RELIABILITY OF LOW GLASS TRANSITION TEMPERATURE COTS PEM'S FOR SPACE APPLICATIONS[1]

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ABSTRACT

Microcircuit manufacturers of Plastic Encapsulated Microcircuits (PEM's) have made changes in epoxy molding compound materials and chemistry, which lower Glass Transition Temperature (Tg). PEM users in harsh environments have concerns if either the part in its application, or in evaluation or assembly, is used close to, or above, the Tg. Various Tg measurement techniques are available and discussed. Test results from one technique is reviewed. The implications of the Tg results on usage of these parts in space applications will be presented. Burn-in/ reliability test results of samples with low Tg PEM's will be presented. The reliability experiments include testing under different temperatures. The issue being addressed is whether outgassing of molding compounds occurs when the temperature of the molding compound exceeds the Tg. This is a caution noted by many vendors. As an example outgassing of flame retardants can degrade parametric performance and wire bond integrity. This would be the case when PEMS are being qualified for Space applications using burn-in or in storage environments. JPL's past experience has shown that COTS PEMS parametrics can degrade significantly even when the burn-in temperature is well below the Tg. Two different microcircuits exhibiting low Tg were evaluated. Assessment of final electrical test measurements and yield are shown.

Introduction

Plastic Encapsulated Microelectronics (PEM) reliability is affected by many factors. Glass transition temperature (Tg) is one such factor. Other related factors that influence reliability are the thermal expansion coefficient (CTE) of the epoxy mold compound and the CTE of the underfill (if used). The Jet Propulsion Laboratory (JPL) and NASA are investigating how the Tg and CTE for PEM's effect device reliability under different operating and screening temperatures and other aging conditions.

Other issues with Tg are also under investigation. In this presentation issues relating to PEM reliability and the effect of low glass transition temperature epoxy mold compounds are presented. Data is presented on measurement of glass transition temperature. Also some data is presented on reliability investigations using various burn-in tests at a variety of temperatures on two part types that may be representative of current production low glass transition temperature PEM's.

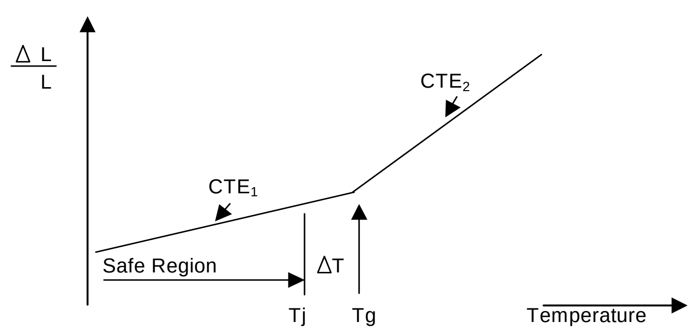

Figure 1 – Definition of Glass Transition Temperature

The Glass Transition Temperature (Tg) is determined as the midpoint of the temperature range at which a dramatic change in CTE occurs. The lower temperature region for the epoxy mold compound is characterized by a lower CTE up until a transition region where the CTE increases (eventually to a value 2 to 3 times the lower temperature

Glass Transition Temperature Measurement Methods

value). The lower temperature regime is called the Hard or Glassy state. The upper temperature region is called the Soft or Rubbery state. In the upper temperature region there is a decided mismatch between the CTE of the epoxy package and the leadframe, wires and wire bonds, and the silicon die.

CTE is a measure of the fractional change in dimension (usually thickness) per degree rise in temperature. For microelectronics encapsulants, the usual units are "ppm/°C" (value X 10-6 per degree Celsius). CTE is highly dependent on detailed chemical composition of the epoxy mold compound including filler loading and cure cycles of the encapsulant. From a reliability point of view, it is desirable to have both high Tg and low CTE. Also CTE should be as close as possible to matching the CTE of the other package elements such as leadframe, wire bonds, and silicon die.

The three methods to test are delineated here:

1) Differential Scanning Calorimetry (DSC): The sample is heated in a closely calibrated thermocel where the temperature of the sample is compared to the temperature of a blank reference point within the same cell. The change in heat capacity at Tg is seen as a shift in the baseline for the cured encapsulant. This method has the advantages of being a quick and simple test and no special sample preparation is needed.

   DSC detects extra thermal absorptions/emissions from a plastic (cured) epoxy . These materials can undergo many thermal reactions when heated. Only one of these reactions is the glass transition, i. e. the temperature at which the polymer strands realign from a crystalline like state to an elastic state. Many other energetic peaks may show up on DSC spectra including additional chemical reactions, solids melting, amorphous reorganizations to a crystalline state. These other DSC peaks may interfere with the glass transition peak. For example, these other peaks may make the glass transition peak broaden.

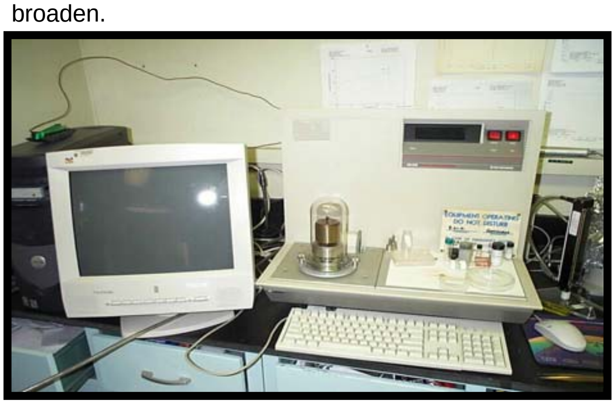

Figure 2 JPL DSC Tester

2) Thermal Mechanical Analysis (TMA): The sample is heated upon an expansion calibrated platform and measuring the dimensional change of the sample with an instrumented probe. Probe placement can alter the reading. This test method is delineated in ISO 11359.

TMA directly measures motion as a sample is heated. There can also be an abrupt change of shape when a polymer goes from a crystalline to a more amorphous state – this is the glass transition. TMA analysis yields the CTE of the cured resin.

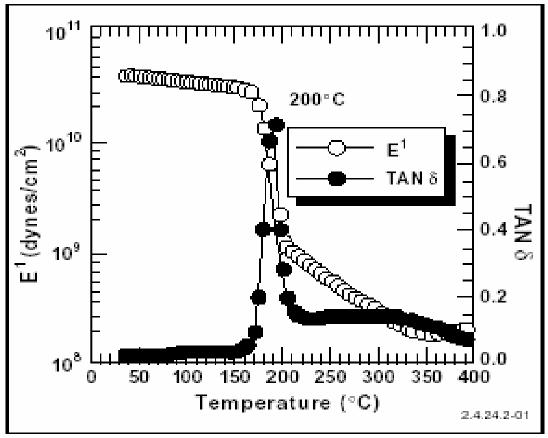

Figure 3 TMA Data

If the major concern is CTE mismatch and its affect on reliability this measurement method is preferred.

Figure 4 JPL TMA Tester

3) Dynamical Mechanical Analysis (DMA): Measure changes in dynamic characteristics of the epoxy mold compound including Modulus (stiffness), Damping (energy dissipation), Creep, and Stress Relaxation.

Figure 5 JPL DMA Tester

The Jet Propulsion Laboratory preferred Tg measurement method is TMA since that method is more repeatable and sample preparation is simpler and less critical.

Reliability Concerns if Glass Transition Temperature is exceeded

Discussions with industry personnel and in the user community have surfaced the following concerns:

- CTE of the epoxy encapsulant will permanently change (breakdown of chemical cross-linking of polymers)
- Displacement of wire bonds , which, in turn, may result in premature wearout and breaking of wires
- Premature aging in storage
- Induced stresses between materials internal and external (for example, underfill) because of the CTE mismatch. This would reduce capability to withstand temperature cycling stress.
- Adhesion degradation (of epoxy mold compound to either leadframe or silicon die)
- Release (precipitation) of flame retardants used within the epoxy mold compound. This would include Bromine compounds, and Red phosphorous. Release of mobile halogen compounds would attack the gold-aluminum ball bond leading to enhanced possibility of Kirkendall voiding (purple plague).
- Electrical device performance degradation

Glass Transition Temperature Measurements of Typical Modern Plastic Encapsulated Microcircuits

The Jet Propulsion Laboratory (JPL) Analytical Chemistry Laboratory has tested typical recent production PEM's. It has been reported that Tg of most modern PEM's ranges between 150 and 160 degrees Celsius, however, many of the parts tested at JPL have shown Glass Transition Temperatures much lower, sometimes below 120 degrees Celsius. Furthermore, the measured Tg was different among samples within the same date code lot of PEM's. Some results are shown in the Figure Measured Glass Transition Temperature (color coded items are the same part number but differing date codes).

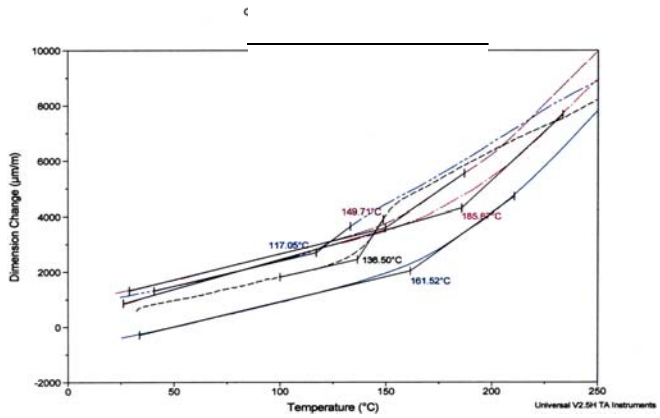

Figure 6 TMA Data Output

These results are tabulated:

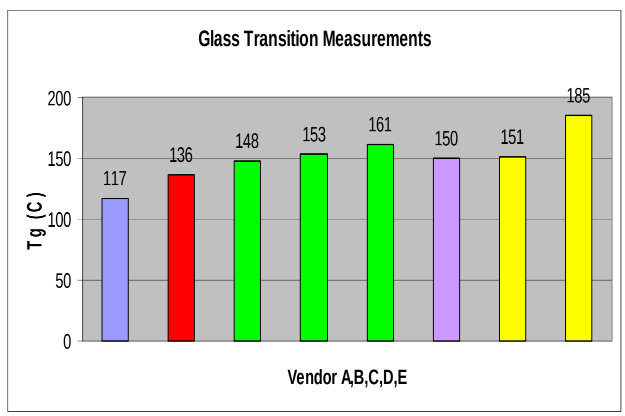

Figure 7 Measured Glass Transition Temperatures

Trends in Epoxy Mold Compound Characteristics

Newer Epoxy Mold Compounds are being produced with lower Glass Transition Temperatures. Biphenyl compounds and the complex molding materials used in Plastic Ball Grid Arrays and Chip Scale Packages often have a glass transition temperature below the traditional military temperature range (e. g. +125°C). Examples of mechanical characteristics of modern epoxy mold compounds are shown here:

General Properties					
Item	Unit	Condition	Newly Developed		Conventional
			CEL-300*	CEL-310*	CEL9200*
Spiral Flow	cm	MMI-1-66	100	90	90
Gelation Time	sec	175°C	40	30	28
Tg	°C	TMA	120	110	120
CTE(a1)	ppm/°C	TMA	7	8	8
Flexural Modulus	GPa	JIS-K-6911	28.0	26.0	26.0
Water Absorption	wt%	PCT 20h	0.28	0.31	0.30
Flammability	-	UL-94	V-O	V-O	V-O

Figure 8 Epoxy Mold Compound Properties

Reliability Investigations Planned at JPL Relating to Glass Transition Temperature Concerns

Various experimental and analytic efforts are planned to determine the significance of use of low glass transition temperature PEM's in future space missions. The area being investigated now is the question of maximum allowable burn-in temperatures for lower glass transition temperature molded integrated circuits. Early results will be presented later in this paper. Future investigations will involve looking at operation derating considerations dependent on Tg, comparative reliability of low and high glass transition temperature PEM's. Also planned is a review of ASTM E595-93 methodology, which is the test method for outgassing assessments for use of parts and materials in space missions.

Burn-in Investigation

The purpose of this initial series of experiments is to determine if some typical modern devices fail or degrade anomalously if burned in at a temperature near or above the glass transition temperature of the epoxy mold compound in the PEM being tested.

Two device types were selected for these initial tests: an Analog to Digital Converter for which the glass transition temperature has been measured as 117 degrees Celsius and a Operational Amplifier, for which the glass transition temperature has been measured as 136 degrees Celsius.

Thirty parts were available for each part type. They were each broken into three splits. All parts were initially electrically tested at three temperatures. Burn-in was then performed for 240 hours at three different temperatures (for each of the split groups):

Device Type	Split Number	Burn-in Temperature
Analog to Digital Converter (Tg=117°C)	1	85 degrees Celsius
	2	115 degrees Celsius
	3	145 degrees Celsius
Operational Amplifier (Tg=136°C)	1	85 degrees Celsius
	2	130 degrees Celsius
	3	150 degrees Celsius

Figure 9 Burn-in Splits

Results to Date

Only the room temperature electrical characteristics have been assessed to date. The A/D converter results are discussed first. The first split contains parts burned-in at 85°C. Pre-test electrical measurements showed no failures to the specification. The data is seen to be very similar in all the pre burn-in electrical measurements:

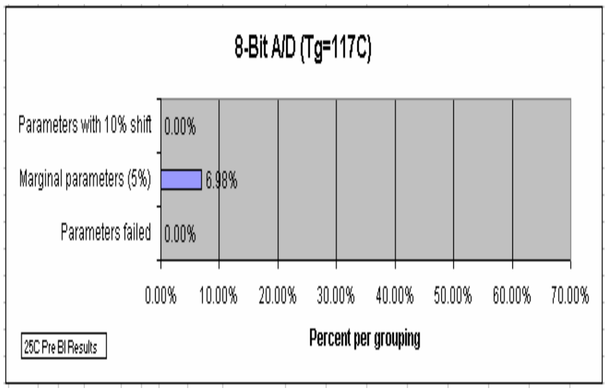

Figure 10. Pre Burn-in Electrical Tests of First Split

Post burn-in results for the group burned-in at 85°C are shown below. Note: there was one functional failure in this group (this is not graphed since it was not a parametric failure). It is seen that there was significant drift in electrical parameters. However there was no significant increase (in fact, a small decrease was observed) in parameters near the specification limit

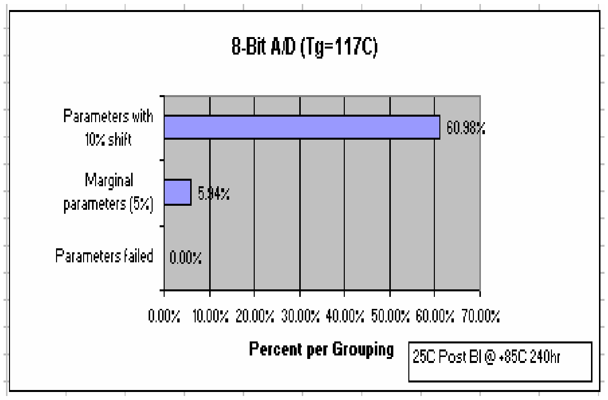

Figure 11. Post Burn-in Electrical Tests of the First Split

The second split was burned-in at a slightly higher burn-in temperature (115°C)

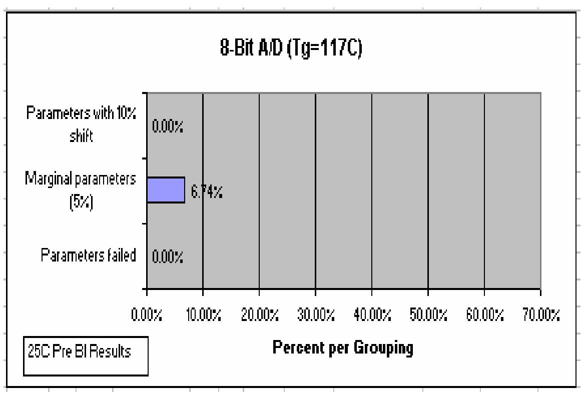

Figure 12. Pre Burn-in Electrical Tests of Second Split

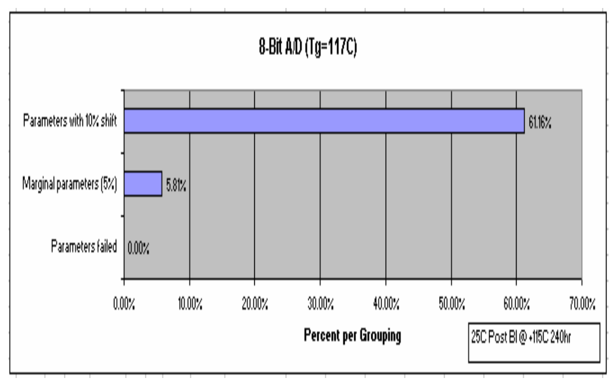

Figure 13. Post Burn-in Electrical Tests of Second Split

Post burn-in results were similar to those at the lower temperature burn-in.

The third split was burned-in at 145°C. Here is the pre-burn-in electrical data:

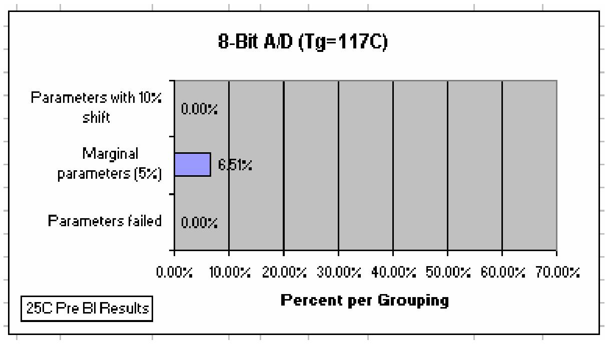

Figure 14. Pre Burn-in Electrical Tests of the Third Split

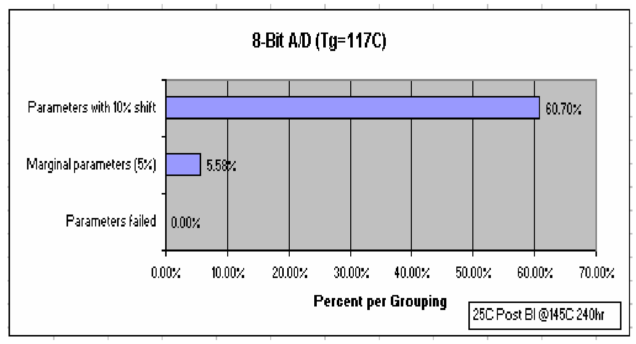

Figure 15. Post Burn-in Electrical Tests of the Third Split
No electrical failures were seen in this group.

The results for the Operational Amplifier are now presented. All the pre-burn-in electrical measurements showed no failures or marginal parameters (using the format that was used for the A/D converter the three categories of electrical measurement data were all zero.

Post burn-in results for 85°C burn-in showed some shifting but no failures.

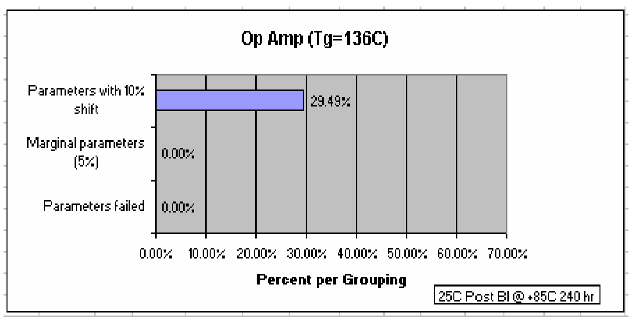

Figure 16. Post Burn-in Electrical Tests of the First Split

Post Burn-in data for the 130°C burn-in showed two parametric failures in this group.

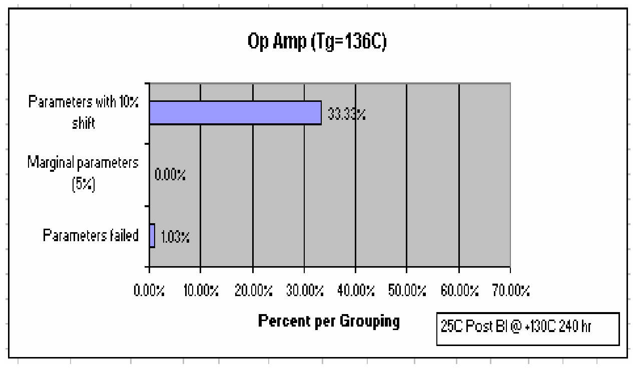

Figure 17 Post Burn-in Electrical Tests of the Second Split

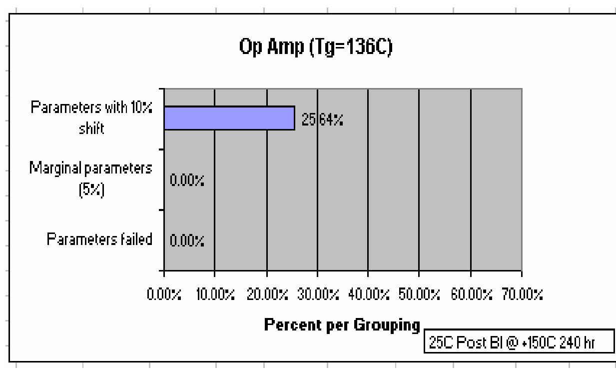

Figure 18. Post Burn-in Electrical Tests of the Third Split

Conclusions

Based on room temperature measurements of the two device types, each burned in at three different temperatures, it does not appear there is a correlation between Burn In temperature, glass transition temperature values measured and changes in electrical characteristics after burn-in. Because of the small sample size, ***additional investigation is needed*** to be more conclusive about these results, e. g. longer burn-in/life test duration and higher burn-in temperatures. It is also very important to review and analyze the high and low temperature electrical test data results (see follow-up work). In this work, only the room temperature electrical test data was analyzed.

Three burn-in failures (functional & parametric) occurred. It would be desirable to understand the cause of these failures and if the glass transition temperature and/or burn-in temperature had a role in the failures.

Consistent parametric shifts are apparent with all burn-in conditions used. For the Analog to Digital converter integrated circuits the predominant parameters exhibiting >10% shift were input leakage and high output current.

For the Op Amp the predominant parameters exhibiting >10% shift were input offset voltage/current, input bias, and large-signal voltage gain.

Further study is needed to establish if Tg has an affect.

These results represent an initial assessment of these parts from these suppliers. Since changes in vendor's material properties are continually occurring for Plastic Encapsulated Microcircuits further testing is needed to determine their impact. Furthermore, users of Plastic Encapsulated Microcircuits, particularly in critical applications, must exercise continuous surveillance of the reliability impact of these changes.

JPL Planned Follow-up Work

This study was a limited investigation. The sample size and the number of device types and part manufacturers was small, as befitted an initial investigation. Other issues deserve serious scrutiny and testing:

Tg changes after burn-in (investigate correlation to burn-in temperature)

Review of cold and high temperature electrical read & record data taken on the test samples

Failure analysis on the three burn-in rejects

Post burn-in measurements of the epoxy mold compounds that were life tested to determine if there was changes in the extractable ions within that material

Investigate the cause of variation in Tg among vendors and date codes of the same part by a vendor.

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[1] The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration