## 2006 DMSMS Conference Pb-free Solder Technical Issues (Not Including Tin Whiskers)

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# What's the problem; it is just solder?

- Who would consider changing the alloy of an airplane wing or a turbine blade without a lot of materials testing and analysis?
- It is no longer "just solder"
- Surface-mount technology changed the game:
  - Solder provides structural connection
  - Solder behaves like a viscoplastic material
- During the SMT insertion into high performance applications in the '80s, much was learned that can be applied to Pb-free
- Pb-free solder is different from Sn-Pb



Cross-polarized inspection reveals SnAgCu BGA ball with ~10 grains

L.P. Lehman and S.N. Athanvale et. al, "Growth of Sn and Intermetallic Compounds in Sn-Ag-Cu Solder," J. Electronic Materials, Vol. 33, No. 12 (2004) pp 1429-1439.

# Solder Microstructure

- The mechanical response of Sn-Pb Solder is dominated by the micron-scale inclusions of the relatively soft Pb
- SnAgCu structure is more complex mechanical response is different



Conical PbSn Eutectic



Reflow at 250 °C; Cooling Rate 0.1 °C Pb-free SnAgCu near eutectic

E. Cotts, Binghamton University, at the Universal Instruments Consortium Meeting, June 2006

# Crack development variation observed



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cycles -45 to +125 °C

# Alloy additions impact grain structure

• A little bit of copper significantly changes the grain structure





#### ~Sn-3.5Ag

~Sn-3.5Ag-0.6Cu

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# Failures in electronics hardware

#### **Environmental conditions**

- Temperature
- Vibration
- Acceleration
- Moisture
- Pressure
- Ionic contamination
- Radiation

#### **Operational conditions**

- Power
- Current
- Voltage

#### People

• Training/skill level



#### Failure modes

- Parameter drift
- Short
- Open

#### Types of failure

- Overstress
- Wearout

Failure mechanisms

Failure mechanism interactions

- Complimentary
- Competitive

# What makes this challenging?

#### **Pb-free solder:**

- Multiple Pb-free alloys
- Higher Sn content
- Higher processing temperature
- Higher strength/more creep-resistant
- Different fatigue characteristics
- Solder alloy compatibility
- New solder fluxes
- Greater copper dissolution
- Less wetting/different appearance

### Intermetallic

- Increased Sn content yields thicker
- (i.e., weaker) IMCs
- Voiding of Cu from IMC growth
- Rapid loading is main concern
- •Sn-Cu-Ni IMCs nuances

 Component

 Printed Wiring Board

 Pb-free solder thermo-mechanical behavior is different from Sn-Pb

# What else?

#### **Printed Wiring Board and Component**

- New materials that can withstand higher soldering temperatures
- CAF/SIR Service risk from high soldering temperatures and new fluxes
- Delamination/decomposition/moisture sensitivity



#### Plated through hole

- Higher soldering temperature increases stress
- Pad susceptible to dissolution during "Wave Solder"
- New aspect ratio design rules?

# Pb-free transition is driving changes to a majority of the material system

# In addition, the military has:

- Qualification requirements
  - Both "as built" and when mixed with Sn-Pb
  - Rework/repair: single(multiple) alloy(s) and process(es)
- 20 yr. service, configuration management, solderable shelf life, and solder compatibility issues:
  - SAC, SnCu, Sn-Pb, low melting point alloys, bismuth bearing alloys
- Long-term harsh-service reliability considerations
  - Solder reliability is dependent on the parts, the PWB, the metallurgy and the environment
  - Reliability requirements differ significantly across applications
  - Thermal cycling, vibration/shock, humidity, and other environments



# Solder interconnect fatigue

•Modeling: Fatigue life can be related to any parameter directly proportional to the damage in the solder failure site

- Some models use cyclic strain range
- Some models use cyclic work dissipation due to cyclic hysteresis



Military equipment experiences a broad range of cyclic loads

Real missions have combined thermal/vibe/shock

Need to validate combined models

# Vibration/shock loading

- Vibration/shock performance was a tough topic with Sn-Pb solder,
  - Pb-free didn't make things easier
- Not much vibration/shock data available
  - Cell phone drop-shock testing driving commercial industry
  - Data from JCAA/JGPP testing
- What heritage Sn-Pb tests need to be different for Pb-free?
  - Intermetallics grow thicker
  - Does there need to be thermal preconditioning prior to vibration?
  - Should vibration/shock testing be performed over temperature?
  - CALCE project under way to address some of these issues



MIL-STD-810 tests may need revision for Pb-free

# JCAA/JGPP tests

- Full military environmental testing of many part types, two Pb-free solders (SAC and SAC with Bismuth) and various rework combinations.
  - http://www.jgpp.com/projects/lead\_free\_soldering/presentations.html
- Recently completed -55 to +125 °C thermal cycling test
  - 4743 thermal cycles completed during the 12 month test duration
  - CLCC 20: SACB > SnPb > SAC
- In-process thermal cycle testing -20°/+80°C
  - As of April 2006, 10300 thermal cycles completed. Need ~3000 more.
  - CLCC 20: SAC = SACB > SnPb
- Combined environment (thermal cycling + vibration)
  - CLCC 20: SACB > SnPb > SAC
- Vibration (room temperature)
  - CLCC 20: SnPb > SACB > SAC

Need to take test results as a whole Performance depends upon environment

Too Bad SACB is

incompatible with

Sn-Pb

# Mixing of alloys – today's problem

It would be better not to, but if you have to, what can be done to help mixing without getting hotter?



P. Snugovsky (2006)





# **Undesirable:**

A moderate volume of Sn-Pb results in partial dissolution of Pbfree Ball

#### **Better:**

More Sn-Pb results in a fairly uniform composition and phase distribution

Increasing deposited paste volume improves mixing. Process details affect both initial manufacturing and repair

# Technical gap analysis

- Topics needing further study for high performance applications
- Combined environments:
  - High temperature, low temperature
  - Vibration, shock
- Thermal cycling dwell and mean temperature variation (CALCE Project under way)
- Humidity/SIR/CAF Testing to failure (CALCE Project under way)
- Solder processes/flux assessment
- Workmanship guidance
- Printed wiring boards dissolution, PTH, laminate integrity
- Components moisture/temperature sensitivity
- Mixed alloys (Sn-Pb/Pb-free) including double sided reflow assemblies.
- Repair of large complex devices



(JCAA/JG-PP Test Board)

A Considerable amount of data is still needed

# Summary

- Much Good Data Available
  - Need to be sure assembly stiffness and test details are relevant to application
  - Check that adequate thermal cycling dwell time is used to allow proper Pb-free solder alloy creep (dwell time can be modeled, but should be longer than Sn-Pb)
- Considerable data still needed as indicated in gap analysis
- Pb-free alloy(s) are not a drop in replacement for Sn-Pb for all applications
  - Need to examine the details
  - The reliability of solder is a function of the material and the application where it is used.
- Service Center Logistics will be important
  - Configuration management
  - Components/PWB: Finish, temperature rating, moisture sensitivity, shelf life
  - Repair process: temperature profile, solder type, flux



E. Cotts, Universal Instruments Consortium Meeting, June 2006