SAND2019-9750PE

Low and Medium Melting Temperature Solders

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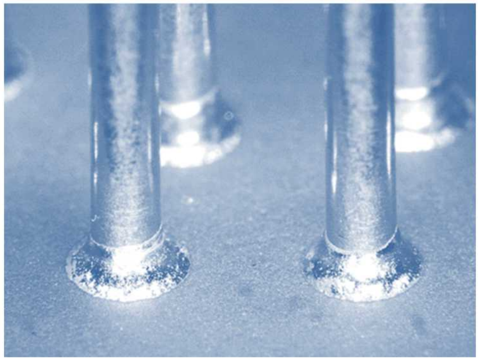

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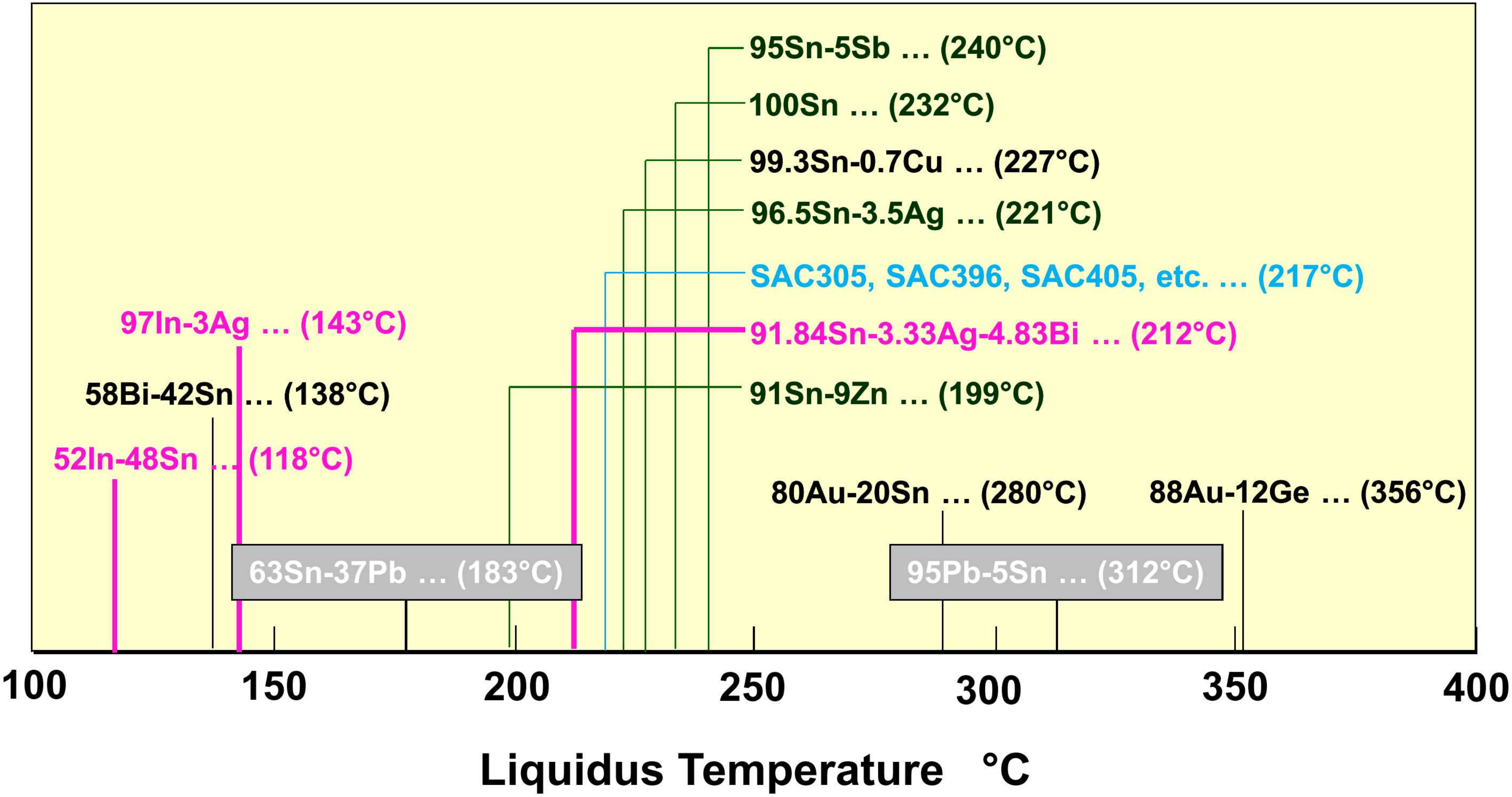
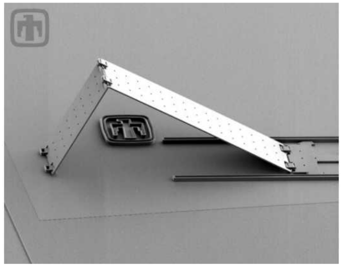
Materials – Alloy Compositions

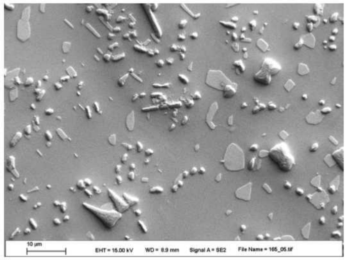
- **The definition of low, medium, and high melting temperature solder has evolved over the history of Pb-free solders : *1986 – present*.**



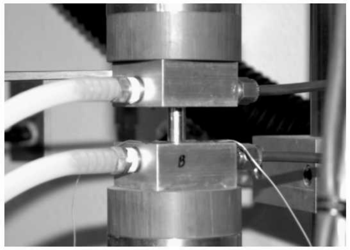
Outline

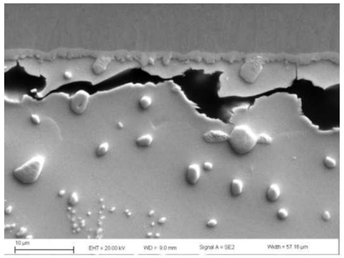


- **“Traditional” Low Melting Temperature Solders**
  - **97In-3Ag (wt.%), 58Bi-42Sn, 52In-48Sn**
- **“Current” Medium Melting Temperature Solders**
  - **91.84Sn-3.33Ag-4.83Bi**
  - *Sn-Ag-Bi-X-Y-Z-etc.*



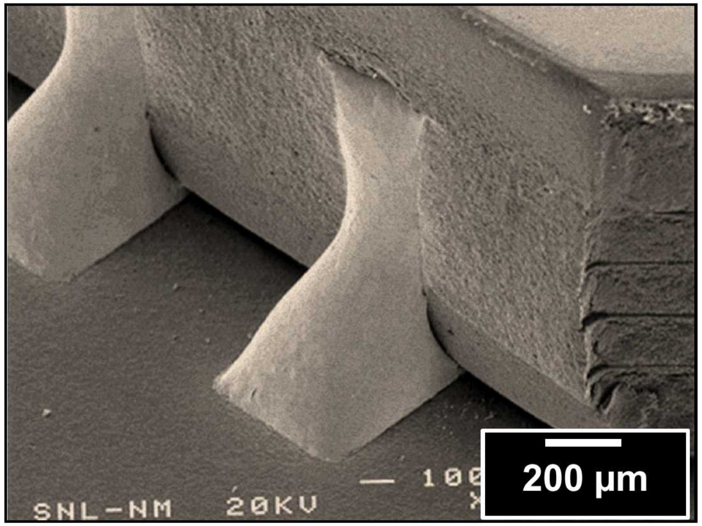
- **“Novel” Medium Melting Temperature Solders**
  - **66Sn-5.0Ag-10Bi-5.0Au-10In-4.0Cu (T$_s$ = 178°C)**
- **Focus topics:**
  - ○ ***Physical metallurgy***
  - ○ ***Mechanical metallurgy***
  - ○ ***Thermal mechanical fatigue (TMF)***





Mechanical Metallurgy

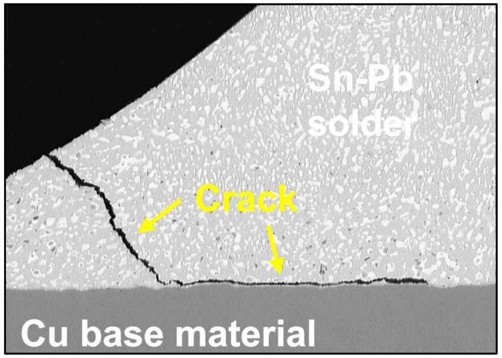
- **At room temperature, solder alloys are performing at temperatures that are equivalent to conditions in the combustion chamber of an operating jet engine   !!!**



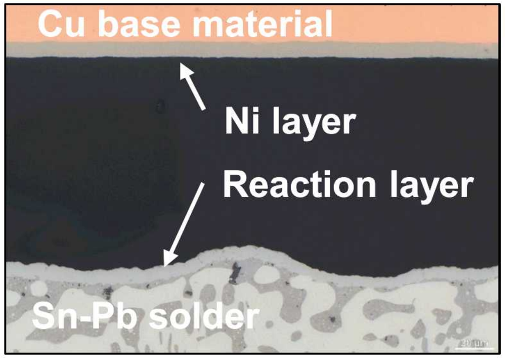
It’s HOT … *even when it’s not* ...

Mechanical Metallurgy

- **Traditionally, base materials were stronger than Sn-Pb solders.**
  - Solder joint failures occurred in the filler metal or at an interface.

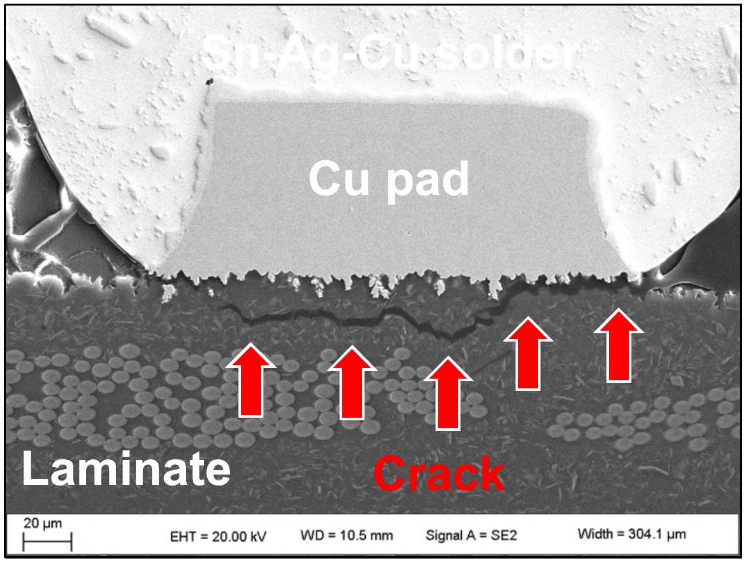


Solder (bulk) failure



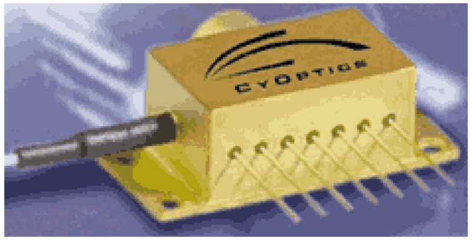
Interface failure

- **However, high strength solders can "push" the failure into printed circuit board (PCB) or component structures.**
  - As the strength of the solder increases, so does the risk of this "collateral damage."

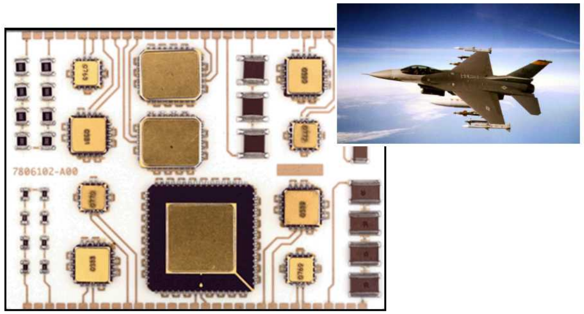


Traditional Low Temperature Solders

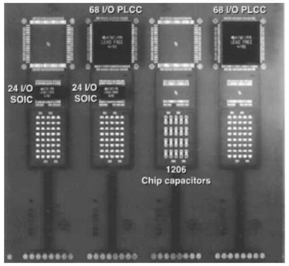
- **The three "traditional," low-temperature eutectic solders are:**
  - **52In-48Sn (wt.%): $T_s = T_l = 118°C$**
  - **97In-3Ag: $T_s = T_l = 143°C$**
  - **58Bi-42Sn: $T_s = T_l = 138°C$**

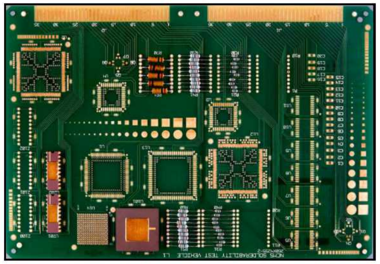


- **The In-Sn and In-Ag alloys are used in opto-electronics components and hybrid microcircuit (HMC) products.**



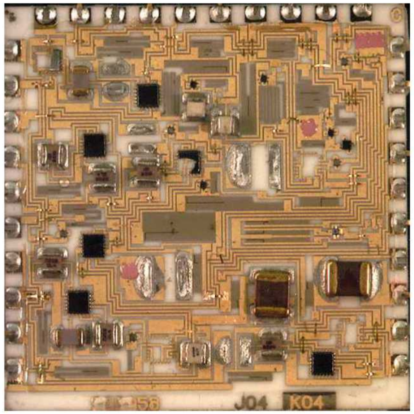
- **The In-Sn and Bi-Sn alloys were evaluated for solder joints on organic laminate, printed circuit board (PCB) test vehicles of *1990's technologies*.**





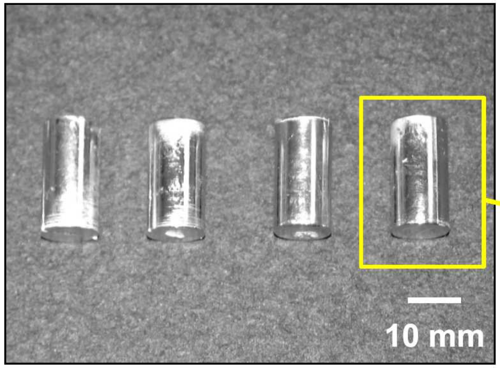
Traditional Low Temperature Solders

- **The 97In-3Ag and 58In-42Sn were suitable replacements for Pb- and Cd-containing solders used on hybrid microcircuit (HMC) products.**



Established alloys		Replacement alloys
• In-Pb-Ag	→ → →	In-Ag
• In-Sn-Pb-Cd	→ → →	In-Sn

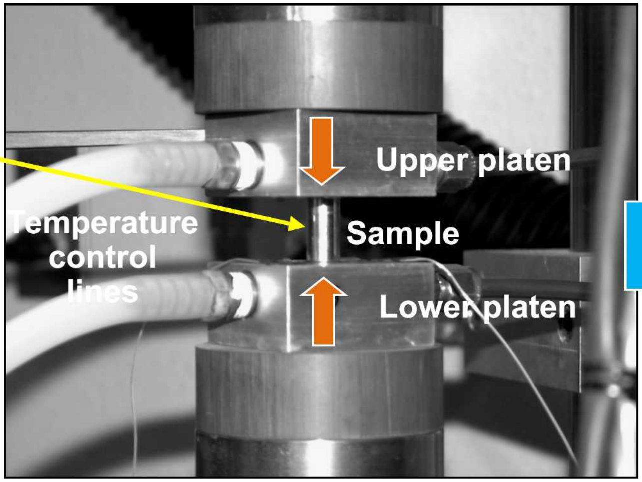
- **Modeling and test programs examined both time-independent and time-dependent mechanical properties of In-Ag and In-Sn.**

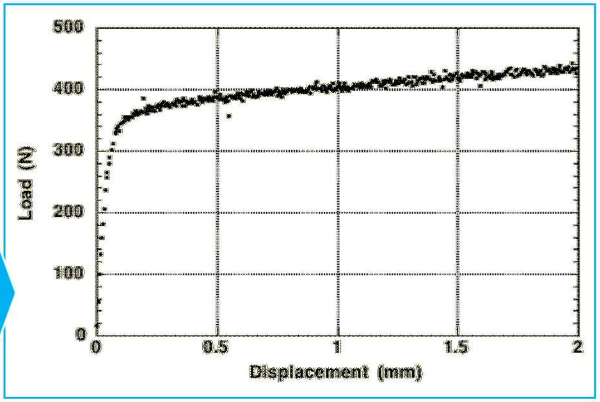


Test specimens

P. Vianco, et al., J. Mater Sci. (2006)

Compression test

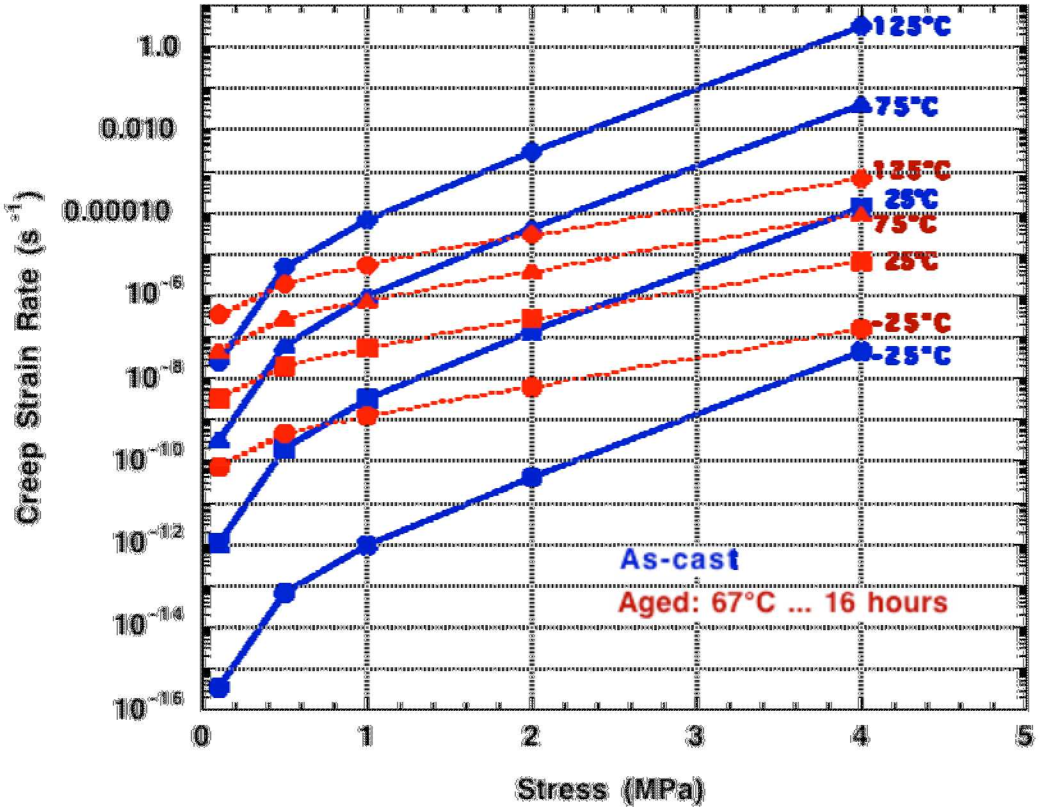




Stress-strain, In-Ag (25°C)

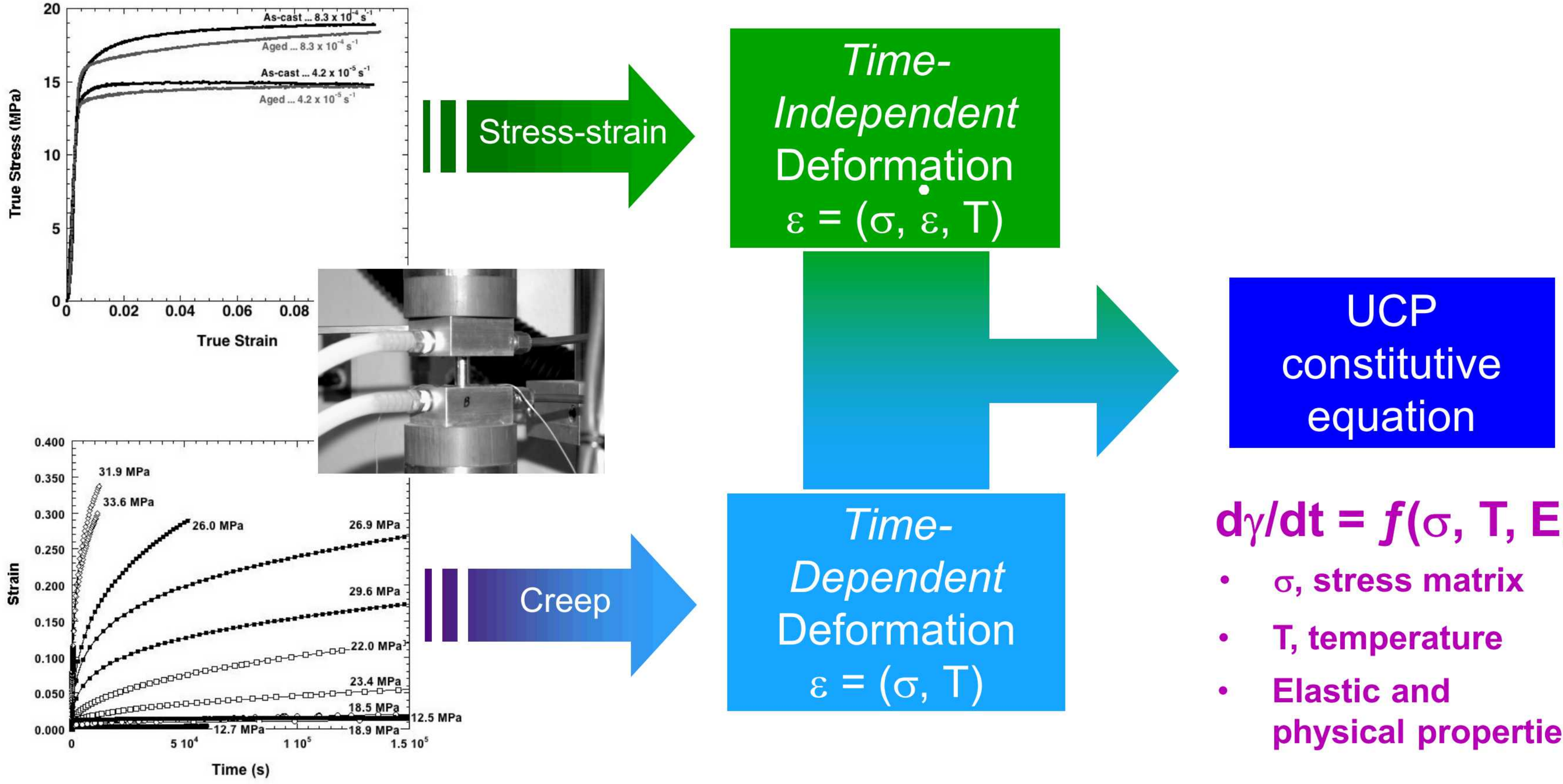
Traditional Low Temperature Solders

- **As the solidus temperature decreases, mechanical properties can change significantly at seemingly innocuous temperatures.**
  - **The eutectic 97In-3Ag alloy ($T_s = T_l = 143°C$) experiences orders-of-magnitude changes to creep rate after aging at 67°C for 16 hours.**



Traditional Low Temperature Solders

- **The computational modeling approach was used, which was based upon the unified creep-plasticity (UCP) equation.**
  - **Combine time-independent and time-dependent deformation behaviors into a single UCP constitutive equation; $d\gamma/dt = f(\sigma, T, E)$.**



Stress-strain

Time-Independent Deformation
$\varepsilon = (\sigma, \dot{\varepsilon}, T)$

Creep

Time-Dependent Deformation
$\varepsilon = (\sigma, T)$

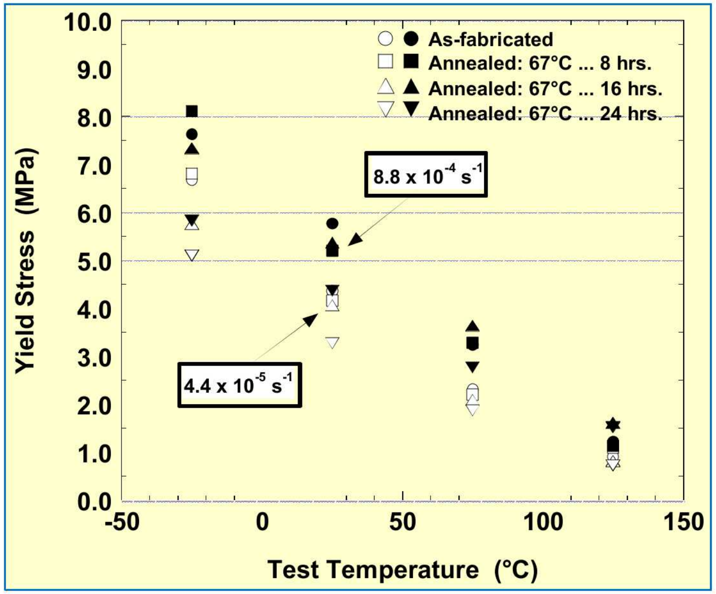
UCP constitutive equation

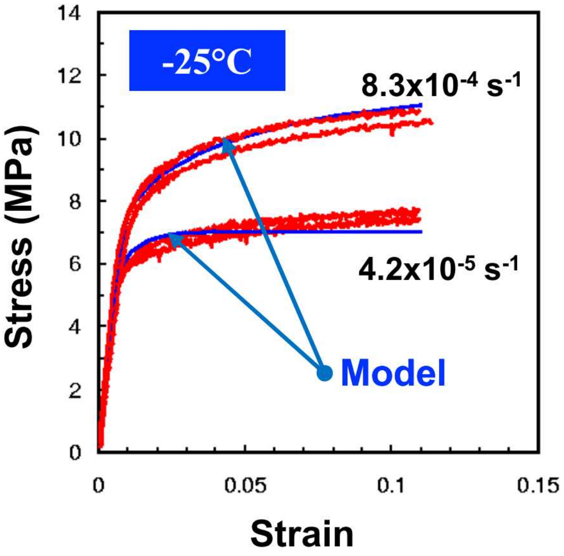
$d\gamma/dt = f(\sigma, T, E)$

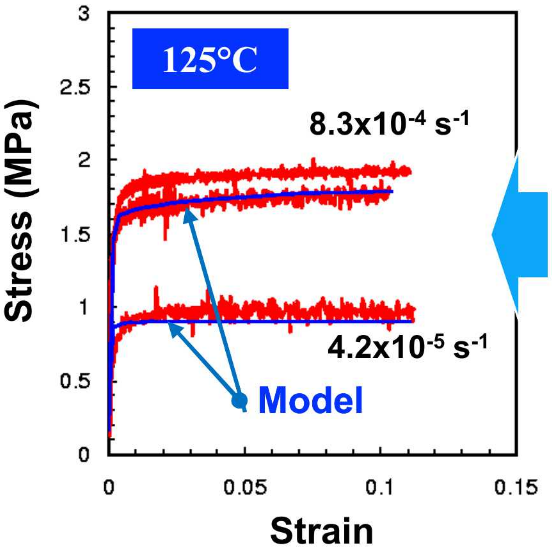
- **σ, stress matrix**
- **T, temperature**
- **Elastic and physical properties**

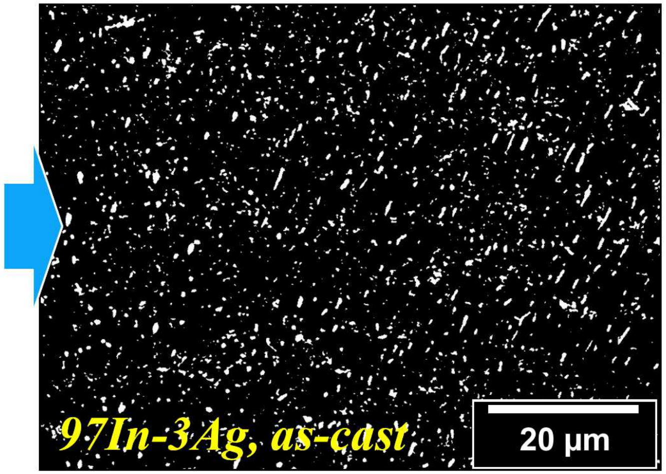
Traditional Low Temperature Solders

- **In-Ag solder:** The time-independent deformation curves were also used to validate the UCP equation.
  - The stress-strain curves provided a first-level validation of the model.
  - The microstructure/mechanical properties relationship is not always well-understood for these solders.





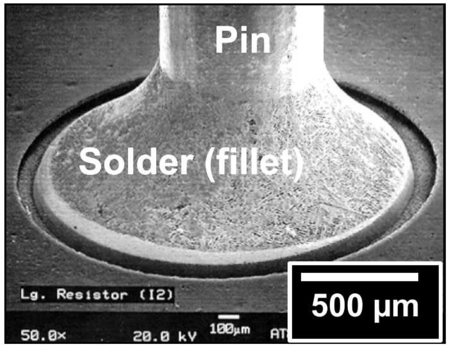


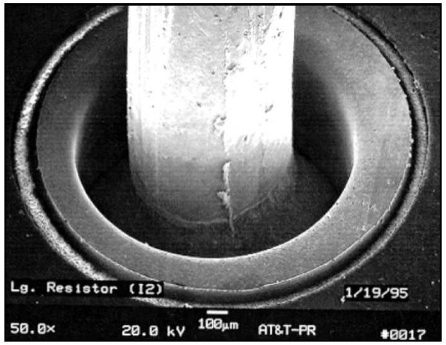


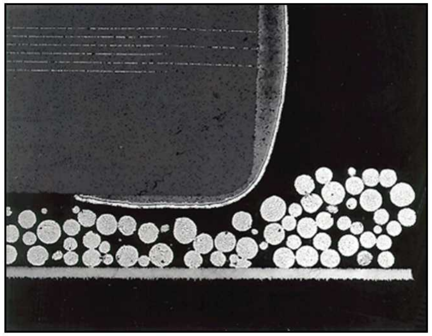
Traditional Low Temperature Solders

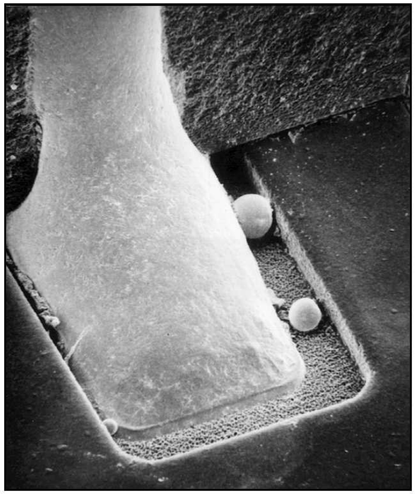
- **Solderability controls the final joint geometry (fillet size, voids, etc.), which in turn, affects long-term reliability.**

58Bi-42Sn







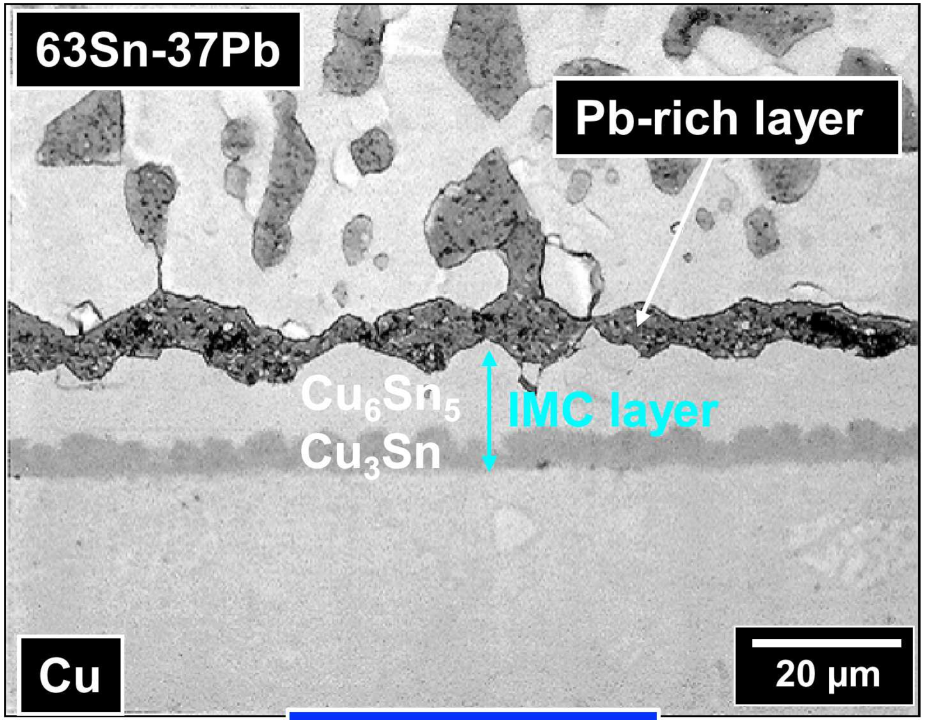


  - **In this instance, the flux did not activate at the *low* soldering process temperature – 160°C.**

- **The adoption of the Sn-Ag-Cu alloys further curtailed the impetus for suppliers to develop low-temperature fluxes.**

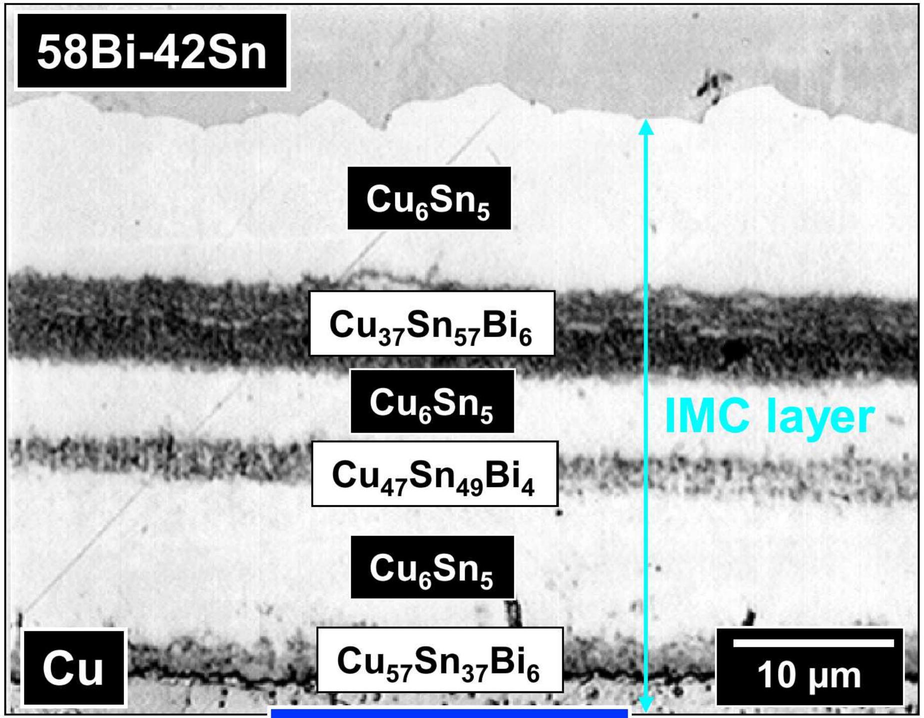
Traditional Low Temperature Solders

- **The interface reactions were documented for the Sn-Bi alloy on Cu.**
  - **Elements in the solder, which are rejected by the interface reaction, form a layered microstructure.**



135°C, 40 days

P. Vianco, et al., JEM 24 (1995).

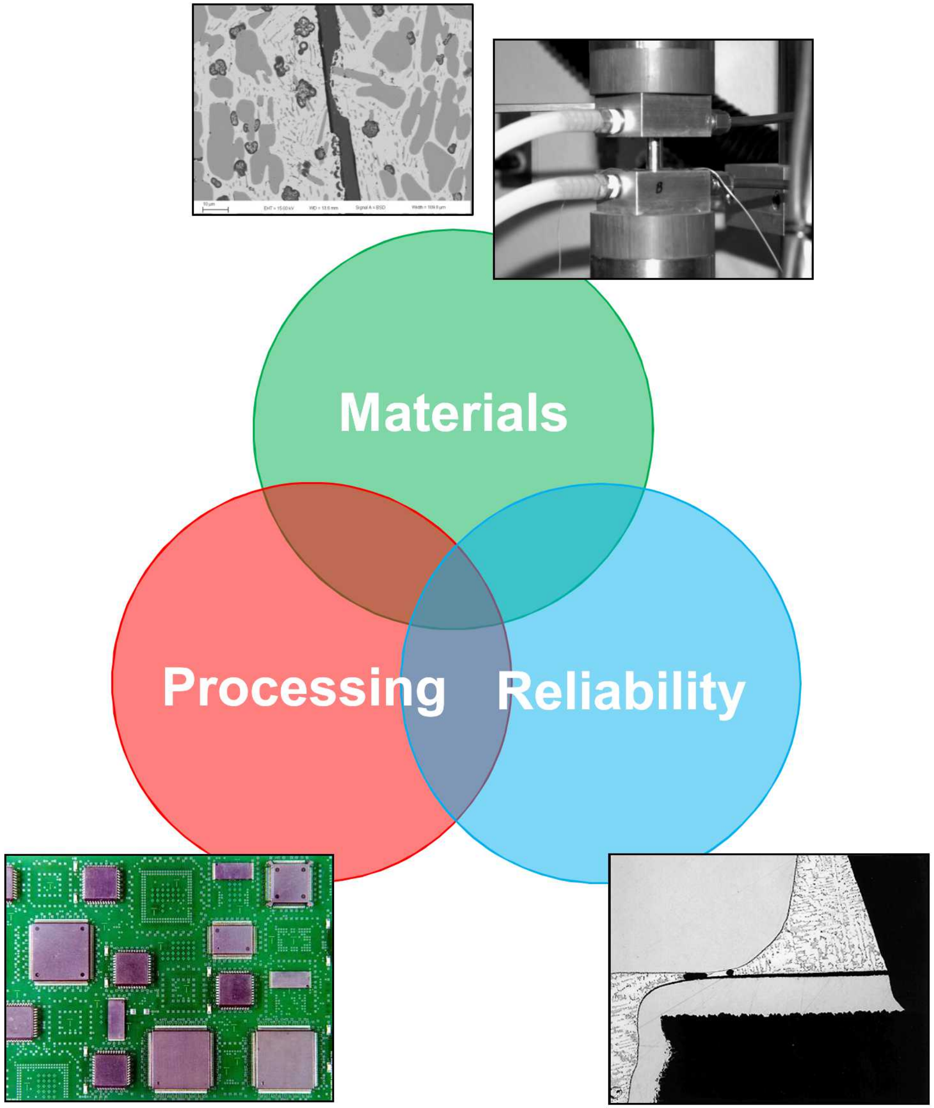


120°C, 40 days

Layered interfaces create paths of easy crack propagation.

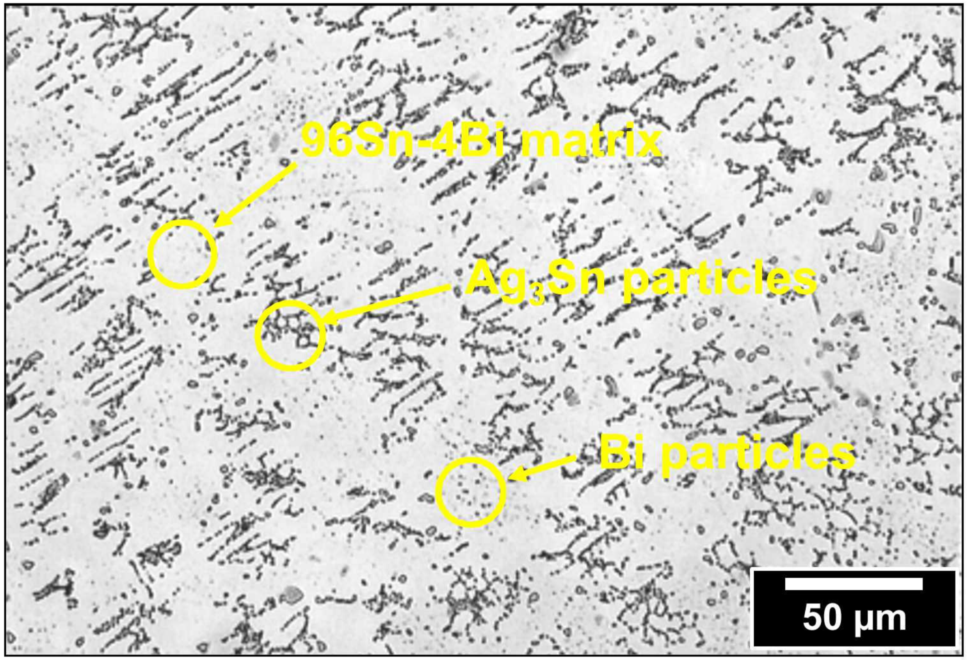
Medium Melting Temperature Solder – Sn-Ag-Bi

- **Materials**
  - Alloy microstructure
  - Mechanical performance
- **Processing**
  - Solderability performance
  - *Pb-contamination effects*
- **Reliability**
  - Interface reactions
  - Solder joint fatigue
  - *Pb-contamination effects*
- **Summary**



Medium Melting Temperature Solder – Sn-Ag-Bi

- The as-cast microstructure is shown below for the 91.84Sn-3.33Ag-4.83Bi (T_s - 212°C) alloy:



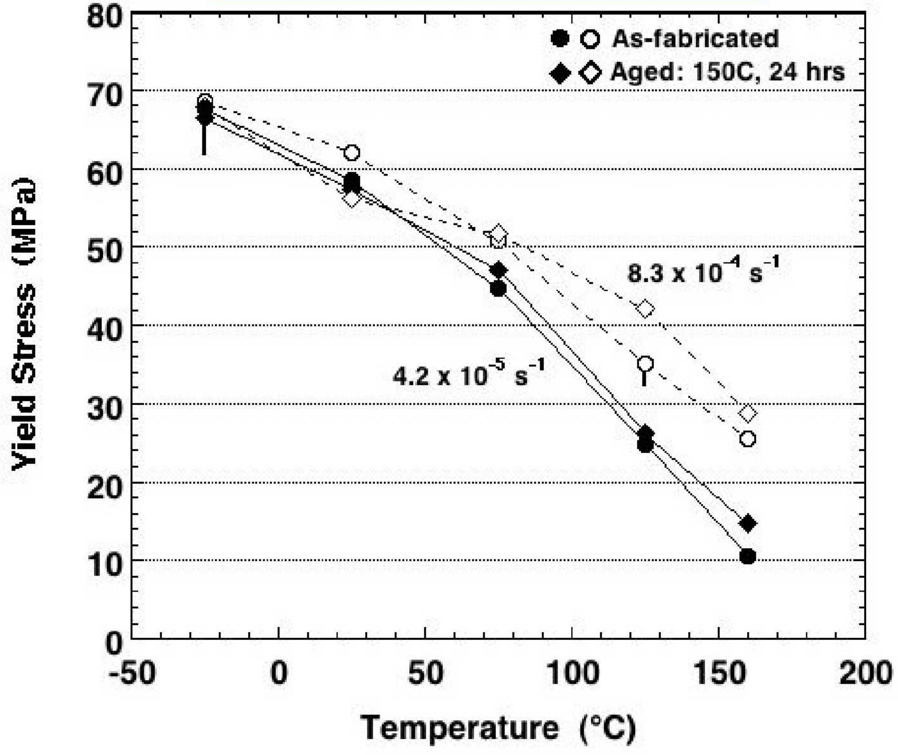
P. Vianco, et al., JEM 28 (1999).

- This solder was engineered to have the same strengthening mechanisms that are found in high-performance alloys:
  - Precipitation hardening
  - Solution strengthening

Medium Melting Temperature Solder – Sn-Ag-Bi

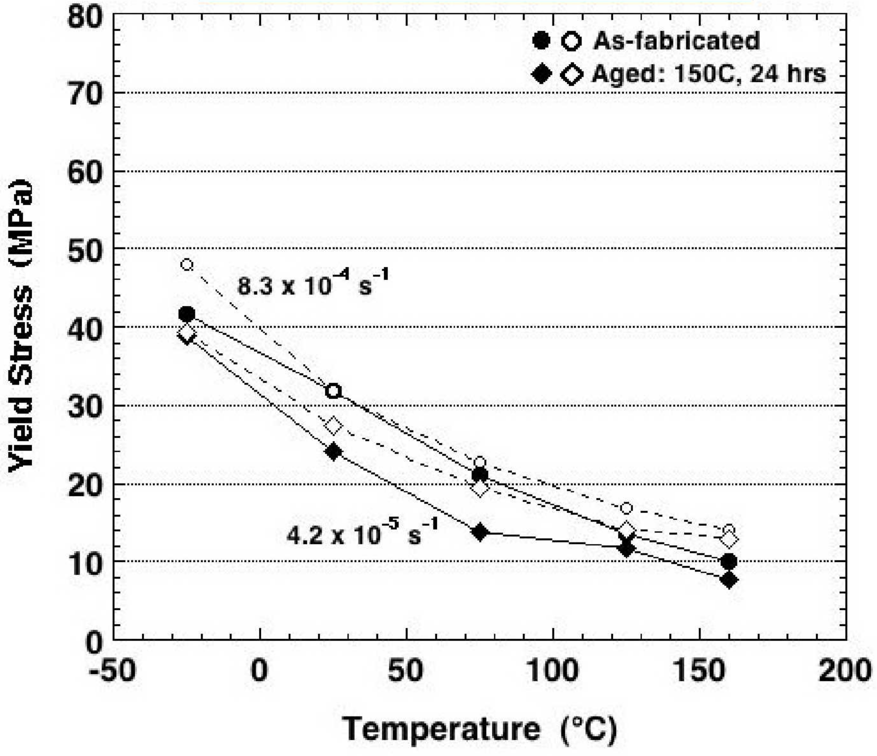
- **The improved strength of Sn-Ag-Bi is evidenced by its yield stress properties when compared to those of the SAC396 alloy.**
  - **The Sn-Ag-Bi maintains a higher strength over temperature and shows little sensitivity to aging (125°C or 150°C, 24 hours).**

91.84Sn – 3.33Ag – 4.83Bi



P. Vianco, et al., JEM *28* *(1999).*

95.5Sn – 3.9Ag – 0.6Cu

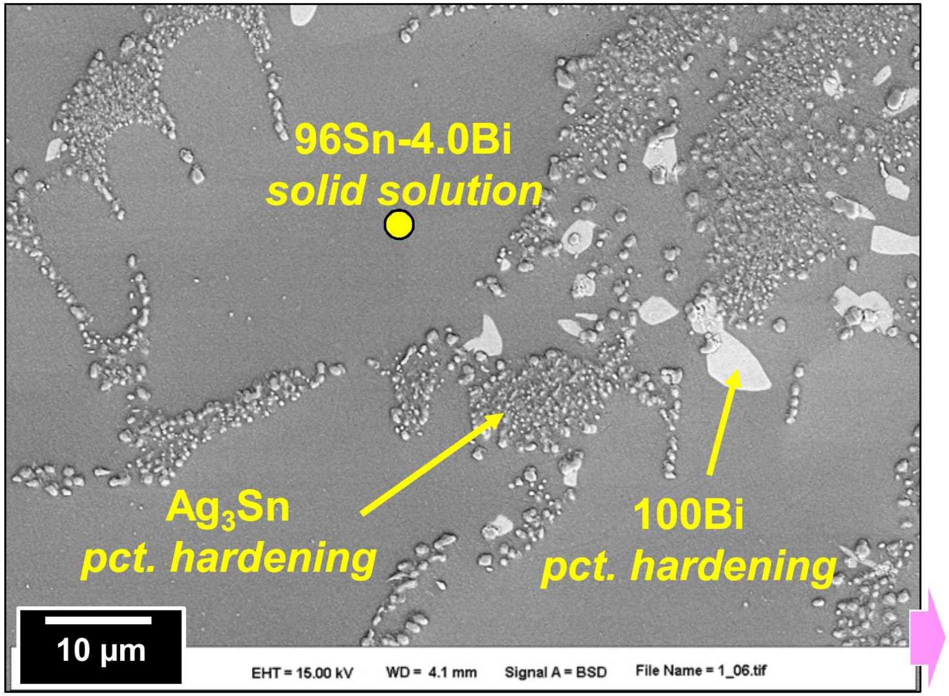


P. Vianco, et al., JEM *32* *(2003).*

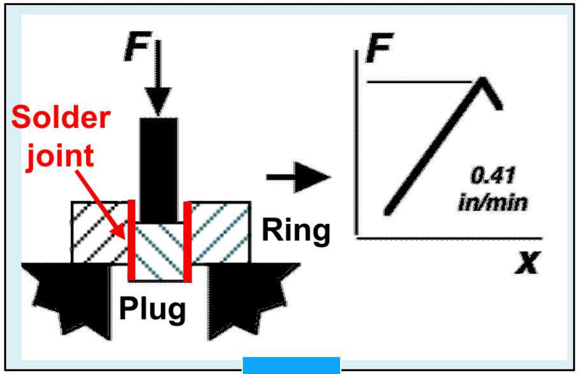
Medium Melting Temperature Solder – Sn-Ag-Bi

- **The solder is tested in joint configurations to include the effects of gap thickness and (area) footprint on mechanical performance.**
  - **The ring-and-plug shear test provides a method to measure the shear strength of Sn-Ag-Bi *solder joints*.**

91.84Sn – 3.33Ag – 4.83Bi



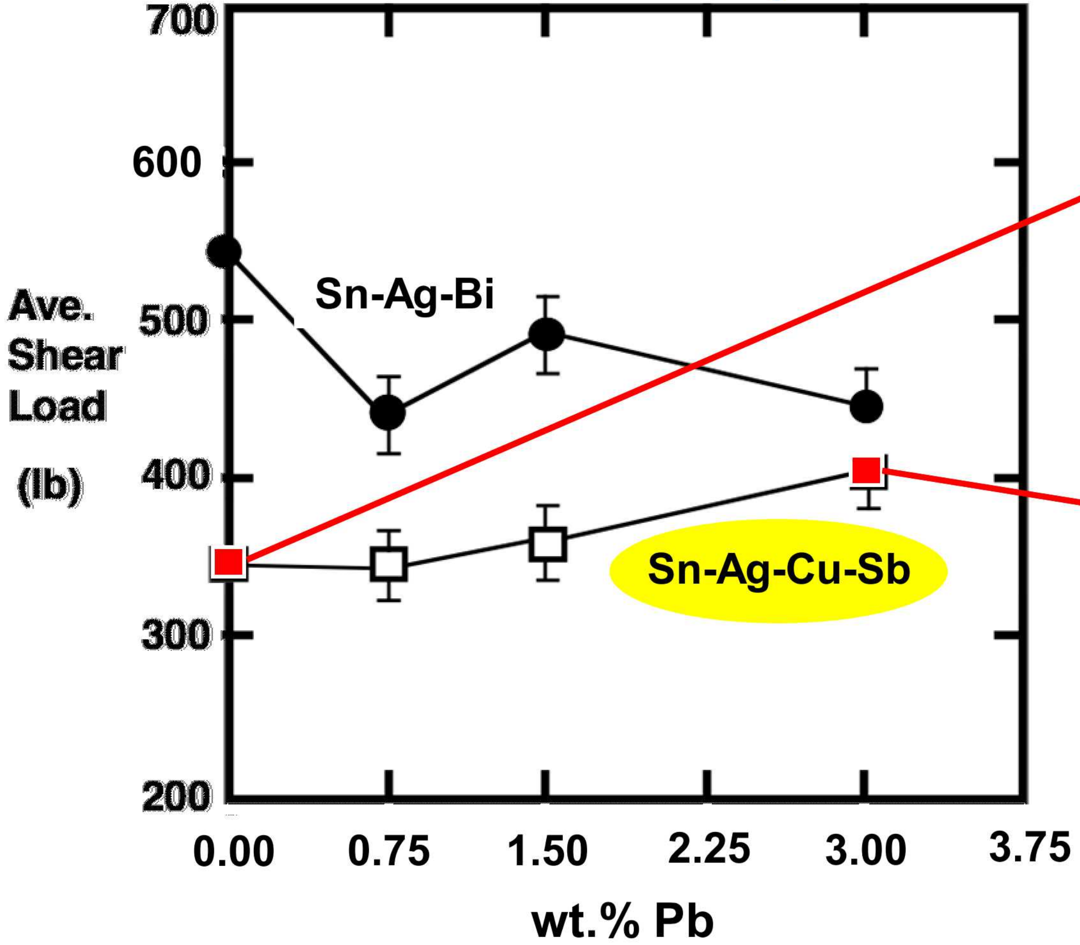
Ring-and-Plug Shear Test

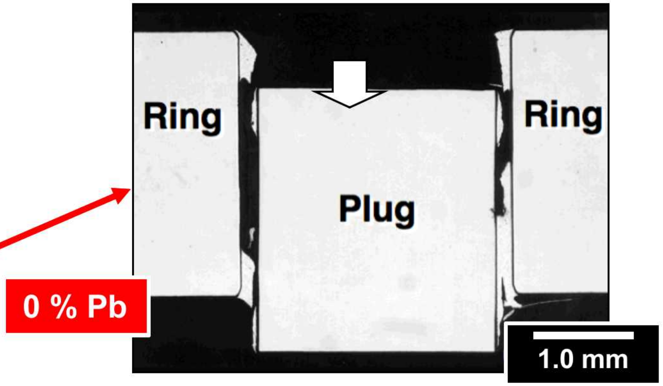


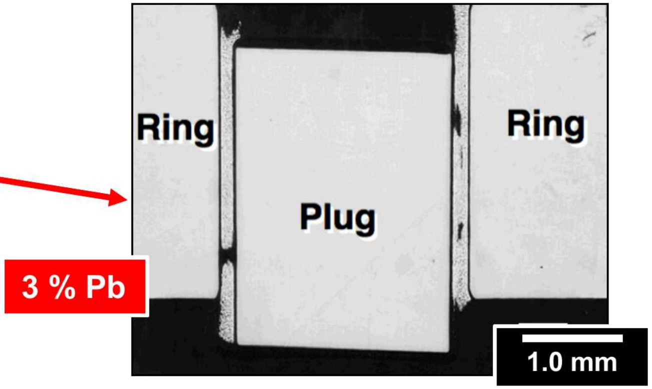
Solder	Stress (psi)
Sn-Pb	5840
Sn-Ag	7970
Sn-Ag-Bi	**11800**

Medium Melting Temperature Solder – Sn-Ag-Bi

- **Alloy additions affect the mechanical properties of the solder.**
  - **Additions of 0 – 3.75 wt.% Pb were made to two alloys.**



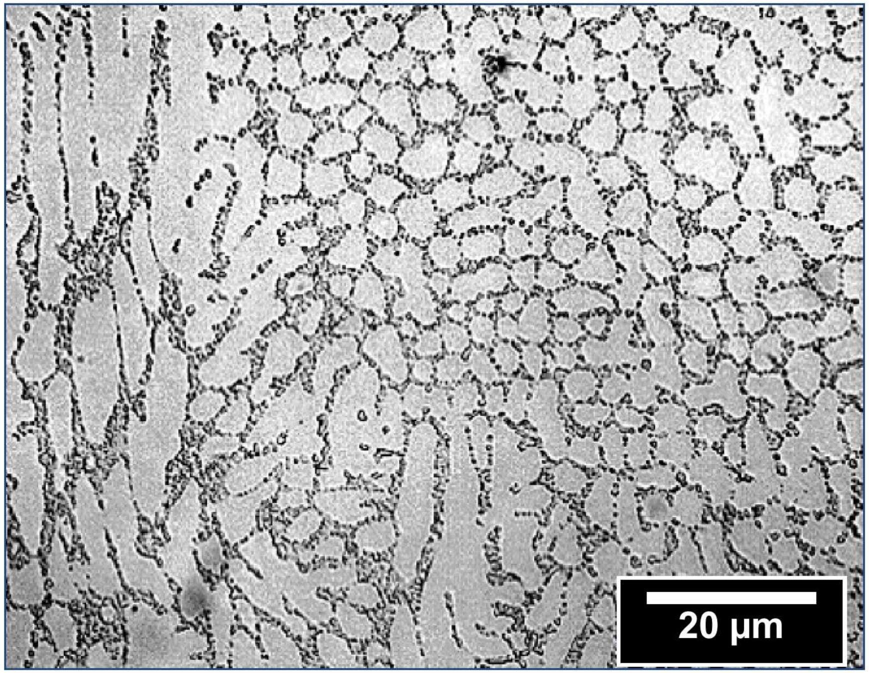




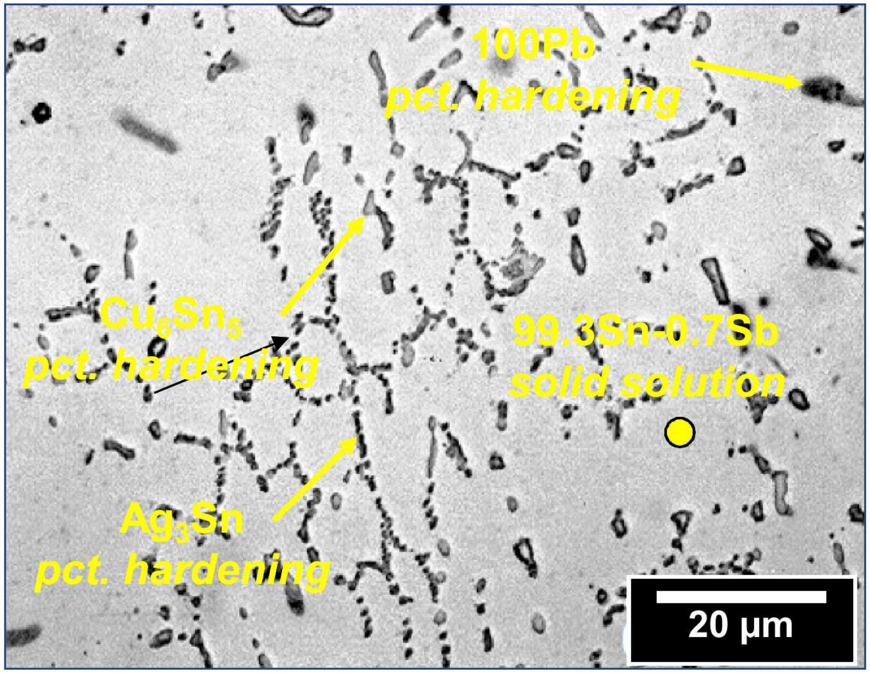
The strength increase was accompanied by a change of failure mode, from the bulk solder to the interface.

Medium Melting Temperature Solder – Sn-Ag-Bi

- **Sn-Ag-Cu-Sb: The addition of Pb broke up the Ag_3Sn particle network,** ***thereby enhancing the precipitation hardening effect.***



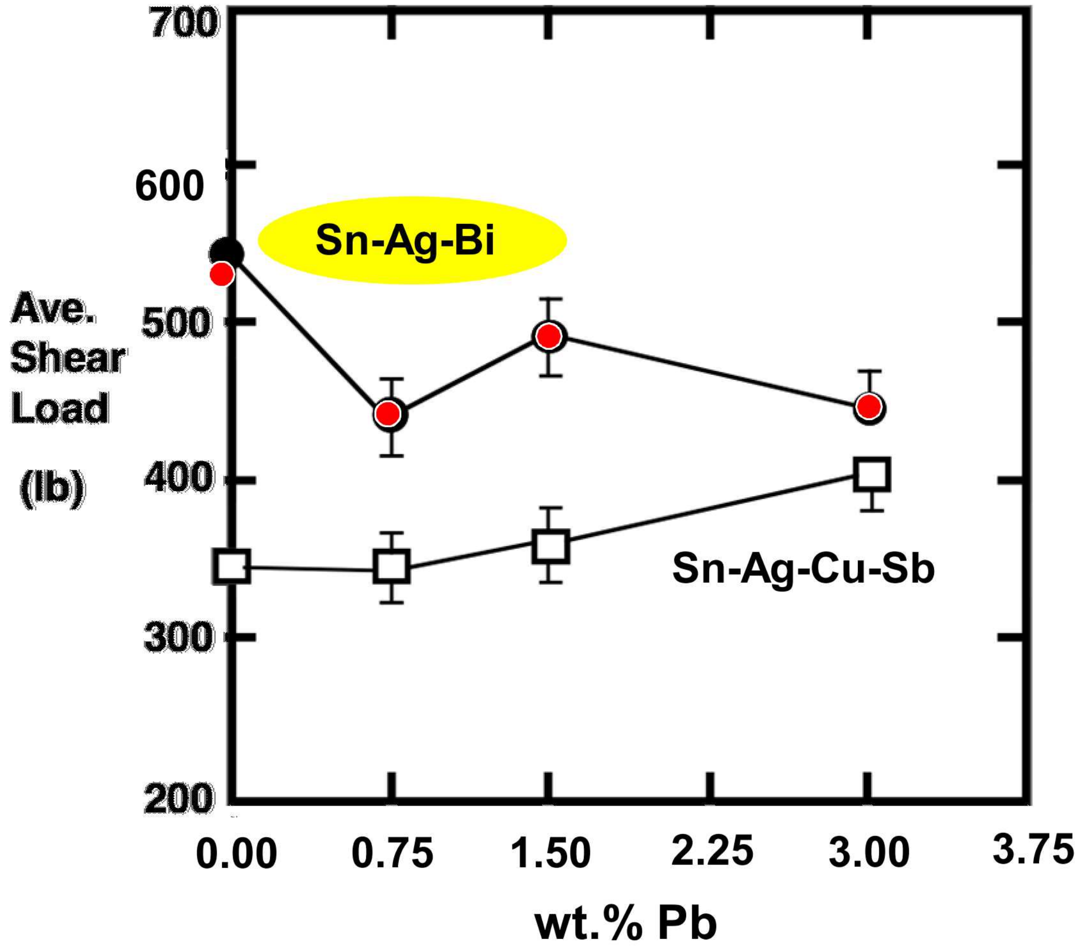
0.00 % Pb

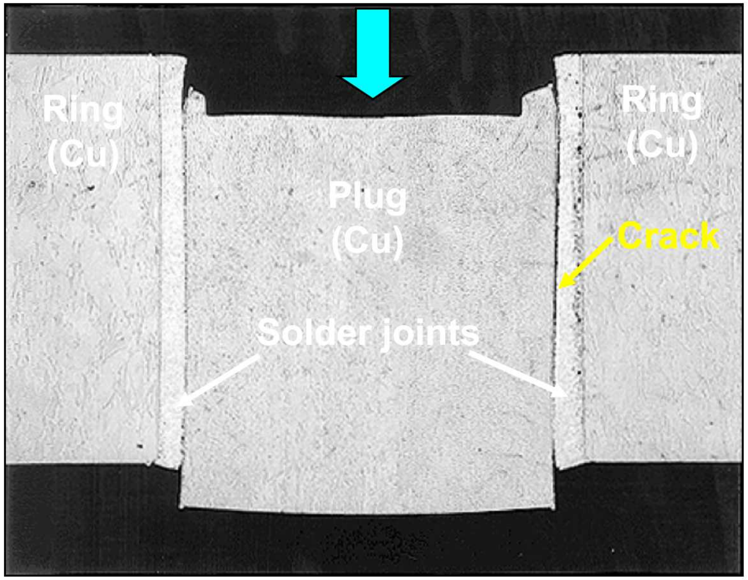


3.00 % Pb

Medium Melting Temperature Solder – Sn-Ag-Bi

- **Sn-Ag-Bi:** **The fracture path remained along the solder/base material interface for all Pb additions.**

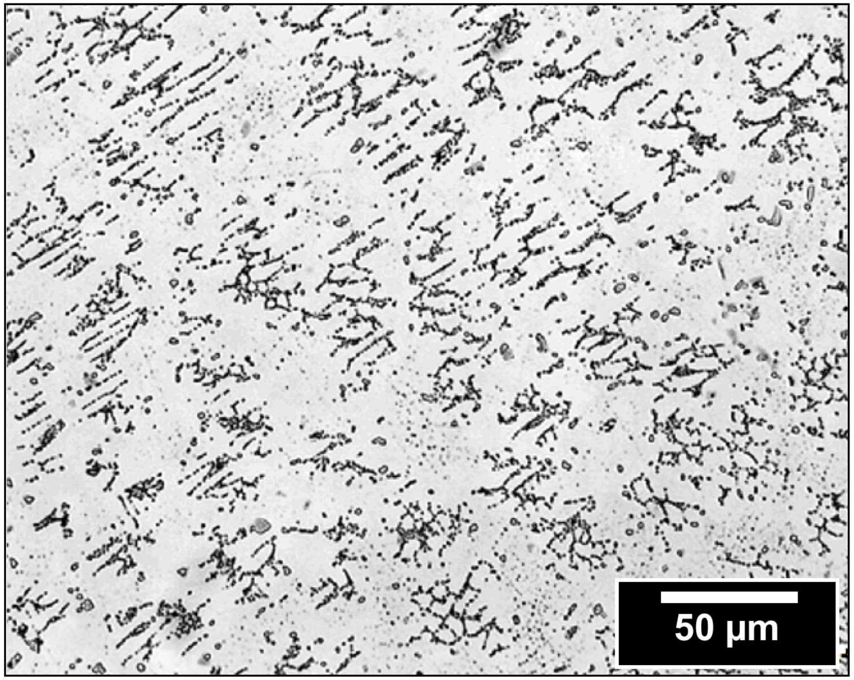




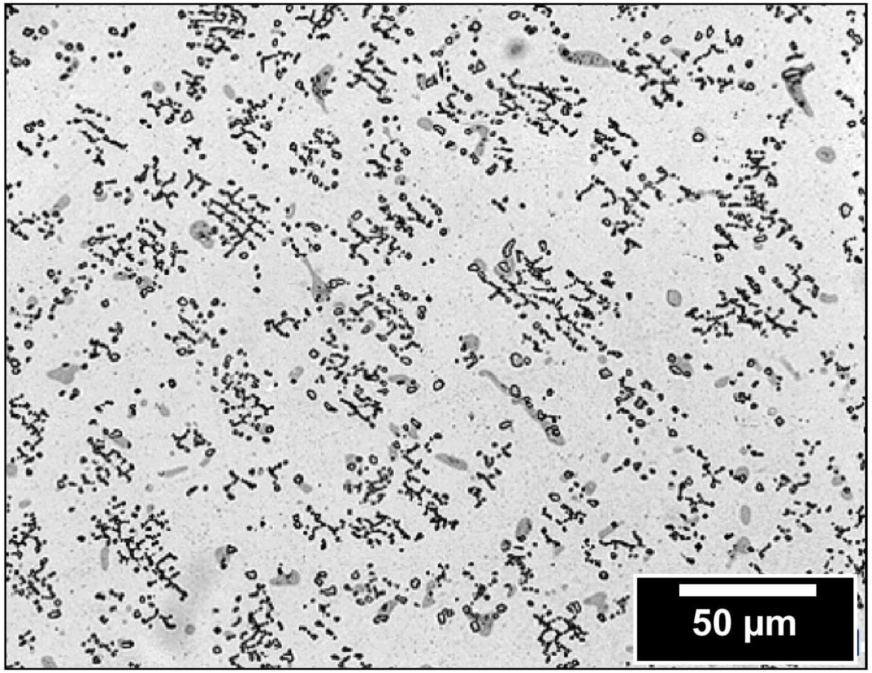
The nominal strength remained greater than the ≈ 400 lb. level above which failure occurs typically at the interface.

Medium Melting Temperature Solder – Sn-Ag-Bi

- **Microstructural effect:** **The Pb additions did not alter the microstructure on the *large size scale*.**



0.00 % Pb

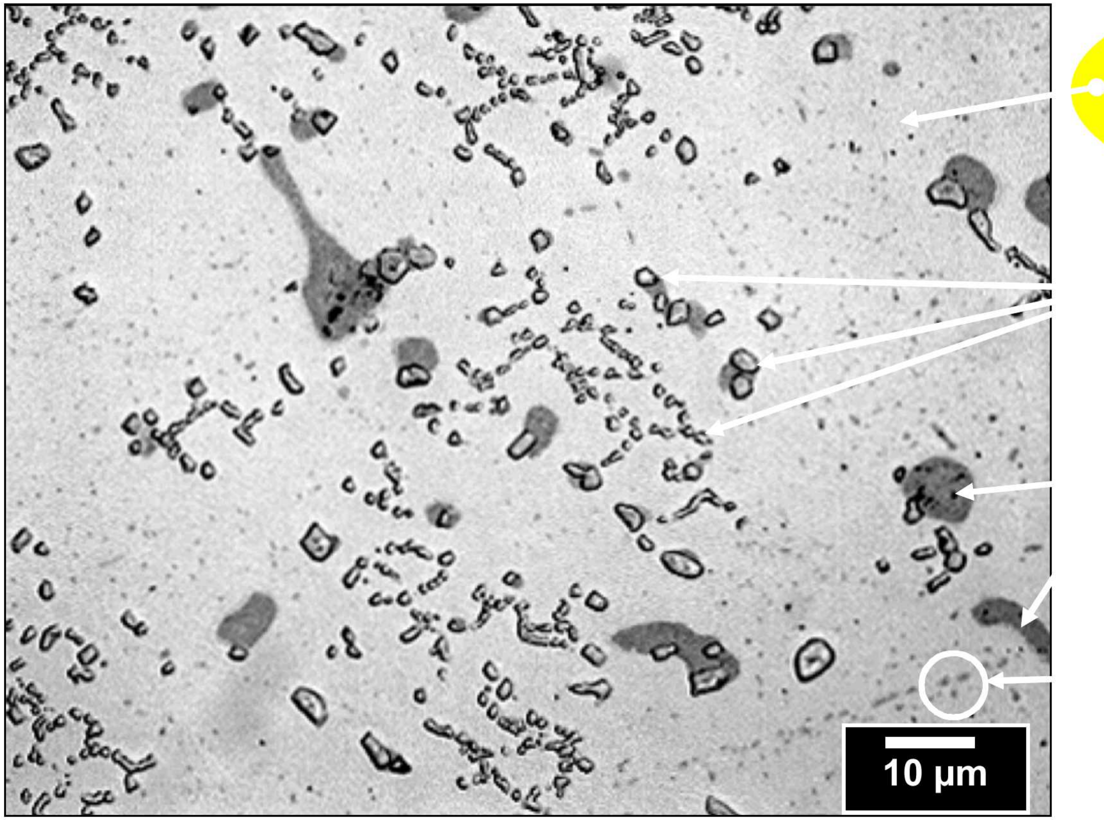


3.00 % Pb

- **On the other hand …**

Medium Melting Temperature Solder – Sn-Ag-Bi

- **… The Pb additions altered the small-scale phase distributions within the Sn-Ag-Bi microstructure.**



96.5Sn-3.5Bi
Solid solution

Ag_3Sn

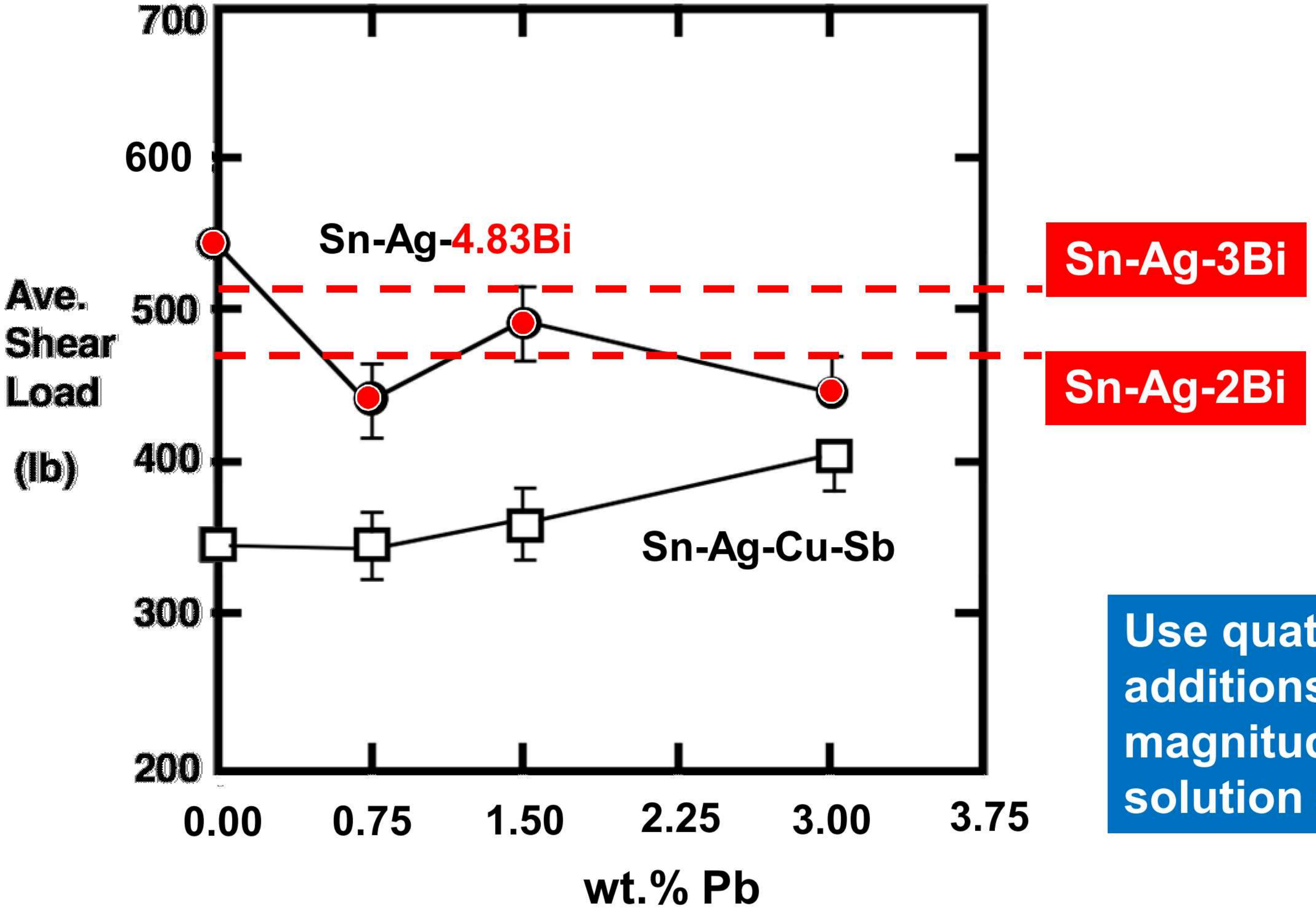
64Pb-33Bi-3Sn

63Sn-24Pb-13Bi

The Pb scavenged Bi from the matrix phase, thus reducing the solid-solution strengthening effect.

Medium Melting Temperature Solder – Sn-Ag-Bi

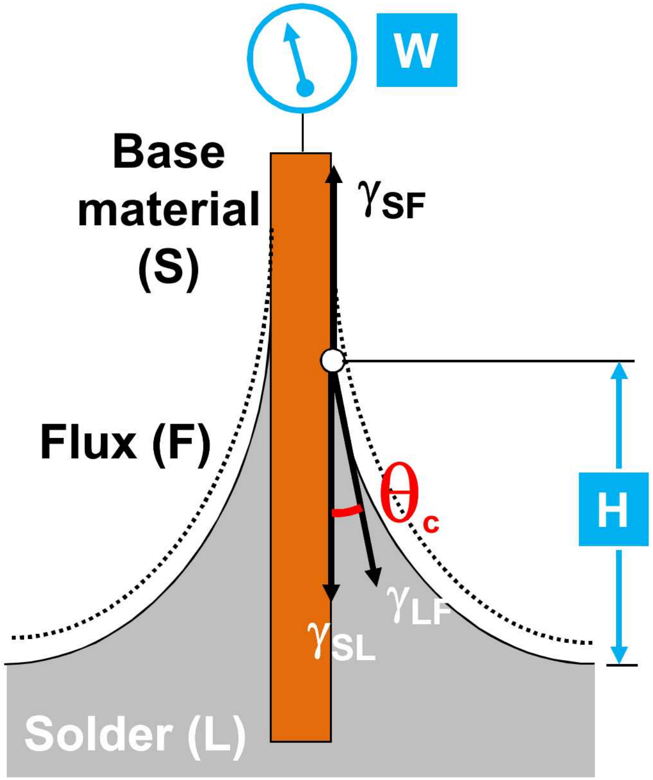
- Ring-and-plug shear tests performed on Sn-Ag-XBi (X = 2, 3 wt.%) confirmed a similar drop of strength.



Use quaternary element additions to adjust the magnitude of the solid-solution strengthening.

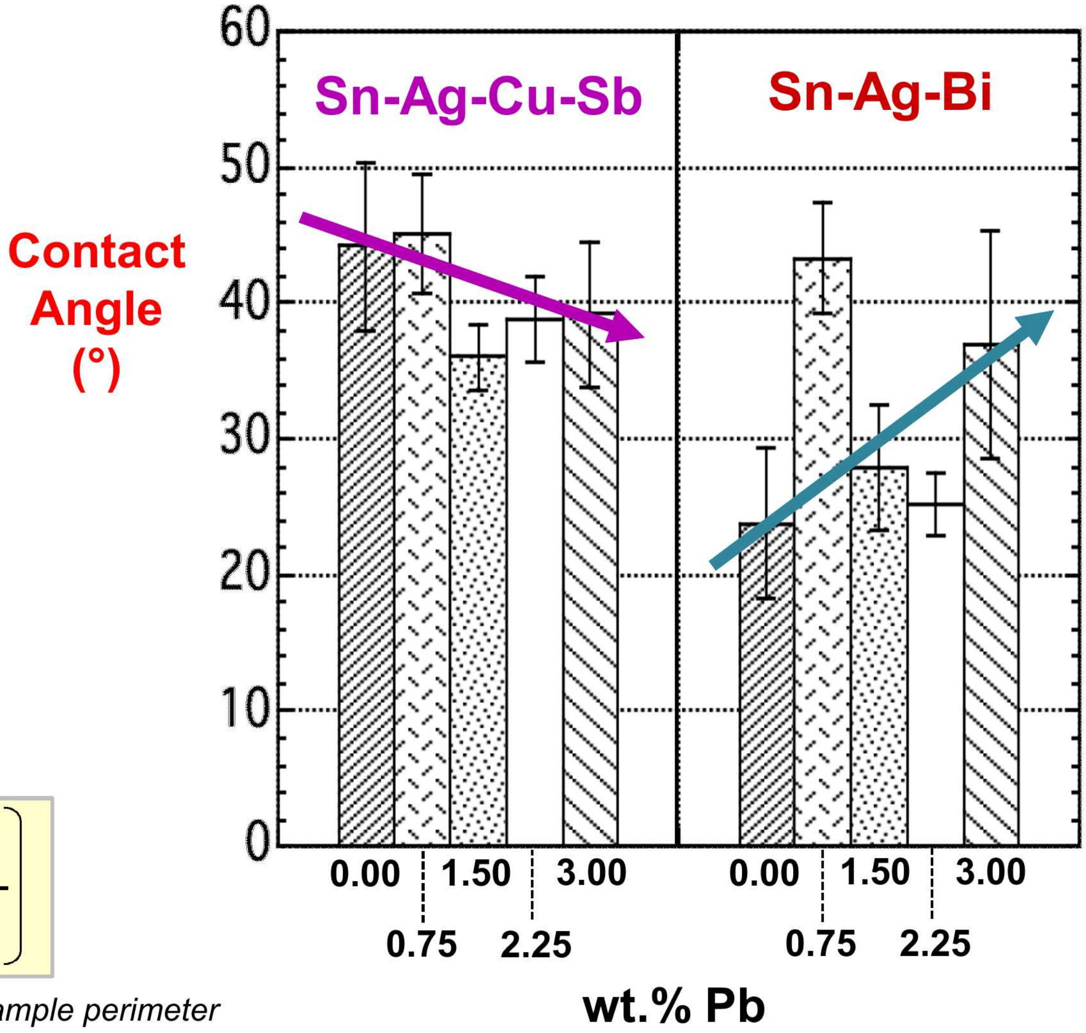
Medium Melting Temperature Solder – Sn-Ag-Bi

◆ **Careful … alloy additions also affect solderability.**



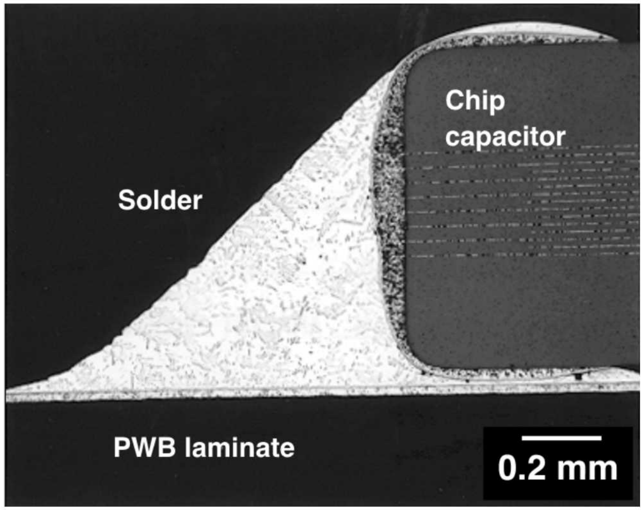
$$\theta_c = \arcsin\left(\frac{4\,W^2 - (\rho\, g\, P\, H^2)^2}{4\,W^2 + (\rho\, g\, P\, H^2)^2}\right)$$

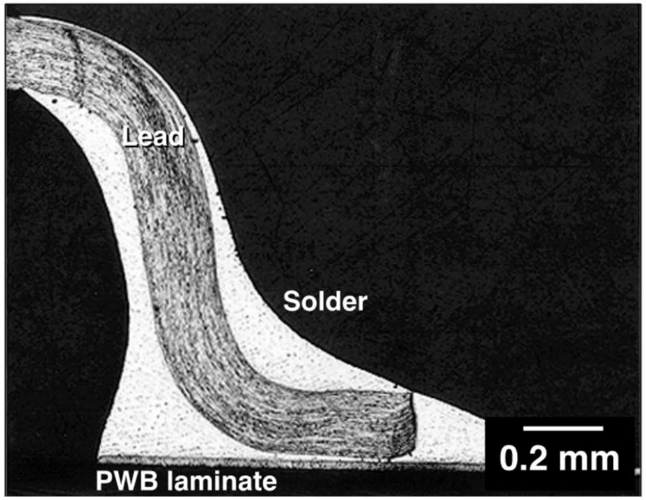
ρ = solder density; g = accn. due to gravity; P = sample perimeter

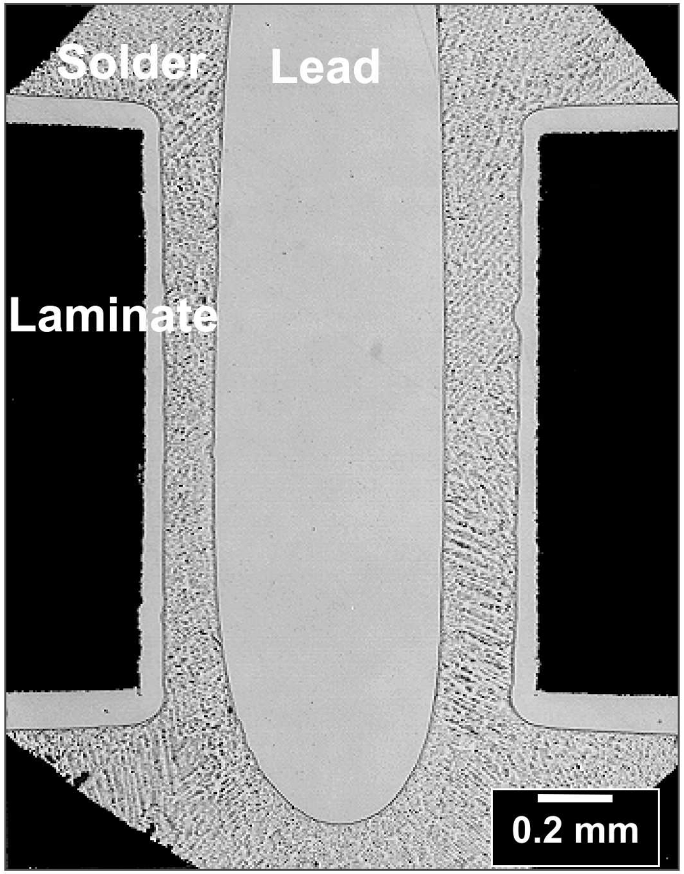


Medium Melting Temperature Solder – Sn-Ag-Bi

- **Overall, the processibility of the Sn-Ag-Bi alloy was observed to be excellent for fine-pitch SMT and through-hole technology.**



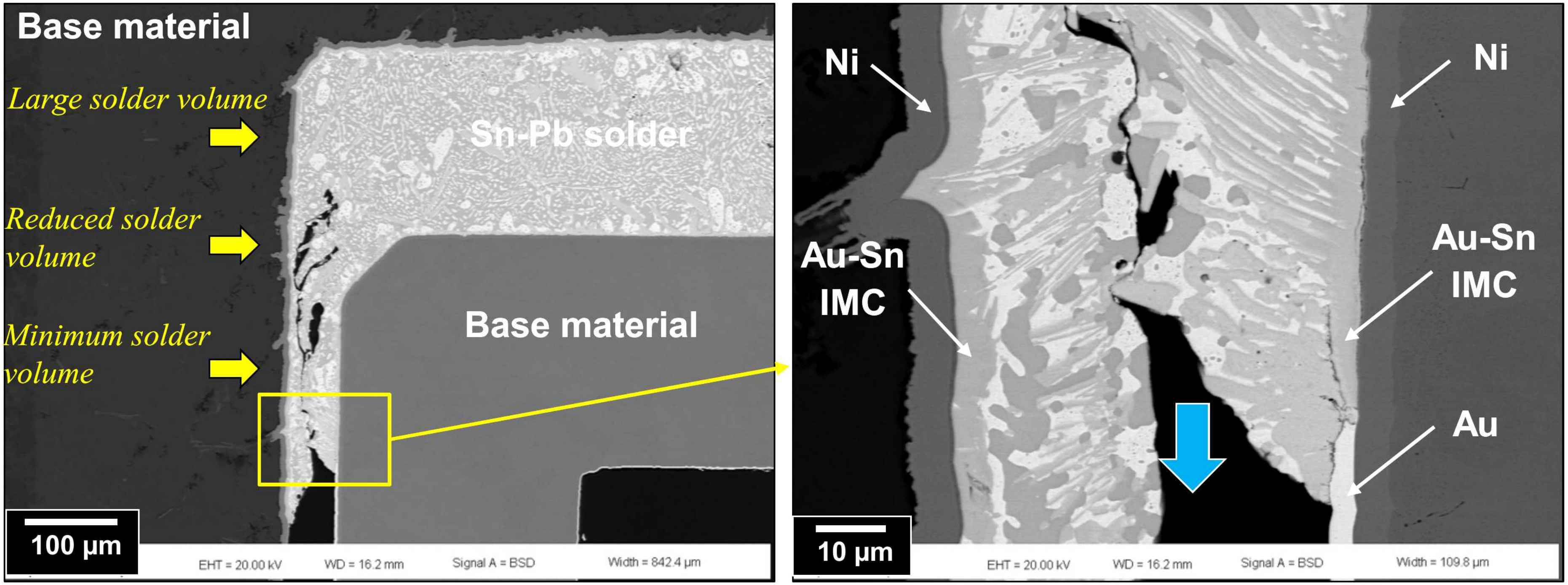




The Sn-Ag-Bi alloy exhibits excellent capillary actions

Medium Melting Temperature Solder – Sn-Ag-Bi

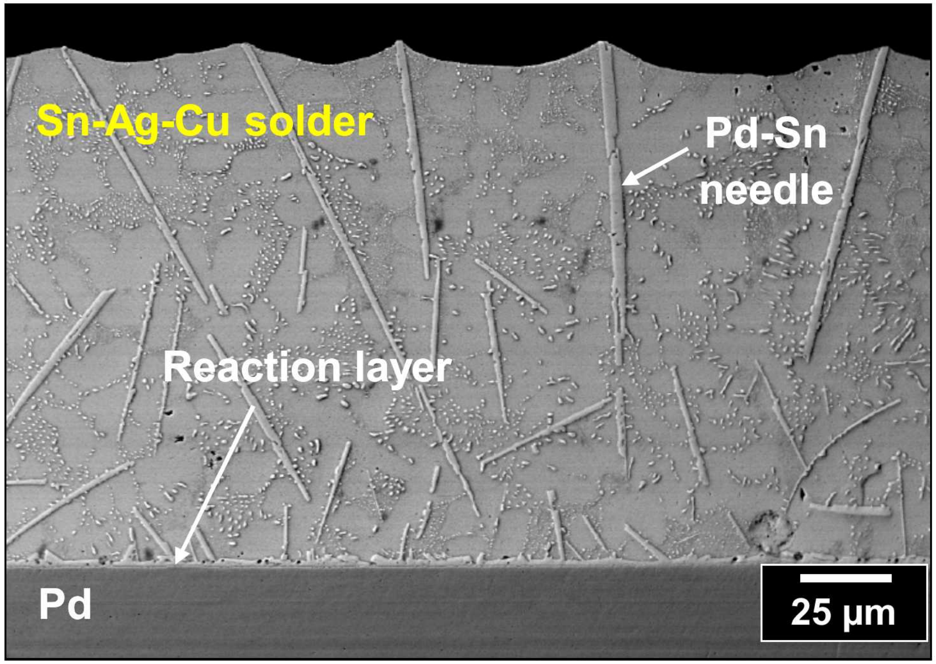
- **There is a shortage of data describing the liquid-state interactions between Sn-Ag-Bi solder and *new surface finishes (e.g., ENEPIG)*.**
  - **Increasing the solidus temperature (T_s) and/or liquidus temperature (T_l) can lead to constitutional solidification.**



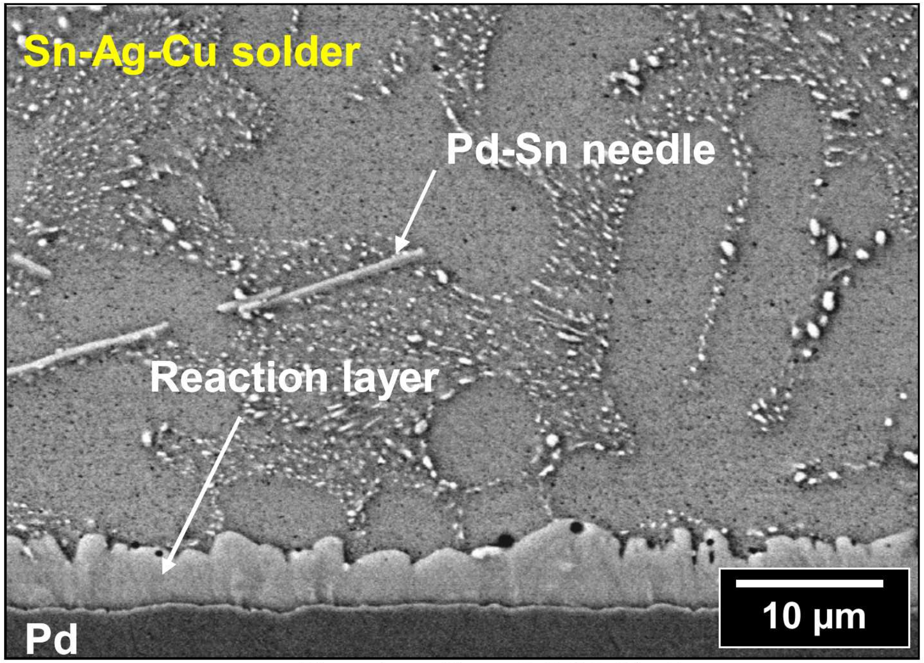
Higher solder strengths amplify the brittle failure of solder.

Medium Melting Temperature Solder – Sn-Ag-Bi

- **Also, base material dissolution has not been documented for the Sn-Ag-Bi alloy.** ***Reliability impacts may include:***
  - **Changes to the solder's bulk mechanical properties**
  - **Properties of the interface reaction layer – e.g., use of ENEPIG finish**



Sn-Ag-Cu, 350°C, 5s

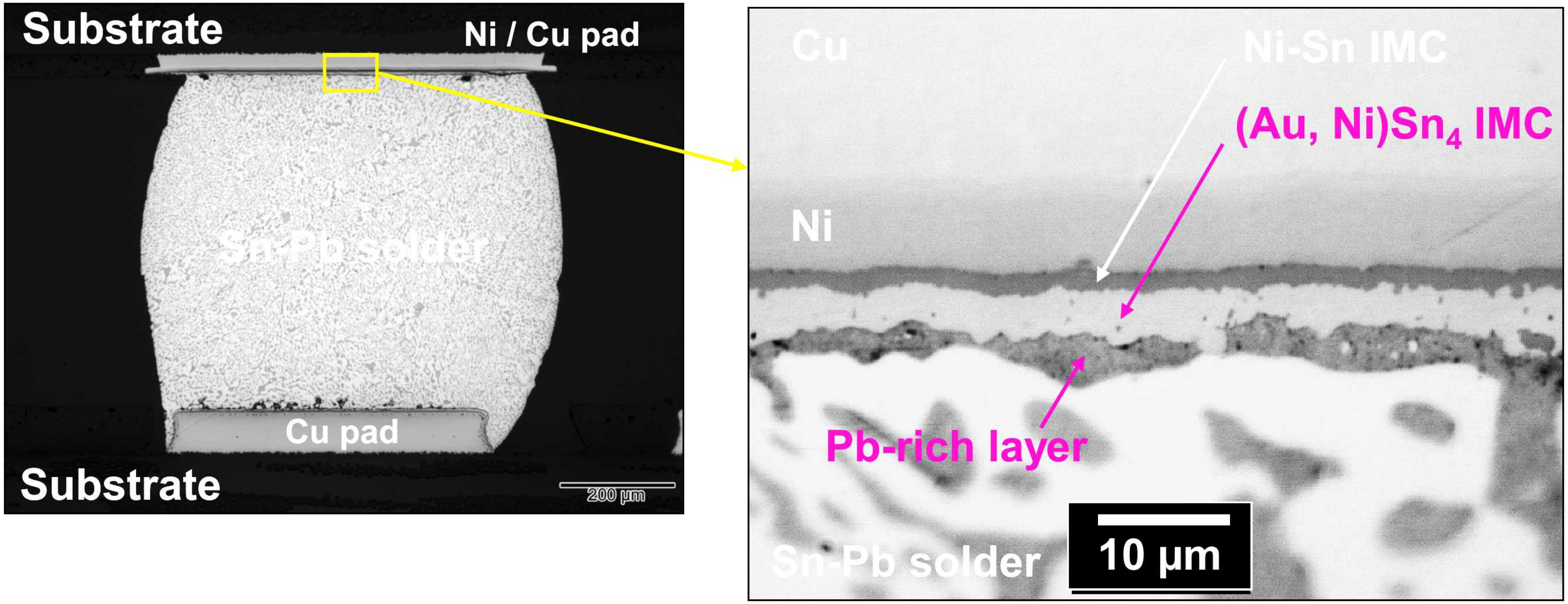


Sn-Ag-Cu: 290°C, 5s

A database must be developed of these fundamental properties.

Medium Melting Temperature Solder – Sn-Ag-Bi

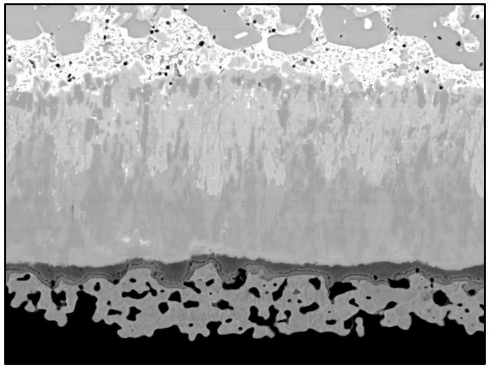
- **Solid-state interactions have not been fully vetted between Sn-Ag-Bi solder and alternative surface finishes.**
    - **Long-term reliability effects: "return-of-Au" phenomenon.**

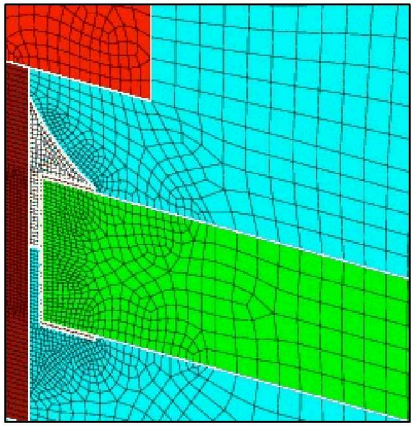


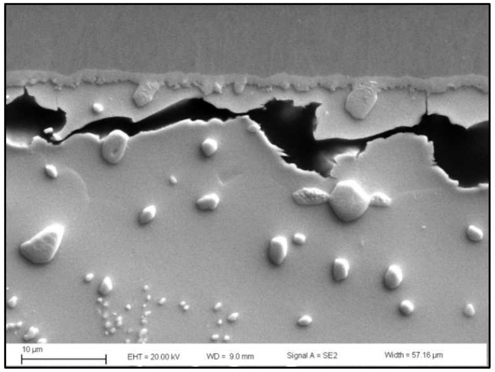
- **The (Au, Ni)Sn_4 IMC layer and Pb-rich layer negatively impact shock and thermal cycling reliabilities, respectively.**

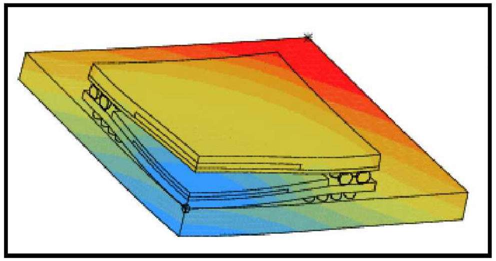
Medium Melting Temperature Solder – Sn-Ag-Bi

- **Reliability**
- **Static properties**
    - Interface reactions (solid-state)
    - Monotonic strength
- **Cyclic (fatigue) properties**
    - Empirical studies
    - Computational modeling



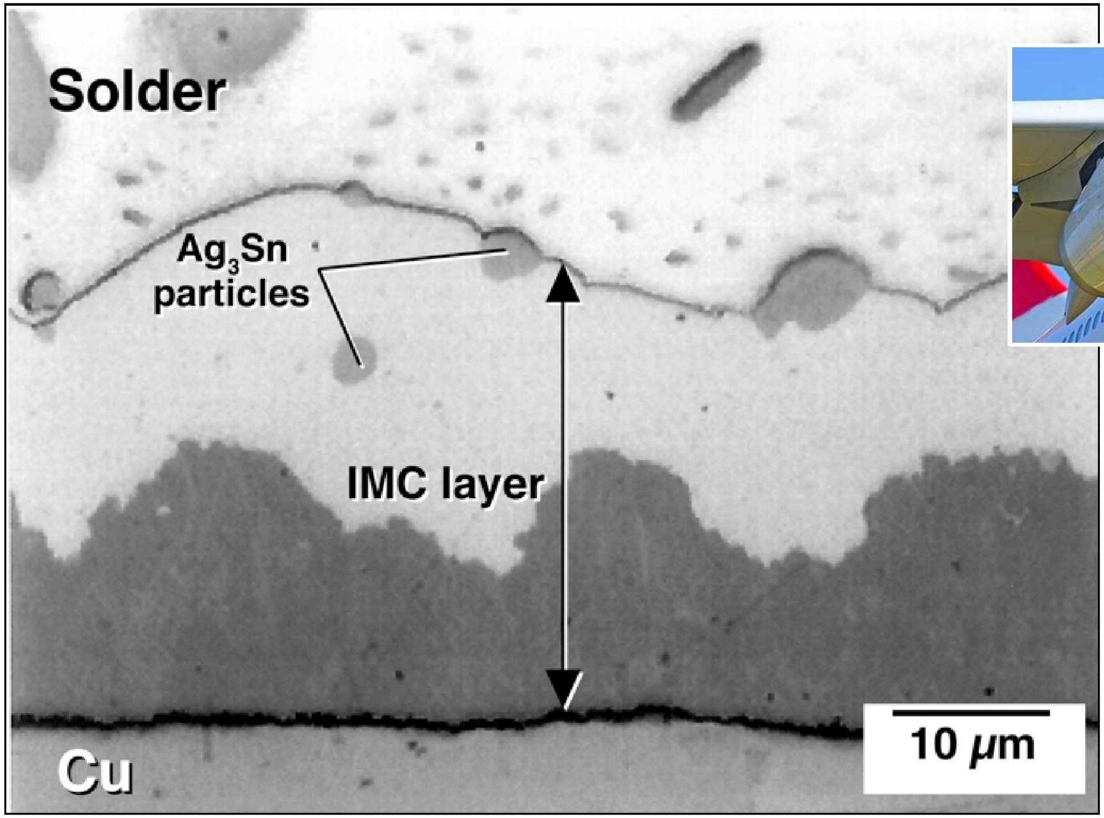






Medium Melting Temperature Solder – Sn-Ag-Bi

- **After solidification, solid-state reactions continue to take place at the solder / base material interface:**
  - **Interfaces are non-equilibrium structures**
  - **Solid-state diffusion readily occurs in the solder.**

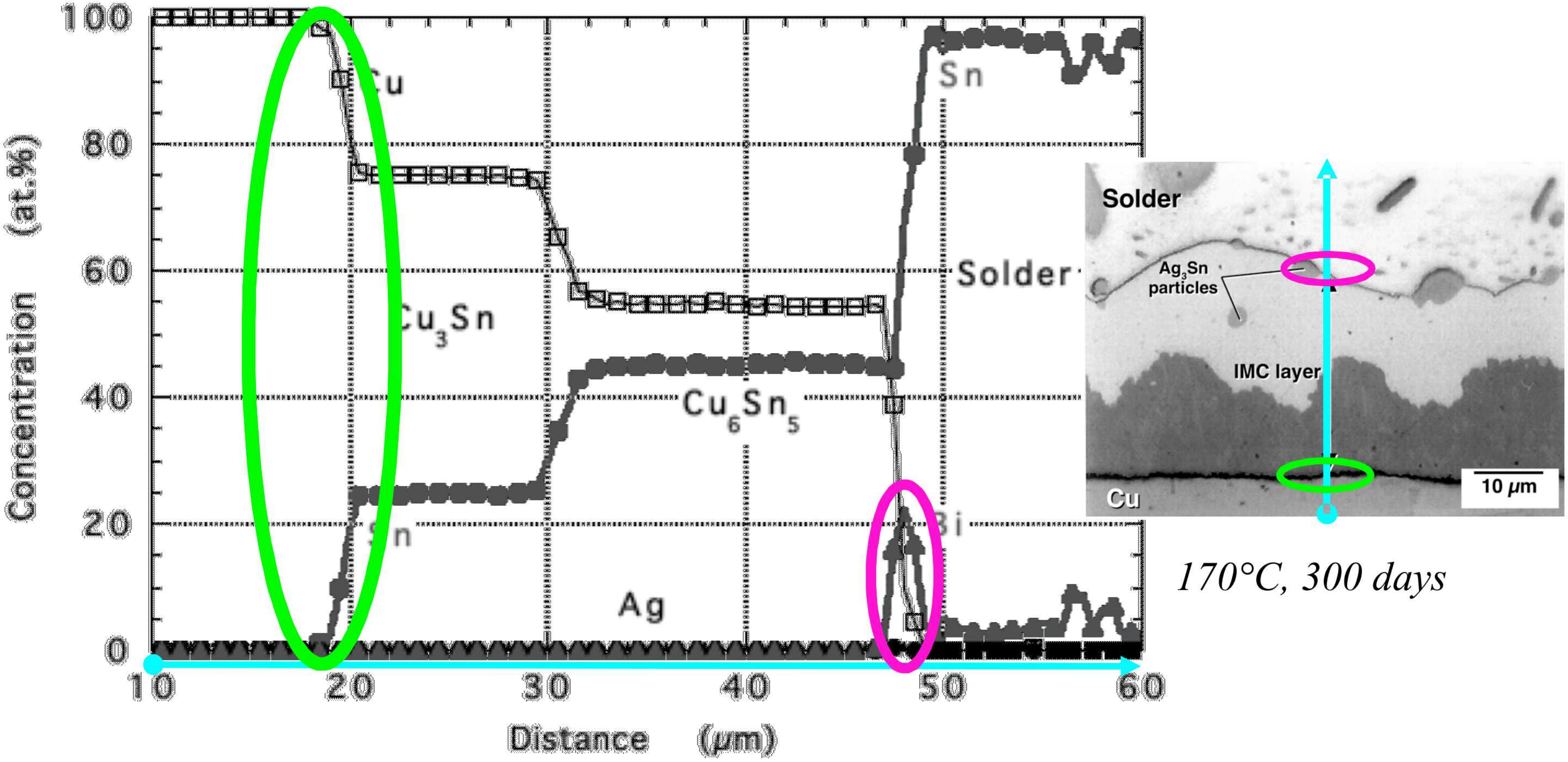


Remember …

Sn-Ag-Bi:
170°C, 300 days

Medium Melting Temperature Solder – Sn-Ag-Bi

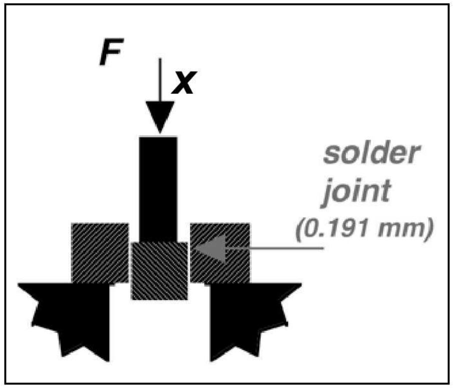
- **The Sn-Ag-Bi / Cu interface microstructure was documented following solid-state aging.**
  - **Limited Bi accumulation was observed along the IMC/solder interface; *none was observed along the IMC/Cu interface.***



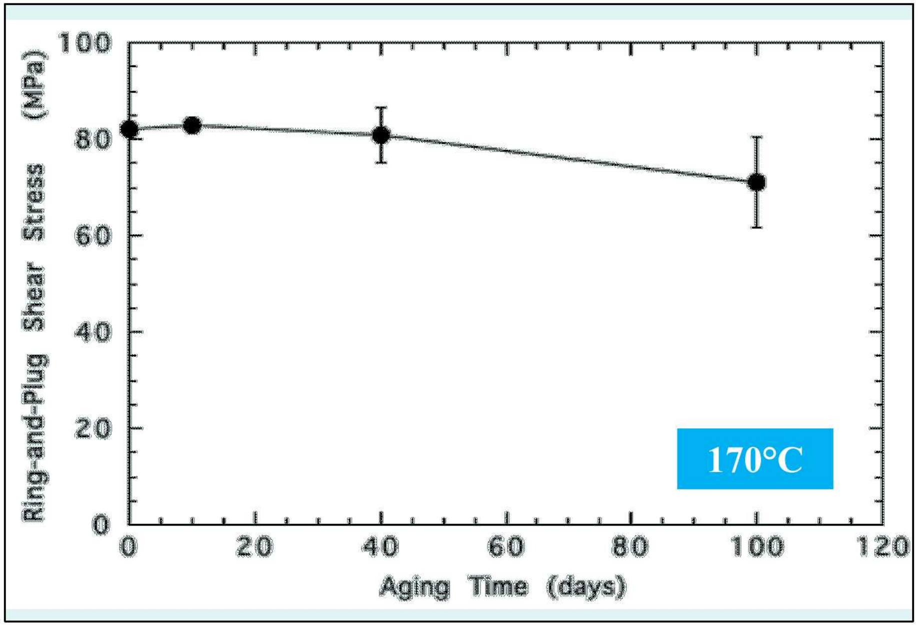
170°C, 300 days

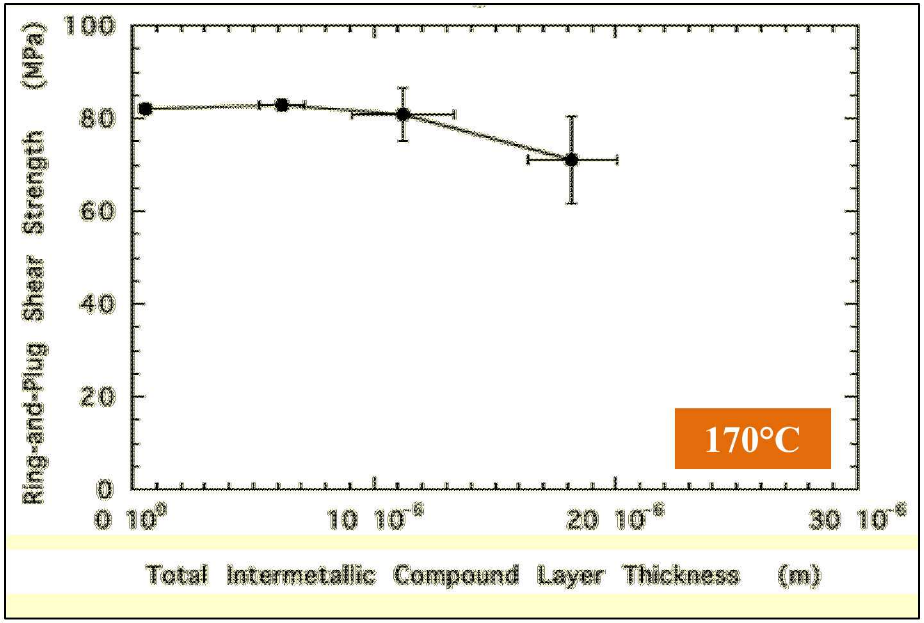
Medium Melting Temperature Solder – Sn-Ag-Bi

- **The effect of solid-state IMC layer growth on joint strength was examined for Sn-Ag-Bi/Cu couples using the *ring-and-plug shear test.***
  - **Isothermal aging did not cause a significant shear strength loss to the solder joints.**
  - ***Moreover, the development of the IMC layer caused a small strength loss, but only when the IMC thickness exceeded ≈10 µm.***



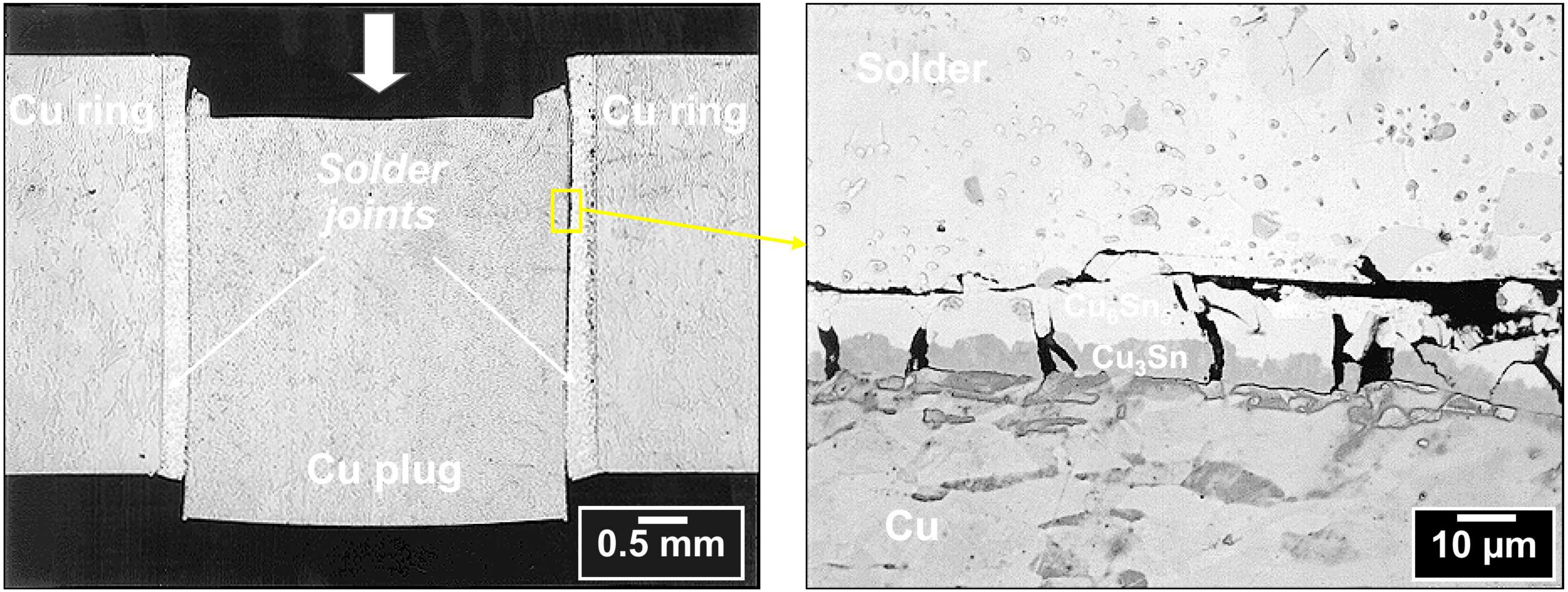
Ring-and-plug shear test





Medium Melting Temperature Solder – Sn-Ag-Bi

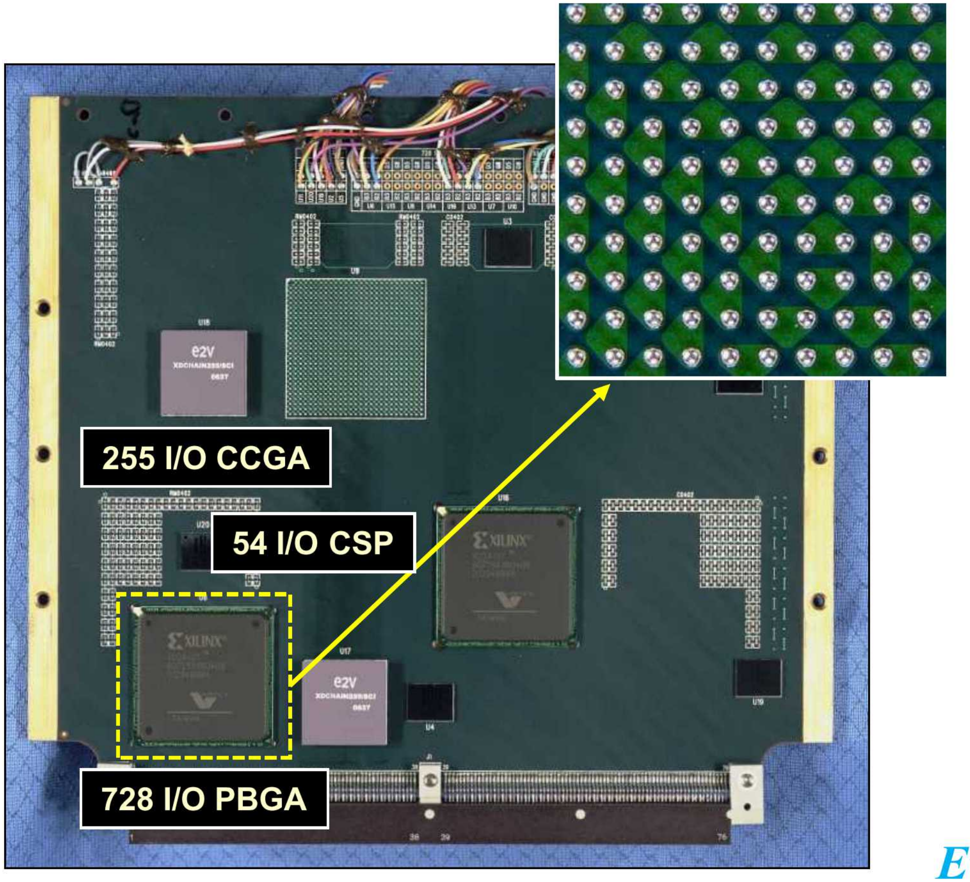
- **The strength study included a failure mode analysis.**
  - **The crack path followed the IMC/solder interface, which is often the case at this displacement rate.**
  - **However, the concurrent presence of cracks in the IMC layer implies that Bi at the IMC/solder interface did not, itself, reduce solder joint strength.**

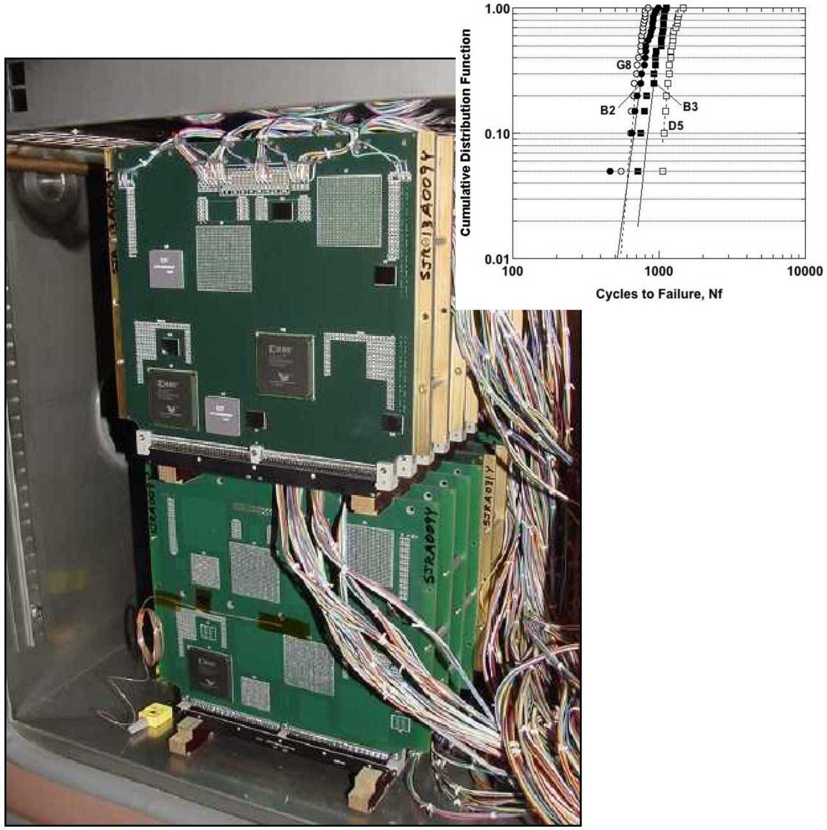


170°C, 100 days

Medium Melting Temperature Solder – Sn-Ag-Bi

- **Temperature cycling data** per IPC 9701 data are being developed at the present time for assessing **thermal mechanical fatigue (TMF)** of Sn-Ag-Bi and Sn-Ag-Bi-X-Y-Z solder interconnections.



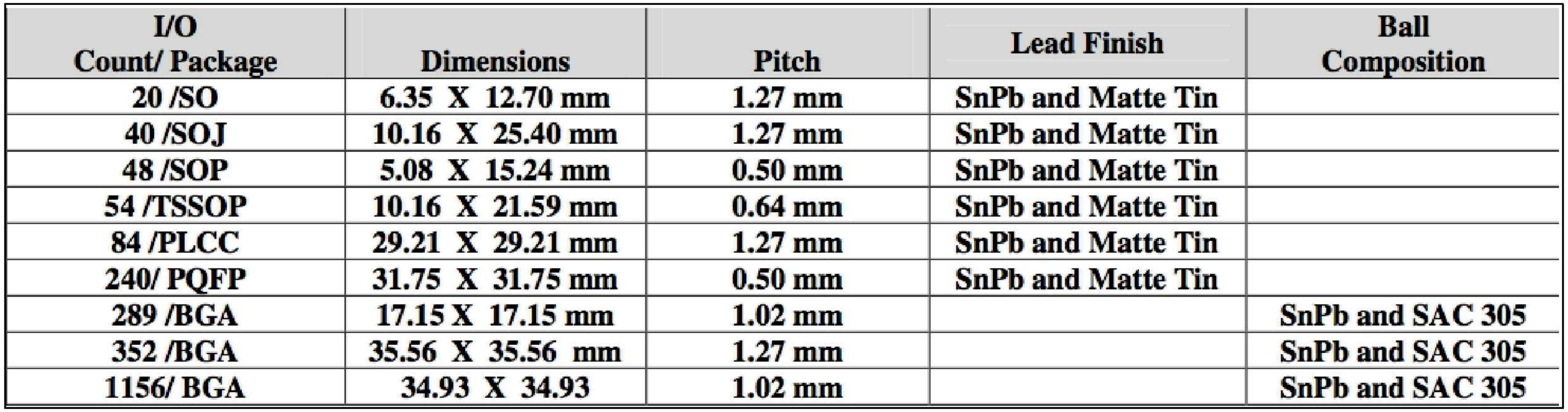


Event detection and Weibull statistics

Medium Melting Temperature Solder – Sn-Ag-Bi

- **The most extensive database developed for the Sn-Ag-Bi solder has come from the Honeywell-Celestica study.**
  - “Reliability Screening of Lower Melting Point Pb-free Alloys Containing Bi,” J. Juarez, et al, *APEX 2014*

- **The test vehicle included a variety of present-day packaging technologies as well as ENIG, ENEPIG, and OSP surface finishes.**

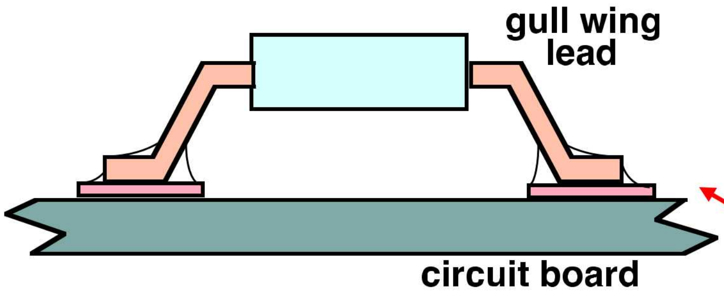


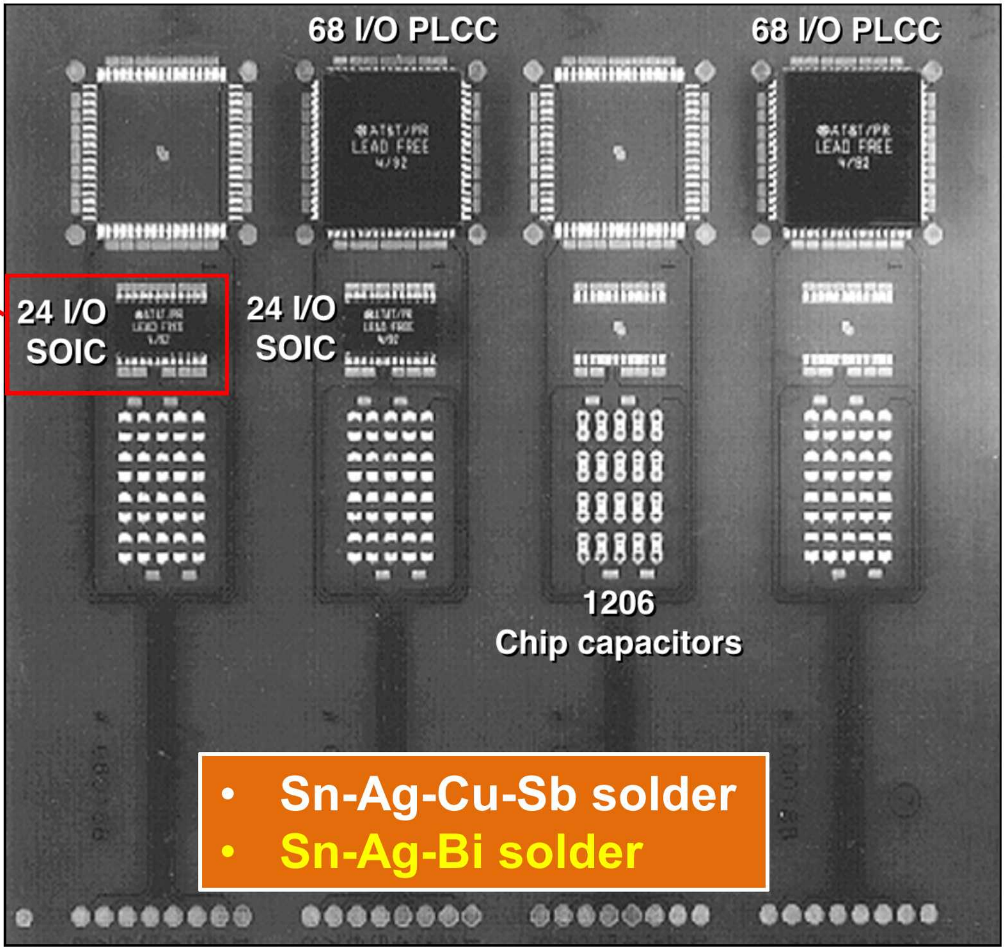
I/O Count/ Package	Dimensions	Pitch	Lead Finish	Ball Composition
20 /SO	6.35 X 12.70 mm	1.27 mm	SnPb and Matte Tin	
40 /SOJ	10.16 X 25.40 mm	1.27 mm	SnPb and Matte Tin	
48 /SOP	5.08 X 15.24 mm	0.50 mm	SnPb and Matte Tin	
54 /TSSOP	10.16 X 21.59 mm	0.64 mm	SnPb and Matte Tin	
84 /PLCC	29.21 X 29.21 mm	1.27 mm	SnPb and Matte Tin	
240/ PQFP	31.75 X 31.75 mm	0.50 mm	SnPb and Matte Tin	
289 /BGA	17.15 X 17.15 mm	1.02 mm		SnPb and SAC 305
352 /BGA	35.56 X 35.56 mm	1.27 mm		SnPb and SAC 305
1156/ BGA	34.93 X 34.93	1.02 mm		SnPb and SAC 305

The Sn-Ag-Bi solder joints completed 3010 temperature cycles of -55°C/125°C without an electrical failure.

Medium Melting Temperature Solder – Sn-Ag-Bi

- **Insight was provided into the temperature cycling performance of this alloy by means of early, Pb contamination studies.**



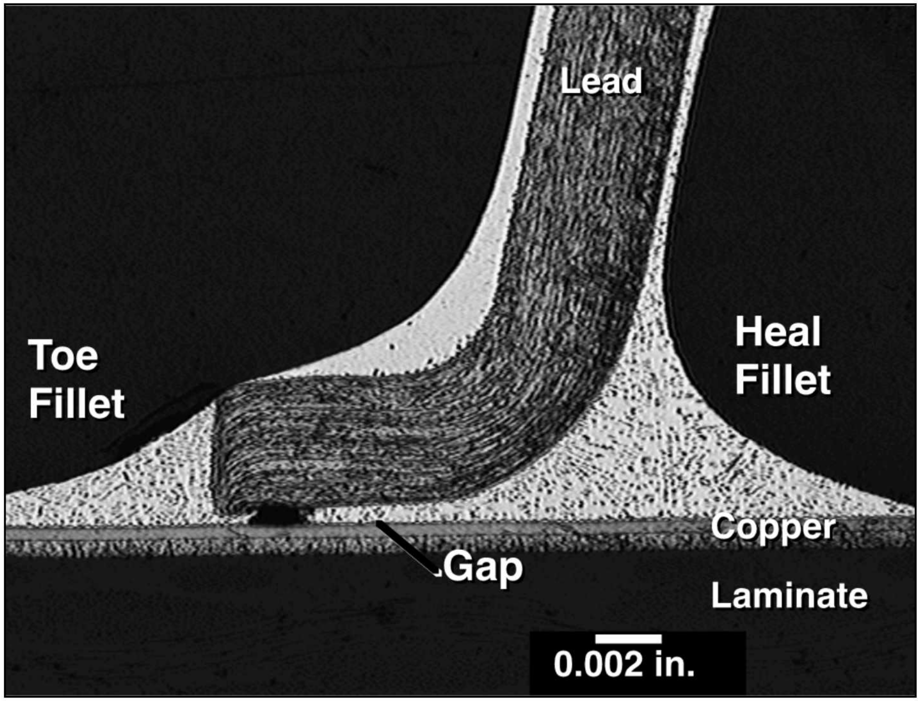


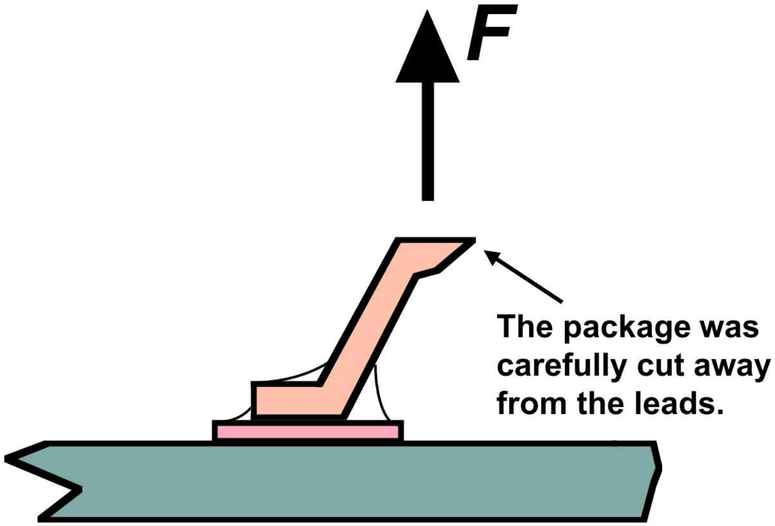
P. Vianco, et al., ECTC (1996)

- **Temperature cycling:**
  - 0°C ….. 100°C
  - 15 min hold times
  - 20°C/min ramp rates
- **Measurement points;**
  - 0 (as-fabricated), 2608, 5068, and 10,106 cycles

Medium Melting Temperature Solder – Sn-Ag-Bi

- **Visual inspection and metallographic cross sections confirmed the excellent solderability of the test vehicle joints.**
- **The molded package was cut from the leads and the latter were then subjected to a pull test.** ***The metric was the maximum force.***





Pull Test

Cross-head speed ….. 9 mm/min

Medium Melting Temperature Solder – Sn-Ag-Bi

- The table shows the effect of thermal cycling on maximum force.

Thermal cycles	Sn-Ag-Cu-Sb			Sn - Ag - Bi		
	Sn-Pb/Sn-Pb (lb)	Sn-Pb/OSP (lb)	Sn/OSP (lb)	Sn-Pb/Sn-Pb (lb)	Sn-Pb/OSP (lb)	Sn/OSP (lb)
0	5.42±0.32	5.47±0.53	5.81±0.59	******	2.75±0.61	5.31±0.67
2602	4.79±0.79	5.57±0.52	4.22±0.55	******	******	******
5068	4.77±0.82	4.71±0.38	4.05±0.99	******	******	******
10,106	4.24±0.43	4.91±0.68	4.56±0.67	******	3.13±1.24	5.34±0.74

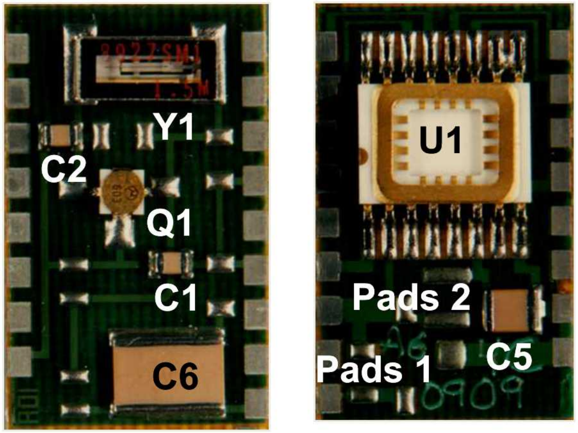
Δ = -10% -22%

Δ = +13% +1%

- Pull strength of the Sn-Ag-Cu-Sb is affected by thermal cycling.
- Although the Sn-Ag-Bi pull strengths were decreased by Pb additions, in either this condition or Pb-free, the pull strength is stable against thermal mechanical fatigue (TMF) effects.

Medium Melting Temperature Solder – Sn-Ag-Bi

- **A large-pitch, surface mount test vehicle was used to assess both the processibility and long-term reliability of Pb-free solder joints:**
  - **91.84Sn-3.33Ag-4.83Bi**
  - **96.5Sn-3.5Ag**
  - **63Sn-37Pb** *(control)*



Ni-Pd Finish

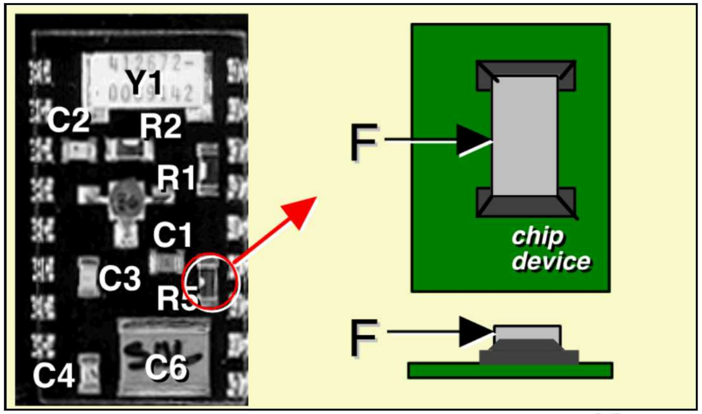
“1 oz.” copper
3.8 μ electroless Ni
0.51μ electroless Pd

- ***Acceleratated aging environments:***

Cycling	Shock
(1) Limits: -55°C, 115°C	(1) Limits: -40°C, 115°C
(2) Ramp: 4°C/min	(2) Ramp: liquid-to-liquid
(3) Hold time: 30 min.	(3) Hold time: 15 min.
(4) 300 cycles	(4) 400 cycles

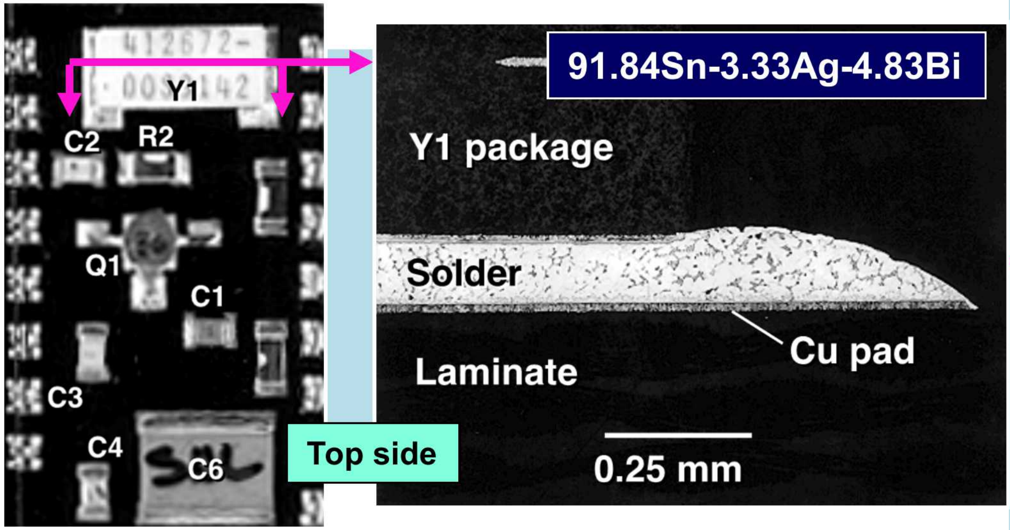
- ***Mechanical (shear strength) testing:***

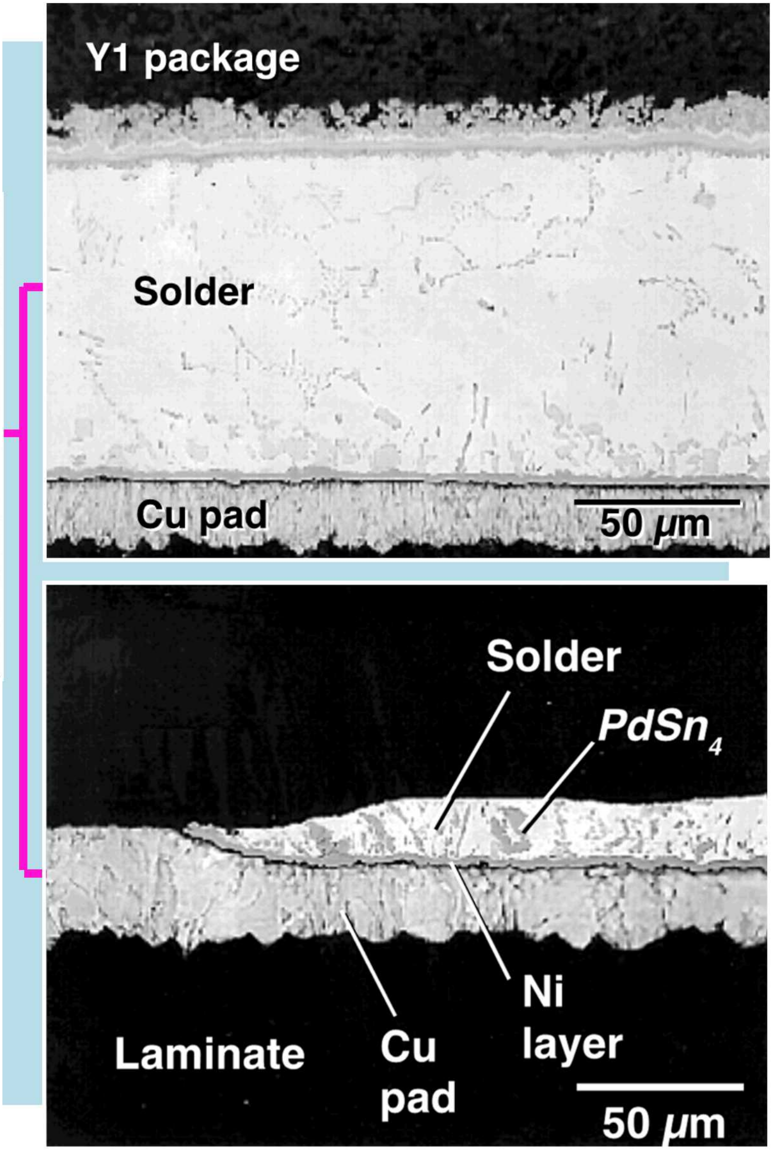
(1) C1, C2, C3, C4, C5, and C6 were tested
(2) R1, R2, R3, R4, and R5 were tested
(3) Y1 package was tested.
(4) Test speed: 10 mm/min



Medium Melting Temperature Solder – Sn-Ag-Bi

◆ This examination focuses on the Sn-Ag-Bi solder joints:



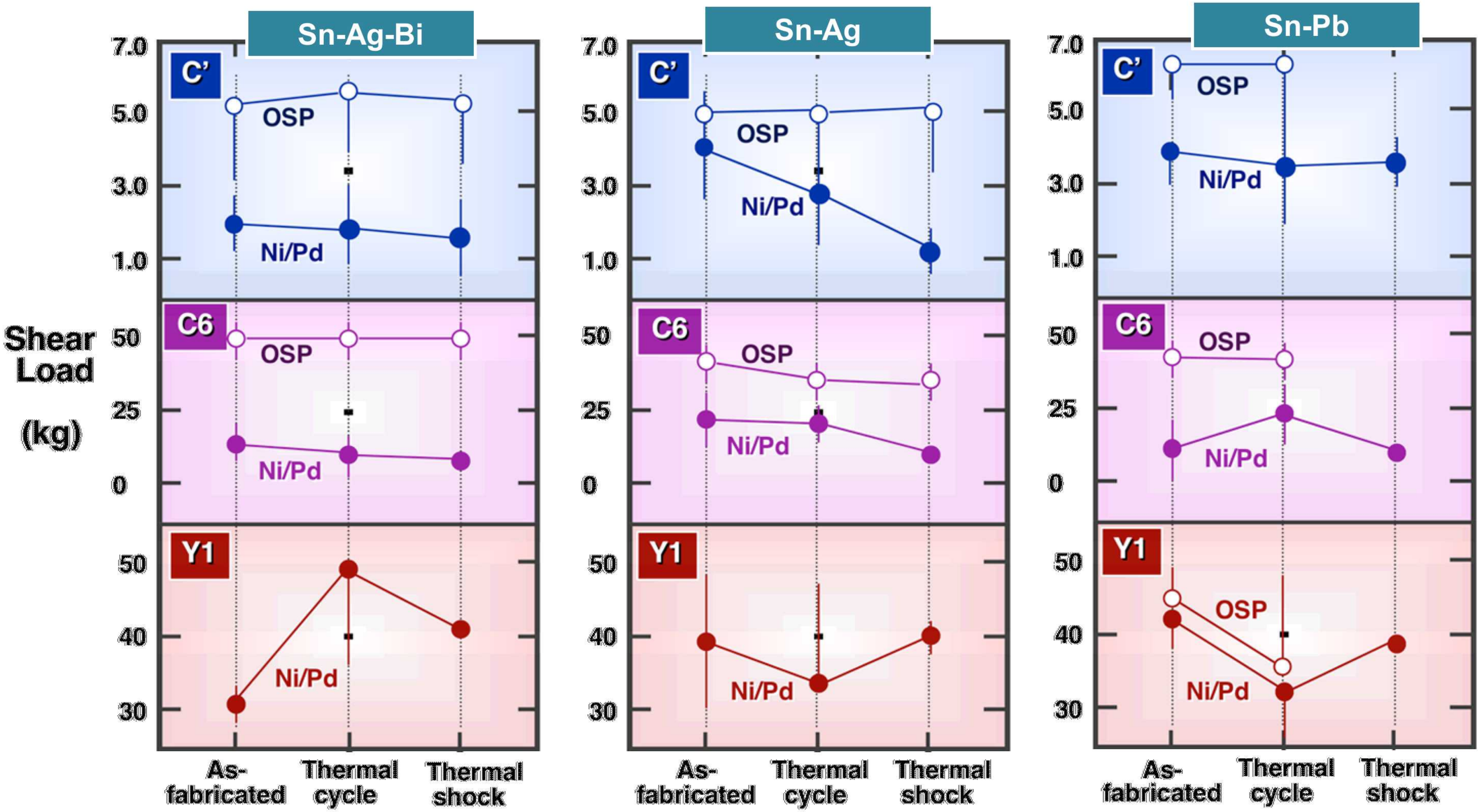


◆ Observations critical to the use of ENEPIG and ENIG surface finishes:

- The Pd layer fully was dissolved into the solder, forming $PdSn_4$ particles.
- Ni dissolution was *reduced* with the Sn-Ag-Bi alloy vs. Sn-Ag or Sn-Pb.

Medium Melting Temperature Solder – Sn-Ag-Bi

- A reduced shear strength was observed with Ni/Pd finish.

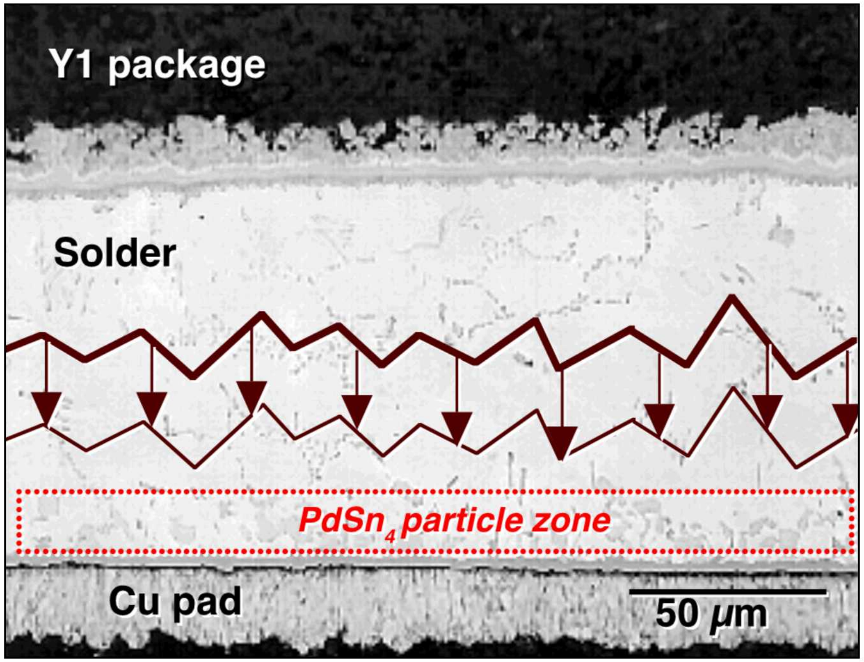


Medium Melting Temperature Solder – Sn-Ag-Bi

- A scenario was developed to explain the reduced strength of the solder joints made to the Ni/Pd finish.

- The higher intrinsic strength of the Sn-Ag-Bi alloy, and to a lesser extent, the Sn-Ag solder, forced the crack path closer to the solder/Cu pad interface.

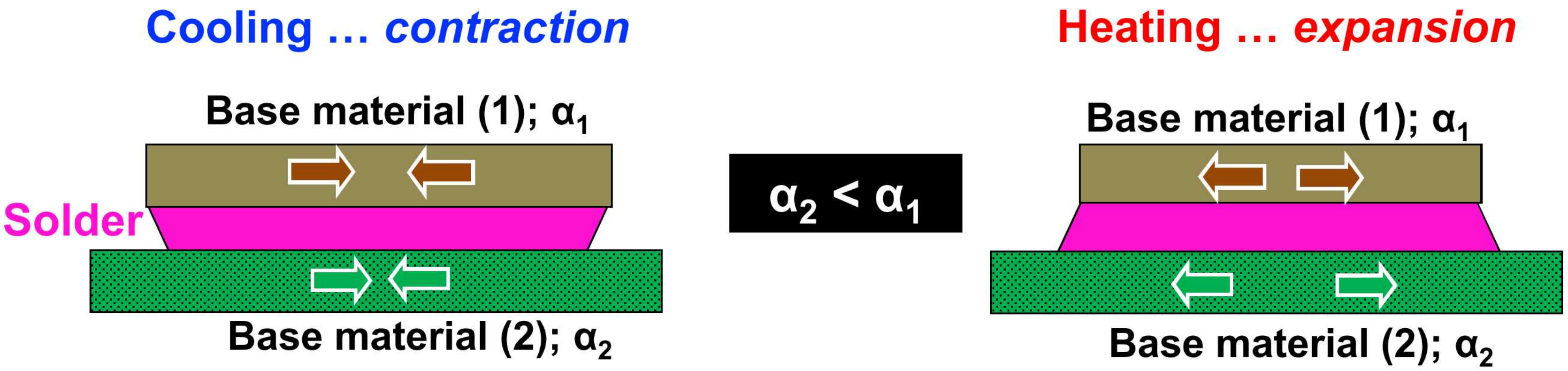
- The concentration of $PdSn_4$ particles near that interface locally reduced solder ductility.



The higher strength of the Sn-Ag-Bi solder caused the joints to have an increased sensitivity to small microstructure changes, including *a loss of ductility generated by surface finishes*.

Medium Melting Temperature Solder – Sn-Ag-Bi

- **Failure mode analysis has only recently begun development for the thermal mechanical fatigue (TMF) failure of Sn-Ag-Bi solder joints.**



Cooling … *contraction*

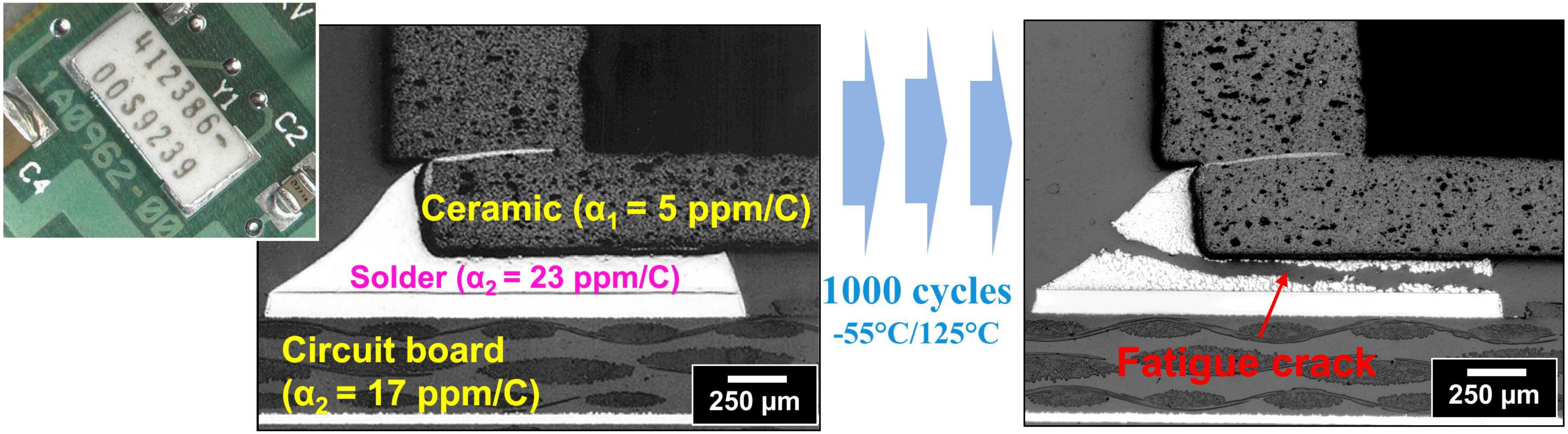
Heating … *expansion*

Base material (1); α_1

Solder

Base material (2); α_2

$\alpha_2 < \alpha_1$

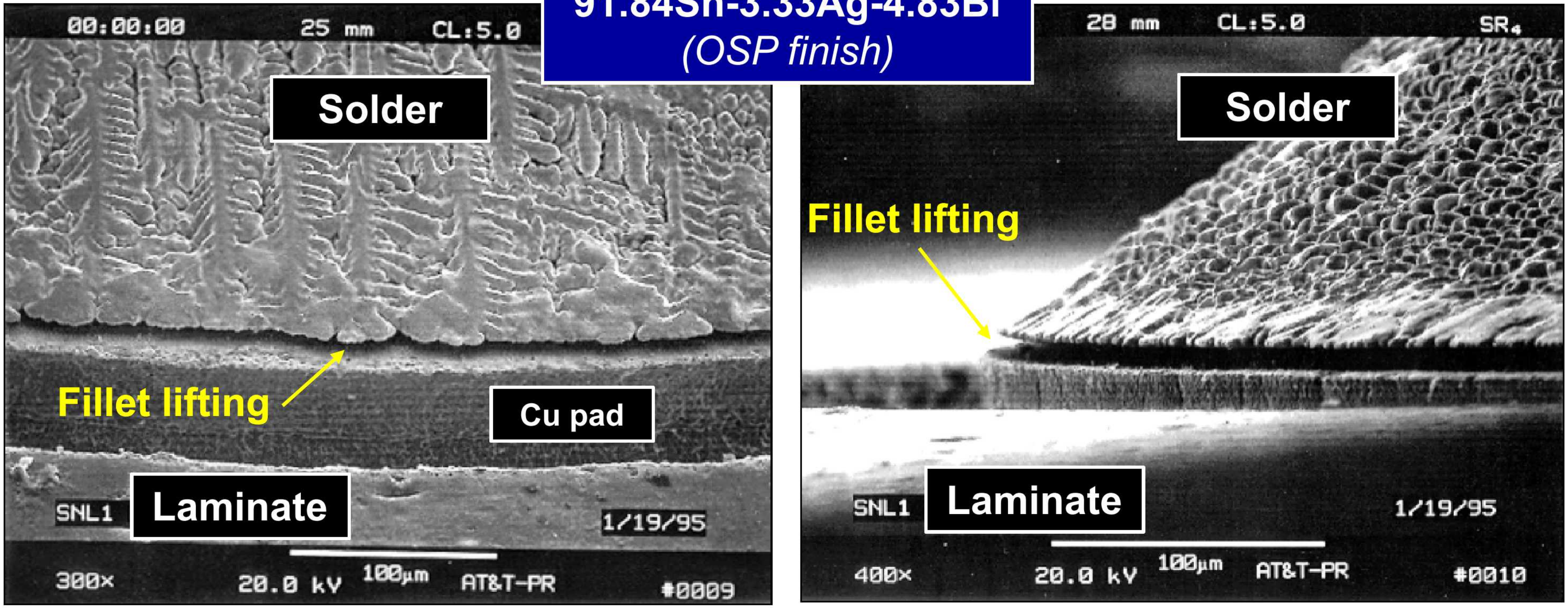


Medium Melting Temperature Solder – Sn-Ag-Bi

◆ **Fillet lifting** was pronounced in the Sn-Ag-Bi through-hole joints.

- This phenomenon is observed with other solders, but not with the same prevalence.

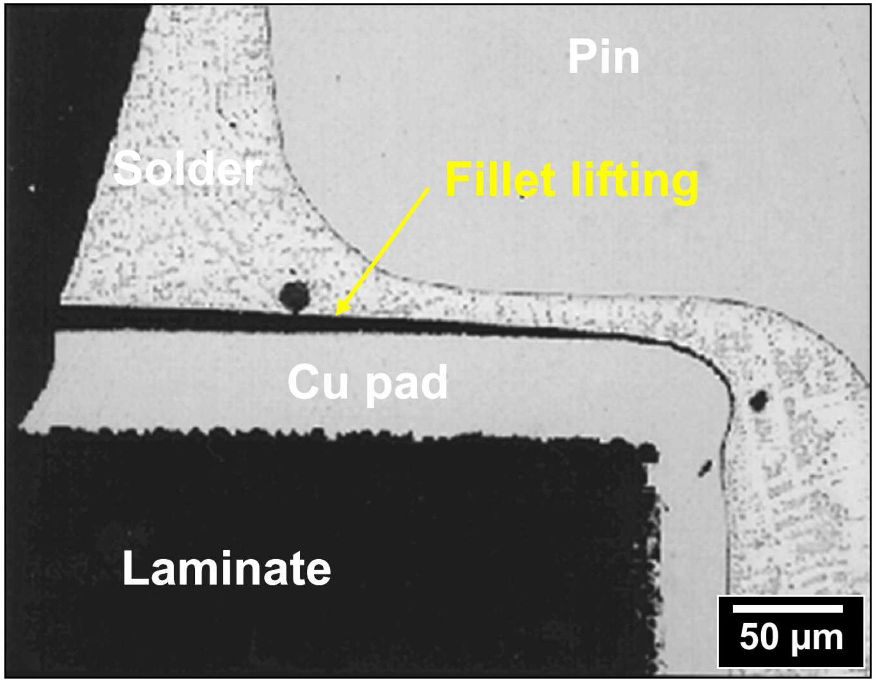
91.84Sn-3.33Ag-4.83Bi
(OSP finish)

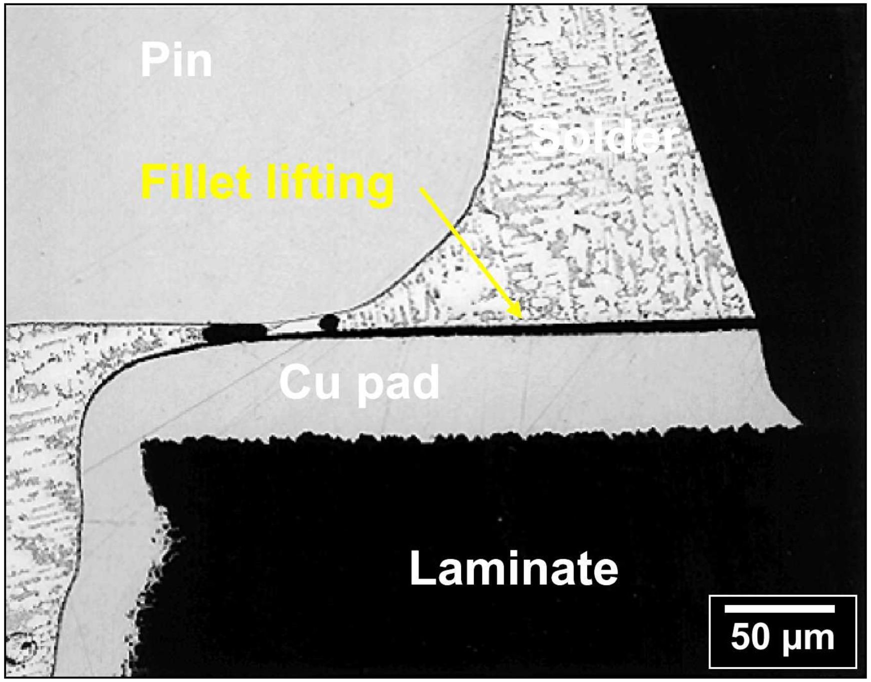


◆ Fillet lifting is very likely to appear in current through-hole joints.

Medium Melting Temperature Solder – Sn-Ag-Bi

- **Fillet lifting was characterized for a variety of joint geometries.**
  - ***Example*: Sn-Ag-Bi solder; plastic, dual in-line package (PDIP).**

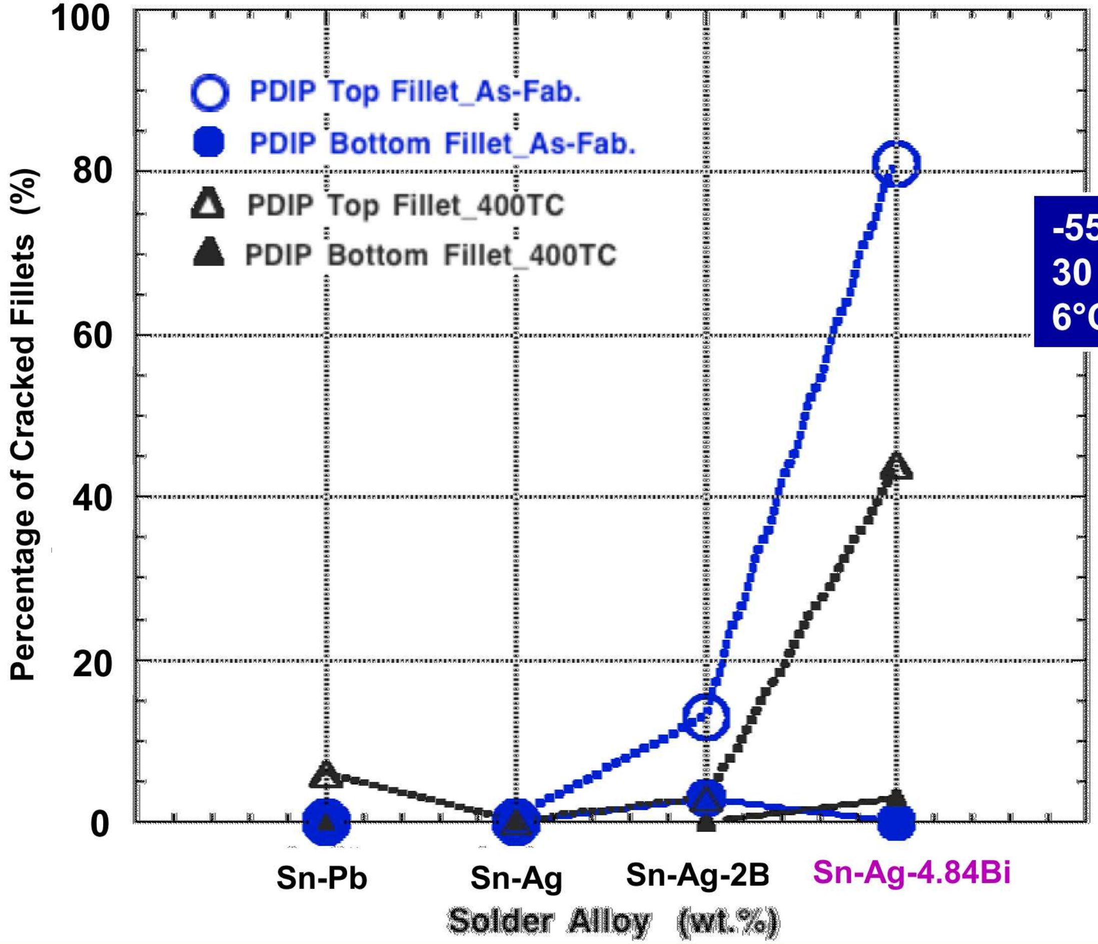




- **Fillet lifting was observed on the component side.**
- **Fillet lifting was *not* observed on the bottom side.**
- **Cracks progressed around the knee, and arrested, there.**
- **Damage to the circuit board (Cu pad) was absent.**

Medium Melting Temperature Solder – Sn-Ag-Bi

- **Fillet lifting did not increase with temperature cycling, which *reduced the reliability risk* posed by its occurrence.**



-55°C / 115°C;
30 min hold times;
6°C/min ramp rates

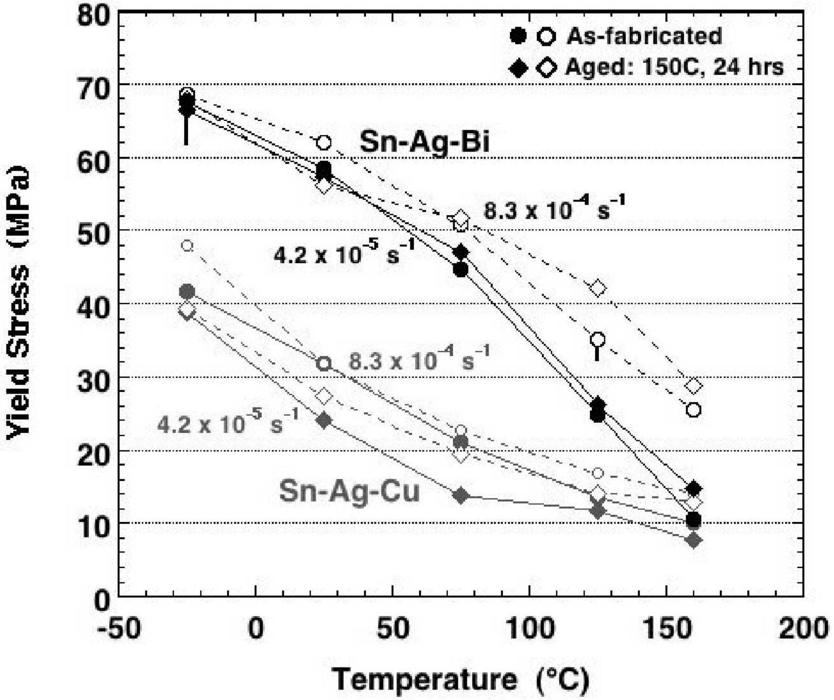
Anticipate fillet lifting on jumper wires and connector pins.

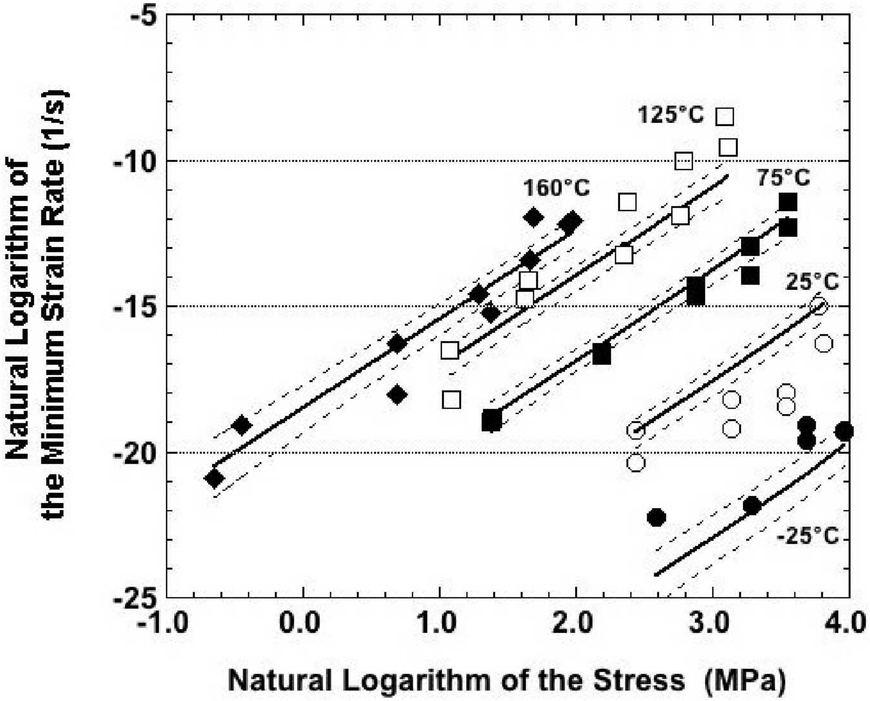
Medium Melting Temperature Solder – Sn-Ag-Bi

- **Both time-independent (stress-strain) and time-dependent (creep) data are being compiled to build the UCP computational model.**

Time-Independent Deformation
$\varepsilon = (\sigma, \varepsilon, T)$

Time-Dependent Deformation
$\varepsilon = (\sigma, T)$





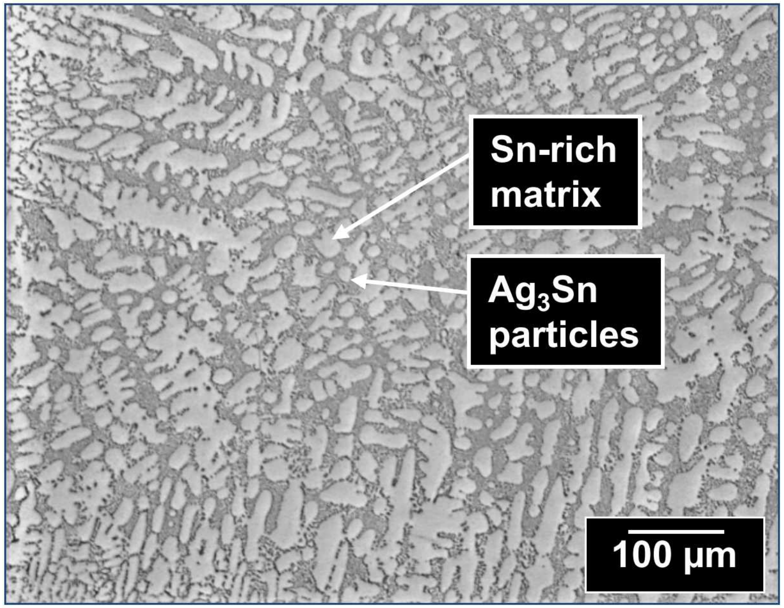
$$d\gamma/dt = f(\sigma, T, E)$$

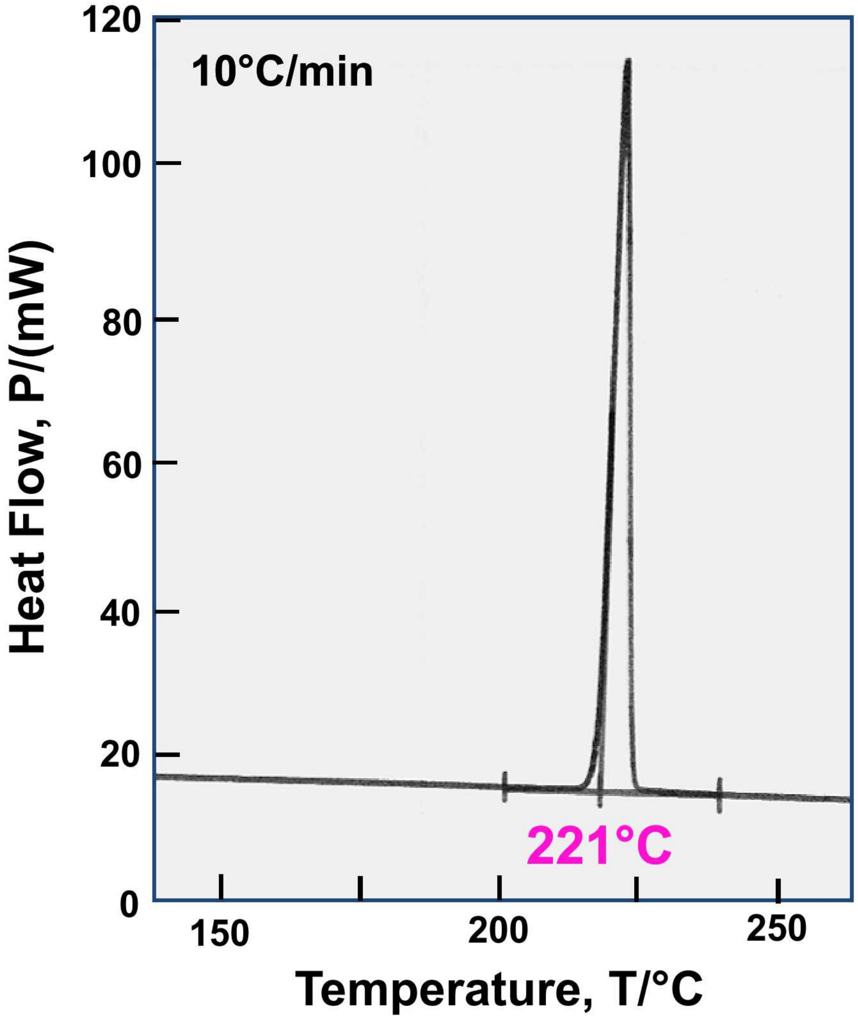
σ, stress matrix; T, temperature; elastic and physical properties

Novel Medium Melting Temperature Solders

- **Objective:** *"Develop a Pb-free solder having solidus and liquidus temperatures close to the* ***183°C eutectic temperature*** *of 63Sn-37Pb."*

- **The starting point was the eutectic 96.5Sn-3.5Ag alloy (T_e = 221°C).**

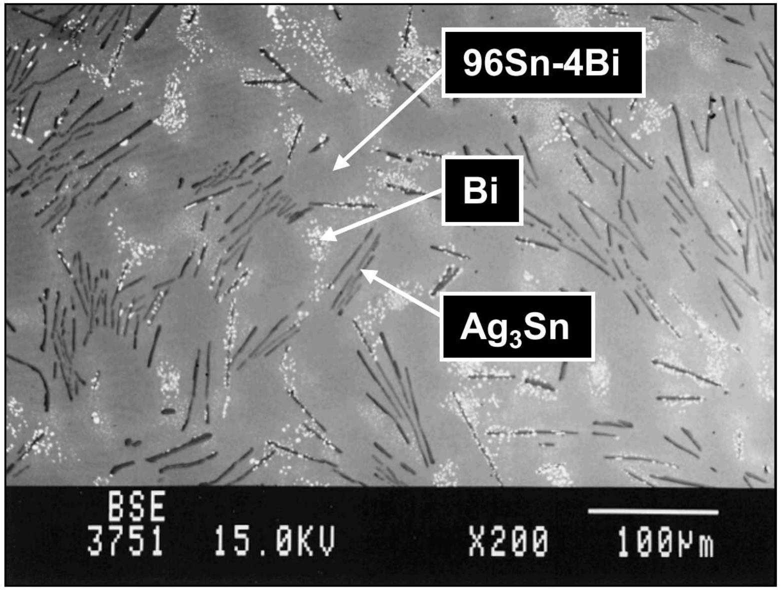


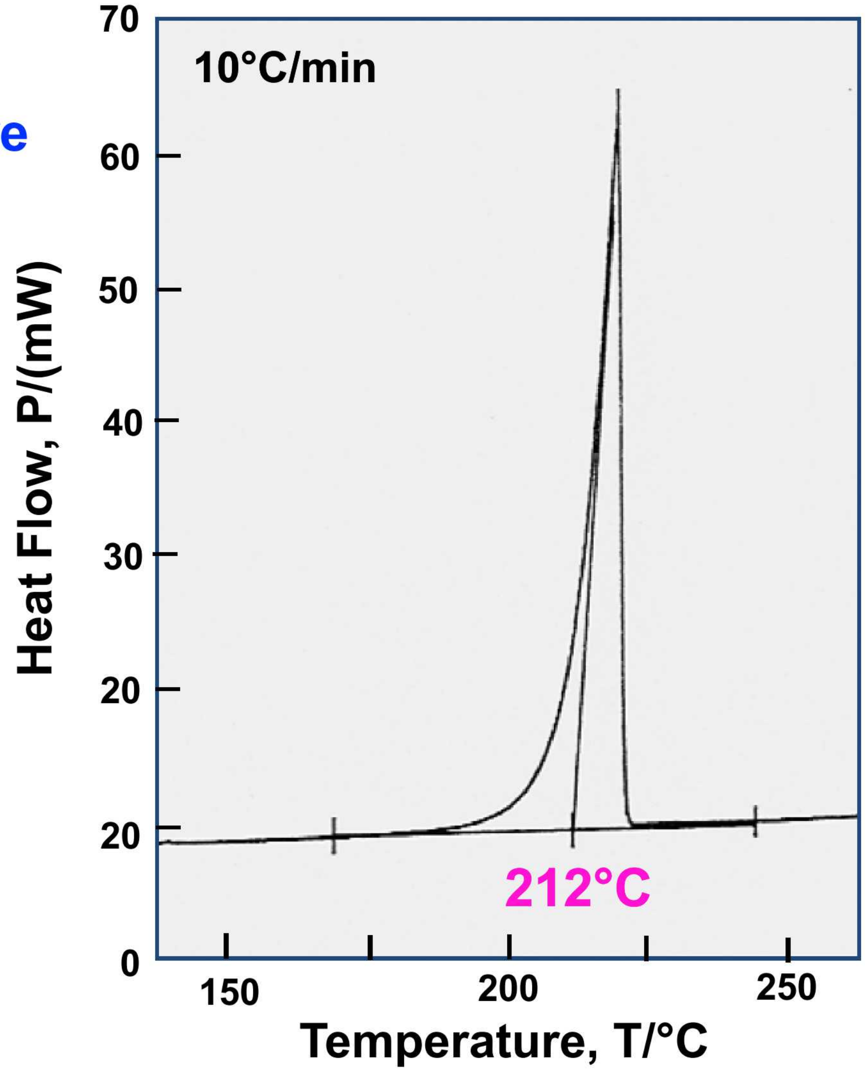


P. Vianco, et al., Mater. Trans of JIM (2004)

Novel Medium Melting Temperature Solders

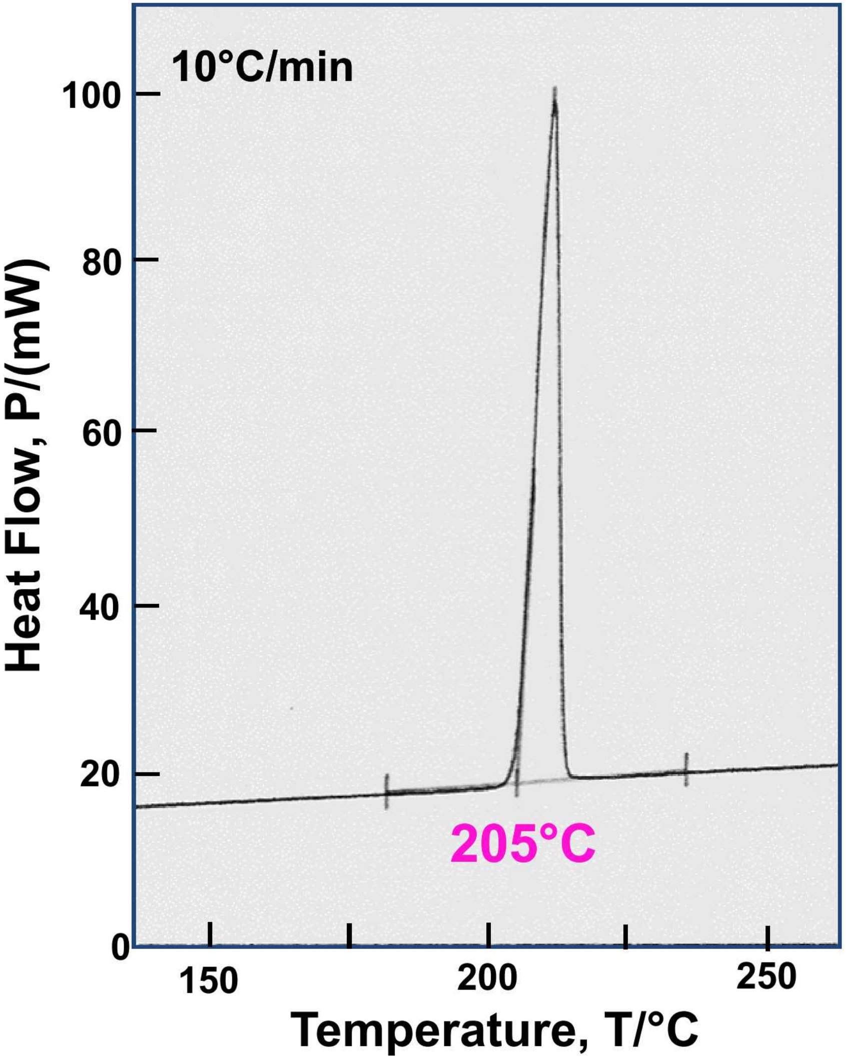
- An extensive development effort led to the 91.84Sn-3.33Ag-4.83Bi alloy having a solidus temperature of 212°C (ΔH = 55 J/g).





Novel Medium Melting Temperature Solders

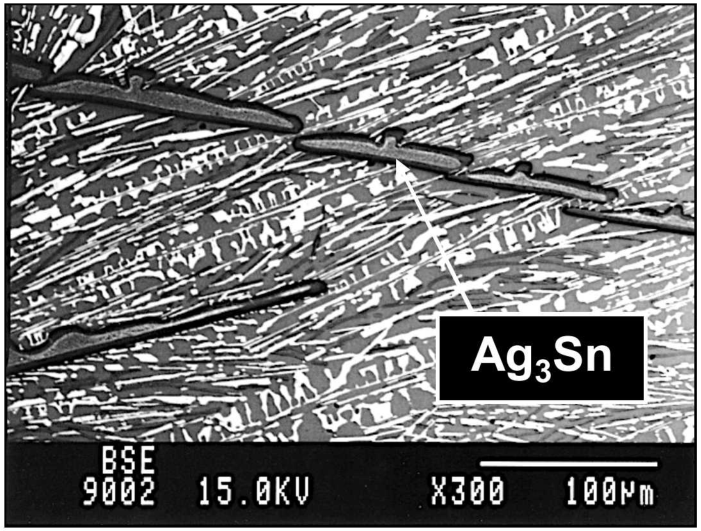
- **Two ternary alloys were developed that confirmed the effectiveness of gold (Au) as a melting point depressant.**
- **The 86.4Sn-5.1Ag-8.5Au was developed from this precept:**
  - **95% confidence intervals (mass%) were: Sn, 1.5; Ag, 0.33; and Au, 0.06**
  - **$T_s = 205°C$; $\Delta H = 55$ J/g**
- **The very sharp peak implies that: *$T_l - T_s$ is less than 5°C*.**

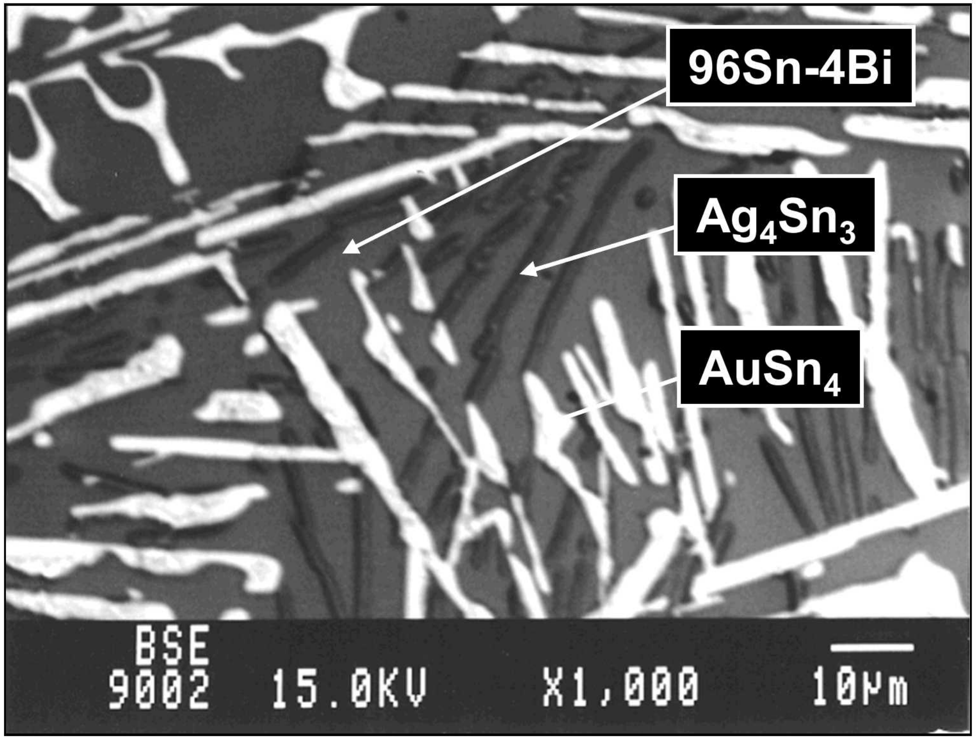


Novel Medium Melting Temperature Solders

◆ **The 86.4Sn-5.1Ag-8.5Au microstructure was comprised of a solid-solution (matrix) phase, 96Sn-4Bi, and three particle phases:**

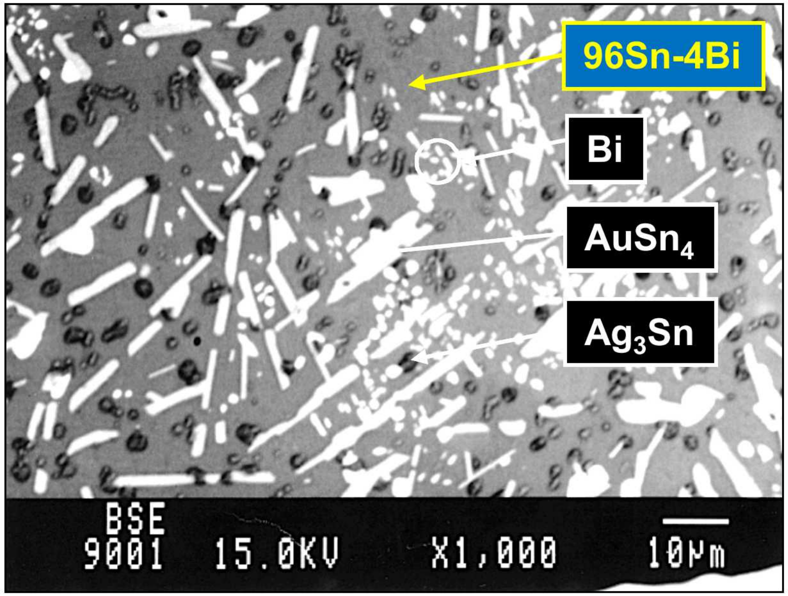
- **Ag_3Sn**
- **Ag_4Sn_3**
- **$AuSn_4$**

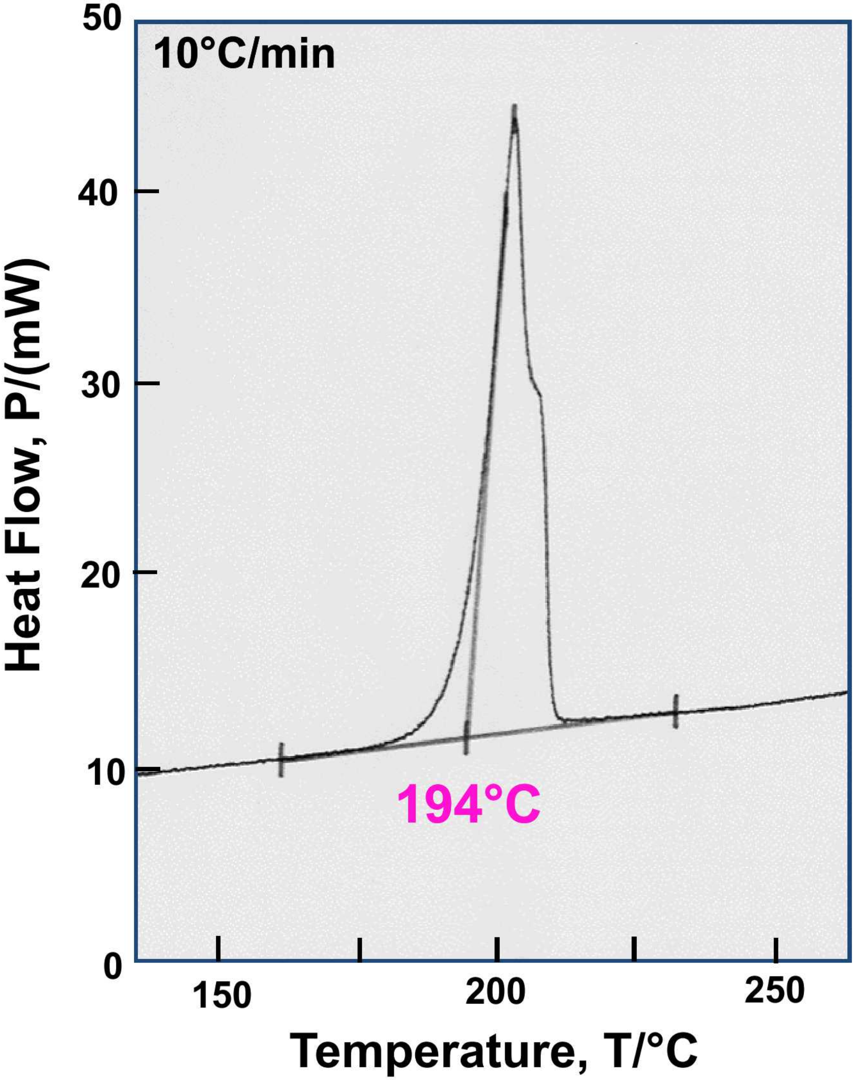




Novel Medium Melting Temperature Solders

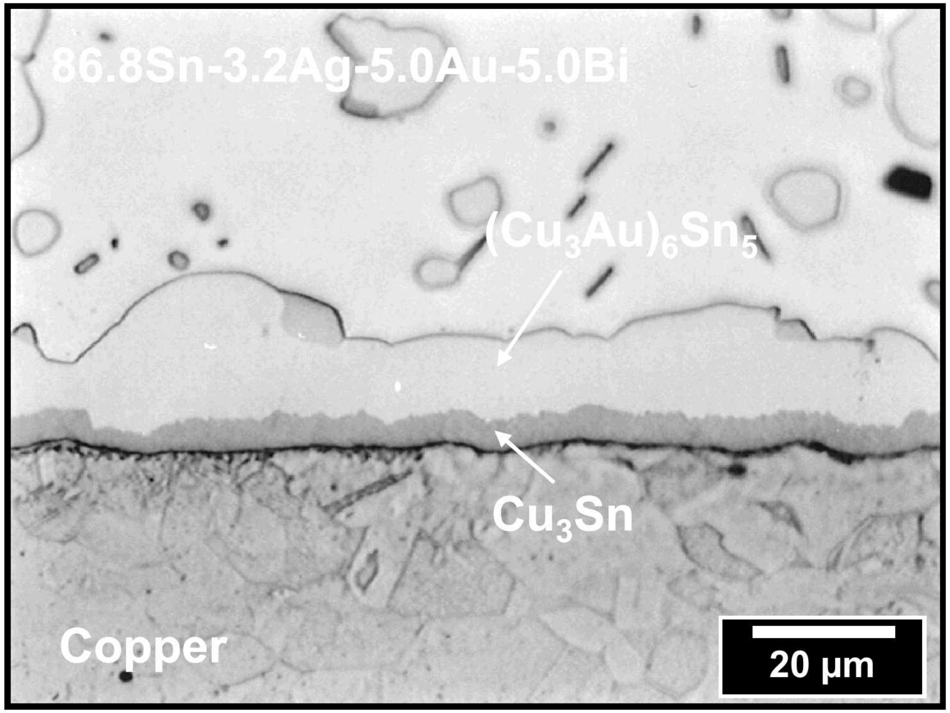
- **The 86.8Sn-3.2Ag-5.0Au-5.0Bi exhibited a shoulder that is indicative of a liquidus point of ≈ *204°C*.**
  - **T_s = 194°C; ΔH = 53 J/g**
  - **Besides the particle phase, the matrix phase was a solid solution: 96Sn-4Bi.**





Novel Medium Melting Temperature Solders

- An extensive analysis was performed on the 86.8Sn-3.2Ag-5.0Au-5.0Bi alloy (T_s = 194°C).



Aged:
170°C, 100 days

- The complexity of the solder composition *did not alter* intermetallic compound (IMC) layer development along the Sn-Ag-Au-Bi/Cu interface vis-à-vis other high-Sn solders.
  - The rate kinetics were similar to the Sn-Ag, 100Sn, etc. solders.

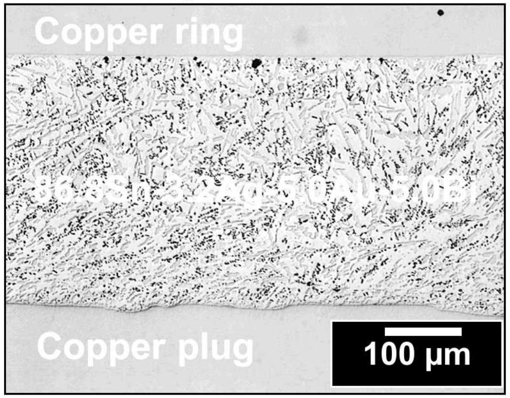
Novel Medium Melting Temperature Solders

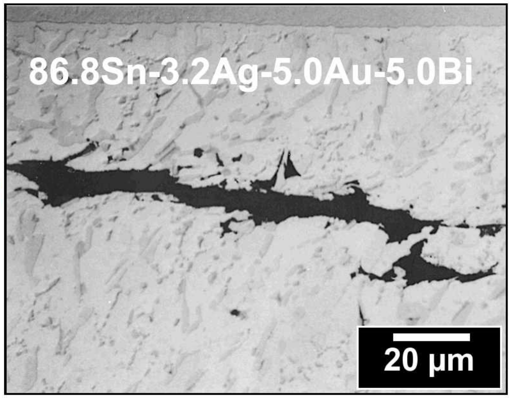
- **Ring-and-plug mechanical testing was performed using the 86.8Sn-3.2Ag-5.0Au-5.0Bi alloy (T_s = 194°C).**

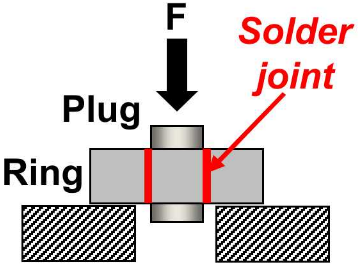
Solder alloy (mass%)	Ring-in-plug shear strength	
87.5Sn-5.0Bi-7.5Au	80 ± 2 (MPa)	11,600 ± 300 psi
86.8Sn-3.2Ag-5.0Bi-5.0Au*	84 ± 2 (MPa)	12,200 ± 300 psi
96.5Sn-3.5Ag	55 ± 1 (MPa)	8,000 ± 100 psi
60Sn-40Pb	40 ± 2 (MPa)	5,800 ± 300 psi
91.84Sn-3.33Ag-4.83Bi	80 ± 10 (MPa)	11,600 ± 300 psi

**The ring-and-plug shear strength of the Sn-Ag-Bi-Au alloy remains as the highest value recorded of any solder alloy.*

- **The fracture path remained in the solder, *not at the interface*.**

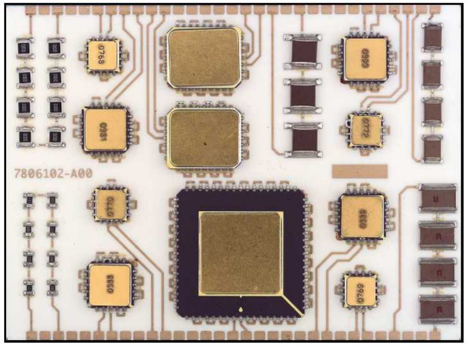




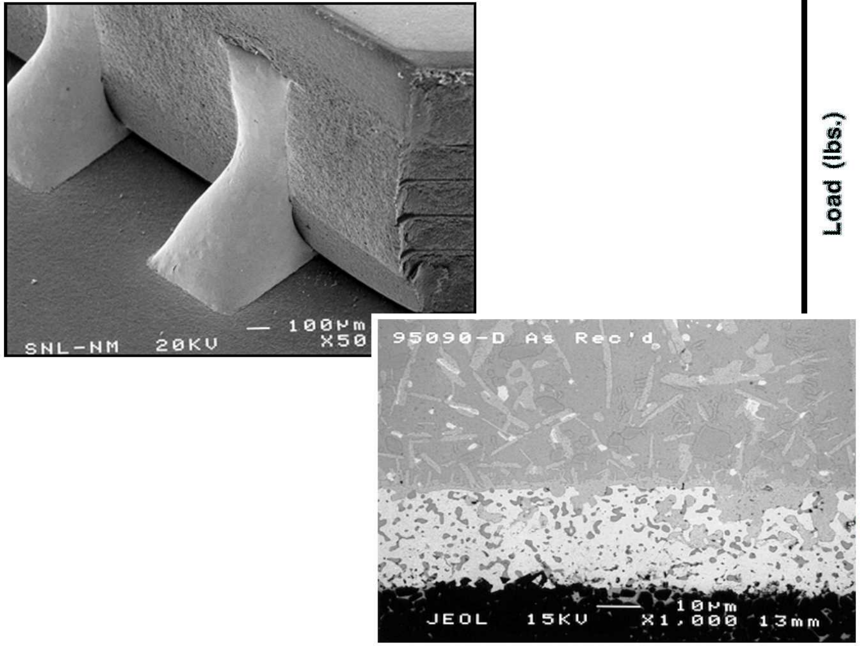


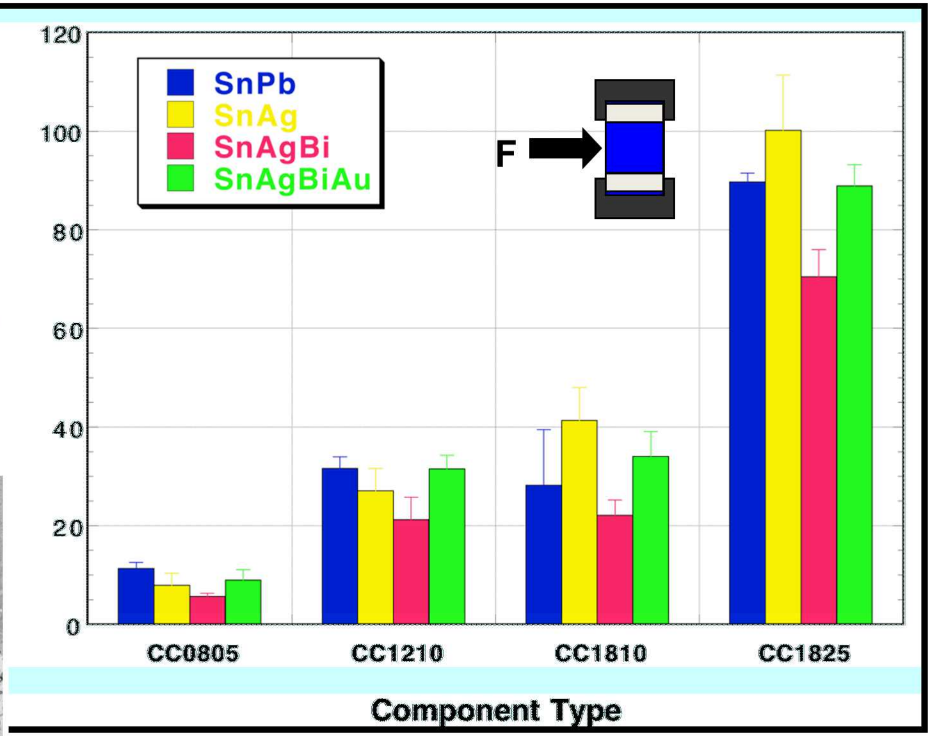
Novel Medium Melting Temperature Solders

- Hybrid microcircuit (HMC) test vehicles were made with this solder, expecting reduced scavenging of Au- and Ag-based thick films.



- The shear strength of the chip capacitor solder joints did not reflect the ring-and-plug (Cu) shear strengths because failure occurred in the capacitor structure.

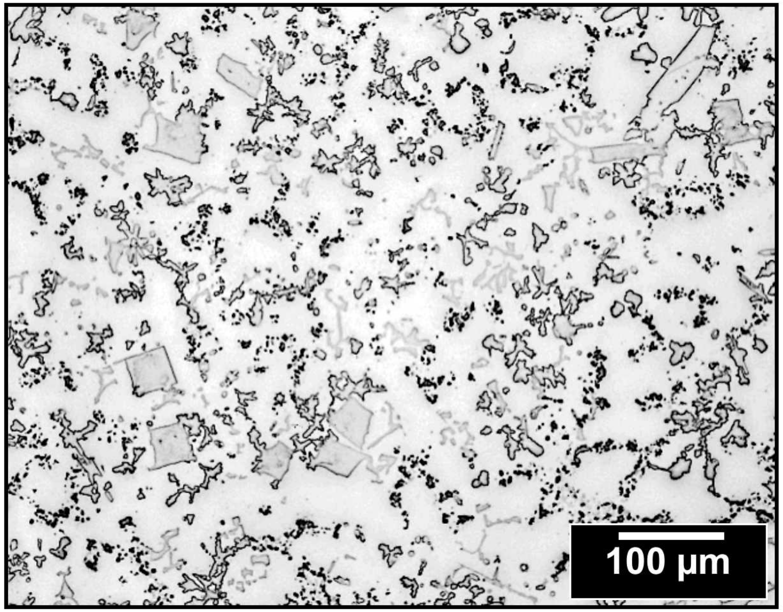


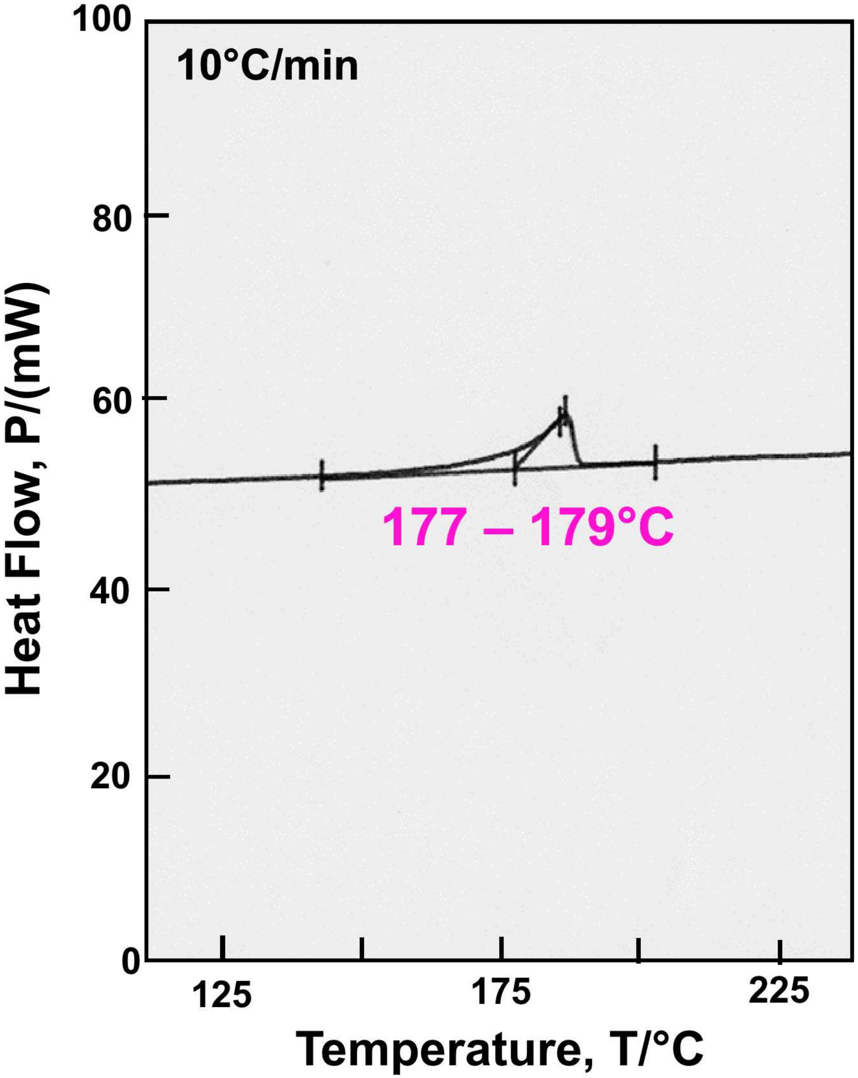


Novel Medium Melting Temperature Solders

- **66Sn-5.0Ag-10Bi-5Au-10In-4.0Cu had a solidus temperature that was in the range of 177-179°C and $\Delta H = 31$ J/g.**

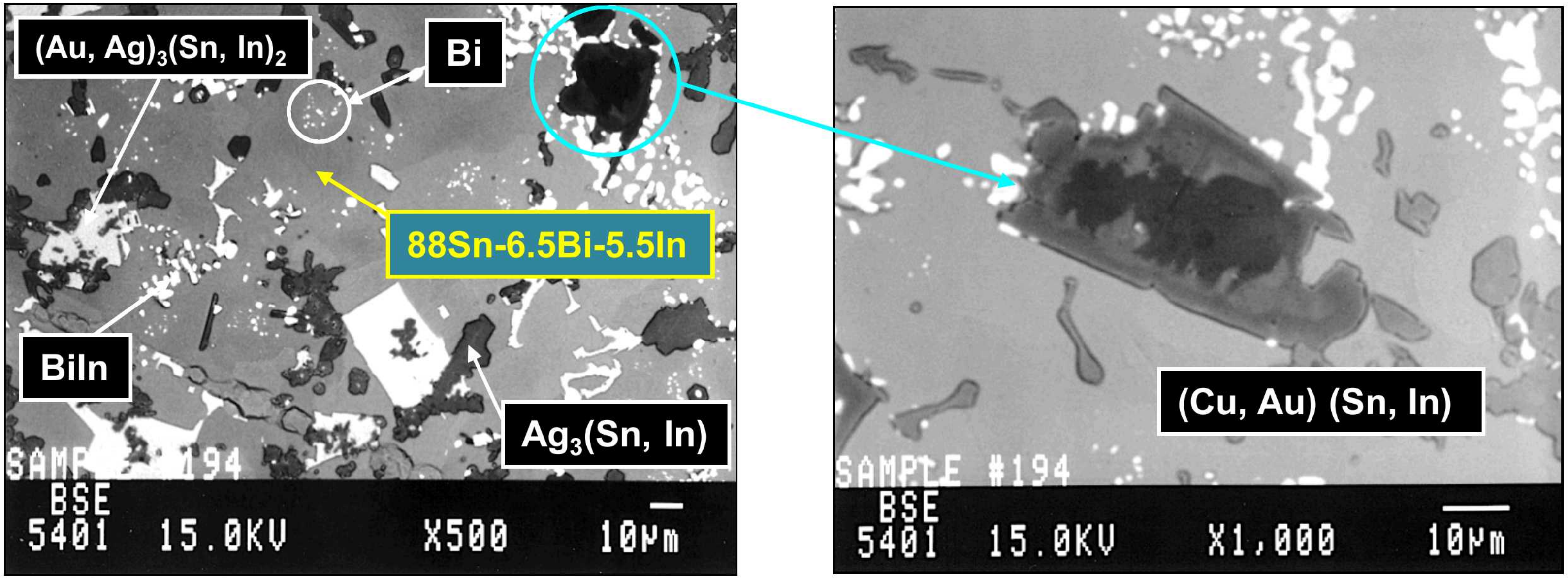
- **Although complicated, the particle phases were uniformly distributed within the microstructure.**





Novel Medium Melting Temperature Solders

- The 66Sn-5.0Ag-10Bi-5Au-10In-4.0Cu microstructure was comprised of several particles and a 88Sn-6.5Bi-5.5In matrix phase.



- Solderability:

"… pretty good"

Solder alloy (mass%)	Contact angle (°)	Solder-flux interfacial tension (dynes/cm)
66Sn-5.0Ag-10Bi-5.0Au 10In-4.0Cu	34.2±0.7	418±9
96.5Sn-3.5Ag	36±3	460±30
95.5Sn3.9Ag-0.6Cu	40±5	500±40
91.84Sn-3.33Ag-4.83Bi	31±5	420±30

250°C, RMA flux

Summary

◆ Low and medium melting temperature solders were examined with respect to the current segments of the electronics marketplace:

- High volume, consumer electronic product
- Low-to-medium volume, medium reliability products
- Low volume, high-reliability aerospace and defense products

◆ The traditional, low melting temperature alloys …

- 52In-42Sn,
- 58Bi-42Sn, and
- 97In-3Ag

… are not supported by the supply chain to implement into any of the three marketplaces.

Summary

- **Current medium meltingtemperature solders are based upon the 91.84Sn-3.33Ag-4.83Bi ternary composition.**
  - **An extensive database exists of the physical and mechanical properties of the material.**
  - **Semi-quantitative, thermal cycling studies were performed on older technologies (e.g., peripheral leaded packages).**
  - **"High-fidelity", temperature cycling reliability data (e.g., IPC-9701) are just now being accumulated for the Sn-Ag-Bi alloy.**
  - **Data is limited with respect to long-term interactions between this solder and current PCB surface finish technologies.**

- **Several novel compositions were developed that had melting temperatures commensurate with the eutectic Sn-Pb alloy.**
  - **Although highly unlikely to achieve "mainstream status," they showcased *metallurgical methods to optimize alloy performance*.**

Acknowledgements

Sandia Nat. Labs.

- A.C. Kilgo
- B.M. McKenzie
- R.L. Grant
- M.K. Neilsen
- J.A. Rejent (ret.)
- J.M. Grazier (ret.)

AT&T / ERC

- I. Artaki
- A. Jackson (ret.)
- U. Rey
- G. Wenger (ret.)