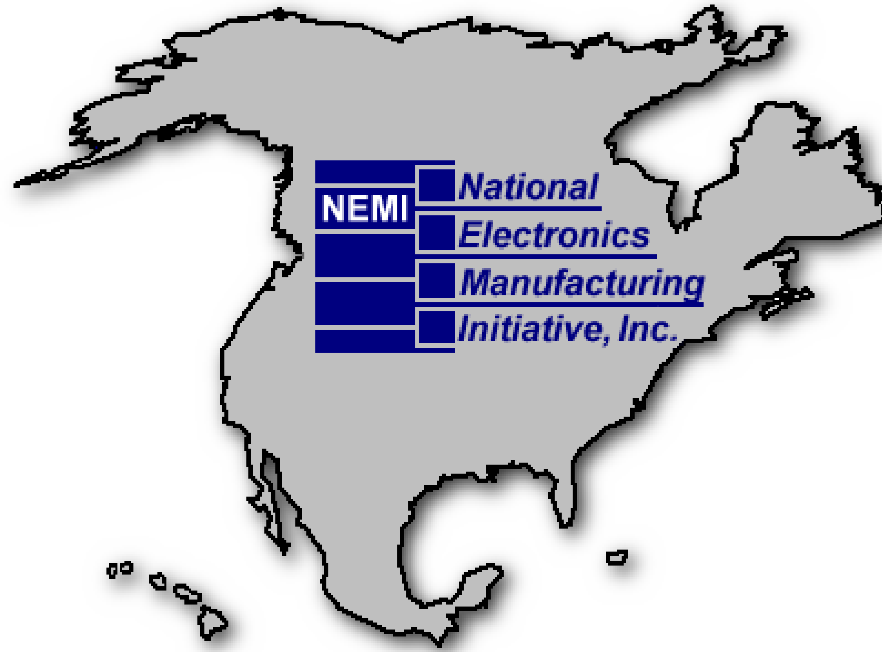
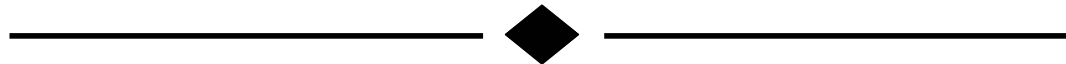


NEMI Pb-free Alloy Group Status

Carol Handwerker



2002 APEX Free Forum

January 23, 2002

Agenda

- Acknowledgements
- Statement of Work
- Melting Behavior
- Lead-Free Alloy Roadmap for Data and Modeling
- Public Domain Data Base Development
- Data Needed for Accurate Modeling of Thermal Cycling Test Configurations
- Accomplishments
- Alloy Group Schedule

Acknowledgements
NEMI Lead Free Alloy Team (Active)

Name	Company
Angela Grusd	Agilent
Polina Snugovsky	Celestica
Prasad Swaminath	ChipPAC
Bret Zahn	ChipPAC
Dianne Mitchell	ChipPAC
Richard Parker	Delphi Delco
Jean-Paul Clech†	EPSI
Jay Bartello	IBM
Don Henderson	IBM
Mke DiPietro	IEEC
Ted Martin	Intel
Jack T. McCullen	Intel
Edwin Bradley	Motorola
Srini Chada	Motorola
Alek Zubelewicz	Motorola
Ron W.Gedney	NEMI
Dave Godlewski	NEMI
John E. Sohn	NEMI
Carol Handwerker	NIST
Tom Siewert	NIST
Paul Vianco†	Sandia
Jasbir Bath	Solectron
Sundar Sethuraman	Solectron
Ric Charbonneau	StorageTek
Leonard Poch	Universal Instr.

† - invited contributors

Statement of Work - Alloy Team

Main Task:

Provide the Task Force with critical data and analyses needed for making decisions with respect to solder alloys, manufacturing, and assembly reliability.

- ✓ **Provide assessment of candidate solder systems to choose industry "standard" lead-free alloys for reflow and wave soldering.**
- ✓ **Generate key data for decision making if not available in the literature.**
- ♦ **Develop "best practices" experimental procedures to measure the mechanical, thermal, electrical and wetting properties of lead-free solders. This document will be distributed to interested universities/organizations via Internet and hard copy.**
- ♦ **Develop public domain solder databases for properties and literature references for lead-free alloys.**
- ♦ **Promote modeling for reliability through generation of best possible data and modeling methods.**

Solder Alloy Team Accomplishments

- ✓ Conducted extensive literature search including Europe and Far East
- ✓ Determined ternary eutectic melting temperature of Sn-3.9Ag-0.6Cu
- ✓ Investigated patent issues and selected Sn-3.9Ag-0.6Cu for reflow and Sn-0.7Cu for wave
- ✓ Examined sensitivity of melting behavior of Sn-Ag-Cu to composition and temperature in response to request from team members

Lead-Free Solder Reference Database

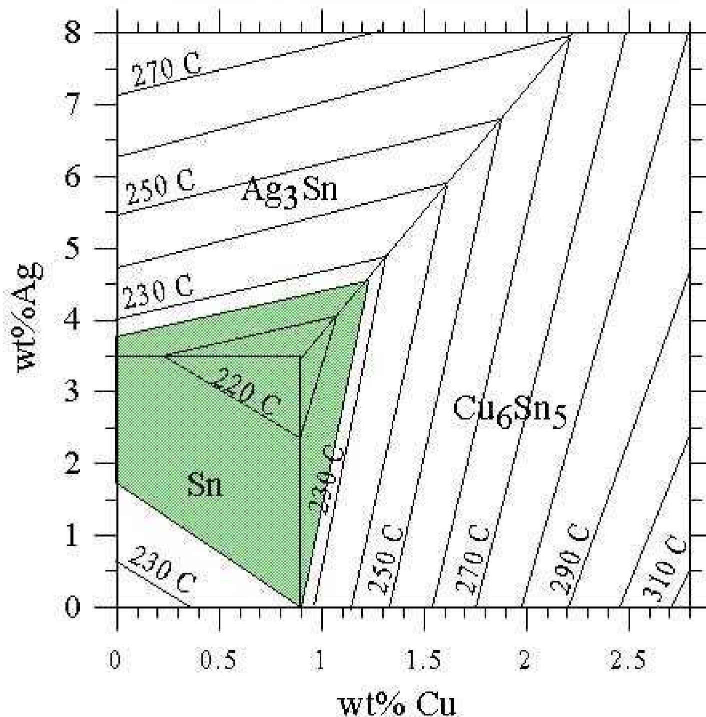
- **Extensive literature search including North America, Europe and Far East**
- **Reference list will be available from NEMI public domain website on February 1**
  - ➔ downloadable in WORD form alphabetical by author and by date
  - ➔ request for references missing from list; format for information and NIST email address to send it on NEMI website
  - ➔ also request electronic or hard copy of paper sent to NIST

http://www.nemi.org

Eutectic of Sn-Ag-Cu solder system

- Kilwon Moon, Bill Boettinger, Ursula Kattner, Carol Handwerker of NIST performed studies to determine the true Sn-Ag-Cu eutectic composition

Ternary Liquidus Surface
based on data from NIST,
Marquette U., and Northwestern U

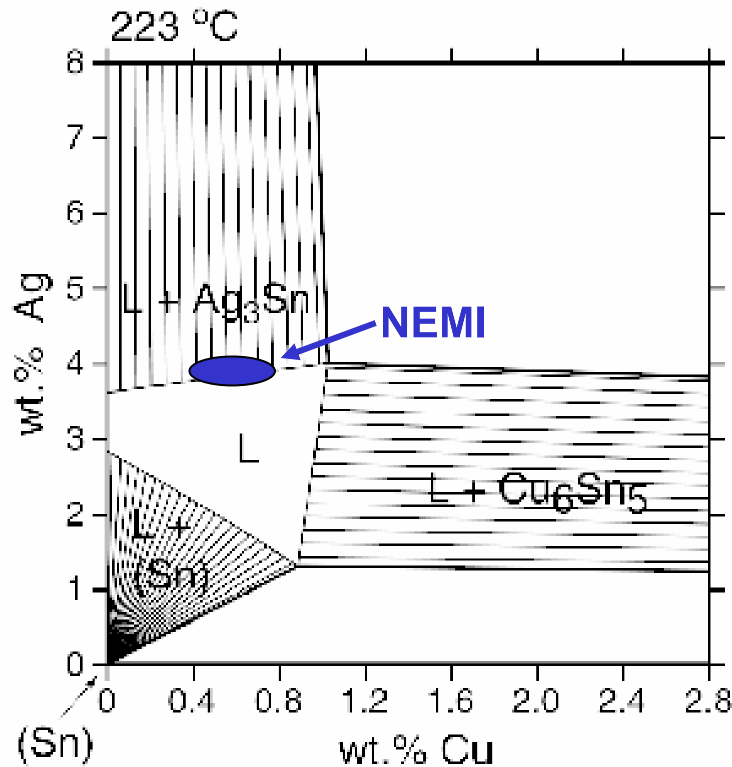


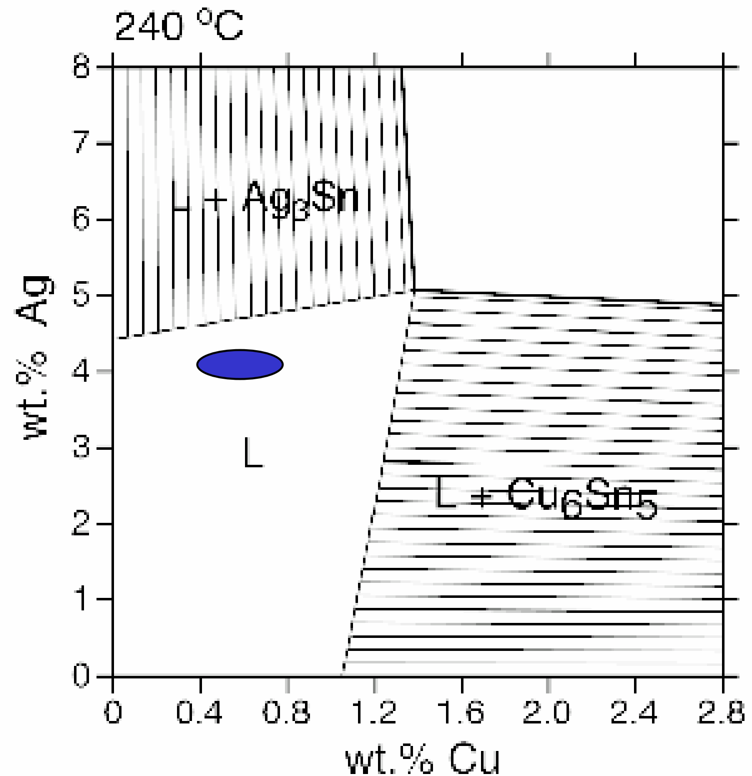
Ternary Eutectic Composition
Sn - 3.5 Ag - 0.9 Cu
at 217°C

Alloys in shaded area have freezing range <10°C.

Reflow Profile: Minimum Allowable Joint Temperature

For 223°C and 240°C composition ranges over which solder is 100% liquid - denoted by "L"





Helped to clarify solder melting temperatures from solder paste wetting dynamics and effect of air reflow

Results of Workshop

Modeling and Data Needs for Lead-Free Solders

✓ Held in conjunction with TMS meeting in New Orleans, LA on February 15, 2001

✓ Workshop report serving as roadmap for developing and analyzing data

http://www.nemi.org/PbFreePUBLIC/index.html

Prioritized Data needed for finite element modeling of thermal cycling test results

- Comprehensive test datasets: thermal cycling conditions, materials, component and board geometries, assembly information
- Mechanical and thermal property data as function of composition, temperature and test method with goal: robust data

Database for Solder Properties with Emphasis on Lead-free Solders Release 3.0

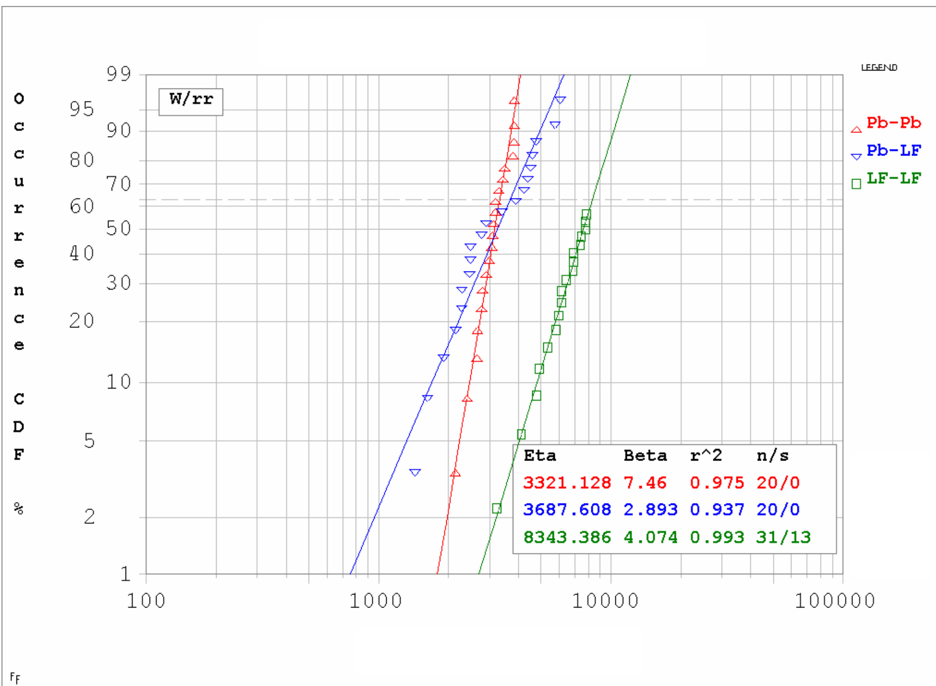
developed by
National Institute of Standards & Technology and
Colorado School of Mines (under contract to NIST)

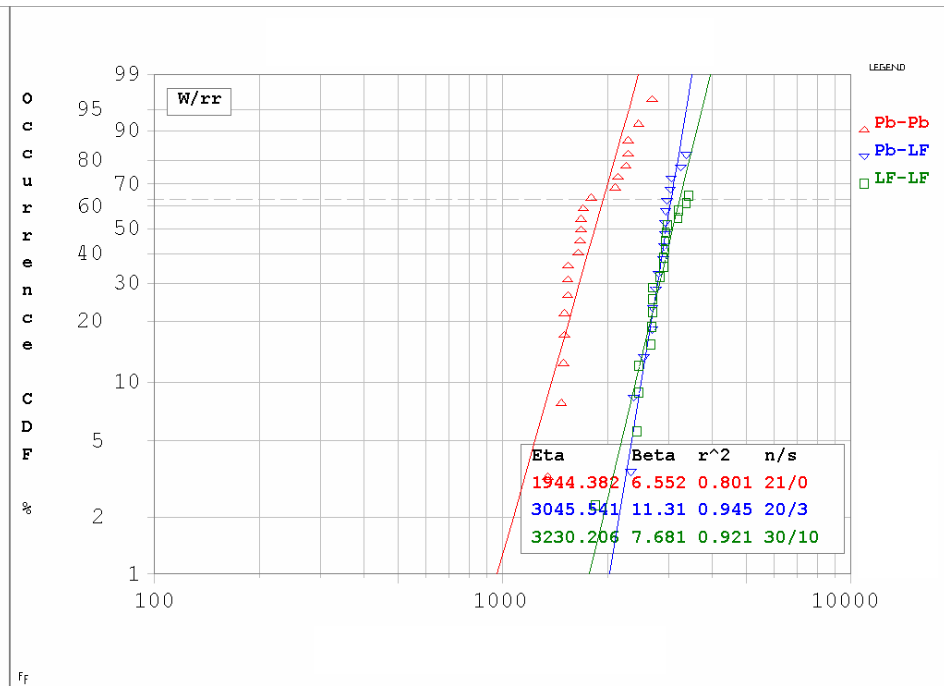
http://www.boulder.nist.gov/div853/

- Viewable using web browsers
- Downloadable in Microsoft Word formats
- Release number changes as database is updated

169CSP Weibull Analyses

0 to100°C cycling	-40 to +125°C cycling





	Pb-Pb	Pb-LF	LF-LF
η (N63)	3321	3688	8343
β	7.5	2.9	4.1

	Pb-Pb	Pb-LF	LF-LF
η (N63)	1944	3046	3230
β	6.6	11.3	7.7

Does mechanical model fit measurements?

60Sn-40Pb

HALL'S STRESS/STRAIN LOOP

Model developed by J-P. Clech
EPSI Inc.

- **Simulation uses classical approach**
  - **Total strain** $\gamma_t = \gamma_e + \gamma_p + \gamma_c$

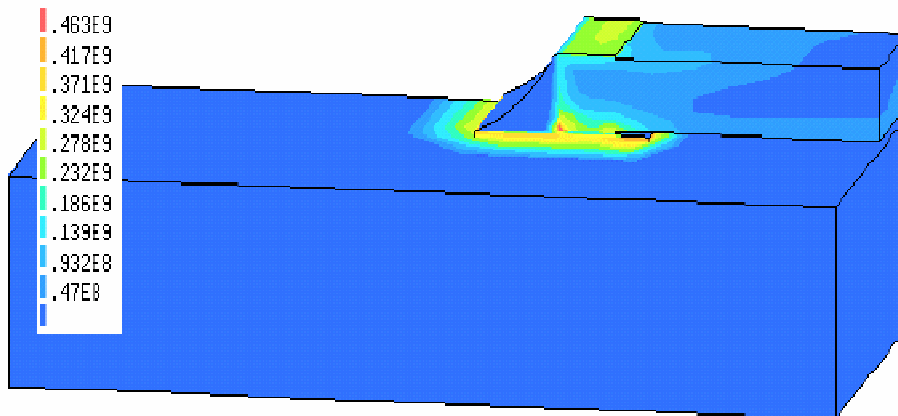
0.5ºC/min ramps, 120 min dwells

Manufacturing and Reliability Modeling

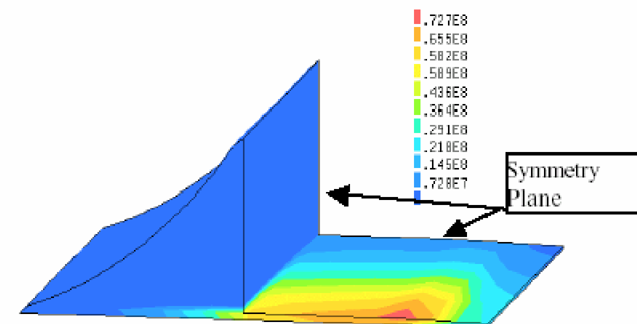
Models and calculations - Prof. Christopher Bailey

U. Greenwich, UK

Accumulated strain energy density per thermal cycle is an indicator of damage

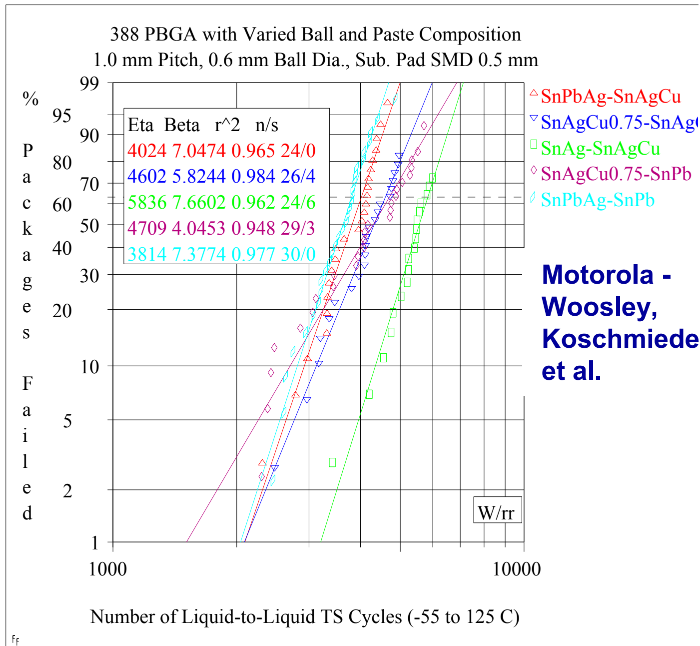


Effective stress when thermal load is applied.



Strain energy density at the end of a thermal cycle

Data Needed for Finite Element Modeling



Description	625 I/O CBGA
Footprint details (Pitch, Area/Perimeter Array)	1.27mm, 25 x 25 I/O Area Array
Module Dimensions	32mm x 32mm x 1mm
Ceramic Substrate Size (length and width)	32mm x 32mm
Ceramic Substrate thickness	0.8mm
Ball diameter (**A**)	0.89mm
Joint Stand-off height (**B**)	0.6mm
Molybdenum Pad diameter (Component Side) (**C**)	0.86mm
Molybdenum Pad thickness (Component Side) (**D**)	≈1.5mils
Cu Pad diameter (Board Side) (**E**)	0.74mm NSMD
Cu Pad thickness (Board Side) (**F**)	1.8mils
PCB Board Solder Mask thickness (SMD/NSMD) (**G**)	NSMD
Board dimensions (6 modules per board – single sided)	230mm x 280mm x 1.8mm
Board type (FR-4 etc) and Number of Layers	FR-4 Epoxy glass, 4s4p

Notes:
1. These parameters could be obtained from cross-sectioning.
2. There is no chip or heat spreader attached to the module.

Materials data

Developed using existing IBM and Motorola PBGA data and current NEMI data - should be collected for any thermal cycling tests

Joint geometries

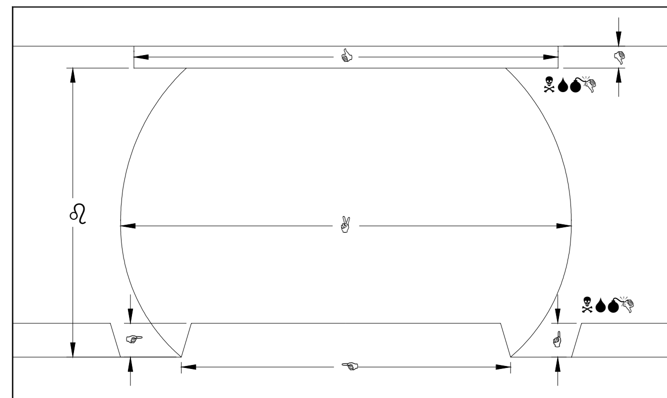


Figure 1: Typical Cross-section dimensions required for modeling (refer to Table 1)

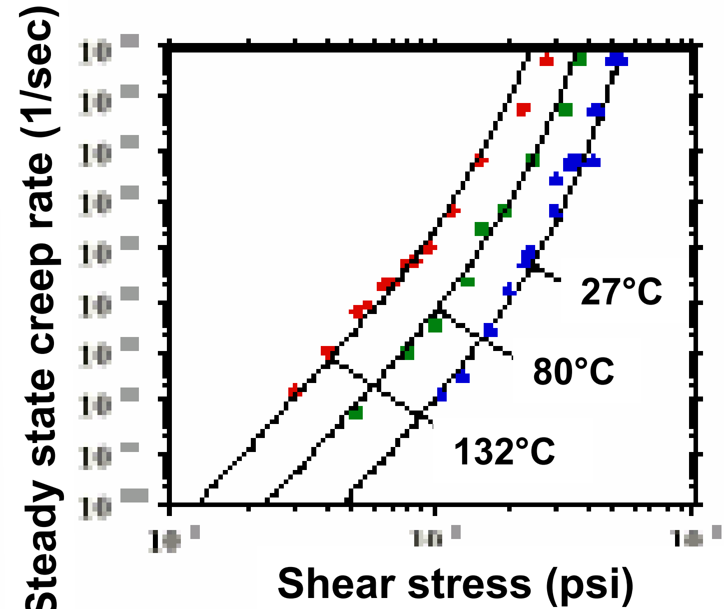
Critically Evaluated Thermal and Mechanical Property Data

Critically evaluating literature data with J.P.Clech -

SnAgCu, SnAg, SnCu, SnPb

some data available for

- Sn-3.5Ag
- Sn-3.0Ag-0.5Cu
- Sn-3.5Ag-0.7Cu
- Sn-3.8Ag-0.7Cu
- Sn-4.0Ag-0.5Cu
- Sn-3.6Ag-1.5Cu



From Darveaux and Banerji

Steady State Creep data on Sn/Ag by Darveaux and Banerji (1992)

Creep - tension, compression, shear

Critical Evaluation of Experimental Creep Data and Evaluation of TMF Models

TENSILE STRAIN RATE (/SEC)

1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
1.E-08
1.E-09

Schubert 150C (creep)
Schubert 70C (creep)
Schubert 20C (creep)
Kariya 125C (strength) Sn3.0Ag0.5Cu
Kariya 75C (strength)
Kariya 22C (strength)
Kariya -10C (strength)
Kariya 75C (creep)
Neu 125C Castin
Neu 75C Castin
Neu 23C Castin
Neu -55C Castin

Kariya et al. 2001
125C 75C 22C -10C
125C
75C
23C
-55C
Neu et al. 2001
Schubert / Wiese et al. 2001
150C
70C 20C
75C

Bulk Sn-3.8Ag-0.7Cu
+Sn-3.0Ag-0.5Cu
+Castin™ data

1.E+00 1.E+01 1.E+02 1.E+03

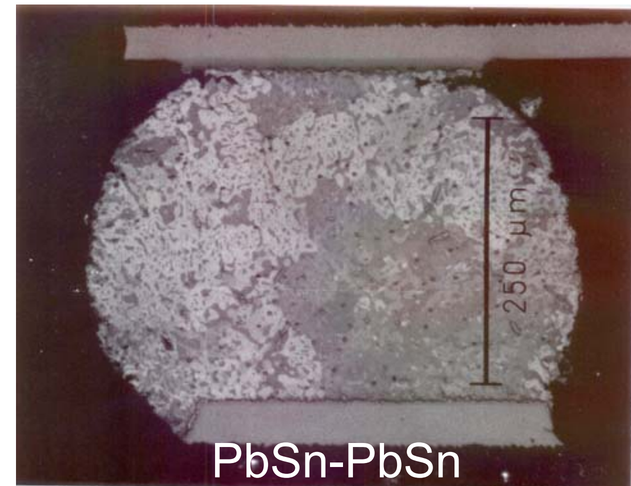
TENSILE STRESS (MPa)

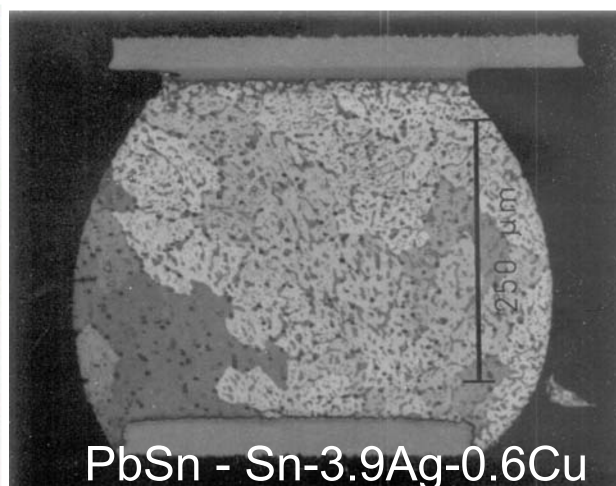
J-P. Clech
EPSI Inc.
jpclech@aol.com
tel: (973)746-3796

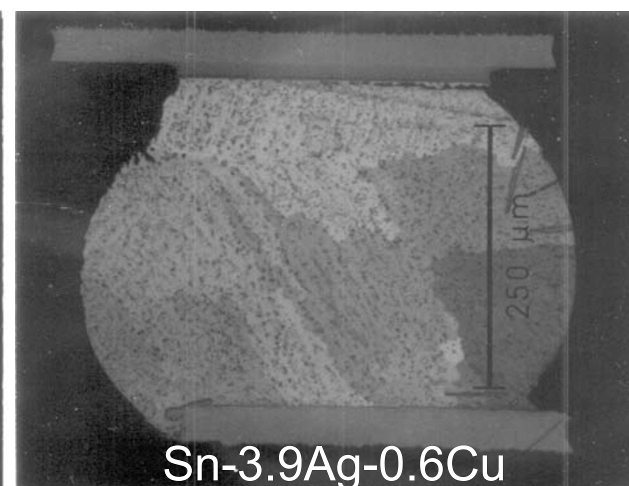
Alloy Team Accomplishments

- ✓ Lead-free solder reference database available
- ✓ Determined ternary eutectic melting temperature of Sn-3.9Ag-0.6Cu
- ✓ Investigated patent issues and selected Sn-3.9Ag-0.6Cu for reflow and Sn-0.7Cu for wave
- ✓ Examined sensitivity of melting behavior of Sn-Ag-Cu to composition and temperature in response to request from team members
- ✓ Held workshop on modeling and data needs for lead-free solders with workshop report being used as roadmap for developing and analyzing data
- ✓ Public domain properties and reference databases available.
- ✓ Database format developed for archiving information on PBGA thermal cycling tests needed for FEA

169CSP Cross Sections - Polarized Light







Microstructures composed of domains in all three cells.

Need to develop understanding of role of microstructures and microstructural changes during thermal cycling on properties.

No one really is dealing with microstructure - but it has been ignored to first order in PbSn-PbSn, but may be a hidden variable that could be more important for other systems.

Looking at structures/ archiving important now.

Alloy Group Schedule

- Reference database for lead-free solders: on NEMI website by February 1, 2002 - on-going
- Public domain website available at NIST for lead-free solder property data - on-going
- Critical evaluation of mechanical property data for NEMI alloys: in progress
- Data formats developed and data archived for NEMI thermal cycling tests: in progress
- *Best Practices* Test Method Guide for Solder: March 2002
- Public domain, evaluated database for NEMI alloys: in progress, estimated summer 2002