SILVER SINTERING DIE ATTACH: GALLIUM NITRIDE DIE TECHNOLOGY PACKAGING SOLUTION AND ALTERNATIVE TO EUTECTIC GOLD-TIN (AuSn) DIE ATTACH

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ABSTRACT

GaN packaging solutions have emerged as a technological advancement in the RF power market, particularly for broadband communication and base stations, where they outperform LDMOS predecessors due to their robust reliability and efficiency. The shift from LDMOS to Gallium Nitride (GaN) die technology has revolutionized the semiconductor manufacturing landscape, enabling high-performance and reliable RF power and data transfer solutions. GaN's capabilities have expanded the range of applications and increased the expected product lifetime, transforming the semiconductor manufacturing industry.

Since the development activity started in Ampleon assembly and release in early 2020, the GaN manufacturing has experienced setbacks in terms of assembly manufacturing performance particularly at die attach process which suffer yield losses and poor die attach machine utilization. The die attachment process is performed by utilizing a solder pre-form alloy, made up of 80% gold (Au) and 20% tin (Sn), which bonds the material into the backside of the die and the header when subjected to specific temperature according to the material elemental composition. The metallic bond formed by the interconnect produced an efficient thermal and electrical connection which best fits the Gallium Nitride packaging as a more robust packaging solution compared with other die attach technology. The eutectic Au-Sn die attach process, despite offering optimum electrical and mechanical advantages, is not defect-free and can be prone to defects such as thermal interface voids, which can negatively impact thermal conductivity and reliability over time.

To tackle the challenges encountered in the die attach process, a novel approach was introduced. The evaluation focused on an alternative die attach technology that employed a low-temperature silver sintering method and has significantly improved die attached performance by effectively addressing problems such as voids and delamination. By adopting this advanced technique, the drawbacks faced in the previous process can be efficiently overcome, ensuring better reliability and performance in the die attach procedure.

1. 0 INTRODUCTION

Die attach voids due to poor and intermittent adhesion of solder pre-form during formation of interconnect between the die and header has immensely affected the die attach quality of GaN manufacturing from the development phase up to the high-volume manufacturing. The three-year yield performance of GaN manufacturing from 2021 to 2023 (Fig. 1) reveals that die attach rejects account for 50% of total assembly yield losses, with 75% of these rejects attributed to AuSn defects, and the remaining 25% due to setup and other visual mechanical issues in die attach.

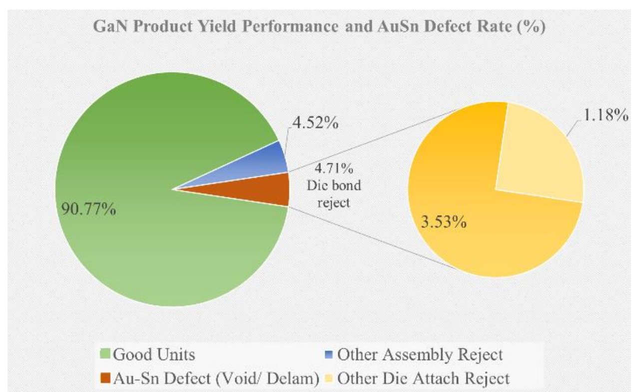

Fig.1 GaN Product Yield Performance and AuSn Defect Rate

Likewise, the void which is mostly associated with gold-tin die attach, was one of the main reasons of product underperformance in electrical testing and package reliability based on recent failure analysis and reliability studies (Fig. 2). These voids may propagate into a complete failure or detachment of die as simulated in an accelerated applied stress testing which translates to imminent catastrophic failure in the device application as the package outfits high power and high frequency products.

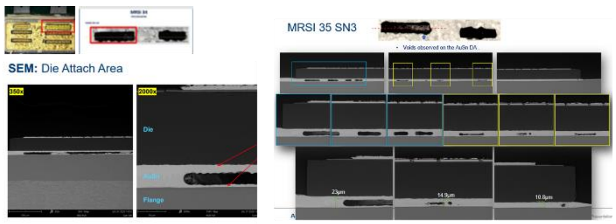

Fig.2. Die attach void in GaN product in AuSn.

Several reasons ranging from surface contaminant on header, oxidation, die attachment planarity, temperature delta from pre-heat to dwell, and solder preform material variations have been recognized as causes of failure. Meanwhile, various containment action and mitigation were employed, from adhesion promoters that helps intermetallic bond in-between surface elemental composition using inert mixed gases, to machine set-up optimization that harnesses the bonding temperature of alloying element and pick and place planarity during die attachment process, leading to a significant improvement reducing the proliferation of die attach voids but still failed to eliminate the defect. The containment actions have caused inconsistent performance and varying outcome through time which led to the process development of introducing a more robust die attachment process which can both eliminate the die attach voids but will also improve the cost by simply eliminating the costly gold-tin preform which is expensive have caused substantial losses in assembly yield.

2. 0 REVIEW OF RELATED WORK

The evolution of semiconductor manufacturing towards Gallium Nitride (GaN) has been significant, as it caters to high power and high-frequency application products. This shift has imposed an adaptation in a more robust packaging solution that will both address the assembly manufacturing variation and development gaps that is still in a rigid learning landscape in the recent years. By embracing advanced techniques, the industry can efficiently produce GaN-based components that meet the growing demand for high-performance electronic devices in various sectors, ultimately driving innovation and progress.

In high-reliability and high-temperature applications where traditional Pb-free solders show inadequate strength, creep resistance, thermal conductivity, and corrosion resistance, eutectic gold-tin (AuSn) is being employed more and more with solder crack initiation, excessive void presence, and expansion as well as irregular phase formation are important factors governing the reliability of the solder junction (F. Arabi et al., 2017). This motivation has brought the development of silver sintering die attach for RF, Power, and Automotives application which was proven to withstand higher operating temperature requirement and higher reliability requirement which drive the need for high performing die attach technology (R. d. Wit et al., 2021). Silver sintering technology has demonstrated its effectiveness in addressing numerous thermal dissipation and high-temperature stability issues such as die attach void and delamination. Due to its increasing popularity and proven effectiveness, silver sintering technology has become the preferred choice for die attach applications in various high-performance electronic devices and systems. This widespread adoption highlights the growing recognition of its advantages in thermal management, high-temperature stability, and overall system reliability, making it a suitable packaging solution for numerous industries and applications.

3.0 METHODOLOGY

The research on silver sinter die attach technology compared to eutectic AuSn die attach specifically examines their applicability on Gallium Nitride (GaN) products. It focuses on evaluating their equivalent performance in terms of critical die attach process requirements, conducting comparative analysis of test performances, and ensuring reliability through extended reliability testing, including various read points. The evaluation process consists of qualification lots using similar materials, with the primary difference being the die attach method. It compares two approaches: silver epoxy that will be sintered at a maximum temperature of 200°C and the existing method of using gold-tin preforms in eutectic bonding technology. To further validate the effectiveness of void-free die attach, a comprehensive analysis will be conducted alongside the comparison. This includes chemical decapsulation and cross-sectioning to examine the die attach interface in detail. Additionally, visual checks will be performed using SCAT (Scanning Acoustic Tomography) and X-ray imaging for a thorough evaluation of the die attach quality. These methods combined will provide a comprehensive understanding of the technology's performance and help establish its reliability and suitability in GaN-based devices and systems, ultimately providing valuable insights for the potential adoption of silver sinter die attach technology in the industry.

4.0 RESULTS AND DISCUSSION

Evaluating the applicability of silver sintering for GaN products requires the fulfillment of critical to die attach process requirement to guarantee the conformance of the process to the specification. By adapting the established critical parameters and variable controls from other die technologies into GaN product manufacturing, it becomes possible to streamline the process, ensure consistency, and achieve high-quality results in the production of GaN-based devices. This approach allows for a more efficient and effective transition of existing knowledge and practices from the semiconductor assembly industry to GaN manufacturing.

Critical Process Requirement

Silver sinter thermal interface is known to produce lower thermal resistance compared with other die attach processes. Therefore, characterization of die attach bond line thickness versus thermal resistance (Rth) was initiated to determine the acceptable test performance in critical test parameters and guarantee the appropriate die attach bond line thickness for the reliability assessment and micro-structural analysis on GaN products. An initial study on a test vehicle helped define the optimal wet bond line thickness capable of withstanding thermo-mechanical stress at high temperatures. The study adopted a baseline wet bond-line thickness used in other technologies utilizing silver sinter at optimal performance, creating a simple low-mid-high setting with similar intervals. Evaluating nominal wet bond-line thickness with a ±20µm tolerance and verifying epoxy shrinkage, the results show a uniform shrinkage rate from the lowest to the highest evaluated bond-line thickness, as illustrated in Figure 3.

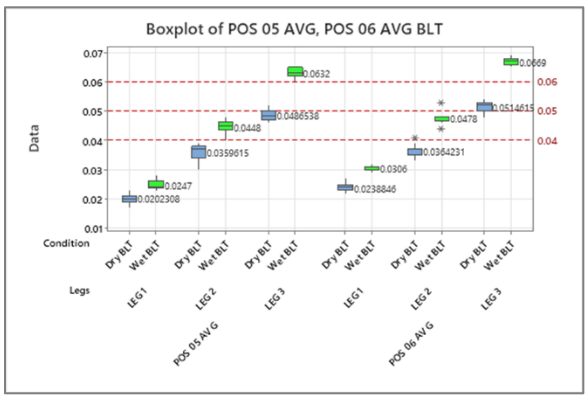

Fig. 3. Wet and after cure Bond-line thickness shrinkage

This crucial information, derived from actual testing, ensures improved performance and reliability in GaN product manufacturing under varying temperature conditions.

Process controls such as visual inspection at high power magnification was performed to verify the required epoxy flow out and epoxy fillet height requirement for silver sintering, likewise, the x-ray inspection of the process control units to examine the performance of die attach voids with respect to eutectic die attach technique.

Considered as void free die attach process, silver sintering in die attach has notably improved the micro-structure characteristic of soldering metal alloys in die attach and has achieved better solder dispersion and voiding performance (Fig. 4) as observed in the engineering evaluation using GaN products as test vehicle.

Fig. 4. GaN product in silver sinter die attach process.

Electrical Performance[3]

Comparative analysis and test distribution shift were reviewed by test product engineering, comparing the electrical performance of gold-tin die attach and silver-sinter to identify significant difference in data sheet parameters as well as test parameters that are assignable to die attach process. Evaluation lots shows no significant difference in critical parameters for DC, SPAR, and RF testing. No failure in bin and statistical limit for critical parameters, while median shift and sigma ratio performance of silver sinter have comparable process capability index (Cpk) with the current gold-tin die attach for GaN product.

Figure 5 summarizes the final test yield comparison, including median shift, sigma ratio, and process capability check for all critical final test parameters in DC, SPAR, and RF testing.

Final Test Yield	Median Shift	Sigma Ratio	CpK Check	Conclusion
Acceptable	Acceptable	Acceptable	Acceptable	➢ Acceptable results in critical parameters for DC, SPAR and RF
➢ Comparable yield between control and evaluation lots	➢ SPAR shift in S2_S11_Fres – can be accepted loop height and SPAR wirecal data for both control and evaluation lots are within the +/-30MHz tolerance	➢ Parameters that falls outside the acceptable limits have comparable CpK between control and eval lots on all FT test.	➢ Parameters with lower CpK in eval shows same response in production lots	

Fig. 5 Test Analysis and Distribution Shift Analysis

Reliability Assessment[4]

Extensive package reliability testing with accelerated applied stresses were performed to simulate the product lifetime of GaN product in Ag sinter. The TMCL(-65°C/+150°C) and uHAST(130°C/85%RH/2atm) with preconditioning both passed the required (500c TMCL/96hr uHAST) and extended (1000c TMCL/192hrs uHAST) read points with no observed test failures related to die attach in silver sinter. Time zero SCAT imaging shows excellent die attach with zero voids and did not deteriorate across all reliability read points. High

Temperature storage Life (1008hr HTSL 175°C) and time stability testing such as High Temperature Reverse Bias (1008hr HTRBVgs=-10V, Vds=120V, Ta=150°C), Cycled Temperature Humidity Bias (1008hrs C-THB 30°C-65°C/90~95%, precon MSL3+3x reflow 245°C, Vds=65V; Vgs=-8V) and Biased Highly Accelerated Stress Test (96hr BHAST130°C/85%, DC Bias Vds=48V; Vgs=-8V, precon MSL3 +3x reflow 245°C) also passed the required read points with no observed electrical parameter shift over time confirming the relative performance of silver sinter to gold-tin die attach GaN product.

The reliability test results guarantee the new die attach material can withstand the industry requirements for thermomechanical stress, exposure to high temperature, high moisture environment, and will not cause further degradation during application.

Microstructure characteristics

a. Non-destructive test result: SCAT Images

Process control monitoring and 100% SCAT imaging has confirmed the void free die attach thermal interface of silver sinter die attach on GaN, achieving the desired level of die attach performance for the package compared with gold-tin die attach with a level of 2~4% voids defect at 100% SCAT inspection. Reliability testing also shows that the die attach performance in terms of void is better compared with silver sintering with no observed propagation of delamination during reliability testing leading to secondary failure.

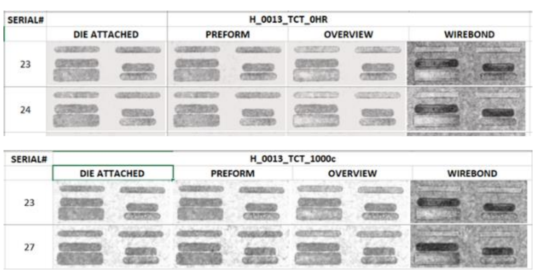

Fig. 6. SCAT image showing time zero (0) until 1000 cycles with no voids and delamination propagation.

b. Destructive test result: Ion-mill cross sectioning

Construction analysis of representative units has proven that silver sinter die attach will produce void-free die attach process with excellent soldering material dispersion and wettability (Fig. 7) and thus promoting better thermal efficiency and reduced electrical resistance at high power-frequency application.

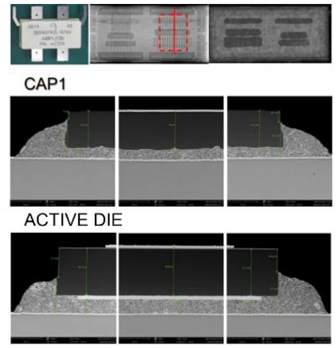

Fig. 7. Ion-mill cross section of silver sinter die attach.

5.0 CONCLUSION

A comparative study on workmanship and reliability between GaN product in silver sinter die attach and the conventional gold-tin die attach revealed that the silver sinter die attach technique exhibits better voiding performance. SCAT imaging was utilized for a straightforward comparison which outlines the improvement in silver sintering with zero die attach void observed during qualification and large-scale validation. In addition, the electrical performance and overall reliability of GaN products with silver sinter and defined wet bond line thickness were found to be on par with those of the gold-tin die attach, demonstrating the potential of silver sinter as a viable alternative in GaN product manufacturing.

6.0 RECOMMENDATIONS

To further bolster confidence in GaN manufacturing with silver sinter die attach, a high-volume and high-capacity manufacturing to supplement the study presented in this paper. The transition from eutectic to silver sintering material in a product or process should be carried out in collaboration with customers, ensuring their acceptance and understanding of this change. This partnership is crucial to guarantee the new material's suitability for their specific requirements, minimize potential challenges, and maintain a smooth transition. Understanding specific customer qualification requirements and exploring other potential failure mechanisms will help improve the void-free performance benefits offered by silver sintering in the die attach process. Assessing the functional performance of GaN products in silver sinter die attach packaging at customer applications is vital for verifying the effectiveness of this new packaging solution. This evaluation allows for the identification of any potential issues, fine-tuning of the packaging process, and ensuring that the product consistently meets performance expectations in its new packaging.

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