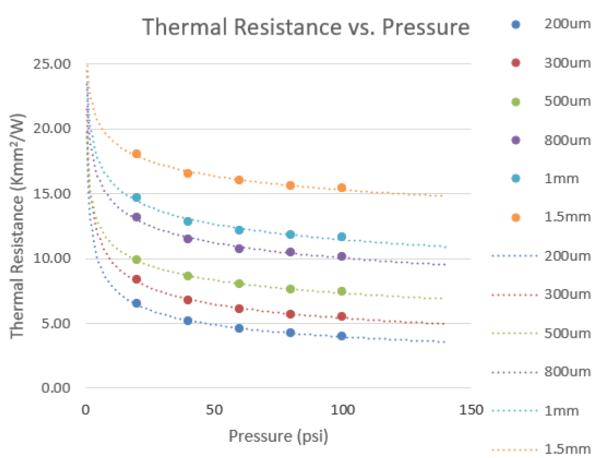

Figure 6. GT90PRO thermal resistance vs. bonding pressure curve

After the immersion up to 1-month, the sample is still intact, as shown in Figure 7.

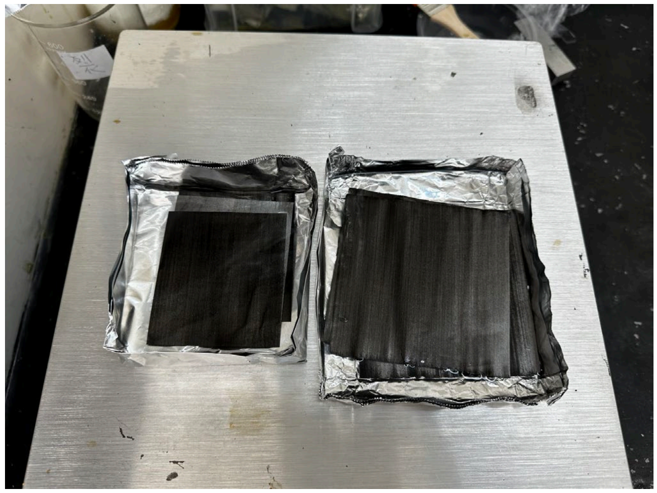

Figure 7. No change of the sample situation of the TIM: GT90.

The thermal resistance after 1-month immersion is 4,1 and 5,0 Kmm2/W on average for the sample with 0,15 and 0,2 mm thick pad respectively as can be seen in Table 1 and 2. Compared to the initial value of 4,0 and 5,0 Kmm2/W for the 0,15 and 0,2 mm thick pads, there is no significant change.

Table 1. Thermal resistance, compressibility and recovery degree of 0,15 mm GT90 pad thickness after immersion after 1-month immersion test.

Pads No.	Thermal resistance (Kmm2/W)	Compression (Kpa))@10 mins.	Recovery(%)@ 1min
1	4.2	1191	87.0
2	3.9	1214	86.0
3	4.2	1218	93.0
4	4.4	1254	87.4
5	4.1	1462	87.4
6		1414	79.4
7		1475	86.3
8			78.4
Average	4.1		

From Table 1 and 2, it can also be seen that the recovery degree still can reach over 80% in both cases.

Table 2. Thermal resistance, compressibility and recovery degree of 0,2 mm GT90 pad thickness after 1-month immersion test.

Pads No.	Thermal resistance (Kmm2/W)	Compression (Kpa))@10 mins.	Recovery(%) @ 1min
1	5.4	1015	70.3
2	4.6		80.2
3	4.7		79.3
4	4.3	1171	85.6
5	4.8	1030	81.1
6	4.7		84.7
7	5.6		84.7
8	5.7		77.5
Average	5.0		

The results indicate that the immersion does not influence the thermal performance negatively up to 1-month in such a biocompatible liquid.

Conclusions

A novel graphene-enhanced TIM has been developed. It is compressible, has high degree of recovery and offers very low thermal resistance at moderate bonding pressure. In the era of AI, ubiquitous connectivity, this new graphene-enhanced thermal interface material has a huge potential use for immersion cooling of electronics devices for these applications.

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References

[1] Guo S, J. Liu et al. Toward ultrahigh thermal conductivity graphene films. 2D Materials. 2022;10(1):014002.
[2] JS. Lewis and AA. Balandin et al. Thermal interface materials with graphene fillers: review of the state of the art and outlook for future applications. Nanotechnology. 2021;32(14):142003.
[3] Y. Fu and J. Liu et al, 2D materials, 2020
[4] S. Chen and J. Liu et al. Scalable production of thick graphene films for next generation thermal management applications. Carbon 167, 270–277 (2020).
[5] S. Guo, J. Liu et al. Toward ultrahigh thermal conductivity graphene films. 2D Mater. 10, 14002 (2022).