Solder-induced HAST Failures

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ABSTRACT

Reliability testing is an integral part of semiconductor manufacturing. Through this, developers can evaluate the longevity and robustness of their products. One of the most important tests in reliability is the biased Highly Accelerated Stress Test (HAST), which uses temperature and humidity as the environmental parameters. During HAST, the units will be stressed by increasing the water vapor pressure to high level to speed up the infiltration of moisture inside the sample. Moisture ingress inside the package dissolves hydrolysable chlorides and creates an electrically conductive medium. This leads to a possibility of corrosion, ionic contamination, and electro-chemical migration. Nonetheless, it cannot just be assumed that the aforementioned causes induced the HAST failure when it is encountered. The said reliability test is required when a new material is being qualified and to qualify a new material, it will go through a thorough study to make sure that there will be no anomaly in the product performance, and it must match or outperform the existing material that is being used. This paper will focus on the investigation and intensive root cause analysis of the HAST failure encountered during the qualification of a new solder paste material used in LFPAK packages and results have shown that the halogen content on the solder paste flux induced the HAST failure through electrochemical migration.

1.0 INTRODUCTION

1.1 Background of the Study

As automotive and industrial applications of electronic devices develop and their operating environment become more severe, the qualification process becomes more stringent. New materials that are proposed to be used for the package assembly will go through a thorough investigation and will undergo the specification phase, assembly trial runs, construction analysis, moisture assessment, reliability testing, and more.

Reliability testing is the most critical part of the study process during the qualification of new materials as it can assess the ability of the product to withstand the complexity of the application. This can help identify failure issues as early as the development cycle by modifying the recipes used during the process to obtain the best characteristics of the product.

One of the most common reliability tests that are being used during the predevelopment study of a product is the Highly Accelerated Stress Test (HAST) where a device is subjected to high temperature and high humidity conditions while under voltage bias to accelerate the penetration of moisture through the package. It is performed to evaluate the resistance of the product to humidity by raising the water vapor pressure inside the test channel to a level that is much higher than the water vapor pressure inside the sample.

Based on AEC – Q101, which is the document for the failure mechanism-based stress test qualification for discrete semiconductors in automotive applications, one of the qualification test methods is HAST 96 hours at TA = 130°C/85% RH with part reverse bias at 80% and the only acceptable criteria are zero fails. Being subjected to extreme conditions of high humidity, high temperature, and high voltage bias applied, the metals and alloys used inside the devices are most likely to be electrochemically unstable and ionized, which leads to an insulation breakdown causing the failure of the unit.

1.2 Problem Statement

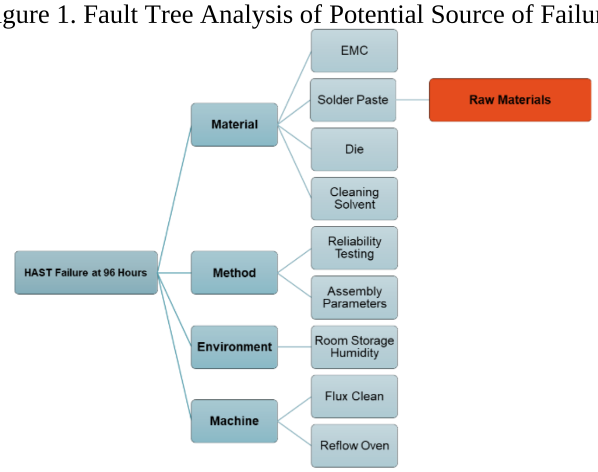
During the qualification of new stencil print material for the die attach process, a look-ahead reliability test was conducted. Multiple samples of the new material failed

HAST 96 hours, while all samples using the existing stencil print material are passing. The said failure required an intensive root cause analysis as HAST failure is considered a risk in Automotive applications.

The failure mode observed is short on drain-source leakage current (Idss) during the electrical testing after HAST process, and the failure mechanism of the said samples was the excessive stress applied to it during life testing. In the process of HAST, devices are subjected to extreme conditions of temperature, humidity, and voltage. Thus, resulting for some devices being not able to withstand the excessive stress.

Investigation on the potential source of the failure was started by conducting a gap analysis between the materials and the processes used during the assembly of both qualification and control lots. To check whether there are any abnormalities during the assembly process, the running history of the following was investigated:

Figure 1. Fault Tree Analysis of Potential Source of Failures



Material

a. **EMC.** The interaction of the molding compound with the paste and die passivation was considered, but no commonality was found since the same failures are observed on different types of EMCs.
b. **Solder Paste.** The difference in the raw materials used on the flux system of both pastes has been verified on the technical data sheet.
c. **Die.** A possible difference in the performance of the die types was examined. However, no commonality has been found since all types of die encounter various failures.
d. **Cleaning Solvent.** Probable insufficient cleaning is suspected due to the high count of devices cleaned using the same chemical, but it is validated that the chemical used during the cleaning of the samples is still within the defined chemical life.

Method

a. **Reliability Testing.** There is a possibility that a defective board was used during HAST, but no abnormality was observed upon checking.
b. **Assembly Process.** An error might have been encountered during production, however, both control and evaluation lots are processed together.

Environment

The humidity on the storage of the units before transferring to the next process might have caused possible moisture absorption in the unit if there is any occurrence of improper handling, although it is still considered an invalid potential root cause, since both control and evaluation lots are processed together.

Machine

a. Flux Clean. Possible insufficient cleaning or the parameters used is not enough for the cleaning of the new solder paste, but no abnormality was seen in the process and both lots are processed together.
b. **Reflow Oven.** Flux residues that can be accumulated by the evaluation lots might be present in the chamber, but still not a potential root cause as both lots are processed together plus the controlled environment inside the oven.

All the potential sources of failure were considered, no gap found in the process as both lots run through the same parameters. The only distinct difference between the two assembly trials is the solder paste material used in the die attach process making it a valid potential root cause of the failure.

Upon investigation of the flux system of the new paste, it was discovered through elemental analysis using Ion Chromatography that the new solder paste material has a larger amount of Bromine as compared with the existing material. The bromine content is obtained from one of the components of the solder paste flux, called activators.

Table 1. Comparison of Br contents of solder paste

Material	Br Content
Solder Paste X[a]	< 10 mg/kg (detection limit)
Solder Paste Y[b]	> 700 mg/kg

[a] Solder Paste X – existing stencil print material
[b] Solder Paste Y – new stencil print material

The base of the flux system of the new material is rosin, which is known to have limited fluxing activity. Thus, the addition of activators is needed to increase the capability of flux in promoting and removing oxide films and the most used activators are halogens like Chlorine and/or Bromine. [1]

In addition to this, halogen content like Bromine on solder paste has various risks that are associated with its presence, it can reduce the efficiency of metals by forming metal salts and this will create an electrically conductive medium once it is introduced to moisture, which will lead to a possibility of corrosion, ionic contamination, and electromigration.

To validate whether the bromine content induced the life test failure, a new formulation with zero halogen content was produced and used for assembly trial, which will also be subjected to reliability testing.

Table 2. Comparison of old and new formulations of Solder Paste Y

Material	Br Content
Solder Paste Y[a]	> 700 mg/kg
Solder Paste Z[b]	< 30 mg/kg (detection limit)

[a] Solder Paste Y – old formulation of new stencil print material
[b] Solder Paste Z – new formulation of new stencil print material

The change in formulation was validated by conducting another Ion Chromatography and results have shown 0 ppm of halogen content with < 30 ppm detection limit.

2. 0 REVIEW OF RELATED WORK

In the study of Kim et al. the Case study of copper dendrite growth under the HAST test, the dendrite growth was suspected to influence the electrochemical migration (ECM). ECM develops when moisture adheres between electrodes made of a material such as copper, solder, or silver. When the devices are tested in HAST, moisture penetrates between the PCB and the die surface, and the voltage bias applied leads the metal from the anode to ionize and move toward the cathode. The moisture that penetrated through the device vaporizes into steam and the heat of gasification causes damage to the surroundings, causing delamination between the passivation layer and the insulating layer. [3] Thus, making delamination a pre-requisite of the failure induced by electrochemical migration.

In addition to this, another study discussed the important failure causes relate to the changing of temperature and humidity, such as corrosion, delamination, and electrochemical migration. Corrosion can be caused by water diffusing into the package, while delamination can relate to increased humidity. Meanwhile, ECM takes place by forming dendrites or dendrite-like deposits, which lead to a short circuit in the device and can cause catastrophic failure. [4]

Another HAST failure mechanism has been discussed at the study of Chang et al. in which they have concluded that halogen-ions from the substrate are released at higher HAST temperature during their investigation of the HAST failure encountered in BGA packages. The investigation started when they encountered HAST failure at 96 and 192 hours. The substrate material they used during the assembly process consists of Chlorine, which is considered as Halogen, and upon conducting a substrate analysis through extraction and Ion chromatography, a significant increase in Cl content was observed when the temperature increased from 110°C to 130°C. Therefore, concluding that HAST at 130°C will result more fails than HAST at 110°C. [5]

3.0 METHODOLOGY

Two sets of samples were submitted for reliability testing, one is considered as a control lot, which used the existing bill of materials (BOM) released in the production, while the evaluation lot used the same BOM except the solder paste used the die attach material.

Table 3. Summary of lots processed.

Expt	Test Condition	Setup Used
1	TA = 130°C/ 85%RH Vds = 80% Vmax, Vgs = 0V	Control Lot[a]
2	TA = 130°C/ 85%RH Vds = 80% Vmax, Vgs = 0V	Qual Lot[b]

[a]Control Lot used the existing BOM released in production.
[b]Qual Lot used existing BOM except solder paste material on the die pad area.

The conditions stated in Table 3 are similar to the conditions applied in the assembly process of the old formulation to assure that the only gap between the two studies is the difference in the formulation of the new solder paste material that is being qualified.

Before HAST, a preconditioning method is executed first by subjecting the sample units on TA = 85°C/85 RH to simulate the assembly process of board mounting of the devices that will be done on the customer's side. The devices will be subjected to dry baking, temperature and moisture soaking, solder IR reflow, and functional tests before HAST.

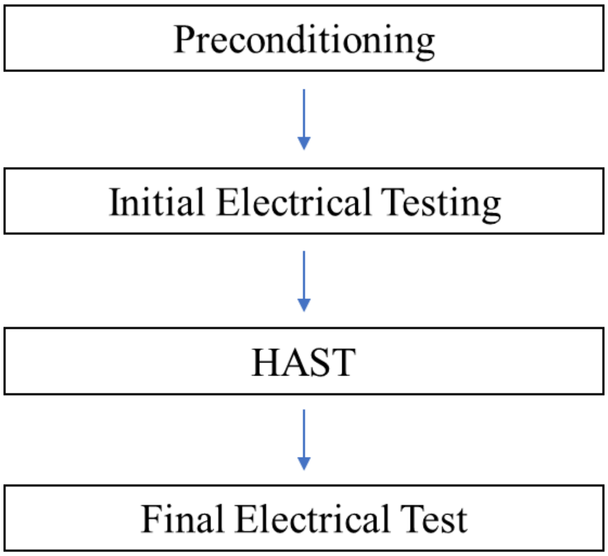


Figure 2. Process flow of HAST

The units will go through an electrical test before and after HAST to examine if any of the units has been affected by the stress subjected to it.

4.0 RESULTS AND DISCUSSION

4.1 Failures encountered on the old formulation

Failure Analysis of the HAST96 failed unit did not display any visual and x-ray anomalies. However, electrical verification from Figure 2 has shown that the failed unit has a current leakage on the on drain-source leakage current (Idss) parameter at the level of 100uA, which is the maximum current that flows through a FET transistor when there is no bias being supplied on the gate.

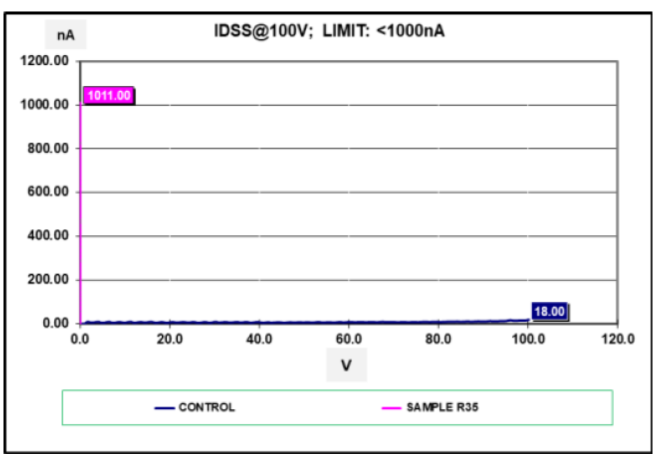


Figure 3. Electrical Curve Trace of HAST96 failed unit.

Table 4. Failure Analysis Results of HAST Failure from old formulation

Failed Lifetest	**HAST @ 96 Hours**
External Visual Inspection	**Passed**
Electrical Verification	**Valid**
Xray	**Passed**
SAM	**Delamination on all target surfaces**
Failure after HAST	**Shorted on D – S**
Curve Trace Verification	**D – S Current Leakage**
Logslope Analysis	**Graph shifted → moisture ingress** **(Possible electrochemical migration)**

Logslope analysis of failed units shown in Figure 5 exhibited a shift on the graph, which indicates that a moisture ingress during the process of HAST possibly triggered an electrochemical migration to occur inside the unit. This possibly took effect if the bromine content of the solder paste is deposited on the drain and source area, causing corrosion.

Figure 4. Decapsulation of the failed unit

Decapsulation was performed to observe if there was any damage inside the unit that can lead to failure. However, no visual anomaly was found on the failed unit. Hence, corrosion cannot be concluded as the reason of failure after HAST.

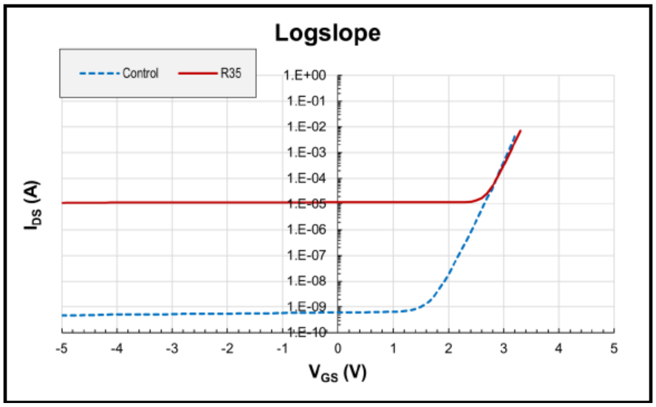


Figure 5. Logslope Analysis of the failed sample having "shifted" graphical representation.

This can be related to the study of Kim et al. where the delamination caused by the moisture ingress induced the electrochemical migration inside the device. In addition to that, ECM is known as the transport of ions between two metallization stripes under bias through an aqueous electrolyte. [2]

Moreover, with reference to Chang et. al study about the investigation of HAST failure mechanism, the halogen content was released at higher temperature [5] and relating this to our study, the HAST process conducted is at T_A = 130°C condition, causing Bromine content on the solder paste to be released during life testing.

Thus, it is viable that the failure originated from the moisture obtained from the HAST process, which resulted in delamination that triggered the bromide to dissolve on the drain and the source causing an insulation breakdown.

4.2 Failures encountered on the new formulation

A short failure on the gate area occurred on one unit after HAST 96 hours and upon verification using an electrical curve trace, it was found that the unit failed on all terminals - gate, source, and drain. Meanwhile, all samples from the control lots passed the post-HAST electrical test.

To identify the possible cause of the failure, a log slope test after curve trace verification can be performed. However, it is not attainable as the unit failed on all terminals, which implies that there is no current flowing within the unit.

Table 5. Failure Analysis Results of HAST fail from new formulation.

Failed Lifetest	**HAST @ 96 Hours**
External Visual Inspection	**Passed**
Electrical Verification	**Valid**
Xray	**Passed**
SAM	**Delamination on all target surfaces**
Failure after HAST	**Shorted on S – G**
Curve Trace Verification	**Failed on all parameters**
Logslope Analysis	**Not applicable for units that fail on all parameters**
Decapsulation	**Burnt Mark observed**

For further analysis, chemical decapsulation was performed to verify if there is any anomaly on the hotspot found using a thermal emission microscope (TEM). Upon decapsulation, the burnt mark was observed on the failed unit indicating that a severe failure materialized on the unit.

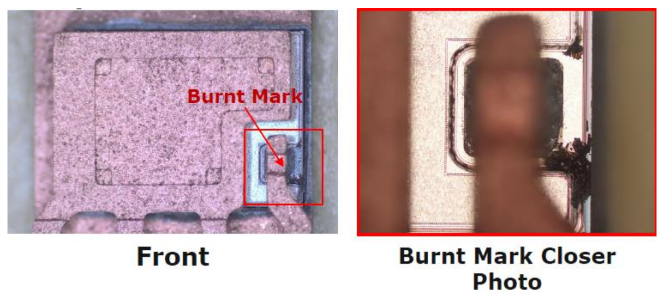


Figure 6. Burnt Mark on the failed unit after decapsulation.

5.0 CONCLUSION

Through the above analysis and study, there are no commonalities found in the failures encountered from assembly trials of the old and new formulations. The failure from the past trial encountered a current leakage on the drain to the source area and no corrosion was observed after decapsulation. Meanwhile, the failed unit on the latest trial could be a die-related failure as burnt marks are observed inside the unit.

Therefore, based on the investigation and the data gathered using the same parameters in assembly and similar conditions on reliability testing for both trials, it is verified that the Bromine content induced the HAST failure encountered in the selected clip-bonded packages.

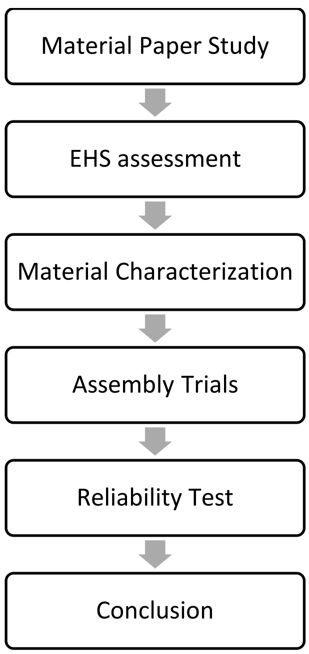
6.0 RECOMMENDATIONS

Conduct further study using the new formulation by making more assembly trials to validate if similar failures will be encountered on other trials.

In addition, the team would like to recommend a new process flow in selecting new solder paste material for qualification.

Before going straight to an intensive industrialization or qualification process that consumes a lot of time and resources, this can be shortened by performing a capability study, which prevents the company from the risk of using excessive resources and budget.

Figure 7. Recommended process flow on selection of new materials for qualification.



1. **Paper Study.**
   - To compare of documents of new material and existing material, such as technical data sheet (TDS) and material safety data sheet (MSDS).
   - Halogen test report must be provided by the supplier to prevent Halogen-induced failures in the future.

2. **Environmental, Health, and Safety Office assessment**
   - To confirm if the content of the new material will pass RoHS and our company's standards. Material Declaration Form (MDF) must be accomplished by the supplier.

3. **Material Characterization**
   - To observe if the properties (i.e., viscosity, flux residue level, solder balling test) of the new material is comparable with the existing material.

4. **Assembly Trials**
   - To assess the manufacturability performance of the new material and to define the point parameters needed.

5. **Reliability Test**
   - To assess the robustness of the product.

6. **Conclusion**
   - To assess all the data gathered and conclude if the material will be considered for industrialization.

7.0 ACKNOWLEDGMENT

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9.0 ABOUT THE AUTHORS

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Emmanuel Subida Jr is a graduate of Bachelor of Science in Industrial Engineering and Engineering Management from Mapua Institute of Technology. He completed his Bachelor in Electronics Engineering Technology at Technological University of the Philippines-Taguig and he has almost 20 years of experience in semiconductor manufacturing in the field of process development, package development and project management. Currently, he is working in Nexperia as Chief Package Architect and leading the team of package development engineers.