NEPP Electronic Technology Workshop
June 22-24, 2010

National Aeronautics
and Space Administration

Working With Consortia - Advanced Packaging Reliability

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Working With Consortia -
Advanced Packaging Reliability

Description:

- **Support the responsible NASA official for lead-free solder evaluation**
- **Serve as the NASA technical liaison to the NASA/DoD Pb-free Project**
- **Assure NASA areas of interest are included in JG-PP follow-on work**
- **Support NASA/DoD telcons and face-to-face meetings**
- **Update MSFC lead-free solder lessons learned report**

FY10 Plans:

-**Reliability data on lead-free solder applications for various part lead finishes and board finishes**
-**Update lead-free solder risks and risk mitigation strategies for NASA**
-**Evaluate lead-free alloy/lead-free finish reliability in design application**
-**Status CAVE project on Pb-free solder aging effects**
-**Compile the LTESE flight and bench data**

Schedule:

(task)	2009			2010								
	O	N	D	J	F	M	A	M	J	J	A	S
Pb Free Lessons Learned	Ongoing											
CAVE^3 Status						◆						◆
NASA/DoD Pb-Free Status1			◆			◆			◆			◆

Deliverables:

- **Updated MSFC Lead-free lessons learned report**
- **Report on lead-free alloy/lead-free finish reliability**
- **Provide status of reliability data from Space Station Pb-free experiment**
- **NASA/DoD lead-free solder follow-on project status**

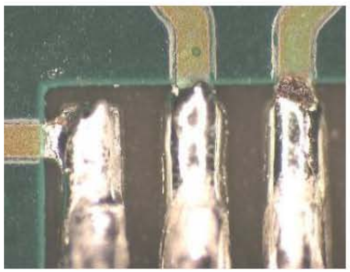
Working With Consortia -
Advanced Packaging Reliability

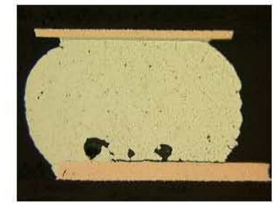
- The Parts, Packaging and Fabrication Branch, Space Systems Department of Marshall Space Flight Center is currently working with two Consortia
  - The National Science Foundation Center for Advanced Vehicle and Extreme Environment Electronics ($CAVE^3$) at Auburn University
  - The NASA/DoD Lead-Free Electronics Project which is the follow-on to the JCAA/JGPP Pb-free Project

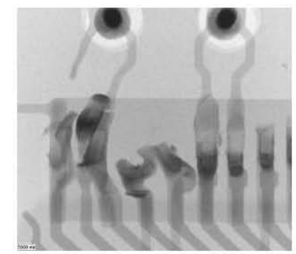
(http://www.jgpp.com/projects/projects_index.html)

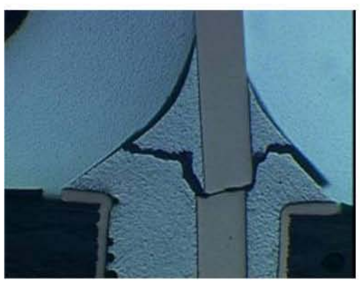
Project Number: S-01-EM-026

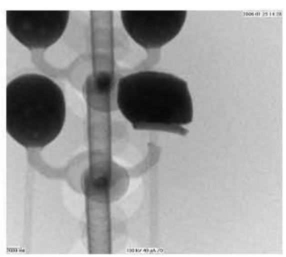
NASA/DoD Lead-Free Electronics Project

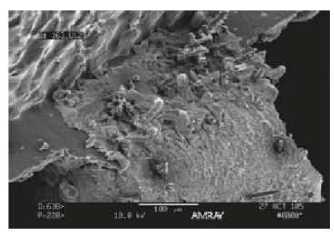


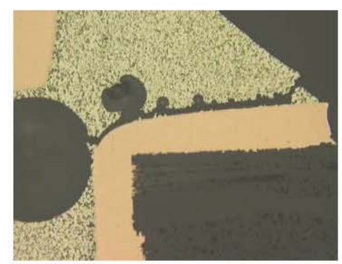


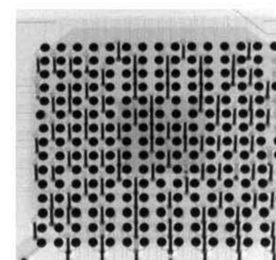












Why Consortia?

- Because with CAVE^3 for each $1.00 invested in our membership we get $148.00 in core research
- Because they are working in research areas of great interest to NASA
- Because they are very responsive to the wishes of the membership as identified by semi-annual Industry Advisory Board meetings
- Because with the NASA/DoD Lead-free Electronic Project we are pooling the experience of some of the most knowledgeable people in the Aerospace Industry
- Because together we can accomplish much more than could be accomplished independently

Working With Consortia -
Advanced Packaging Reliability

- With CAVE^3 the research areas of particular interest to NASA are Lead-free Solder , Tin Whiskers, and Prognostics to predict the life of electronic hardware

- The NASA/DoD Lead-free effort is evaluating Pb-free and mixed solder test vehicles as manufactured and reworked to assess if they equal or exceed 63Sn37Pb control vehicles under extreme environments. They are undergoing vibration, mechanical shock, thermal cycling (2 ranges), combined environments testing, drop testing, and copper dissolution testing.

CAVE³ Current Projects

Pb-Free Soldering Research Area

- **Aging Behavior of Next Generation Pb-Free Alloys**
  The stress-strain and creep behaviors of Pb-free solders are being measured as a function of environmental exposures, which include isothermal aging at room and elevated temperatures, thermal cycling, and strain rate. The goal is to provide accurate values of key solder mechanical properties for use in modeling applications.

- **Extreme Low Temperature Behavior of Solders**
  This work seeks to evaluate the mechanical behavior and microstructural changes of solder alloys exposed to extreme low temperatures (NASA: -190 to -270ºC). The goals are to evaluate the room temperature behavior of solders after exposure to extreme low temperature and to characterize the effects of extreme thermal cycling on solder behavior.

- **Composition, Microstructure, and Reliability of Mixed Formulation Solder Joints**
  This project examines cross-sections of mixed formulation solder joints to determine composition and microstructure, effects of reflow cycle, and effects of Sn-Pb paste volume (mix ratio). The goals are to extend the mechanical behavior database to develop accurate stress-strain relations for reflowed Sn-Ag-Cu-Pb alloys and to develop and evaluate reliability modeling procedures for mixed formulation solder joints.

CAVE³ Current Projects
Pb-Free Soldering Research Area

- **100% In-Situ Studies of Mixed Formulation Wetting**
  Technological advantages result when wetting can be studied entirely in-situ using materials (board finishes) common to the industry. Previous studies in the laboratory have been "nearly" in-situ, meaning they have used SEM/EDX but then transferred the specimen to do AES/XPS. The limitation is based on heating a laminate-based board finish in a UHV environment, which is risky due to excessive outgassing. They have recently overcome this difficulty and can now do everything in one UHV surface analysis system without breaking vacuum or using cooling/reheating cycles.

- **Microstructure Evolution of Mixed Formulation Alloys**
  This work utilizes their temperature-programmable SEM to observe in-situ microstructure evolution in mixed-formulation alloys. The goal is to record time-lapse SEM micrographs of the alloys at various intervals to understand how the alloy microstructure changes (e.g., coarsening, phase alterations, grain growth) under isothermal and cycling conditions.

The Influence Of Aging Conditions On The Mechanical Behavior SAC Solders

OBJECTIVES - Current Work

- **Measure Stress-Strain and Creep Curves for Lead Free Solders Over a Wide Range of Aging Temperatures and Aging Time.**
- **Study Different SAC Alloys**
  - **SACN05: SAC105, SAC205, SAC305, SAC405**
- **Explore the Effects of Dopants to Reduce Aging Effects**
  - **SACX0307, SAC305X, etc.**
- **Provide the Basic Constitutive Laws and Mechanical Properties of Different Lead Free Solder Materials for Use in Finite Element Reliability Simulations**

AGING SUMMARY

- **The Stress-Strain and Creep Responses of SAC and Sn-Pb Solders were Measured as a Function of Aging for Several Different Aging Temperatures(T = 25, 50, 75, 100, and 125 ^{o}C)**

- **The Elastic Modulus, Yield Stress, and Ultimate Tensile Strength of the SAC Alloys Decrease Dramatically with Aging Time, While the Effect is Much Weaker with the Conventional Sn-Pb Alloy**

- **Empirical Degradation Models have been Established to Fit the Mechanical Property vs. Aging Time Responses**

- **The Effect of the Aging Temperature is Much Stronger for the SAC Alloys**

AGING SUMMARY
(cont'd)

- **Silver Content Plays an Important Role in Determining the Mechanical Properties and Microstructure Evolution of SAC Alloys During Aging. In General, Higher Ag Content Alloys Have Better Mechanical Properties and Smaller Changes in Microstructure, or in Other Words, Greater Aging Resistance.**

- **During Aging, the IMC Particles in the SAC Alloys Tended to Conglomerate and Coarsen. In Addition, the ß Sn Dendrites Grew Larger.**

- **Fractography Analysis of Failed SAC Specimens Showed Transition in the Failure Mode (from Transgranular to Intergranular) During Aging. In Contrast, the Dominant Failure Mode of 63Sn-37Pb Remained Transgranular for All Aging Conditions.**

Reliability Of Aged Lead-free Solder For Mechanical Accelerated Life Testing

- **Objectives**

  To evaluate the effect of lead-free solder mixes SAC105 and 305, PC Board plating, mechanical and temperature aging on the reliability of ball grid array (BGA), chip scale packages (CSP), connectors, and quad flat no lead packages (QFN) for harsh environment electronics

- **Schedule/Milestones**

  Start aging test – 4/2010

  Start vibration test – after 4/2010

  Will last about 2.5 years

- **Deliverables**

  Reliability data from the aging and vibration test

  Reliability report for the CAVE members

  FEA modeling and simulation results

  Publications

Temperature Accelerated Reliability Test

Thermal cycle test profiles:

1)-40°C to +125°C, 15m dwell, 30m transition

2)-40°C to +85°C, 15m dwell, 30m transition

3) 3000cycles

Thermal shock test profiles:

1)-40°C to +125°C, 10m dwell, 30s transition.

Hot storage test:

1)25°C, 55°C, 85°C, 125°C.

2)0.5 year, 1 year, 2 years

Drop Reliability Test

- 55°C aging samples will be used for drop test
- Aging will last 0.5 year, 1 year, 2 years.
- Drop tower: Lansmont-M23

Vibration and Thermal Test

- Vibration test: 6 cycles (1 day)
- Followed by thermal cycle test:
  -40°C~+85°C, 250 cycles
- Repeat this process till 3000 thermal cycles.

•Vibration is 25 minutes per hour of power-on time in a logarithmic sweep of 5 minutes duration from 5 to 500 to 5 Hz.
Amplitude is 0.35" DA 5 to 10.5 Hz, 2g 10.5 to 50 Hz, 1.5g 50 to 70 Hz, 1g 70 to 500 Hz

Extreme Low Temperature Behavior of Solders

Objectives:

- Evaluate mechanical behavior and microstructural changes of solder alloys exposed to extreme low temperatures (NASA: -190 to -270 ^{o}C)
  - Room Temperature Behavior of Solders after Exposure to Extreme Low Temperatures
  - Low Temperature Behavior of Solders
  - Effects of Extreme Thermal Cycling on Solder Behavior

Milestones:

-Stress-Strain behavior of Sn-Pb and SAC305 Solder from -190 to +25 ^{o}C

-Effects of extreme thermal cycling on solder behavior

-Room temperature behavior of solder specimens exposed to extreme low temperatures (e.g. Liquid Nitrogen @ -196^{o}C and Liquid Helium @ at -269^{o}C) for various durations

Deliverables:

- Report Documenting Results
- Journal Publication

EXPERIMENTAL

- **Solder Alloys**
  - SAC305 (96.5Sn-3Ag-0.5Cu)
  - Pb-Sn (63Sn-37Pb)

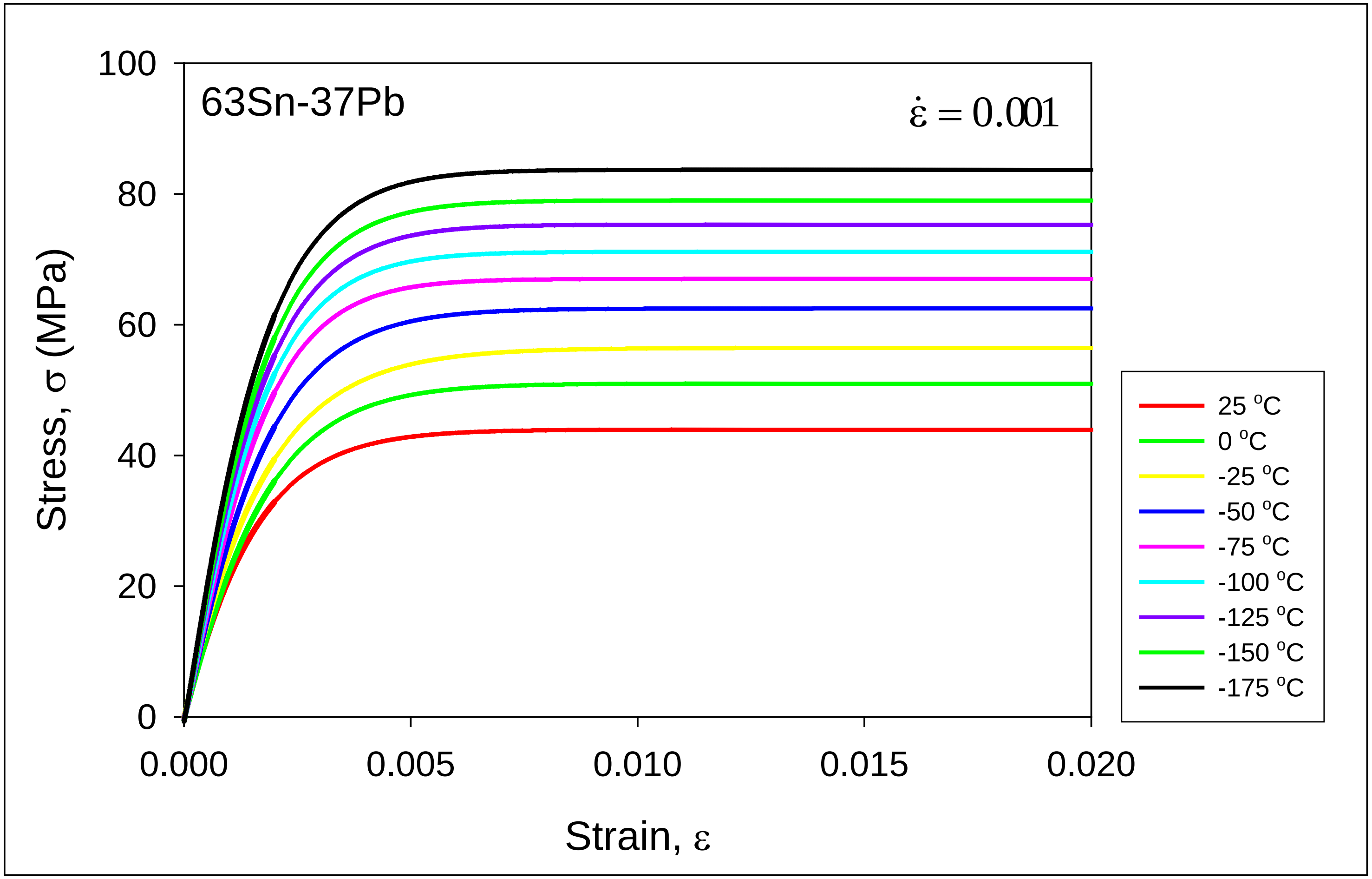
- **Strain Rate**
  - 0.001 (1/sec)

- **Testing Temperatures**
  - Room Temperature Down to -175 ^{o}C

- **Cryogenic Exposures**
  - Immersion in LN_2 (24 Hours)
  - Cycling/Shock by 100 Immersions in LN_2 and Heated Water (~20 C)

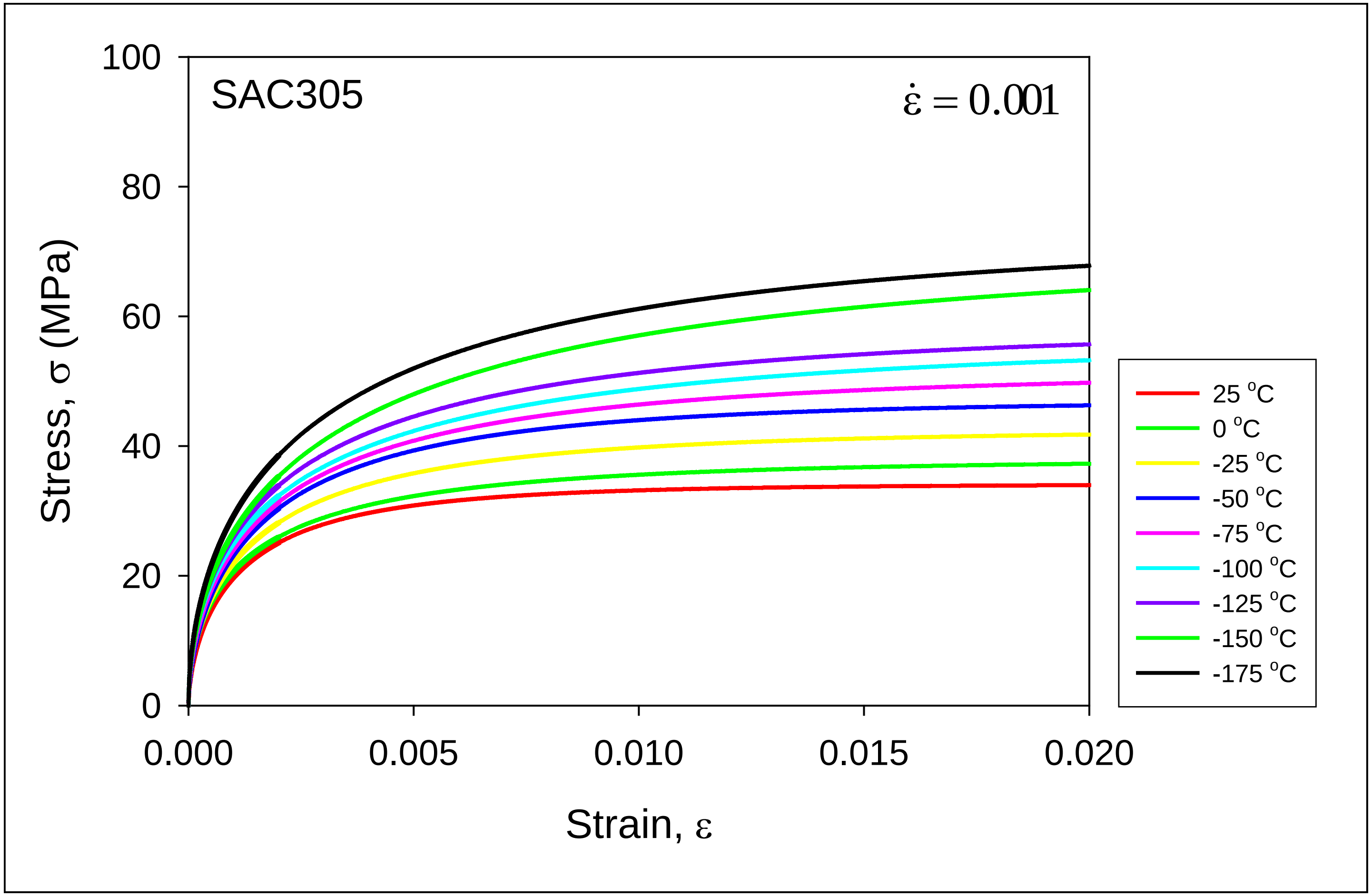
TESTING RESULTS

Stress Strain Curves (Pb-Sn)



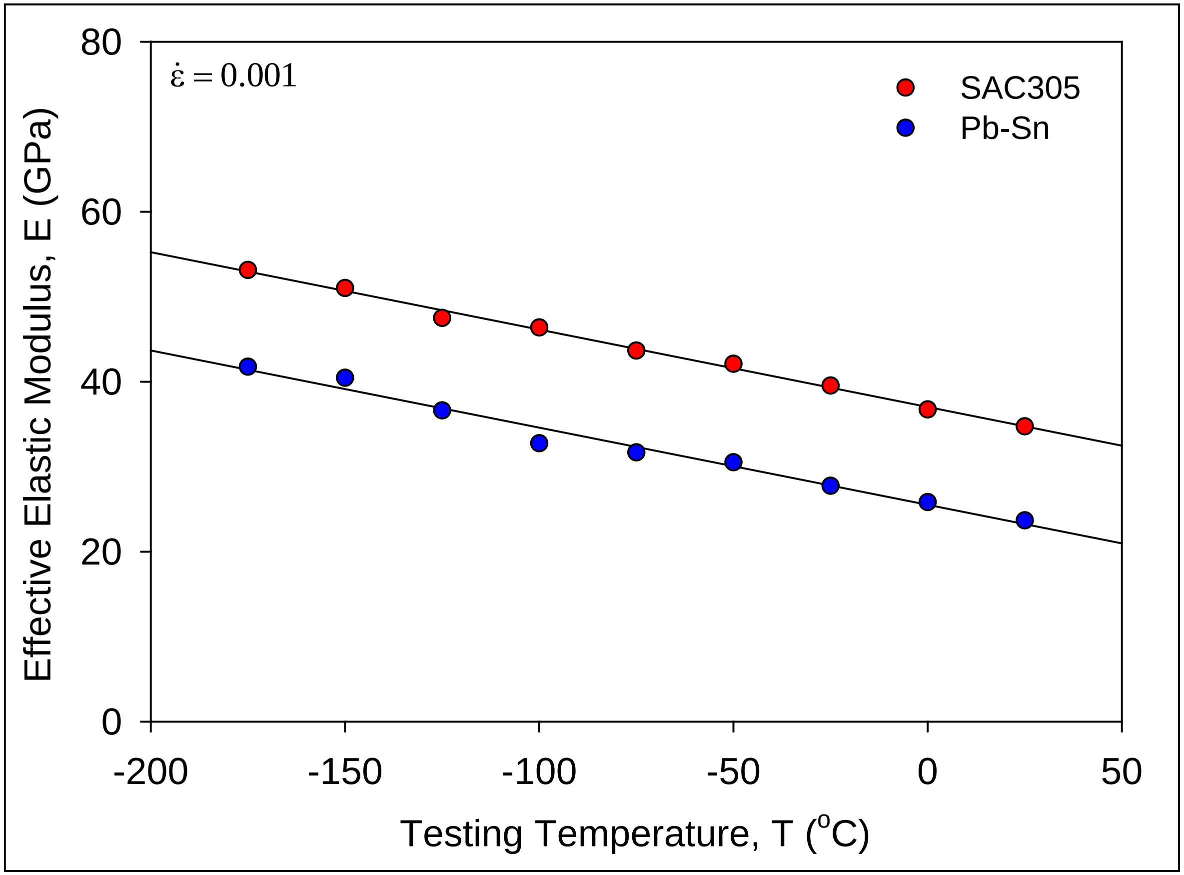
TESTING RESULTS

Stress Strain Curves (SAC305)



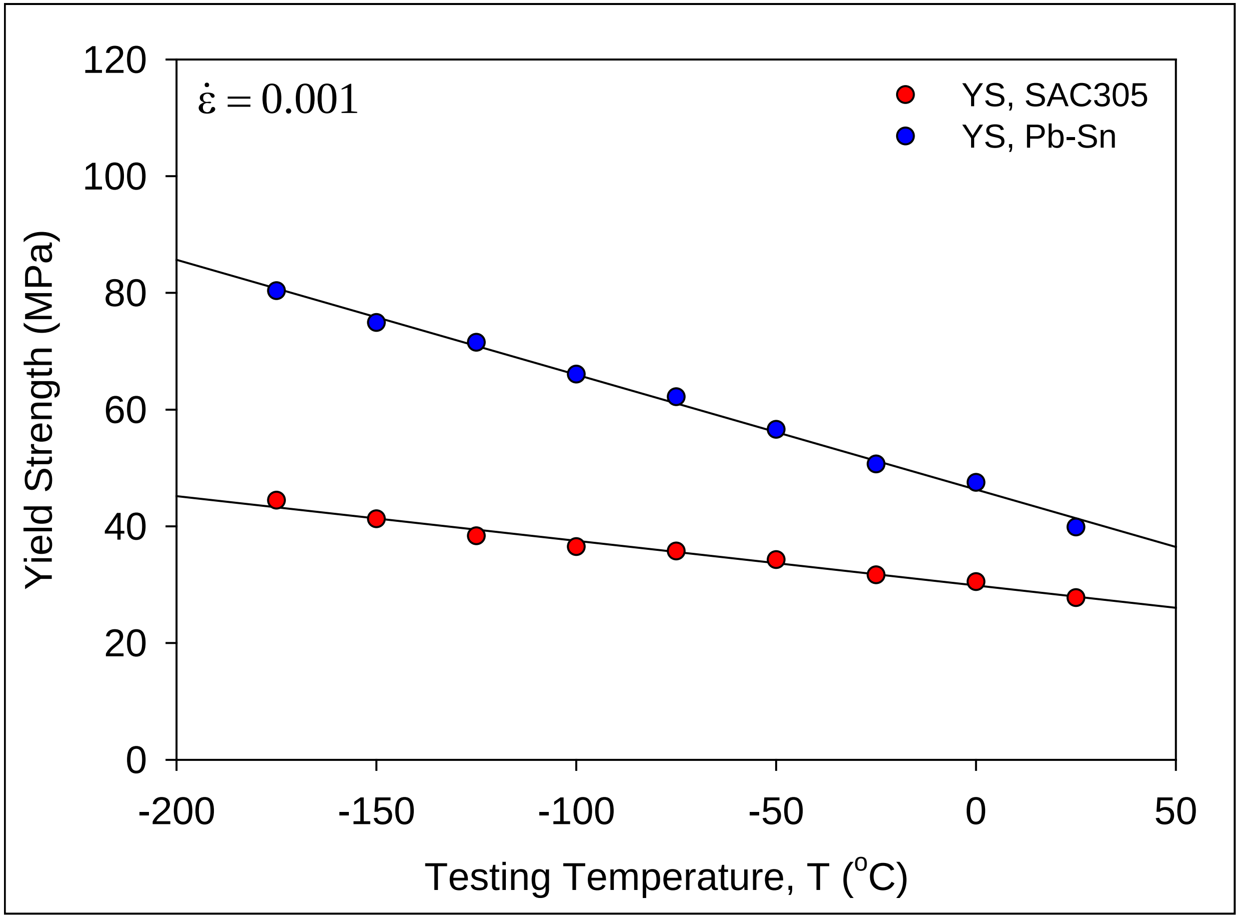
TESTING RESULTS

Effect of Testing Temperature on Effective Elastic Modulus



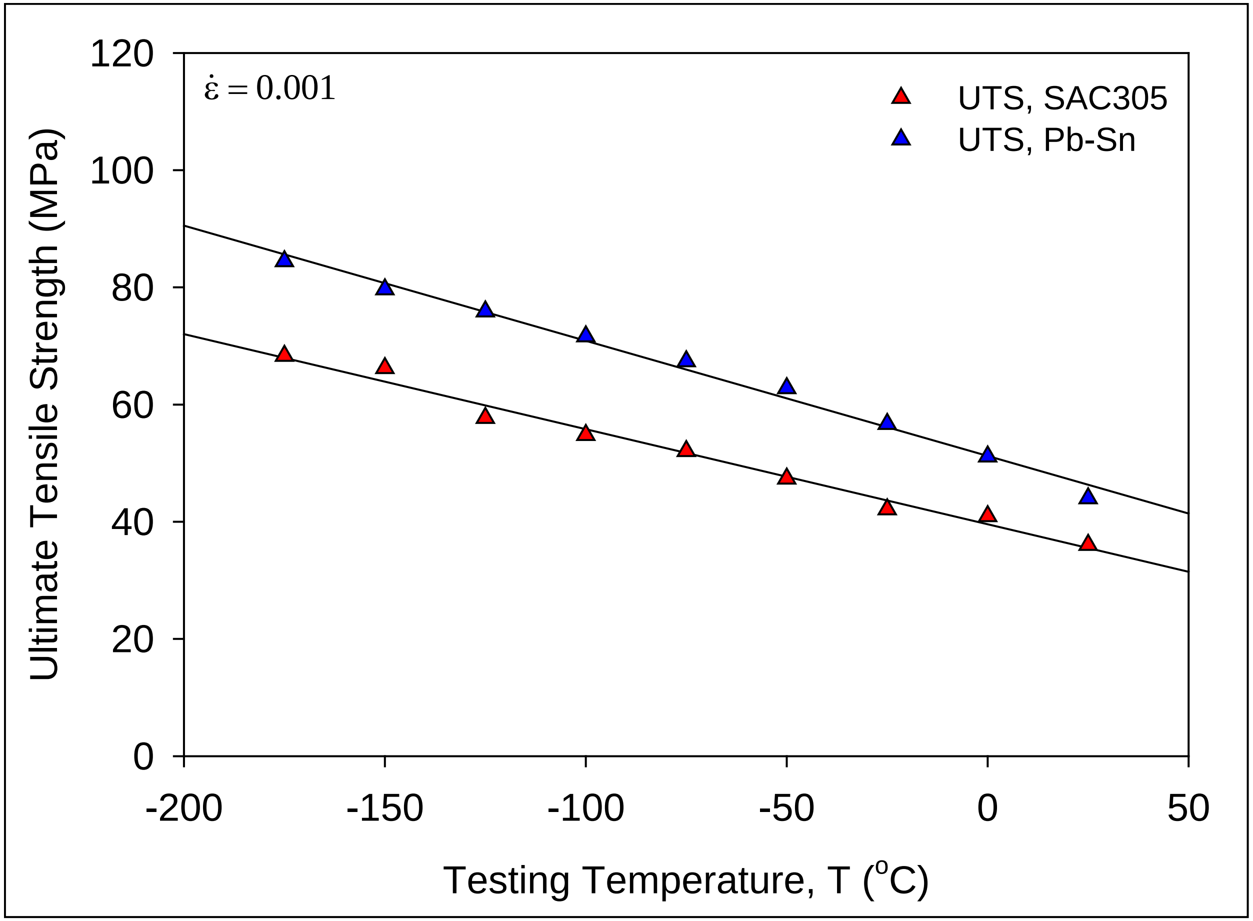
TESTING RESULTS

Effect of Testing Temperature on Yield Strength



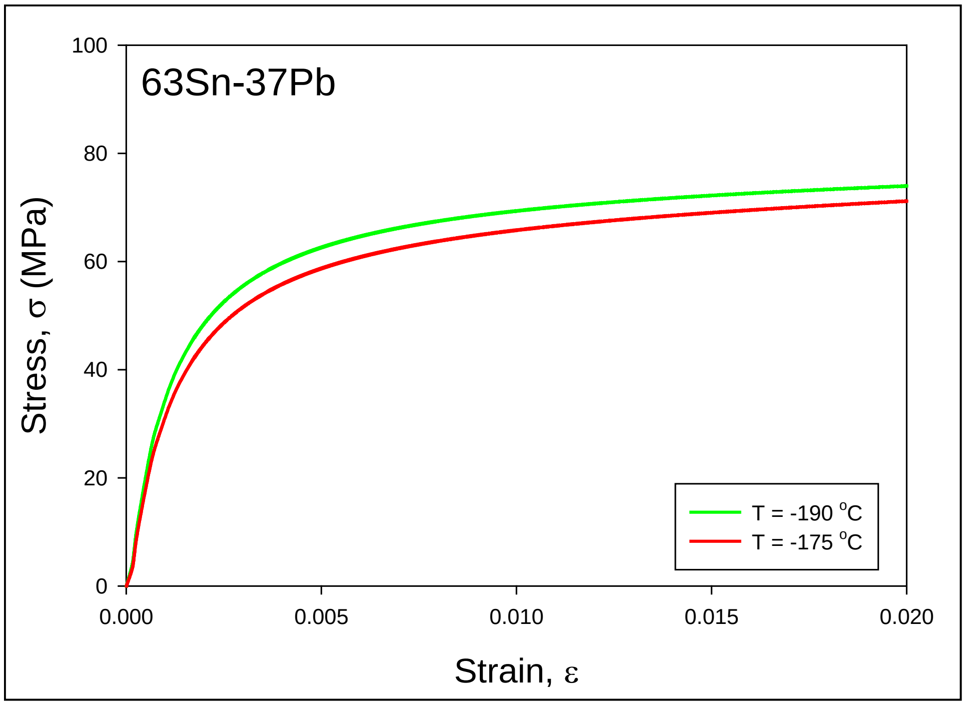
TESTING RESULTS

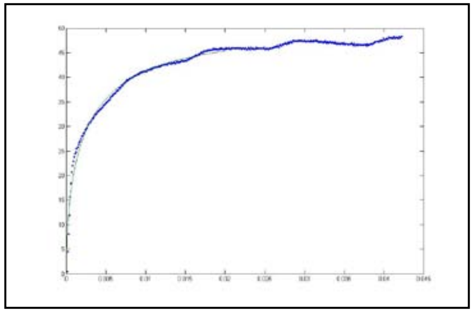
Effect of Testing Temperature on Ultimate Tensile Strength



LIQUID NITROGEN

Pushing the System to the Limit (-190 °C)





Testing Temperature	-190 °C	-175 °C
Elastic Modulus, E (GPa)	44.41	40.52
Yield Stress (MPa)	56.82	53.25
UTS (MPa)	89.31	78.99

COMPARISONS

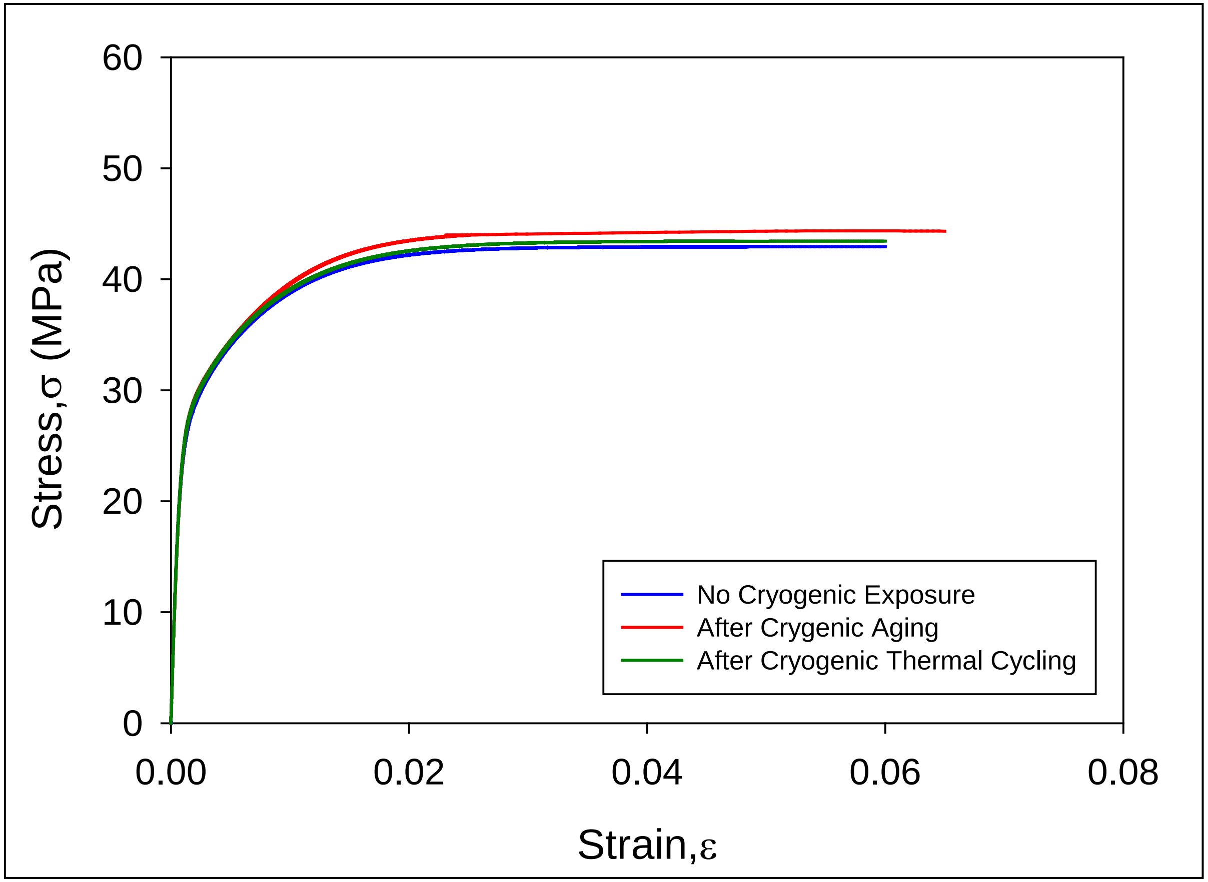
Mechanical Properties 63Sn37Pb

Testing Exposure	E (GPa)	UTS (MPa)
Room Temperature	35.5	42.9
Cryogenic Aging (24 Hours)	35.8	44.4
Cryogenic Cycling (100 Cycles)	35.7	43.4

Conclusion: No Changes!

COMPARISONS

Stress-Strain Curves 63Sn37Pb



<u>Conclusion</u>: No Changes!

SUMMARY AND CONCLUSIONS

- Preliminary Tensile Tests were performed on Solder Alloys (SAC 305 and 63Sn-37Pb) at Various Testing Temperatures Including Extreme Low Temperatures (T = -175 ºC).
- As Expected, the Elastic Modulus, Yield Strength, and UTS Decrease Linearly with the Testing Temperature.
- Tensile Tests have been Performed on SAC 305 Samples that have been Subjected to:
  - No Cryogenic Exposure
  - Cryogenic Aging (Immersion in LN_2 for 24 Hours)
  - Cryogenic Thermal Cycling (100 Immersions in LN_2 and Heated Water (~20 C))
- The Measured Data Demonstrate That There is No Significant Change in the Stress-Strain Behavior of the SAC Alloy Due to the Cryogenic Exposures

Tin Whisker Research Area

Current Projects

- **P09-401**
  - **Sn Whisker Growth from Sputtered SAC 305 Film on Brass**
- **P09-402**
  - **Mitigation of Sn Whisker Growth Using a Ni Underlayer**
- **P09-403**
  - **Whisker Growth During Exposure to Controlled Humidity**
- **P09-404**
  - **Sn Whiskers Formed in Electric Fields**

Sn Whisker Growth from Sputtered SAC 305 Film on Brass

CAVE Review, March 2010

E. R. Crandall, M. J. Bozack, and G. Flowers

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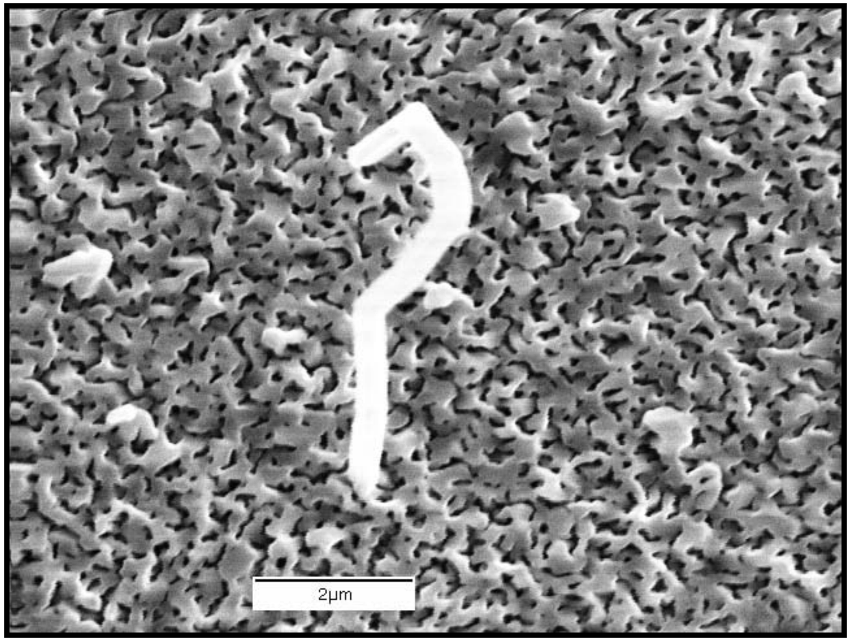


Sn Whisker Growth from Sputtered SAC 305 Film on Brass

- **Rationale and Objectives:**

-SAC305 is now one of many common replacements for eutectic 63Sn-37Pb solder

-Does SAC 305 pose a whisker reliability risk in our electronics?

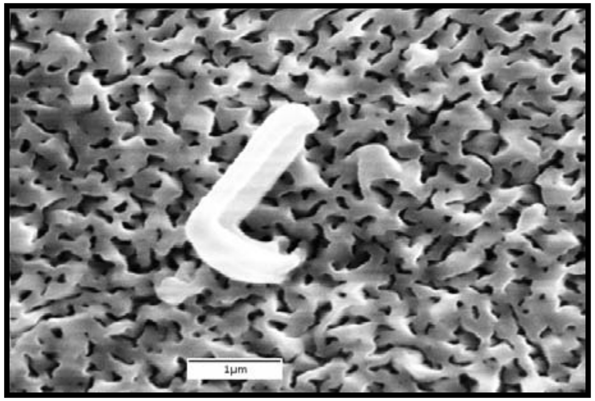
-If SAC produces whiskers, what are the statistics and characteristics of these whiskers?

-Are they a threat?

Whisker Growth Statistics

36 Days of Incubation

SAC Thickness (Å)	Whisker Density (cm^{-2})	Average Whisker Length (μm)	Standard Deviation (μm)	Mode* (μm)
2400	1048	2.3	0.7	2

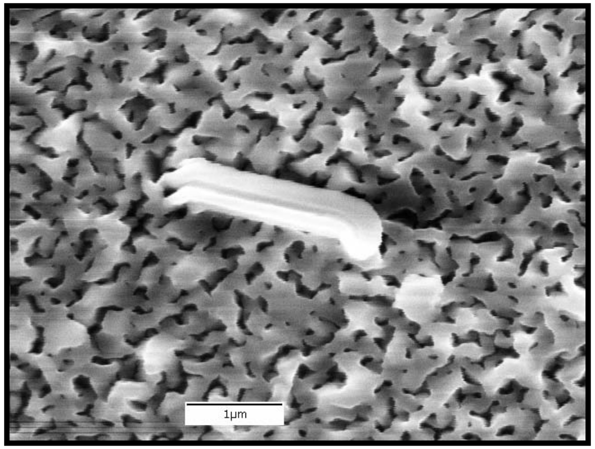


13,500 X

100 Days of Incubation

SAC Thickness (Å)	Whisker Density (cm^{-2})	Average Whisker Length (μm)	Standard Deviation (μm)	Mode (μm)
2400	12,444	3.3	1.7	2

*Mode is defined as the most frequently observed whisker length



14,000 X

30

SAC and Sn on Polished Brass

Whisker Growth Comparison

Sn on Polished Brass (old work)

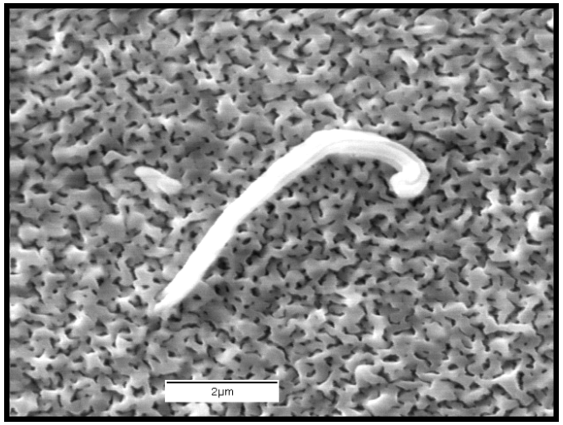
Sn Film Thickness (Å)	Whisker Density (cm^{-2})	Average Whisker Length (µm)	Standard Deviation (µm)	Mode
3000	4666	33.9	49.8	5

SAC on Polished Brass (current work)

SAC Thickness (Å)	Whisker Density (cm^{-2})	Average Whisker Length (µm)	Standard Deviation (µm)	Mode* (µm)
2400	12,444	3.3	1.7	2

After similar incubation times . . .

- **The SAC film produced a > 2.5X higher whisker density than the pure Sn film.**
- **However, the average whisker length on pure Sn is >10X that on SAC.**



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Conclusions

- **A SAC 305 film on brass has been shown to produce whiskers. After 100 days of incubation, the whisker density exceeds 12,000 whiskers/cm^2, but the average whisker lengths are only around 3 μm.**
- **SAC on brass produced > 2.5X the whisker density of Sn on brass but the Sn on brass sample grew whiskers > 10X longer than the average length on SAC.**
- **After ~100 days of incubation time, there is no evidence of a plateau in the whisker number vs time plot for the SAC film.**
- **EDX/XPS show the presence of Ag on the deposited film, which means that the film does not suffer from incongruent sputtering effects and is truly a SAC film.**

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The Two Consortia Meet

Materials Analysis Report
Center for Advanced Vehicle and Extreme Environment Electronics ($CAVE^3$)
Auburn University

M. J. Bozack and E. R. Crandall

March 15, 2010

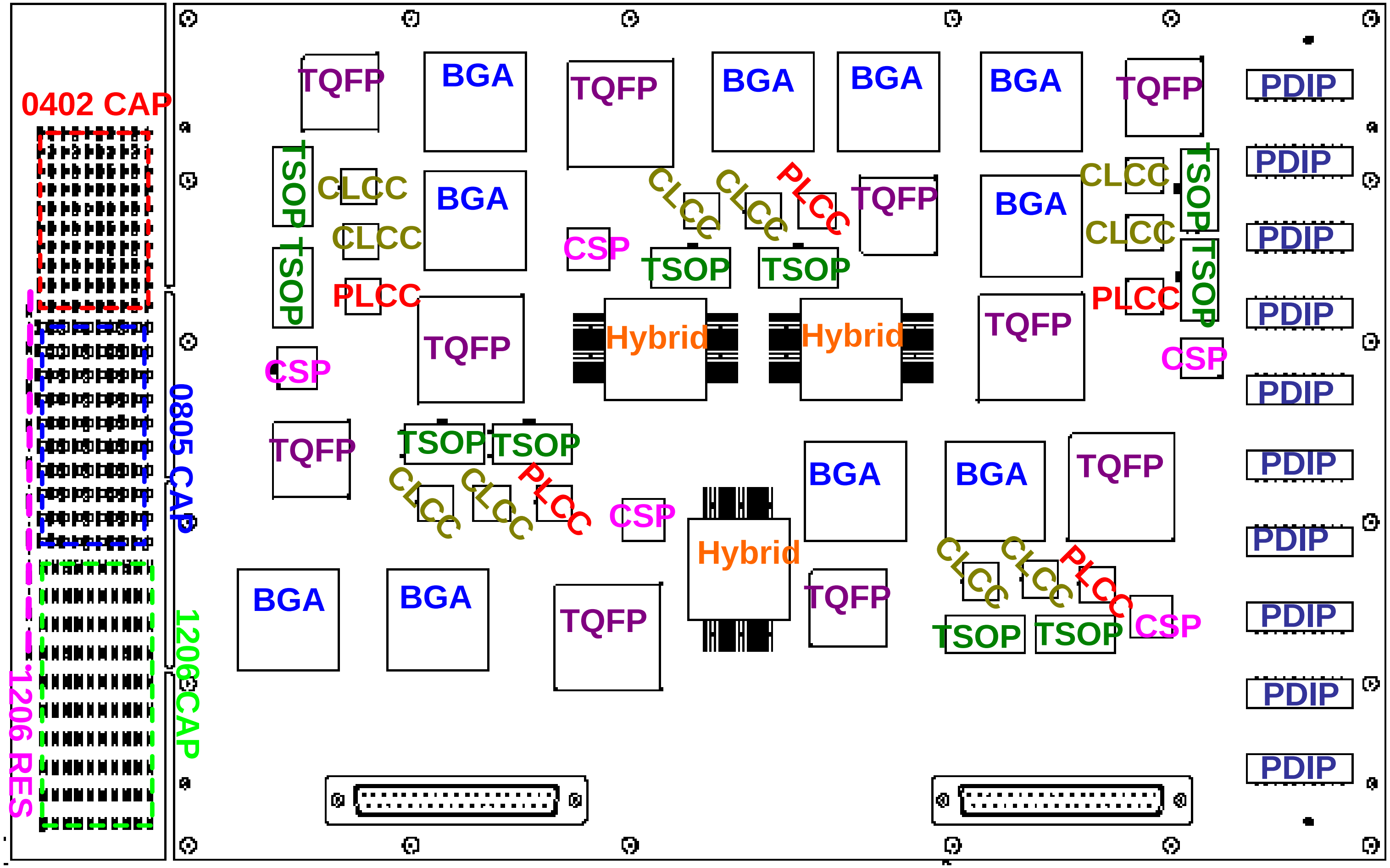
Whisker Search on Mechanical and Thermal Shock Components

Kurt Kessel
Kennedy Space Center, FL

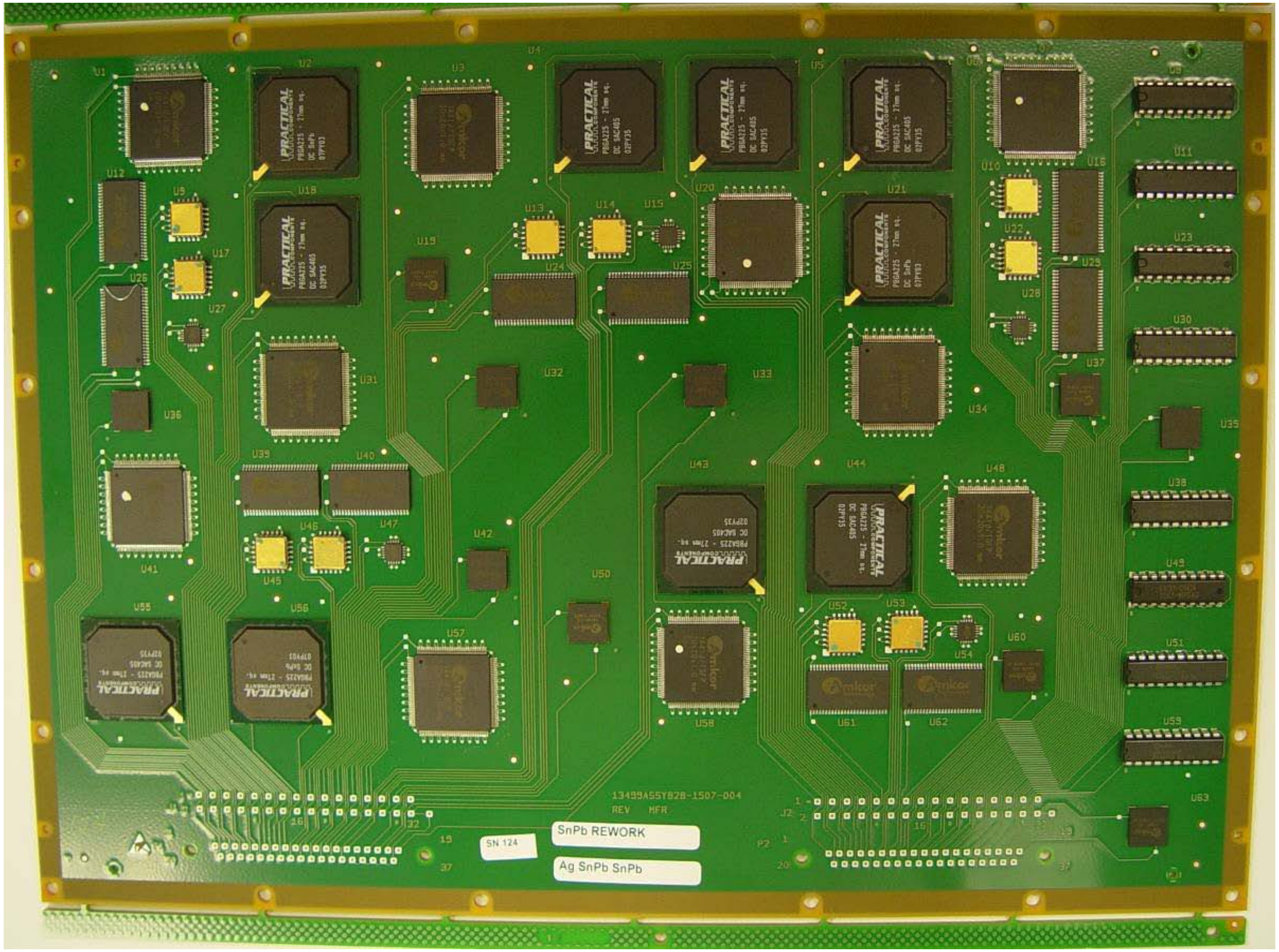
CAVE^3 Tin Whisker Investigation

- CAVE^3 at Auburn University examined five JCAA/JG-PP test boards for tin whiskers using Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectroscopy (EDX)
- The boards were assembled in July 2004
- Three boards had been mechanically shocked and two had been thermally shocked
- Per NASA's request the investigation focused on TSOPs and TQFPs with finishes of Sn, SnCu, NiPdAu, and SnPb

CAVE³ Tin Whisker Investigation



CAVE^3 Tin Whisker Investigation



CAVE^3 Whisker Investigation

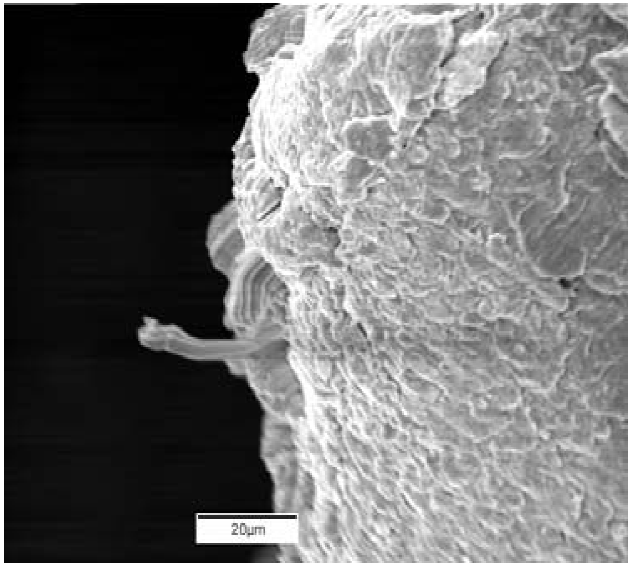
- **Whisker Observation Summary**
- **Whisker Characteristics vs. Finish Type**

Component Finish	Whisker Observations	Typical Whisker Diameter (µm)	Typical Whisker Length (µm)
NiPdAu	No Whiskering	----	----
Sn	Intermediate Whiskering	9	7 - 25
SnCu	Sporadic Whiskering	5	10 - 30
SnPb	Significant Whiskering	7	5 - 25

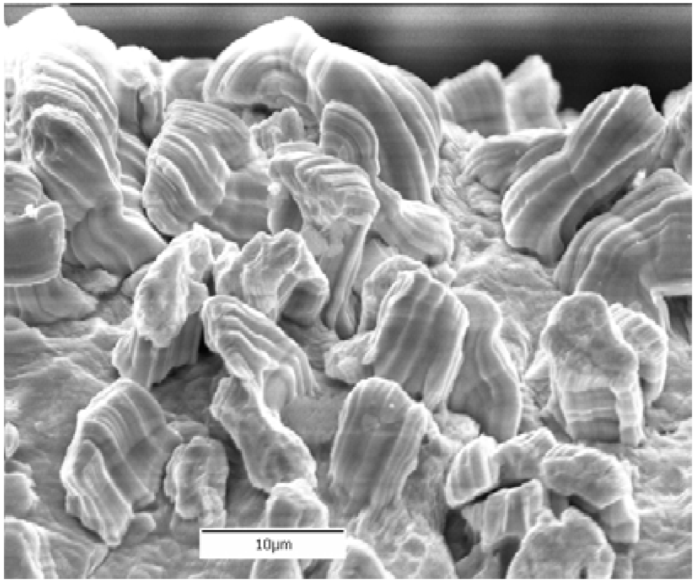
Lead Free Solder

CAVE^3 Whisker Investigation

Thermal Shock Test Board
S/N 82, Manufactured SAC Board
U12/TSOP-50/SnCu



Thermal Shock Test Board
S/N 158, Reworked SAC Board
U26/TSOP-50/SnPb



CONCLUSION

- We find a great value in participating in Consortia research that is of basic interest to NASA
- We leverage our research dollar
- We draw on the experience of technical experts
- We have access to data not available to Non-members

QUESTIONS ?????