In-situ Measurements of Thermo-Mechanical Characteristics of PEMs' Molding Compounds

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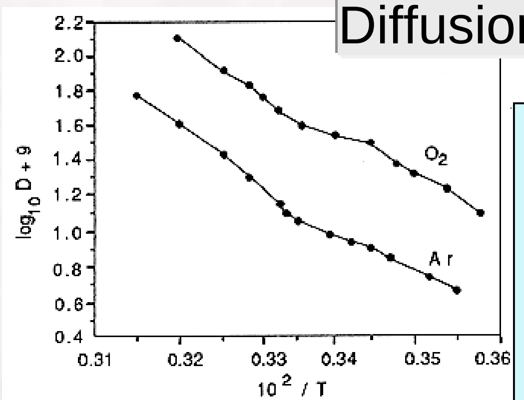
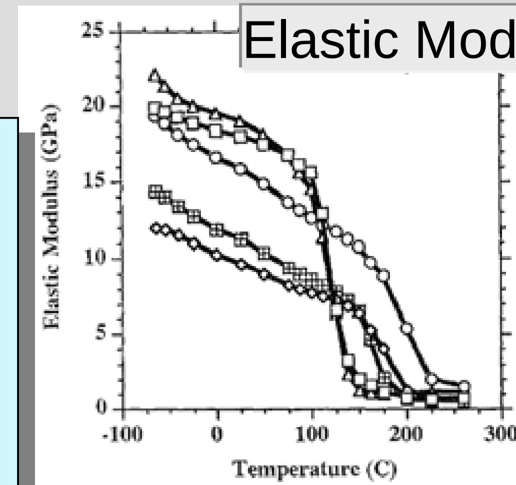
Background

Diffusion



Vieth '91

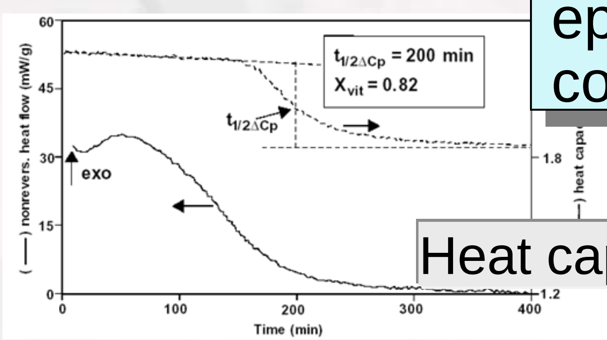
Elastic Modulus



Darveaux et al.' 95

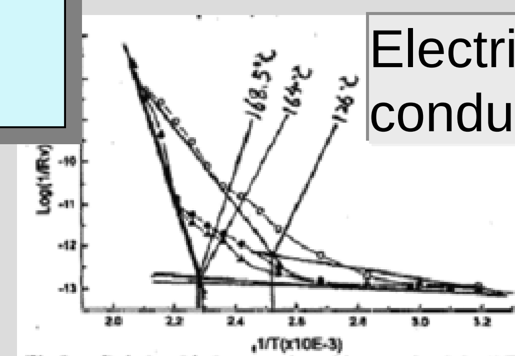
Transition from a glassy to rubbery state drastically changes thermal, mechanical, electrical, and diffusion characteristics of epoxy molding compounds.

Heat capacity



TA Instruments

Electrical conductivity



P.Chen et al.' 2000

Background. Cont'd.

- Several techniques can be used for Tg measurements: DSC, TMA, DTMA. Thermo-mechanical analysis (TMA) is most suitable for PEMs. It also allows to obtain CTE.
- TMA might be useful to ensure consistent quality of MC and check for proper curing.
- Tg and CTE might affect the performance and reliability of PEMs at extreme temperatures and change the rate of failures.
- High temperature stress testing is commonly used to screen and qualify COTS PEMs for high reliability applications. Exceeding Tg might introduce new failure mechanisms. (Analysis of the significance of Tg for screening and qualification will be discussed in a separate paper.)

Purpose

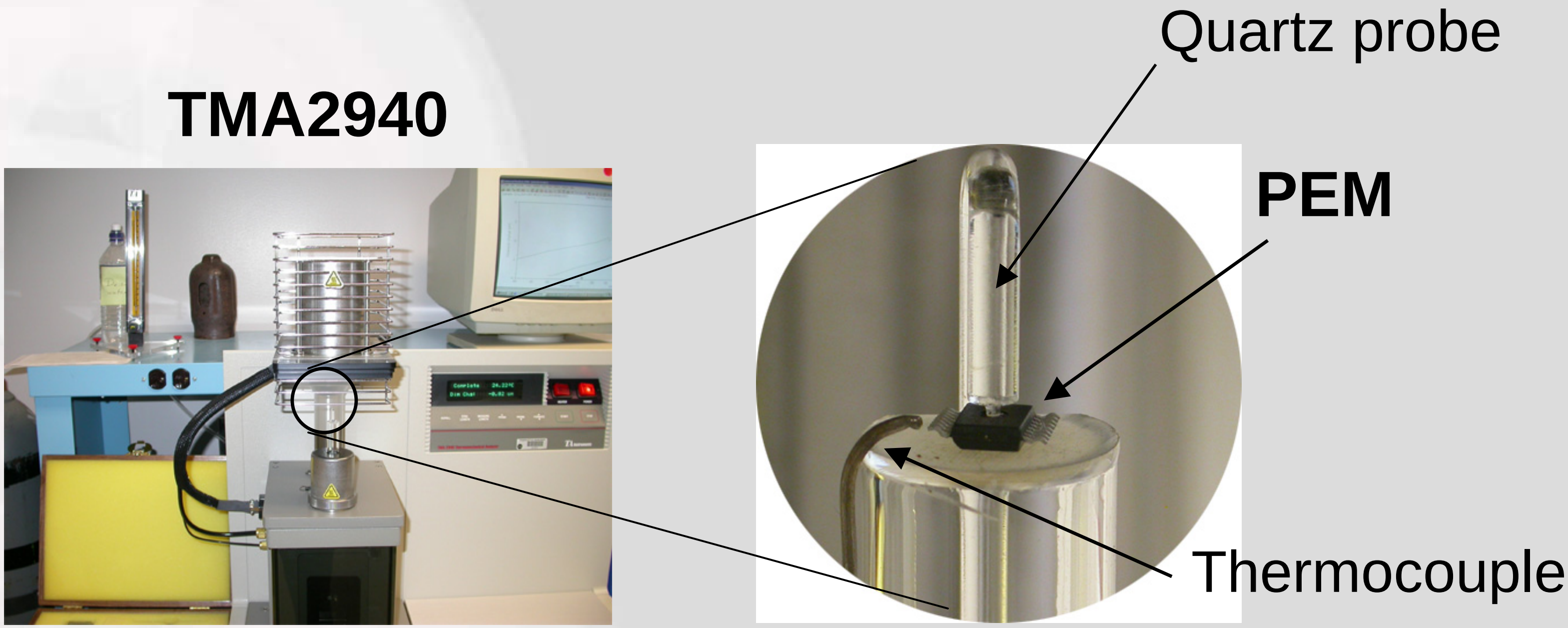
- To analyze possible errors of in-situ thermo-mechanical analysis (TMA) of PEMs.
- To develop a procedure for assessment of Tg and CTE of MCs directly on PEMs.
- To illustrate the effectiveness of TMA for qualification of PEMs.
- To demonstrate the value of TMA for failure analysis.

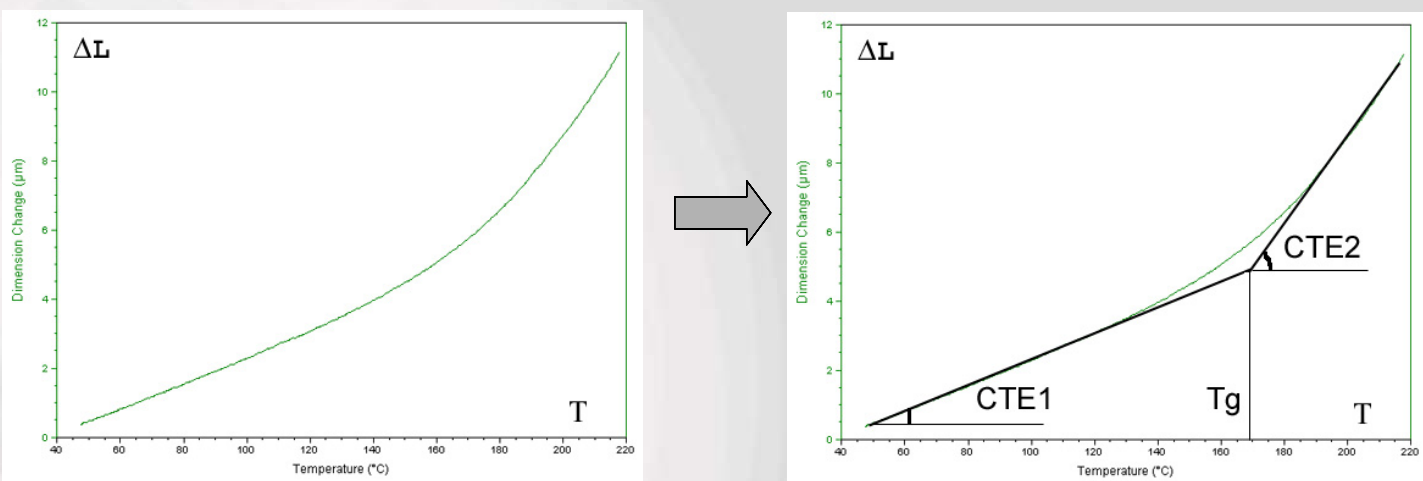
Outline

- Factors affecting Tg and CTE measurements on PEMs:
  - Temperature rate;
  - Lead frame;
  - Warpage;
  - Moisture content;
- Standardized procedure for TMA on PEMs.
- TMA application for lot qualification:
  - Effect of curing conditions;
  - Lot-to-lot variation.
- History cases of PEM failures:
  - Delaminations after BI;
  - Delaminations after HAST;
  - Wire bond failures in parts with silicone die coating.

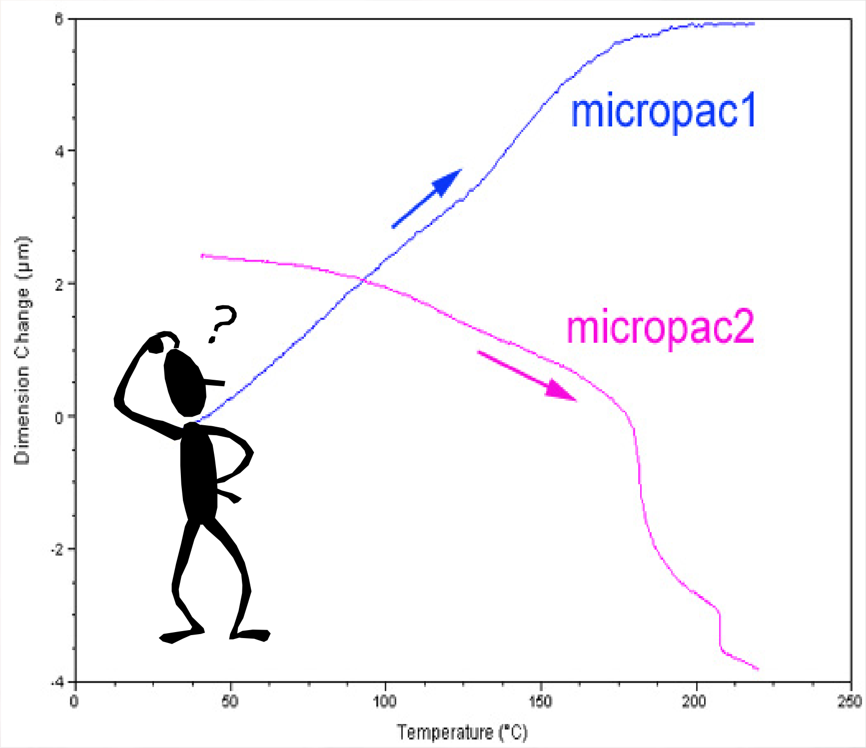
TMA of PEMs is very simple …

TMA2940





…understanding the results might be more challenging.



Major problems with TMA measurements on PEMs:

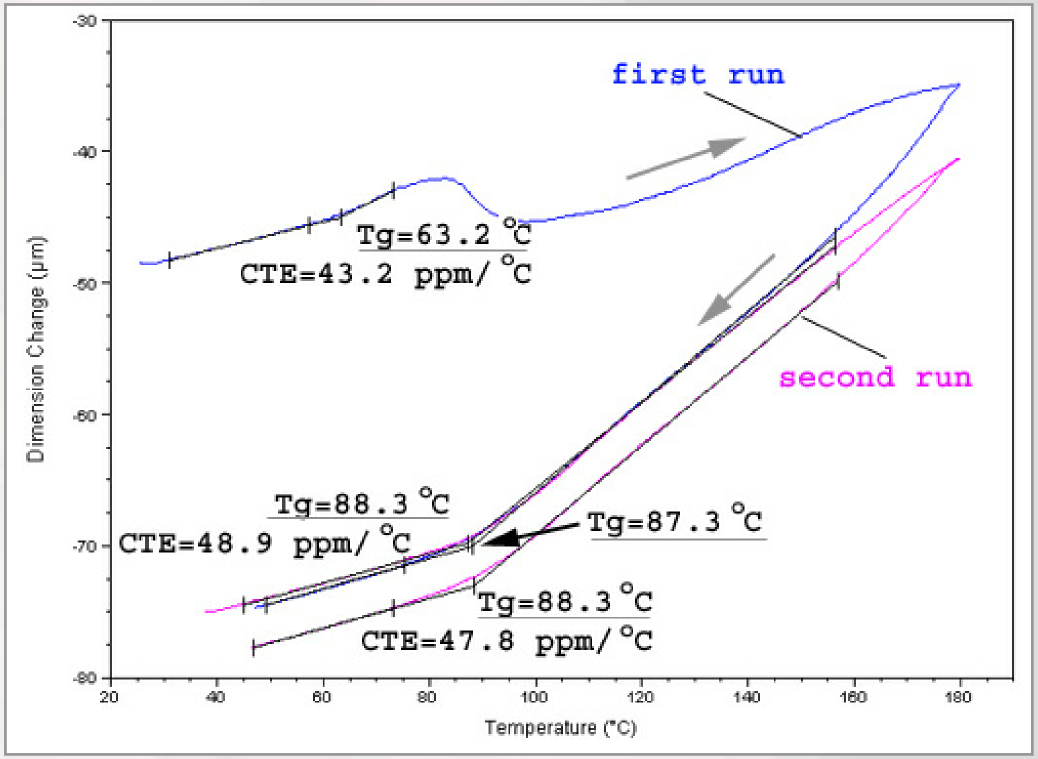
- Warpage;
- Stress relief;
- Moisture;
- Lead frame;
- Temperature rate;
- Cooling vs. heating

Existing TMA standards

Standard	Materials	Preconditioning	Rate, $^{o}C/min$	Comments
ASTM E 831	All solid materials	Not specified	5	Heating rate might be adjusted depending on thermal characteristics of materials
IPC-TM-650, N 2.4.41.1	Laminated materials	Isopropyl alcohol	2	Two thermal cycles per test is recommended. 1st to normalize the specimens, 2nd to measure
IPC-TM-650, N 2.4.24	Printed boards	2 hr 105 ^{o}C	10	If residual stress cause irreversible deflection at glass transition, a second scan shall be run
IPC-TM-650, N 2.4.24.3	Organic films	24 hr, 50% RH, 23 ^{o}C	5	Prescan: 20 $^{o}C/min$ up 50 ^{o}C above Tg, hold 10 min, cool to 50 ^{o}C below Tg, hold 10 min.
IPC-TM-650, N 2.4.24.5	Dielectr. HD interconnection	1 hr 105 ^{o}C	5	If unexpected shrinkage observed the two-heat test method is required. 1st cycle at 10 $^{o}C/min$

- There is no standard for TMA on PEMs.
- Existing standards have:
  - different heating rates,
  - insufficient baking for PEMs,
  - warning about stress relief problems.

Factors affecting Tg and CTE measurements: Heating vs. Cooling



Dexter Hysol liquid epoxy EO1016

Measurements during the first run at cooling gave same Tg and CTE as the second testing run.

Cooling curves give accurate Tg and CTE values.

Factors affecting Tg and CTE measurements: temperature rate

Characteristic time of temperature distribution:

$$\tau \approx \rho \times C \times H^2/\lambda$$

H – thickness; λ - specific thermal conductivity, C - heat capacity; ρ - specific density.

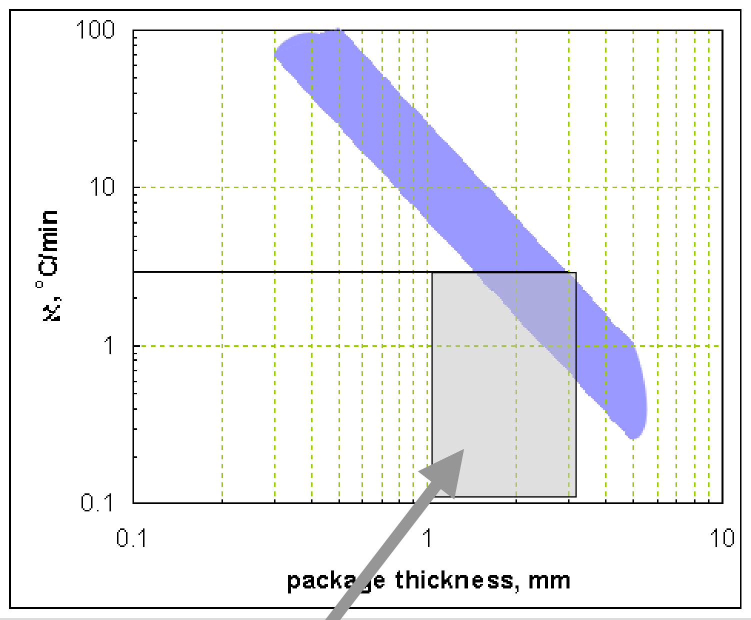
To ensure that T variations < ΔT:

$$\frac{\Delta T}{\alpha} \geq \tau$$

the maximum temperature rate:

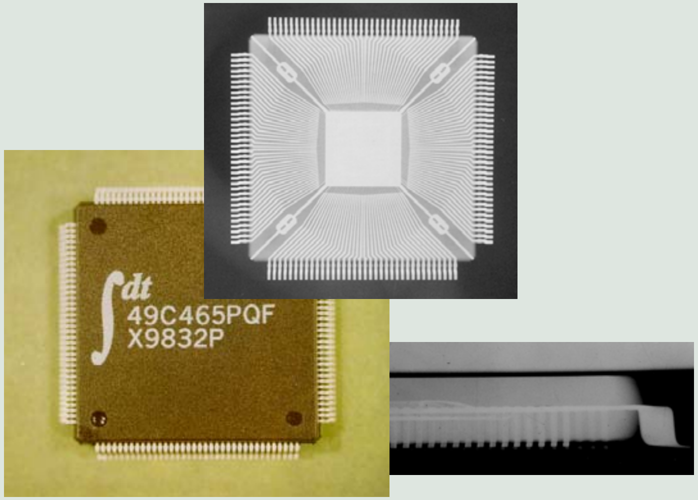
$$\alpha_{\max} = \frac{\Delta T \times \lambda}{\rho \times C \times H^2}$$

Calculated maximum temperature rate vs. package thickness



Most PEMs can be tested at a rate of 3 ^{o}C/min

Factors affecting Tg and CTE measurements: lead frame



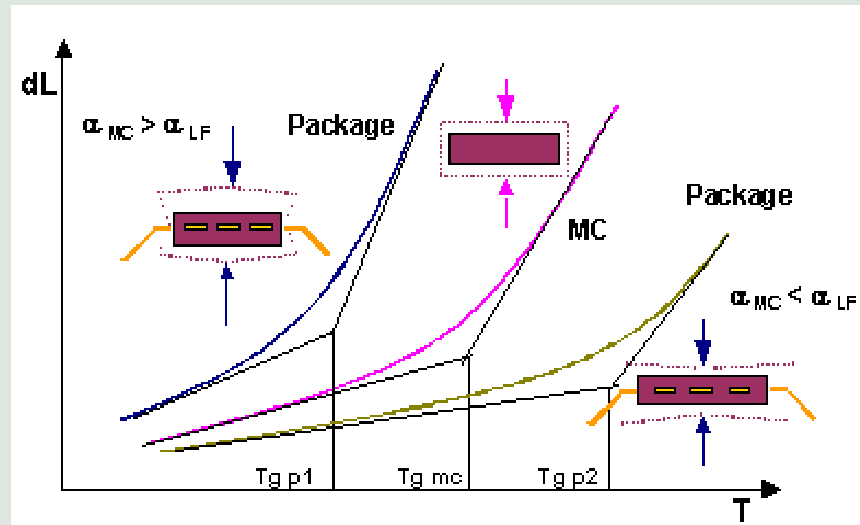
When deformation of MC and LF are independent:

$$\alpha_{MC} = \alpha_{pac} + \frac{H_{LF}}{H_{MC}} \times (\alpha_{pac} - \alpha_{LF})$$

At $H_{LF} << H_{MC}$ and/or $\alpha_{pac} \approx \alpha_{LF}$

$$\boldsymbol{\alpha_{MC} \approx \alpha_{pac}}$$

In some cases LF might affect deformation of MC



LF constrains are similar to glass fiber effect in PWB and might change CTE in Z-axis.

Factors affecting Tg and CTE measurements: lead frame. Cont’d.

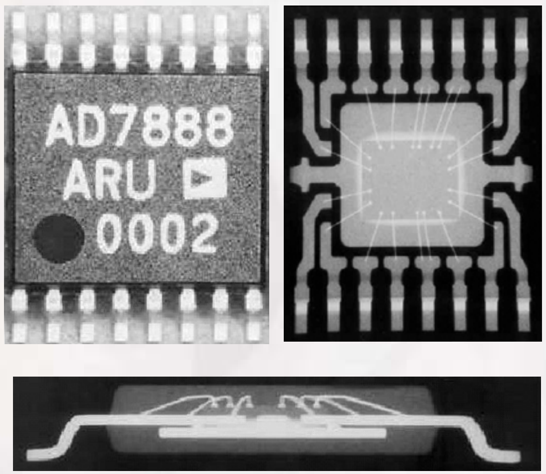
Average Tg and CTE measured on MC and packages

	Tg MC	Tg pack	CTE1 MC	CTE1 pack	CTE2 MC	CTE2 pack
PEM1	149.8	143.3	22.5	24	75.5	79.5
PEM2	162.9	165.1	21.4	23.7	61	71.5
PEM3	171.4	165.8	21.8	26.6	62	72.4
PEM4	166	159.1	21	23.2	69.7	65.6
PEM5	155.5	153.3	16.2	18.4	74.7	92.2

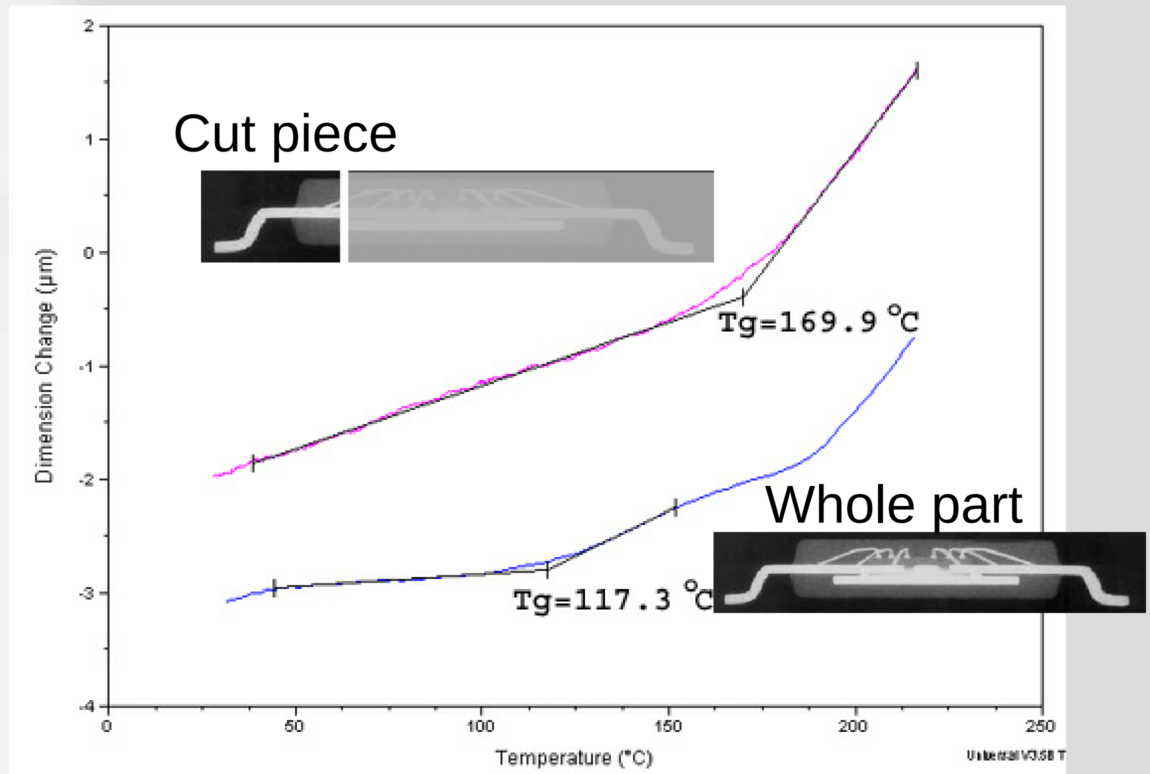
- CTE of MC is 6% to 22% lower than for packages.
- Tg of MCs are 2 to 7 ^{o}C higher than for packages.

[Hongsmatip T. ’97]: packages had ~5% lower Tg than molded test specimens.

Factors affecting Tg and CTE measurements: warpage, example 1.



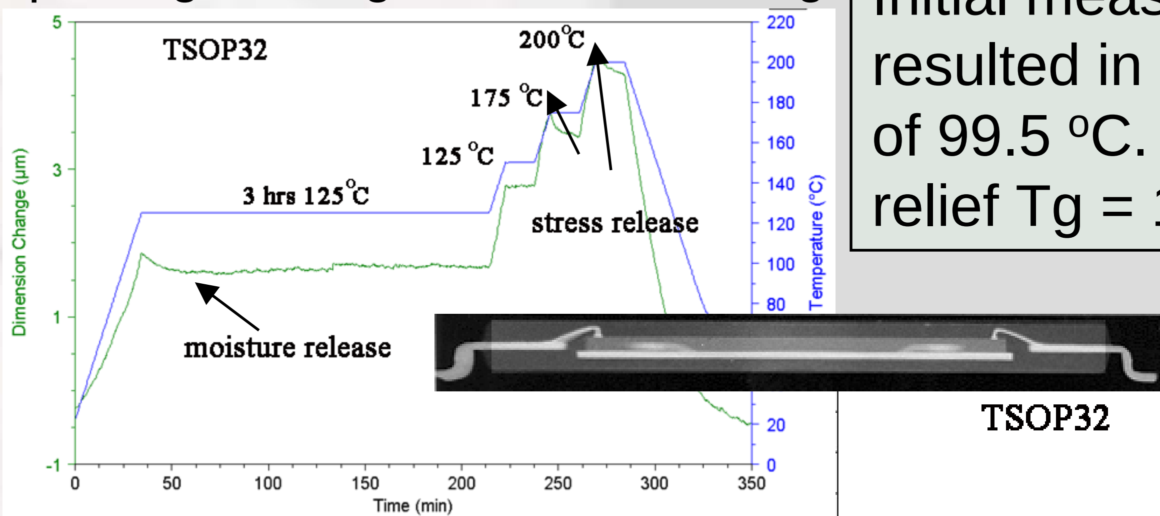
TMA on the whole part and on cut pieces



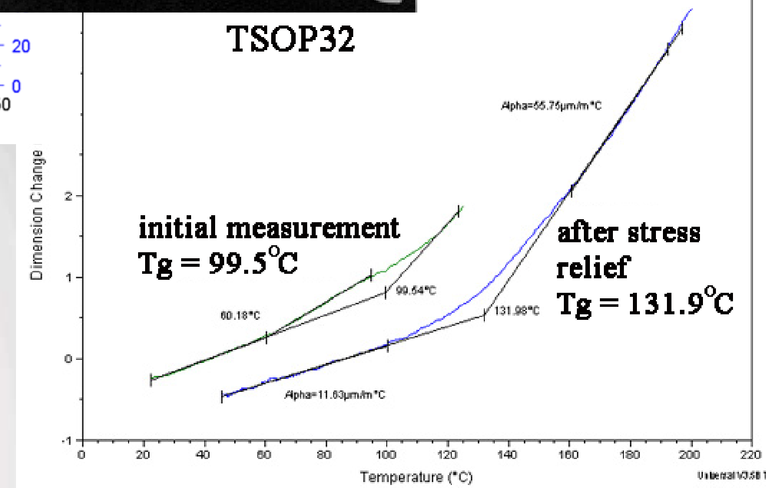
Anomalies in TMA on thin packages are due to warpage.

Factors affecting Tg and CTE measurements: warpage, example 2.

Deformation of a thin TSOP32 package during isothermal baking



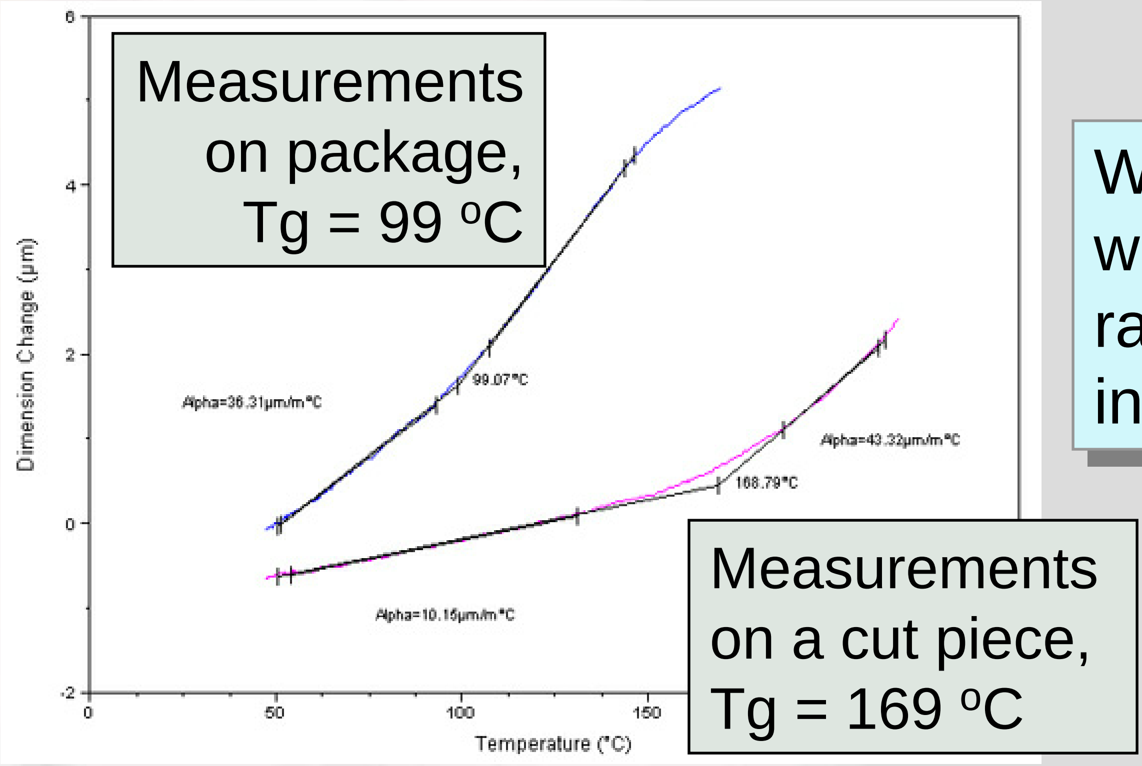
Initial measurements resulted in erroneous Tg of 99.5 ^{o}C. After stress relief Tg = 132 ^{o}C.



At H = 0.95 mm, the characteristic time for moisture outdiffusion at 125 ^{o}C is ~ 3 hrs.

Factors affecting Tg and CTE measurements: warpage, example 3.

Package TSSOP24, size: $7.8 \times 4.5 \times 0.9$ mm^3



Warpage of PEMs with high aspect ratio might result in anomaly low Tg.

Factors affecting Tg and CTE measurements: moisture

- Moisture sorption in humid environments causes swelling of MC.
- Heating during TMA will release moisture and cause shrinkage.
- Resulting deformation is due to thermal expansion and moisture-induced shrinkage:

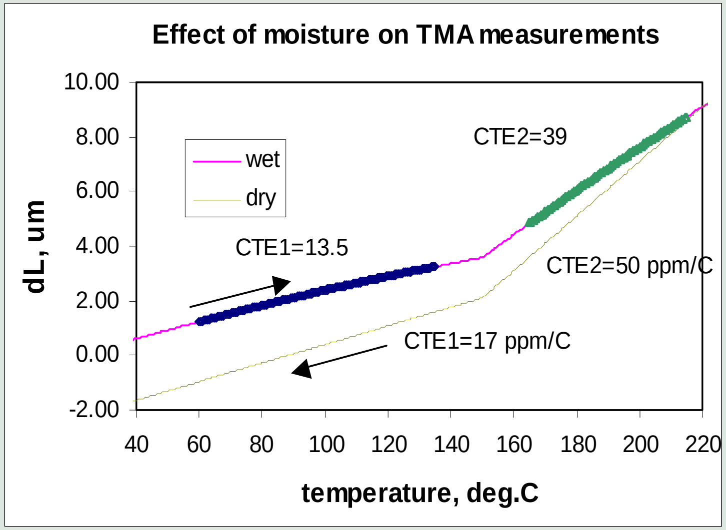
$$\Delta L(T,t) = CTE \times L_0 \times (T - T_0) - CME \times L_0 \times dM(T,t)$$

Moisture release, dM(T,t), can be calculated based in moisture diffusion characteristics of MC:

$$dM(t) = 2\frac{dM_\infty}{h \times \sqrt{\pi}} \times \sqrt{\int_0^t D(T(t)) \times dt}$$

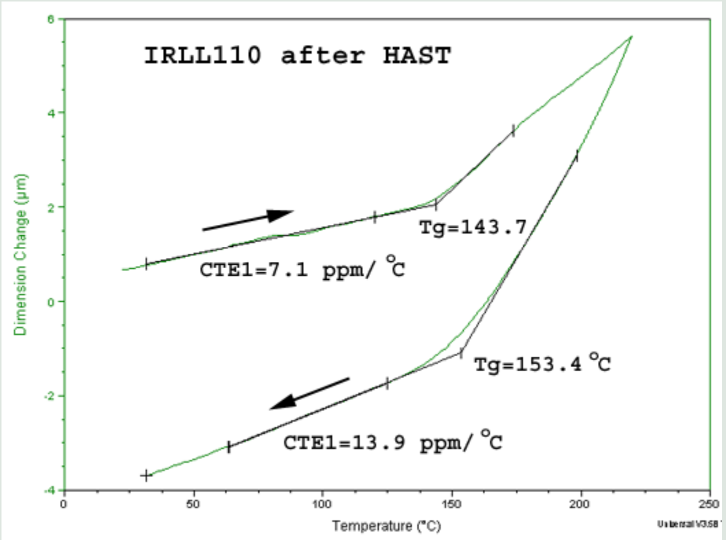
$$T(t) = T_a + \alpha \times t \qquad D(T) = D_o \exp(-U / kT)$$

Factors affecting Tg and CTE measurements: moisture. Cont'd.



Results of calculations.

$D_o=7.3\times10^{-2}$ cm^2/s, U=0.43 eV, α=1 $^oC/min$, CTE1/2=17/50 $ppm/^oC$, Tg=150 ^oC, dM_∞=0.5%, CME=0.5



Experimental TMA results.

PN IRLL110 after HAST. Hysteresis is due to moisture desorption.

Moisture release results in shrinkage and reduces CTE.

Factors affecting Tg and CTE measurements: moisture. Cont'd.

Effect of HAST on Tg, ^oC

	Package	Tg HAST	Tg bake
PEM1	DIP28	135	135
PEM2	TO220	144	144
PEM3	TO220	157	157
PEM4	QFP144	156	156
PEM5	DIP8	158	158
PEM6	TO220	157	157
PEM7	SOT223	155	155
PEM8	SOIC8	169	175
PEM9	SOIC8	152	182
PEM10	SOIC8	170	181
PEM11	SOIC8	120	137

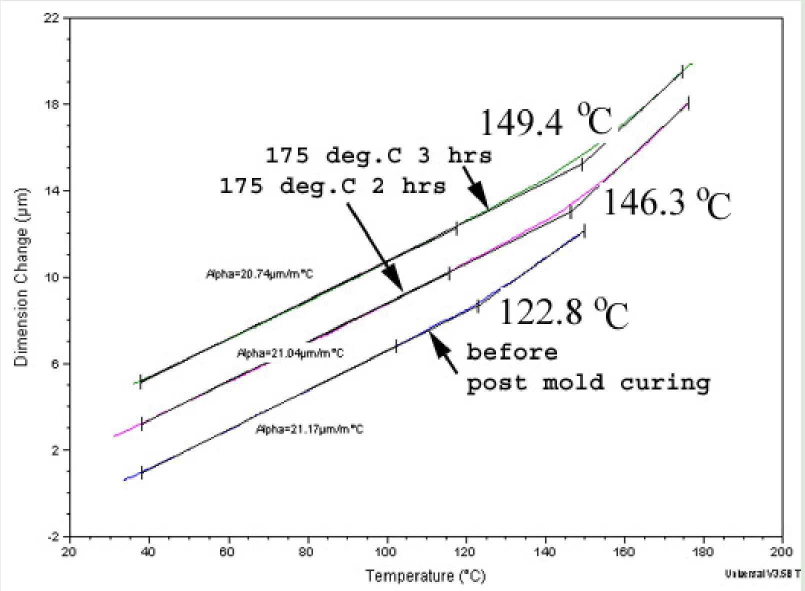
The presence of moisture plasticizes epoxy matrix in molding compounds and reduces Tg from 10 ^oC to 30 ^oC.

Standardized procedure for Tg and CTE measurements

- Two purposes of PEMs' TMA:
  - Assessment of Tg and CTE of molding compound;
  - Analysis of anomalies in package deformation (FA);
- Procedure for Tg and CTE assessment:
  - Bake the part at 150 ^{o}C for $1.9 \times H^2$ hours, where H is the thickness of the package in mm.
  - Record the data at 3 ^{o}C/min during heating up from RT to 220 ^{o}C and cooling to 50 ^{o}C at the same rate.
  - Calculate Tg, CTE1 and CTE2 using cooling curve. If moisture and stress relief are not sufficient repeat the test.
  - <u>Note</u>: warpage of PEMs results in erroneous measurements especially for parts with high aspect ratio (H ~ 0.8 to 1.5 mm and L of > 3 mm). For these parts the measurement shall be performed on small pieces cut from the package.

Lot qualification: effect of curing conditions

Effect of post-mold curing on Tg and CTE



Effect of post-mold curing on M, V, and density of two MCs

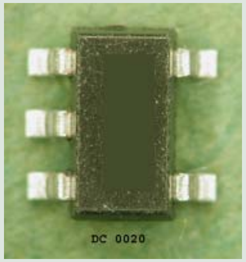
Encapsulant	dM/M, %	dV/V, %	$d\rho/\rho$, %
MC1	0.114	0.357	0.47
MC2	0.106	0.364	0.47

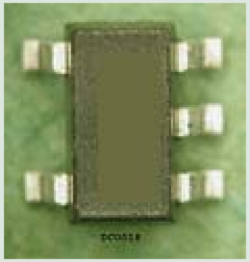
- Density decreases ~0.47%.
- Post-mold curing does not improve diffusion characteristics of MCs.

The higher Tg the more porous MC is?

Post-mold cure does not affect CTE and increases Tg from ~20 to 30 °C

Lot qualification: lot-to-lot variations





Two lots of PEMs had close DC (0020 and 0018) and were suggested to be accepted based on one-lot qualification.

However, TMA measurements showed that these lots are manufactured with different MCs.

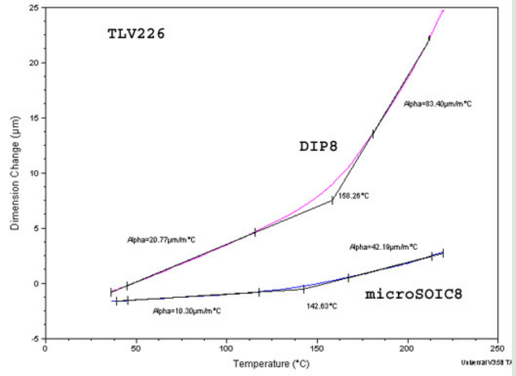
Lot	Tg, °C		CTE1, ppm/°C		CTE2, ppm/°C	
	avr.	std.dev.	avr.	std.dev.	avr.	std.dev.
DC 0018	171.1	0.26	9.1	1.84	42.6	7.21
DC 0020	164.3	0.7	10.25	0.78	65.5	4.03

TMA on PEMs can reveal lot-to-lot variations in MCs

Lot qualification: MC for different package types

There is an assumption that better quality MC have higher Tg.

Do newer design packages have higher Tg?



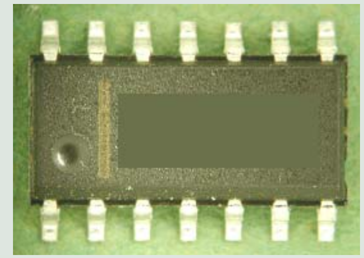
TM characteristics of MC for the same part in different packages

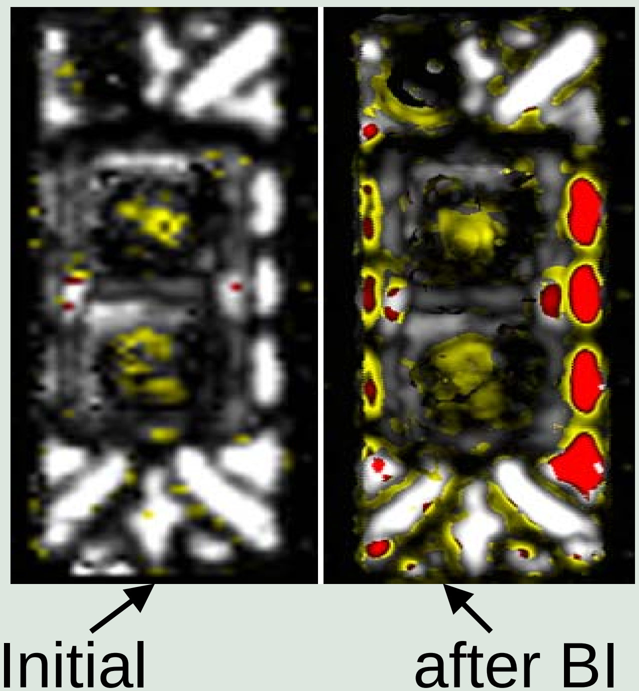
Part	Package	Tg, °C	CTE1, ppm/°C	CTE2, ppm/°C
PEM1	DIP8	156	16.4	102
	uSOIC8	169	14.7	76
PEM2	DIP8	158	20.8	83.4
	uSOIC8	142	10.3	42.2

Low Tg MC are not inferior compared to high Tg.
Newer design of PEMs might employ MCs with lower Tg.

FA history case 1: BI-induced delaminations

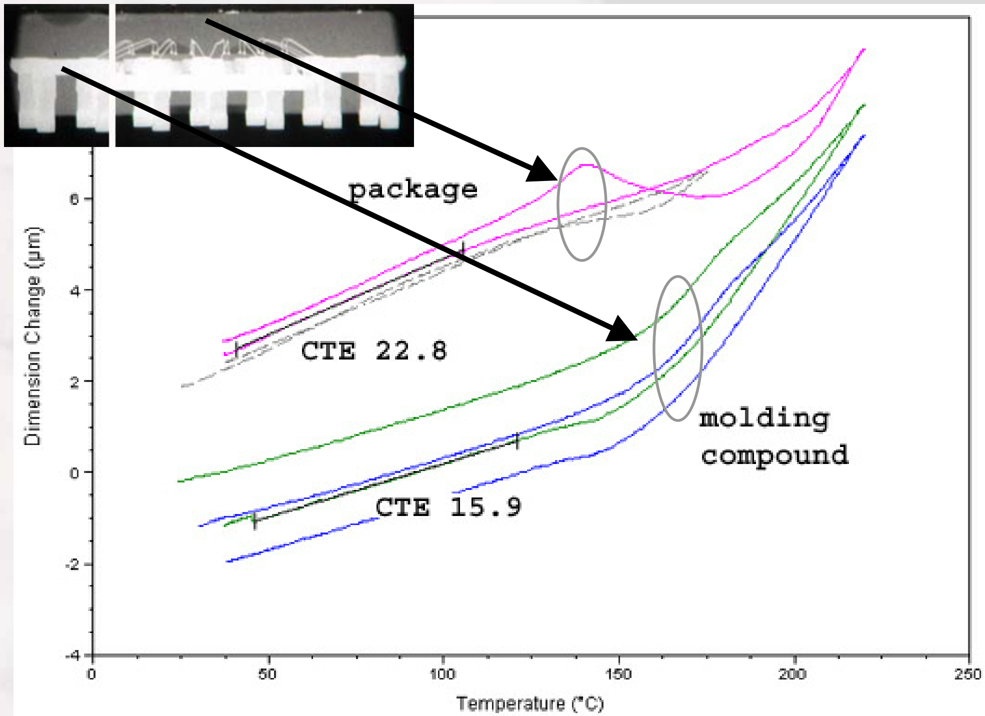
Typical acoustic images showing finger-tip delaminations after burn-in testing at 85 ºC

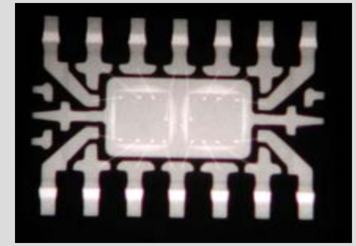


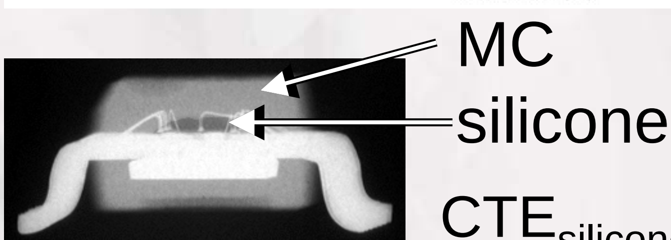


- Delaminations were observed at critical wire bond areas in all tested after BI parts. Is there a reliability problem?
- This result was difficult to predict considering relatively low temperature of the stress.
- Note: no delaminations on the corner leads.

FA history case 1: BI-induced delaminations. Cont'd.







$CTE_{silicone} >> CTE_{MC}$

Failure mechanism:

- Redeposition of silicone may have occurred during curing reducing adhesion between MC and LF.
- At high T silicone coating might create forces causing repulsion of MC from lead frame.

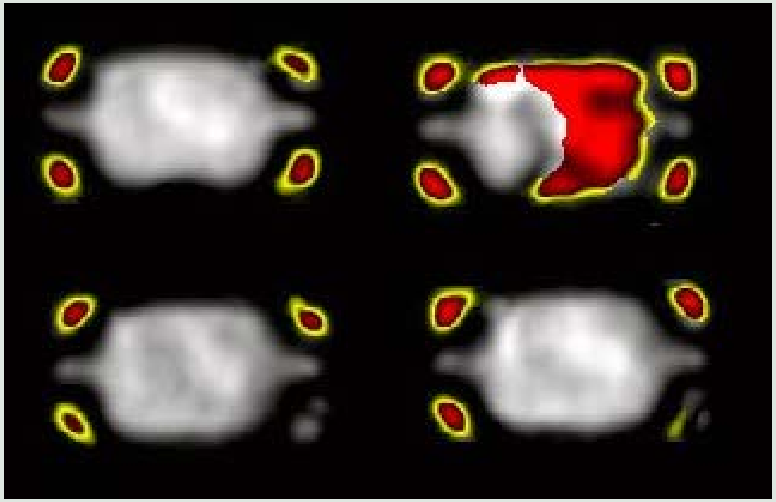
FA History case 2: HAST-induced delaminations

Background: Multiple CSAM failures of PEMs in SOT-23-5 packages were observed after HAST. No electrical failures occurred.

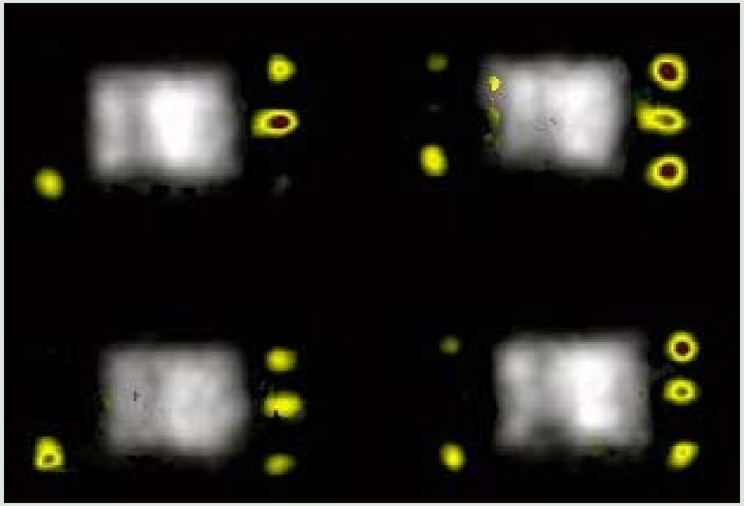
FA purpose: Why, and is there a reliability concern?

Acoustic images after HAST

Top side view



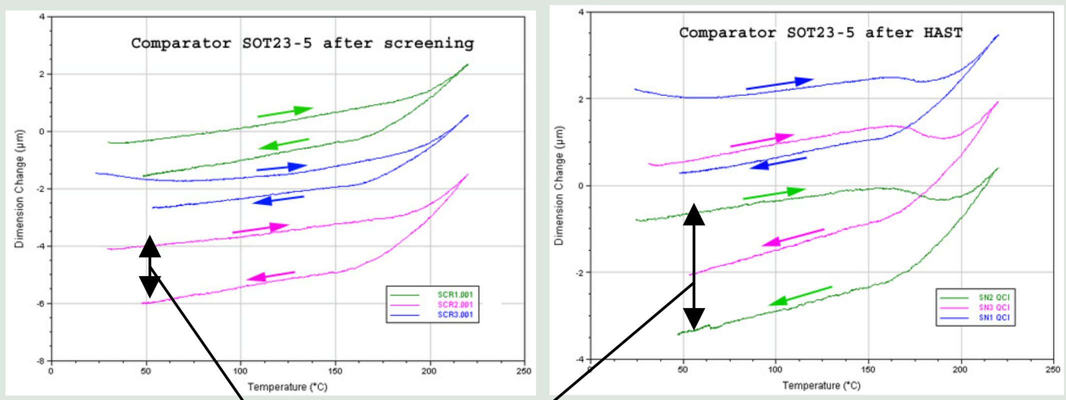
Bottom side view



FA History case 2: HAST-induced delaminations. Cont'd.

TMA of 3 samples

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

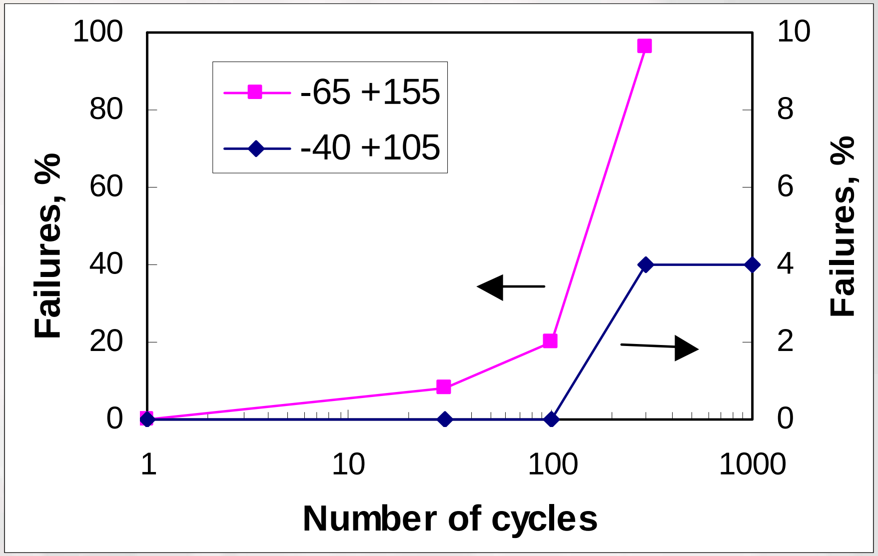
condition	dL/L, %	
	avr.	std.dev.
before HAST	0.21	0.048
after HAST	0.12	0.05

The results indicate that 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.

FA history case 3: wire bond failures during TC

- ***Parts:*** PEMs in DIP16 packages.
- ***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.

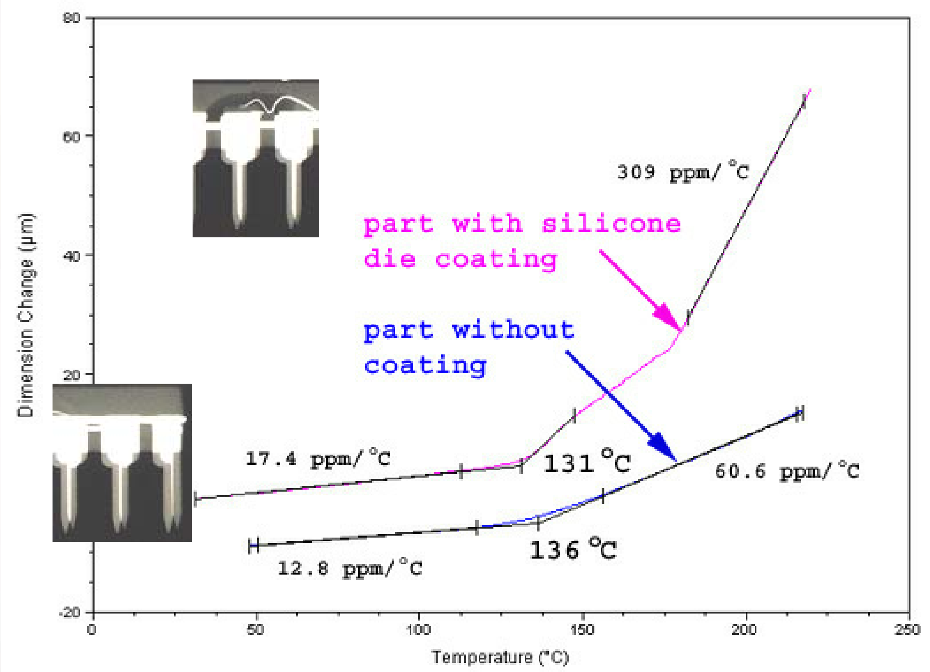
Failures during temperature cycling

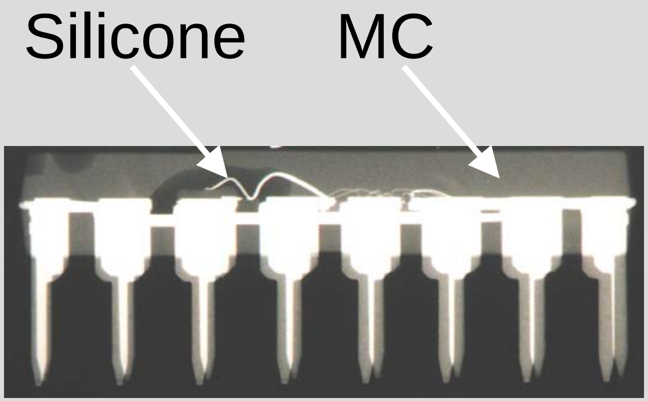


- Test results indicated catastrophic failures in both TC conditions.
- Estimated Coffin-Manson exponent => m > 5.5

FA history case 3: wire bond failures during TC. Cont'd.

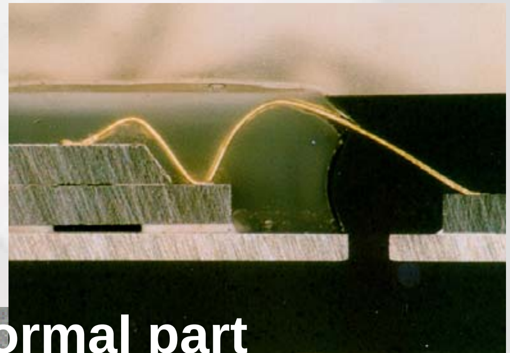
TMA showed that deformation of the package above silicone is much larger than without silicone.

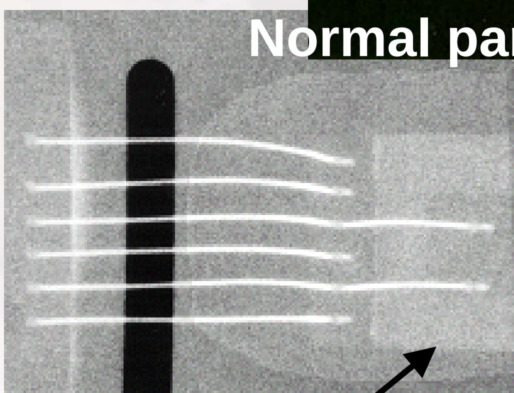




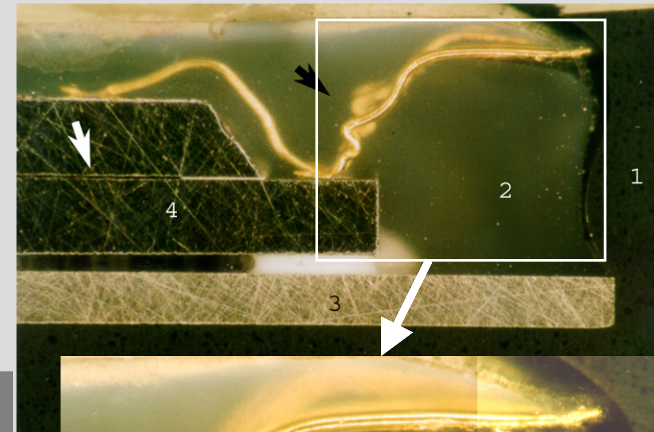
Deformation of the silicone caused significant strains in bonding wires, which might result in fractures.

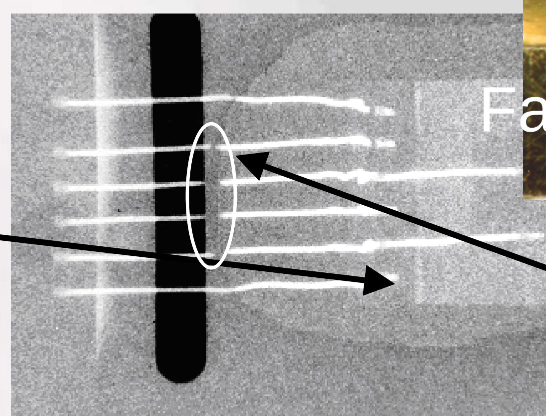
FA history case 3: wire bond failures during TC. Cont'd.





X-ray and cross-sectioning confirmed wire bond fractures





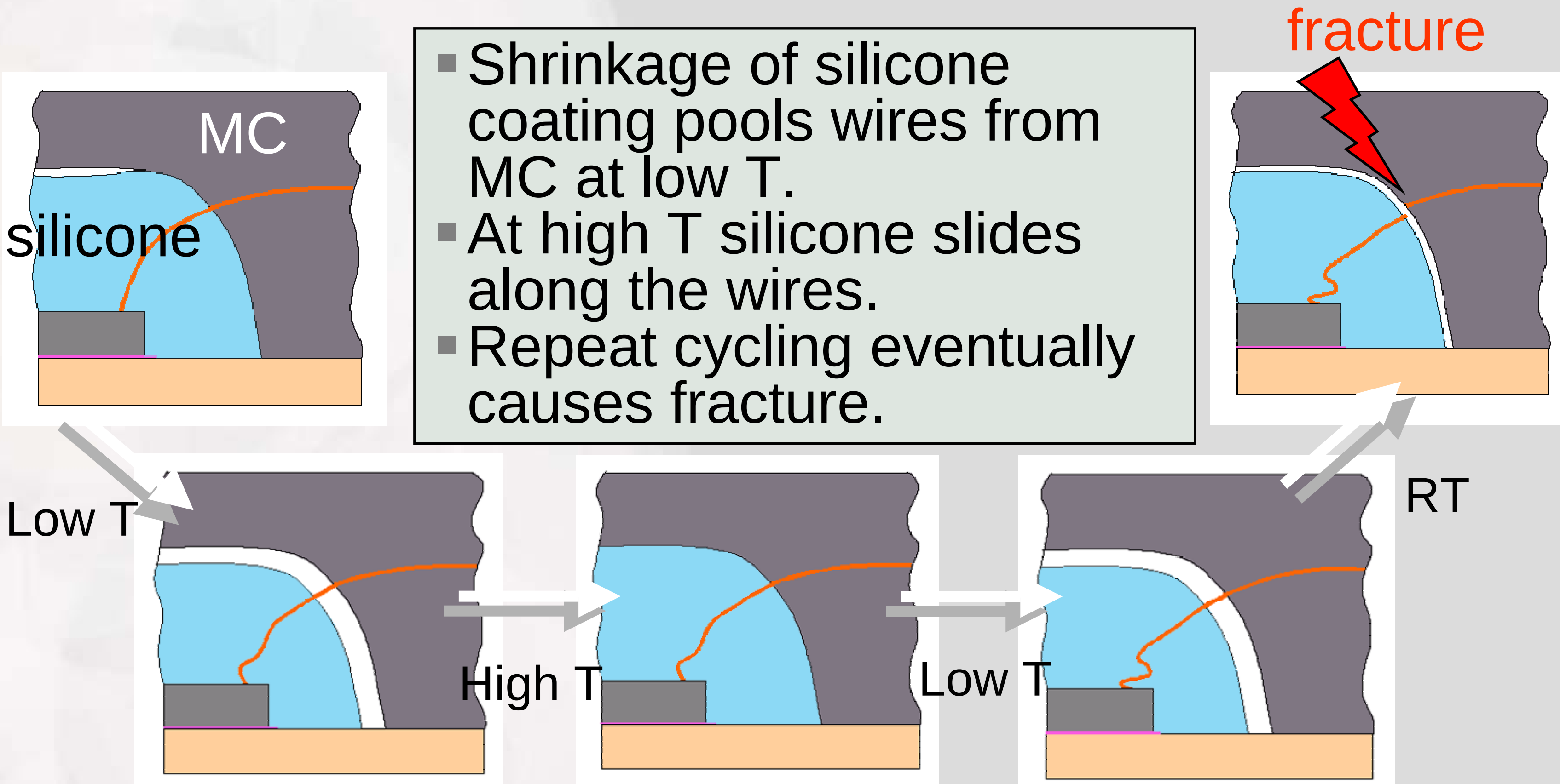
Silicone die coating

Pictures courtesy of F.Felt

Broken wires

FA history case 3: wire bond failures during TC. Cont'd.

- Shrinkage of silicone coating pools wires from MC at low T.
- At high T silicone slides along the wires.
- Repeat cycling eventually causes fracture.



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

Conclusions

- Tg and CTE of MC can be accurately assessed by TMA measurements of PEMs provided care is taken regarding possible warpage, stress relief, and moisture content.
- A standardized procedure for in-situ TMA of PEMs is suggested.
- TMA of plastic packages is a useful tool for lot qualification of molding compounds and for analysis of PEMs' failures.