The Impact of Glass Transition Temperature of Molding Compounds on Screening and Reliability Qualification of COTS PEMs

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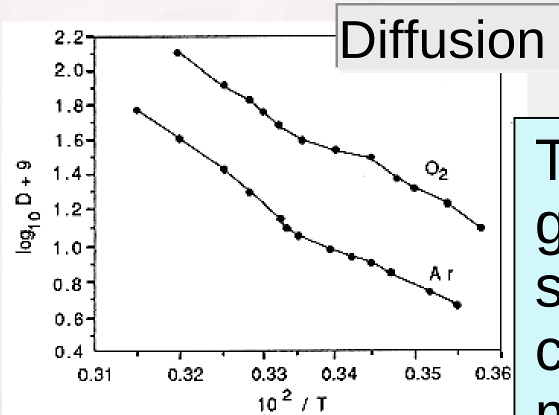
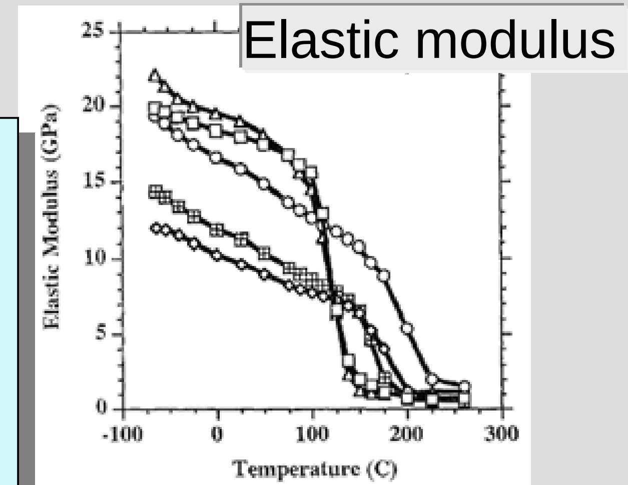
Background

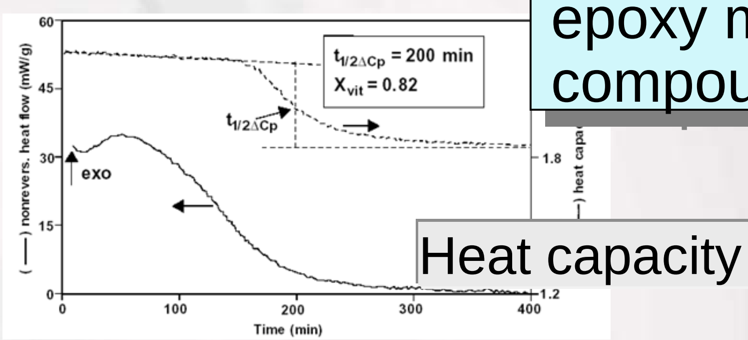


Vieth '91

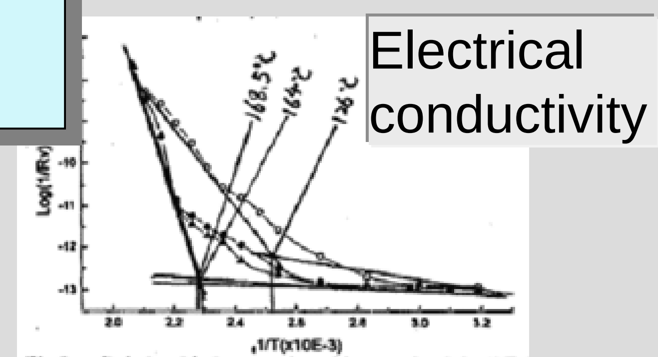


Darveaux et al.'95

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



TA Instruments



P. Chen et al. '2000

Background Cont'd.

- 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.
- Can we screen and qualify PEMs at T > Tg?

Purpose and Outline

Analyze the validity of typical screening and qualification tests at temperatures exceeding Tg of molding compounds.

- Experiment.
- High-Temperature Operational Life (HTOL) and Burn-In (BI) testing.
- High-Temperature Storage Life (HTSL).
- Temperature Cycling (TC).
- Highly Accelerated Stress Testing (HAST).

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>

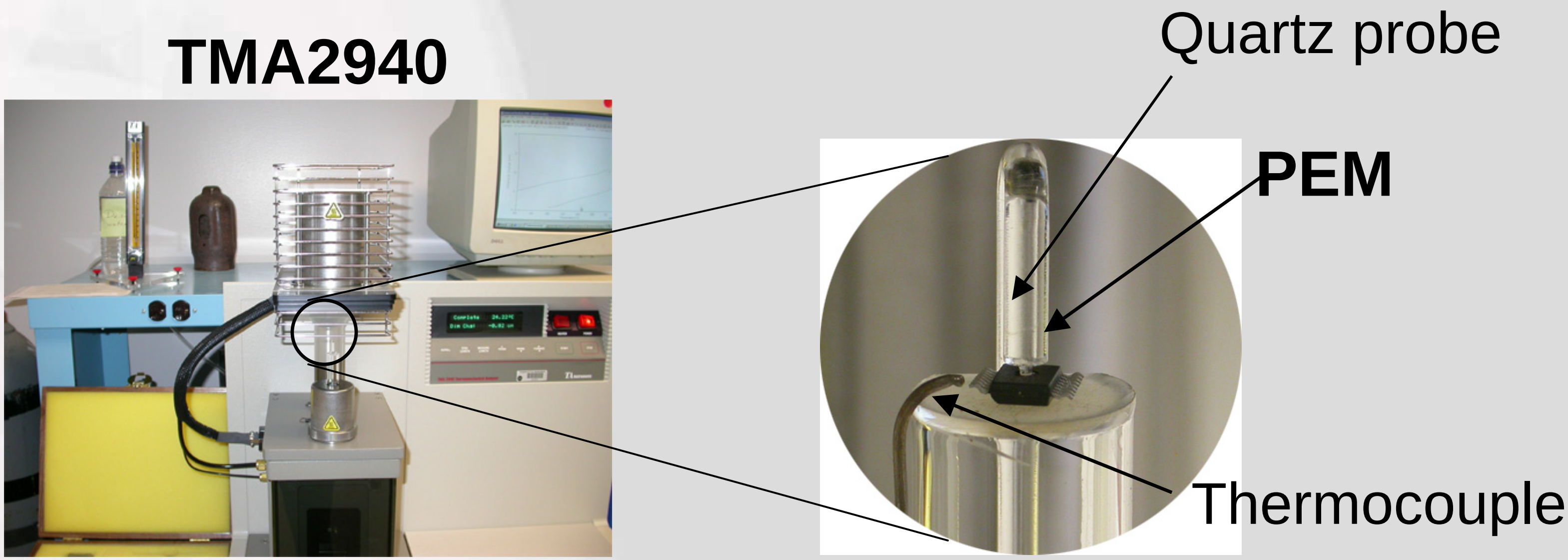
Multifunctional and orthocresol novolac: Tg ~ 150 to 190 °C.

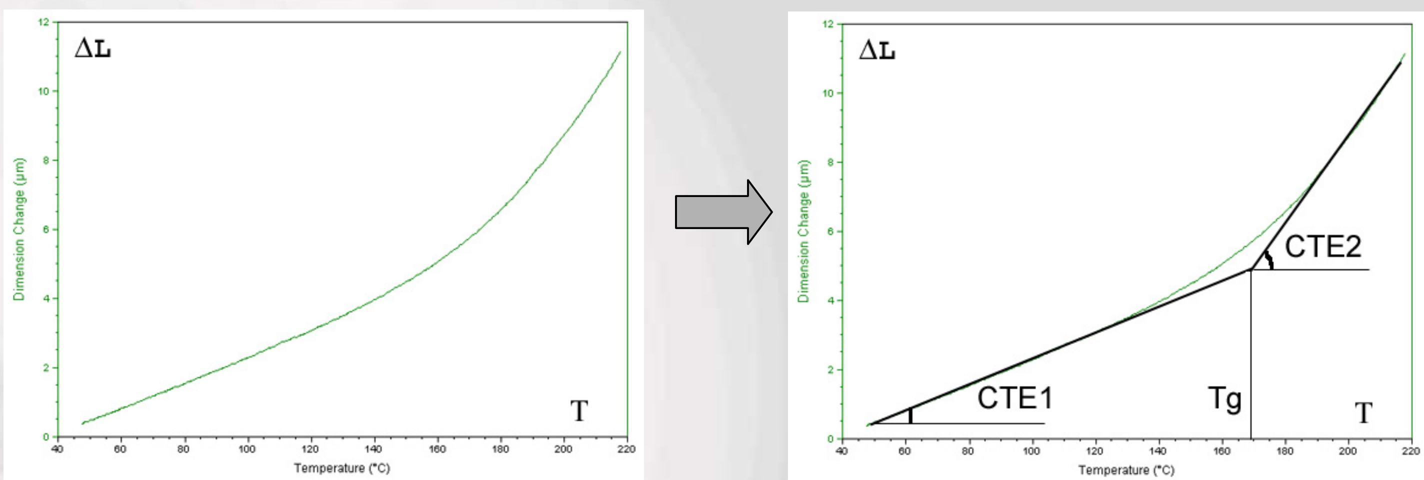
Low mechanical stress biphenyl epoxy: Tg $\lesssim$ 120 °C.

It is quite possible that some tests are performed at T>Tg.

Tg Measurements Directly on PEMs

TMA2940





BI & HTOL: Possible Effect of Tg

At T > Tg, the concentration of mobile charges in MC increases, thus accelerating degradation of PEMs by the charge instability mechanisms.

Ionic conduction model: Charge carriers are ions generated by dissociation of impurities (salt MA):

$$\boxed{M^+A^- \xleftrightarrow[T]{} M^+ + A^-}$$

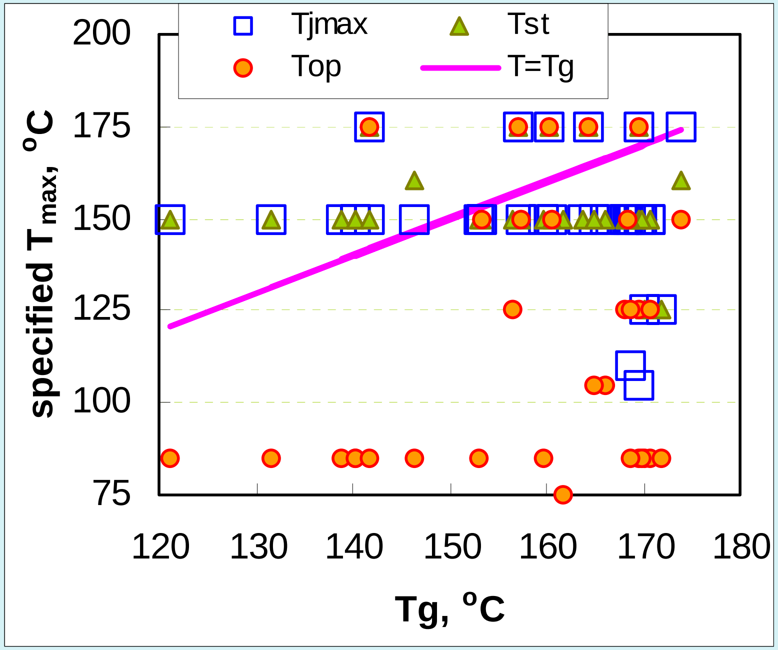
The equilibrium constant:

$$\boxed{K = \frac{[M^-]\times[A^-]}{M^+A^-} = \frac{f^2 n_0}{1-f} = K_o \times \exp\left(\frac{U_0}{\varepsilon \times kT}\right)}$$

Where n_o is the concentration of salt molecules;
f is the fractional degree of dissociation;
Uo is the energy of ions separation.

BI & HTOL: Comparison of Tg With Manufacturers' Data

- Tg was measured in 35 parts manufactured by Analog Devices, MAXIM, International Rectifier, and Linear Technology.
- No correlation between Tg and operational temperature (Top), storage temperature (Tst), and/or maximum junction temperature (Tjmax) was found.
- 43% of parts had T_{jmax} > Tg.



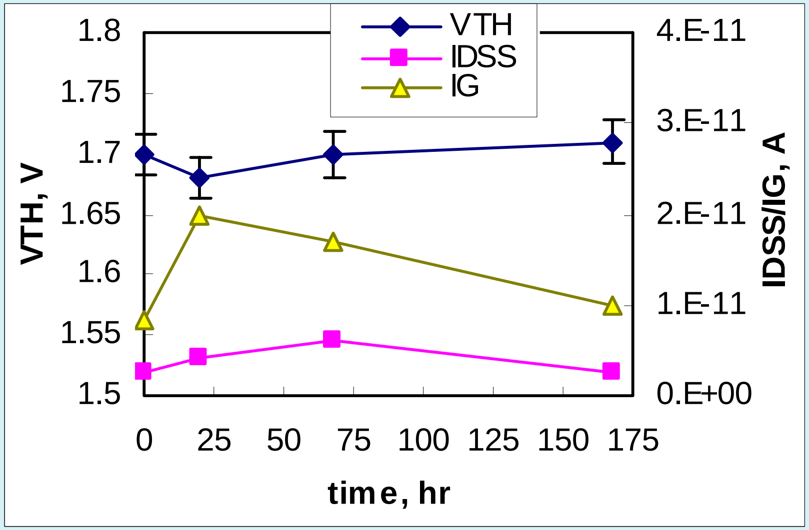
Relationship between Tg of MCs and maximum temperatures specified by manufacturers

Manufacturers do not have much concern regarding Tg

BI & HTOL: Stability of High-Voltage Devices at T > Tg

- HEXFET plastic parts with Tg=167 °C were tested at 150 and 175 °C for 168 hrs; first at VG=10 V and VDSS=0 (gate stress test), and then at VG=0V, VDSS=180 V (HTRB test).
- Two parts in SOIC8 and SOIC16 packages had Tg<135 °C. HTOL testing of these parts at 135 °C showed no failures.

BI testing at 175 °C

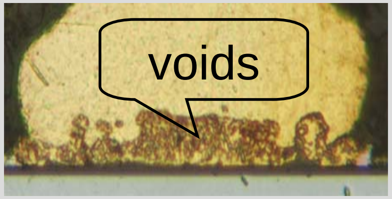


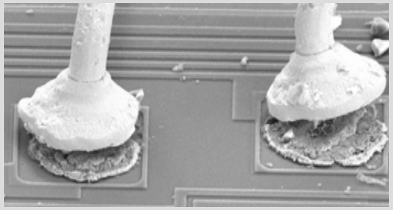
No degradation at T>Tg was observed

Exceeding Tg during BI and HTOL normally does not introduce new failure mechanisms

HTSL: Possible Effect of Tg

- 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.
- Several researchers reported on changes in the rate of WB degradation at high T; however, these changes occurred at T>Tg.





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

HTSL: Test Results

High-Temperature Storage Test Results (Failed/Total)

PN (Tg)	T_{st} °C	Time, hrs. 24	100	250	500	1000	6300
FM1608 (135 °C)	150	-	-	0/5	0/5	0/5[1]	0/5[1]
	175	-	-	0/5	0/5[1]	0/5[1]	0/5[1]
FM 1808 (135 °C)	150	-	-	0/8	0/8	0/8	-
	175	-	-	0/8	0/8	0/8	-
	200	-	-	0/8	0/8[1]	-	-
OP283 (164 °C)	175	-	0/30	0/30	0/30	0/30	-
	200	0/30	2/30	9/30	16/30	27/30	-
	225	2/30	6/30	18/30	27/30	-	-

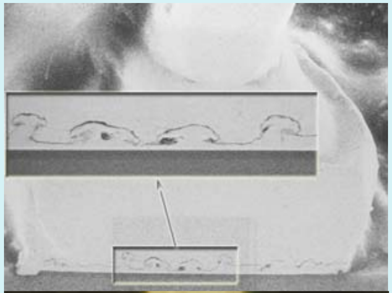
[1] memory cell failures

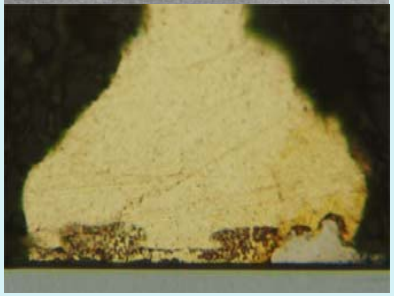
Low Tg materials can withstand X1,000 hrs at T>Tg

HTSL: Failure Analysis

FA of memory IC after 6300 hrs. testing at 150 and 175 ^{o}C indicated Kirkendall voiding in the wire bonds above Au/Al intermetallic; however, the degradation was not significant enough to cause failures.

Most of the opamp failures at 200 ^{o}C and 225 ^{o}C were due to increased wire bond contact resistance.

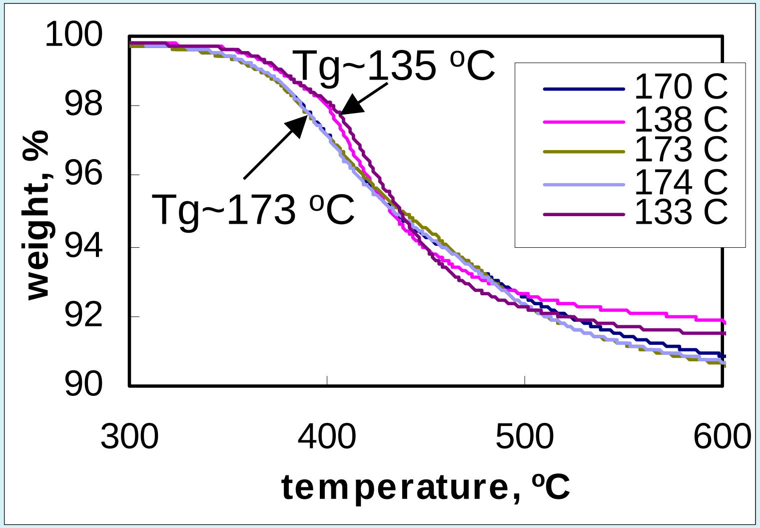

a)


b)

Voids in wire bonds after 6300 hrs. at 175 ^{o}C (a) and 1031 hr at 200 ^{o}C (b)

- Increased Rc is less important for digital IC and can cause failures in linear devices.
- Tg effect is conceivable and might be related to changes in mechanical stresses applied to bonds.

HTSL: Does Thermal Stability of MC Depend on Tg?



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 used in electronics, silicone rubbers and Teflon, have extremely low Tg of -20 to -120 ºC for the rubbers and -90 ºC for Teflon.

Tg is not an indicator of thermal stability of MC

TC: Possible Effect of Tg

- Most TC failures are due to passivation stress cracking and damage to metallization and to wire ball bond rupture associated with MC/die interfacial delaminations.
- Cory [‘00] revealed that results of TC depend not only on the temperature swing, but also on the maximum temperature, and explained it by the Tg effect.
- However, the effect of T_{max} was observed when MC remained in a glassy state.

TC: Test Results

Test conditions:

- **TC1**: 1000 c -55 +125^{o}C;
- **TC2**: 1000 c -65 +150^{o}C;
- **TC3**: 300 c 0 +180^{o}C;
- **TC4**: 300 c +20 +200^{o}C.

Temperature Cycling Test Results (Failed/Total)

package	Tg, ^{o}C	TC1	TC2	TC3	TC4
SOIC8_1	171	0/30	0/16	0/30	1/15*
SOIC8_2	138	-	0/16	0/16	-
SOIC8_3	165	0/30	-	0/30	0/15
SOIC8_4	168	0/30	-	0/30	0/15
SOIC8_5	169	0/30	-	0/30	0/15
SOIC8_6	170	0/30	-	0/30	0/15
DIP28_1	135	-	0/5	-	-
DIP28_2	135	-	0/20	-	-
TO220_1	153	0/30	-	0/30	0/15
TO220_2	163	0/30	-	0/30	1/15*
TO220_3	167	0/30	-	0/30	0/15

* Parametric changes

Exceeding Tg during TC did not cause failures.

HAST: Possible Effect of Tg

Mechanism I.

Moisture decreases Tg and increases dielectric constant, thus intensifying the charge instability failures.

Mechanism II.

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.

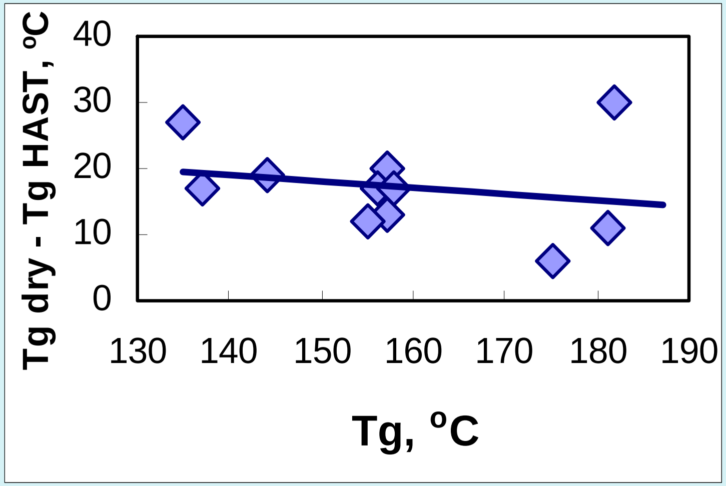
Mechanical stresses in the presence of moisture:

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

where E is the Young's modulus, CME is the coefficient of moisture expansion, and δ is the moisture sorption.

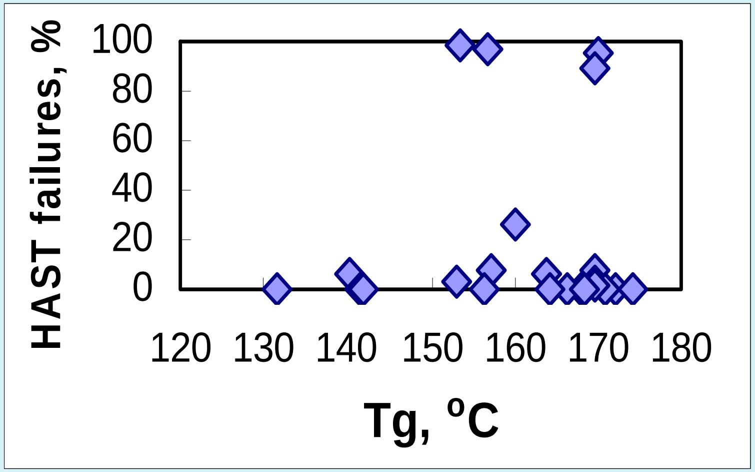
HAST: Test Results

Effect of initial Tg on the HAST-induced decrease of Tg



Average decrease in Tg ~15 °C

Correlation between Tg and HAST failures for different PEMs

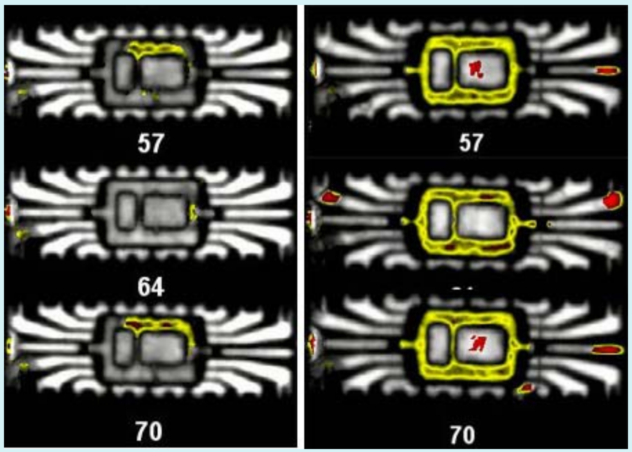


24 part types HAST 130 °C/85% RH/250 hrs under bias conditions (each lot 30 samples)

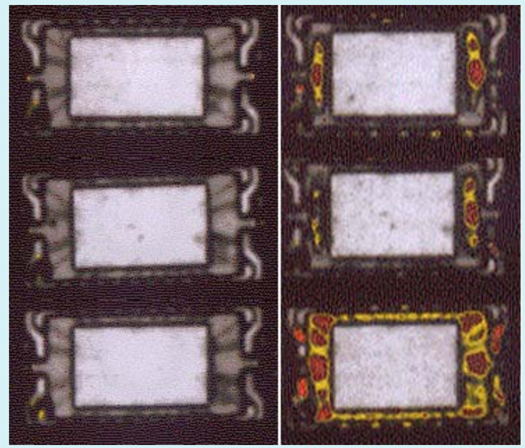
No correlation between initial Tg and the decrease of Tg after HAST, and between Tg and the proportion of HAST failures.

HAST: FA Results

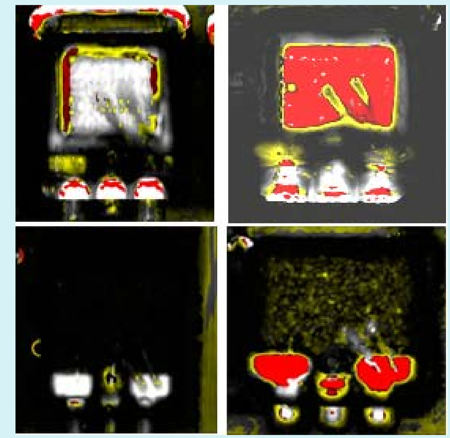
Acoustic microscopy of parts before (left) and after (right) HAST at 130 ºC/85% RH/96 hrs.



SOIC16



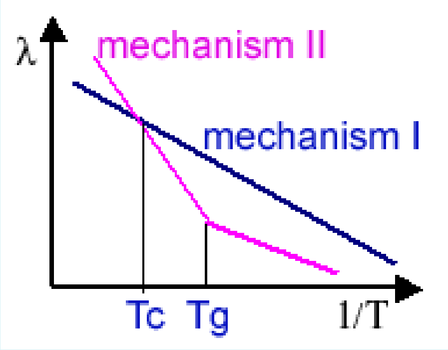
SSOP28



TO220

- Delaminations in HAST failures are typical and are due to swelling of MC.
- The probability of delaminations might depend on Tg.
- Delaminations might introduce new failure mechanisms.

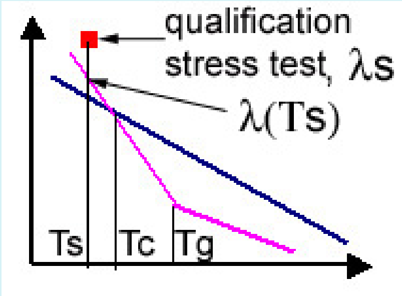
Effect of Tg on Failure Modes and Mechanisms



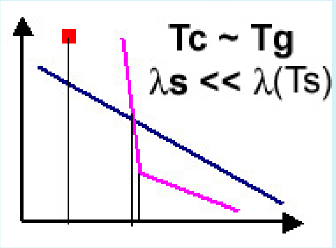
When characteristics of MC affect reliability of PEMs, the Tg effect might be expected.

This is important for analysis of acceleration factors and for prediction of long-term reliability based on high-temperature stress testing.

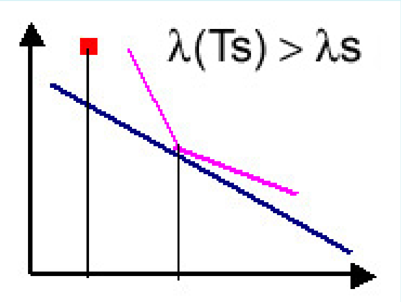
Conceivable Situations



Most probable case:
Ts>Tc>Tg
$\lambda_q >> \lambda_{exper}$



Little likelihood case



Parts prone to failures related to MC ⇨ poor quality lot.

Summary

- Performed experiments did not reveal effect of Tg on results of standard screening and qualification testing.
- Changes in failure rates at T>Tg are conceivable and should be considered for analysis of acceleration factors and prediction of long-term reliability of PEMs based on high-temperature stress testing.
- For a normal quality lot there is no immediate danger in exceeding Tg during standard reliability testing.