Lead Free Reliability

A brief summary of Quality and Reliability issues associated with the lead free transition

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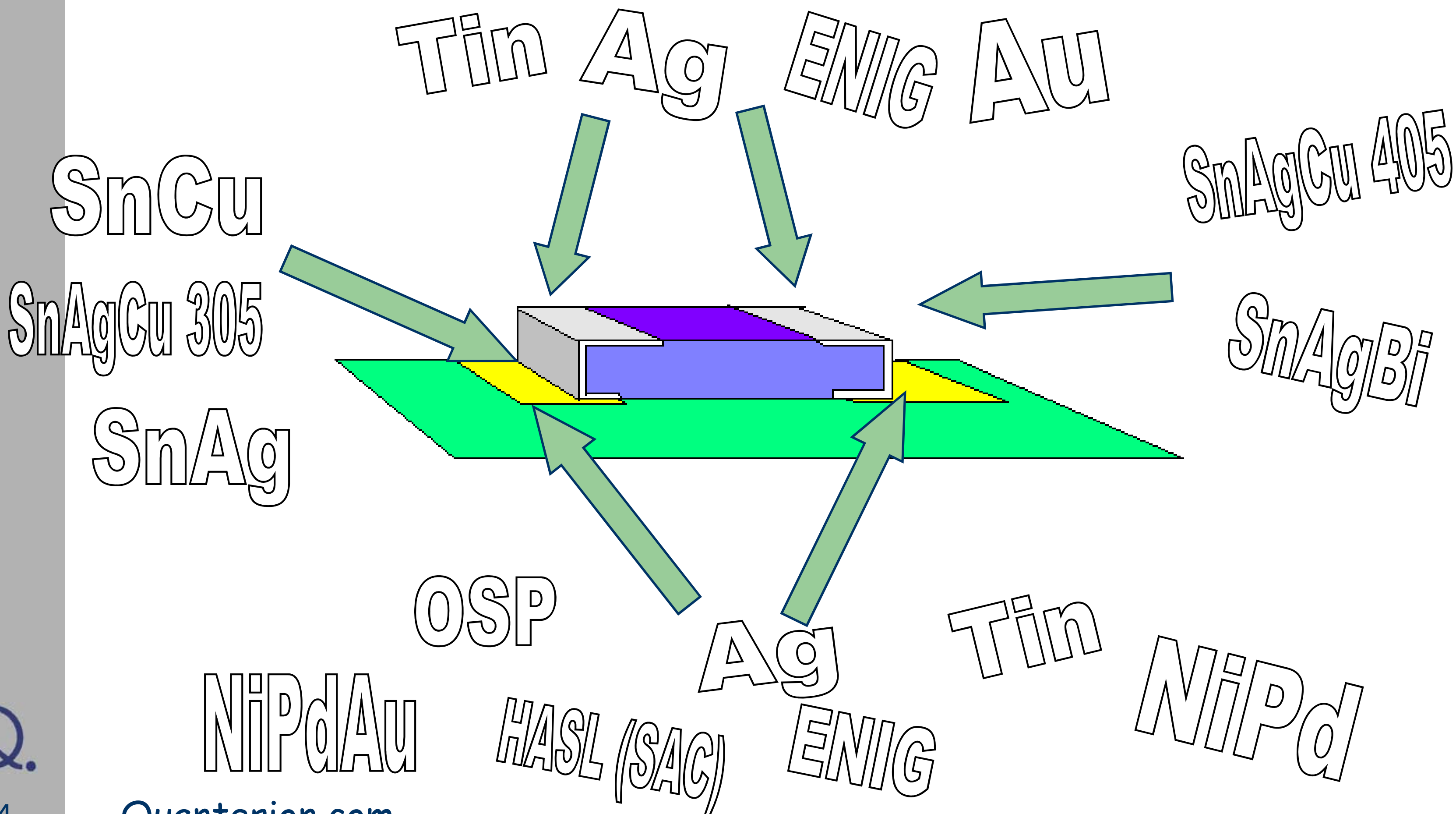
Going from Tin-Lead

- Decades of experience
- Similar plating and soldering materials
- Relatively low melting temperature (~183C)
- Understood Processes
- Established Quality criteria
- Known failure mechanisms
- Tabulated Reliability Data
- Existing Time to failure models

Transitioning to Lead-Free

- No one metallurgy for all applications
- Mixed plating and Solder chemistry
- Little tabulated data
- Typically higher melting points (217C+)
- New material behaviors resulting in new quality characteristics
- New material and process related issues
- Mixed messages in reliability tests

What is Lead Free?



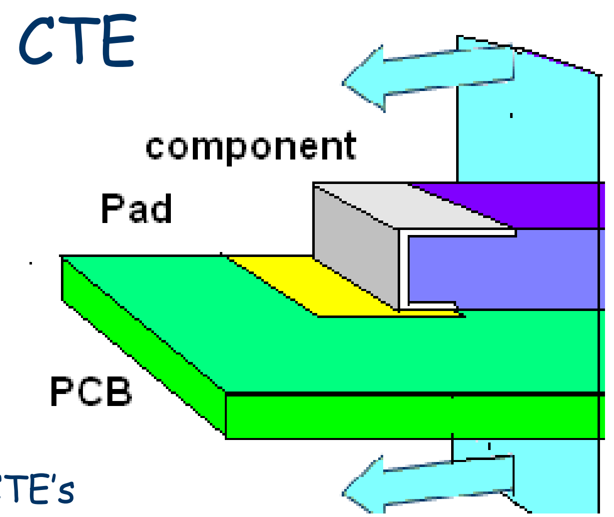
Traditional Solder Reliability

- Primarily focuses on two damage mechanism for solder joints:
  - Dislocation Failures- The crystalline movement of grain boundaries
    - Driven by mechanical and thermal shock
    - Brittle fractures
  - Grain Boundary Sliding – The deformation of grain boundaries
    - Grain coarsening from applied thermal or mechanical loads
    - Grains move relative to one another and relocate- creep
    - Contaminants are forced into the grain boundaries
    - Micro cracks form at grain boundaries and grow

- For SnPb solders the primary failure mechanism used in life prediction is creep

Traditional Solder Reliability

- Most life testing based on cyclic fatigue models
- CTE mismatches drive the component and the PCB apart applying a shear stress on the solder joint.
- The stress will result in strain on solder, leading to plastic deformation then creep, until failure

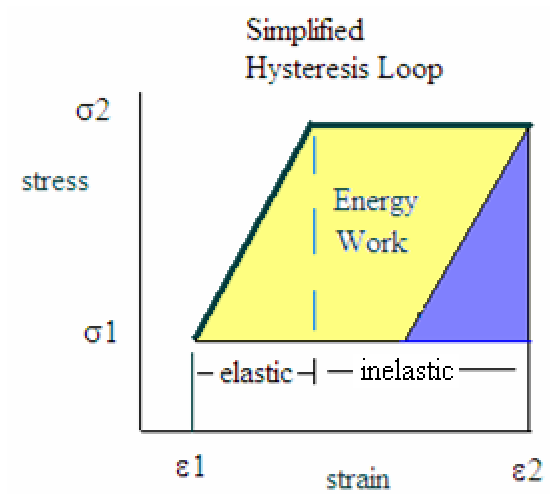


Example CTE's

Component:	6-21 ppm/C
PCB	x,y, 6-21 ppm/C, z 75/360 ppm/C
Solder	~24 ppm/C
Pad/Leads:	4.5-15 ppm/C

Traditional Solder Reliability

- The cyclic load creates accumulated energy in the solder joint –represented by the area within the hysteresis loop
- Most cyclic fatigue models are generally empirical power law relationships between strain range or strain energy density and the cycles to failure point
- Acceleration models then relate test conditions to usage conditions.



total strain $\varepsilon = \varepsilon_{el} + \varepsilon_{pl} + \varepsilon_{cr}$

Generally predict

within 2x or 3x

Traditional Solder Reliability

- Models vary:
  - In their complexity for calculating the accumulated work
  - In the complexity of tools required (FEA, 2D/3D models)
  - In their inclusion or exclusion of different strain regions
  - In the choice of material property relationships

- Because SnPb solder is used above its homologous temperature its material properties are temperature and strain rate dependent (Homologous temperature is half of the melting temperature expressed in Absolute Temperature: For example SbPb solder melts at 183C or 456K. Half of this is 228K or -45C)

- Other factors covered by the damage mechanisms
  - IMC growth
  - Diffusion voiding

Lead Free Solder

- How applicable is this to lead-free solder?
  - Models for lead free solder are less than 2 years old
  - Existing models have been used with mixed success
- What's the hang up?
  - New damage mechanisms
  - Much slower creep rates
  - Lack of data to test models against
  - Evolving Solder formulations and industry trends
    - Patented solder formulations
    - Shift toward lower silver content solders

Lead Free Solders

- What do we know?
  - Creep rates are slower for SAC alloys
  - leads to Mixed temperature cycling results
- In additional to grain boundary movement and grain coarsening
  - IMC layer growth –Shear strength may decrease with the increase in IMC layer thickness
  - Diffusion Voiding - Cu diffuses through the IMC layers, leaving micro voids-Most prevalent with long term exposures ~100C
- Damage mechanism for mixture of materials is much more complex and less understood

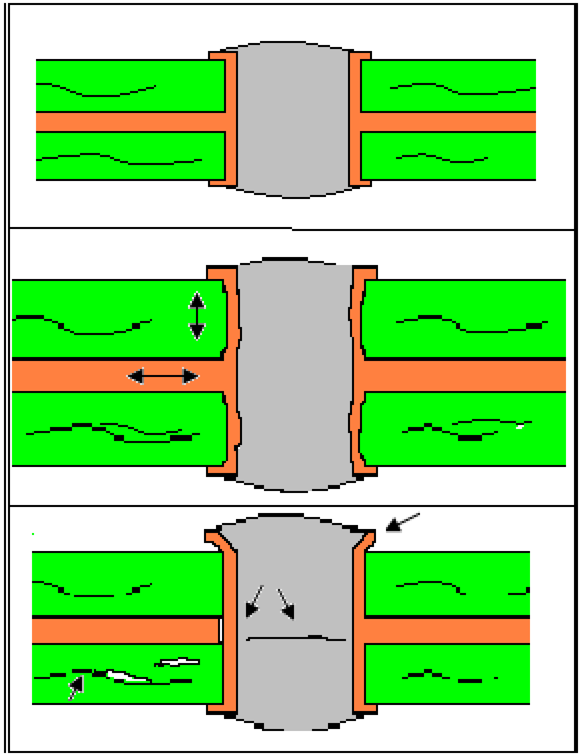
More Lead Free Solder Issues:

- General Concerns with Lead free solders
  - Bismuth sometimes added to reduce reflow temperatures
    - Bismuth containing solders appear to weaken sharply in the presence of lead contamination
  - Grainier Structures and poorer wetting compared to SnPb
  - High content tin solders may have a corrosive effect on the Steel in Wave solder equipment, Solder pots and on thin pads or joints.
  - Shrinkage tears are not uncommon, but generally not considered a reliability issue

Printed Circuit board (PCB)

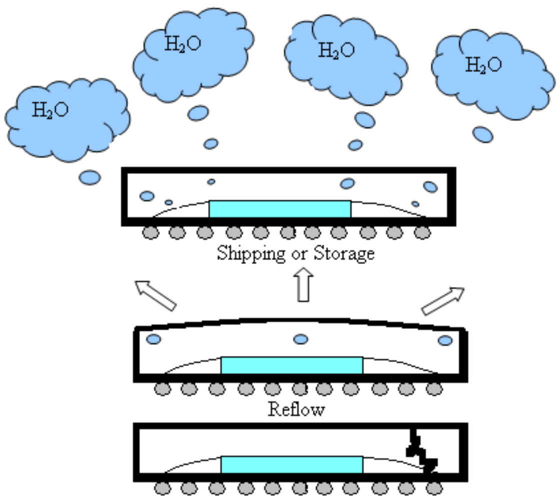
- Higher soldering temperatures result in higher levels of z-axis expansion impacting Vias and Plated through holes (PTH)
- Stiffer properties of lead free solders can lead to pad lifting and
- Decomposition, or breaking of polymeric bonds, happens during high-temperature soldering. Potentially leading to moisture inclusions and even reduced Tg
- PCB warping impacting adhesives, markings, components

- IPC-9701A: Soldering Temperature Impact Index (STII): proposed metric for the minimum peak temperature a laminate could withstand

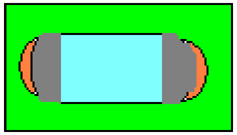


Component Issues

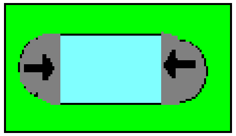
- Component warpage
- Internal component reflow
- Multiple Reflow and Rework sensitivity
- Handling and storage requirements
  - Shelf Life issues
  - Corrosion and oxidation issues



- Moisture Sensitivity Level- Popcorning
  - MSL testing required on IC chips J-STD-020D
  - Recommended on non-IC enclosed components



- Compression during reflow can lead to cracked components



Lead Free Finishes

- Leading Lead-free plating finishes:
  - Tin (Sn, ImSn)
    - Immersion and Electrodeposited
    - Matte and Bright variety
  - Silver (Ag, ImAg)
    - Immersion predominantly
  - Electroless Nickel Immersion Gold (ENIG)
    - Direct Immersion Gold (DIG)
  - Organic Solder Preservative (OSP)
    - Organic layer that burns off during reflow
    - Not as common in Lead Free applications due to high temperatures
  - Palladium/Platinum/Nickel Palladium
    - Expensive and typically used with a Nickel barrier and gold overcoat

Tin

- Whiskers: (Zinc whiskers too)
  - Result from internal stresses on the Tin
  - Bright Tin more susceptible than Matte tin
  - Easily detached potentially causing a short in an unrelated area
  - Countermeasures:
    - Avoidance, Barrier plating, Annealing
- Tin Pests
  - A transformation of pure white tin to gray tin under extreme cold conditions, 13C and below.
  - Material strength and integrity is lost.
  - Is rarely an issue due to impurities
- Oxidation and IMC growth
  - lead to very short shelf life
- Banned in most high reliability applications

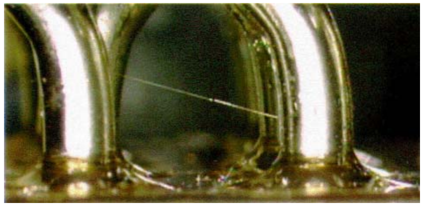
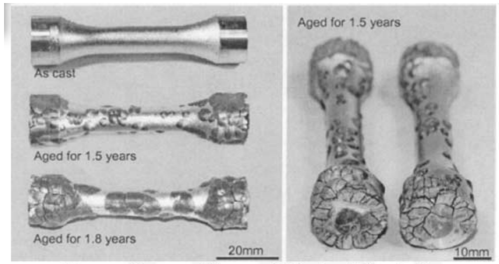


Image from NASA http://nepp.nasa.gov/WHISKER



Transformation of Beta-Tin into Alpha-Tin in Sn-0.5Cu at T <10°C

Karlya, C. Gagg, and W.J. Plumbridge, "Tin pest in lead free solders", Soldering and Surface Technology, 13/1 [2000] 39-40

Image from Gagg & Plumbridge, "Tin Pest in Lead Free Solder" Soldering and Surface Technology 13/1 (2000) 39-40

Silver

- Silver Migration/Dendrite Growth
  - Process of Silver Ionization, migration and re-deposition in the presence of moisture and an electric potential
  - Frequently incorrectly grouped with tin-whisker formation
- Silver Oxidation –Tarnish Manufacturability and Appearance
  - Sulfur and Chlorine reactions (Latex Gloves, Rubber bands, water, white paper)
  - Thin layer is easily damaged leading to oxidation of Copper layer
- Micro voids on the printed circuit board side of the solder joint :
  - More common on thicker layers & Solder Mask Defined (SMD) pads
  - Unknown cause, may be corrosion mechanism
- Not recommended in many high reliability applications

ENIG

- Black Pad-
  - The high phosphor is formed as a result of Nickel depletion during Ni-Sn Intermetallic formation
  - Gold attaches itself to a brittle Ni-P IMC
  - As Gold dissolves in reflow, weak layer is left
- Gold Embrittlement
  - Gold reacts with the Sn to form IMC's
  - Been shown to occur when gold is >3-5 wt% in solder joint
- Tin-Nickel strength
  - Tin-Nickel bonds are more brittle than SnCu joints
  - May be an issue where Thermal/Mechanical shocks are present

Shift towards Lower Silver content

Industry has shifted to the use of lower silver content SAC alloys

SAC405/396/387- SAC305 – SAC205– SAC105

Positives:

- Fewer Sn-Silver Platelets
- More ductility-Improved drop test performance
- Less stiff so less solder pad lifting & less cracking of components and tombstoning of resistors

Negatives:

- Faster creep rates resulting in worse TC test performance
- Higher Concentrations of Tin (Copper Dissolution)
- Less existing data- resetting the modeling efforts

Summary

- The transition to lead-free is not simply drop in place
- Considerations must include:
  - Storage and handling of materials w/ attention to shelf life
  - Verification of laminate and component readiness
  - Updated quality inspection and test plans
  - Assessment of finishes for long term environmental impacts
- While life models are still being developed, current industry standards can provide benchmarking and guidance

Industry Guidelines

Additional Documents:

JEDEC/IPC JP002- Current Tin Whiskers Theory and Mitigation Practices Guideline http://www.jedec.org/DOWNLOAD/search/JP002.pdf

iNEMI, High-Reliability Task Force "Position Statement on RoHS5 & RoHS6 Subassembly Modules" http://thor.inemi.org/webdownload/projects/ese/High-Reliability_RoHS/High_Rel_position_061206.pdf

JESD201, "Environmental Acceptance Requirements for Tin Whisker Susceptibility of Tin and Tin Alloy Surface Finishes" http://www.jedec.org/DOWNLOAD/search/JESD201.pdf

iNEMI's "Recommendations on Lead-Free Finishes for Components Used in High-Reliability Products" (v4, updated 12/1/2006)

(http://thor.inemi.org/webdownload/projects/ese/tin_whiskers/Pb-free_Finishes_v4.pdf)

iNEMI Tin Whisker Acceptance Test Requirements (iNEMI Tin Whisker User Group, July 28, 2004)

(http://thor.inemi.org/webdownload/projects/ese/tin_whiskers/Tin_Whisker_Accept_paper.pdf

iNEMI High-Reliability RoHS Task Force: "Recommendations to Electronics Industry Component Supply Base", August 19, 2005, http://thor.inemi.org/webdownload/projects/ese/High-Rel_RoHS_recommends.pdf

Industry Guidelines

Additional Documents:

IPC-J-STD-001D: Requirements for Soldered Electrical & Electronic Assemblies

IPC-J-STD-002C: Solderability Tests for Component Leads, Terminations, Lugs, Terminals and Wires

IPC-J-STD-003B: Solderability Tests for Printed Boards

IPC-HDBK-005: Guide to Solder Paste Assessment

IPC-J-STD-005: Requirements for Soldering Pastes

IPC/JEDEC J-STD-020C: IPC/JEDEC Moisture/Reflow Sensitivity Classification for Nonhermetic Solid State Surface Mount Device

IPC-A-610D: Acceptability of Electronic Assemblies

9701A: Performance Test Methods and Qualification Requirements for Surface Mount Solder Attachments

Industry Guidelines

Additional Documents:

GEIA-STD-0005-1, Performance Standard for Aerospace and High Performance Electronic Systems Containing Lead-free Solder

GEIA-STD-0005-2, Standard for Mitigating the Effects of Tin in Aerospace and High Performance Electronic Systems

GEIA-HB-0005-1, Program Management / Systems Engineering Guidelines For Managing The Transition To Lead-Free Electronics

GEIA-HB-0005-2, Technical Guidelines for Aerospace and High Performance Electronic Systems Containing Leadfree Solder

GEIA-STD-0005-3 Lead-Free testing standards