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reliability designed, reliability delivered

Developing a Pb-Free Qualification Plan for Hi-Rel Applications

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Motivation

- Initial transition to RoHS compliant product
  - Consumer and computer
- Minimal change in product qualification procedures
  - Relatively benign environments
  - Short lifetimes (2 to 5 years)
  - Low level of failures can be acceptable
- Now: Hi-Rel companies considering Pb-free assembly
  - Product qualification can be critical
  - ‘Test-in’ reliability

What is a Reliability Test Plan?

- It is the process of ensuring the product design and manufacturing process are sufficiently robust to provide the product performance and lifetime required by the customer in their use environment
- What does this mean?
  - Testing should not be performed on prototypes
  - Validate the Pb-free process before or as part of the product qualification
  - Relevant failure modes and their environmental stressors must be identified
  - Acceleration factors must be determined to calculate test parameters and length

Reliability Test Plan (Prototypes)

- Prototypes are often built by different vendors
  - Suppliers specializing in ‘quick turn’
- Prototypes can involve processes or materials not used in the standard production process
  - Hand soldering, mold release, etc.
- Can result in failures not relevant to production or successes

Process Assurance and Validation

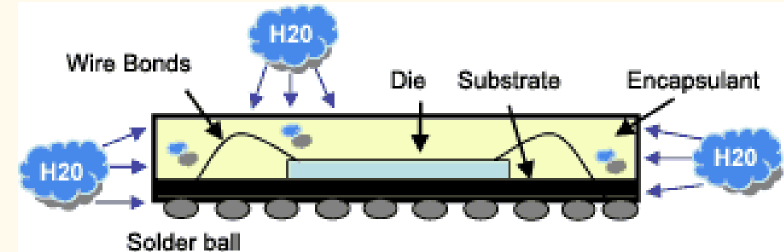
- The first step in process assurance and validation is a ‘scrub’ of the bill of materials (BOM)
  - Identification of incompatible or ‘at-risk’ components
- Aspects of a BOM scrub
  - Peak reflow temperature
  - Moisture sensitivity levels
  - Interconnect material (solder and plating)

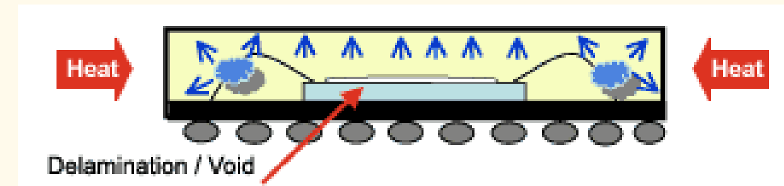
BOM Scrub (Peak Reflow Temperature)

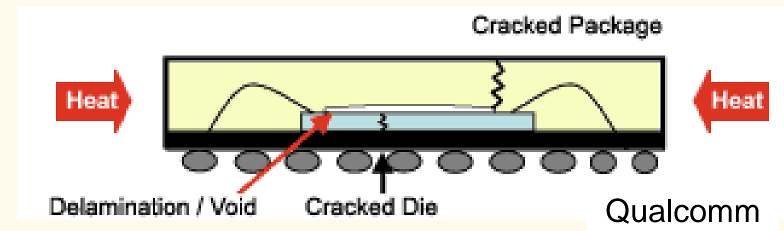
- The maximum temperature the component can experience during assembly
  - Identified by the manufacturer in the datasheet
  - May also include time (e.g., not to exceed 30 seconds above 230C)
- Common conflicts
  - Manufacturer of ball grid array package requires a *minimum* peak temperature of 250C
  - Manufacturer of passive component requires a *maximum* peak temperature of 245C

BOM Scrub (Moisture Sensitivity Levels)

- Moisture can be absorbed by polymeric material during transportation, storage and handling
  - Epoxy encapsulant
  - Die attach
  - Printed substrate
- Trapped moisture can experience sudden liquid-gas phase transition during reflow
  - Sudden volume increase due to vaporization
- Cracking and delamination – sometimes accompanied by a popping sound







Qualcomm

MSL (cont.)

- Popcorning controlled by moisture sensitivity levels (MSL)
  - Defined by JEDEC documents J-STD-020C and J-STD-033A
  - Transition from SnPb to Pb-free reflow can increase moisture sensitivity by up to 2 levels
- Most CEMs and OEMs will try to avoid components with MSL greater than 3 or 4
  - Too high of a risk
  - Use of these devices can require changes in procedures or implementation of controlled storage
- Common problems
  - MSL is not listed in the datasheet or easily available from the manufacturer
  - Listed MSL value is per an older version of J-STD-020

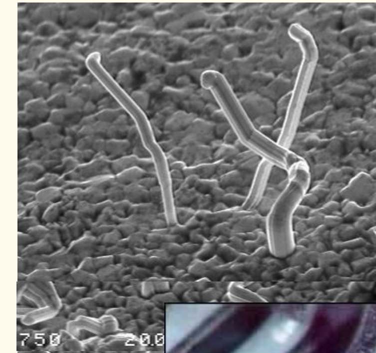
LEVEL	FLOOR LIFE	
	TIME	CONDITIONS
1	Unlimited	≤30 °C/85% RH
2	1 year	≤30 °C/60% RH
2a	4 weeks	≤30 °C/60% RH
3	168 hours	≤30 °C/60% RH
4	72 hours	≤30 °C/60% RH
5	48 hours	≤30 °C/60% RH
5a	24 hours	≤30 °C/60% RH
6	Time on Label (TOL)	≤30 °C/60% RH

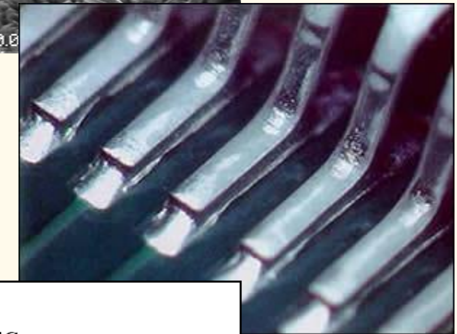
BOM Scrub (Interconnect Material)

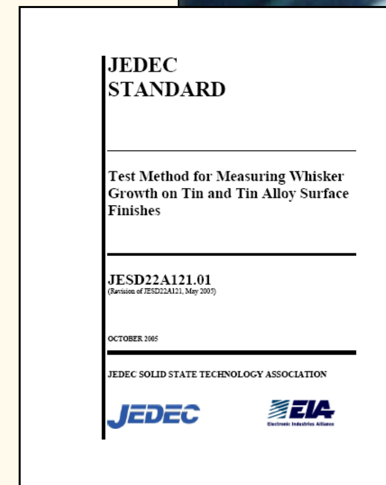
- Ball Grid Arrays
  - Knowledge of 2nd Level interconnect material (solder balls) is important for
    - Establishing peak reflow temperature
    - Understanding potential failure modes
    - Deriving acceleration factors
  - SAC405, SAC205, SAC105, Sn3.5Ag, etc.
- Leaded Devices
  - Critical for mitigating the risk of tin whiskers

Tin Whiskers

- Avoid the ‘scary’ plating systems
- Identify critical components
  - Less than 1 mm pitch
  - Metal can housing
  - Contact points
  - Welds
- Request evidence of mitigation
  - Anneal for 1 hour at 150C
  - Nickel or silver underplate (>0.5 microns)
  - Thick tin plating (>7 microns)
  - Alloying element (Sn-Bi or Sn-Ag)
- Request evidence of testing and process control







JEDEC
STANDARD

Test Method for Measuring Whisker Growth on Tin and Tin Alloy Surface Finishes

JESD22A121.01
(Revision of JESD22A121, May 2005)

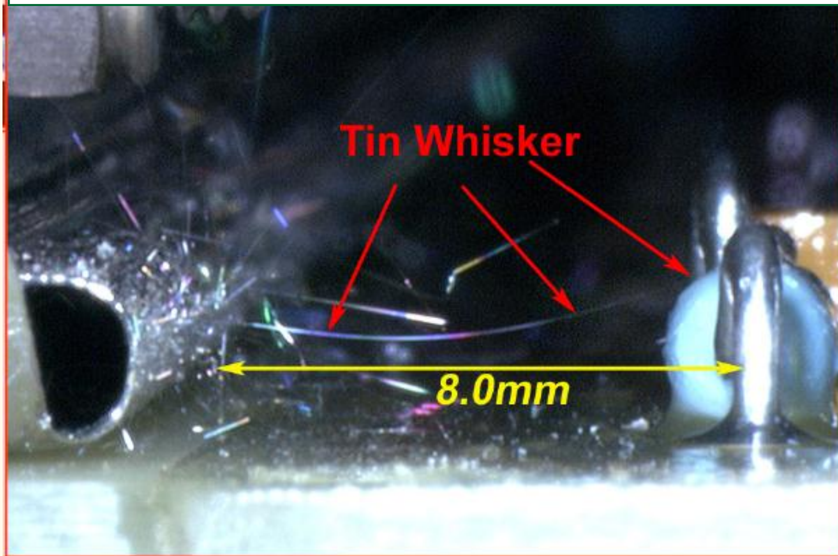
OCTOBER 2005

JEDEC SOLID STATE TECHNOLOGY ASSOCIATION

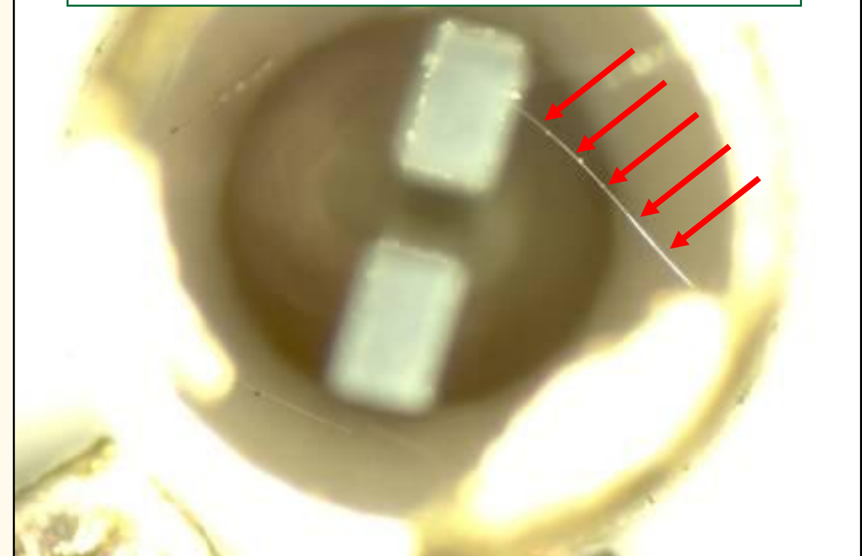
JEDEC EIA

Where are the Scary Whiskers?

- When do really long whiskers occur?
  - Usually bright tin and/or plating over a substrate material other than copper (brass, bronze, steel, etc.)



Tin (bright?) over steel



Tin (matte?) over brass

Analysis after Manufacturing

- Construction analysis should be performed before reliability testing
  - Faster and easier way of capturing gross or obvious defects
- Activities
  - Acoustic microscopy on components with MSL 3 or higher
  - X-ray of BGAs to assess degree of voiding and other solder anomalies
  - Ion Chromatography to ensure cleanliness

Pb-Free Failure Modes

- Failure modes are very similar to SnPb
  - Fatigue (Elastic / Plastic)
  - Creep
  - Fracture
  - Dendritic Growth
  - Etc.
- Therefore, the tests will be similar, but the parameters and duration will change
- However, common test limitations will continue to apply
  - Availability of resources
  - Number of samples
  - Time
  - Cost
  - Desire to stay in the ‘mainstream’ (stay close to industry specs)

Reliability Tests

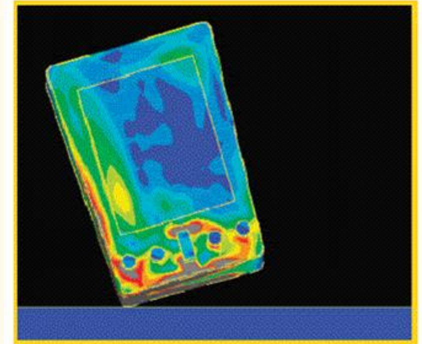
- Drop / shock testing
- Vibration
- Temperature cycling
- Temperature-humidity-bias (THB)
- Power cycling
- Constant temperature

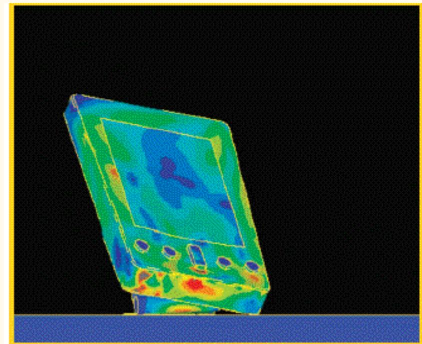
Case Study: Industrial Monitoring

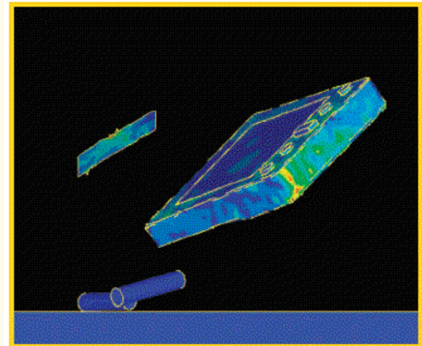
- Product is expected to last 10 years
- Product is portable
- Environmental stressors
  - The unit can be dropped (mechanical shock)
  - The unit can be stored and used in uncontrolled environments (temperature cycling, temperature/humidity)

Drop Testing

- To identify potential embrittlement or damage affiliated with Pb-free solder that could reduce robustness during exposure to drop conditions
  - Stiffer solder may cause damage to PWB and solder intermetallic
  - Standard failure modes are either bond pad pullout or intermetallic fracture

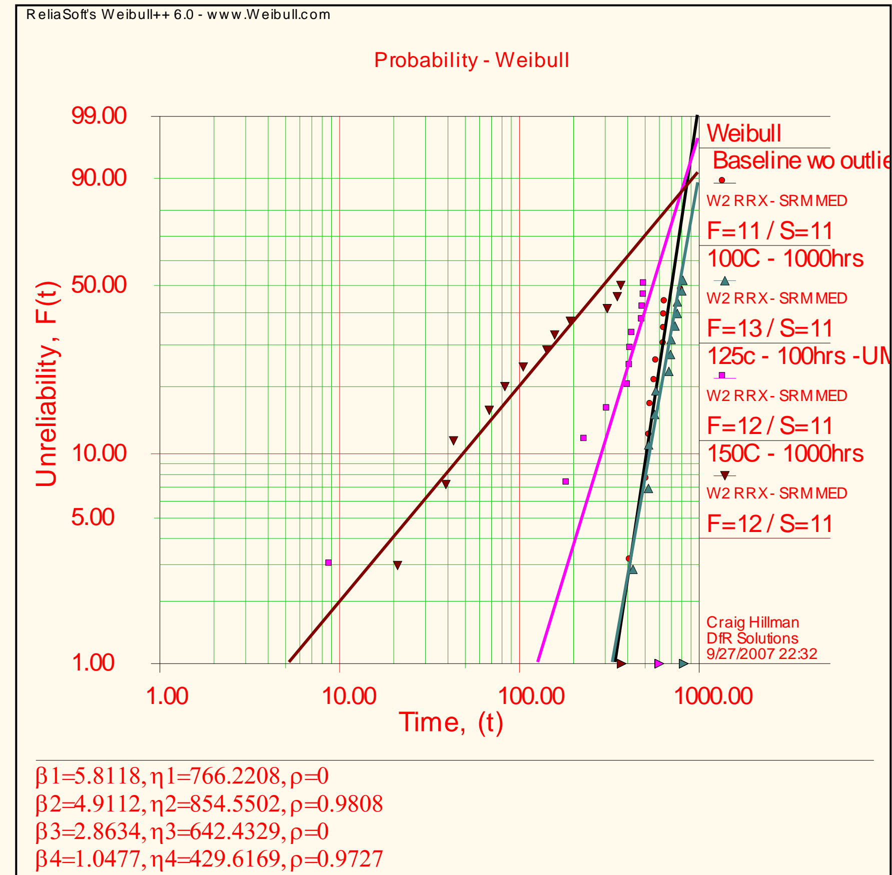






Drop Testing (cont.)

- Drop testing does not usually require the development of an acceleration factor
  - Number of drops in test = number of drops in field
  - Severity of drops in test = severity of drops in field
- However, preconditioning required to replicate aging in the field
  - Increase in intermetallic thickness can result in decrease in solder robustness



Increasing preconditioning time and temperature results in decreasing Weibull slope (β)

Preconditioning

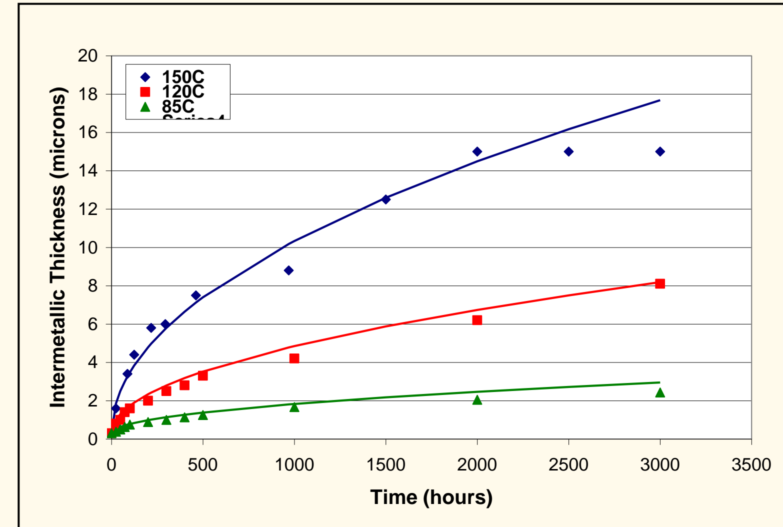
- How to extrapolate field conditions to preconditioning?
  - Fick's Law of Diffusion

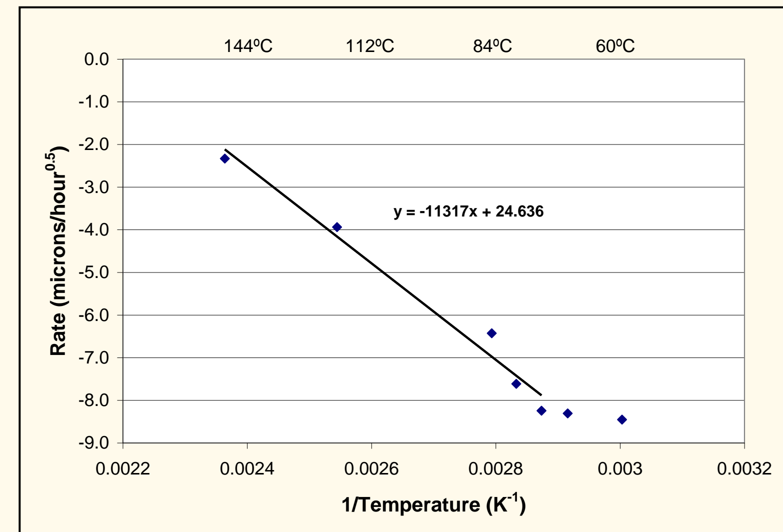
$$Z = \sqrt{Dt}$$

$$D = D_0 \exp(-E_A / kT)$$

- Worst case environment
  - 40C during the heat of the day
  - 8 hours per day for 10 years
- Prior work on Pb-free solder
  - Activation energy (E_a) = 0.975 eV
  - Diffusion coefficient (D_0) = 5 x 10^{10}

- Precondition should be 85C / 310 hrs to duplicate 10 year life

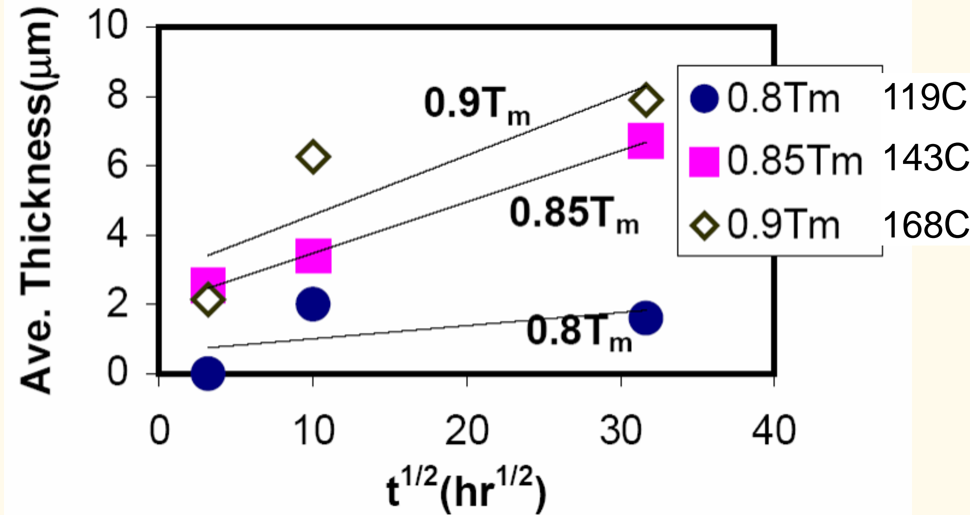




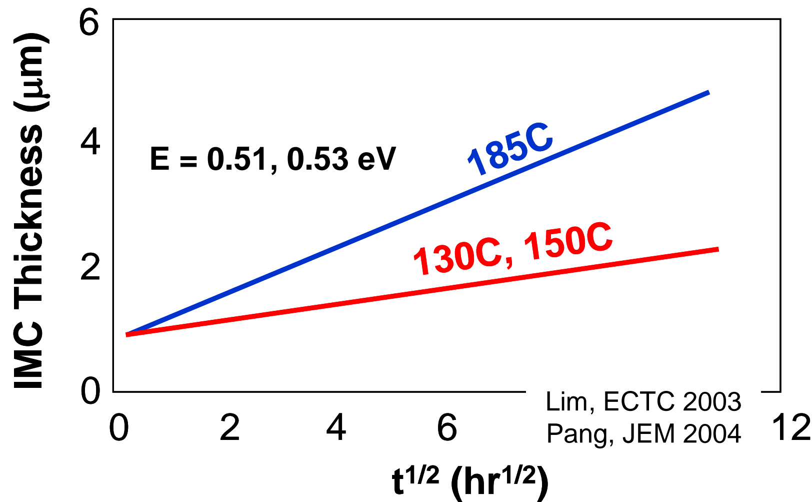
Hot Temperatures (Intermetallic Growth)

Surface Mount Solder Paste	BGA Solder Ball Metallurgies	Activation Energy (kJ/mol)
63Sn-37Pb	63Sn-37Pb	45
Sn-4.0Ag-0.5Cu	63Sn-37Pb	48
	Sn-4.0Ag-0.5Cu	33
	Sn-2.5Ag-1.0Bi-0.5 Cu	68
	Sn-0.75 Cu	50
	Sn-3.5Ag	31

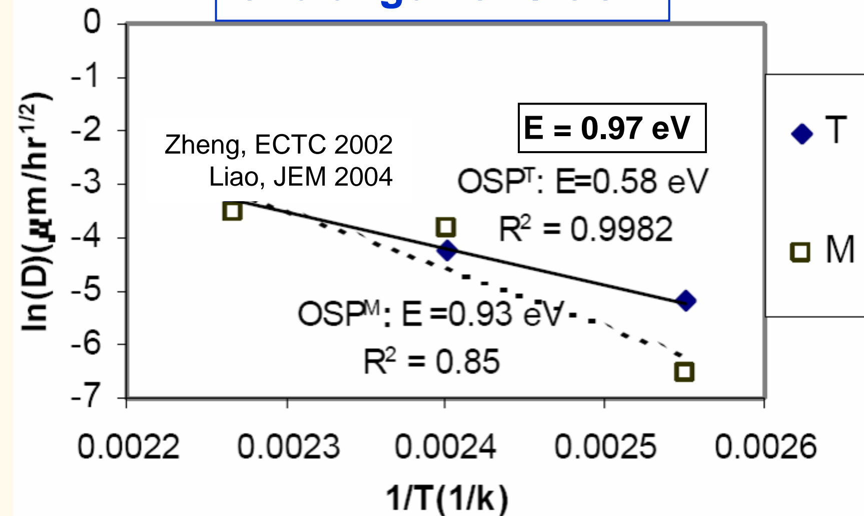
Henshall, APEX 2001



Sn3.5Cu0.7Cu / ENIG



Sn3.8Ag0.7Cu / OSP



How Many Drops? How Severe?

- Initially based on industry standard
  - JEDEC JESD-B110 Subassembly Mechanical Shock
- P4 Service Condition (3 foot drop)
  - Unit is heavy; unlikely to be held above the waist
- # of drops = 42
- Orientation to be based on analysis of worst case impact

Table 2a — Portable subassembly service condition test levels (English units)

Service condition	Equivalent drop height (in) max / reduced	Velocity change (in/s) max / reduced	Peak acceleration (G) max / reduced	Pulse duration (ms) max / reduced
P1	59 / 32	214 / 157	235 / 188	3.7 / 3.4
P2	51 / 28	199 / 147	225 / 181	3.6 / 3.3
P3	44 / 24	184 / 136	214 / 173	3.5 / 3.2
P4	36 / 18	167 / 118	199 / 153	3.4 / 3.1
P5	30 / 12	152 / 96.3	188 / 130	3.3 / 3.0
P6	24 / 10	136 / 87.9	173 / 123	3.2 / 2.9
P7	18 / 8	118 / 78.6	153 / 114	3.1 / 2.8
P8	12 / 6	96.3 / 68.1	130 / 102	3.0 / 2.7
P9	10 / 4	87.9 / 55.6	123 / 87	2.9 / 2.6
P10	8 / 2	78.6 / 39	114 / 61	2.8 / 2.6
P11	6 / 2	68.1 / 39	102 / 61	2.7 / 2.6
P12	4 / 1	55.6 / 28	87 / 43	2.6 / 2.6
P13	3 / 1	48.1 / 28	75 / 43	2.6 / 2.6
P14	2 / 1	39.3 / 28	61 / 43	2.6 / 2.6

Drop Testing (Modifications)

- Customer indicated 5 drops a year
  - 10 year life = 50 drops
- Customer requested 90% reliability with 80% confidence, but only had 7 samples
  - Solution? Extend testing to 130% life (65 drops)
  - Assumes Weibull slope (β) of 3

- Finished? Nope

The Reality of Reliability Testing

- The desire to be like 'everyone else' will almost always be a major driver in test selection
- Customer determined sister division was using MIL-STD-810
  - Specifies 4 to 6 drops over the lifetime of the product
  - Requires drops on every corner (8), every face (8), every edge (12)
    - Drops can be randomly divided among 5 samples
  - No preconditioning required

Temperature / Humidity

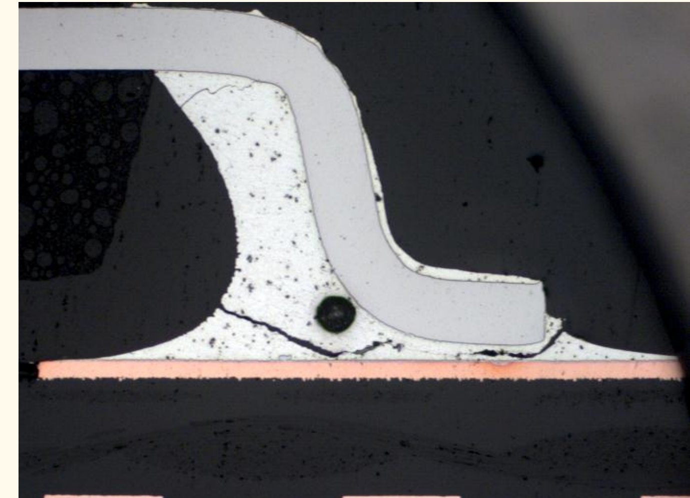
- Designed to identify and accelerate corrosion-based mechanisms
  - Electrochemical migration (ECM) and conductive anodic filament (CAF)
  - Possible concern due to more aggressive fluxes used for Pb-free
- Tests to date indicate little to no difference in the acceleration factors for corrosion based mechanisms between SnPb and Pb-free solders
  - Continue with industry best practices established with SnPb

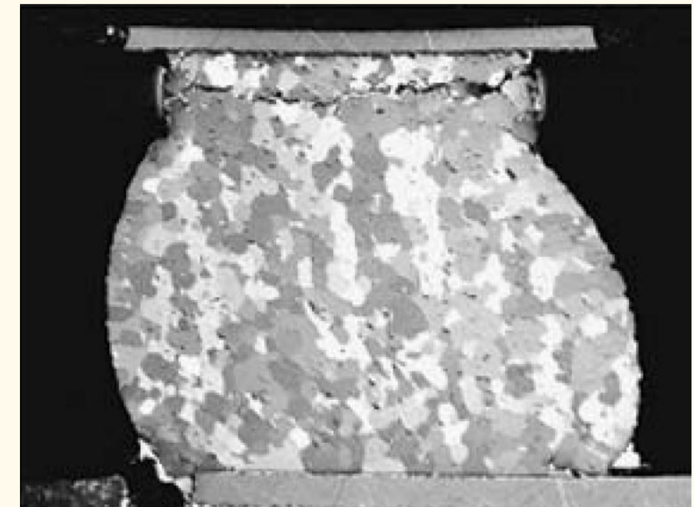
Temperature / Humidity (Best Practices)

- Two approaches
  - ECM: Step-stress approach with 96 hours at 40C/93%RH; 96 hours at 60C/88%RH; product must be biased
  - CAF: 300 to 500 hours at 60C/85%RH at bias
    - IPC-TM-650, Method 2.6.25, Conductive Anodic Filament (CAF) Resistance Test (Electrochemical Migration Testing)
- Temperature cycling (T/C) is not expected to induce interconnect failures and can help aggravate potential process defects
  - Therefore, THB is performed in after T/C

Temperature Cycling

- Purpose is to accelerate and identify potential thermo-mechanical degradation mechanisms
  - Solder joint fatigue
  - Plated through hole fatigue
- How to derive a test condition representative of the field environment?
  - Acceleration factor based on physics of failure (PoF)
- What is the realistic worst-case field environment?
  - American Southwest (Phoenix)
  - Dominated by diurnal cycling





Month	Cycles/Year	Ramp	Dwell	Max. Temp (°C)	Min. Temp. (°C)
Jan.+Feb.+Dec.	90	6 hrs	6 hrs	20	5
March+November	60	6 hrs	6 hrs	25	10
April+October	60	6 hrs	6 hrs	30	15
May+September	60	6 hrs	6 hrs	35	20
June+July+August	90	6 hrs	6 hrs	40	25

+10C at max temperature due to solar loading

SnAgCu Life Model

- Modified Engelmaier
  - Semi-empirical analytical approach
  - Energy based fatigue
- Determine the strain range ($\Delta\gamma$)

$$\Delta\gamma = C\frac{L_D}{h_s}\Delta\alpha\Delta T$$

- C is a correction factor that is a function of dwell time and temperature, L_D is diagonal distance, α is CTE, ΔT is temperature cycle, h is solder joint height

SnAgCu Life Model (cont.)

- Determine the shear force applied to the solder joint

$$(\alpha_2 - \alpha_1) \cdot \Delta T \cdot L = F \cdot \left(\frac{L}{E_1 A_1} + \frac{L}{E_2 A_2} + \frac{h_s}{A_s G_s} + \frac{h_c}{A_c G_c} + \left(\frac{2 - \nu}{9 \cdot G_b a} \right) \right)$$

  - F is shear force, L is length, E is elastic modulus, A is the area, h is thickness, G is shear modulus, and a is edge length of bond pad
  - Subscripts: 1 is component, 2 is board, s is solder joint, c is bond pad, and b is board
- Takes into consideration foundation stiffness and both shear and axial loads

SnAgCu Life Model (cont.)

- Determine the strain energy dissipated by the solder joint

$$\Delta W = 0.5 \cdot \Delta\gamma \cdot \frac{F}{A_s}$$

- Calculate cycles-to-failure (N_{50}), using energy based fatigue models for SAC developed by Syed – Amkor

$$N_f = \left(0.0019 \cdot \Delta W\right)^{-1}$$

Validation – Chip Resistors

10000
1000
100
100
1000
10000

Cycles to Failure (Predicted)

Cycles to Failure (Experimental)

Thermal Cycle Test

- Total damage in Phoenix environment over 10 years — 0.02604
- Total damage in one cycle of -40C to 85C test environment — 0.00012
- Total cycles at -40C to 85C to replicate 10 yrs in Phoenix — 222 cycles

At 1 cycle/hour, approximately 1 day of test equals 1 year in the field

Conclusion

- Planning and initiating reliability test plans for RoHS compliant product requires an understanding of the risks and behavior associated with Pb-free
  - Capture the ‘easier’ defects before actual test
  - Identify the test based on the field environment
  - Develop test parameters and duration using knowledge of material behavior and derivation of acceleration factors