COMPARATIVE STUDY OF THERMAL RESISTANCE IN PURE AND HYBRID AG SINTER DIE ATTACH MATERIALS UNDER THERMAL CYCLING CONDITIONS FOR GAN DEVICES

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ABSTRACT

The increasing utilization of Gallium Nitride (GaN) devices in high-power and high-frequency applications requires advanced packaging materials that can withstand significant thermal and mechanical stresses. This study presents a comparative analysis of thermal resistance (Rth) in pure silver (Ag) sinter and hybrid Ag sinter materials under thermal cycling conditions, with the objective of assessing their reliability and thermal performance for GaN package. Samples were subjected to thermal cycling with varying temperature swings: -65°C to 175°C and 200°C to simulate extreme operating environments.

Experimental results showed that while pure Ag sinter provided lower initial thermal resistance; hybrid Ag sinter epoxy demonstrated better mechanical and long-term reliability, withstanding up to 1000 cycles with an Rth shift of 10% to 15%. In contrast, pure Ag sinter exhibited premature degradation, failing after 300 cycles with 30% increase in Rth. This is the first study to provide a direct comparison of pure and hybrid Ag sinter materials using GaN-based air cavity ceramic (ACC) devices, which operate under high switching frequencies, high junction temperatures, and high voltage and power conditions.

1. 0 INTRODUCTION

The advancement of GaN technology has significantly transformed the landscape of RF power electronics, allowing devices to operate at higher frequencies, voltages, and power densities than their silicon counterparts. GaN-based RF devices are now widely used in applications such as wireless infrastructure, radar systems and satellite communications where reliability and thermal efficiency are crucial.

In a GaN device, the die attach layer is one of the most thermally and mechanically stressed regions as it serves as the primary heat dissipation path between the die and substrate. Inadequate thermal performance or mechanical degradation in this layer can lead to increased junction temperatures, reduced efficiency, and early device failure.
Silver sinter die attach materials are widely recognized for their high thermal and electrical conductivity, making them an ideal choice for high-power applications. Pure Ag sinter material may exhibit mechanical brittleness, particularly under repeated thermal cycling, leading to delamination at the die-substrate interface. Due to these limitations, hybrid Ag sinter epoxy – a composite die attach material that combines Ag particles with a polymer matrix – has been developed to provide improved mechanical stability while maintaining acceptable thermal performance.

The die attach layer Rth has about 10-20% of total package Rth. Typically, it is related to thermal conductivity and bond line thickness (BLT). For this study, hybrid Ag sinter epoxy has about half of the thermal conductivity of pure Ag sinter paste. Through thermal transient tester (T3ster), it was examined that for the same BLT, the hybrid Ag sinter has higher Rth of about ~5% compared to pure Ag sinter.

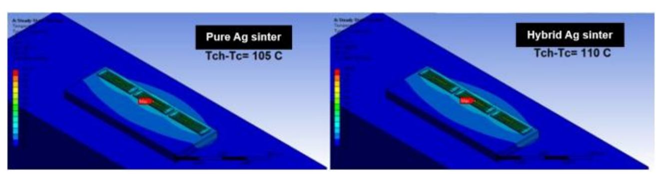

Fig. 1. 3D Finite Element Model (FEM) temperature distribution of pure and hybrid Ag sinter

Due to these results, varying bond line thickness of die attach layer was also analyzed to verify its influence on the thermodynamic properties and delamination or cracking behavior of the die-substrate interface.

2. 0 REVIEW OF RELATED WORK

Thermal management remains a major challenge in GaN-based RF power devices, where rapid switching speeds generate significant localized heat. As a result, the reliability

and performance of die attach materials under thermal stress have been the focus of extensive research.
In RF power applications, comparative evaluations of pure and hybrid Ag sinter materials remain relatively limited. While most research has focused on power switching applications, few studies have addressed how these materials perform under RF-specific conditions such as short thermal transients, rapid cycling, and non-uniform heating.

To address the gap, we designed a study that integrates thermal performance and microstructural analysis focused on GaN-based RF power devices. This study provides insights about how material composition, interfacial behavior, and thermomechanical properties of die attach materials influence RF package reliability.

3.0 METHODOLOGY

3.1 Materials

The standard materials of air cavity ceramic (ACC) package were used in the evaluation:

- Substrate
- GaN die, 4.93 mm x 1.20 mm
- Group A: Pure Ag sinter paste
- Group B: Hybrid Ag sinter epoxy

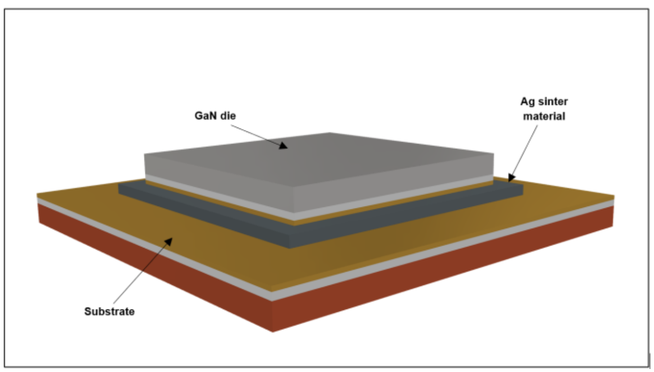

Fig. 2. Die Attach Configuration of the sample used in the evaluation

3.2 Thermal Characterization and Modelling through T3ster

The initial thermal performance of both pure and hybrid Ag sinter materials was simulated through T3ster, following the JEDEC JESD51-14 Transient Dual Interface Method. This assessment was used to determine the appropriate BLT levels for subsequent testing.

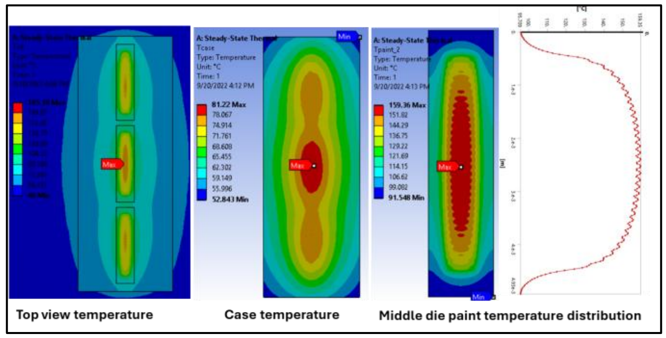

Fig. 3. T3ster thermal model for both pure and hybrid Ag sinter materials

The Rth of hybrid Ag sinter material is ~30% higher compared to pure Ag sinter. Increasing the case temperature by 30°C or heat dissipation to 30W, increases the Rth by about 5%.

3.3 Assembly

All samples were assembled in a single machine with integrated dispense and die attach features. Process controls such as BLT measurement, C-mode Scanning Acoustic Microscopy (CSAM), and electrical tests were performed.

Table 1. Process conditions for Die Attach with different Ag sinter groups

Material Group	Sample size	Condition
A (Pure)	120 pcs	Wet BLT: 60 um to 80 um
		Sintering temperature: 215°C Total curing time: 11 hours
B (Hybrid)	120 pcs	Wet BLT: 55 um to 75 um
		Sintering temperature: 250°C Total curing time: 5 hours

3.4 Reliability Test

To simulate long-term thermal stress experienced in RF environments, all samples were subjected to temperature cycling according to JEDEC standards JESD22-A104, loaded in the chamber with the following conditions:

- Cycling profile: –65 °C to +175 °C / +200°C
- Total cycles: 300 to 1000 cycles

Rth measurements were conducted using a manual electrical test equipment at predefined intervals (0, 300, 500, and 1000 cycles) to monitor die attach degradation.

3.5 Microstructural and Failure Analysis

Selected samples were cross-sectioned for microstructural examination to investigate failure modes such as delamination, cracking, and void growth after every predefined read point.

Tools used for failure analysis were Scanning Electron Microscopy (SEM), optical microscopy and CSAM. Critical responses focused on interfacial integrity and microcrack formation across the die attach layer.

3.6 Data Analysis

Statistical analysis of Rth measurements was performed using Minitab 19, while failure distribution and predictive reliability analysis were conducted using Weibull SuperSMITH version 5.0J.

4.0 RESULTS AND DISCUSSION

4.1 Initial Thermal Resistance Performance

Based on one-way ANOVA, the initial thermal resistance measurements showed statistical difference between pure Ag sinter joints and hybrid Ag sinter epoxy (P-value = 0). Pure Ag sinter joints exhibited significantly lower Rth compared to hybrid Ag sinter epoxy. Specifically, the average Rth for pure Ag was in the range of 0.23 to 0.28 K/W, while hybrid samples recorded slightly higher values around 0.33 to 0.37 K/W. The performance difference is attributed to higher intrinsic thermal conductivity of the sintered Ag structure, which forms dense metallic interconnects with minimal polymer content.

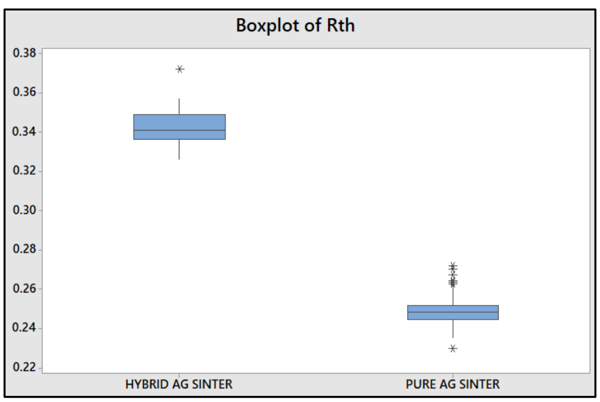

Fig. 4. Comparison of Rth of Pure Ag sinter vs Hybrid Ag sinter

4.2 Effect of Thermal Cycling on Thermal Resistance

Thermal cycling introduced progressive changes in thermal resistance for both material types.

- Pure Ag Sinter Paste:
  Thermal resistance increased significantly with a ~20 to 30% rise after 300 cycles. This increase is mainly attributed to die attach delamination and microcrack formation between the die and substrate due to the brittle nature of the sintered metal structure under thermal stress.

- Hybrid Ag Sinter Epoxy:
  In contrast, hybrid samples exhibited greater stability, with thermal resistance increasing by only 10 to 15% up to 1000 cycles. The epoxy matrix helped buffer thermal expansion mismatches, reducing mechanical stress and hindering delamination or void growth at interfaces.

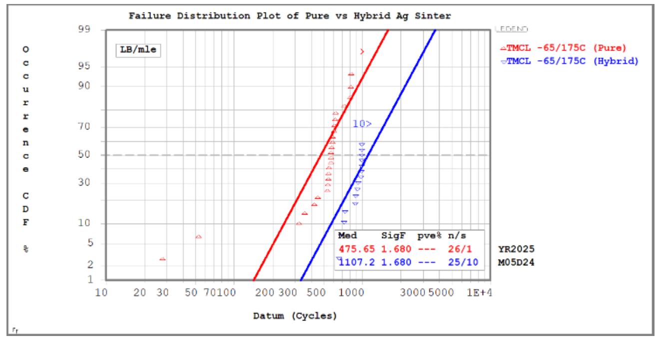

Fig. 5. Failure distribution plot of pure vs. hybrid Ag sinter materials

Based on the failure distribution plot using Lognormal approach, the time to fail (TTF0.1) of the device using pure Ag sinter material is 76.18 cycles, which is below the required read point for the application of 300 cycles. In contrast, the TTF0.1 of hybrid Ag sinter material is 331.2 cycles.

4.3 Post-cycling Cross-section Analysis

Failure mechanisms of both group samples were analyzed through cross-section SEM analysis with accelerating voltage of 15kV and magnification of 350x:

- Pure Ag Sinter Samples:
  Observable microcracks developed at the die attach interface, particularly near the corners of the die. In some regions, partial delamination and void coalescence were detected, aligning with the increase in thermal resistance over cycling.

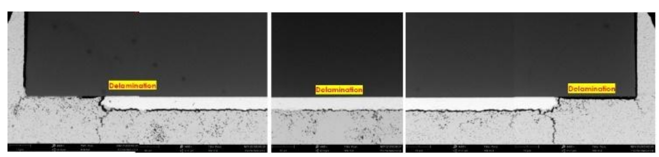

Fig. 6. Cross-section SEM result of pure Ag sinter with delamination after 300 cycles

- Hybrid Ag Sinter Epoxy Samples:
  Interfaces exhibited greater structural integrity, with no crack propagation or delamination. Some polymer shrinkage was visible, but the overall bond line retained structural cohesion. The reduced stiffness of the epoxy layer likely absorbed and redistributed the thermal stress more effectively.

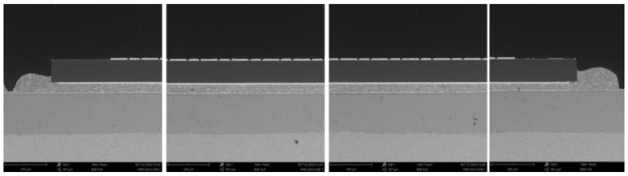

Fig. 7. Cross-section SEM result of hybrid Ag sinter after 1000 cycles

5.0 CONCLUSION

The thermal resistance and reliability of pure Ag and hybrid Ag sinter materials under thermal cycling were analyzed using GaN dies in ACC package.

Initial measurements showed that pure Ag sinter offers higher thermal conductivity, resulting in lower channel-to-case Rth. However, its intrinsic brittleness under thermal stress resulted to more significant degradation in thermal performance over repeated thermal cycling. Microstructural analysis revealed formation of interfacial cracks and delamination in the sintered Ag joints, resulting in higher Rth shift and posing long-term reliability issues.

In contrast, the hybrid Ag sinter epoxy demonstrated a more stable performance up to 1000 cycles with lower Rth shift. While the 0-hour Rth result was considerably higher compared to pure Ag sinter, the presence of polymer matrix in the hybrid structure effectively absorbed thermomechanical stresses, reducing the risk of interfacial cracks and delamination resulting to longer product lifetime.

These findings point to a key compromise in die attach material selection: while pure Ag sinter may be preferable for applications demanding the lowest thermal resistance, hybrid Ag sinter epoxy offers more reliable performance for RF power devices. For long-term operations, hybrid solutions provide a balance between conductivity and mechanical robustness.

6.0 RECOMMENDATIONS

Based on the results of this study, it is recommended to extend the reliability assessment to High Temperature Storage Life Test (HTSL). This will help identify other potential failure mechanisms such as epoxy degradation, silver migration, and microstructural evolution under static thermal stress due to prolonged exposure to elevated temperatures.

For product applications, it is proposed to consider Power Cycling Test (PCT) to provide more insights on the electromigration or fatigue-induced cracking at the die attach interface due to real electrical and thermal loads, causing localized and temperature changes at the die due to rapid cycle switching.

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