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Thermal Interface Material of High Conductivity and Thermomechanical Reliability

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ABSTRACT

Heat exchange in printed circuit boards is enabled by the thermal interface material (TIM) between the heat source (silicon die) and the heat sink (copper cold plate). While solder-based TIMs have high thermal conductivity, they can melt during reflow procedures, leading to reliability problems. Polymer TIMs are pliant and stay in place through reflow procedures; however, their thermal conductivity is substantially lower than solder TIMs.

This disclosure describes techniques to apply solder and polymer TIMs in a composite manner that leverages their complementary properties - the high thermal conductivity of the solder TIM and the higher reliability of the polymer TIM. Solder TIMs applied in small, non-contiguous tiles are bounded by thin lines of polymer TIMs. Solder-TIM tiles are held in place by the polymer TIMs, thus increasing reliability. Heat exchange, being mostly done by the high-conductivity solder TIM, is efficient.

KEYWORDS

- Thermal interface material (TIM)
- Polymer TIM
- Solder TIM
- Metal TIM
- Heat sink
- Delamination
- Warpage
- Semiconductor package fatigue
- Thermo-mechanical strain
- Reflow soldering
- Coefficient of thermal expansion (CTE)
- Heat exchange
- High-volume manufacturing
- Bond line thickness (BLT)

BACKGROUND

The growing performance of applications such as artificial intelligence or machine learning is sustained by increasing the chip complexity and transistor density. This translates to very high power densities and correspondingly high transistor temperatures. Even advanced cooling techniques such as liquid cooling are often unable to dissipate heat sustainably.

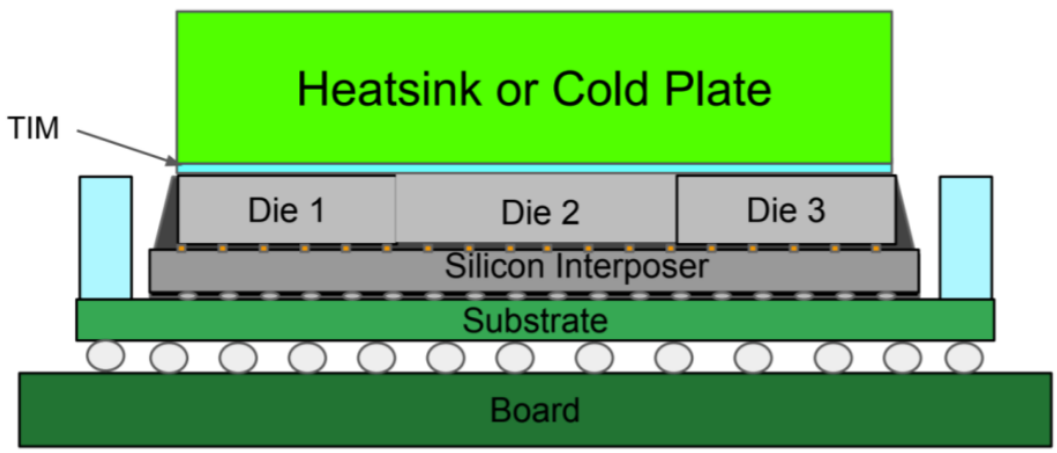
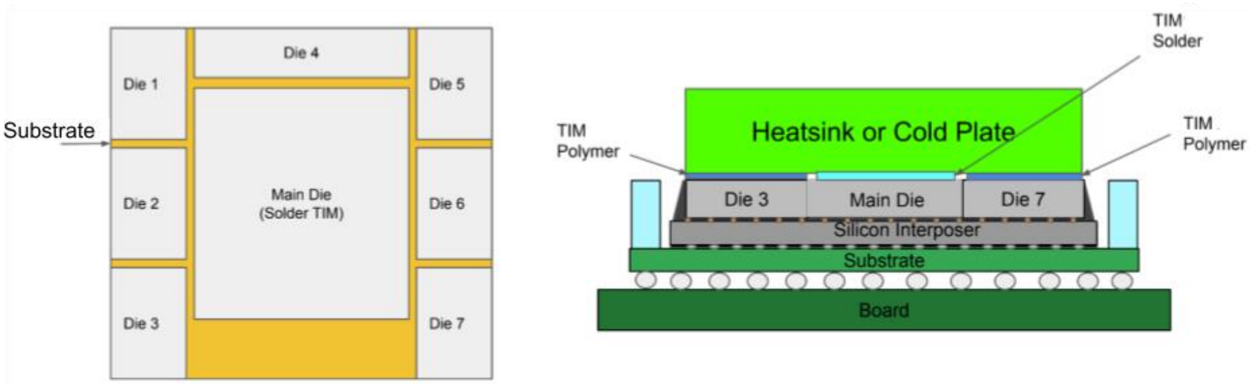


Fig. 1: A thermal interface material (TIM) installed between heat sources (dies 1-3) and a heat sink

Illustrated in Fig. 1, a critical bottleneck to heat transfer from the heat source (the silicon dies) to the heat sink (the copper cold plate) is the thermal resistance (reciprocal of thermal conductivity) of the intervening thermal interface material (TIM). While solder-based TIMs (also known as metal TIMs) have the apt quality of high thermal conductivity, they can also melt and get displaced during reflow procedures, leading to reliability problems. Further, solder TIMs mechanically bond to the heat sink and heat source and, with increasing temperature, experience differential expansion compared to the sinks and the sources, leading to thermo-mechanical strain that can damage (delamination, warpage, fatigue cracks, etc.) the silicon and the package. Polymer TIMs are pliant, are able to absorb differential expansion rates between sinks and sources, remain unbonded to the sinks and sources, can handle wide tolerances, stay in place through the reflow procedure, and are more reliable; however, their thermal conductivity is substantially lower than solder TIMs.

DESCRIPTION



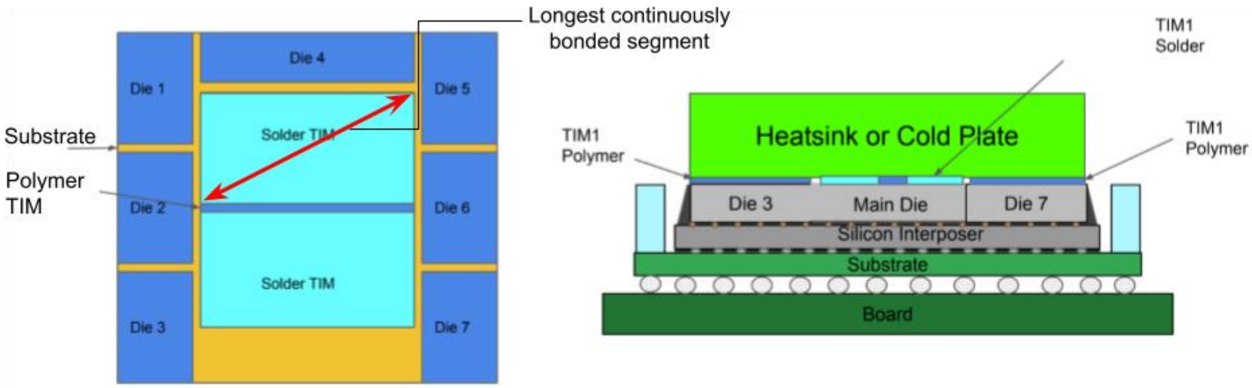
(a) **(b)**

Fig. 2: Applying solder and polymer TIMs in a composite manner to achieve increased reliability and heat transfer: (a) Top view; (b) Side view

This disclosure describes techniques to apply solder and polymer TIMs in a composite manner that leverages their complementary properties, e.g., the high thermal conductivity of solder TIM and the higher reliability of polymer TIM, as illustrated in Fig. 2. Metal TIMs (Fig. 2b, light blue) are applied in small, non-contiguous tiles with gaps between them. The gaps between the metal-TIM tiles are filled with polymer TIMs (Fig. 2b, dark blue). During reflow soldering, the metal TIMs are held in place by the polymer TIMs that bound them, thus increasing reliability. At the same time, the bulk of the heat exchange area is occupied by the high conductivity metal TIM, thereby providing efficient rates of heat transfer.

The relatively small size of the metal TIM tiles reduces the longest length of bonding between the tiles, the silicon (heat source), and the copper cold plate (heat sink). Even though silicon, TIM, and copper have substantially different coefficients of thermal expansion (CTE), their short lengths of mutual bonding ensure that the absolute differences in heat-induced expansion (or contraction) are low, thus reducing stress-related failures in the package during assembly and operation.

The techniques of punctuating metal TIM with polymer TIM are similar to gaps introduced in railroad tracks to enable the tracks to expand or contract with temperature without bending.

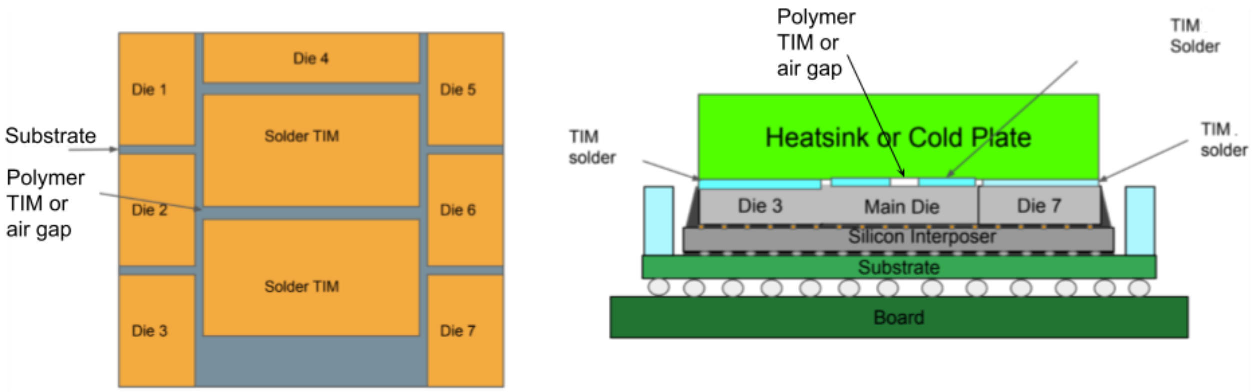


(a) **(b)**

Fig. 3: Solder tiles can be smaller in area than a single die: (a) Top view; (b) Side view

As illustrated in Fig. 3, the risk of warpage or delamination can be further reduced by making the size of the solder tiles smaller than the die. For example, in Fig. 3, the main die is thermally covered by two solder tiles (light blue), and the gap between them is filled with polymer TIM (dark blue). By thus splitting the solder TIM (which is bonded to both heat sink and heat source), the longest continuously bonded segment (e.g., the diagonal of a solder-TIM tile, in red) is relatively small, such that even substantial differences in CTE between various bonded materials result only in small absolute differences in heat-induced expansion. In this manner, warpage and delamination damage is minimized.

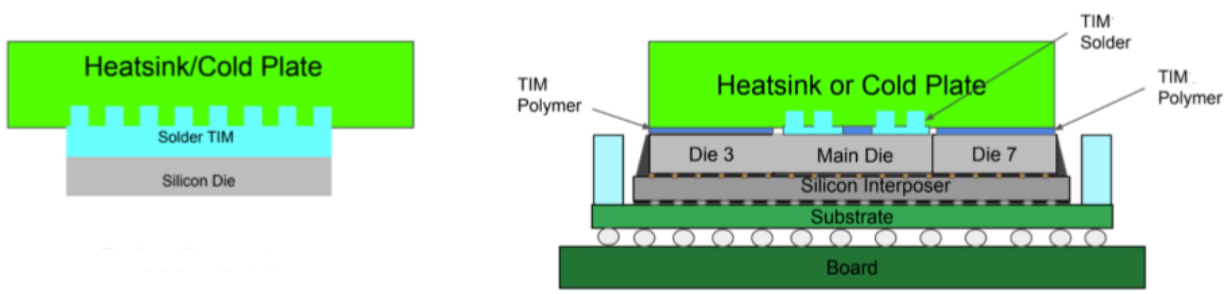
The tiles can also be placed over one or multiple separate silicon dies that are interconnected together on a common substrate, and their size and shape modified to achieve optimal coverage of hotspot areas. For example, the tiles can be placed in repeating geometric configurations that match the hotspots of the silicon die, thereby further optimizing heat transfer.



(a) (b)

Fig. 4: Space between solder-TIM tiles can be air-filled: (a) Top view; (b) Side view

As explained before, a thin line of polymer TIM can be dispensed across the die to break the contiguity of the solder TIM. Alternatively, as illustrated in Fig. 4, the gap between the solder-TIM tiles can simply be air-filled. Non-contiguous metalized areas that enable non-contiguous solder TIM can be implemented using a masked backside metallization.



(a) (b)

Fig. 5: Grooves etched in the heatsink to prevent solder from leaking out during reflow. (a) Top view (b) Side view

As illustrated in Fig. 5, to prevent the solder TIM from leaking out during reflow, small grooves can be etched in the base of the heat sink (cold plate), such that any excess solder flows into the grooves. The grooves also increase the surface area of solder TIM in contact with the cold plate, helping improve heat transfer and mechanical robustness.

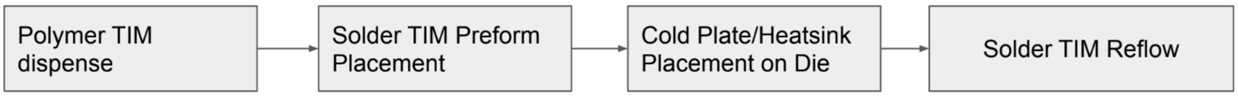


Fig. 6: Assembly procedure

Fig. 6 illustrates an example procedure to assemble composite solder-polymer TIM. The polymer TIM is dispensed on the die. The solder TIM is pre-formed and placed. The heat sink (cold plate) is placed on the die. The module comprising the heat sink, the TIMs, and the die is subjected to reflow soldering. The polymer TIM is selected such that it can withstand the reflow temperatures of the solder TIM material. For example, such polymer TIM materials include high-temperature greases with low, controlled bond line thickness (BLT) and high baseline thermal conductivity.

Some advantages of the described techniques include:

- During assembly, the risk of solder bleeding out and causing shorting, or impacting the thermal bond line thickness, is reduced by using smaller soldered areas and grooves in the heat sink/ cold plate.
- During reflow, the risk of voids in the TIM developing, growing, or migrating, is reduced since the soldered area is only focused on key hotspot areas.
- Solder-TIM BLT control, which is harder with large solderable areas, is easier with the smaller solder tiles, resulting in lower BLT variation in high-volume manufacturing.
- The relatively small size of the metal-TIM tiles reduces the area of application of the metal TIM, thereby reducing heat-induced stresses (delamination, die and package fatigue cracks, etc.) in the package.

- Conventionally, a large solderable area entails a higher reflow temperature to ensure reliable solder joints. The higher reflow temperature exposes the ball grid array (BGA) joints and other package components to liquefaction and displacement, increasing the risk of failure. With the smaller solder areas (tiles) as described herein, there is more margin to ensure that the BGAs and other package components are not overexposed to high temperature during reflow.

CONCLUSION

This disclosure describes techniques to apply solder and polymer thermal interface materials (TIMs) in a composite manner that leverages their complementary properties, e.g., the high thermal conductivity of the solder TIM versus the higher reliability of the polymer TIM. Solder TIMs applied in small, non-contiguous tiles are bounded by thin lines of polymer TIMs. Solder-TIM tiles are held in place by the polymer TIMs, thus increasing reliability. Heat exchange, being mostly done by the high-conductivity solder TIM, is efficient.

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