

Effect of Thermal Contact Conductance and Bond Line Thickness on Thermal Measurement Condition of Thermal Interface Material Tester

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Abstract

With the trend of towards high power and high frequency applications, heat dissipation of a package is become crucial. Thermal contact resistance is one of the important issues for those applications, especially in the architecture of microprocessor, which a thermal interface material (TIM) is implemented between die and heat spreader. The focus in this work is on the measurement condition of TIM tester. The thermal correlation between analytical solution and finite element analysis (FEA) as well as the thermal impact comparison of varied thermal contact conductance (TCC) and bond line thickness (BLT).

Keywords: Thermal interface material (TIM); thermal contact conductance (TCC); bond line thickness (BLT)

1. Introduction

With the continual increasing power of the packaging from generation to generation, there has been a driving force on developing thermal solutions. Among existence constituent components of a package, TIM is still a progress space to go owing to its low thermal conductivity, void-containing and adhesion characteristics in present. Besides, the contacting surface is the other major factor to affect the thermal conducting efficiency between two solids. Figure 1 shows a typical schematic drawing of the various thermal resistances and temperature differences of a TIM compressing by two materials. In the figure, one can see that there is a temperature discontinuous around contact surfaces and TIM and induce temperature differences around ΔT_{C1} , ΔT_{C2} and ΔT_{TIM} , which represent the being of thermal resistance of contact surfaces (R_{C1} and R_{C2}) and TIM (R_{TIM}), respectively.

In this paper we propose analytical solutions for the TIM tester measurement conditions and correlate with FEA. Verified model is then examined and compared the thermal impact of varied TCC of the contact surfaces and BLT of TIM.

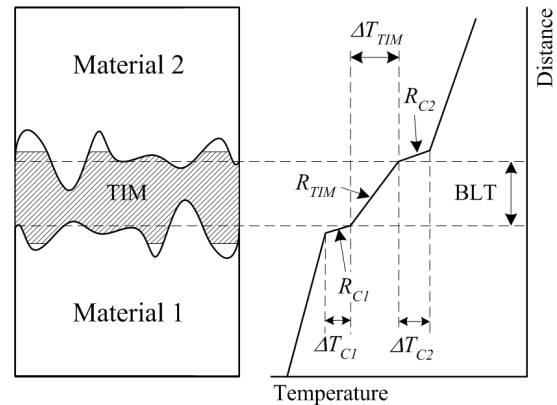


Figure 1. Schematic drawing of the various thermal resistances and temperature differences of a TIM compressing by two materials

2. Analytical solution

2.1 Thermal resistance of a block

For the one-dimensional plane wall as shown in Figure 2, having a temperature gradient $\frac{dT}{dx}$, the heat rate equation [1] is expressed as

$$q = -kA \frac{dT}{dx} = \frac{kA}{L} (T_{s1} - T_{s2}) \quad (1)$$

where k is the thermal conductivity and A the cross-sectional area. The minus sign is a consequence of the fact that heat is transferred in the direction of decreasing temperature. Defining

resistance as the ratio of a driving potential to the corresponding transfer rate, it follows from eq. (1) that the thermal resistance for conduction in a plane wall is

$$R = \frac{T_{s1} - T_{s2}}{q} = \frac{L}{kA} \quad (2)$$

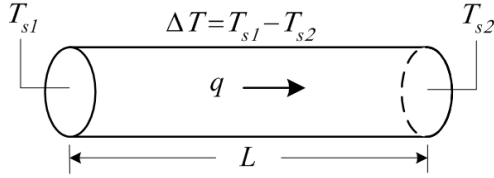


Figure 2. One-dimensional heat conduction block

2.2 Thermal conductivity assessment of the TIM

An advantage of the TIM tester is capable of assessing thermal conductivity of the TIM. The way is measured through two tests with different BLT and acquired their respective total thermal resistances:

$$R_{total,x} = R_{C1,x} + R_{TIM,x} + R_{C2,x} \text{ for } BLT_x \quad (3)$$

where R_{C1} and R_{C2} are the thermal contact resistance of the material 1 and 2, respectively and R_{TIM} is the thermal resistance of the TIM under the test of number x , which is named 1 and 2 in this study. Assume that thermal contact resistances are about the same:

$$R_{C1,1} + R_{C2,1} = R_{C1,2} + R_{C2,2} \quad (4)$$

Therefore, by $R_{total,2} - R_{total,1}$, thermal contact resistance can be eliminated and substituted into eq. (2), the thermal conductivity of the TIM can be extracted as:

$$k_{TIM} = \frac{BLT_2 - BLT_1}{A} \left(\frac{1}{\frac{\Delta T_{TIM,2}}{q_{TIM,2}} - \frac{\Delta T_{TIM,1}}{q_{TIM,1}}} \right) \quad (5)$$

and in turn the thermal resistance of the TIM:

$$R_{TIM,x} = \frac{BLT_x}{k_{TIM}A} \quad (6)$$

2.3 Thermal conductivity assessment of the contact (asperity) surfaces

It is hard to determine the thermal contact resistances of respective contact surface. A typical treatment is simplified them as an identical thermal contact resistance, $R_{C1,x} = R_{C2,x} = R_{C,x}$. By combining between eqs. (3) and (6), thermal contact resistance is available through [2]:

$$R_{C,x} = \frac{1}{2} \left(\frac{\Delta T_{C1,x} + \Delta T_{TIM,x} + \Delta T_{C2,x}}{q} - \frac{BLT_x}{k_{TIM}A} \right) \quad (7)$$

as well as the thermal conductivity of the contact surface,

$$k_c = \frac{2h_c}{A \left(\frac{\Delta T_{C1,x} + \Delta T_{TIM,x} + \Delta T_{C2,x}}{q} - \frac{BLT_x}{k_{TIM}A} \right)} \quad (8)$$

where h_c is the thickness of the contact surface. However, it is difficult to determine the magnitude in reality. By drawing out the h_c , eq. (8) can be rewritten as

$$k'_c = \frac{2}{A \left(\frac{\Delta T_{C1,x} + \Delta T_{TIM,x} + \Delta T_{C2,x}}{q} - \frac{BLT_x}{k_{TIM}A} \right)} \quad (9)$$

where $k_c = k'_c h_c$, is the TCC of the contact surface.

3. Finite element modeling

In this work, thermal analysis incorporated with contact methodology is conducted on the thermal measurement condition of TIM tester. The TIM tester consists of two identical copper blocks in the shape of cylinder with a 15 mm diameter and a 10 mm thickness. A 30- μ m-thick TIM is placed between the blocks. This thickness is also known as BLT. Due to the axial symmetry, only the portion from the center to the edge of the TIM tester and TIM, Figure 1, is modeled. The model is composed of 900 axisymmetric elements and every single element has four nodes with one degree of freedom, temperature, at each node. Both exposed vertical lines are free of setting to let them to be adiabatic while both exposed horizontal lines are set specific temperatures as note at next section. Table 1 tabulates the thermal properties of the

components, where k is the thermal conductivity. The analysis is carried out using ANSYS v. 10.0.

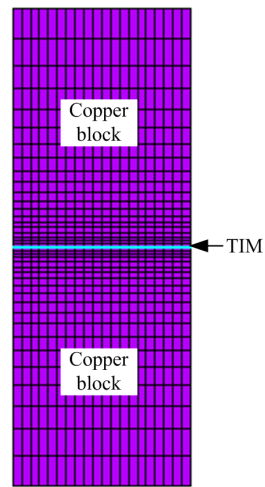


Figure 3. Finite element model.

Table 1. Thermal properties of the components

Component	k (W/m-K)
TIM	2.3
Copper block	389

4. Verification between analytical and FEA

In order to verify the validity between analytical and FEA, verification is conducted through following conditions: Under room temperature, 25 °C, a power of 100 W is supplied through the top surface of the upper Cu block. Assume that there is a 25-degree-C difference from upper contact surface, TIM to lower contact surface. Therefore, temperature ought to be provided at the upper surface of the upper block and TCC of a single contact surface are 79.094 °C and 64232.036 W/(m²K), respectively through the calculations as shown in Appendix.

These conditions are then imposed to the finite element model. Figures 3 (a) and (b) show the overall temperature distribution and temperature curve along axisymmetric line. From the Figure 3(a), it can be seen that the temperature ranging correctly between 25 and 79.094 °C. Large temperature changes exhibit around the TIM. To precisely observe its distribution, temperature along the axisymmetric line, Figure 3 (b), are examined. Clearly, the temperature distribution around there (10 mm in the x-axis) is ranged 25 °C. It is perfectly matched between analytical and FEA.

5. Results and discussion

Thermal performance of a TIM pressing by two specific materials is typically affected by TCC and BLT and even more, mutually. Here,

these two factors are studied independently at following subsection.

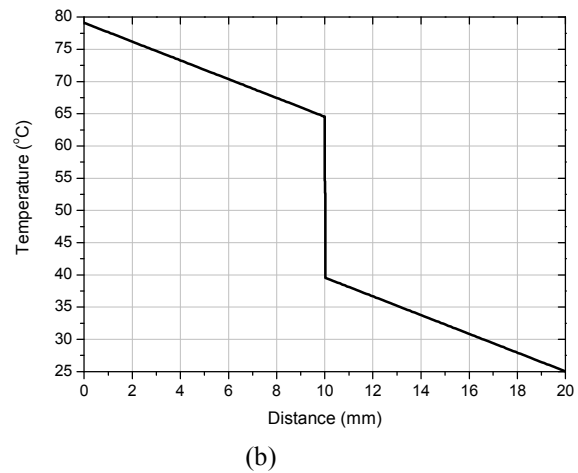
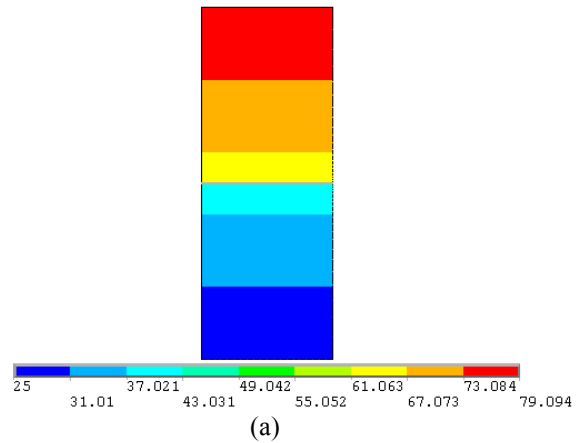


Figure 3. (a) Overall temperature distribution (Unit: °C) and (b) temperature curve along axisymmetric line

5.1 TCC effect

TCC is an important factor to affect the thermal conduction on two interfacial surfaces. As commonly known, a higher TCC can be achieved by just pressing the interfaces with a higher pressure. However, it is out of the scope in this study that to involve the pressure-dependent TCCs to this pure thermal FEA. Nevertheless, it is still feasible by keeping constant TCC to the interfacial surfaces. Constant TCCs of 20 000, 40 000, 60 000, 80 000 and 100 000 W/(m²K) are examined with keeping other conditions and dimensions the same as section 4.

Figure 4 (a) and (b) show the overall temperature distributions and their corresponding temperature curves along axisymmetric line for different TCCs, respectively.

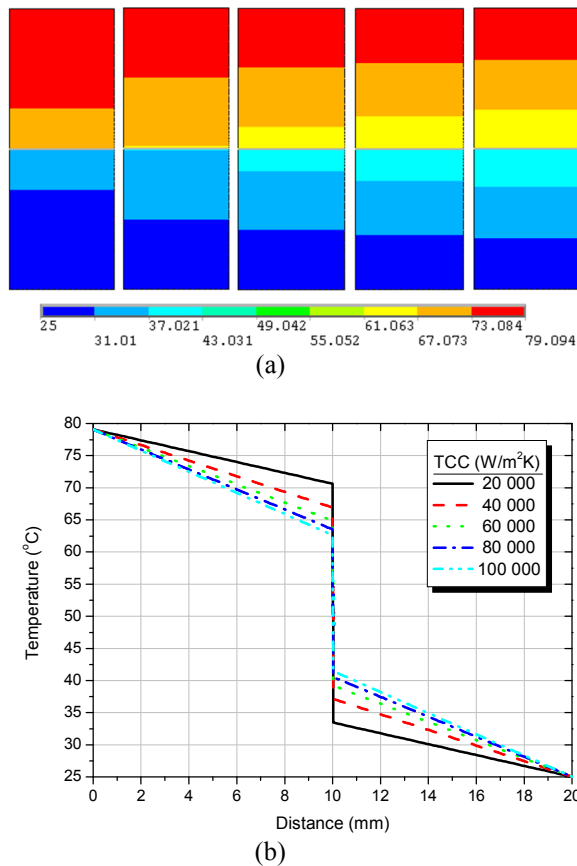


Figure 4. (a) Overall temperature distributions (Unit: °C) for different TCCs. There are 20 000, 40 000, 60 000, 80 000 and 100 000 W/(m²K) from the left to the right. (b) Their corresponding temperature curves along axisymmetric line

It is apparent that the higher the TCC, the lower the temperature range between contact surfaces and TIM, i.e. the better the efficiency of the heat transfers. Moreover, the temperature can disperse more evenly to the Cu block with a higher TCC. Due to this, the temperature range between contact surfaces and TIM can be expected to distribute from around 37 °C of 20 000 W/(m²K) to 21 °C of 100 000 W/(m²K), as shown in Figure 5. There is 43 % temperature reduction at this comparison.

5.2 BLT effect

The other important factor is BLT of TIM. Similarly, by keeping the same conditions as section 4, BLTs of 10, 30, 50 and 70 μm are examined. Such chosen BLTs are based on the existence elsewhere [3-4].

Figure 6 (a) and (b) show the overall temperature distributions and their corresponding temperature curves along axisymmetric line for different TCCs, respectively. From the figures we can reasonably seen that the better thermal conduction around

TIM and contact surfaces is with the thinner BLT since it diminishes the barrier of low thermal conductivity of TIM. Similar phenomena can be found around there that a wide dispersed temperature distribution for a thinner BLT while a tight one for a thicker BLT. The BLTs range between 22 and 30 °C and cause a 33% temperature increase.

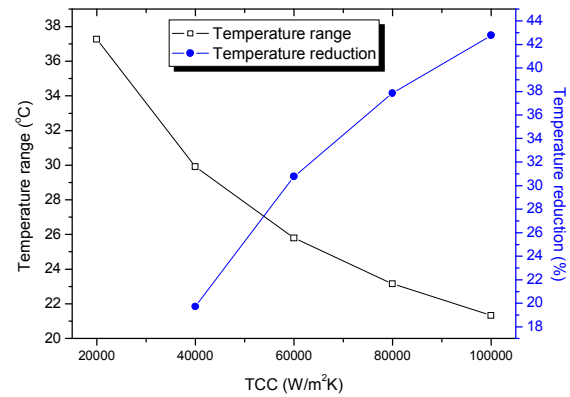


Figure 5. Temperature ranges for different TCCs between contact surfaces and TIM, corresponding to 10 mm at x-axis of Figure 4 (b) and their temperature reductions using TCC of 20 000 W/(m²K) as base

6. Conclusion

We demonstrate in this paper the thermal analysis incorporated with contact methodology on the thermal measurement condition of TIM tester. The thermal measurement condition can easily infer through analytical solutions. Verification between analytical and FEA is perfectly matched. This verified FEA is thus studied on the thermal performance of TCCs and BLTs on specific conditions. Both increasing TCC and BLT have had great influence up to 43 % temperature reduction and 33% temperature increase compared to the lowest magnitude. On the other hand, for the sake of enhancing the thermal performance, TCC and BLT should be increased and decreased, respectively.

For the nature of soft and low thermal performance as available TIM behaved, a pressure is inevitable to apply on it. The pressure-dependent pump-out and TCC is therefore required to involve through a coupled-field thermal-mechanical analysis.

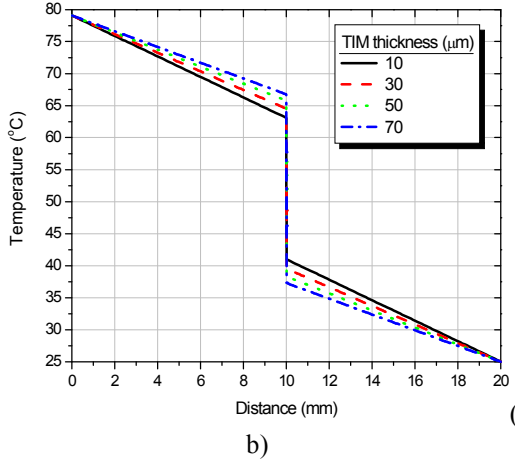
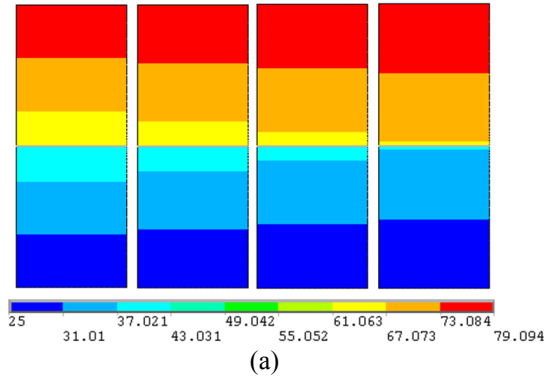


Figure 6. (a) Overall temperature distributions (Unit: °C) for different TIM thickness. There are 10, 30, 50 and 70 μm from the left to the right.
(b) Their corresponding temperature curves along axisymmetric line

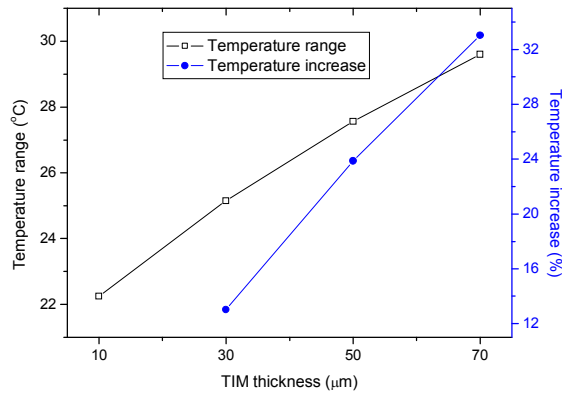


Figure 7. Temperature ranges for different BLTs between contact surfaces and TIM, corresponding to 10 mm at x-axis of Figure 4 (b) and their temperature increases using TIM thickness of 10 μm as base

7. Appendix

a. Temperature difference of a single Cu block:

$$\Delta T_{Cu} = \frac{qL_{Cu}}{k_{Cu}A} = \frac{100 \times 10 \times 10^{-3}}{389 \times \pi \times (7.5 \times 10^{-3})^2} = 14.547^\circ\text{C} \quad (10)$$

b. Temperature difference among both contact surfaces and TIM:

$$2\Delta T_C + \Delta T_{TIM} = 25^\circ\text{C} \quad (11)$$

c. Total temperature difference:

$$\Delta T_{total} = 2\Delta T_{Cu} + 2\Delta T_C + \Delta T_{TIM} = 29.094 + 25 = 54.094^\circ\text{C} \quad (12)$$

d. Contact conductance of single surface:

$$k'_c = \frac{2}{A \left(\frac{\Delta T_{C1,x} + \Delta T_{TIM,x} + \Delta T_{C2,x}}{q_{C1,x} + q_{TIM,x} + q_{C2,x}} - \frac{BLT_x}{k_{TIM}A} \right)} = \frac{2}{\pi \times (7.5 \times 10^{-3})^2 \left(\frac{25}{100} - 0.0738 \right)} = 64232.036 \text{ W}/(\text{m}^2\text{K}) \quad (13)$$

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