A NOVEL HIGH THERMAL CONDUCTIVE UNDERFILL FOR FLIP CHIP APPLICATION

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ABSTRACT:

Silicon dioxide is normally used as filler in underfill. The thermal conductivity of underfill is less than 1 w/mk, which is not able to meet the current flip chip application requirements such as 3D stacked multi-chips packaging. No matter which direction the heat will be dissipated through PCB or chip, the heat has to pass through the underfill in 3D stacked chips. Therefore the increase of thermal conductivity of underfill can significantly enhance the reliability of electronic devices, particularly in 3D package devices. YINCAE Advanced Materials, LLC has developed a novel high thermal conductive underfill for flip chip applications. Diamond powder is selected as filler in our product system due to its excellent thermal stability and high thermal conductivity. Three different diamond powders have been used as filler in underfill, the thermal conductivity has been increased many times (up to 6w/mk), which can greatly reduce the thermal stress for solder joint. The flowability, pressure cooking test and other properties of underfill have been characterized and investigated. All details will be discussed in this paper.

INTRODUCTION:

Flip Chip has been being used in the industry for many years. In order to enhance the reliability, flip chip underfill has been developed to overcome the stress from CTE mismatch. With the advancement of flip chip technology, the pitch (20µ) is getting smaller and bump getting tinier (5-10µ), so the tiny solder joint needs more and more enhancement from underfill to secure the reliability for the electronic device. Recently, 3D packages have been increasingly implemented in the industry due to the flexibility in device design and supply chain, reduction of the gap between silicon die and organic substrate, and the demands of size miniaturization, cost reduction, high speed and high memory, and multiple functions from end customers. In order to achieve further size miniaturization, higher speed and cost reduction, 3D TSV (Through Silicon Via) package has been introduced into the packaging industry. In addition, the bump size has been reduced from 80µ to 10µ.

However, there are the same issues as normal flip chip packages such as weak joints and thermal dissipation issues. In order to resolve these issues for advanced package such as high density flip chip package or 3D package, it is essential to develop high filler load and highly thermal conductive underfill for these applications. YINCAE Advanced Materials, LLC has successfully developed diamond filled underfill, which has demonstrated excellent flowability, high thermal conductivity and good reliability. In this paper we will discuss in detail.

EXPERIMENT:

a. Materials:

Three diamond powders with different particle sizes (size: Z2, Z3 and Z6) have been selected to use to develop a new underfill materials. A commercial flip chip underfill has been used as control.

b. Underfill Flowability Test:

A double side tape was adhered to the two edges of the glass and then covered by another fresh glass to form the sandwich structure and the middle tunnel for underfill flow test. The sandwich of glass slides was heated up to 110°C, and underfill was dispensed onto the end of the sandwich of glass slides and automatically flew into the sandwich tunnel. The flow time was recorded for a certain distance.

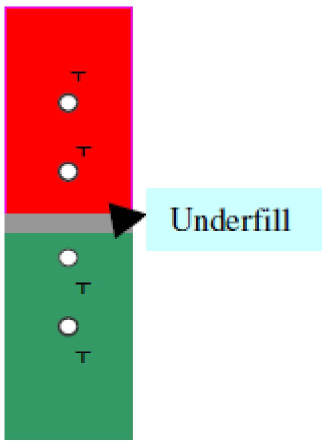

Figure 1. Schematic thermal conductivity test.

c. Thermal conductivity and Delta T measurement:

The test vehicle is shown in Figure 1. The hot surface of heat source is kept at 108.1°C and measure the temperature of the cooler substrate. Silica filled underfill is used as reference because silica filled underfill is normally known as 0.4-0.5W/mk. The Delta T = 108.1-T3. The smaller Delta T, the higher thermal conductivity.

d. Sample Preparation

Dispense diamond filled underfill onto one copper coupon, then covered with another copper coupon to form sandwich structure. Put the sandwich copper coupon onto 110°C hotplate for 10 minutes to complete the curing process. The samples prepared are for thermal conductive performance measurement.

e. Pressure Cooking Test

The underfilled flip chips were inspected via C-SAM to check for underfill voids or delamination before and after pressure-cooking for seven days at 121°C and 15 psi.

f. Thermal Cycling Test

Thermal cycling test was conducted for the underfilled flip chips. The test conditions were: -65°C to 150°C; 15 min each at two extreme points; 15 min for temperature ramping up from -65°C to 150°C and 15 min for temperature cooling from 150°C to -65°C with total time of one hour per cycle.

RESULTS AND DISCUSSION:

A. The Flowability of Underfill

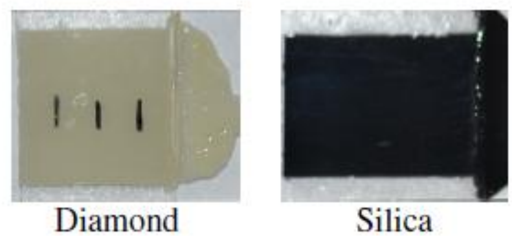

Figure 2. Underfill images of flow test.

It can be seen from Figure 2 that the underfill flow front is straight line and no voids were generated in flow test during curing step. The curing behavior and speed were also examined and was found that there was no significant difference between silica filled underfill and diamond filled underfill. All these results indicates that this diamond filled underfill could be very promising for being used in the high end electronic industry due to cost concern (maybe not for the entire electronic industry).

The flow test results are shown in Figure 3. It can be seen that the underfill flows slower with increasing flow distance due to cure reaction in flow process; and the flow is also getting slower with increasing diamond load.

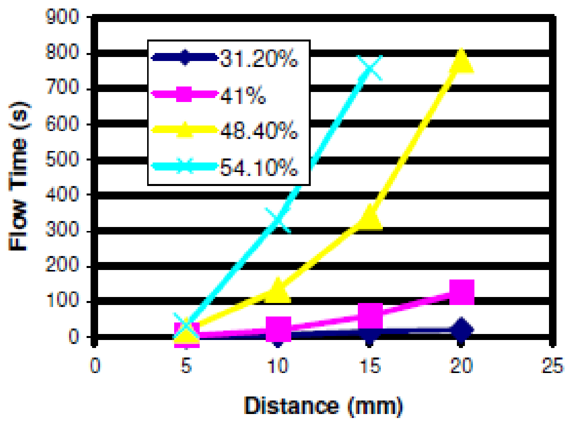

Figure 3. Flow time vs. flow distance of underfill using diamond Z2

It is very interesting to note that the diamond filled underfill still flows faster even at about 50% diamond load, particularly for the first 15mm distance, which is good enough for commercial applications.

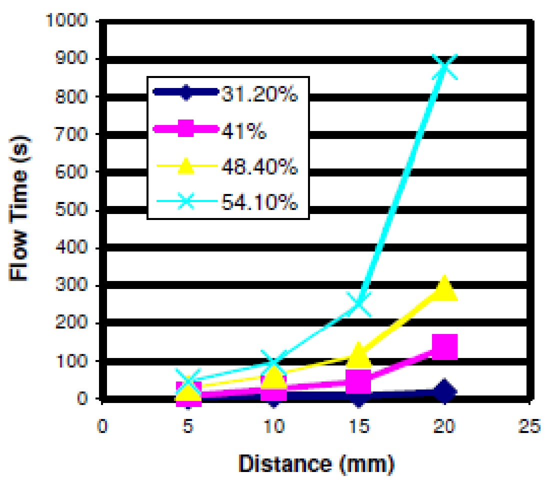

Figure. 4 Flow time vs flow distance of underfill using diamond Z3.

From Figure 4 we can see that the results of flow test using diamond powder Z3 has shown similar flow behavior to the diamond powder Z2. However, when the diamond load increases from 48.4% to 54.1%, the flow speed dramatically dropped due to the increase of viscosity and the friction in-between diamond particles with non-spherical shape.

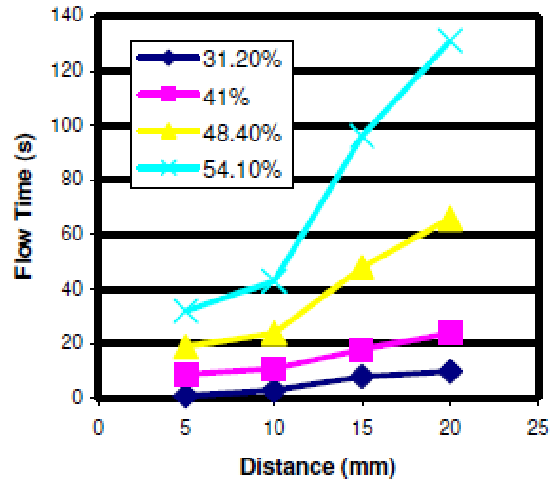

Figure 5. Flow time vs flow distance of underfill using diamond Z6.

From Figure 5 it is very interesting to note that using diamond powder Z6, the flow is much faster than the finer powders of powder Z2 and Z3. This could be contribution of larger powder size and lower viscosity.

Figure 6 below shows the flowability of silica filled underfill changing with flow distance. At the beginning, the silica filled underfill flows very fast and with increasing distance, it flows slowly. By comparing Figure 6 with Figure 5, it is very obvious that diamond filled underfill has similar flowability to silica filled underfill even though diamond powder doesn't have spherical shape, which is shown in Figure 7.

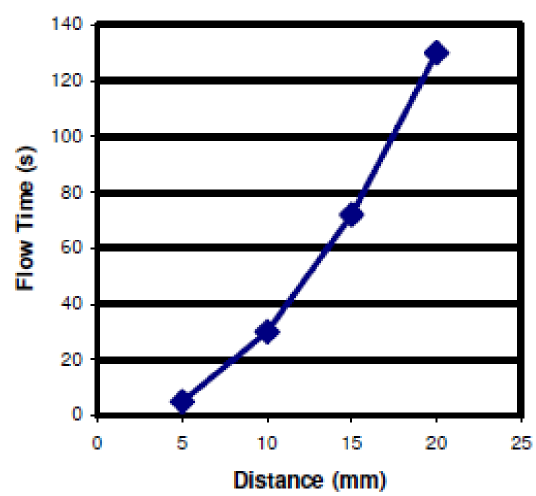

Figure 6. Flow time vs flow distance of silica filled underfill.

Figure 7. Image of diamond particle

B. Thermal Conductivity

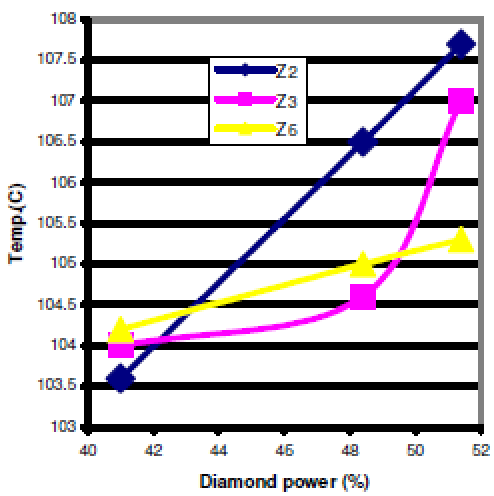

Figure 8. The temperature of cool surface changing with diamond load.

From Figure 8 we could easily see the temperature of the cool surface increases with increasing diamond load, which sounds very reasonable. It was also found that at diamond load of less than 41%, the temperature at the cool surface follows this order: Z6>Z3>Z2. Increasing the diamond load, e.g. 54%, the temperature at the cool surface changed the order to opposite: Z6<Z3<Z2. This could be because at low diamond load, larger diamond particles are easily in contact with each other so that thermal conductive channels are built among diamond particles. While diamond particle size is smaller with lower volume percentage of diamond, there is large chance for epoxy filled in-between particles, so the larger diamond particle size (Z6) has better thermal conductive performance. At the higher diamond load, the diamond with smaller particle size (Z2) has large surface area so that diamond particle can be easily tightly packed; while the diamond with large particle size has difficulty in packing tightly due to irregular shape of the diamond particle, so the diamond with small particle size demonstrated better thermal conductive performance. Figure 9 below shows the delta T changing with the diamond load. The Delta T decreases with increasing diamond filler load. It shows a similar trend as the temperature of the cool surface.

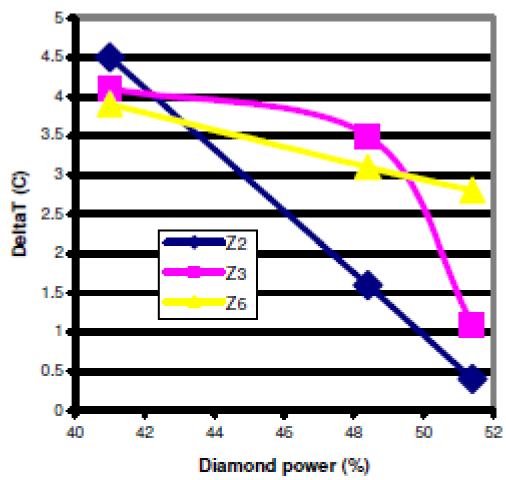

Figure 9. Delta T Vs. diamond filler load.

From Figure 10 it could be found that the thermal conductivity of underfill increases with increasing diamond filler load. At the higher diamond filler load, the thermal conductivity can reach to 6 W/m.K, which is much higher than the thermal conductivity of silica filled underfill. The higher thermal conductivity is mainly contributed to the high thermal conductive diamond filler and high filler load.

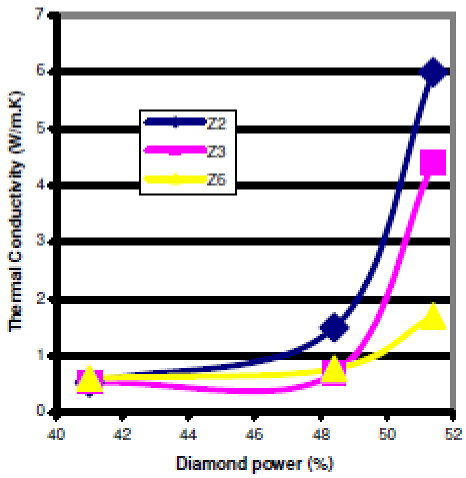

Figure 10. Thermal conductivity Vs. diamond filler load.

C. Pressure Cook Test

The diamond (Z2) filled underfilled flip chip undergo the pressure cooking test (PCT) for 168 hours. The C-SAM was used to detect voids and delamination before and after PCT. Figure 11 shows the images of C-SAM before and after PCT. From Figure 11 we can find that there are no underfill voids in underfilled flip chip before PCT, and no delamination and voids in underfilled chip after PCT. All these results have shown that diamond filled underfill not only has good adhesion but also has good moisture resistance.

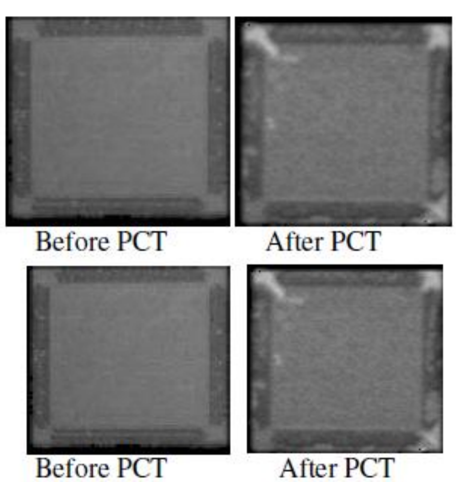

Figure 11. C-SAM images of diamond underfilled flip chips after 168 hrs PCT

D. Thermal cycling Test

The diamond Z2 underfilled flip chips were subject to C-SAM inspection before and after thermal cycling 1000 cycles. All C-SAM images are listed in Figure 12. From Figure 12 it is easily found that there are no underfill voids and delamination in diamond underfilled flip chip before and after thermal cycle test (TCT) for 1000 hours.

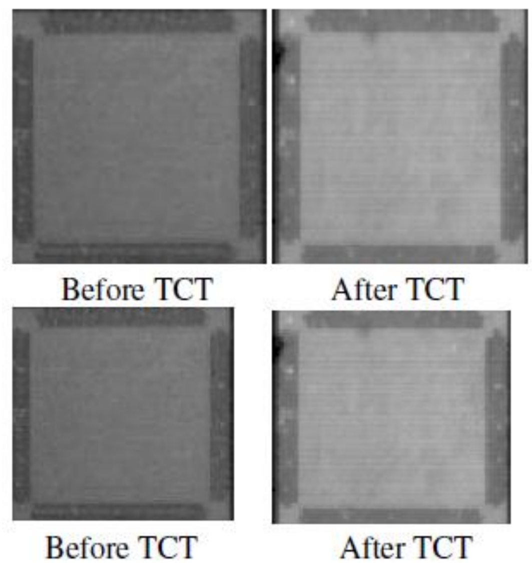

Figure 12. C-SAM images of Diamond Z2 underfilled flip chips after 1000 hrs cycles

CONCLUSION:

The diamond powder filled underfill has been developed with different particles. All diamond filled underfill has good flowability and the diamond particle size not only affects flowability but also affects thermal conductivity of diamond filled underfill. The thermal conductivity of diamond Z2 filled underfill can reach to 6W/m.K, which is much better than silica filled underfill (0.5W/m.K).

The diamond filled underfill has passed the pressure cooking test and thermal cycling test. All results from these tests have shown that diamond filled underfill is good for high end applications.

References:

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