Moisture Diffusion in Molding Compounds and Quality Assurance of PEMs for Space Applications

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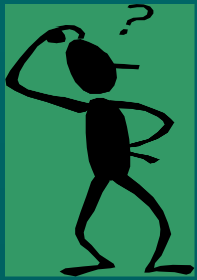
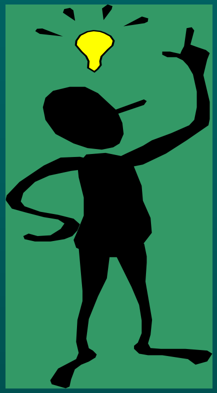
No humidity in space. Why moisture concerns?



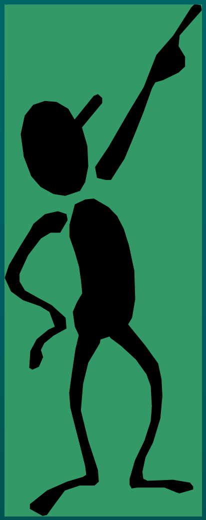


We need to assure that no moisture related failures occur during the ground phase integration and testing period (2 to 5 years).

Quality assurance strategy for PEMs:

- **Moisture prevention**
- **Adequate qualification testing**

Quality assurance strategy for PEMs for military and space applications



Moisture prevention strategy:

- **Military applications:** Wafer Applied Seal for PEM Protection (WASPP)**;**
- **Space applications**: Virtual monitoring/simulation of the moisture level variations and baking of components and assemblies.

Adequate testing:

- **Military applications**: To assure reliability for 15 to 20 years of storage and operation in harsh humid environments.
- **Space applications**: To assure reliability for 5 years maximum in controlled laboratory conditions.

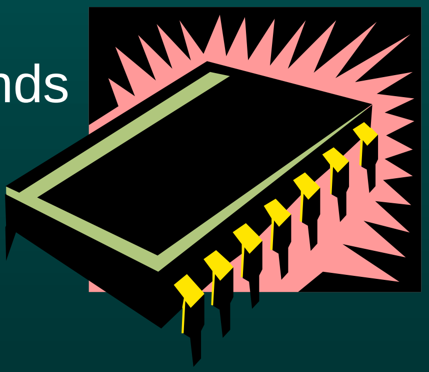
Purpose and Outline

The purpose is to discuss:

- Moisture characteristics of MCs and how they can be used for the moisture prevention strategy and for development of adequate testing.
- The relevance of HAST for PEMs intended for space applications.

Outline:

- **Part I:**
  - Bake-out conditions for PEMs;
  - Diffusion characteristics of molding compounds
- **Part II:**
  - Acceleration factors of HAST.
  - What might be an adequate testing?



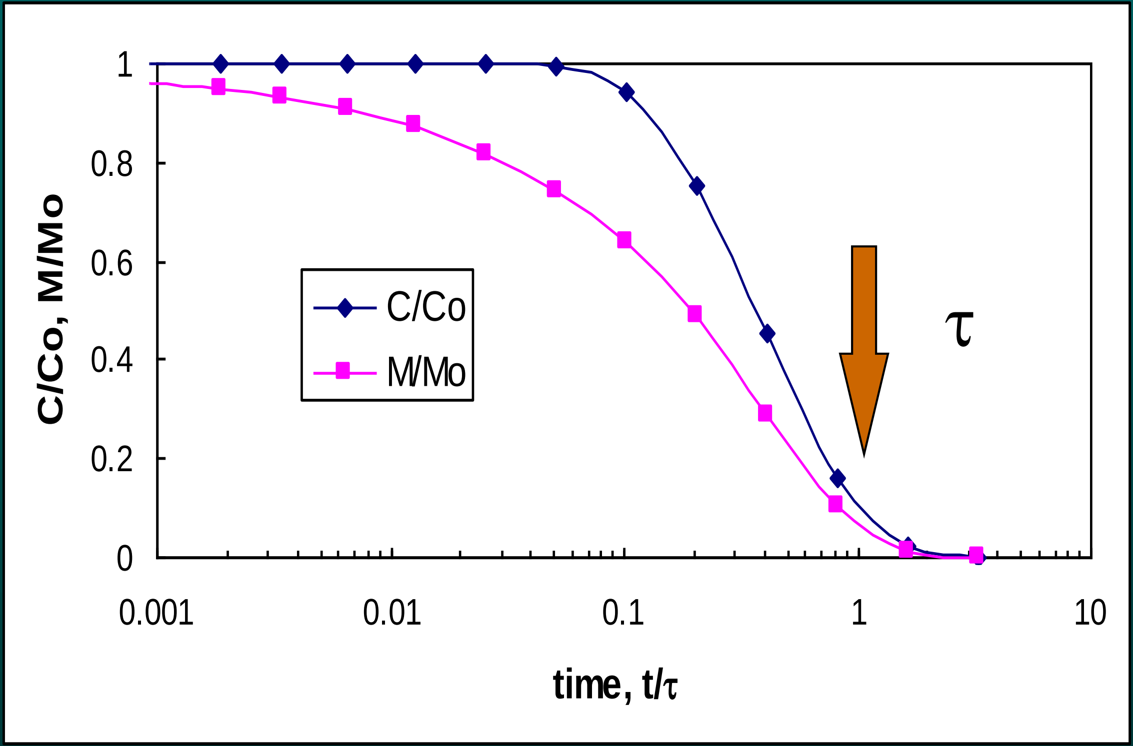
Part I. Moisture Diffusion Characteristics and Their Measurement

The first step in any MC or PEM degradation process is moisture diffusion.

→ The characteristic times of diffusion are important for implementing the moisture prevention strategy.

Characteristic times of moisture diffusion in plastic encapsulated parts

The master curve for moisture diffusion



Moisture concentration at the die surface and mass losses of a flat package with rated baking time.

Bake-out time:

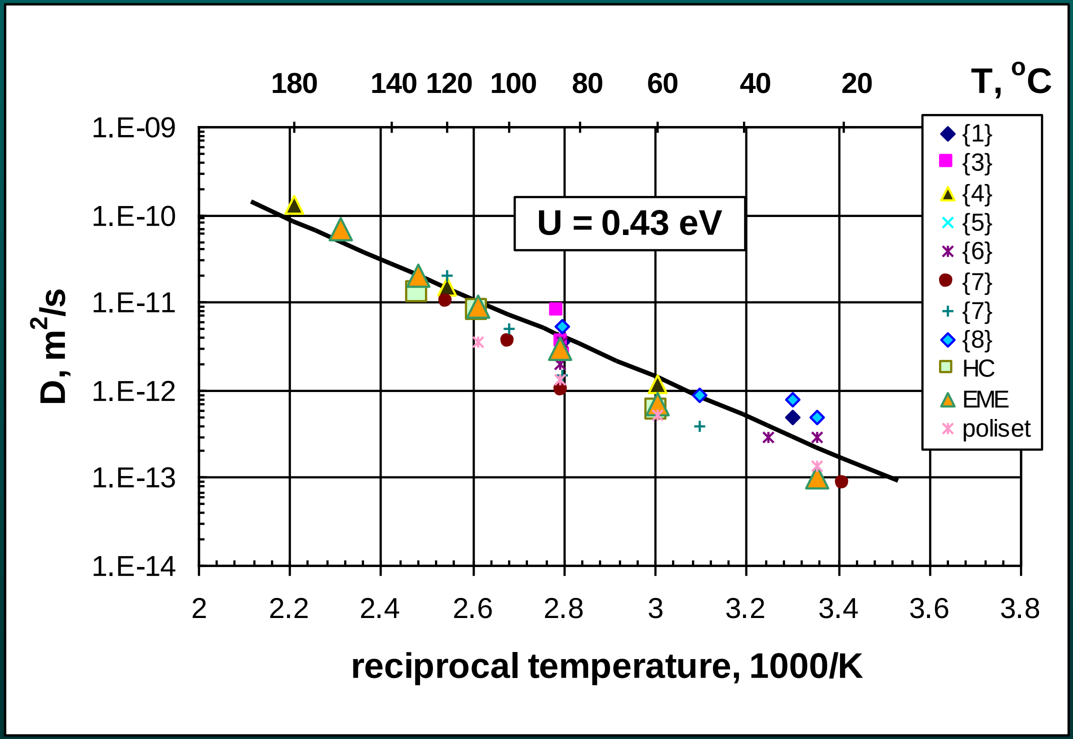
$\tau(T) = h^2/D(T)$

2h – package thickness

At $t = \tau$ =>
C/Co=0.1,
M/Mo=0.06

Diffusion characteristics of epoxy encapsulating materials

Data reported in literature.



D_{85} varies ~ 10 times

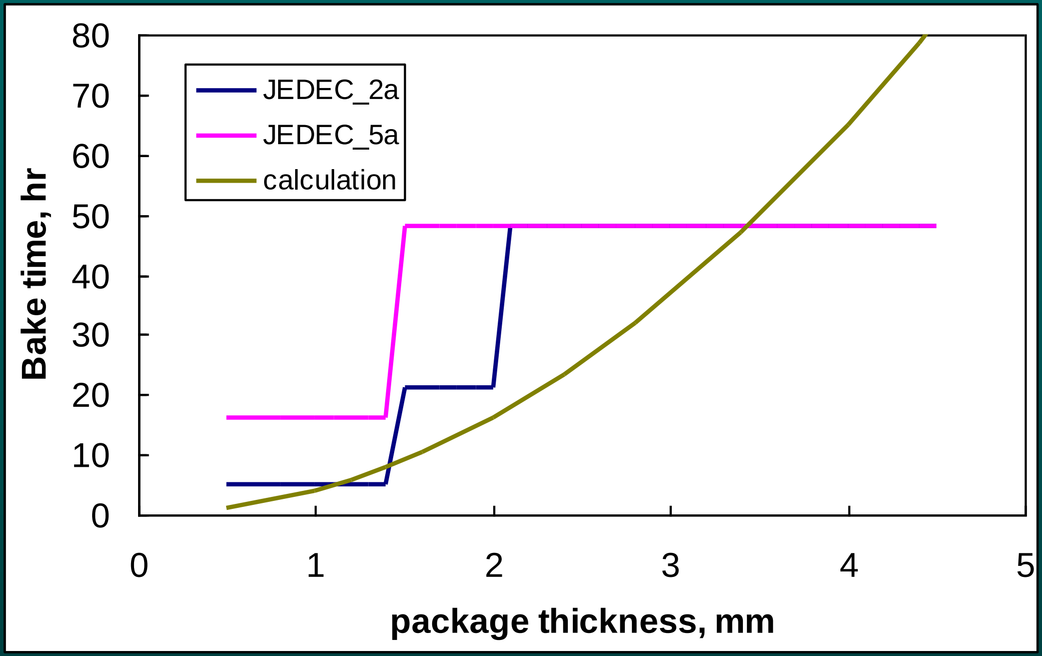
$$D = D_o \exp(-U / kT)$$

Averaged characteristics of MC:

$D_o = 7.35\times10^{-6}$ m²/sec

U = 0.43 eV

Calculated bake times at 125 ºC and JEDEC recommendations



- **Ignoring real size of the parts causes significant errors.**
- **JEDEC is focused on SMT reflow soldering and might be not adequate for moisture control purposes.**

Three body thickness groups per IPC/JEDEC J-STD-033A, July 2002: <1.4 mm; <2 mm;< 4.5 mm

IPC-SM-786A, '95: < >2 mm

Note:

- **2a and 5a are levels of moisture sensitivity.**
- **part saturated at 30 ºC/85% RH**

In-situ non-isothermal technique for D(T) measurements

A. Teverovsky, “A Rapid Technique for Moisture Diffusion Characterization of Molding Compounds in PEMs“, http://nepp.nasa.gov

Areas of application

- Moisture sorption simulation (virtual monitoring of moisture level).
- Calculation of bake-out conditions.
- Lot characterization of molding compound. (ROBOCOTS: need rapid assessment methods)
- Evaluation of moisture leaks along the leads of a plastic package.
- Development of adequate moisture stress testing (HAST alternative).

Part II. Highly Accelerated Stress Test (HAST)

Do we need to use same environmental stress testing as for PEMs intended for harsh humid conditions?

Accelerated moisture resistance tests

- **JESD22-A102-C (unbiased autoclave):**
  121 °C, 100% RH, 24 to 336 hrs (96 hr typical).
- **JESD22-A118 (unbiased HAST):**
  Cond. A: 130 °C, 85% RH, 96 hrs.
  Cond. B: 110 °C, 85% RH, 264 hrs.
- **JESD22-A110-B (biased HAST):**
  Cond. A: 130 °C, 85% RH, 96 hrs.
  Cond. B: 110 °C, 85% RH, 264 hrs.

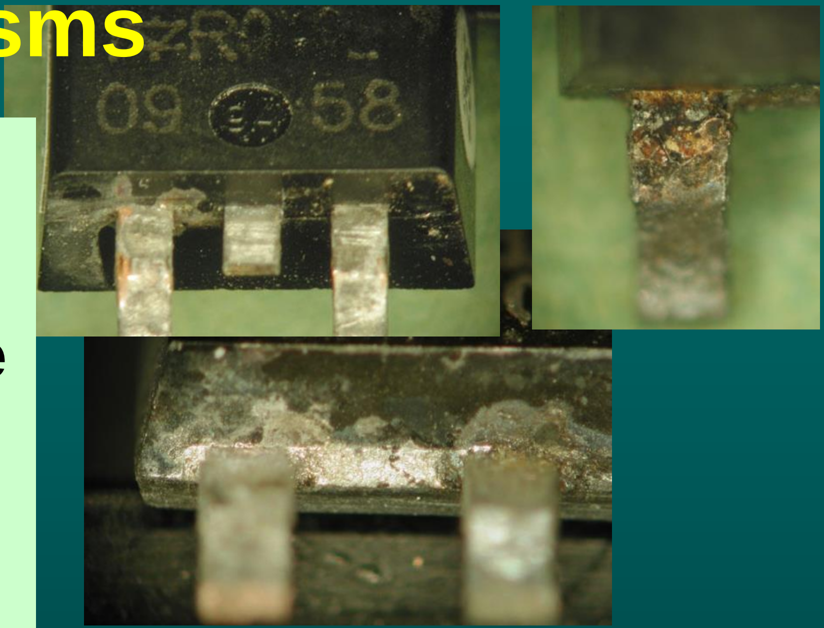
Equivalent to 1000 hours at 85 °C and 85% RH

<u>Typical HAST conditions: bias at 130 °C, 85% RH</u>

- 96 hrs per JESD22-A110-B.
- 150 hrs per NAVSEA SD18 (Part Requirement & Application Guide).
- 500 hrs per PRF38535 spec. (for technology characterization).

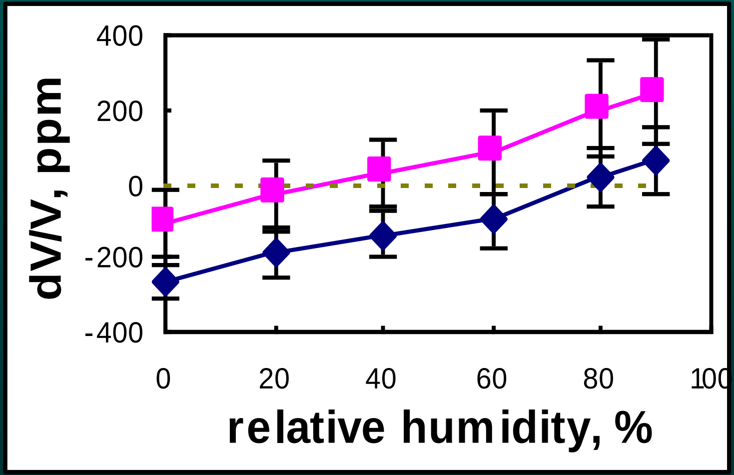
NASA projects: 250 hrs?

HAST failure mechanisms



<u>Package level</u>

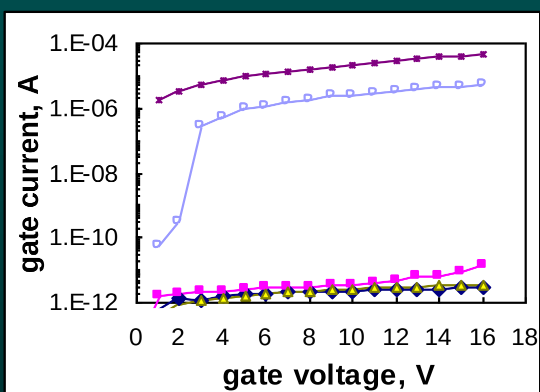
- **Corrosion of the leads.**
- **Dendrite formation (on the surface and inside packages).**
- **Swelling/shrinkage:**
  - ✓ Delaminations;
  - ✓ Solder ball failures in PBGA and flip-chip technology;
  - ✓ warpage of large packages;
  - ✓ parametric shifts in linear devices.

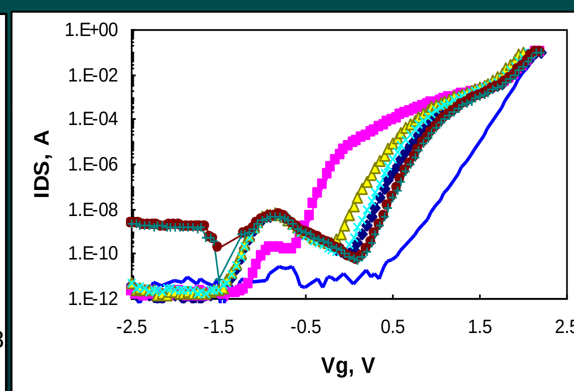


HAST failure mechanisms

Die level:

- **Corrosion of Al metallization.**
- **Dendrites between metallization lines.**
- **Leakage currents.**
- **Charge instability (lateral, ion drift, hot electron).**

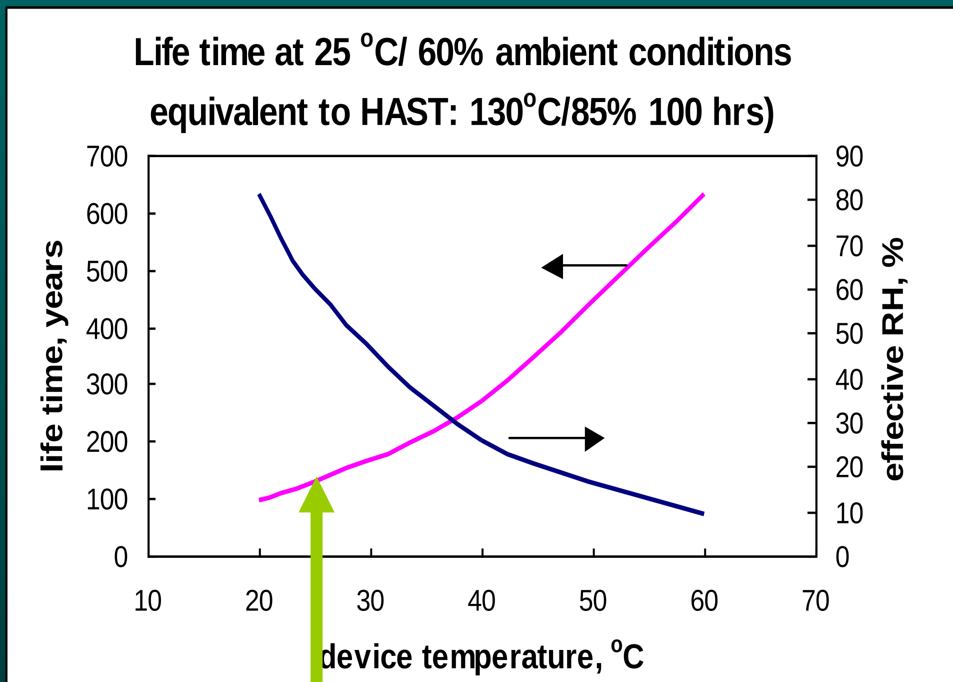




HEXFET failures

Mechanisms of moisture induced parametric degradation require additional analysis

What is the HAST acceleration?



Life time increases with device temperature

Best-fit model:
S. Peck [86];
Hallberg and Peck [91];
S. Tam [95]; SSB-1 [2000];
J. Sweet [02]:

$$t_f = A(RH)^{-n} \exp\left(E_a / kT \right)$$

$0.7 < Ea < 1.1$ eV;
$1 < n < 5$

Ea = 0.8 eV; n = 2.7

$$RH_{eff} = RH_a \times \frac{P_s(T_a)}{P_s(T_{dev})}$$

Test results on linear devices

11 part types out of 25 failed HAST

HAST: 130 ^{o}C, 85% RH, 250 hours

Part	DC	Pack. type	QTY tested	QTY failed	Failure mode
Vref	0112	SOIC8	31	3	1- increased V_{out} 2 - catastrophic
Opamp	0101	SOIC16	30	2	-
Instr. amp	0033	SOIC8	30	30	Excessive input currents
FET1	0041	SOT223	29	28	I_{DS}, V_{GTH}
FET2	0040	D^2Pak	30	29	~ 60% parametric shift

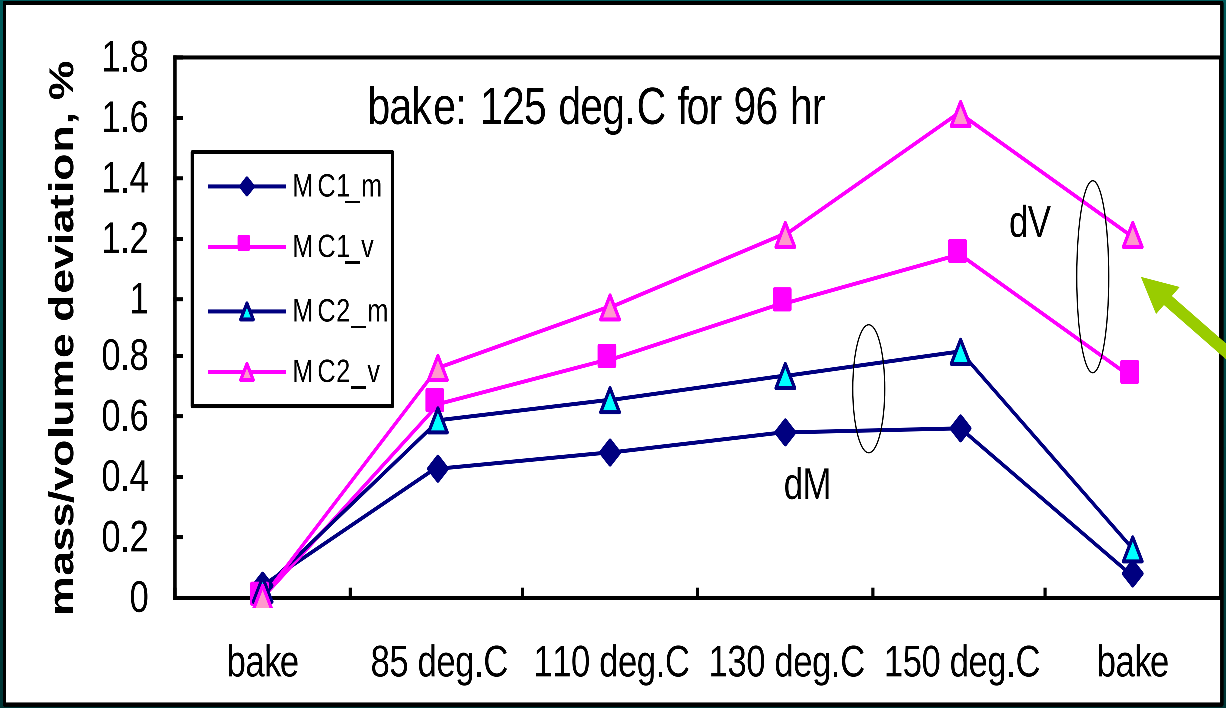
Is HAST adequate for normal conditions?

- **Testing temperature (130 ºC) is above the operational range for many parts.**
- **Degradation of molding compound:**
  - Decrease of Tg (up to 100 ºC in resins and up to 30 ºC in MCs).
  - Enhanced creep.
  - Decrease of the tensile stress and adhesion.
- **The model accelerates mostly corrosion failures, but corrosion is no longer a prime concern.**
- **Moisture assisted hot-carrier degradation might have U < 0.**

Irreversible changes in MCs: An example

Test: moisture uptake and swelling after HAST were measured on two epoxy molding compounds.

Conditions: saturation with moisture at 85% RH and different temperatures.



Additional mechanical stresses due to swelling:

$\sigma \approx A \times E \times [(\alpha_{MC} - \alpha_{LF}) \times \Delta T + \beta \times \Delta m]$,

At $\alpha_{MC} \approx \alpha_{LF}$ **mechanical stresses are due only to moisture sorption.**

An increase in volume might cause delaminations and mechanical failures.

Do we need moisture testing?

Ionic dissociation in polymer:

Charge carriers are impurity ions generated by dissociation of a salt MA

$$M^+A^- \longleftrightarrow M^+ + A^-$$

The equilibrium constant:

n_o is the concentration of salt molecules; f is the fractional degree of dissociation

$$K = \frac{[M^-]\times[A^-]}{M^+A^-} = \frac{f^2 n_0}{1-f}$$

In a medium with low ε:

Uo is the energy of ions separation in vacuum

$$K = K_0 \times \exp\left(\frac{U_0}{\varepsilon \times kT}\right)$$

$$n = A\exp\left(\frac{U_0}{2\varepsilon \times kT}\right)$$

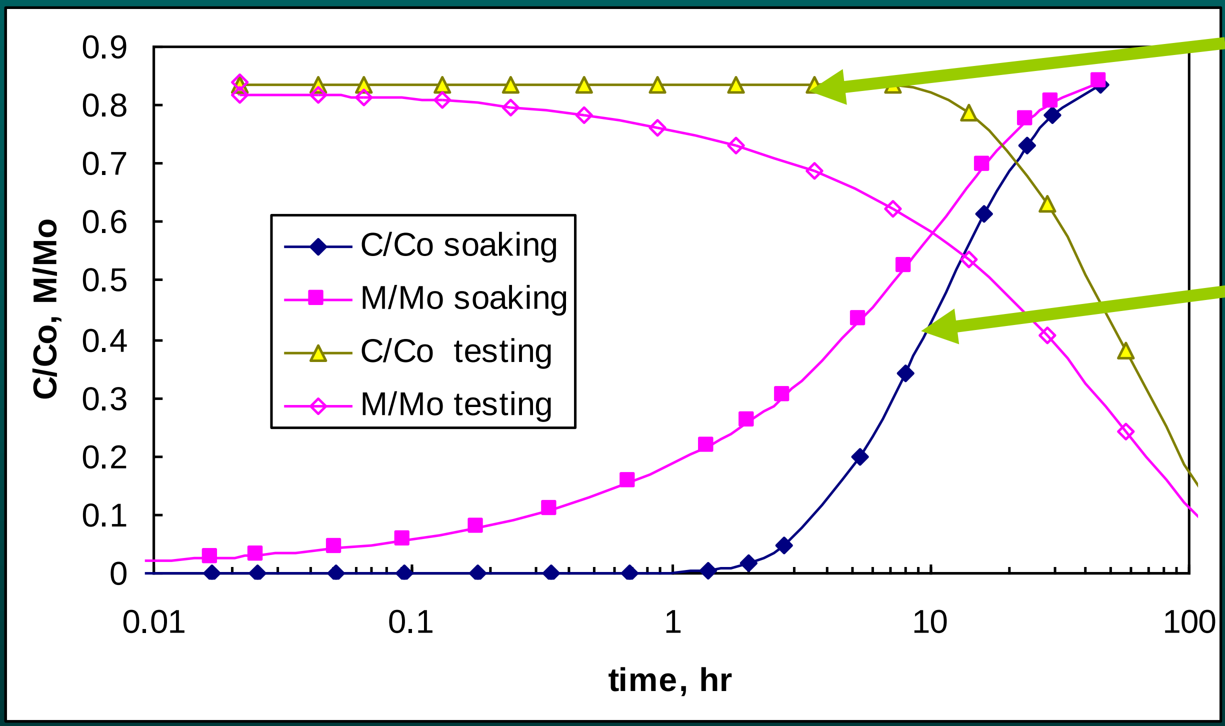
$$\varepsilon_{mc} = \varepsilon_{mc}^0 + \delta m_{mc} \times \varepsilon_w \times \frac{\tilde{\rho}_{mc}}{\tilde{\rho}_w}$$

1. Moisture concentration at the die surface at RT is approximately the same as at high T/RH conditions.

2. Another reason:
Moisture activates ionic impurities similar to temperature. Moisture testing might accelerate degradation mechanisms related to charge instability.

A possible alternative to HAST: MS + HTB

Moisture evolution in a 2 mm thick package

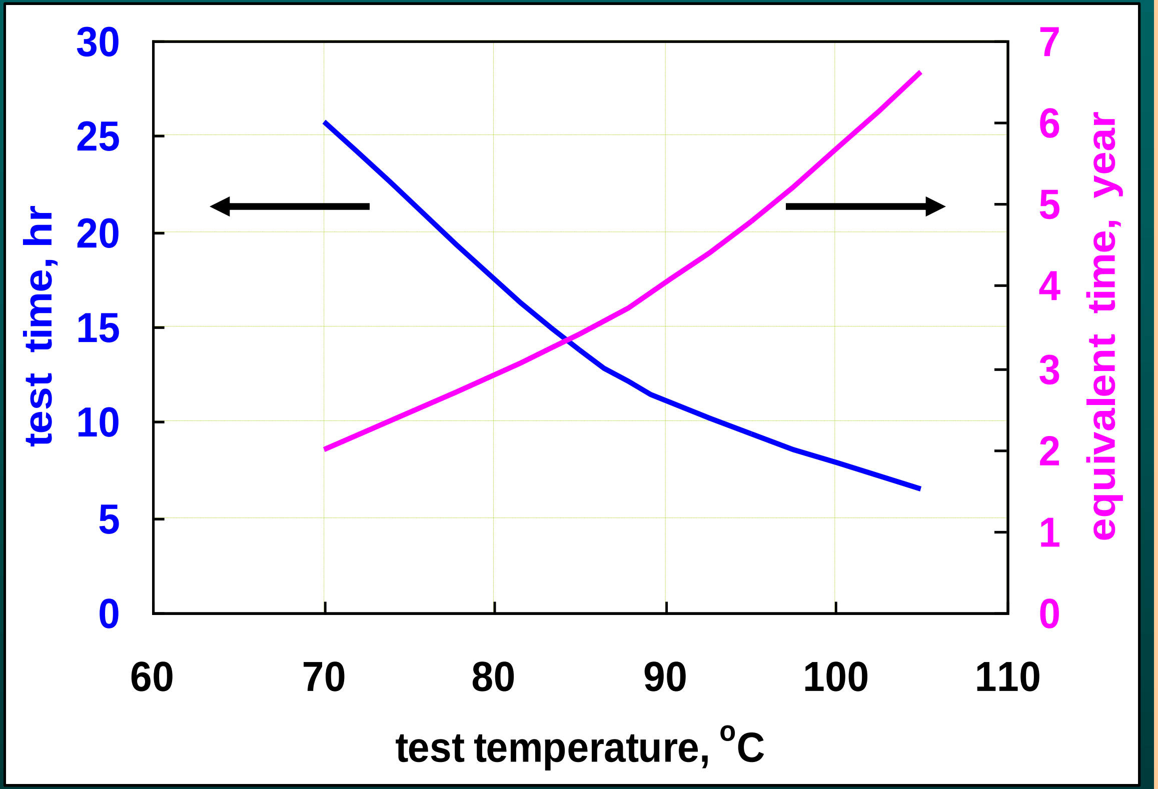


Testing at 85 °C.

Soaking in humidity chamber for 48 hrs at 110 °C and 85% RH

Note: $C/C_o = 1$ corresponds to the equilibrium moisture saturation at 100% RH.

Calculated test time and equivalent time of operation



Package thickness 2 mm

Soaking conditions:

RH = 95%,
T = 110 °C,
t = 30 hr

Test conditions:

$RH_{eff} \geq 90\%$
70 °C < T < 105 °C

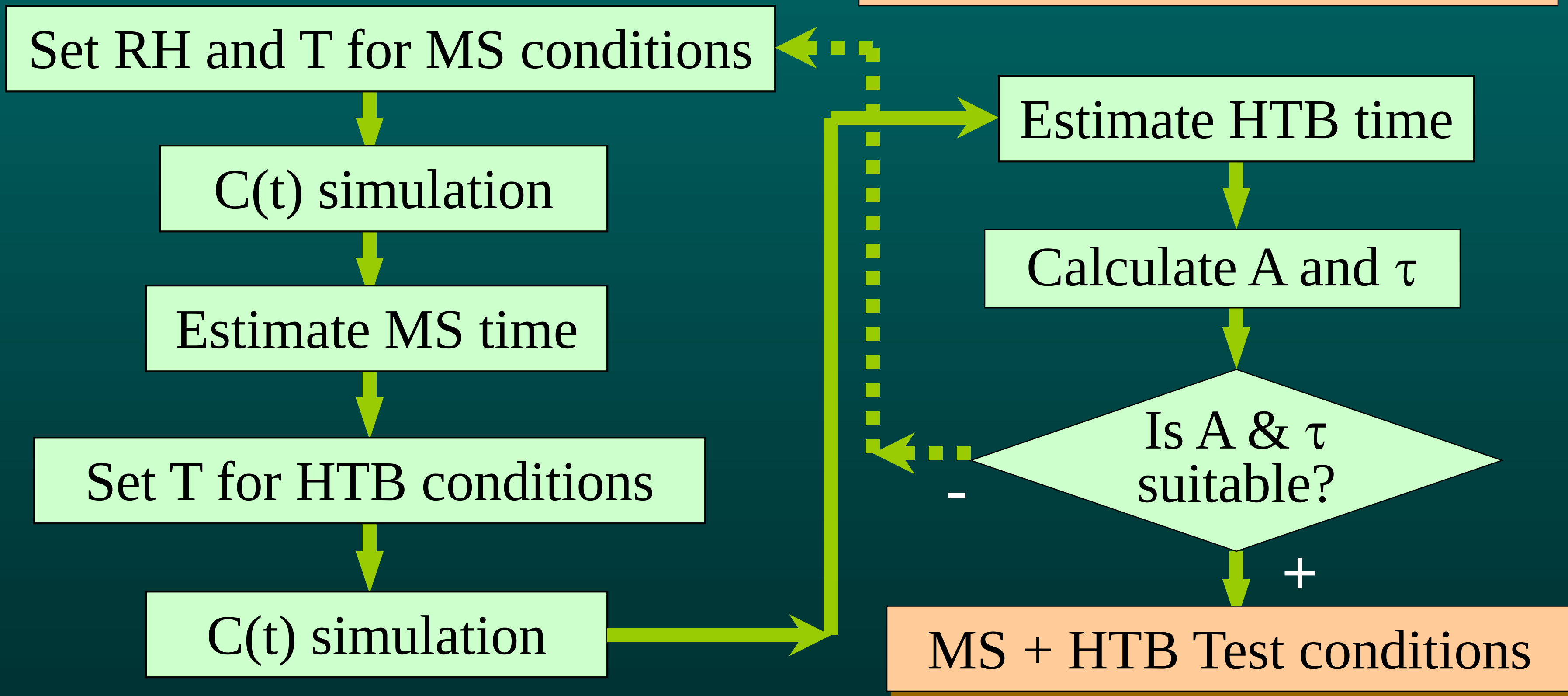
Operating conditions (environment):

RH =50%
T = 20 °C

HAST alternative: MS + HTB testing

Algorithm for calculation of MS+HTB testing conditions

<u>Input:</u> Package size; D(T) data; ground phase conditions; maximum storage and operation temperatures.



Conclusion

- Suggested quality assurance strategy: moisture content control (virtual monitoring and baking) + adequate testing.
- The moisture prevention strategy can be implemented by assessment of moisture content and calculations of the bake-out conditions based on D(T) data.
- The existing HAST conditions are too harsh for PEMs intended for space applications. A possible alternative to HAST might be MS + HTB testing.
- Additional analysis of moisture induced parametric degradation and acceleration factors is necessary.