Design of Hybrid Composites for Thermal Interface Materials

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SUMMARY : We have been designing thermal interface materials(TIMs) for use in between chips and heat spreaders or heat sinks. TIM is composed of conductive fillers (such as carbon fiber) and phase changeable polymer matrix. The matrix consists of two different materials, one of which is Trilene that is liquid state at room temperature, and the other is Astorwax whose melting point is around 54°C. Due to the low melting point of the matrix, the thickness of the TIMs is reduced under certain pressure if TIM is heated up over 50°C. So, the thermal conductivity of TIM is significantly reduced when it is heated over 50°C for the first time. Likewise, the thermal resistance of the TIMs is also decreased. Thermal resistance is usually stable after the first heat up, reaching to the constant value, as the thickness of the TIM remains constant. The measured thermal resistance of several different types of TIM turns out to be an almost linear function of specimen thickness.

KEYWORDS : thermal conductivity, thermal interface materials, thermal resistance

INTRODUCTION

Many people studied thermal interface materials (TIM) for the last decade. M. F. McGuiggan studied two types of thermally conductive adhesives (TCA) in the surface mount technology (SMT); electrically-thermally conductive adhesives and electrically insulating–thermally conductive adhesives[1]. Bolger studied silver-filled adhesives that providing the very high thermal conductivity, even higher than diamond-filled adhesives[2]. The silver-filled adhesives are electrically-thermally conductive adhesives, so it cannot be used if a power device requires electrical isolation from heat sink. Li and Chung studied TCA that contains ceramic fillers[3]. These TCAs, containing ceramic fillers, have lots of advantages; high thermal conductive, thermal stability, ease to processing, etc.

The purpose of this research is to develop and evaluate thermal interface materials (TIM) with lower thermal resistance for use in electronic packaging. The TIM should be very thin, flexible, and thermally conductive comparing to other materials such as grease and so on. Fig. 1 shows the location of the TIM film in electronic packaging.

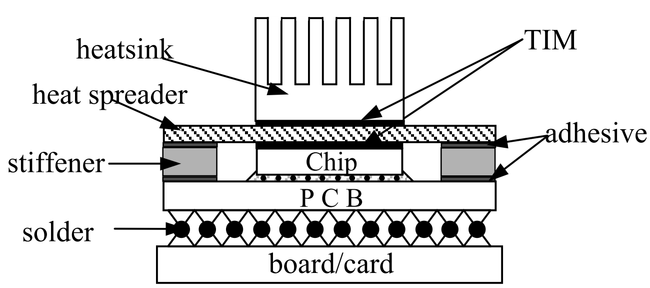

Fig. 1. Sketch of electronic packaging system with TIM film

Thermal resistance (R) is defined by

$$R = \rho \frac{t}{A} \quad (1)$$

where, ρ is the thermal resistivity, equal to 1/k (k is thermal conductivity), A is the area and t is the thickness of TIM. Therefore, there are two approaches to reduce R; reducing ρ or reducing t. The first can be achieved by increasing k-value of TIM where use of higher thermal conductivity materials are desired, while the second by thinning the TIM by use of phase changeable polymer matrix with minimum thickness graphite fibers as shown in Fig. 2.

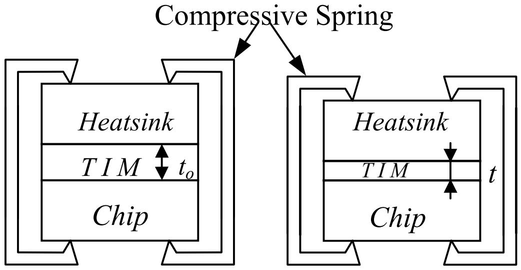

Fig. 2. Phase changeable polymer;
(a) before heating(Switch Off)
(b) after heating(Switch On)

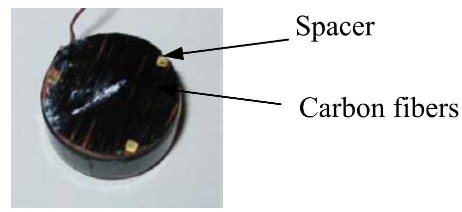

Fig. 3. Spacers and carbon fibers

MATERIALS AND PROCESSING

The diameter of the carbon fibers is around 5μm and they have lots of carbon nano-tubes. Matrix is composed of two different materials; Trilene and Astorwax. Trilene is liquid state at room temperature while Astorwax is solid state at room temperature and its melting point is around 54°C. In order to measure the specimen thickness correctly, 4 different spacers are used, as shown in Fig. 3. The thicknesses of the spacers are 0.001″(25μm), 0.002″(51μm), 0.003″(76μm), and 0.004″(102μm) and the lengths of one side of the rectangular are 2mm.

THERMAL RESISTANCE MEASUREMENT TECHNIQUE

Fig. 4 shows the experimental apparatus used for measuring the thermal resistance of the specimen. The heater consists of a copper disk and a thin silicon heater whose diameters are 3-inches. As a reference material, stainless steel whose thermal conductivity is 14.80 W/mK and whose thickness is 12.60mm is used. The thin 25.4mm-diameter specimen is placed between the reference material and Cu plate as shown in Fig. 4. The entire assembly is wrapped with glass insulation to promote one-dimensional heat flow. Three thermocouples are inserted to measure temperatures.

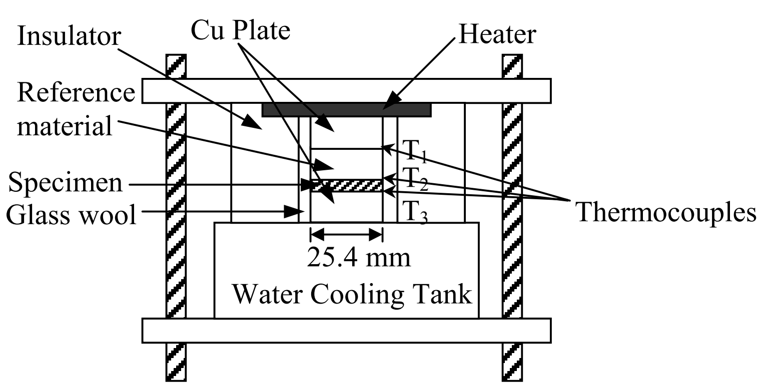

Fig. 4. Experimental Setup for measuring the thermal resistance of 25.4mm diameter specimen

Assuming that heat flows one-dimensionally from heater to water cooling tank, thermal conductivity and thermal resistance of the specimen are calculated by the following equations.

$$k_s = k_r \frac{t_2}{t_1} \frac{T_1 - T_2}{T_2 - T_3} \tag{2}$$

$$R_s = \frac{1}{k_s} \frac{t_2}{A} = \frac{1}{k_r} \frac{t_1}{A} \frac{T_2 - T_3}{T_1 - T_2} \tag{3}$$

where, Q_1 : heat flow through the reference material
Q_2 : heat flow through the specimen
k_r : thermal conductivity of the reference material
k_s : thermal conductivity of the specimen
R_s : thermal resistance of the specimen
t_1 : thickness of the reference material
t_2 : thickness of the specimen
A : cross-sectional area of the specimen
T_1, T_2, T_3 : temperatures measured by the 3 thermocouples, respectively.

RESULTS

1. Thermal conductivity

A specimen is made and tested with 4 different thickness spacers for 3 times. When the spacemen is cut with 25.4mm diameter, the fiber weight of specimen is 0.0167g while matrix weight of specimen differs each other and it changes during the test. A result with 51µm spacers is shown in Fig. 5. This thermal conductivity is calculated with final specimen thickness that is 51µm. Other tests have the same behaviors as shown in Fig. 5. The thermal conductivity has significantly changed between 49°C and 59°C, because Astorwax changes from solid status to liquid status around 54°C.

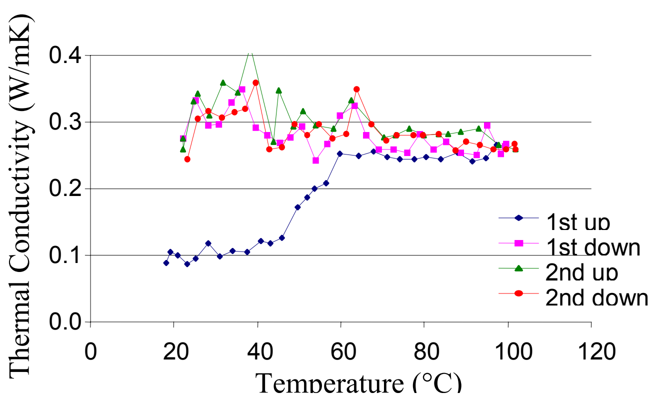

Fig. 5. Thermal conductivity(k_s) vs. temperature(T_2)

2. Thermal resistance

For the same test shown in Fig. 5, thermal resistance is shown in Fig. 6. It shows the thermal resistance varies as temperature changes. Especially, thermal resistance has been significantly reduced from 49°C up to 59°C like thermal conductivity. These phenomena occurred by phase-changeable matrix. After increasing the temperature up to 100°C, the specimen is subjected to cool down to 20°C and its thermal conductivity and resistance are also measured during the period. After heating and cooling the specimen, the specimen is subjected to one more cycle and its thermal conductivity and resistance are also measured and plotted as shown in Fig. 5 and Fig. 6. Thermal resistance is stable after the specimen is heated for the first time. Finally, the thermal resistance reached to around 0.357K/W.

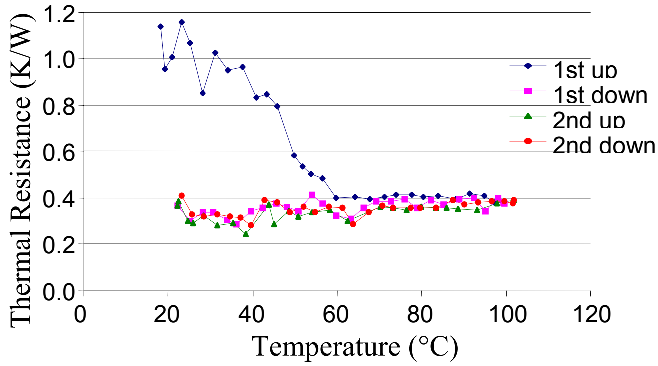

Fig. 6. Thermal resistance(R_s) vs. temperature(T_2)

3. Thermal resistance vs. Thickness

Fig. 7 shows thermal resistance with respect to the spacer thickness. There are strong relations between spacer thickness and thermal resistance. Measured thermal resistance is composed of thermal resistance of TIM and thermal interface resistance. According to the Fig. 7, thermal interface resistance, R_{int}, is estimated as 0.13K/W.

$$R = R_{TIM} + R_{int} \tag{4}$$

where, R_{TIM} : thermal resistance of TIM

R_{int} : thermal interface resistance

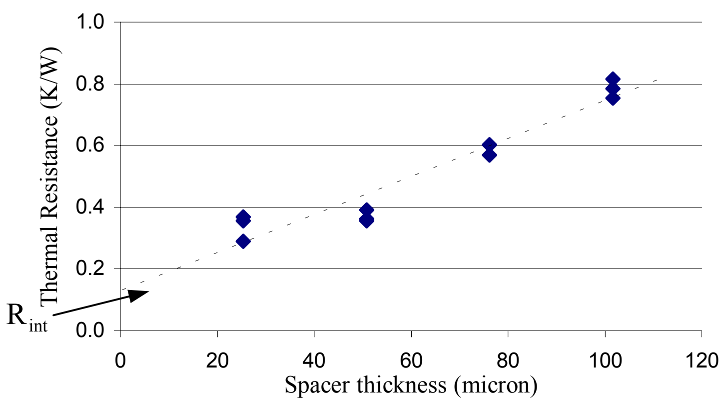

Fig. 7. Thermal resistance vs. spacer thickness

CONCLUSION

We focus on the thermal property data of TIM made by continuous graphite fibers and phase changeable polymer matrix (Paraffin based). Based on the results, especially Fig. 7, thermal resistance is proportional to the spacer thickness, which explains that the thermal resistance also decreases as final thickness decreases.

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