

## **Determining the Compatibility of Sintered Silver Die Attach in Terms of Delamination Performance as Compared to Existing High Lead Solder Types in a Semiconductor Power Package**

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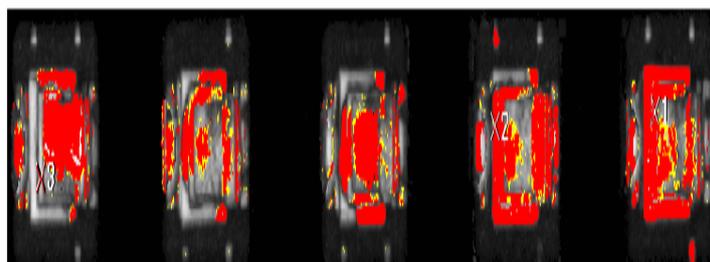
**Abstract:-** A quick and simple method for determining thermo-mechanical compatibility of sintered Ag die attach is presented without assembling samples for moisture level sensitivity assessments. Material components of a power semiconductor package such as the die attach material (high lead or SnPb solder and sintered silver die attach), copper lead frame, silicon die and epoxy mold compounds were isolated. Each component was studied individually by subjecting samples of SnPb, sintered Ag and epoxy mold compound to digital scanning calorimetry (DSC). The purpose is to be able to simulate thermal stimulus during manufacturing process. After the 1<sup>st</sup> heat treatment, a second heating step was employed on all components which additionally includes a copper lead frame and silicon die. The purpose of this step is to simulate customer reflow conditions during board mount. This step also derives the thermal graphs to determine the thermo-mechanical behavior of each constituent material from low to high temperature stimulus. The results suggest that sintered silver performs better compared to the SnPb die attach thermo-mechanically. The reason lies in the processing of these materials, SnPb transitions from a solid to liquid state at temperatures above 187°C. Hence during board mount, SnPb die attach has a tendency *not* to maintain structural integrity and thus prone to delamination. Sinter Ag on the other hand does not necessitate melting during its process steps and therefore maintains its structural integrity. Furthermore since sintered silver does not require melting process, the thermo-mechanical profile compared to other component material deviates less as compared to the SnPb solder types.

**Keywords:-** Sintered Silver, Die Attach, Tin Lead Solders, Thermal Analysis, Digital Scanning Calorimetry

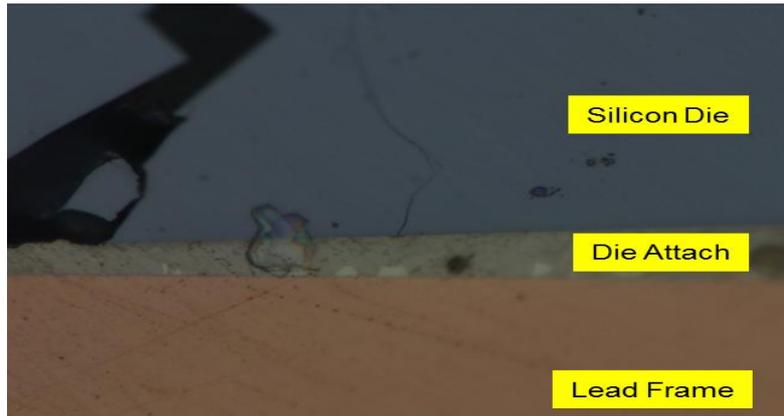
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### **I. INTRODUCTION**

A semiconductor package protects the die from external stimulus that can affect the performance of the device thermally, mechanically or chemically. The silicon die is housed on an outer covering or an encapsulant material called mold compound. A leadframe typically copper is used to connect the final device to the printed wiring board. To connect the silicon die into the leadframe a die attach material is used. There are 3 main functions of a die attach material. First is to attach the die into the lead frame. Second is to dissipate heat across the lead frame and third is to provide reliable connection and not fluctuate electrical stimulus when the device is in operation [1]. Depending on the complexity, sometimes wirebonds connect the silicon die into the lead frame. Discrete semiconductor devices particularly of high power applications utilize a clip which eliminates the use of the wire thus increasing the reliability performance by effectively dissipating heat and providing a robust connection on the die [2]. The reliability in terms of connection is compromised if the interface delaminates. This could cause catastrophic effects which may lead to device failures during use [3]. This can also result into thermo mechanical defects such as die or package cracks [4]. Figure 1a and 1b illustrates some failure mechanisms that can be rooted to incompatible thermal expansions.

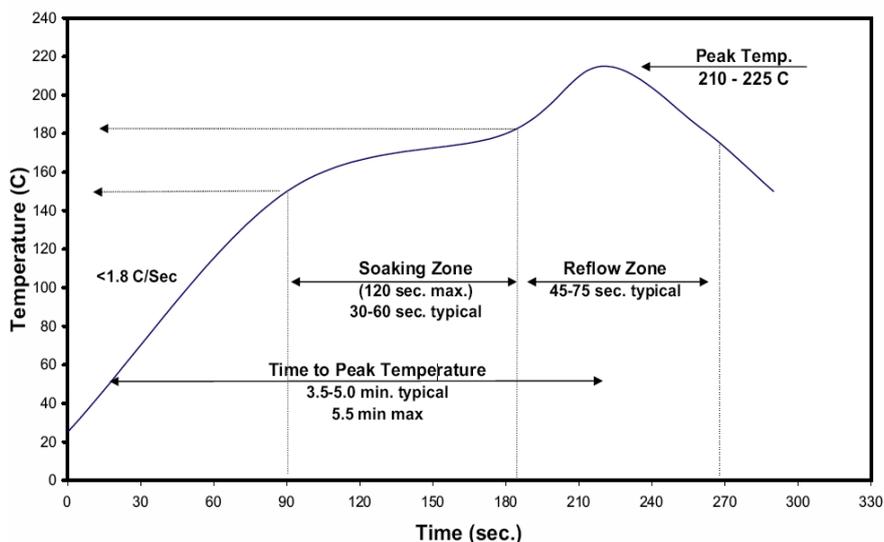


**Figure 1a: Delamination occurrences on a clip power package**



**Figure 1b: Die crack images rooted to CTE mismatch**

In order to ensure the material compatibility, understanding the behavior prior assembly is necessary. This can be achieved by subjecting samples to individual thermal assessments resulting into different temperature graphs. Oftentimes, the thermal processing during assembly process is not understood as well as its interaction that results into field failures and reliability problems. Mold compounds and die attach materials are composed of thermosets wherein a pre heat treatment is necessary to activate the flowability and processing [5]. On the otherhand the lead frame and silicon die does not require pre heat treatment since they are not polymeric materials. In order to determine material compatibilities digital scanning calorimetry (DSC) and thermo mechanical analyzers are utilized. The DSC is utilized to provide pre heat treatment for the thermo setting materials and the thermomechanical analyzer mimics the heat experienced by the package during board mount or reflow process. Individual TMA graphs are produced and overlaid across each other to determine if the constituent materials are compatible toward each other. This is the reason why exhaustive research and experimentations are done on materials in order to understand both thermal and mechanical behaviors. Thermomechanical analyzers provides a necessary information such as Tg and CTE. The equipment is composed of a pedestal that heats the specimen of interest. TMA's output data can be in a form of a temperature versus time graph that can be vital in understanding thermal and mechanical behavior of materials. When applied to semiconductor components, the information provides a powerful insight to visually determine if the interaction is probable to delaminate. Figure 2 illustrates a Pb reflow profile. The typical peak temperature of the graph for Pb solders is around 210°C to 215°C. The value for peak reflow temperature is derived from the fact that board manufacturers use this temperature to mount semiconductor devices on the PCB. Previous studies were implemented on delamination [6] using such methods. In this case, this paper focuses on the interaction of the sinter Ag die attach materials in relation to the components making up the power semiconductor package.



**Figure 2: Pb profiles used for attaching semiconductor devices during board mount [7]**

## II. METHODOLOGY

A Thermomechanical Analyser (TMA2940) and Digital Scanning Calorimetry (DSC 204 F1 Phoenix) were used to derive thermal graphs for components making up the semiconductor power package. Differential Scanning Calorimetry measures the heat flow in a material as a function of temperature and time. A sample is placed in a small Aluminium pan. Depending on the heating profile used, the tool can heat or cool a specimen. Nitrogen is employed in the process of heating and or cooling to ensure non-reactivity of the specimen [8]. DSC is effective in supplementing heating profiles for thermoset materials such as mold compounds and die attach materials.

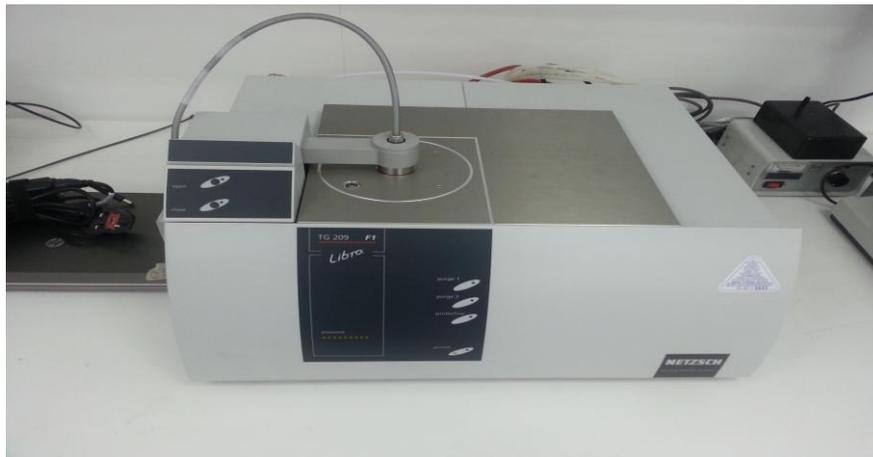
TMA is used to characterize linear expansion, glass transitions, and softening points of materials by applying a constant force to a specimen while varying temperature. For expansion measurements, a probe rests on a sample on a stage with minimal downward pressure.

Sample preparation for sinter Ag die attach material, SnPb and epoxy mold compounds were thawed based on supplier recommendations. Table 1 shows the thawing time for these materials.

Material	Thawing time (room temperature)
Epoxy Mold Compound	24 hours
Sinter Ag die attach	1.5 hours
High Pb Solder	4 hours

**Table 1: Thawing conditions for mold compound, sintered Ag and SnPb solder.**

After thawing, both sinter Ag and SnPb solder paste was placed in an aluminium pan. Powdered mold compound were prepared using a mortar and pestle; this is to ensure constant particle sizes. The thawed samples were eventually subjected to their required thermal profiles based on supplier recommendation.



**Figure 3: DSC equipment to be used for the pre heating profiles of the mold Compound and die attach material**

The following heat treatments were implemented:

Sinter Ag paste requires a thermal profile illustrated below

- 1.) Temperature ramp from 23°C to 150°C
- 2.) Followed by 150°C for 30 minutes
- 3.) Another ramp from 150°C to 250°C
- 4.) Followed by 250°C for 1.5 hours
- 5.) Cool down from 250°C to 27°C for 1 hour

High Pb solder paste requires a thermal profile illustrated below

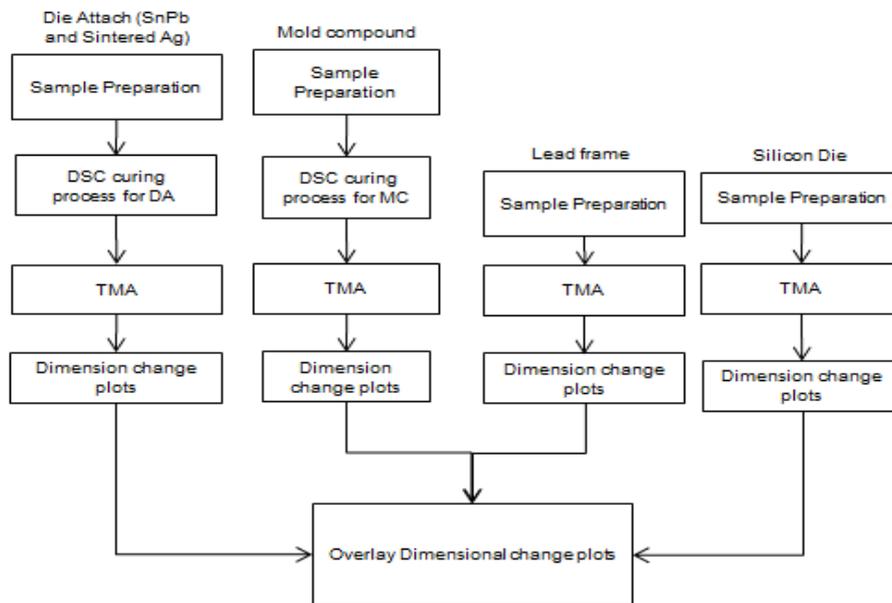
- 1.) Initial ramp from 27°C to 150°C at 2.5°C/sec
- 2.) Ramp from 150°C to 180°C for 60 to 120s
- 3.) Ramp from 180°C to 220°C for less than 90s
- 4.) Cool down from 220°C to 27°C

The mold compound was cured from 185°C for 50s followed by a post mold cure step at 175°C for 3 hours. All material components that were subjected to DSC excluding the copper lead frame and the silicon die. Both samples were subjected to TMA along with all other components to determine the individual temperature profiles that will be superimposed.



**Figure 4: TMA equipment to determine temperature profiles.**

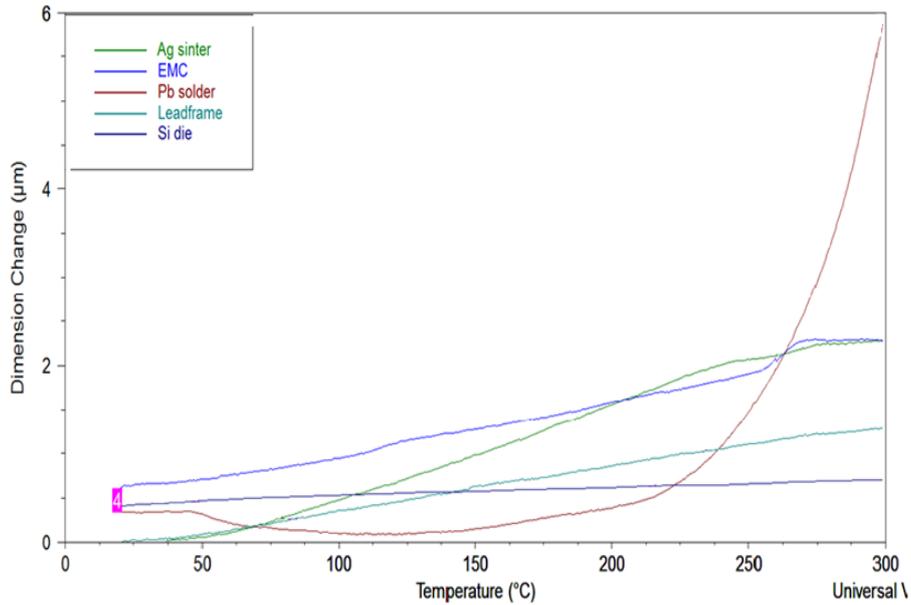
The materials were subjected to the same heating condition starting from room temperature until 300°C with a heat rate of 10°C/min. Full summary of the experimental procedures is illustrated in Figure 5.



**Figure 5: Material Sample preparation methods in determining mechanical Thermographs of individual material components**

### III. RESULTS AND DISCUSSION

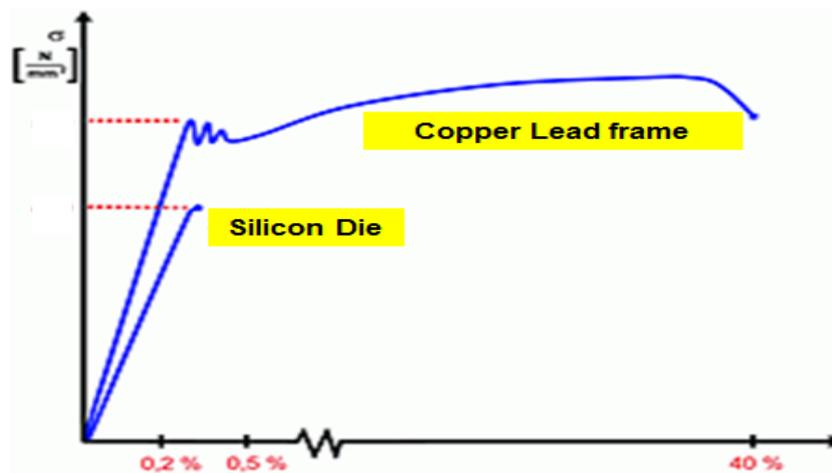
The TMA graphs are shown in the figure below. It contains individual plots of each material component. Ideally a delamination free package should follow the curves of other component material. A large deviation suggest a possibility of delamination occurring. The graph is helpful in evaluating a series of materials or looking into a combination of materials for semiconductor packaging. Individual discussion is illustrated below.



**Figure 6: Superimposed thermographs for material components making up the clip package.**

**Silicon Die and Copper Lead frame**

The silicon die and the lead frame material underwent a single heat treatment. The pre heat treatment is necessary for mold compound and die attach materials to activate polymeric components for the particles to agglomerate and thus enabling full mechanical stability of the semiconductor package. From the graph in figure 6, it is expected that the silicon die has minimal coefficient of thermal expansion with approximately 1/10 of a micron when heated from room temperature until 300°C at a heating rate of 10°C/sec. the findings here can be also related to the stress strain curves shown in figure 7 wherein the silicon die has lesser elastic limit and has the tendency to break instantly when it reaches a certain yield limit. For the copper lead frame, the curves extend to a regime after the yield stress wherein strain hardening and necking across the specimen is attained before fracture. This indicates that the copper lead frames can absorb and deform before it fractures. Contrary to the silicon die which break in an instant when the yield limit is reached.

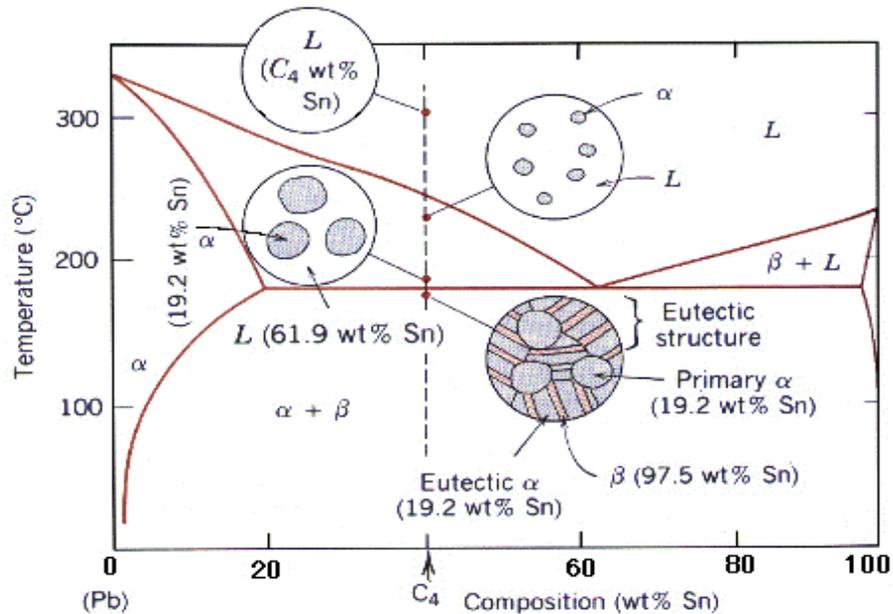


**Figure 7: Stress Strain Curves for the Silicon Die and Copper lead frame**

**High lead solder (SnPb) die attach**

The SnPb die attach material, which is the current adhesive material being used in this semiconductor package underwent 2 heating process. The first process was to simulate lead frame to chip attachment that necessitates a Pb solder profile. Another heat treatment was implemented to be able to simulate board mounting conditions at application level. Some of solders that are used in the semiconductor industry are of SnPb types. Depending on composition the solder properties can be varied. The concentration used in this experiment is

63%Pb and 37%Sn. The reason is that this combination yields the least melting temperature (eutectic) which is attractive for semiconductor manufacturing. From the SnPb phase diagram, the eutectic solder melts around 187°C. A temperature below 187°C maintains the solder's solid phase while a temperature higher than this changes the solder from a solid to a liquid phase. The TMA curves behave as expected based from the phase diagram. It is observed that at low temperatures the solder has slight changes in size. This can be attributed to the flux evaporation that did not escape the pre heat treatment so a small change in dimension is reflected. Further heating at temperatures from 150°C onwards we observe an exponential increase in size due to the phase transition from solid to liquid. This is also in unison to the phase diagrams in figure 8.



**Figure 8: High lead Solder (SnPb) Phase diagram [11]**

### **Epoxy Molding Compounds**

The epoxy molding compound underwent two pre heat treatments. The first pre heat was for the purpose of simulating assembly process and the second heat treatment was to simulate actual reflow conditions. The epoxy mold compounds are polymeric types which are classified as thermosets. The epoxy mold compound requires a thermal reaction to be able to form cross linking chains among other polymeric species. Once the required thermal stimulus is achieved the reaction is said to be irreversible meaning that the mold compound cannot be reformed, re-melted and reused [9]. This is contrary to another type of polymer which is called thermoplastics which can be reused and reformed. The curing step for the mold compound in this experiment includes 2 stages. The first step is subjecting the samples for 185°C for 50s. This is to complete thermal reaction among the additives of the mold compound. The next steps include a longer step called post mold cure. The profile used is 175°C for 3 hours. The purpose of this step is to be able to complete the agglomeration of polymeric species and achieve full crosslinking of polymeric chains.

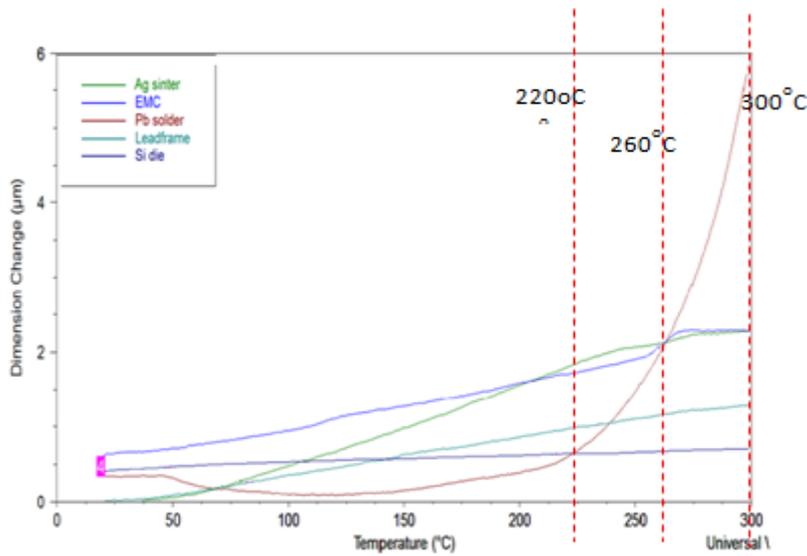
### **Sinter Ag Die Attach**

The sintered silver types underwent 2 heating profiles. Similar to SnPb die attach, the first pre heat was used to simulate the process of attachment. This consists of 5 steps [10] systematically arranged to produce a chemical reaction in the right chronological order to achieve a good and reliable bond. The temperature ramp from 23°C to 150°C is designed to force solvent evaporation from the sinter paste. The solvent acts as an additive material to aid in the formation of the Ag paste. Once good formation is attained it is necessary for this material to evaporate otherwise would hinder the formation of bulk solder. The ramp is followed by a constant temperature at 150°C for 30 minutes, this is to allow enough time for full solvent evaporation. An incomplete solvent evaporation leads to void formation bought about by the remaining gas escaping during the liquid to gas phase transformation of the solvent. Another ramp from 150°C to 250°C is designed for the dispersant and binder to interact, this is where full organic burn off happens which eventually creates solid state fusion [11]. This heat treatment is responsible for agglomeration and aggregations of Nano-silver particles in the die attach material.

The second heat treatment was used to be able to understand board mounting behaviors at customer side. The thermo-mechanical graphs for sintered Ag are illustrated in Figure 6. It is observed that the graphs of sinter Ag and copper lead frame behaves in unison compared towards each other. Whereas the SnPb die attach has a high thermal expansion above 150°C. The low melting point of SnPb warrants the occurrences of delamination in the die attach interfaces. Contrary to Sinter Ag materials which do not involve melting process. Hence, the

**Analysis of combined thermal graphs for the components of the clip power package**

From the TMA graphs obtained we can now derive if the material is compatible at a specified temperature this is determined by drawing a line on the temperature of interest. For instance, a temperature 220°C denotes the reflow profile for Pb containing solder alloys, 260°C denotes a typical reflow profiles for lead free. 3 temperature points were selected to see the compatibility of the following material sets. This is to determine if the new sinter Ag die attach material is performing better at this 3 temperature values. Figure 9 illustrates the TMA graphs with line markers. Table 2 summarizes the dimensional change values given the specific temperature. From table 2, we observe dimensional changes on various components. SnPb varies from 0.5um to 6um given this temperature values. This can pose delamination problems as this material expands abruptly. The sinter Ag material also varies however it was observed to be resistant to temperature changes compared to the current SnPb die attach material. Hence sinter Ag material could be an option for lead free packaging which could be resistant to delamination.



**Figure 9: Temperature intercepted points at 220°C, 260°C and 300°C**

Dimension Change (um)	at 220°C	at 260°C	at 300°C
Ag sinter	1.8	2	2
Epoxy Mold Compounds	1	1.5	2
Pb solder	0.5	2	6
Leadframe	1.1	1.2	1.3
Si Die	1E-07	1E-07	1E-07

**Table 2: Derived Dimensional Change for various materials for critical temperature range**

**IV. CONCLUSIONS**

Different material components making up a semiconductor power package was subjected to thier respective heating profiles. This is to simulate the thermal stimulus each of the material would experience at manufacturing and application levels. Temperature markers were drawn from collective thermal graphs and it was observed that sinter Ag performs better in comparison to the Pb solder. This is seen on 3 temperatures present in manufacturing and application environment. The reason behind this is that the Pb containing solders involves phase changes and the structural stability of this material weakens up at higher temperature. Contrary sinter Ag die attach, the material does not change its phase therefore mechanical stability is maintained. Looking at the TMA graphs, the temperature profile of sintered Ag follows the profile of other component materials whereas at 300°C, the SnPb solder experience significant thermal expansions.

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