NEMI Pb-Free Solder Projects: Progress and Results

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Gaithersburg MD

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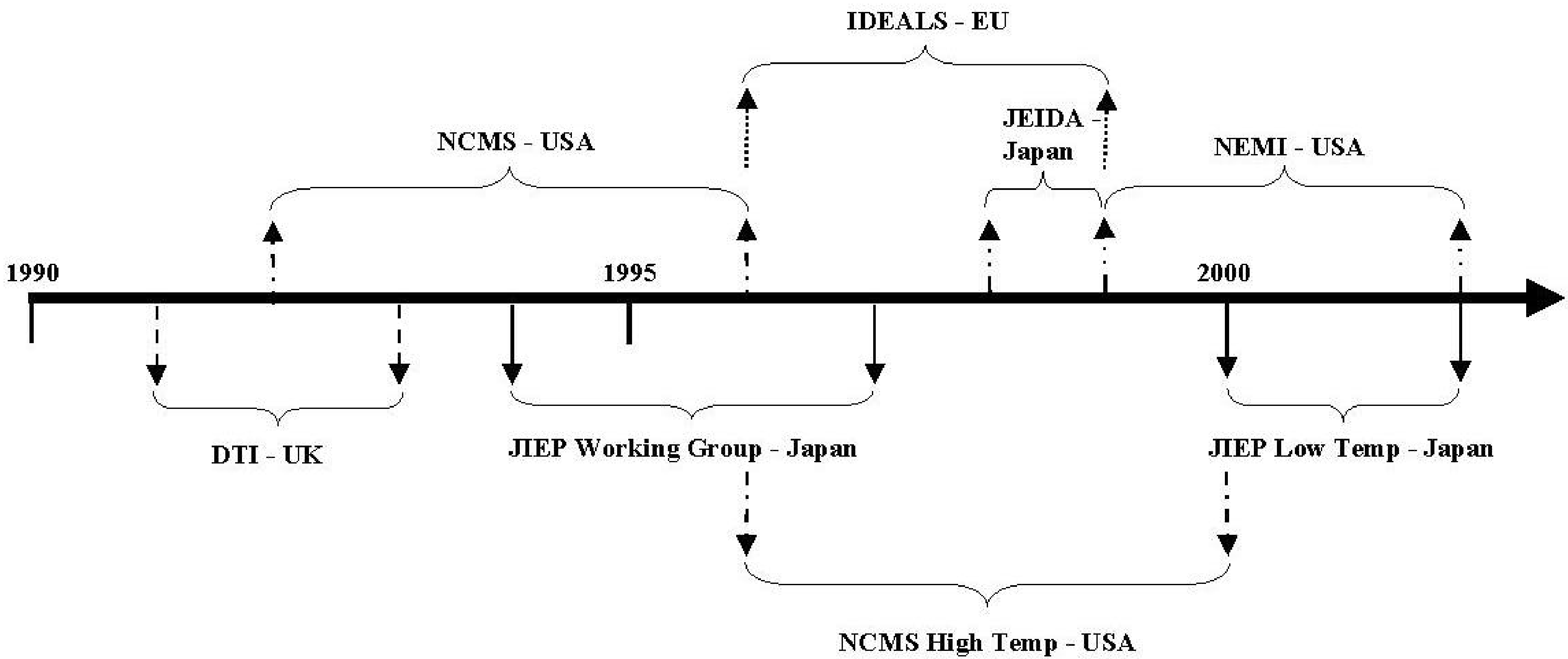
DoD Pb-Free Solder Implementation Meeting

Washington DC

Outline

- History of Pb-Free Projects Worldwide and NEMI Project Structure
- Analysis of Sn-Ag-Cu Alloy Results
  - Issues in processing, particularly in the transition period
  - Reliability testing results
- Tin whiskers: is any tin surface finish worth the risk?


IDEALS - EU
JEIDA - Japan
NCMS - USA
NEMI - USA
1990
1995
2000
DTI - UK
JIEP Working Group - Japan
JIEP Low Temp - Japan
NCMS High Temp - USA

NCMS Lead-Free Solder Consortium

- AT&T/ Lucent Technologies
- Ford Motor Company (Ford)
- General Motors (GM) —Hughes Aircraft
- General Motors—Delco Electronics
- Hamilton Standard, Division of United Technologies
- National Institute of Standards and Technology (NIST)
- Electronics Manufacturing Productivity Facility (EMPF)
- Rensselaer Polytechnic Institute (RPI)
- Rockwell International Corporation
- Sandia National Laboratories
- Texas Instruments Incorporated

1993-1997

NCMS High Temperature Fatigue Resistant Solder Consortium (1998-2001)

OEMs

Delphi Delco Electronics Systems

Ford Motor Company

Rockwell International

AlliedSignal

Component manufacturer

Amkor

Solder suppliers

Heraeus Cermalloy

Indium Corporation

Johnson Manufacturing

Federal Laboratories

Ames Laboratory

NIST

NEMI Task Group Structure: 1999-2002

NEMI Pb-free Assembly Task Force
Edwin Bradley, *Motorola*
Rick Charbonneau, *StorageTek*

Solder Alloy
Carol Handwerker, *NIST*

Reliability
John Sohn, NEMI

Components
Rich Parker, *Delphi*

Assembly Process
Jasbir Bath, *Solectron*

Tin Whiskers
Swami Prasad, *ChipPAC*

NEMI Assembly Project Participants

- **<u>OEMs/EMS</u>**
- Agilent
- Alcatel Canada
- Celestica
- Compaq
- Delphi Delco
- IBM
- Intel
- Kodak
- Lucent
- Motorola
- Sanmina-SCI
- Solectron
- StorageTek

- **<u>Solder Suppliers</u>**
- Alpha Metals
- Heraeus
- Indium
- Johnson Mfg.
- Kester

- **<u>Components</u>**
- ChipPac
- Intel
- Motorola
- Texas Instruments
- FCI USA Electronics

<u>Govt. & Other</u>

NIST
SUNY-B/IEEC
ITRI (US)
IPC

<u>Equipment</u>

BTU
DEK
Orbotech
Teradyne
Universal
Vitronics-Soltec

NIST Projects in Solder Science

- Phase Transformations in Pb-Free Solder Systems

  http:// www.metallurgy.nist.gov/solder
- Effect of Pb Contamination on Melting and Solidification Behavior of Sn-Bi Alloys
- Failure Analysis for Reliability Trials in NEMI Pb-Free Task Force
- Fillet Lifting in Pb-Free Solder Alloys
- Properties Database for Pb-Free Solder Alloys

  http://www.metallurgy.nist.gov/solder
- Solderability Test Methods - Sn-Pb and Pb-Free
- Sn Whisker Growth in Sn-based Surface Finishes
- Modeling of Solder Joint Geometries and Forces for SMT, Wafer-Level Underfill, and Photonics

Transition Issues

Lead-free surface finishes

- ✓Organic surface finishes already a problem for Sn/Pb solder
- ✓Higher reflow temperatures with Sn-Ag-Cu is even more of a challenge; second side reflow

Sn-Ag-Cu solders with Sn/Pb balls

- ✓No discernable issues

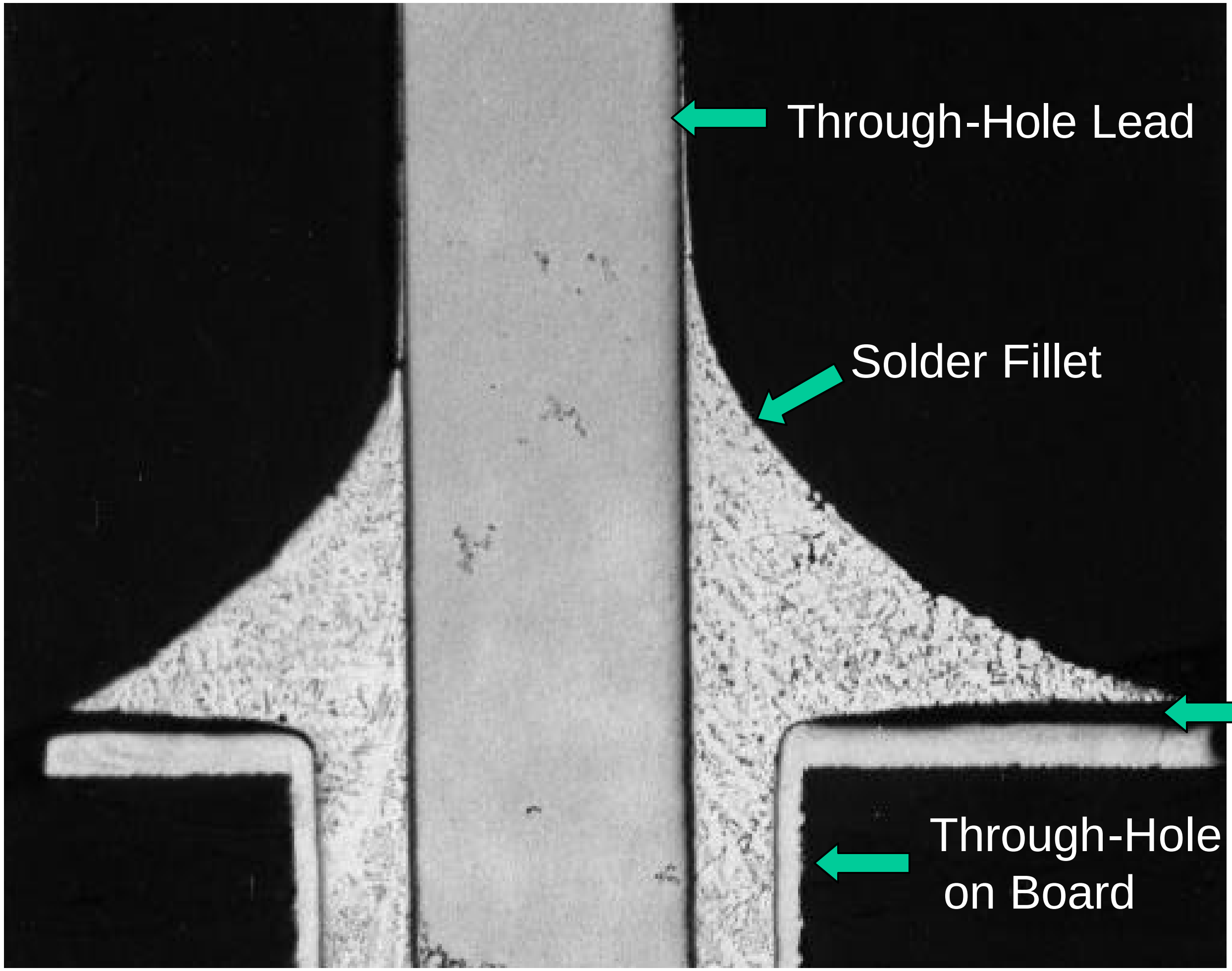
Sn-Ag-Cu balls with Sn/Pb solders

- ✓May be some issues of backward compatibility with respect to reliability for area array joints

Sn-Ag-Cu solders with Sn/Pb surface finishes

- ✓Through-hole fillet lifting

Morphololoy of Fillet Lifting



NCMS Lead-Free Solder Project and collaboration between NIST and Tsung-Yu Pan, Ford

Separation during Cooling

Effect of Pb Additions on Fillet Lifting

Sn-3.5Ag used as base alloy

A4 - Sn- 3.5Ag			F59 (A4 + 2.5Pb)			F60 (A4 + 5Pb)		
Board	Pad	Avg.	Board	Pad	Avg.	Board	Pad	Avg.
Thin	Small	0	Thin	Small	0.7	Thin	Small	0.4
	Large	0		Large	0.9		Large	0.2
Med.	Small	0	Med.	Small	1	Med.	Small	0.6
	Large	0.5		Large	1		Large	0.7
Thick	Small	0	Thick	Small	1	Thick	Small	1
	Large	0.5		Large	1		Large	0.8

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Reliability Test Matrix

Component	Source	Description	Reliability Testing	
			-40 to 125°C	**0 to 100°C**
Type 1 TSOP	AMD	48 Pin TSOP with leads on short sides, SnPb and NiPd finishes	Solectron	
2512 Resistor	Koaspeer	zero ohm chip resistor, SnPb and pure Sn finishes	Sanmina-SCI	
169 CSP	Lucent	0.8mm pitch, 11x11mm, 7.7 x 7.7 mm die, SnAgCu and SnPb balls	Kodak	Lucent
208 CSP (HDPUG)	ChipPac	0.8mm pitch, 15x15mm, 8.1 x 8.1 mm die, SnAgCu and SnPb balls	Kodak (both SnAgCu alloys)	Sanmina-SCI
256 BGA (NCMS)	Amkor	1.27mm pitch, 27x27 mm, 10.0 x 10.0 mm die, SnAgCu and SnPb balls	Celestica	Sanmina-SCI
256 CBGA	Vendor part; IBM ball attach	1.27mm pitch, no die, SnAgCu and SnPb balls		Motorola

SnAgCu balls: Sn4.0Ag0.5Cu - provided by Heraeus

ATC Relative Performance

	-40 to +125			0 to 100		
Component	Relative Performance			Relative Performance		
	SnPb - SnPb	SnPb - LF	LF-LF	SnPb - SnPb	SnPb - LF	LF-LF
AMD 48 TSOP - im Ag bds	0	-	0			
AMD 48 TSOP - NiAu bds	0	+	+			
2512 Resistors - im Ag bds	0	0	0			
2512 Resistors - NiAu bds	0					
169 CSP	0	+	+	0	0	+
208 CSP	0	0	+	0	+	+
208 CSP - JEITA alloy			0			
256 PBGA	0	0	0	0	0	0
256 Ceramic BGA				0	-	+

0 equivalent to SnPb-SnPb benchmark (95% confidence bounds)

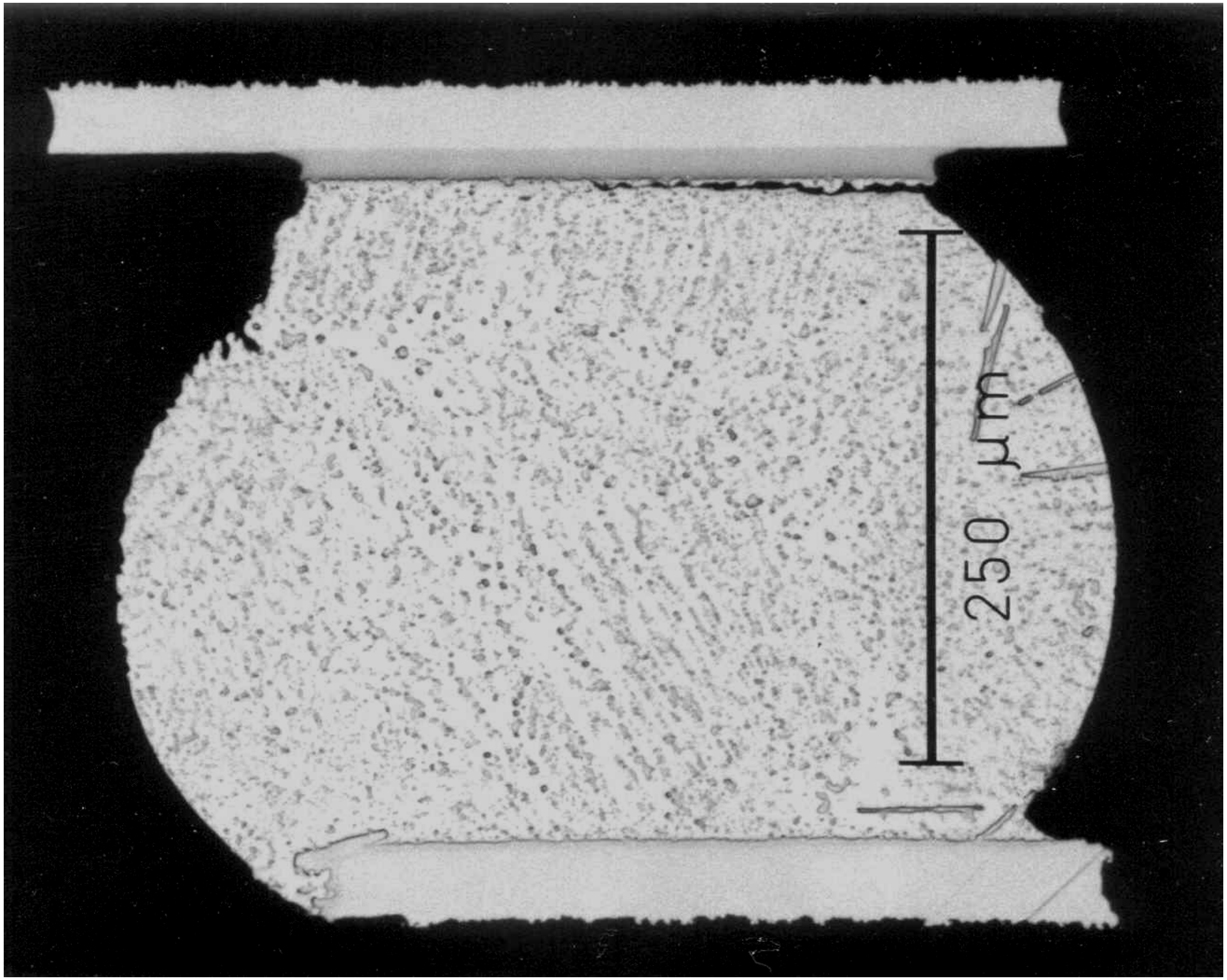
- statistically worse than SnPb-SnPb benchmark

+ statistically better than SnPb-SnPb benchmark

Example of Solder Joint Microstructure: 169CSP, LF-LF, -40 °C to +125 °C

Sn-3.9Ag-0.6Cu

Solder consists of tin dendrites separated by Cu-Sn and Ag-Sn intermetallics



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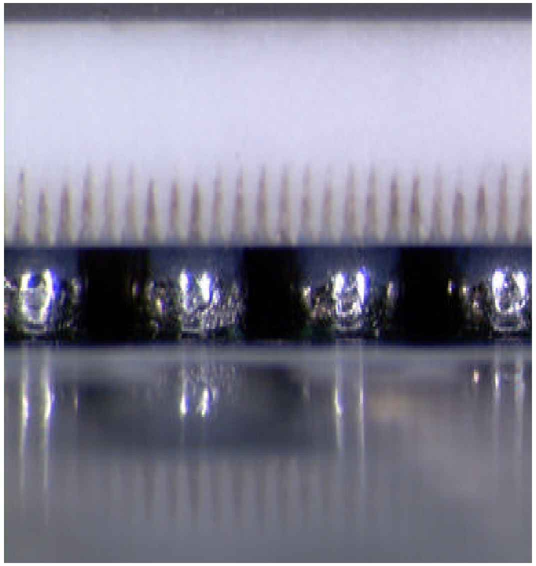
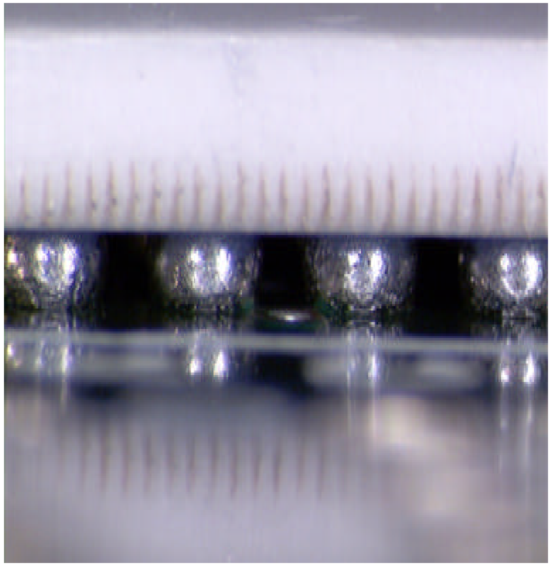
Universal Build Visual Inspection Results: CBGA

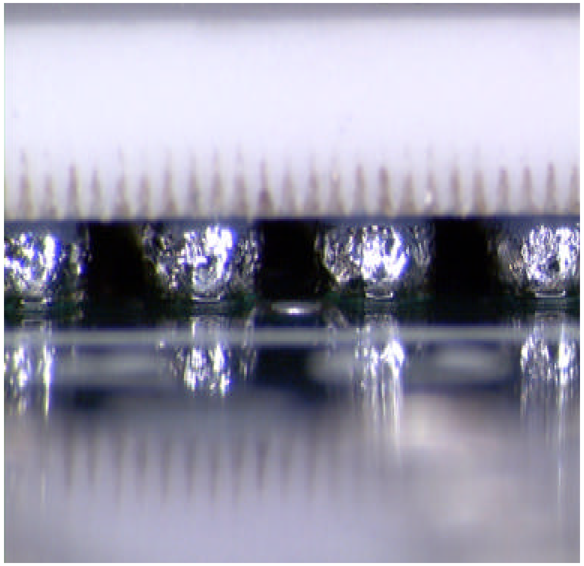
Visual Inspection Criteria must be changed



Tin-lead paste/
tin-lead CBGA
(Shiny joint)



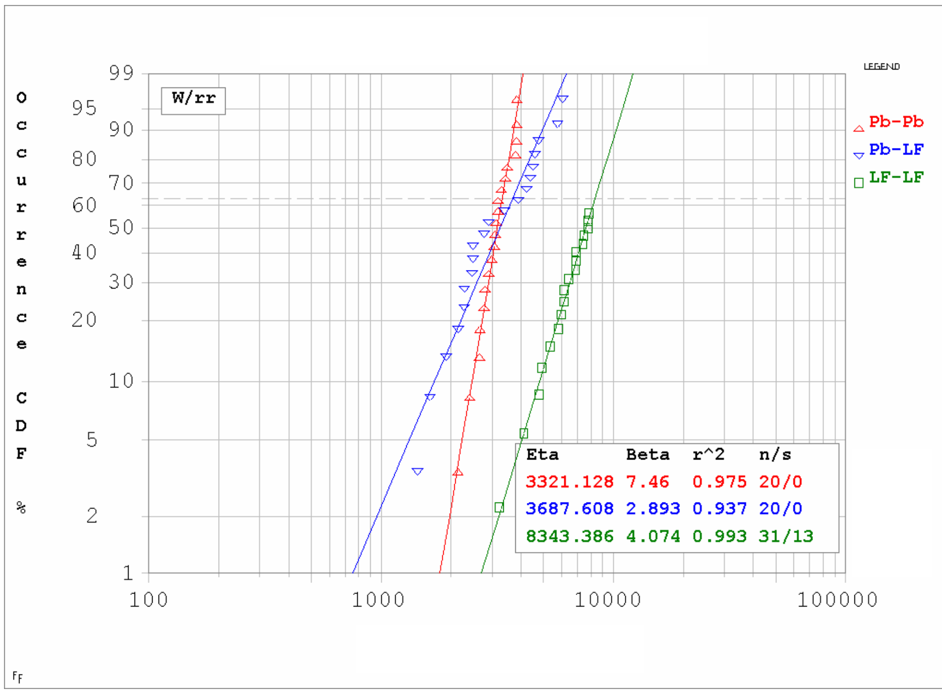
Lead-free paste/
Tin-lead CBGA
(Dull joint)



Lead-free paste/
lead-free CBGA
(Cratered solder joint)

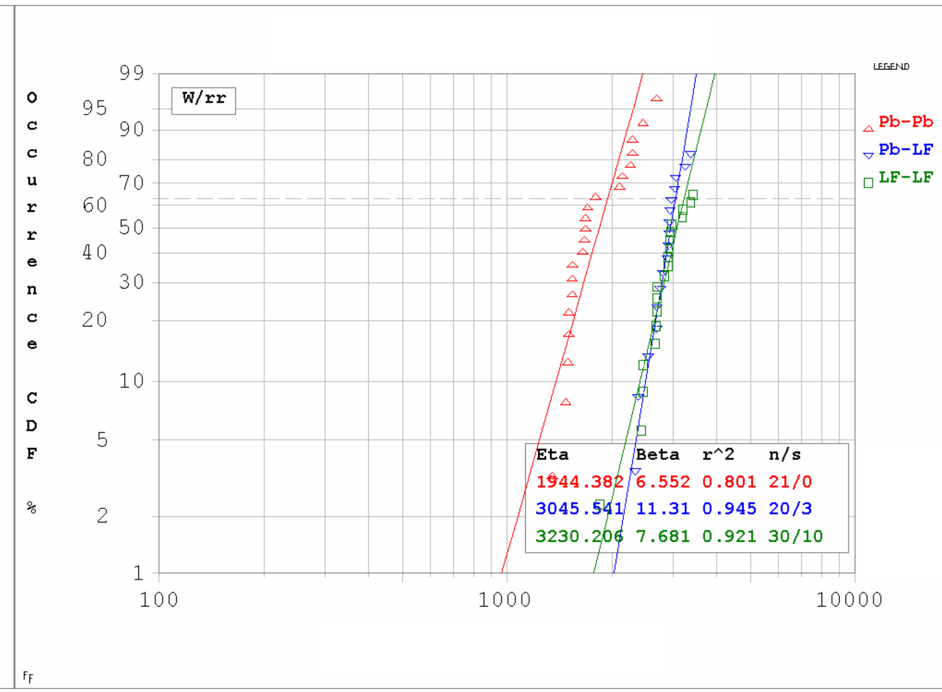
169CSP Lifetime Analyses: What are Acceleration Factors for Sn-Ag-Cu ?

0 °C to 100 °C cycling



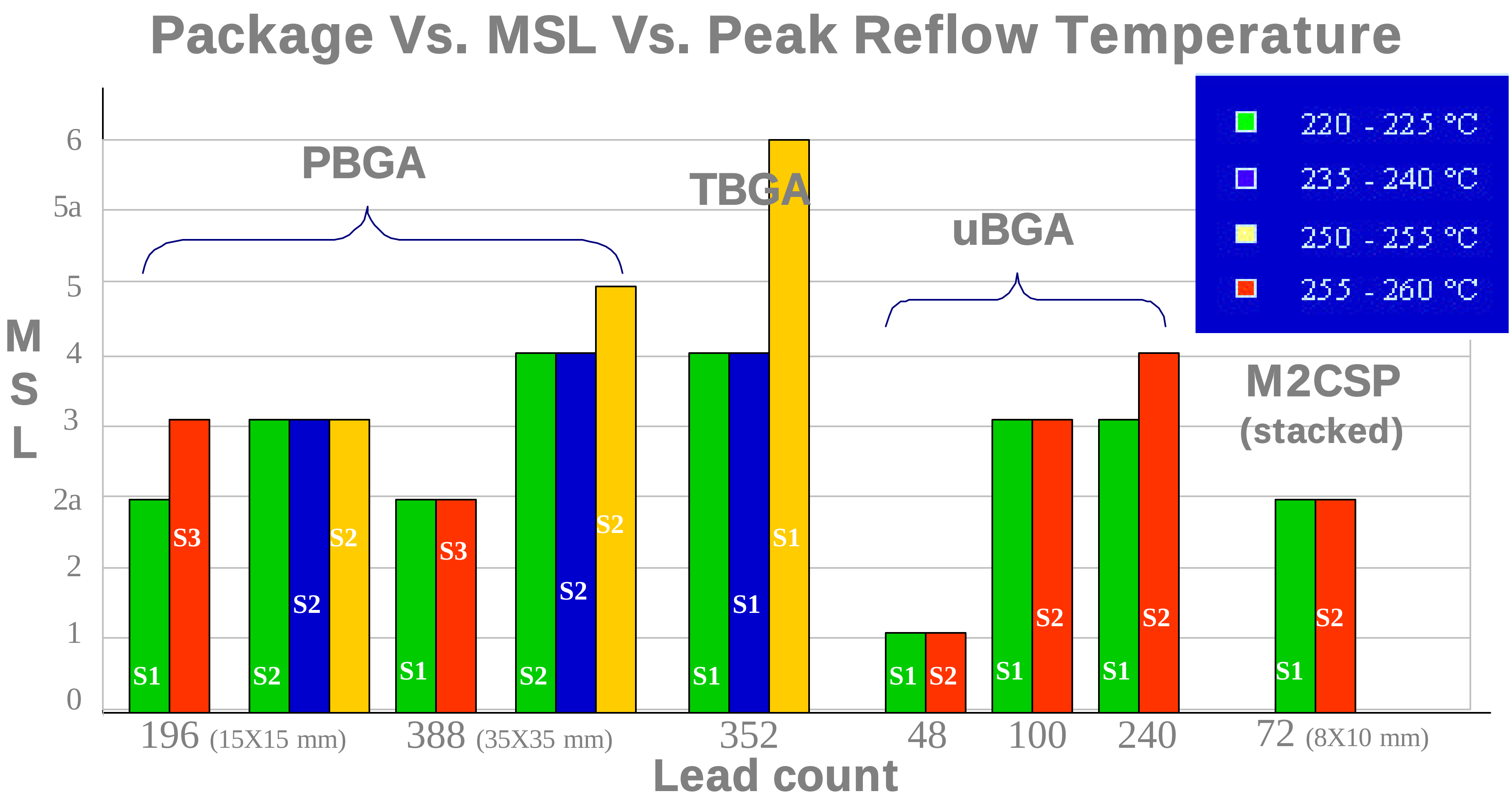
	Pb-Pb	Pb-LF	LF-LF
h **(N63)**	3321	3688	8343
b	7.5	2.9	4.1

-40 °C to +125 °C cycling



	Pb-Pb	Pb-LF	LF-LF
h **(N63)**	1944	3046	3230
b	6.6	11.3	7.7

MSL vs Reflow Temperature: IC Packages



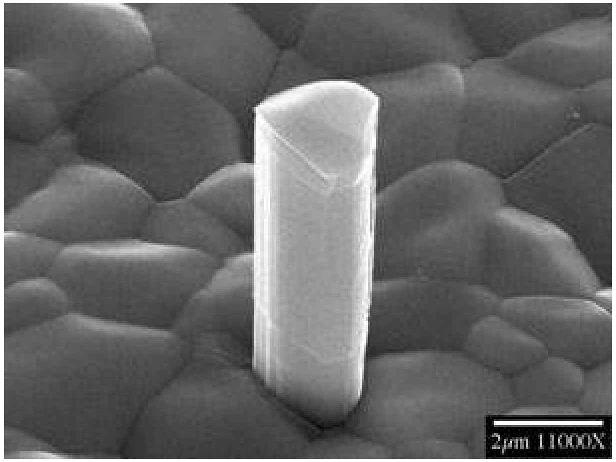
S1, S2, S3, etc. = S1 is existing package structure; S2 is improved package structure; S3 is further improved package structure; S1, S2, S3 may not be the same for each package tested (i.e. new mold compound, assembly equipment, die coat, etc.)

Open Issues

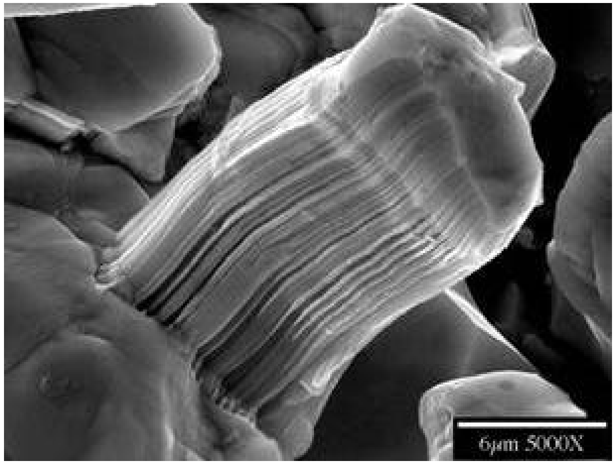
Tin Whisker Formation

- ✓Why? When? How?
- ✓Is there a magic bullet?

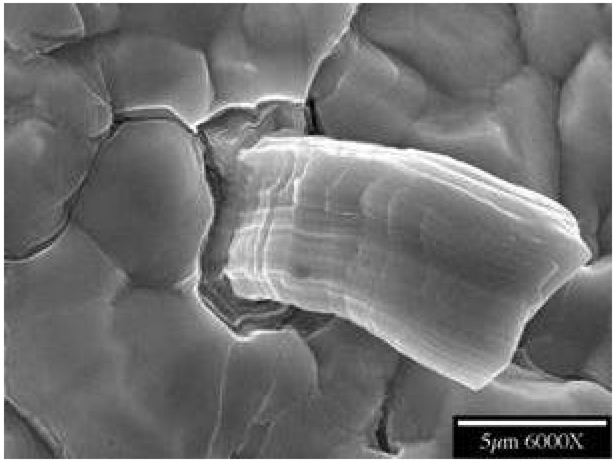
Whisker Examples



Consistent cross-section (column)



Striations



Rings

Surface finish impurities matter

Open Issues

Tin Pest

✓ How much of a problem will there be?

Tin-Pest in Sn-0.5mass%Cu Lead-Free Solder

Yoshiharu Kariya, Naomi Williams, Colin Gagg and William Plumbridge
Materials Engineering Department, The Open Univesity,
Walton Hall, Milton Keynes, MK7 6AA, United Kingdom

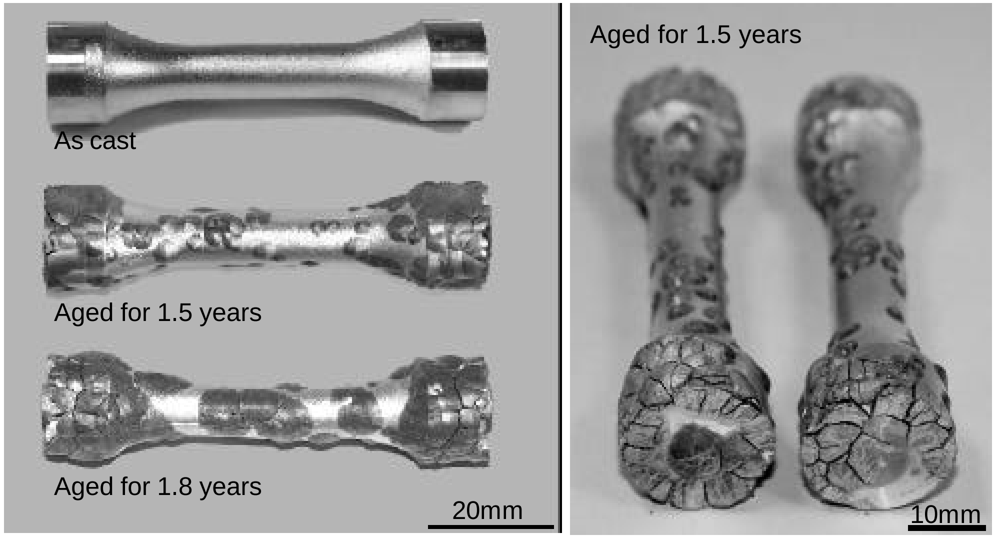
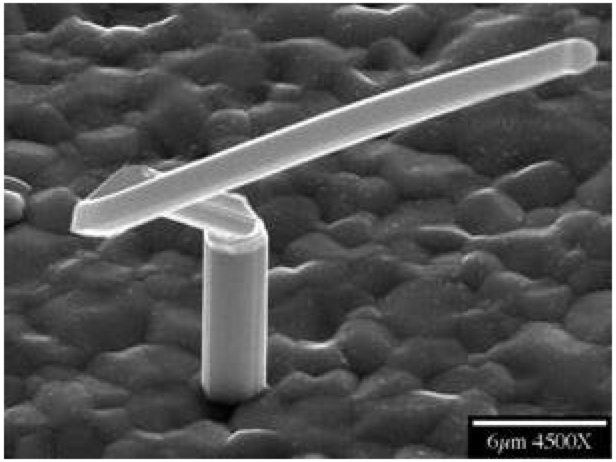
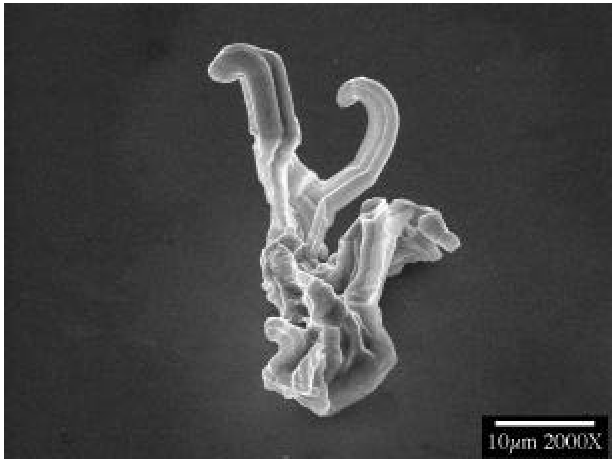


Fig. 2 The transformation of β-tin (white tin) into α-tin (grey tin) occurring in Sn-0.5Cu, aged at 255K for 1.5 and 1.8 years

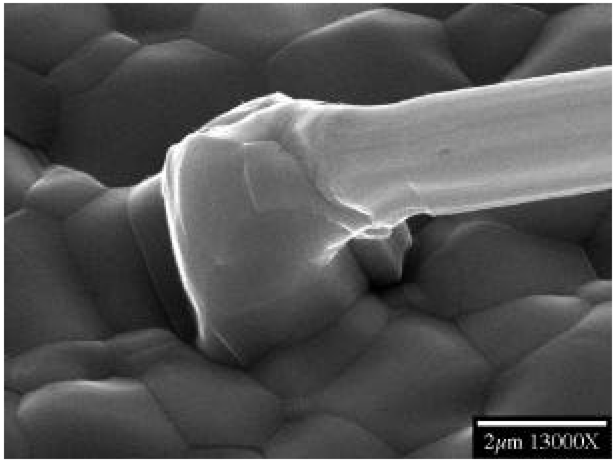
Whisker Examples



Kinked

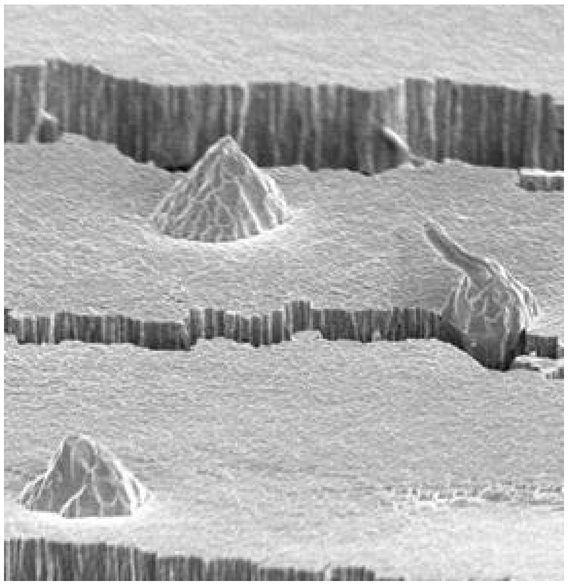


Branched

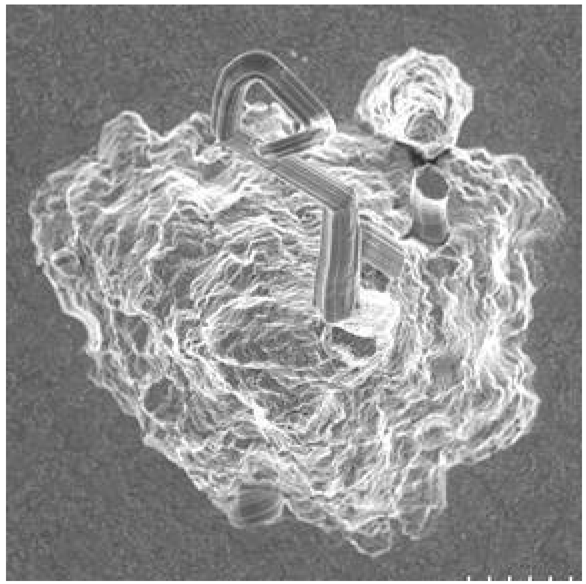


Initiating from Hillock

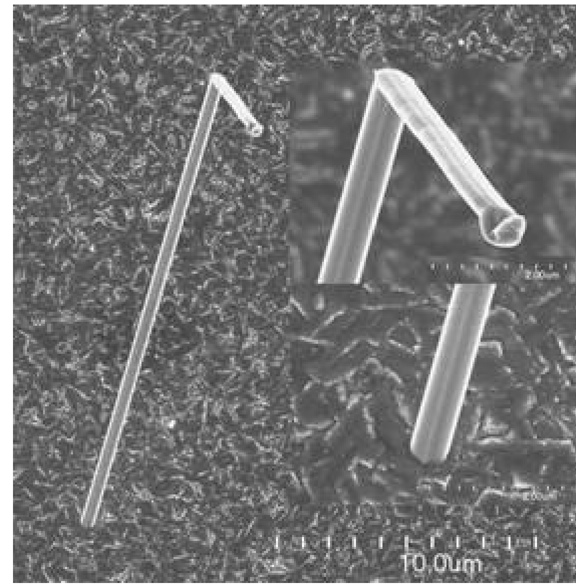
Whisker Examples



Hillocks (Lumps)



Odd-Shaped Eruptions (OSE)



Needles

Debate on Alloy Composition

Which alloy composition should we use?

Three main effects of solder alloy composition:

During assembly:

melting, wetting, reaction, solidification

After assembly:

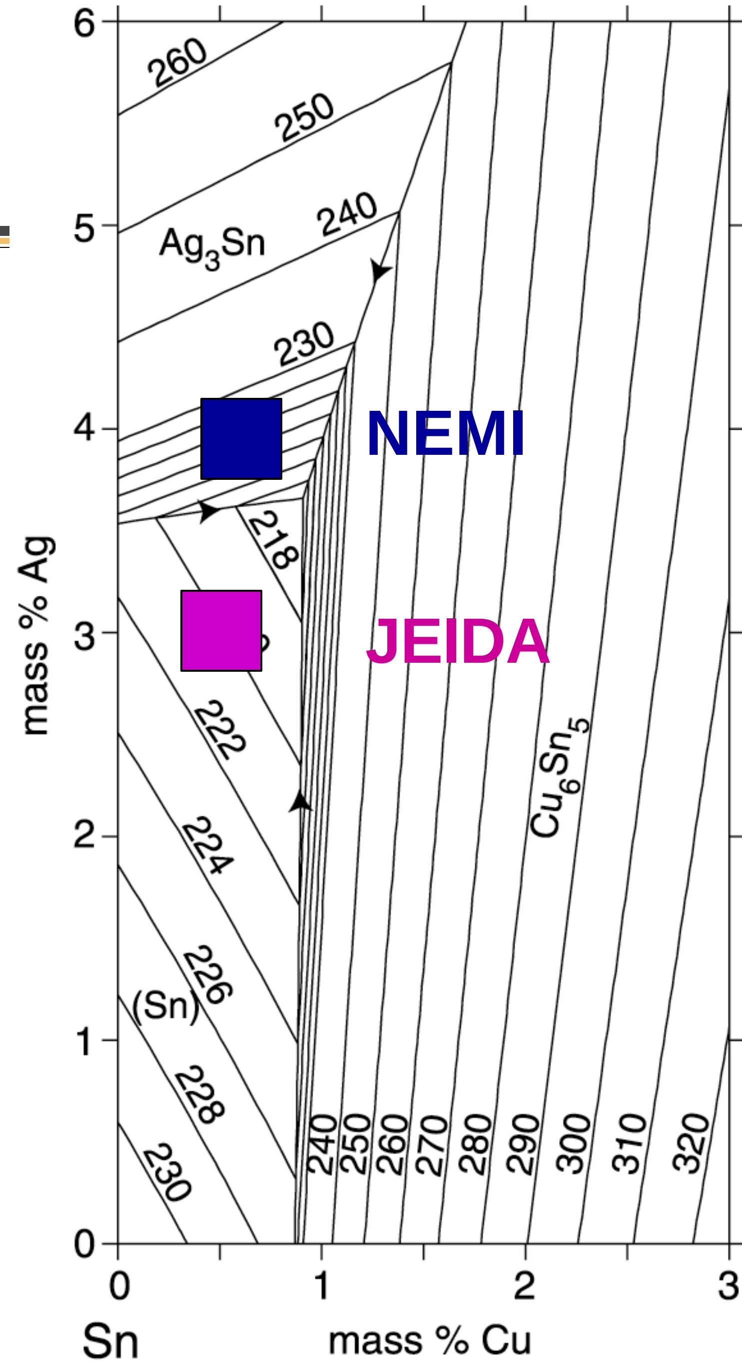
thermal fatigue resistance, fracture, tin pest (?)

Phase Diagram of Sn-Ag-Cu Solders

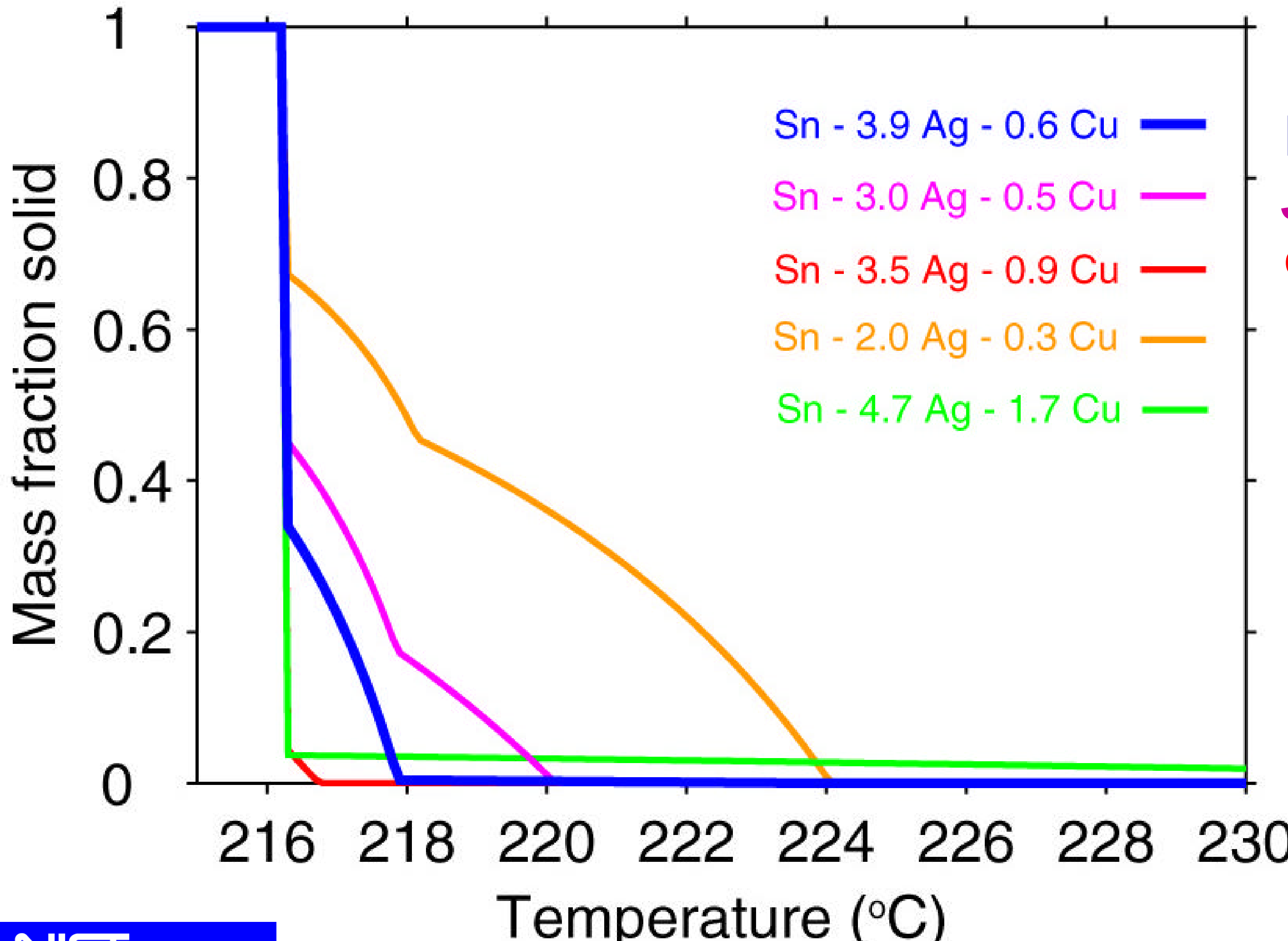
Liquidus Temperatures of Sn-Ag-Cu solder system as a function of composition

- Liquidus temperature is highest temperature where solid is present

- Lines correspond to compositions with the same liquidus temperature



Melting Behavior of Sn-Ag-Cu solders



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JEIDA
eutectic

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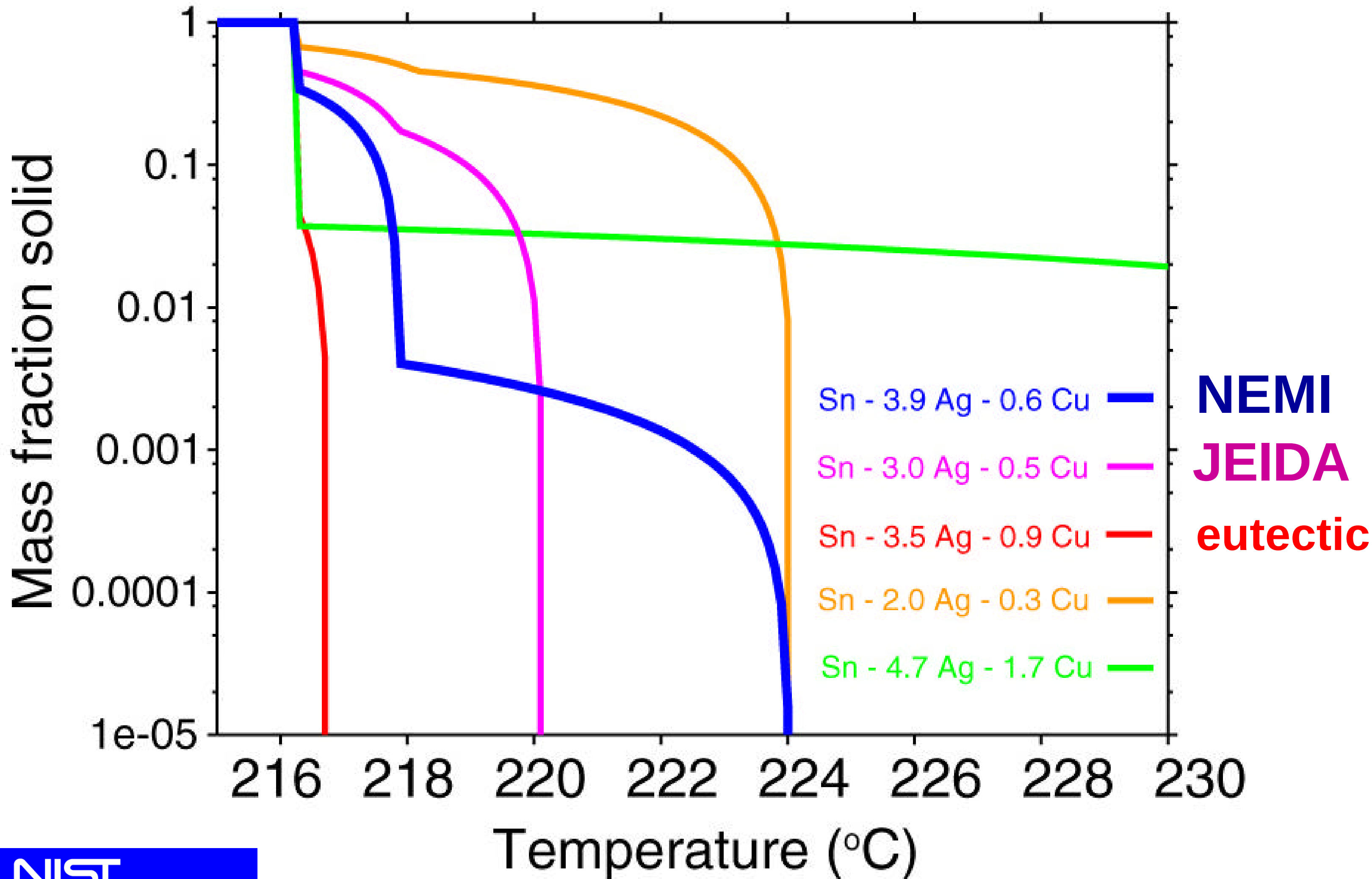
Melting Behavior of Sn-Ag-Cu solders



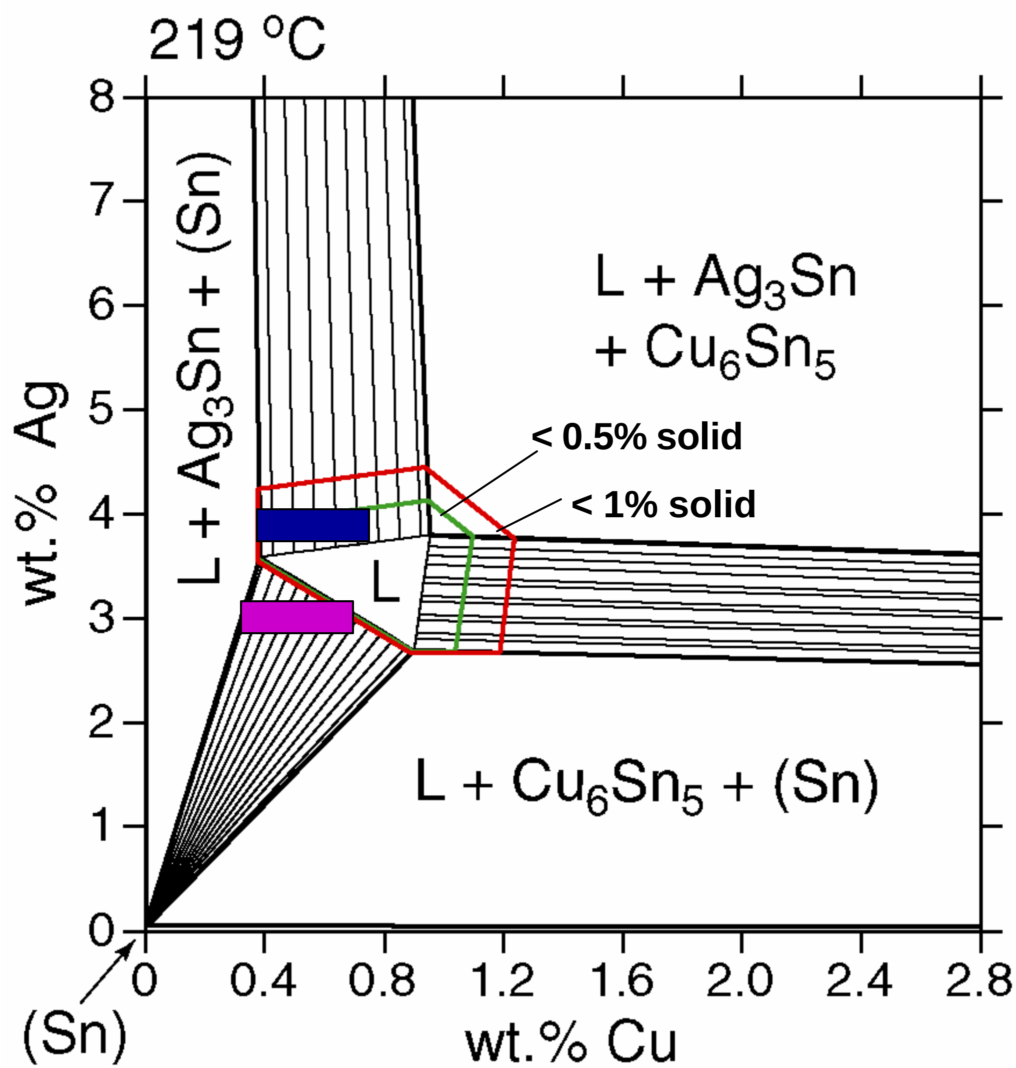
Melting Behavior of Sn-Ag-Cu solders

Inside **green** lines - <0.5% solid

Inside **red** line – <1% solid

NEMI

JEIDA



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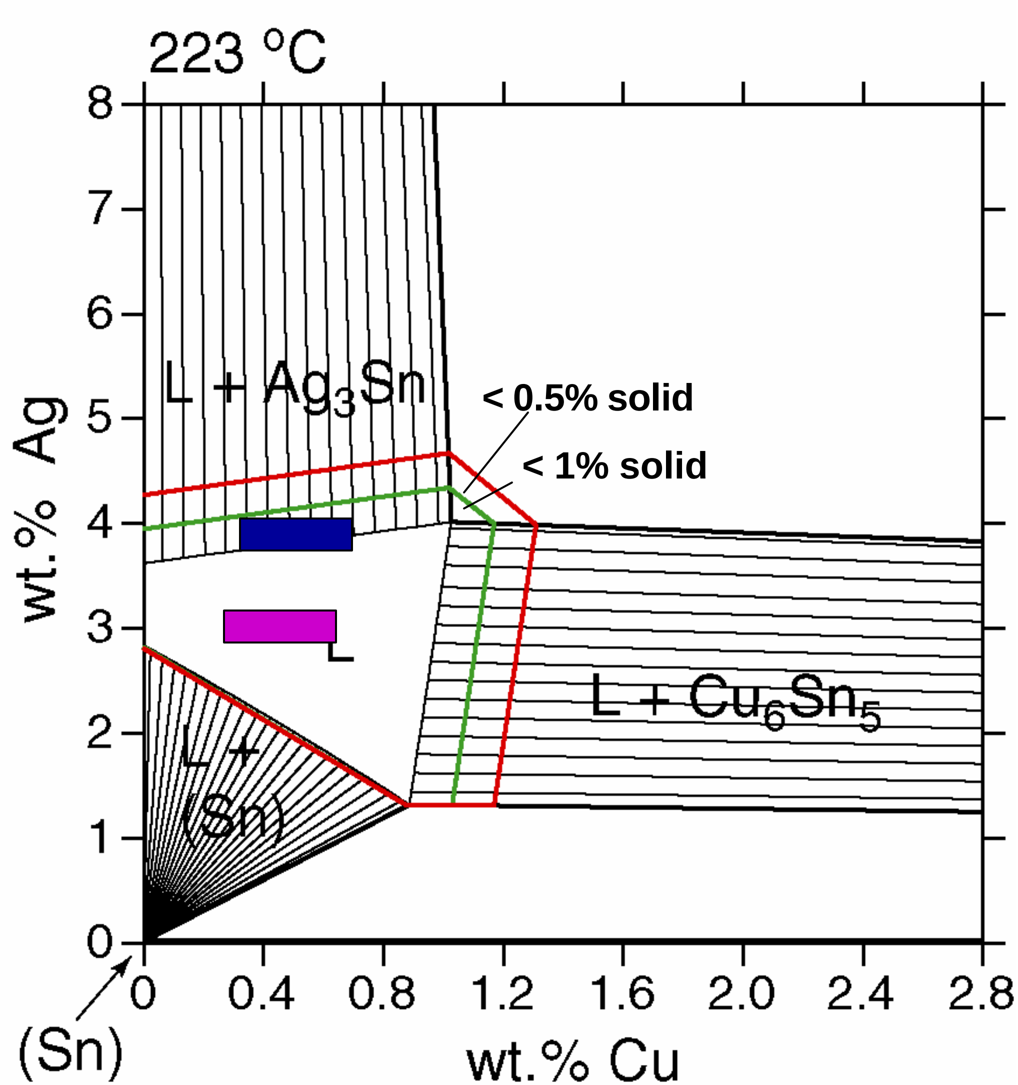

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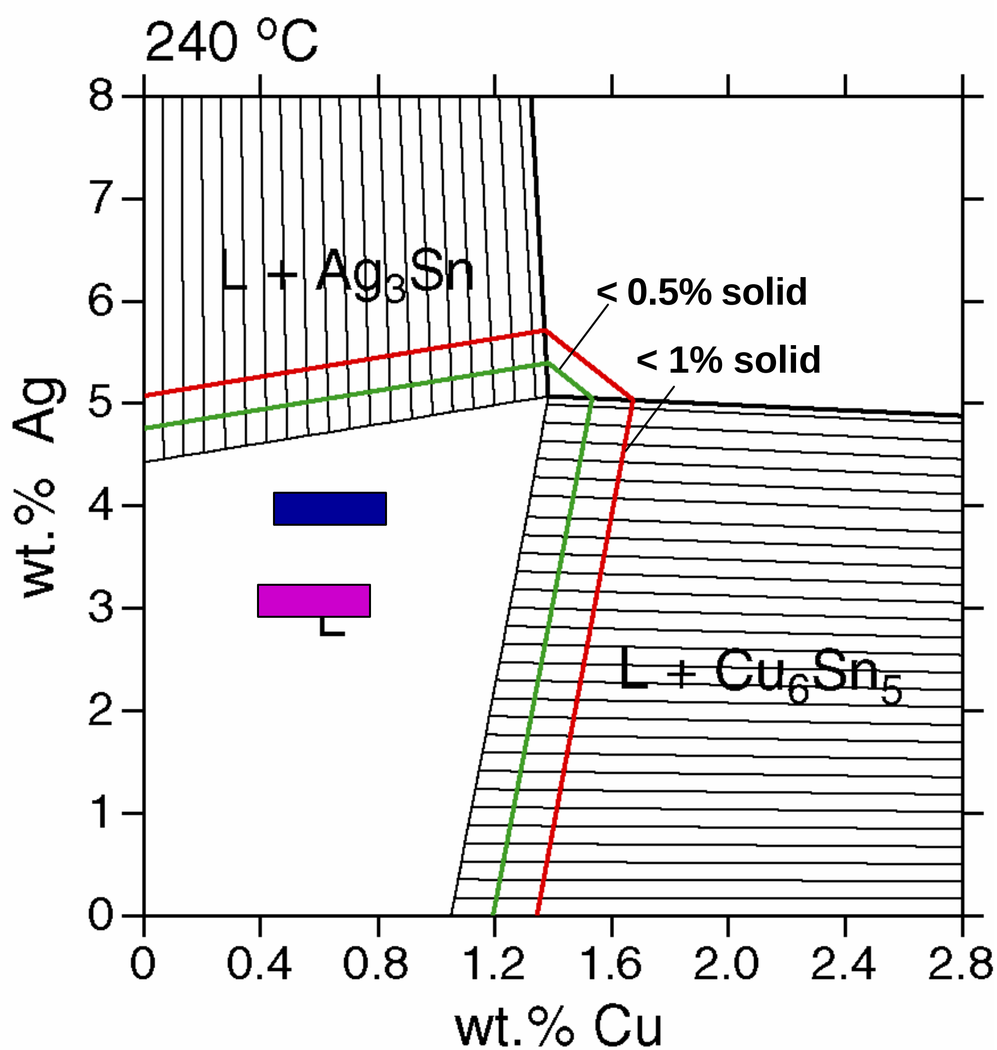


NEMI Committee Structure

- *Tin Whisker Test Standards Committee (Test Group)*
  - *First committee formed*
  - *Objective to develop tests/test criteria for tin whiskers*
  - 42 companies including two governmental organizations
  - Nick Vo (Chair) – Motorola
  - Jack McCullen (Co-Chair) – Intel
  - Mark Kwoka (Co-Chair) – Intersil

- *Tin Whisker Modeling Group (Modeling Group)*
  - *Formed to gain fundamental understanding of whisker formation*
  - 13 companies including one government organization.
  - George Galyon (Chair) – IBM
  - Maureen Williams (Co-Chair) – NIST
  - Irina Boguslavsky (Co-Chair) – EFECT, NEMI Consultant

Tin Whisker Committees

- ***Tin Whisker Users Group (Users Group)***
  - ***Formed by large companies with high reliability products to look at mitigation techniques***
  - **Started in late 2002**
  - **10 companies**
  - **George Galyon (Chair) – IBM**
  - **Richard Coyle (Co-Chair) – Lucent**

Test Team Members

- *Agilent*
- *Alcatel*
- *Allegro Microsystems*
- *AMD*
- *Analog Devices*
- *Boeing*
- *ChipPAC*
- *Cooper Bussmann*
- *Delphi Delco*
- *Engelhard Clal*
- *Enthone*
- *FCI Framatome*
- *Flextronics*
- *HP*
- *IBM*
- *Indium*
- *Infineon AG*
- *Intel (Co-Chair)*
- *Intersil (Co-Chair)*
- *IPC*
- *ITRI Soldertec*
- *Kemet*
- *Lockheed Martin*
- *Microchip*
- *Micro Semi*
- *Molex*
- *Motorola (Chair)*
- *NASA Goddard*
- *NIST*
- *NEMI*
- *On Semi*
- *Philips*
- *Raytheon*
- *Soldering Tech.*
- *Shipley*
- *Solectron*
- *ST Micro*
- *SUNY Binghamton*
- *SUNY Buffalo*
- *Technic*
- *Texas Instruments*
- *US Army*

Overview of Whisker Committee Effort

- ***Direct:***
  - Completed two comprehensive matrices, Phase 1 and 2, both for ICs and Passives.
  - Proposed a definition for whiskers.
  - Developed an inspection protocol.
  - Identified three test methods recommended for plating finish development and characterization.
  - Initiated test method document for potential release by JEDEC.
  - Preparing matrix for Phase 3 DOE (validation and verification).

- ***Indirect:***
  - Generated considerable momentum to understand whiskers and tin plating globally.

Whisker Definition

- ***Purpose:***
  - **To specify the physical and visual characteristics of a tin whisker for use in inspection (not intended as a metallurgical definition)**
- ***Tin Whisker:***
  - **A spontaneous columnar or cylindrical filament, which rarely branches, of tin emanating from the surface of a plating finish.**
- **NOTE, For the purpose of inspection tin whiskers have the following characteristics:**
  - *an aspect ratio (length/width) > 2;*
  - *can be kinked, bent, twisted;*
  - *generally have a consistent cross-sectional shape;*
  - *rarely branch;*
  - *and may have striations/rings around it.*

Further Information

http://www.metallurgy.nist.gov/solder/

Extensive data available on thermodynamics, solder properties, …

http://www.nemi.org

Inspection Protocol

- *Scope:*
  - **Establish an inspection method to quantify the propensity of an electroplated lead finish to develop tin whiskers.**
  - **Examples of electroplated lead finish uses: terminals of ICs and passives, connectors, printed circuit boards, etceteras.**

- *Purpose:*

  To recommend the equipment, locations and area of inspection, sample size and procedure for inspection.

- *Equipment:*

  Scanning Electron Microscope (SEM) is recommended for whisker inspection and verification.

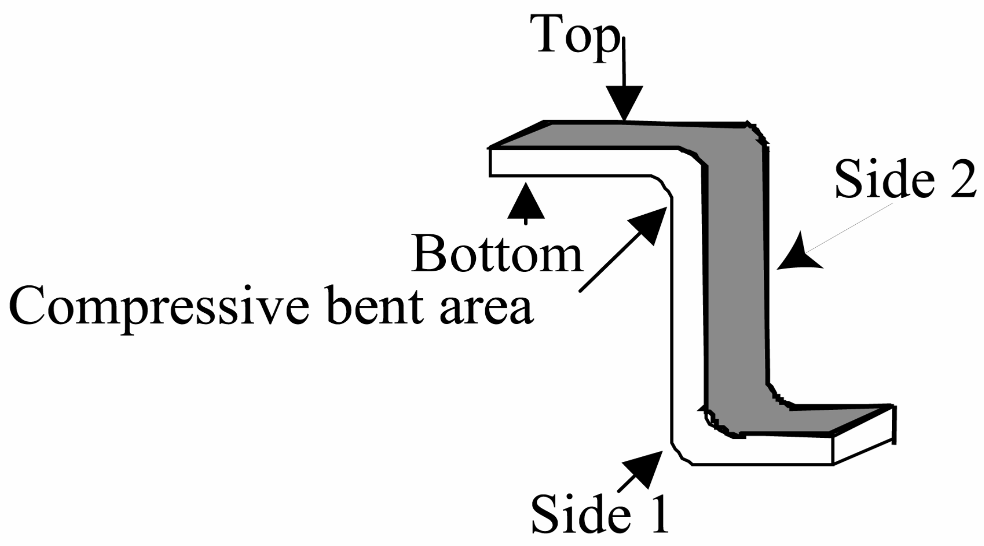
Inspection Protocol

- *Procedure:*
  - Use carbon tape, paint, or other conductive material to attach the sample to the work holder to prevent charging.
    - When handling the samples, care must be taken to avoid contact with the electroplated finish. Contact with the finish may detach whiskers.
  - Inspect each sample for whiskers at a magnification of 300X.
  - The samples should be mounted in the best position (maximize inspection areas and view of critical locations such as bends) for SEM inspection.
  - At each inspection:
    - Record the presence of hillocks, odd-shaped eruptions and whiskers (whiskers ^{3} 10 microns in length or > 2 in aspect ratio).
    - Estimate and record the length of the longest whisker. Whisker length is measured from the termination/electroplate surface. Use higher power as necessary to determine length.
    - Record the whisker density representative of the level of whisker growth (number of whiskers within a 250µm X 250µm area).

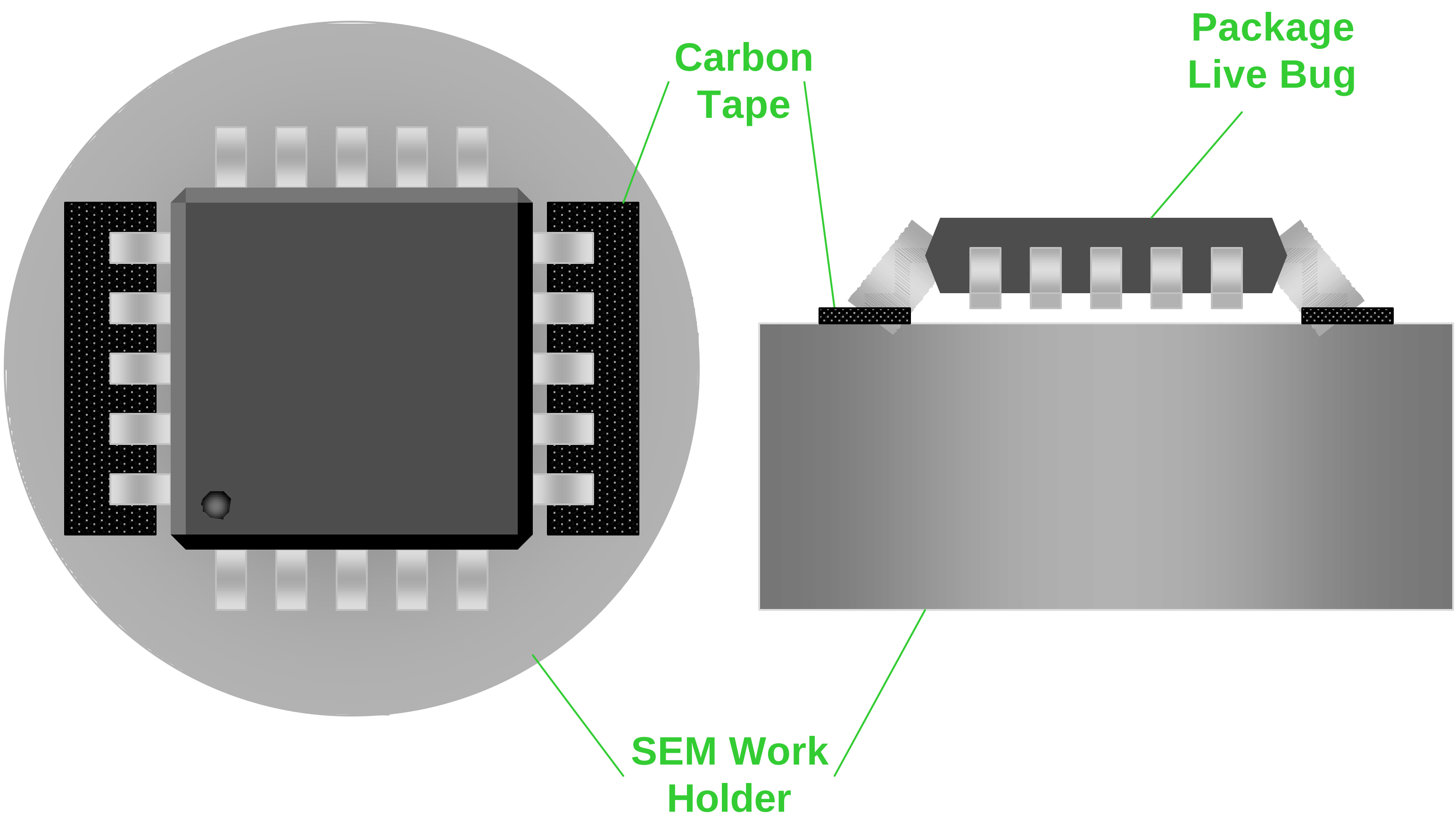
Inspection Protocol

- *Recommended Sample Sizes:*
  - **Example: Leaded Packages**

    Inspect all plated surfaces, as practical, of 3 leads on a minimum of 3 packages randomly chosen from the test samples.



SEM Inspection Set-up



Recommended Test Method

- Prepared whisker test method for release by JEDEC.
- Purpose:
  - Provide test method to aid in the evaluation and development of plating finishes.
  - Provide an industry-standardized test for comparison of whisker-propensity for different plating systems and processes.
  - Not intended for use in reliability assessment or qualification.

Recommended Test Method

- Recommended Test Methods:
  - -55°C (+0, -10) / 85°C (+10, -0) air-air temperature cycle (20minutes/cycle)
  - 60 + 5 °C, 93 +2, -3 % RH
  - 20 - 25 °C, ~30-80% RH
  - All three tests are to be performed using separate samples
  - Each test condition is to be performed independently