Measurements of Thermo-Mechanical Characteristics of PEMs for Failure Analysis and Reliability Evaluation

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Purpose

- Review the effect of TM characteristics of MC in PEMs, in particular Tg, on environmental reliability stress testing (HAST and HTSL).
- Demonstrate the value of TMA for reliability evaluation and failure analysis of plastic encapsulated devices.

Outline

- What is Tg and how it can be measured?
- Typical Tg values and temperatures for reliability testing of PEMs.
- How Tg might affect reliability stress testing:
  - HAST
  - HTSL
- Application of TMA for evaluation and FA:
  - Pop-corning effect in Ta capacitors;
  - Delaminations after HAST;
  - Wire bond failures in parts with silicone die coating.

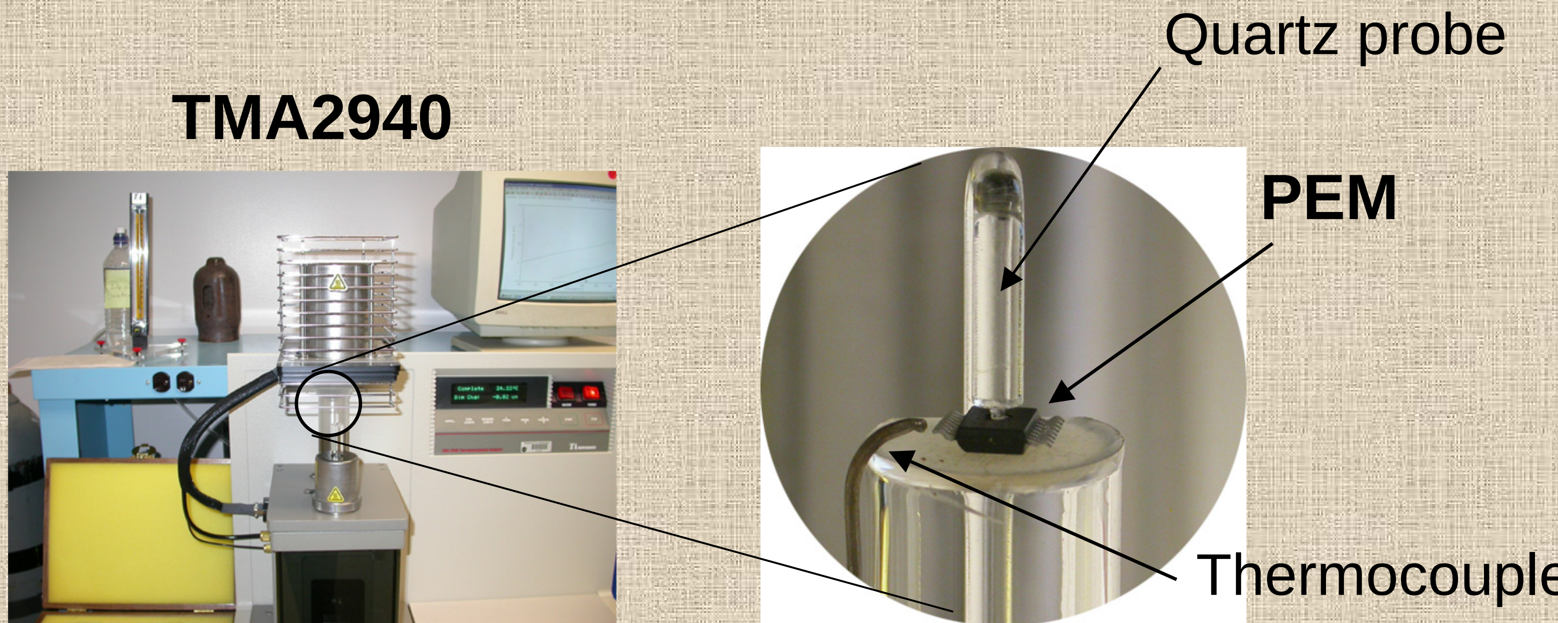
Measurements of the Glass Transition Temperature

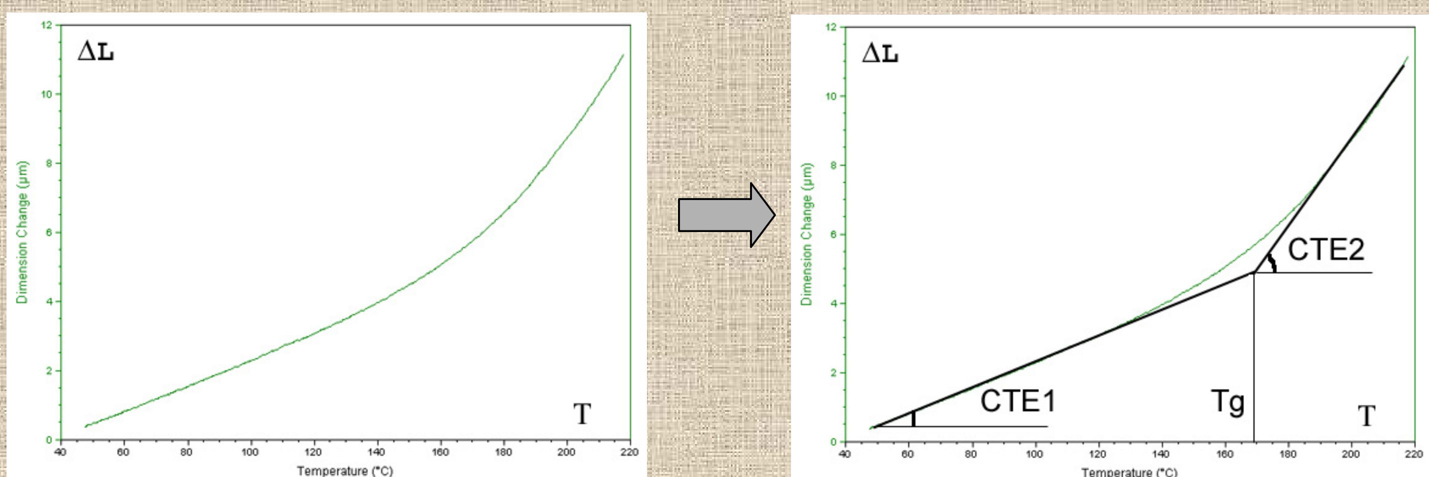
- Tg can be measured using any
  Property = f(T) technique.
- The value of Tg depends on the used method.
- Most popular techniques used for Tg measurements: DSC, TMA, DTMA.

Thermo-mechanical analysis (TMA) is most suitable technique for PEMs. It allows obtaining coefficients of thermal expansion, CTE, and/or analyzing anomalies in package deformations.

TMA Measurements

TMA2940





Typical Screening and Qualification Tests for High-Reliability Applications

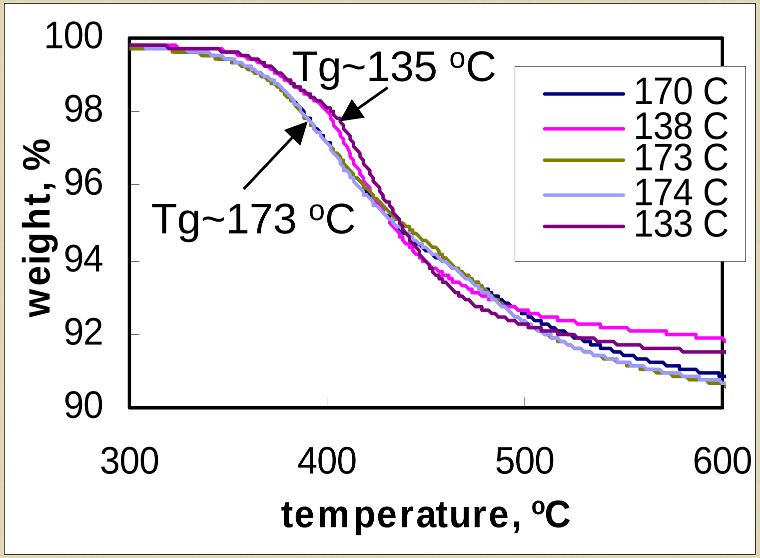
TEST	BI	HTOL	TC	HAST	HTSL
STD	MIL-STD-883, TM 1015	MIL-STD-883, TM 1005	MIL-STD-883, TM 1010	JESD22 - A110/118	JESD22-A 103B
Typical condition	125 °C 160 hrs	125 °C 1000 hrs	-65 °C to +150 °C	130 °C, 85% RH, 96 hrs	150 °C 1000 hrs

<u>Typical values of Tg for MCs:</u>
Multifunctional and orthocresol novolac: Tg ~ 150 to 190 °C.
Low mechanical stress biphenyl epoxy: Tg ~ 120 °C.
Green molding compounds: Tg ~140 °C

- Some parts are tested at temperatures up to 175 °C.
- It is possible that some tests are performed at T>Tg.
- Are these tests valid?

Does Thermal Stability of MC Depend on Tg?

TGA for MC with different Tg



Tg is not an indicator of thermal stability of MC

- TGA measurements of MCs with different Tg showed that materials with Tg ~135 ºC had higher stability compared to MC with Tg ~ 175 ºC.
- The most thermally stable polymers, silicone rubbers and Teflon, have extremely low Tg of -20 to -120 ºC for the rubbers and -90 ºC for Teflon.

HAST: Mechanisms of Tg Effect

Compression caused by the shrinkage of encapsulant prevents water needed for corrosion from accumulating at the bond pad surface.
At T>Tg, the probability of delaminations increases.

Mechanical stresses in the presence of moisture:

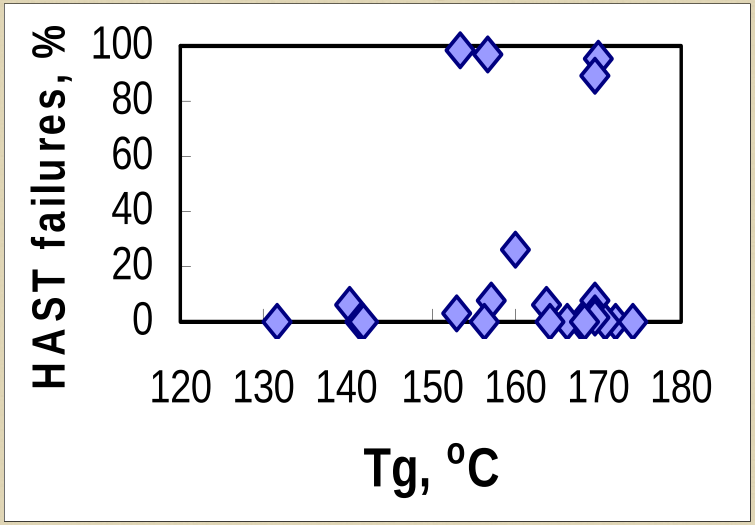
$$\sigma \propto E \times \left[(\alpha_{MC} - \alpha_{Si}) \times (Tg - T) - CME \times \delta \right]$$

Moisture swelling might have an effect equivalent to temperature increase on 50 to 70 ^{o}C.

HAST: Test Results

- 24 part types encapsulated in different plastic packages (mostly linear devices) were tested in a HAST chamber.
- Test conditions: 130 ^{o}C, 85% RH, 250 hrs under bias.
- Sample size: 30 pcs.

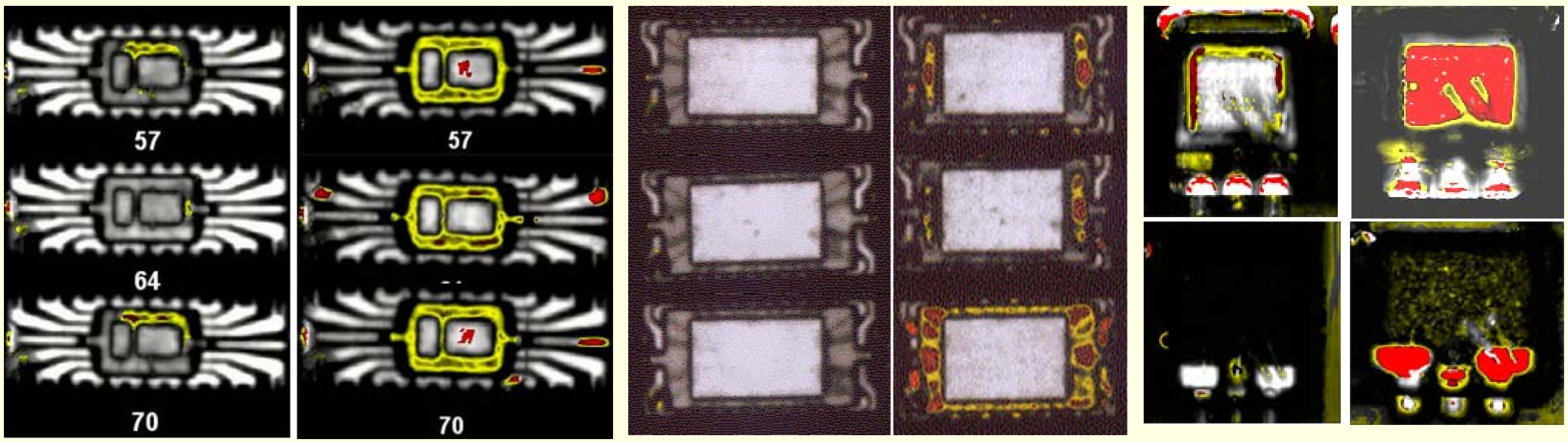
HAST failures for different PEMs vs. Tg of MCs



- No correlation between Tg and HAST failures.
- Tg is not the major factor; however, it might affect test results.

HAST: FA Results

Acoustic microscopy of parts before (left) and after (right) HAST at 130 ºC/85% RH/96 hrs.

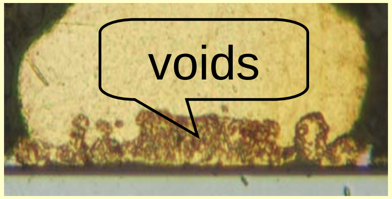


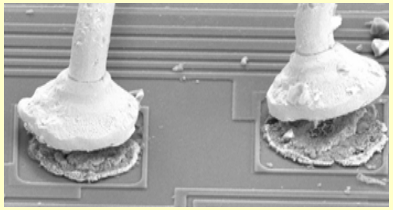
SOIC16 SSOP28 TO220

- Excessive delaminations after HAST is a common effect in PEMs.
- The probability of delaminations might depend on Tg.
- Delaminations might introduce new failure mechanisms.

HTSL: WB Degradation, Mechanism I

- Au/Al WB degradation limits reliability of PEMs at high temperatures.
- Degradation mechanism involves:
  - release of chemically active molecules from MC;
  - diffusion of the molecules to bonds;
  - chemical reaction with the Al/Au intermetallic (dry corrosion).
- If diffusion limits the process, then exceeding Tg might accelerate transport of the corrosive molecules.

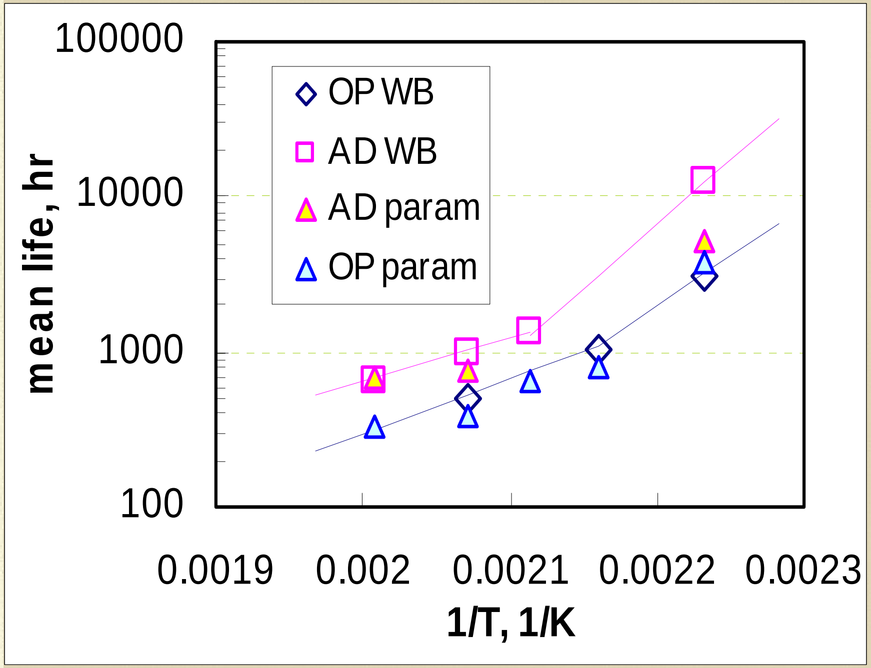




- There is no evidence that diffusion of corrosive molecules is the limiting factor of the process.
- D(T) characteristics are not known.

HTSL: WB Degradation, Experimental Data

Arrhenius plots for mean life of parametric and WB failures, 175 <T< 225 ^oC



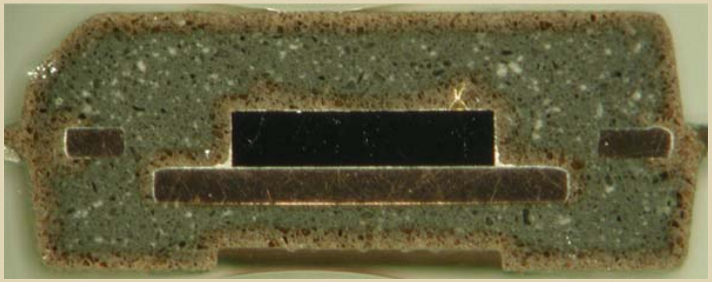
At T < 190 ^oC:
Ea ~1.3 to 1.8 eV.

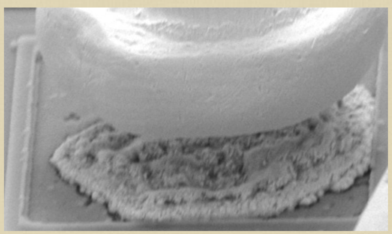
At 190 < T < 225 ^oC
Ea ~0.55 to 0.68 eV.

Different activation energies below and above Tc ~190 ^oC indicate changes in degradation mechanism.

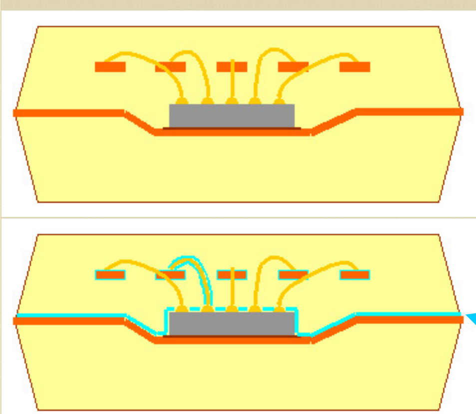
WB degradation: Mechanism II.

Discoloration of MC after HTSL





voids inside WB and along the periphery



T < Tc

T > Tc

air path

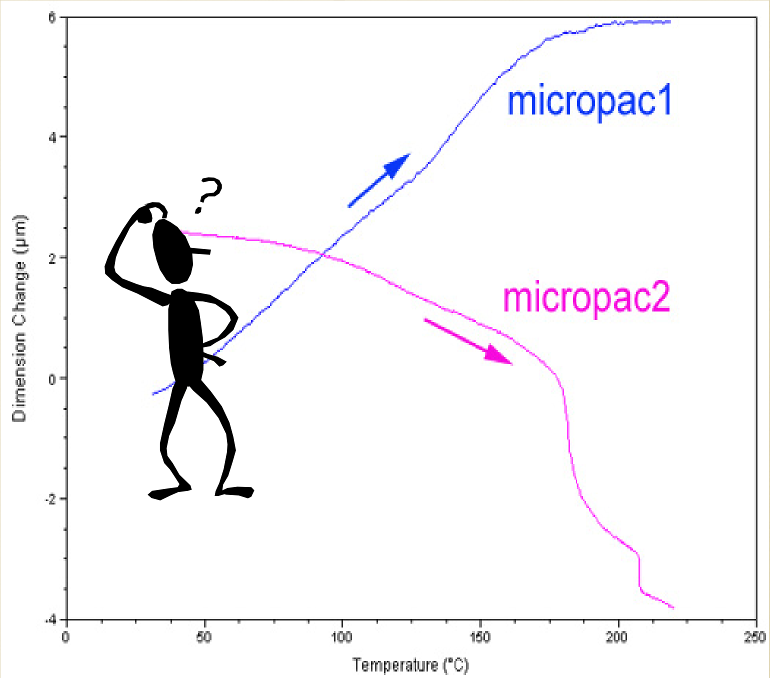
MC tinted not only along the surface of the package, but also along the lead frame, die, and wire bonds.

→ At HT there is a free pass allowing air to reach internal areas of the package.

→ A gap is forming at a critical temperature Tc > Tg to allow thermo-oxidative degradation of MC in vicinity of WB.

Anomalies during TMA Measurements

TMA curves measured directly on PEMs

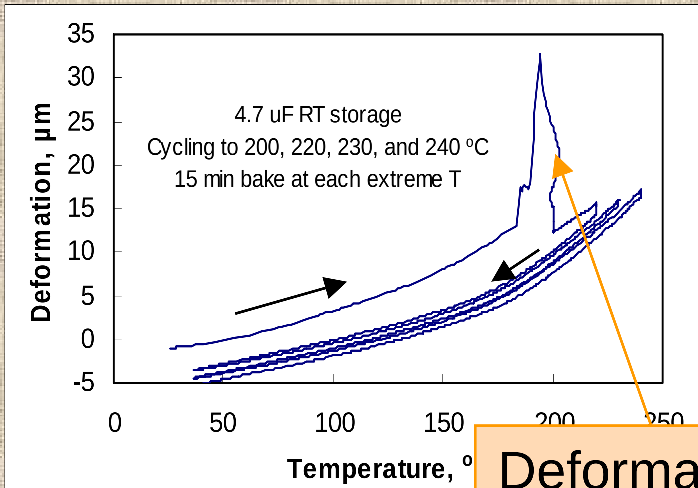


Factors affecting Tg and CTE measurements on PEMs:

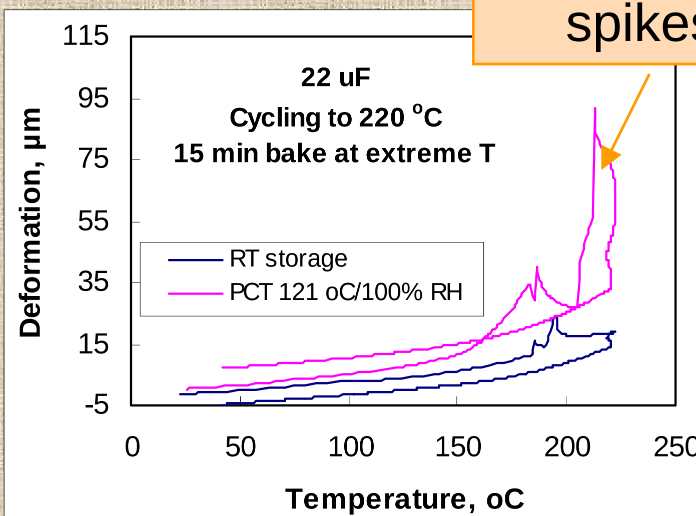
- ❑Warpage;
- ❑Stress relief;
- ❑Moisture;
- ❑Lead frame;
- ❑Temperature rate;
- ❑Cooling vs. heating

Can anomalies in TMA be used to evaluate possible reliability problems?

TMA application: Pop-corning in chip Ta capacitors?



Deformation spikes



Amplitude of spikes, µm

condition	N	Average	Std. Dev.
long RT	5	17.61	3.72
vacuum storage	3	3.85	5.38
121^0C/100% RH	4	17.53	8.65

Deformation spikes were observed during first heating up cycles (20 ^{0}C/min).

- There is a trend of increasing amplitude of spikes after moisture sorption.

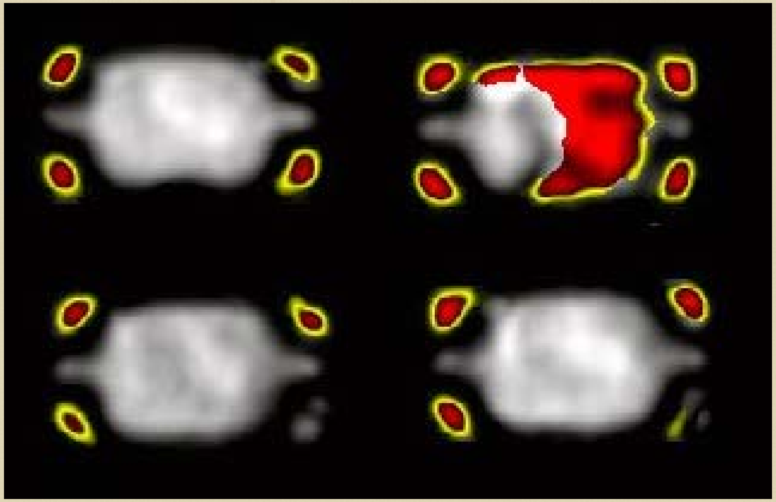
TMA application: HAST-induced delaminations

Background: Multiple CSAM failures of PEMs in SOT-23-5 packages were observed after HAST.

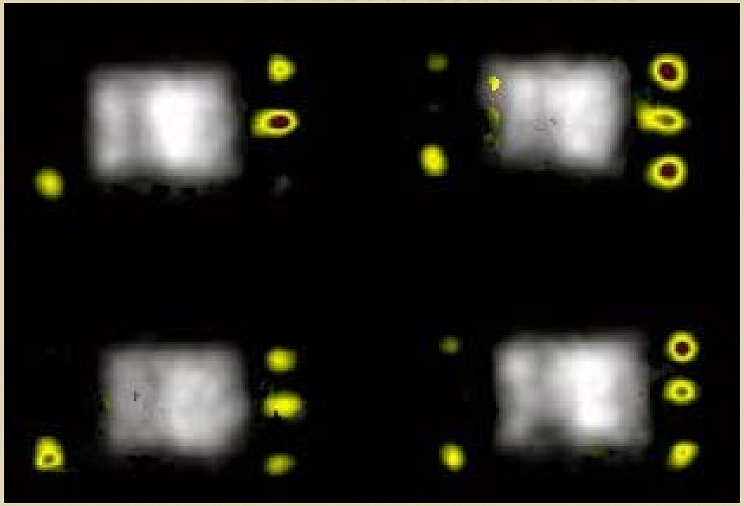
FA purpose: Why, and is there a reliability concern?

Acoustic images after HAST

Top side view



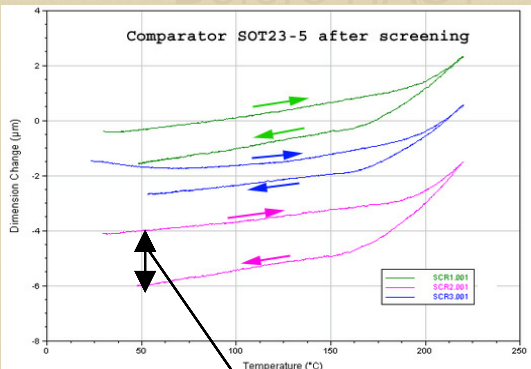
Bottom side view



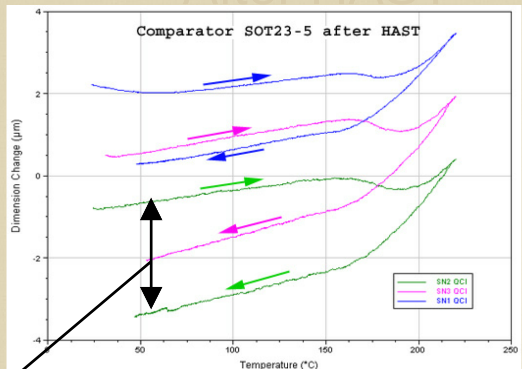
HAST-induced delaminations. Cont’d.

TMA of 3 sample

Before HAST



After HAST



TMA ~1000 hrs after HAST. The time for moisture diffusion: $\tau = L^2/4D$ = 520 hrs => Excessive moisture should have been released. => HAST caused irreversible swelling.

Hysteresis

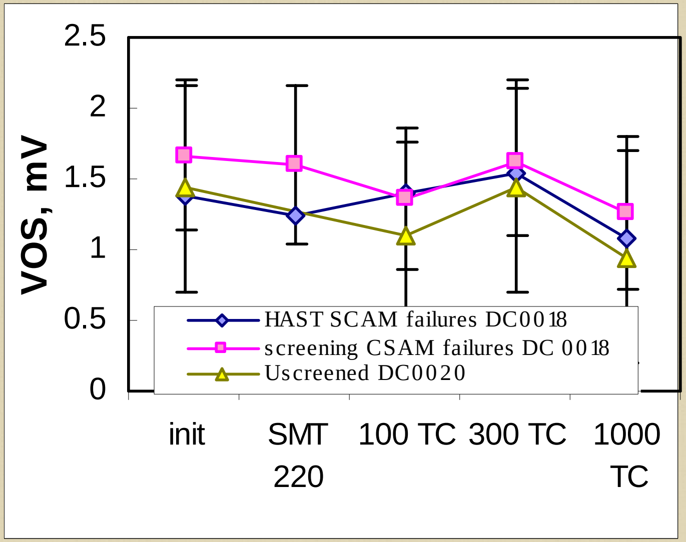
condition	dL/L, %	
	avr.	std.dev.
before HAST	0.21	0.048
after HAST	0.12	0.05

- Swelling of MC was the reason for excessive delaminations after HAST.
- The swelling caused creep of MC, which resulted in delaminations even after moisture release.

How critical delaminations are?

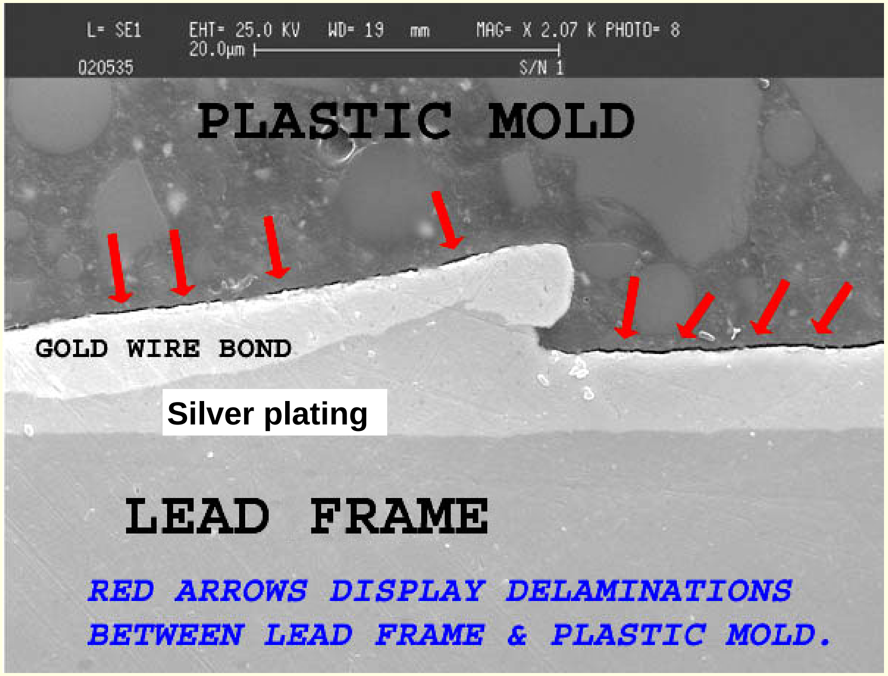
To evaluate the risk related to delaminations, three groups of parts were subjected to preconditioning according to JEDEC JESD22-A113 (three runs through the solder reflow chamber) and 1000 temperature cycles from -55 °C to 125 °C.

Effect of TC on electrical characteristics



- No failures during TC.
- The parts manifested only minor changes in electrical characteristics.

Delaminations at Secondary Bonds

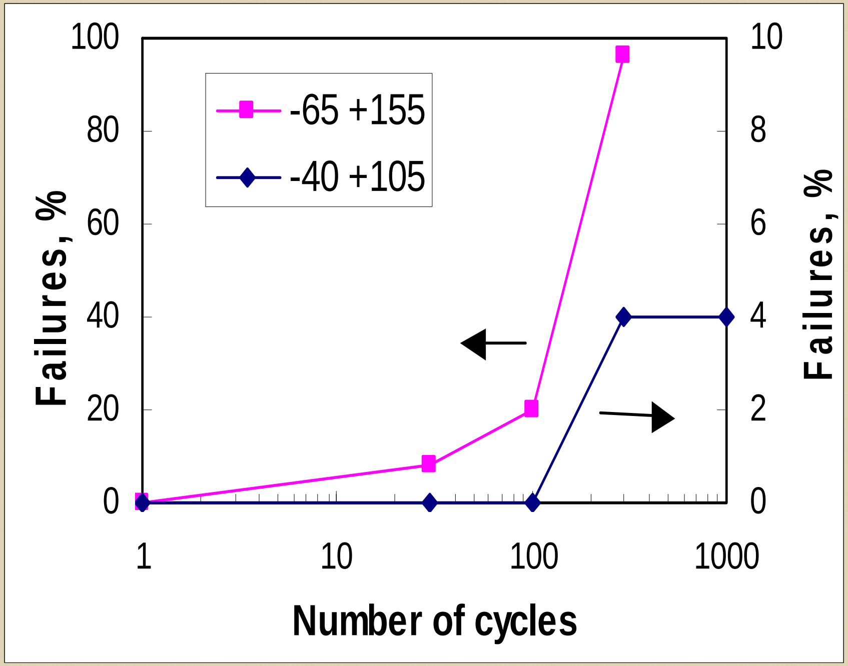


Cross-section of a typical secondary bond delamination indicates a gap above the bond area

- Delamination at gold-to-silver wire bonding at finger tips of leads is a common defect in PEMs.
- Secondary bonds are strong enough to provide reliable connection even in the presence of delaminations.

TMA application: wire bond failures during TC

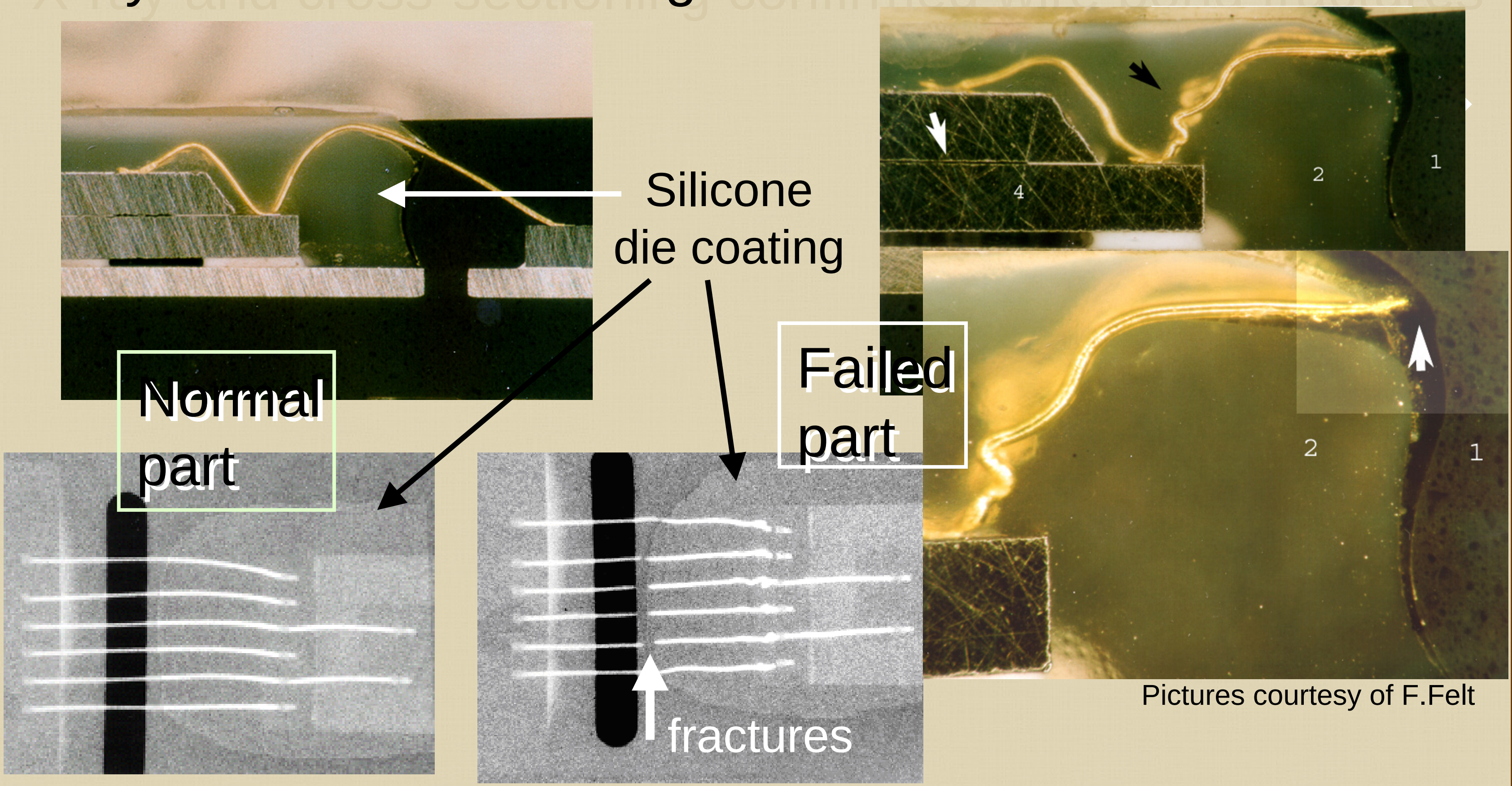
PEM failures at two TC conditions



- ***TC conditions*** (25 samples in each group)***:***
  - Low T range: -40 to +105 °C
  - High T range: -65 to +155 °C .
- ***Electrical tests:*** after 30, 100, 300, and 1000 cycles.
- ***Parts:*** PEMs in DIP16 packages.
- Catastrophic failures in both TC conditions.

Wire bond failures during TC. Cont'd.

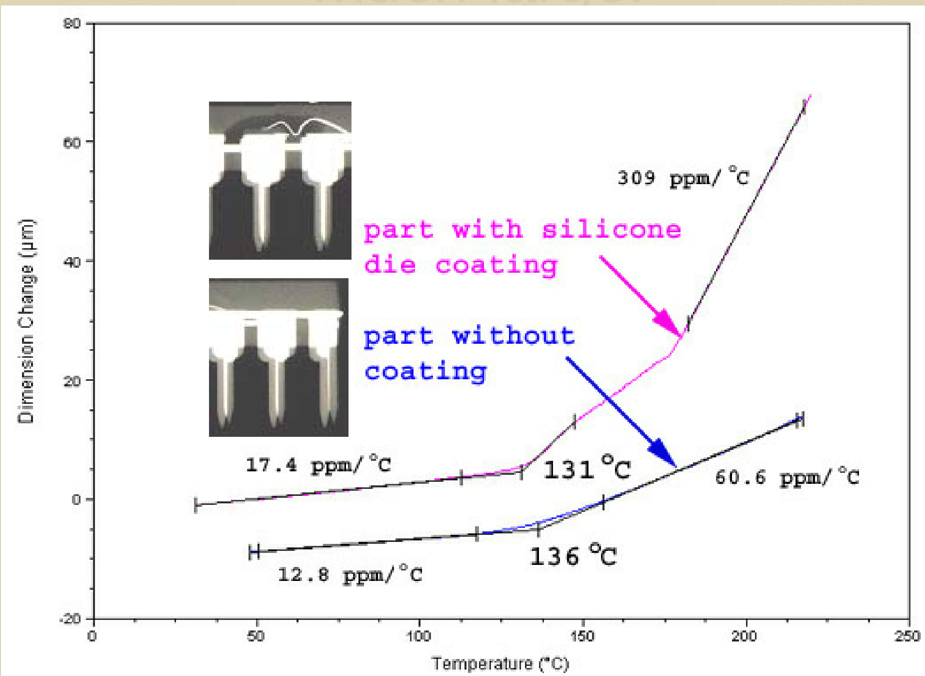
X-ray and cross-sectioning confirmed wire bond fractures



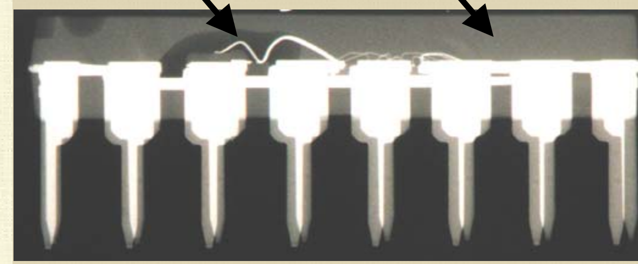
Pictures courtesy of F.Felt

Wire bond failures during TC. Cont'd.

TMA showed that package deformation above silicone is much larger



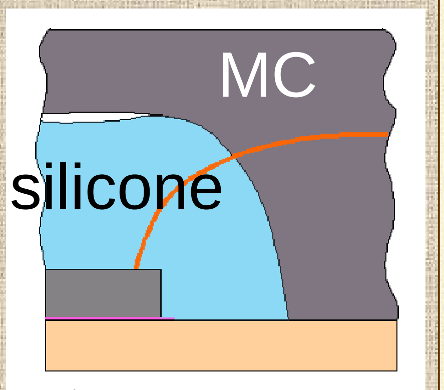
Silicone MC

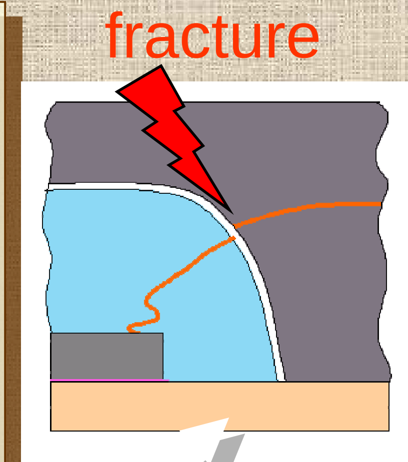


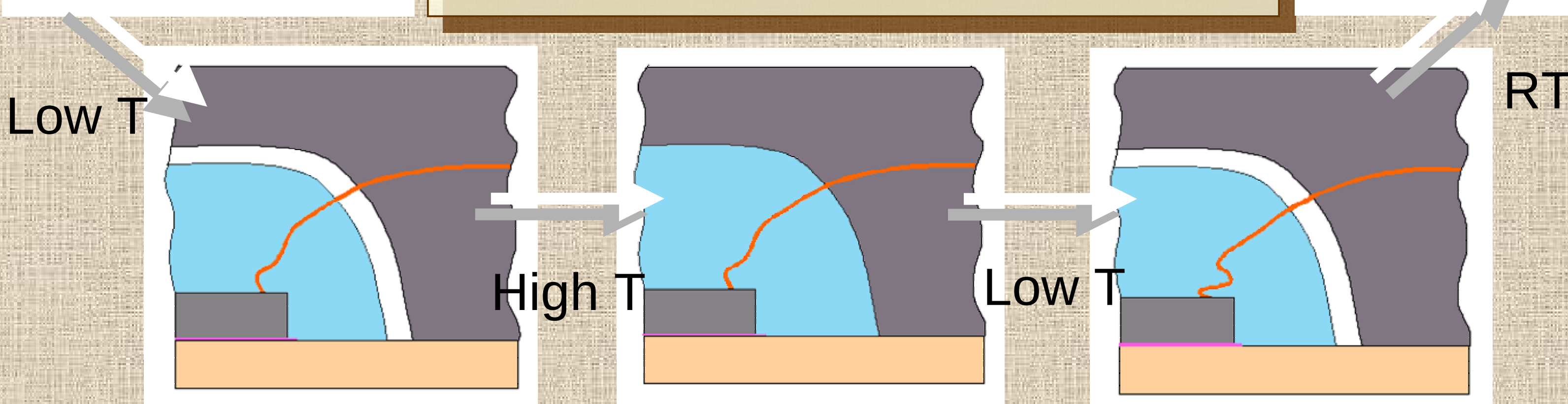
Deformation of the silicone coating caused significant strains in bonding wires, which might result in fractures.

Mechanism of WB Failures During TC.

- LT: silicone shrinks, clamps the wire and pools it from MC.
- HT: the clamp is released and silicone slides along the wire.
- Repeat cycling eventually causes fracture.







Elongation of Au wires ~ 3 to 6 %. =>This type of failures is more likely to happen with thick enough layers of die coating.

Conclusions

- Accelerated stress testing at T > Tg might introduce new failure mechanisms and should be considered for analysis of long-term reliability of PEMs based on high-temperature testing.
- TMA is a useful tool for reliability evaluation and failure analysis of plastic encapsulated devices.
- Swelling of MC increases the probability of delaminations during testing at T ~ Tg and might affect results of HAST.
- The thickness of silicone die coatings affects deformation of PEMs and the probability of wire bonds failures.