EVALUATION OF HIGH GLASS TRANSITION MOLDING COMPOUND AND ITS PREDICTIVE LIFETIME ANALYSIS ON OVERMOLDED HIGH POWER DEVICES USING WEIBULL PLOT

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ABSTRACT

High glass transition (Tg) molding compounds are essential in improving the reliability of high-power semiconductor devices, where thermal stresses often lead to delamination failures.

To understand and fully address performance in the product, the study combined observations from Temperature Cycling (TC) and Power Cycling Test (PCT) through Weibull Analysis. Results indicated the samples with high Tg of Epoxy Molding Compound (EMC) enabled reliability operation up to 600 kcycles in PCT based on TTF0.1 of the Weibull Plot using the Lognormal approach. Norriz-Landzberg calculation showed an equivalent of 2.4 million application cycles. The Supersmith software provided an advantage in predictive lifetime analysis of the over molded high power device using the high Tg molding compound.

1. 0 INTRODUCTION

A wide range of semiconductor devices are adapting to higher power applications because of rapid acceleration in technologies. As such, material change is integrated to assess both the reliability and product application requirements. One of the key failure mechanisms critical to the high-power application is the delamination between mold to lead frame interface which is primarily triggered by low glass temperature molding compound. Current molding compounds available in the market degrade under thermal stress, leading to premature device failure. Such delamination is captured during the temperature cycling (TC) and power cycling test (PCT) with consistent degradation of the molding compound. The failure mechanism was also evident in both functional test and scanning acoustic microscopy (SAM) and validated through the cross-sectional analysis and scanning electron microscope (SEM), thus, decreasing the product lifetime.

To further address the performance of the molding compound in the application, a high glass transition (Tg) epoxy molding compound (EMC) has taken its place to strengthen the adhesion of the material to the lead frame and improve the EMC stability at high temperature application. Thermal simulation showed improvement on lead adhesion for high thermal EMC.

Although several high Tg molding compounds are involved in the high-power applications, predictive lifetime analysis integrating material and statisticaly reliability remains limited. This study evaluates high Tg molding compound in high power packages, the reliability trend under different thermal cycling conditions and the lifetime models using Weibull Analysis.

2. 0 REVIEW OF RELATED WORK

2.1 *Properties of High Tg EMCs and Their Effect on Reliability*

The reliability of over molded high-power semiconductor devices is increasingly influenced by the thermal and mechanical limitations of the packaging materials used. Among these, EMCs with Tg are recognized for their superior thermal resistance, reduced moisture absorption, and improved mechanical integrity. High Tg materials are particularly effective in mitigating stress-related failures, such as delamination and cracking, which arise from repeated thermal cycling in power applications. These materials serve to buffer the mismatch in thermal expansion coefficients between different layers, thus enhancing overall package reliability2.

2.2 *Use of Weibull Analysis in Predictive Modeling*

In parallel, predictive reliability modeling has emerged as an essential tool in evaluating the expected operational lifetime of power packages. Among various statistical approaches, the Weibull distribution remains a widely accepted model for analyzing time-to-failure data due to its flexibility in characterizing early, random, and wear-out failure modes. The Weibull plot provides insight into both failure rate trends and the statistical confidence of reliability assessments. Recent work has applied Weibull analysis to quantify the degradation patterns in over molded power components under accelerated stress conditions, including temperature-humidity bias and power cycling tests.

Several investigations have explored the interaction between molding compound properties and the parameters derived from Weibull analysis. For instance, Q. Zou et al. demonstrated that EMCs with high Tg values maintained modulus and thermal stability after prolonged thermal aging, indicate consistent failure mechanisms. These findings underscore the critical role of material selection in influencing both the physical and statistical aspects of device reliability[2].

Despite these advances, current literature reveals a lack of integrated methodologies that combine material performance evaluation with statistical lifetime prediction. Most studies tend to isolate physical testing from reliability modeling, which limits the ability to predict long-term behavior under field-like conditions. As power devices continue to scale in performance and thermal density, there is a pressing need for a unified framework that incorporates high Tg material characterization, environmental stress data, and robust Weibull modeling. Such an approach would provide a more accurate estimation of lifetime and inform the design of next-generation packaging systems for high-reliability applications.

3.0 METHODOLOGY

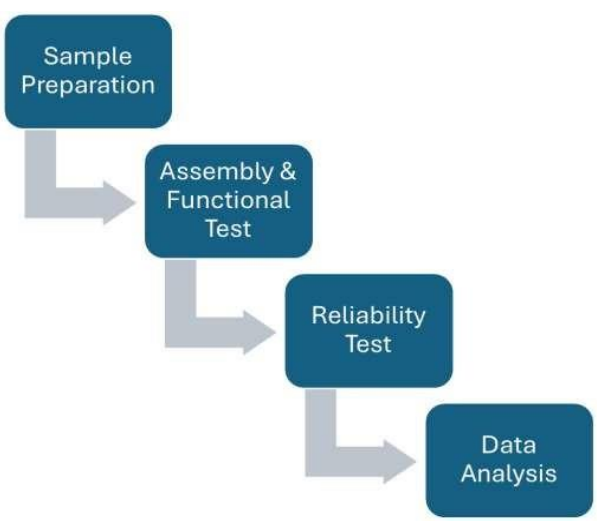

Fig. 1. Flowchart of the Experimental Methodology

3.1 Sample Preparation

Samples were prepared based on the required bill of materials which includes the molding compound with high T_g of 160ºC. Three legs were prepared, incorporating the required assembly requirements and 100 units per leg for data gathering.

3.2 Assembly & Functional Test

The evaluation legs were processed in assembly highlighting the three main factors to assess the performance of the high Tg EMC as shown on Table 1.

Table 1. Factors Monitored in the Study

Lead frame type	Plasma	Molding Compound
Cu+Ag	ArH2 gas	High Tg EMC

3.3 Reliability Test

Assembled samples were assessed and validated through reliability tests and checked the responses based on functional test (FT) and scanning acoustic microscopy (SAM). Main reliability tests implemented in this study were TC(-65/175oC) and PCT with 360W power setting. The read point assessed were 500, 1000 cycles for TC and 168hrs for PCT.

3.4 Data Analysis

To plot and determine predictive lifetime of the high Tg molding compound in high power device, a failure parameter was extracted from the functional test data and plotted into the Weibull software version 5.0J. The plotted data were programmed using Lognormal distribution and calculated the Time to Fail (TTF0.1) of the product. The calculated TTF0.1was converted into corresponding application cycles using the Norriz-Landzberg model to obtain the acceleration factor (AF) formula

$$AF = (\frac{\Delta T_t}{\Delta T_o})^n (\frac{f_o}{f_t})^m$$

Where T is the absolute temperature in degrees Celsius, t is the reliability test condition applied, o is the operating temperature, f is the are the
constants extracted and correlated from separate experimental study.

4.0 RESULTS AND DISCUSSION

The functional test fails extracted from the reliability tests were interpolated based on the fail rate criteria of the thermal resistance <10% and plotted to the Supersmith 5.0J software. Fig. 1 shows the user interface of the platform where the data were plugged into. To get a better fit in the failure distribution, Lognormal or Weibull distribution plot can be used. For this study, Lognormal was utilized.

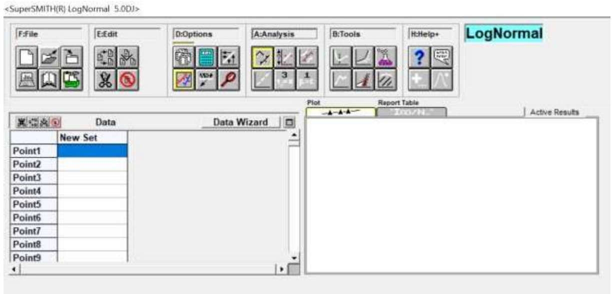

Fig. 2. User Interface of the Supersmith 5.0J Software

The plotted data in the interface reflected the failure distribution plot located at the Plot section of the program.

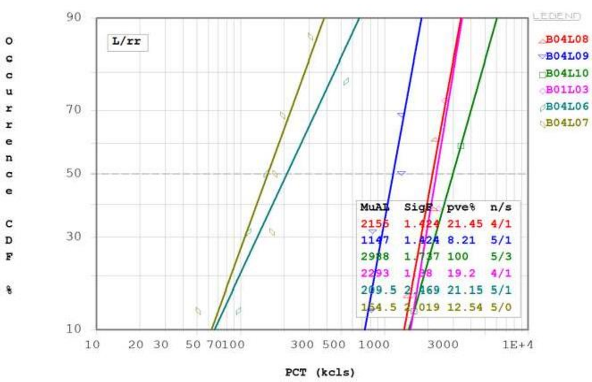

Fig. 4. Failure Distribution Plot of the PCT Samples Using the Lognormal Approach

To obtain the desired predictive plot of the available data, this will be extracted from the "Precise Reading from Plot/Likelihood" command to get the TTF0.1.

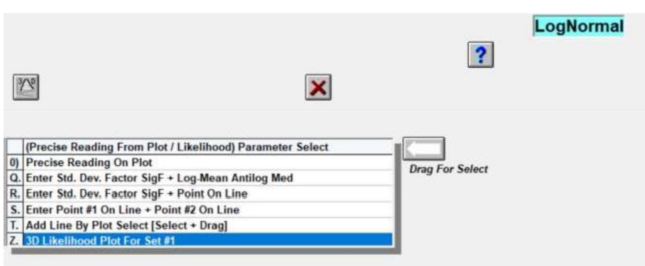

Fig. 3. Precise Reading from Plot/Likelihood Command to Extract the TTF0.1.

Weighted average of 1,900 cycles and sigF of 1.46 was observed on the samples. TTF0.1 extracted from the graph was 600 kcycles and using the Norriz-Landzberg on/off cycling time coefficient of n=0.10, the equivalent application result was 2.4 Mcycles. It describes that the calculated equivalent application cycles was the maximum capability of the product during application.

SAM results showed no delamination between the mold and lead frame interface after TC 1000 cycles and PCT 600k cycles, strengthening the capability and robustness of the high Tg molding compound in high power applications. These results corroborate with Q. Zou's study that high Tg EMC provided an increase in Weibull shape of $\beta > 1$.

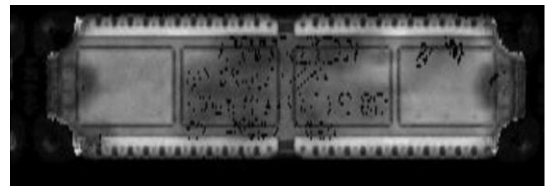

Fig. 4. SAM Image of the Sample After Power Cycling Test

The use of failure distribution plot using the Supersmith Software was able to establish predictive product life time based on the extracted data from the study.

5.0 CONCLUSION

The study demonstrated a quantitative approach in life time prediction of a product. Assessment of the product capability of the high Tg molding compound at high power application was determined through the failure distribution plot, providing maximum reliability of the material. The software is a relevant application for reliability assessments and predictive analysis.

6.0 RECOMMENDATIONS

The authors recommend extending the study on the other reliability tests to extract more predictive lifetime plots of the over molded high-power product using high Tg molding compound. Further study with the application of the Weibull plot will provide extensive results to align with the required product application requirements.

7.0 ACKNOWLEDGMENT

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