



INVESTIGATION ON THERMOCOMPRESSION BONDING USING LEAD FREE SINTERABLE PASTE AND HIGH LEAD SOLDER PASTE FOR HIGH POWER LED PACKAGING

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ABSTRACT

Persistently growing High-power LED packaging is used in various flux applications especially microelectronics, aerospace, oil and gas as well. Thermo-compression die-attach layer is perceived to be the most critical element in high-power LED packages as the increase in operating temperature requires new materials with suitable thermo-chemical properties also with suitable melting points of next generation lead free die attachment material. In this situation, Hi-lead solder (RM218: Pb92.5Sn5Ag2.5) which known as high temperature material is widely being used in most semiconductor assembly for die attach, yet it deduces few reliability challenges like solder voids, the tilt performance and also solder splash which has been considered as major quality issue in assembly of high-power LED packages. As a solution, sintering epoxy paste (SPC073-3: Sn96.5/Ag3/Cu0.5) is being considered as a replacement due to the challenges faced by using Hi-lead solder paste. In this case, sintering epoxy paste demonstrating excellent electrical and thermal performance for High-power LED packages that is known to be demanded in market. Thus, this study investigates the differential pastes sintering paste and solder paste, in order to identify best die attachment material to be used in thermo-compression bonding method. Therefore, the shear strength was resulting good indication where the sintering paste was recorded 2.4 Kg/mm meanwhile the solder paste was recorded 0Kg/mm at peak temperature of 260°C. Besides of that, the pot life seems promising as the sintering paste seems to have constant viscosity of 100Pa*s throughout the 48 hours tested while, high lead solder paste records viscosity from 100Pa*s marginally increase as the time increase which effects the inconsistency of pot life. The voids performance proves sintering epoxy paste has the same pinhole voids as its individual, but the solder paste's pinhole voids are not same as individuals which easily can fail when the particular shear force was applied. Hence, sintering epoxy paste could resolve the quality issue by using thermo-compression bonding method and produce the better reliability than the solder paste.

Keywords: LED, die-attach, sinterable.

INTRODUCTION

High-power LED package is also known as major emitter in many flux applications which previously being denominated by variety types of light bulbs [1]. High-power LED packages is a unique as it will be in first choice because of its high-speed application where heat dissipative performance is demanded in various industry. The assembly processes are simplified from the standard LED assembly with only FET die and ESD die, hence deduces an addition heat dissipation path to the top surface. In thermo-compression bonding the element that perceived to have high importance, ensure fixation of the die on its substrate as well as dissipation of the heat generated in the die [2, 3]. There are essentially, several criteria that a material needs to have in order to be used for die-attach. The material should demonstrate high thermal conductivity, low coefficient of thermal expansion (CTE) mismatches between the die and the substrate, good wettability as well as adhesion to the die also the substrate, good mechanical properties with stress relaxation behaviours, good fatigue resistance, good corrosion resistance, good rework ability, high electrical conductivity and good reliability [3].

Currently, numerous studies were carried out in order to identify the most suitable material and techniques for die-attach. However, studies on identifying the materials with least disadvantages as well as most durable,

with high melting point need to be done. Indeed, existing work and studies have disclosed the processes that includes solder alloys i.e. AuSn, PbSnAg, AuGe and AuSi as well as nano- and micro- particle sintering (regularly with Ag) apart from transit liquid phase bonding [3]. The former is divided into two categories, i.e. Transient Liquid Phase diffusion bonding (TLP) and sintered nanoparticles. TLP bonding using Ag-In can be done either as thin film layers or as the mixture of particles. The ratio of Ag- to In- fundamentally, is chosen in such way so the end product will be in Ag- rich region. Meanwhile, the melting point of In- being as low as 156.6°C enables lower temperature processing. Sintered nanoparticle Ag die attachment is done with Ag nanoparticles in a paste with an average silver particle size of 30nm [4].

On one hand, sintering process could be done at 285 °C and the end product could withstand 400°C. This is because the uniqueness in sintering process where it is an atomic diffusion process, which avoids the liquid phase during the intermediate stage and thus the quality problems such as non-wetting, voids and many more, can be eliminated. Besides, sintering particles basically are applied to delay the instruction of mass diffusion and eliminates densification diffusion at high temperature and melting point which able to stabilize according to process condition which leads to improved properties to support high temperature packages. On the other hand, being a



single metal system, sintered Nano-silver will not have the intermetallic formation that leads to potential failure mechanism for multiple metal systems. Nevertheless, the occurrence of electrical migration and dry migration, which cause Ag to build up at cathode in dendrites form that will reach the anode that, will later cause failure of the device [5].

EXPERIMENTATION

The purpose of this experiment is to introduce new generation lead free die attachment material using thermo-compressive bonding method for High-power LED package. Suitable material and techniques for die-attach are quantified. Temperature, pressure and time are the main parameters that quantify the reliability of bonding. In this case, reliability refers the level sensitivity of impurities and particles where it is necessary to manage the package while accurately controlling the impurities, which promises the product quality upon reaching the market [5]. This experiment also tends to examine the thermal performance. To analyze this experiment, an analysis phase will be conducted where mechanical performance, thermal performance and brightness will be evaluated. Figure-1 shows the bonding diagram used in this study.

a) Die attach materials

Two different die attach materials were used, as described in below table:

Table-1. Die attach materials.

Sample	Type	Thermal Conductivity (W/mK)	Powder	Composition
RM218 (Hi lead Solder)	Water clean	25	Type 3	Pb92.5/Sn5/Ag2.5
SPC073-3 (Sintering Paste)	No-Clean	30	Type 3	Sn96.5/Ag3/Cu0.5

b) Process

i. Screen print

A stencil with a 2mm x 2 mm opening and a thickness of 2 mils was used for manually printing paste onto the DEK machine. Only single print deposit was employed. For each paste, five strips were prepared. Below Table-2 describes the parameter used:

Table-2. Screen print parameter.

Metal Squeegee Thickness	Blade Angle	Force on Blade per inch of Blade	Blade Speed	Work Life on Stencil
10 mils = 250um	45-60 degrees	0.5 - 1.0 kg	2.4 in./sec	16 hours

ii. Die attach

The process of joining metal to metal that brought into atomic contact by applying force and heat simultaneously is known as thermos-compression bonding. The test dies and clips was kept on Nitrogen (N₂) contained cabinet in order to avoid oxidization. For this experiment, the test dies have been made in dices rather than full wafer formation. Then, the lead frame was placed on the hot plate with vacuum chuck. After that, the collet will pick up die with vacuum and proper alignment. The picked die will be brought into metal to metal contact when the desired pressure was achieved. However, as the pressure determined, the temperature will increase rapidly. Table-3 below presents the bonding conditions:

Table-3. Bonding conditions.

Die Attach Material	Bonding Time (ms)	Bond Force (g)	Peak Temperature (°C)	Pressure (MPa)
RM218	100	100	260	0.2
SPC073-3	100	100	260	0.2

Machine ESEC 2000 had been used to perform pick and place process for the selected materials. 10 samples had been built using thermo-compression bonding. Thermo-compression bonding was experimented by varying the bonding time, temperature and pressure in order to achieve the quality of bonding. Yet suitable bonding time, peak temperature and pressure had been identified.

iii. Reflow

The strips were reflowed under air atmosphere via a MALCOM infrared oven. The profile with fixed. Peak temperature and soaking temperature were used. The Soaking temperature was 200 °C, while the peak temperature was 260 °C with total time of 90sec, respectively, as shown in below Figure (1):

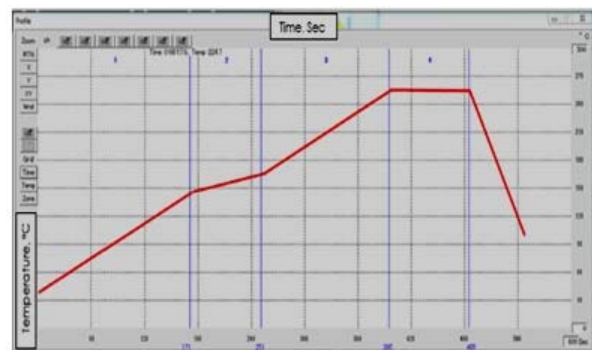


Figure-1. Reflow profile.

RESULTS

The test was planned to compare the different between solder paste and sinterable die attach material which also questions the bonding strength for both paste



used. The sinterable paste was being used to develop the thermo-compression bonding parameters. However, the samples of both materials had been prepared and experimented on variety of bonding conditions.

a) Thermal performance

By considering the die thickness of 5 mils, thermal testing was performed by using the wavelength shift method [6]. Thus, this methodology allows us to use light to measure the device junction temperature by correlating wavelength shift to junction temperature shift. FET die is particularly suitable as it responded linearly for wavelength and junction temperature. The measurement results are shown below in Figure-2(a) and 2(b):

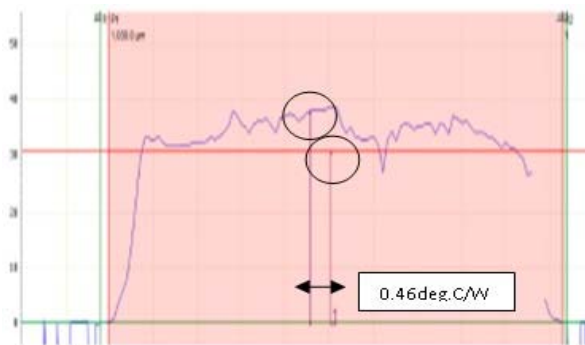


Figure-2(a). Rth measurement for SPC073-3.



Figure-2(b). Rth measurement for RM218.

Thermal measurements deducing in a SPC073-3 records 0.46deg.C/W reduction in thermal resistivity. Meanwhile, for RM218 solder paste records 0.8deg.C/W reduction in thermal resistance. This exhibits the heat dissipation was improved for lead free sinterable paste (SPC073-3).

b) Mechanical Performance

Adhesive strength defines the measurement of the attachment between adhesive and substrate. This may occur either by mechanical reaction where the adhesive reacts by the way of small pores of the substrate or by one of several chemical mechanisms [6].

In this case, the experiment was conducted with variety of peak temperature to identify the range of closure

where it seems passed on preliminary research. However, SPC073-3 performed better than the RM218 high lead solder at peak temperature of 260 °C. It is clearly shown that lead free solder requires a ramp to peak profile unlike the commonly used ramp-soak-peak profile for leaded solder where it describes the significance difference of shear strengths of SPC073-3 samples for the peak temperature of 240 °C, 250 °C and 260 °C. Those reflowed lead free samples were tested with ball shear machine to evaluate the solder joint strength and the joint shear strength seems promising for sinterable paste, meanwhile for solder paste, the joint strength looks promising at peak temperature of 240 °C and its drastically reduce at peak temperature of 260 °C.

Since, high-power LED requires nominal temperature in order to prove best reliability; sinterable supports the data to perform better than the solder paste. The variation is shown in Figure (3) below:

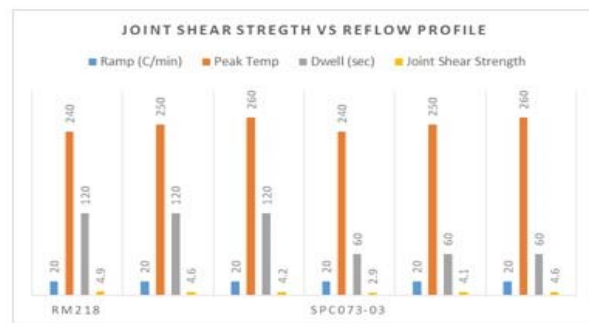


Figure-3. Joint strength analysis.

Thermal cycling had been done on 5 pieces of units from -40 °C to +125 °C for 100 cycles. Thermal resistivity had been identified before and after experiment, hence, no difference was observed. Sinterable paste has a modulus of elasticity of 11GPa, meanwhile hi lead solder paste has 60GPa, which deduces to have more resistivity to cyclic fatigue fracture.

c) Brightness

By considering the thermal resistance measurement results, the potential brightness improvement can be quantified as it differs in heat dissipative. The operating current can be allowed as the junction temperature, T_j remain constant and the limiting factor in control. This tends to increase a package brightness since the operating current will be inversely proportional to the thermal resistance (R_{th}).

$$R_{th} = [T_j(\text{initial}) - T_j(\text{final})] / [V \times I(\text{in}) - P_{90\text{optical}}] \quad [6]$$

Initial brightness calculation will be assumed as steady state operation and no droop [6]. However, the droop's effect need to be quantified by conducting the empirical experiment in both steady state and pulsed operation. In this case, droop refers to a LED phenomenon where photometric flux increased asymptotically as a function of current density to a peak brightness, then



reverses direction and brightness actually decreases at higher current densities. Thus, at high current densities, it is expected that droop may counteract the brightness opportunity to some degree [6,7].

Below table shows the brightness calculation for a differential solder paste used at a fixed junction temperature in a steady state operation and excluding droop.

Table-4(a). Potential brightness excluding droop for RM218.

Hi-Lead Solder Paste (RM218)			
Emitting area	Data Sheet	Hi-Lead Solder	Improvements
mm ²	lumens	lumens	%
4.5	300	558	46%
9	610	795	28%

Table-4(b). Potential brightness excluding droop for SPC073-3.

Sinterable Epoxy (SPC073-3)			
Emitting area	Data Sheet	Sinterable Epoxy	Improvements
mm ²	lumens	lumens	%
4.5	690	1210	46%
9	1580	2012	28%

d) Void performance

Basically, there was two types of voids was identified, which was volatiles and also the pinhole. However, the working structure behind these voids need to be more understand. Below Figure-4(a) and & 4(b) shows the voids from volatiles and pinhole respectively.

i. Voids from Volatiles:

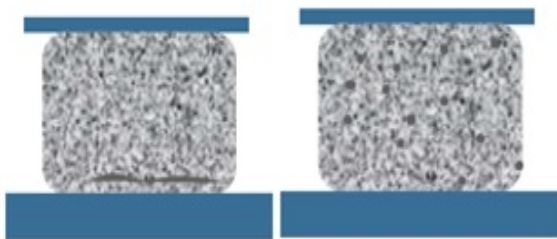


Figure-4(a). Volatiles void.

ii. Voids from Pinhole

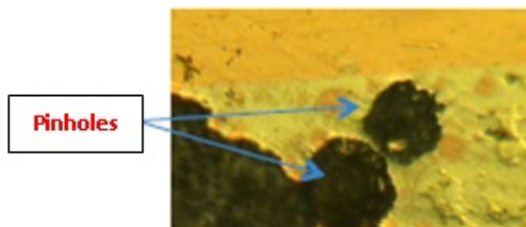


Figure-4(b). Pinhole void.

DISCUSSIONS

Sinterable epoxy die attachment paste seems to be the best choice in building the high-power LED packages, as it is compatible with silver and gold die back, bare copper lead frames and the PPF lead frames [8]. Besides that, TLPS materials have issues with solder such as solder voids, tilting, and others. Even though sinterable epoxy paste does not re-melt, it deduce some good criteria such as reliability and re-workability improvements. Further discussion need to be addressed in order to support sinterable epoxy paste.

a) Hi lead solder paste vs sinterable epoxy paste

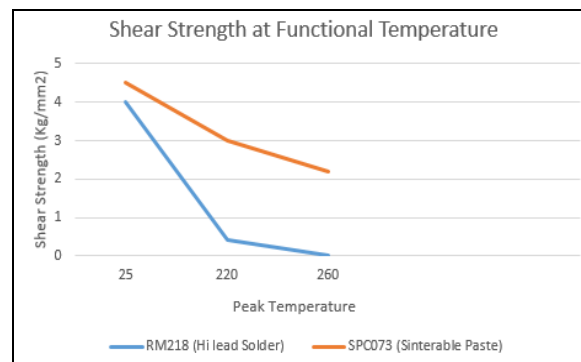


Figure-5. Shear strength at functional temperature.

Generally, shear strength defines the ability of die attaching material to withstand the separation between die and lead frame [6]. Hence, the functional temperature was analysed based on Figure-5 by varying from minimum to maximum peak temperature. For both die attaching material, it is known that minimum peak temperature is 25 °C and the maximum is 260 °C. It is also known that the peak temperature contributes to the shear strength of high-power LED packages.

At minimum peak temperature of 25 °C, the sinterable paste was found to have high shear strength than the solder paste. At 220 °C, the shear strength seems to be dropped drastically; yet sinterable paste seems to be the lower drop than the solder paste that relies on huge gap. When reaching the maximum peak temperature at 260 °C, the solder paste seems to fail the shear strength as it records 0 Kg/mm while sinterable paste records, 2.4 Kg/mm. By means, sufficient force was applied to test the strength of the die. Subsequent strength explains an approximate indication of how well the die was attached on substrate. This clearly results the sinterable paste has the good wettability that joins the particles and melting with good condition.



b) Pot life at room temperature

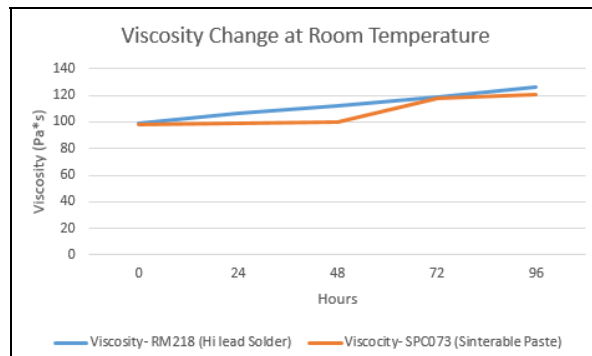


Figure-6. Viscosity change at room temperature.

Viscosity change does affects the reliability of a high-power LED package, as the particles become non-reactive as the pot life at room temperature was not controlled. Thus, the SPC073-3 (sintering) paste storage need to be critically studied as it should be stored on laboratory bench top. However, the viscosity was measured at 25 °C which known as room temperature and placed it 5mins on a parallel plate on Rheometer to stabilize the paste. Meanwhile, for RM218 (Hi lead) solder paste, the thawing time will be one hour as per the specifications and the stabilization will be placed on plate which rotates clockwise and anti-clockwise at 25 °C.

In this case, sinterable paste seems to have lower viscosity which was 120Pa*s at maximum reading of 96 hours, meanwhile, high lead solder paste records 129Pa*s at maximum reading of 96 hours. However, the graph illustrates, the viscosity is directly proportional to the hours of staging for both materials tested. This is a best characteristic in high-power LED packages, as it relies lesser the viscosity, better the performance of the paste [6]. Thus, by comparison of both die attaching material, sinterable paste has stable viscosity change while the solder paste increase rapidly. It has been determined to maintain 24 hour for sinterable paste pot life, while solder paste may be the shorter pot life that is a consideration on the cost of usage of die attaching material.

c) Mechanisms behind voiding

Voids from volatiles is something common when the void structures defined where it's can be visualized in "wormy" condition. However, it can be eliminated or minimized with the adjustments with the certain conditions on reflow profile optimization [8]. Generally, when discuss about the reflow profile, the best profile is defined at ramp to peak temperatures. Considering the thermal mass of high-power LED package, ramp to peak is often not the best option. Balance soak temperature to thermal mass and minimizing the total time to the peak temperature will results voids from volatiles can be eliminated or minimized drastically [8].

Besides that, pinhole voids can be defined as tiny round voids. It may be the cause of time taken to melt the

alloy particles in paste's was fast, as the fast melting time of alloy can reacts with the copper particles and preforms solidification condition. However, the late melting time of alloy particles joins the molecules but cannot lead to collapsing. In this case, these pinhole voids are generally non-contiguous and measured in the parameter of 15-25 micron in diameter.

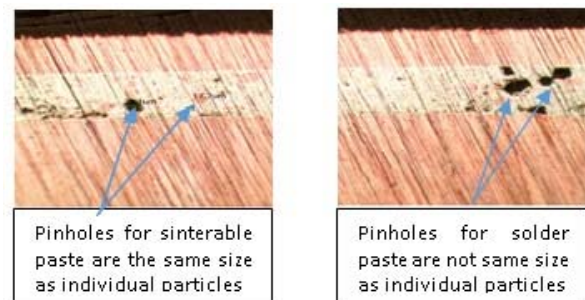


Figure-7. Pinhole voids.

When discuss about the way of eliminate this void as it affects the joint strength, yet this cannot be eliminated through the process optimization as they are a normal feature of sinterable paste, as its alloy particles performance criteria need to be consider. At the same time, it is also known that the pinhole voids of sinterable paste were produced in the same size of holes throughout the unit. Meanwhile the pinhole voids hole size for solder paste was inconsistent, which can affect the joint strength.

CONCLUSIONS

SPC073-3 performed better than the RM218 solder paste at both room temperature and at 260 °C for die shear test on bare die and clip attach. However, sinterable paste is a high lead solder paste replacement, as it consist of few advantages. For special case application like high-power LED packages solder paste, deduce many quality challenges as discussed above such as step soldering, no solder mask and others. Besides that, sinterable paste does not remelt or change footprint in reflow, which promising the stencil printing quality. Furthermore, the storage, shelf life, pot life and work life are comparable as well with the solder pastes [9].

Apart from that, mechanical, electrical and thermal performance are also seems promising and performs better than the solder joint [9]. There was a vital improvement in Rth as the sinterable epoxy records improved heat dissipation than hi-lead solder paste. Therefore, Sinterable paste is more reliable and can be classified as best die attaching material using the thermos compression bonding method. Therefore, other factors rather than die shear test, die tilt test should be considered in order to deduce a conclusion in this experiment. The major contributing factor to shear strength was the amount of die surface area that actually bonded on the substrate [10]. However, the pattern designed for this research seems successful, as there was no die crack occurred. The bond force applied on this research shall be quantified



with different forces, to identify the failures of thermo-compression bonding occurs at which force. Besides that, the possible failures shall be researched in deep by varying more testing methods.

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