# CHARACTERIZATION OF EPOXY GLUE ADHESION PERFORMANCE ON GOLD-PLATED COPPER SUBSTRATES

**Rommel S. Obed Jr**[1]
**Mark Andrew T. Tabucanon**[2]
**Jocy P. Castillo**[3]

Materials Engineering Department[1,2,3]
Binary Street, LISP 1, Brgy. Diezmo, Cabuyao City, Laguna, Philippines 4025
rommel.obed@ampleon.com[1], markandrew.tabucanon@ampleon.com[2], jocy.castillo@ampleon.com3

***ABSTRACT***

Package quality and rigidity is a primary differentiator that Ampleon aims to uphold. On package development the aim is always to maximize the performance of the materials for the final package. The focus of this study is on epoxy glue adhesion.

The plan for this study started with assembly and test which showed favorable results which provided a good baseline performance. Reliability done were temperature cycling (TC) and unbiased highly accelerated stress test (UHAST) where the observation is both favorable also.

For both reliability tests, test performance, hermeticity and glue shear performance outperformed the expectation of baseline MSL3 performance and went beyond even the MSL2 criteria which shows and establishes the high-level performance of the material interfaces involved in this study.

## 1. 0 INTRODUCTION

Safeguarding the electrical interconnects and preserving the device performance and reliability has been the key role of semiconductor packaging. Among the available packaging types, air cavity packages have obtained significant attention and have emerged as a promising option for satisfying the desired functionality. This package provides improved thermal and enhanced electrical properties. Despite these favorable properties, vulnerability against moisture penetration is prevailing as the package main concern. Package delamination, electrical failure, material degradation are the fundamental issues caused by moisture ingression that can be afflicted during manufacturing, staging, and transporting.

As this package type garnered increasing prevalence, the susceptibility on moisture degradation necessitates for further understanding to guarantee device quality and reliability. To resolve these concerns, the response towards Moisture Sensitivity Level (MSL) has been explored to assess the susceptibility of air cavity packages to moisture-related failure.

MSL soaking represents a critical phase in the lifecycle of semiconductor devices, wherein packages are subjected to controlled moisture exposure to simulate real-world operating conditions. During MSL soaking, moisture diffuses into the package structure, potentially leading to moisture-induced defects and reliability issues. Understanding the kinetics of moisture absorption, the distribution of moisture within the package, and its effects on material properties are paramount for assessing package reliability and informing mitigation strategies.

Understanding how air cavity packages respond under MSL condition is essential for securing the quality and reliability performance of the device and guaranteeing the longevity in product application level. This calls for a comprehensive analysis into the interaction between moisture penetration and air cavity packaging, considering the material characteristics and product fabrication.

In this study, we explore the precondition soaking and reliability performance of air cavity plastic (ACP), focusing on the bubble leak yield and ringframe shear performance at various conditions. Through a combination of in-house experiments and analysis, we aim to elucidate the complex interaction of moisture and package response. By advancing our comprehension on this interaction, we target to reduce moisture-induced damage and preserve package robustness.

## 2. 0 REVIEW OF RELATED WORK

Liquid Crystal Polymer (LCP) has been dominating the air cavity packages as the leading cap lids for the primary option for hermetic sealing. Most of the literature studies focus on the electrical properties and wave frequencies of LCP-sealed packages. This is due to the advantages that it offers such as low moisture absorption and permeation, lightweight and affordable cost. These properties support the main benefit of using LCP which is its superb hermeticity or near-hermetic protection that ensures the quality and reliability performance of the air cavity packages. Despite the reliable performance that LCP offers, only a few tackles the interaction between LCP and moisture penetration.

To deep dive further into the characteristics of the LCP sealed packages, the following are the studies that exerted effort to shed light on the functionality of LCP-based packages. Chen et al. (2006) demonstrated the development of an LCP ultrahigh moisture-resistant RF microelectromechanical system (MEMS). The rigidity of the LCP enclosure was validated by checking the outgassing performance, adhesion integrity, structural integrity and hermeticity test. Using ASTM-E 595–93 (1999), Total Mass Loss (TML) of 0.038 and Collected Volatile Condensable Materials (CVCM) of 0.004% were detected, which demonstrated that LCP has passed the outgassing test and satisfies the standard requirements. It was also verified here that the LCP package passes Method 1014, MIL-STD-883 gross leak, and fine leak hermeticity tests. Chen et al established in this study the capability of LCP as a successful enclosure for MEMS devices.

Furthermore, to discuss the functionality of LCP-sealed devices under reliability conditions, Aihara et al. (2012) studied the LCP air cavity package response under series of environmental tests. The LCP package was illustrated to be rigid under stringent conditions as LCP-enclosed devices passed even after subjecting to 85/85, temperature step stressing, moisture resistance, freeze expansion testing, and mechanical shock. Various environmental condition tests are done to check the several responses. Operating Humidity Exposure (OHE) is a common reliability test whereas Nonoperating Temperature Step Stressing (NTSS) is conducted to determine the ability to withstand extreme temperature cyclical conditions. Nonoperating Thermal Shock (NTS) is carried out to evaluate package resistance under instantaneous temperature change, Nonoperating Moisture Resistance (NMR) is performed to evaluate resistance against cyclical heat with high humid condition while Freeze Expansion Stressing (FES) evaluates weak sealing of the package. As units passed the leak test and environmental condition test mentioned above it was ascertained that LCP caps are usable for building a reliable package platform.

The primary challenge of an LCP package or any hermetic package is the lid seal process. In Ampleon, LCP caps are pre-glued with a B-staged epoxy. In an epoxy-sealed package, cap sealing is processed through a curing cycle which can already induce moisture penetration and package weakening. In addition, the storage condition of the finished goods both in-house and at the customer might introduce this concern as well if units are not safely stored. Thus, an investigation into the mechanism of interaction between LCP-based packages and moisture ingression is critical. In this study, we explored the failure mode encountered of air cavity plastics (ACP) packages under MSL2 and MSL3 conditions. This was done to evaluate the reliability performance under stringent conditions to foresee quality concern.

## 3.0 METHODOLOGY

Material characterization was done for the leadframes to be evaluated. The baseline thermal performance of the glue was characterized via differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA)

For the evaluation plan, Ampleon' s full assembly process for air-cavity packages will be done which includes diebond, wirebond, hermetic sealing and electrical testing.

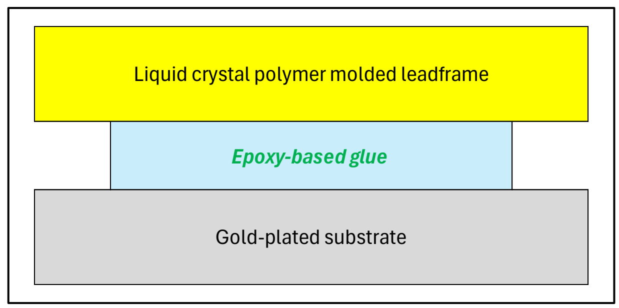



Fig 4.1 Illustration of the material stacking for the glue to be studied.

Figure 4.1 is an illustration on the three main layers to be adhered. A leadframe molded with liquid crystal polymer was pre-glued with a B-stage epoxy. Ampleon pressure seals this with a gold-plated copper substrate.

Bubble leak testing was done by dipping samples in 3M Fluorinert Electronic Liquid FC-40 to test hermeticity. Fluorinert can seep through better in small spaces even better than common fluids. That is why it was used for this study.

Reliability testing was done which includes temperature cycling (TC -65/150, 500 Cycles) and unbiased highly accelerated stress test (UHAST 130oC/85% RH, 96 hours). Preconditioning with MSL3 soak and three times reflow was done prior TC and UHAST.

The glue is pre-glued on the leadframe to be attached during the assembly process. The primary response to be done is ringframe shearing which will be done post-assembly and after every reliability step.

## 4.0 RESULTS AND DISCUSSION

### 4.1 Material Characterization

DSC was done on the epoxy-based glue to be used in the study. Results show a melting point 172.8ºC which is below the process parameters released in Ampleon's processes. This confirms the compatibility of the process released recipe to the glue.


Fig 4.2 glue melt appearance post DSC/TGA

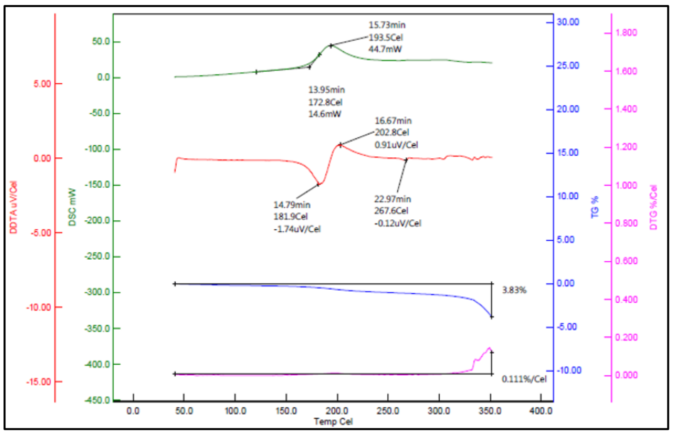



Fig 4.3 DSC and TGA profile gathered from the glue sample.

Thermogravimetric analysis was also done where degradation through weight-loss was observed. Minimal weight loss was observed at the >150ºC which signifies the melting and curing that was happening as heat is applied. Aggravated weight loss was seen past the 300 ºC mark, which indicates the start of polymer degradation.

### 4.2 Assembly and Test Yield Results

Standard Ampleon process and testing flow for air cavity package was done for assembling the units for evaluation. Good yield was achieved so a good baseline was established prior reliability testing. Table 1 shows the favorable results of 0-Hr testing where no glue related fails were encountered.

### 4.3 MSL3 and MSL2 Reliability (TC & UHAST)

Table 1: Tabulated summary of the reliability results

| TC -65/150 with Acc Precon + 3x Reflow at 245°C | | | | | | |
|---|---|---|---|---|---|---|
| | Assembly | | MSL Soak + 3X Reflow | | 500 Cycles | |
| Lot | Yield | Remarks | Yield | Remarks | Yield | Remarks |
| MSL3 Lot | 100% | No Electrical Failure | 97% | Failure unrelated to glue adhesion | 100% | No Electrical Failure |
| MSL2 Lot | 100% | No Electrical Failure | 100% | No Electrical Failure | 100% | No Electrical Failure |

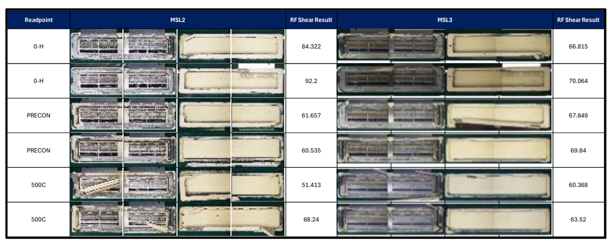
| UHAST 130°C/85%RH/2 atm with Acc Precon+3x Reflow at 245°C | | | | | | |
|---|---|---|---|---|---|---|
| | Assembly | | MSL Soak + 3X Reflow | | 96H | |
| Lot | Yield | Remarks | Yield | Remarks | Yield | Remarks |
| MSL3 Lot | 100% | No Electrical Failure | 97% | Failure unrelated to glue adhesion | 100% | No Electrical Failure |
| MSL2 Lot | 100% | No Electrical Failure | 100% | No Electrical Failure | 100% | No Electrical Failure |

Table 1 shows the favorable results for reliability where both MSL3 and MSL2 passed the required mark of 500 cycles TC and 96 hours uHAST. The reliability test saw no failures related to glue adhesion. The fails encountered were due to other functional components.

### 4.4 Glue shear results

Glue adhesion passed up to planned TC 500 cycles and UHAST 96 hours read point. It was observed that the shear failure appearance changes in the same way for both TC and UHAST. The shear force expectedly decreases as reliability progresses. There is a notable progression of the failure mode signature. At 0Hr, more of an adhesive failure is seen where the failure is between the glue and gold-plated substrate. As preconditioning and reliability tests progress, the failure mode becomes more cohesive where the glue itself is the failing layer. The glue was present on both the LCP layer and the Au-Cu substrate after shear. The same is observable for both TC and uHAST.

The cohesive failure mode are signs of the glue weakening but that is expected in reliability, all values remain passing in reference to a 25kg force criteria. Shear performance is passing.



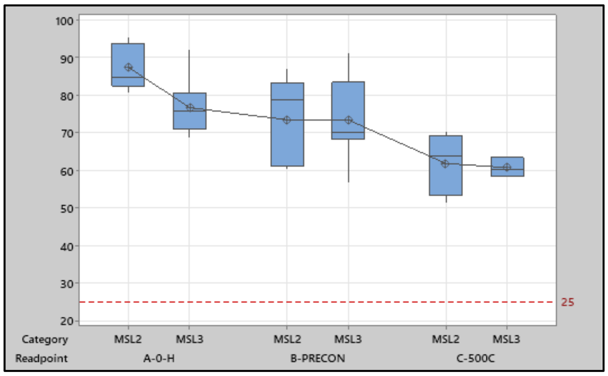



Fig 4.4 Shear fail mode appearance and Ra data for TC.

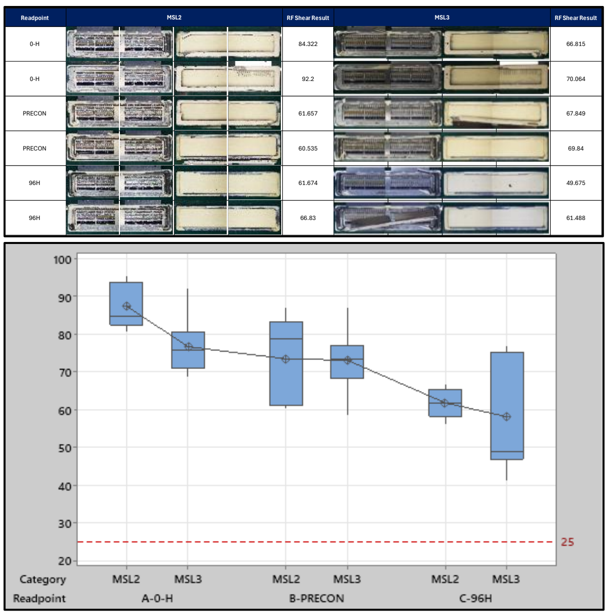



Fig 4.5 Shear fail mode appearance and Ra data for UHAST.

## *4.5 Bubble-leak results*

Table 2: Tabulated summary of bubble-leak hermeticity testing

| TC -65/150 with Acc Precon + 3x Reflow at 245°C | | | | | | |
|---|---|---|---|---|---|---|
| | Assembly | | MSL Soak + 3X Reflow | | 500 Cycles | |
| Lot | Yield | Remarks | Yield | Remarks | Yield | Remarks |
| MSL3 Lot | 100% | No BLT Flange BLT related failure | 100% | No BLT Flange BLT related failure | 100% | No BLT Flange BLT related failure |
| MSL2 Lot | 100% | No BLT Flange BLT related failure | 100% | No BLT Flange BLT related failure | 100% | No BLT Flange BLT related failure |

| UHAST 130°C/85%RH/2 atm with Acc Precon+3x Reflow at 245°C | | | | | | |
|---|---|---|---|---|---|---|
| | Assembly | | MSL Soak + 3X Reflow | | 96H | |
| Lot | Yield | Remarks | Yield | Remarks | Yield | Remarks |
| MSL3 Lot | 100% | No BLT Flange BLT related failure | 100% | No BLT Flange BLT related failure | 100% | No BLT Flange BLT related failure |
| MSL2 Lot | 100% | No BLT Flange BLT related failure | 100% | No BLT Flange BLT related failure | 100% | No BLT Flange BLT related failure |

Table 2 shows the bubble leak performance which aims to test the hermeticity of the package. The criteria only requires that the packages pass MSL3 preconditioning but the built packages outperformed the criteria by passing not only MSL2 preconditioning but also the TC500 and UHAST96 reliability read points that followed.

## 5.0 CONCLUSION

The initial assembly saw no yield issues. The study also established that the glue and the process are compatible from the DSC analysis.

Assembly and Test have favorable results having no failures related to glue adhesion. Reliability performance is the main performance indicator where bubble leak and shear showed better than predicted performance.

For shear, Ampleon criteria requires >25kg force at MSL3 TC and UHAST, the study saw the packages pass this at MSL2. For bubble leak, Ampleon requires the package to be intact after MSL3 preconditioning. The packages pass beyond even MSL2 preconditioning, UHAST 96 hours and TC 500 cycles which shows that the LCP-Epoxy-Au/Cu substrate interfaces are extremely rigid.

## 6.0 RECOMMENDATIONS

The study recommends continuing to test-to-fail since at the established read points, significant failures were still not encountered.

The study was limited to only one glue variant on the Ampleon bill-of-materials (BOM), this was chosen due to the current high volume of the material. A good forward is to establish the same performance for other glues in the Ampleon portfolio while employing the same method used in this study.

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## 9.0 ABOUT THE AUTHORS

Rommel S. Obed Jr. is a graduate of BS Materials Engineering from the University of the Philippines - Diliman. He is a Sr. Materials Engineer currently at Ampleon Philippines, Inc where he handles BOM material qualifications and material cost saving initiatives.. He is a product of the Ampleon Cadet Engineering (ACE) program. He specializes on die attach technologies like 80Au20Sn, Silver sinter, Pb soft solder. He also specializes in substrate surface level material analysis.

Mark Andrew T. Tabucanon is a University of the Philippines – Diliman alumnus who graduated with a degree of B.S. in Materials Engineering. He has an experience in the research field and worked as a Science Research Specialist in academe settings. Currently, he is employed as a Material Engineer at Ampleon Philippines, Inc specializing in epoxy and surface attachment.

Jocy P. Castillo is a Senior Materials Engineering Senior Technician in Ampleon. She started her career in Ampleon Philippines as a FA/ Reliability inspector and then as a Specialist inspector for Incoming Quality Inspector. Her expertise is on Material specifications compliance, product reliability, material-level risk assessment and material characterization.