High Thermal Conductive Die Attach Paste Using Polymer and Micron Size Silver for Power Semiconductor Package

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Abstract

Power semiconductor package manufactures and electronic device suppliers have been looking for Pb-free alternative to traditional high Pb solder die attach adhesives. Lead solders have high thermal conductivity, 30-50W/mK, and known process with some difficulties in high volume mass production such as void, bond line control, and requiring reducing atmosphere such as forming gas. Lead is now categorized as hazardous substance to human body and environment and its products are scheduled to be banned within a few years. Standard silver epoxy pastes and Electrically Conductive Adhesives (ECSs) are other forms of die attach adhesives but the thermal conductivity is not adequate for Power devices. Eutectic gold-tin solder (80Au20Sn) has 57W/mK but it is high cost material. Currently Silver sintering material has become popular for electronic device because it has high thermal conductivity (150~250W/mK) by using nano silver sintering. But it requires high bonding temperature and pressure. It makes brittle bonding structure and has limitation in die size due to high stress.

New silver sintering material in this paper is composed of micron size silver and organic polymer. This technology overcomes all the limitations of conventional silver epoxy, eutectic gold thin solder and silver sintering product by using the unique design of polymer composition. This new silver sintering technology using polymer and micron size silver is a cost effective solution to replace Pb solder for power device and the thermal performance is almost same as nano silver sintering products. The application process is the same as standard silver epoxy and does not require new equipment. It is a cost effective drop in solution.

Key words

Silver sintering, Micron silver, High thermal conductivity, Pb free

I. Introduction

A number of industries are developing new product-lines with innovative electronics packages that require lower thermal resistance and high temperature stability, including hybrid electric vehicles, concentrator photovoltaic and wide bandgap RF amplifiers. One of the largest obstacles in the design and manufacture is the thermal management of the devices. Localized heat generation is a common characteristic of the semiconductor chips used in these devices. For high power applications the thermal impedance of the die attach layer can play significant role in the thermal management and the operating temperature. Therefore, one would like to use the highest thermal conductivity and lowest thermal resistance die attach material that is capable for high volume manufacturing.

In a typical electronic packaging process, chips are attached to substrates and electrically connected before they are encapsulated or sealed for protection. The attachment and electrical interconnections provide the chip with an infrastructure for the flow of electrical signals, mechanical support and heat removal. The die attach materials(1) used in the packaging of high performance power semiconductors are required to have high thermal conductivity. Lead solders, eutectic gold-tin, transient liquid phase sintering (TLPS) pastes(2) and nano-silver sintering technology(3) are typical materials used for the die attachment of power semiconductor. This paper will introduce a new die attach material using thermoset

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Silver sintering materials have become an attractive alternative for power devices because they possess high thermal conductivity achieved through solid state diffusion or "silver sintering". But most often high bonding temperature and pressure are required to achieve a high reliability joint when silver sintering technology is employed. Similar to soldering, silver sintering technology requires backside metallization due to slow diffusion into bare silicon. HSSP (Hybrid silver sintering products) are composed of micron size silver and an organic phase. This technology overcomes the limitations of silver sintering products by using the unique design of polymer composition. The unique organic and polymer composition facilitates silver sintering at relatively low temperature compared with sintering silver and enables up to 250W/mK thermal conductivity without pressure during cure. The polymer enables adhesion to a variety of surfaces, bare silicon, gold and silver metalized die and silver and copper metal surfaces. The viscosity of HSSP adhesives is similar to standard epoxy pastes and its application processing is a drop in to conventional silver epoxy die attach paste.

II. Experimental Procedure

A. Sample preparation

Five silver paste samples were prepared as Table 1. Sample A, B, C, D and E have 91%~98% of silver weight % after cure by different mixing ratio of silver, thermoset resin. The silver used in the formulations is micron size flake and the average size is 5μm. The SEM image of the silver flake is in Figure 1.

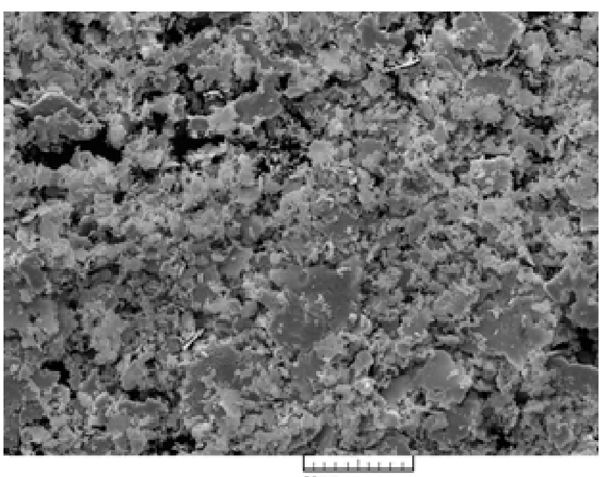

Figure 1. SEM image of micron size silver flake

All of the solvent evaporates during the staged cure process. Silver weight % number were calculated based on TGA weight loss data. The temperature profile of TGA is below.

<u>Cure Profile</u>

1. Ramp 30 min from 23°C to 150°C
2. Hold 30 min at 150°C
3. Ramp 40 min from 150C to 250°C
4. Hold 120 min at 250°C
5. Cool down from 250°C to room temperature

	Silver	Thermoset resin	Solvent	TGA Weight loss	Silver weight % after cure
A	83%	9 %	8 %	8.5%	91 %
B	86%	7 %	7 %	7.4%	93 %
C	90%	4 %	6 %	6.4%	96 %
D	90%	3 %	7 %	7.4%	97 %
E	90%	2 %	8 %	8.4%	98 %
Con trol	80%	20%	0%	1.4%	81%

Table 1. Silver paste composition by weight

B. Test method

(1) Die shear strength

The die shear strength of A, B, C, D and D materials were tested by using a Dage 4000 bond tester equipped with heat block was used for the evaluation. Figure 2 showed the measurement set up. The paste was first dispensed on a lead frame and die was placed on the dispensed paste with appropriate bonding force to achieve 30~40um bond line thickness and ~200 micron filet around the die after die placement. Silver plated copper lead frames and gold plated or bare silicon dies were used for this experiment. The die size was 3mm x 3mm and the thickness is 250 microns. The die attached samples were cured in box oven and the final dry thickness is 25 microns +/- 3 microns. The die attached samples were cured in box oven with Nitrogen environment used during the curing process. The temperature profile of cure condition is the same as TGA temperature profile above. The die shear strength was measured on heated block as shown in Figure 2.

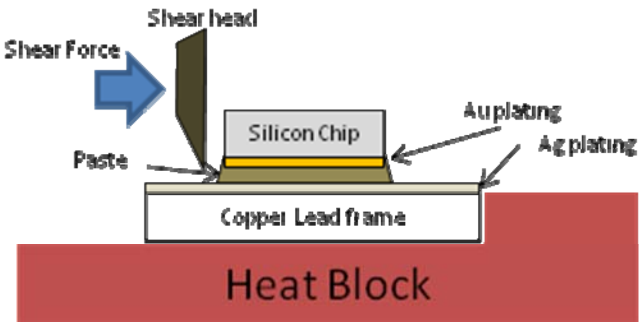

Figure 2. Schematic illustration of die shear test

(2)Thermal conductivity measurement: Bulk & K_{eff}

The bulk thermal conductivity were measured by Netzsch LFA 447N Nanoflash instrument. The samples were cured with the same cure profile as the die shear sample preparation. The sample size is 8mm by 8 mm with 1.5mm thickness.

In many cases, the bulk thermal conductivity data of die attach paste doesn't have correlation with the thermal resistance in the package level because it only represents bulk conductivity and doesn't consider interfacial resistance between die and adhesive layer. To obtain more information about the contact or interfacial resistance, we developed a test method in which we determine the "effective" conductivity, termed K_{eff}, which accounts for the loss of thermal conductivity due to die attach layer to substrate and die attach to die resistance. The K_{eff} sample is prepared by making sandwich with die attach paste and two gold metalized silicon die as shown in Figure 3.

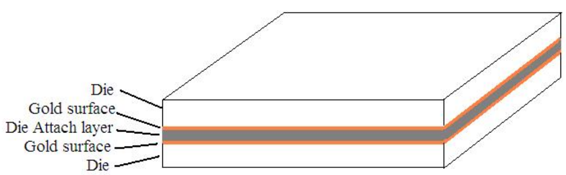

Figure 3. K_{eff} sample

Netzch LFA 447 Nanoflash instrument was used to measure K_{eff} .

C. Result and Discussion

(1) Die shear strength

The die shear strength of A, B, C, D, E materials and the control sample(Ag 80%) were measured at room temperature and 260°C(heat block temperature) and the results are shown in Figure 4 and 5. The room temperature die shear strength has tendency to go down when Ag loading is increased. It is because thermoset resin ratio is decreased and thermoset resin has higher contribution to die shear strength at room temperature than silver. However, the die shear strength data at 260°C is showing different trend. A, B, C and D have similar adhesion at 260°C but the die shear strength of control sample (silver:80%, resin:20%), which showed the highest room temperature die shear strength due to high thermoset resin ratio, drops dramatically at 260°C. The glass transition temperature of the thermoset resin used in this experiments is 84°C and it becomes soft and the adhesion strength gets weaker at 260°C. Thermoset resin has usually strong adhesion and cohesive strength below glass transition temperature but its adhesion becomes very weak above glass transition temperature. So thermoset resin bonding strength has much less contribution to 260°C die shear strength than silver sintering strength.

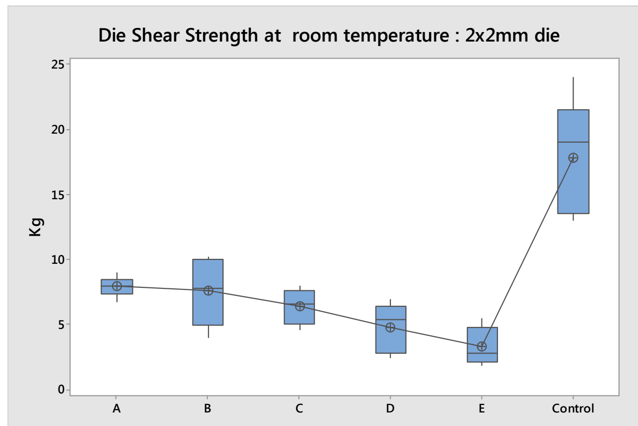

Figure 4. Box plot of the die shear strength at room temperature

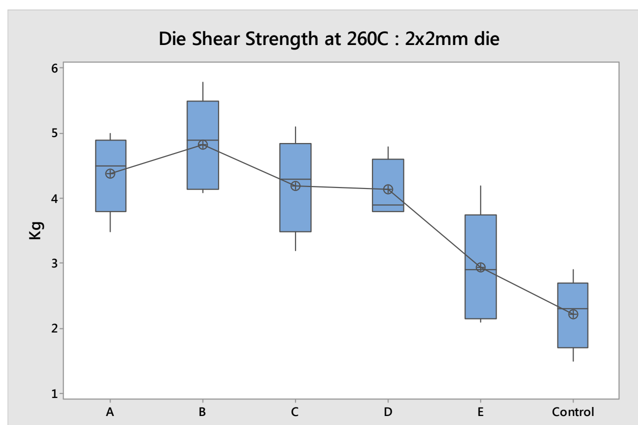

Figure 5. Box plot of the die shear strength at 260°C

Silver sintering bonding to metal lead frame and metalized die is much stronger than thermoset resin adhesion at high temperature and high temperature die shear strength is mostly determine by Ag sintering bonding. Silver in the adhesive layer makes strong bonding to die and lead frame surface. Silver has high melting point and the adhesion should not be changed much by temperature while polymer resin adhesion is significantly changed by temperature. Polymer resin property is significantly changed before and after glass transition temperature. From these die shear strength results, Ag component makes strong bonding and contributes to 260°C die shear strength.

If comparing the die shear strength of E with A, B, C and D, E has much weaker adhesion at 260°C. It shows that a silver paste should have minimum amount of thermoset resin in order to make good silver sintering bonding. The shrinkage of thermoset resin forces the silver particles to diffuse into another silver particle and the metal surfaces [4].

(2) Shrinkage after cure

The volume percentages of solvent, thermoset resin and solvent are shown in Table 2. Silver density is much higher than thermoset resin and solvent so the volume percentage is different from weight percentage.

	Silver Vol%	Thermoset resin Vol %	Solvent Vol%
A	35%	33%	32%
B	40%	29%	31%
C	49%	19%	31%
D	49%	14%	36%
E	49%	10%	42%
Control	31%	69%	0%

Table 2. Silver paste composition by volume

Bond line thickness of each sample was measured before and after cure and shrinkage was calculated from bond line thickness change after cure.

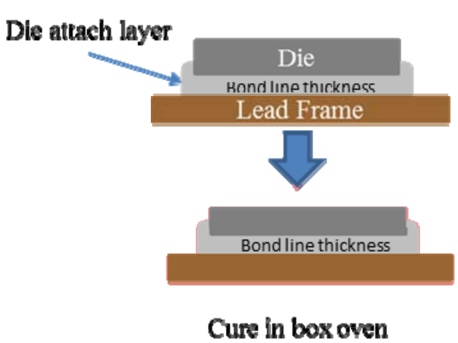

Figure 6. Bond line thickness

Solvent volume percentage and bond line shrinkage are plotted in Fig7.

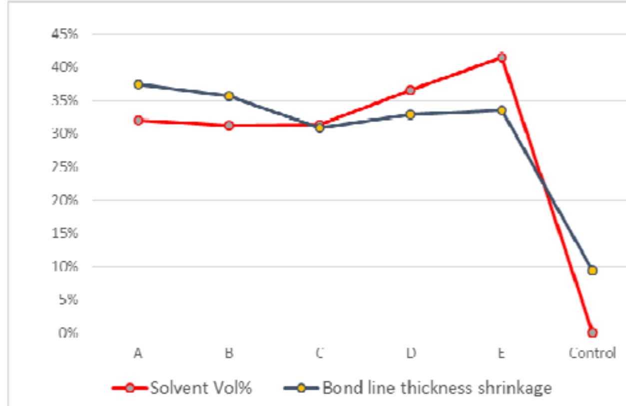

Figure 7. Solvent volume percentage and bond line thickness shrinkage after cure

The control sample doesn't have solvent but 9.4% bond line thickness shrinkage after cure. Some part of this shrinkage is owing to resin evaporation or degradation. The control sample has 1.4% weight loss during cure as shown in Table 1 and the weight loss is converted to 4.8% volume loss. The rest of the bond line thickness shrinkage, 4.6%, can be explained by the thermoset resin crosslinking.

A and B have more bond line shrinkage than solvent percentage and D and E have less bond line shrinkage than solvent volume percentage. The shrinkage number of C is almost same as solvent volume percentage. A and B have 9% and 7% of thermoset resin and the resin crosslinking reaction induced additional shrinkage.

(2) Thermal Conductivity: Bulk Conductivity

The thermal conductivity samples of A, B, C, D, E and control samples were cured by two cure profiles, 200°C cure profile and 250°C cure profile, which are described below. The test results are shown in Figure 8.

<u>200°C Cure Profile</u>

1. Ramp 30 min from 23°C to 150°C
2. Hold 30 min at 150°C
3. Ramp 20 min from 150C to 200°C
4. Hold 120 min at 250°C
5. Cool down from 250°C to room temperature

<u>250°C Cure Profile</u>

1. Ramp 30 min from 23°C to 150°C
2. Hold 30 min at 150°C
3. Ramp 40 min from 150C to 250°C
4. Hold 120 min at 250°C
5. Cool down from 250°C to room temperature

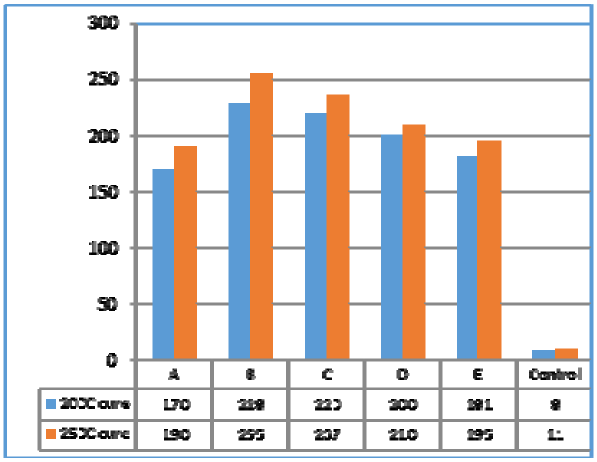

Figure 8. Thermal conductivity of bulk samples cured at 200°C and 250°C.

For each of the paste sample, the sample cured at 250°C has higher thermal conductivity than 200°C. Silver sintering reaction is highly activated by temperature. Paste B showed the highest thermal conductivity among six samples even though C, D and E have higher silver ratio than B. In order to maximize thermal conductivity, paste should have certain level of thermoset resin. The role of thermoset resin is to make the adhesive layer shrink and induce silver particle to sinter into another silver particle and substrate.

Hybrid silver sintering mechanism is described in Figure 9. The silver sintering process is driven by heat and pressure. The usual silver sintering paste, which is composed of nano-silver powder and solvent, requires external force for silver sintering(3). However hybrid silver sintering formulations of A~E have thermoset resin and the cross-linking of thermoset resin during cure process induces shrinkage and silver sintering.

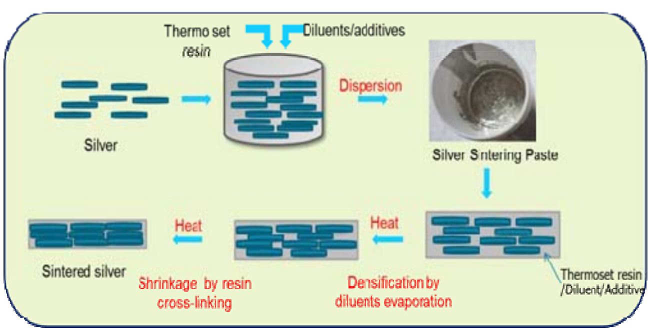

Figure 9. Process diagram for making silver sintering formulation and silver sintering by resin cross-linking

(3) Bond Line Thickness

Bond line thickness is one of critical factors to determine the performance of hybrid silver sintering conductive die attach adhesive paste. It has big influence on conductivity and die shear strength. Die attach paste is generally dispensed by needle dispenser and followed by die placement and die attach cure process as shown Figure 10.

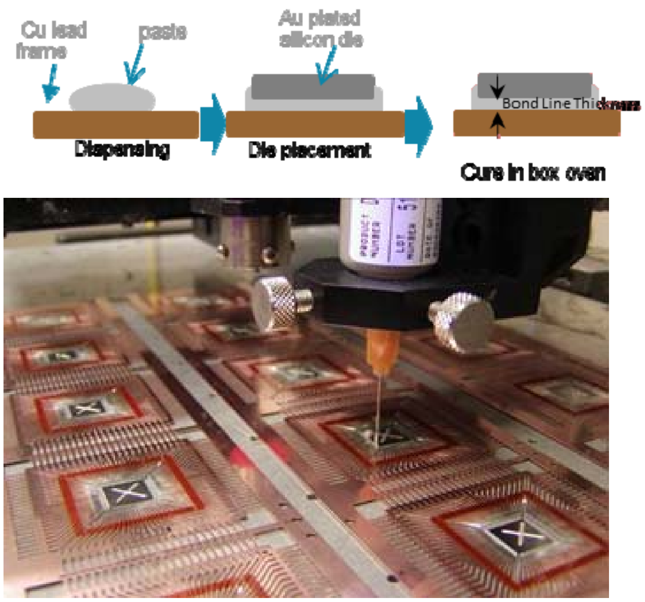

Figure 10. Die attach process diagram and needle dispensing

The die is placed on the paste deposit and the bond line thickness can be controlled by dispensing pump pressure, dispensing time, dispensing needle size and die bonding force. 5μm, 15μm and 25μm bond line thickness were prepared by using B formulation of Table.1 and cured by 250°C cure profile. The results of die shear strength at room temperature and 260C° are shown in Figure 11 and Figure 12.

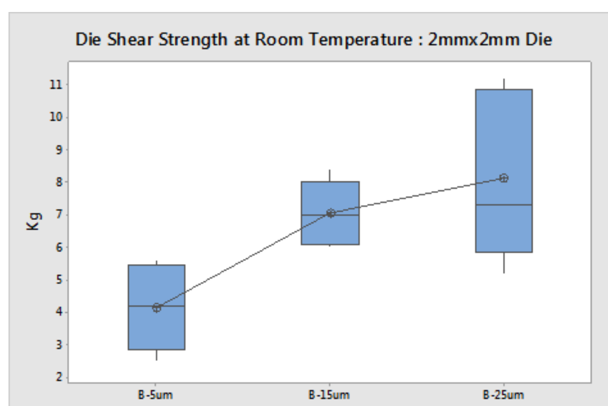

Figure 11. Die shear strength comparison of 5um, 15um and 25μm at room temperature

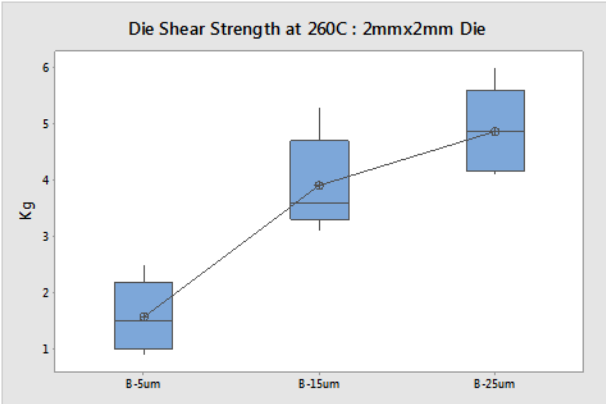

Figure 12. Die shear strength comparison of 5µm, 15µm and 25µm at 260C°

According to the die shear strength result, bond line thickness has great impact on die shear strength of both room temperature and 260C°. Thicker bond line has higher die shear strength.

The K_{eff} of three kinds of adhesive thickness, 5µm, 15µm and 25µm, were measured after being cured with 200C° and 250C° cure profiles. The results are shown in Figure 12. The 25um sample has the highest K_{eff} followed by 15um and 5um. 5um sample has extremely low K_eff compared with 15um and 25um.

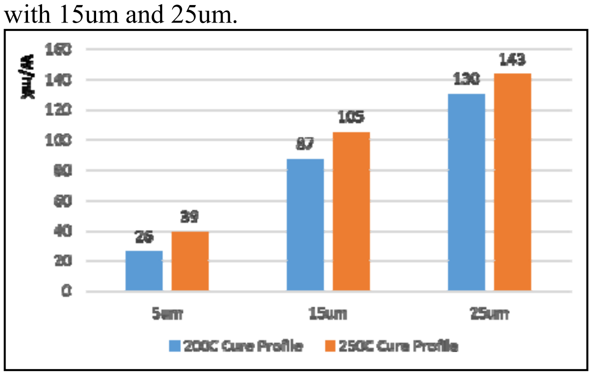

Figure 13. K_{eff} comparison of 5um, 15um and 25um at 260C°

For the sample of 5µm bond line thickness, analysis showed several voids in the bond line which results in a low K_{eff} value since air cannot effectively transfer heat. We believe the voids result from the inability of the solvent vapor to escape from adhesive layer during cure process because of limited space the increasing viscosity due to the cure reaction.

III. Conclusion

We have shown that Hybrid Silver Sintering Paste (HSSP) using thermoset resin and micron size silver can have greater than 200W/mK bulk thermal conductivity by optimizing the ratio of micron size silver and thermoset resin. In this system, the silver sintering process is driven by heat and thermoset resin crosslinking. The adhesive layer shrinkage by crosslinking reaction enable silver flake to sinter without external force.

We have also demonstrated that bond line thickness control is a critical process parameter for hybrid silver sintering paste to have high thermal conductivity and high die shear strength. If bond line thickness is less than 10µm, the conductive adhesive layer easily has void because solvent is trapped inside of the layer. Thicker bond line samples have wider window and is more efficient for solvent to escape from the adhesive layer.

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