Reliability Considerations of Sintered Silver Paste on Clip Semiconductor Packages

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Abstract
Sintered Ag has gained attention as a replacement for high lead applications due to its high thermal, electrical and reliability performance. Today, the temperature requirements for certain business units require higher levels of capability. Coupled with the pressures of converting to lead free, a feasible solution needs to be reached soon. This led to the formation of the DA5 (die attach 5) consortium in 2010. This was composed of semiconductor companies NXP, STMicroelectronics, Freescale, Infineon and Bosch. The main purpose was to look for alternative materials that can support application requirements exceeding the capabilities of solders. Although lab scale tests shows that sinter Ag can be an alternative, limited data is available on sintered Ag performance integrated with high power device applications. Samples were assembled using sinter Ag die attach material on using a Zener diode housed on a clip package. The experimental method was divided in two phases: material characterization at varying amounts of N₂ and reliability phase which subjects these units to Temperature Cycle, Highly Accelerated Stress Test (HAST), and Autoclave. All samples underwent normal assembly except for the sintering process which is necessary for silver die attach to achieve solid state diffusion. Microstructure analysis of sinter Ag die attach results into denser formation of sinter Ag paste when subjected to low N₂ concentration. Die shear results were highest at low N₂ concentration due to increased grain boundary formation over the sinter Ag matrix. However, low N₂ concentration leads to copper oxidation which is detrimental on surface adhesion between the lead frame and mold compound. This was observed during the characterization step wherein oxides were formed on the lead frame surface. Subjecting the copper lead frame with gross oxide formation led to failures at autoclave test. Scanning acoustic tomography reveals gross separation of lead frame to mold compound interface. Also, we have determined that silver migration is a key failure mechanism for sinter Ag die attach when subjected at high N₂ concentration. The reliability results for mid and low N₂ sintering atmosphere show resistive effect on Ag migration. The overall outlook for Sinter Ag based on the current experimentation suggests that sinter Ag could be a viable solution provided that these key failure mechanisms are addressed and fully understood.

Introduction
The need for efficient semiconductor devices coupled with the necessity of moving towards “lead free” has gained attention over the past years. SnPb has been used as a die attach material for power packages due to its inherent reliability, high thermal conductivity and good electrical performance. Though its usefulness, versatility and health risks are known, the repercussion was not fully realized until 1st of July 2006 when the RoHS (Restriction of Hazardous Substance) directive came into effect. This directive prohibits the use of any lead containing alloy in microelectronic devices [1]. In 2010, the DA5 (Die Attach 5) consortium was formed to look into materials that can replace SnPb [2]. Sintered Ag has gained interest due to its compatibility over existing semiconductor process. Also, the low thermal requirement to bond this material is an attractive proposition that brings less thermal stress on other microelectronic components [3]. Based from lab scale results sintered Ag has been proven to perform equal to better in terms of electrical and thermal performance over SnPb [4]. Figure 1 shows the comparison for various die attach materials in terms of thermal conductivity [5].

Figure 1: Thermal conductivities of various solder material interconnect

Sintering on Ag Die attach
Sintering is a heat treatment at elevated temperatures of particles in which the diffusion mechanism is substantial. Sinter Ag methods during the early days are concerned with micron sized Ag particles. It was found out that die attach materials with smaller particles, distribution, temperature are the main factors affects agglomeration on sinter pastes [6]. With the introduction of nano-sized Ag particles, it is possible to achieve sintering with minimal pressure at the same temperature level [7]. This is due to the increased surface energies that provide ease in diffusion between...
neighboring atoms. This is called solid state sintering/diffusion which take place during sinter Ag process [5]. The use of minimal pressure on sintering is favored since it eliminates the risks of residual stress on the microelectronic packaging [1, 8]. This type of sinter paste is obtained by combining micro and Nano-sized Ag particles with organic components. The “organic component” includes a binder, dispersant/capping agent and thinner/solvent [7]. The binder enables consistency of the paste resulting to easier dispensing capability. A dispersant/capping agent is added to inhibit coalescence between Ag particles resulting in better diffusion over the sinter Ag matrix [9,10]. The thinner/solvent enables the paste to achieve optimal viscosity [7]. With the application of temperature during sintering, these organic materials evaporate and sintering action between Ag particles is initiated. Ag particle reaction is divided into 3 phases. First is the shrinkage of the material that occurs due to the particle rearrangement by sliding across each other. This leads to necking formation between silver particles. The second stage leads to densification which results to pore formation due to the interfacial surface energies. The final stage includes the collapse of the isolated pores forming grain growth by which the small grains integrates with the larger grains [5].

Sintering Ag pastes requires a thermal profile to achieve solid state diffusion. This is enhanced by subjecting samples in the oven with an oxygenated environment. However, lead frames were observed to oxidize which could lead to adhesion issues on the microelectronic package. The introduction of N\textsubscript{2} has been an option to minimize oxidation. Experimentation is necessary to achieve a balance between agglomeration of sinter Ag particles and lead frame oxidation.

Reliability of Sintered Ag Pastes

Sinter paste reliability over microelectronic packages has been reported in literature, the major factors affecting the reliability of clip packages are temperature and moisture [11]. For die attach using silver, migration is imminent due to silver’s strong characteristic in terms to thermal conductivity. Recent studies points that moisture accompanied by voltage causes Ag particles to migrate [12]. HAST is a reliability test that has temperature, moisture and voltage components and can be used to exacerbate this failure mechanism. The effect of oxidation can be examined by autoclave test which subjects the samples to high pressure and humidity environment. With oxidation forming on the lead frame, interface separation is imminent. A non-destructive test called scanning acoustic tomography (SAT) is also included to be able to determine interface separation on package components visually.

Experimental Methods

A power device on a clip package using sinter Ag material was assembled. This was divided into two batches. The first batch will be subjected to lab scale characterization and the second batch will be subjected to reliability test. Experimental samples were prepared using a copper lead frame and a silicon die. The dimension of the die is 2.6x2.6mm\textsuperscript{2} having a surface composition of TiNiAg. Lead frame-to-die, clip-to-die top and lead frame to clip attachment was achieved using a die attach machine. A convection oven was used to sinter these samples with a temperature profile composed of 5 steps. The first stage includes a temperature ramp from 23°C to 150°C with a soak time of 30 minutes. The second stage starts from 150°C to 250°C with a soak time of 90 minutes. Cool down is achieved for the next 60 minutes.

![Figure 1: Temperature Profile used in Sintering Ag die attach](image1)

Scanning electron microscopy (SEM), x-ray and, die shear tests were performed on the first batch. To determine sintered Ag formation over different N\textsubscript{2} levels, the samples were subjected for SEM. Samples from each batch were subjected for die shear tests. Minimum shear strengths were collected and plotted in a box chart to determine the statistical significance of each reading.

![Figure 2: SEM image showing sintered Ag paste material. N2 atmosphere were applied during sintering.](image2)

Thirty (30) samples were subjected to die shear strength measurement using a die shear tool. Minimum shear strengths were collected and plotted in a box chart to determine the statistical significance of each reading.

![Figure 2: (a) specimen for SEM imaging (b) polishing of specimen to expose surface of interest in SEM](image3)
Samples from each batch were subjected to X-ray for the purpose of observing the outgassing paths of various sinter paste subjected at different N\textsubscript{2} levels. This is to observe if there is a relationship between the outgassing path and the N\textsubscript{2} concentration levels.

Reliability Test

**HAST and Autoclave:** 84 Zener device on a clip package were subjected for HAST and AC. The samples underwent precondition and were electrically tested to ensure that the samples are still functional. These were loaded in an oven for 96 hours and were electrically tested to determine any failing units.

**Scanning acoustic tomography:** (SAT) was conducted to observe interface separation on material components of the microelectronic package.

**Temperature Cycle:** 84 samples were subjected to temperature cycle by first undergoing moisture preconditioning followed by electrical test. The samples were loaded afterwards on the temperature cycle oven with a temperature swing of -65°C to 150°C. The first readout at 500cyc is followed by an electrical test. Samples were subjected for another 500 cycles to complete 1000 cycles. Samples were electrically tested afterwards to determine if any failures exist.

Results and Discussions

Figure 7 illustrates the corrosion behavior of various lead frames across N\textsubscript{2} concentrations. It has been found that low amounts of N\textsubscript{2} resulted to lead frame corrosion. The copper lead frame with mid and high N\textsubscript{2} concentration was seen to have less corrosion occurrence. The presence of copper oxidation on the lead frame at low temperature is dominated by grain boundary diffusion. The grain boundaries in the lead frame serves as a pathway for copper atoms to diffuse and react with oxygen [13]. N\textsubscript{2} was chosen for sintering due to its abundance, availability and its non-reactive behavior when exposed to copper lead frames. N\textsubscript{2} is composed of strong triple bonds which has weak electron affinity contrary
to O₂ which has strong affinity on electrons which lead to corrosion.

Figure 7: Corrosion presence on low, mid and high N₂ concentrations. Low setting on N₂ shows pronounced corrosion events compared to mid and high N₂ levels.

Die shear results behave in a way that N₂ concentration is inversely proportional to the die shear strength measurements. Sintering atmosphere has a crucial impact on density formation of Ag sinter paste [1]. Microstructure inspections on SEM reveal that low N₂ concentration yields the highest densification rates and the highest shear readings. This can be attributed with the increased grain boundaries present at low N₂ compared to mid and high N₂ sintered paste. This enhances lattice and grain boundary diffusion which contributes to enhanced densification.

Figure 8: Die Shear results on various sinter levels on N₂.

Solid state diffusion depends on the temperature and time which is reflected in reflow profile. This consists of 5 steps 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. The ramp is followed by a constant temperature at 150°C for 70 minutes, this is to allow enough time for full solvent evaporation. From related literature [3, 5] 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 organic burn out happens which eventually leads to densification.

Figure 8: Densification at various Nitrogen loadings at high, mid and low concentration

O₂ plays a crucial role in density formation because sintering is governed by the degradation kinetics of binder/capping agent that is less stable in air than atmospheres not containing oxygen [1,14].

Figure 9: X-ray images showing outgas paths for solvents at varying N₂ levels.

The results for x-ray show outgassing paths for various levels of N₂. These paths are due to the solvents characteristic to vaporize at low temperature (>300°C). No difference was observed in terms of N₂ loading condition.

Reliability Test Results
Reliability test samples were built with low, mid and high concentrations of N₂. These were subjected to HAST, TC, AC reliability tests. Table 1 summarizes the results for these reliability tests.

Five samples failed leakage at post HAST electrical test from Batch 1 which had high N₂ levels. Samples with low N₂ levels had three samples failing autoclave post electrical test. The samples with medium N₂ concentrations did not incur any failures on any reliability test. The units that were

<table>
<thead>
<tr>
<th>Batch #</th>
<th>HAST</th>
<th>Temp. Cycle</th>
<th>AC</th>
<th>N₂ levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lot 1</td>
<td>6/34</td>
<td>0</td>
<td>0</td>
<td>High</td>
</tr>
<tr>
<td>Lot 2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Mid</td>
</tr>
<tr>
<td>Lot 3</td>
<td>0</td>
<td>0</td>
<td>-4</td>
<td>Low</td>
</tr>
</tbody>
</table>

Table 1: Reliability test results for clip packages using sinter Ag at various N₂ concentrations.
failing HAST were de-capsulated to expose the die surface. SEM imaging shows remnants of solidified material. Energy dispersive x-ray revealed Ag peaks which meant that the solder particles migrated to form leakage path between P and N junctions. Correlating these findings with SEM images during characterization, the samples with high N\(_2\) loading was observed to be less densified compared to the batch with low N\(_2\) loading. The un-agglomerated Ag particles under high N\(_2\) loadings formed loose silver micro and Nano particles which have higher surface energies which resulted in Ag migration.

Although the findings suggest that delamination was the reason for failure, further investigation is required in fault isolation due to the limitation of the current SAT tool. This is the reason why the ON Semi reliability specification waives the SAT requirement for clipped packages [15].

**Conclusion**

Sintered Ag die attach material offers an attractive solution moving towards lead free packaging. In the course of experimentation, it was determined that varying amounts of Nitrogen (N\(_2\)) had a drastic effect on achieving densification at the same temperature profile. The right N\(_2\) conditions need to be determined in order to have a balance between densification of sinter Ag material and corrosion of the lead frame. A low N\(_2\) sintering environment resulted into better densification that yields the highest die shear readings. This is due to O\(_2\)’s ability to degrade the binding agent which is restricts densification on the sinter Ag. However, this condition can result to lead frame oxidation. Subjecting these samples at reliability tests resulted to failures of units which were attributed to lead frame and mold compound delamination. High N\(_2\) concentration was observed to have the least densification. Subjection of these samples at reliability test resulted into silver migration due to the presence of un-agglomerated silver in the die attach material. The un-agglomerated Ag particles formed loose silver micro and Nano particles which have higher surface energies resulting to Ag migration. The mid N\(_2\) concentration was observed to resist Ag migration as well as the failures associated with delamination due to oxide formation on the lead frame. Sinter Ag implementation can be viable as long as all these reliability concerns are addressed and fully understood.

**References**


[12] Riva et.al “Migration issues in sintered-silver die attaches operating at high temperature” CNRS, INSA-Lyon, Laboratoire Amp’ere UMR 5005 F-69621, Villeurbanne, France, 2013

