Henkel Pb-Free Soldering Technology

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Transitioning to a Pb-free Process

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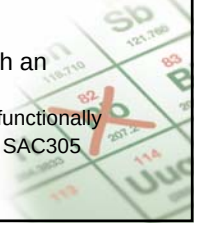
Marketplace - Alloy Selection

- Japan
  - still a range of materials spanning different products (result of original broad spectrum R&D?)
  - focusing down on SnAg3.0Cu0.5 (SAC305)
- Europe and Americas
  - general consensus for SnAg3.8(±0.2)Cu0.7(±0.2) (SAC387)
  - NEMI, IDEALS, IPC, SMART, NCMS
- Industry Groups trying to establish an international consensus
  - the small differences do not matter functionally
  - IPC Solder Value Council – USA -> SAC305



Why Pb-free?

- EU Legislation – July 2006
  - WEEE (August 13,2005) and RoHS
- Japan
  - Market Pressures
- China
  - Copy EU RoHS
  - Testing must be done by Chinese certified lab
- United States
  - State Legislation (WEEE) – California & Maine
  - CA also has a copy of the EU RoHS (Jan 2007?!?)

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Mechanical Properties and Reliability

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Mechanical Properties of Pb-free Alloys

- A great deal of published data on the bulk properties of Sn/Pb
  - this does not generally correlate with reliability in electronic assemblies
- Limited set of data for all the Pb-free options
  - data often contradictory need to understand how data was obtained.

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Accelerated Testing

- Purpose of accelerated test
  - accelerate the real life failure mode
  - generate a “conversion factor” to predict lifetime
- Danger of accelerated tests
  - accelerate a failure mode that does not happen in real life
  - assume the same conversion factor applies to different situations - or different alloys

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Factors Affecting Joint Reliability

- Assembly design - stresses & strains imposed on individual joint
  - Component/PCB size & material
  - Assembly compliance
    - LCCCs, chip components give low compliance
    - Leaded QFPs give high compliance
- Soundness of joint - interfacial defects, fillet size, standoff height, voids
- Joint microstructure
  - Solder alloy composition, dissolution from board/component finishes
  - Local cooling rate, time since joint formation

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Vibration Tests of Joints - IDEALS

Push off strengths as % of initial value	0 cycles	Random Vibration 6 hrs @20G @50-2000Hz	Thermal Shock –40/+125C	Combined RV+TS
0805 SnAgCu	100%	82%	71%	76%
1206 SnAgCu	100%	93%	92%	82%
0805 SnPbAg	100%	100%	78%	70%
1206 SnPbAg	100%	100%	65%	73%

SnAgCu slightly worse in pure vibration, better in combined thermal shock and vibration

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NCMS 2 - All Components

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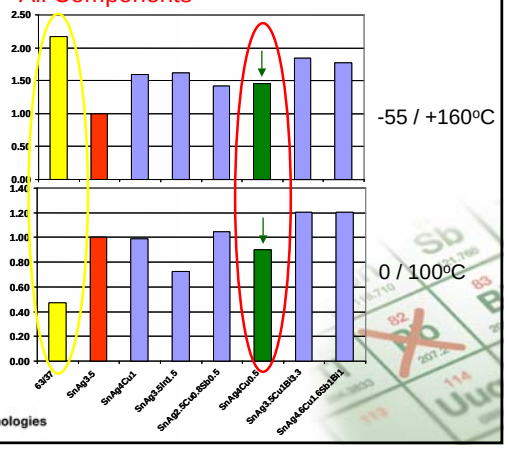

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Assembly With Pb-free Materials

- Alloy Physical Properties
- Impact to Process
- Example of Production Study

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Reliability Summary

- SnPb is better than Pb-free (SAC) under severe reliability test (-55/+160°C) conditions
- Pb-free alloys are superior to SnPb under low-cycle fatigue conditions

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Changing from Sn63 to SAC
Comparison of Alloy Properties

Alloy	Sn63	SnAg3.8Cu0.7
Melting point	183C	217C
Density (g/mm2)	8.5	7.5
Surface tension @ 260C in air	481 mNm-1*	548 mNm-1**
Wetting angle on Cu (deg)	12*	43

* Values for Sn60Pb40
** Values for pure tin

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Physical Properties of Pb-free Alloys Affecting Assembly

- Higher melting temperature than Sn/Pb
  - Effects Reflow
  - Change for components manufacturers
  - Narrower process window
- Higher surface tension than Sn/Pb
  - Pb lowers surface tension of Sn
  - Observable effect in wetting behaviour
- Density Difference
  - Changes metal loading in paste from ~90% to ~88.5%
  - Minor impact to tack and release

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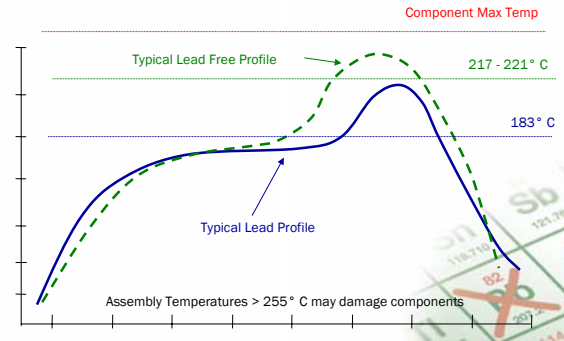
Reflow Profile Types



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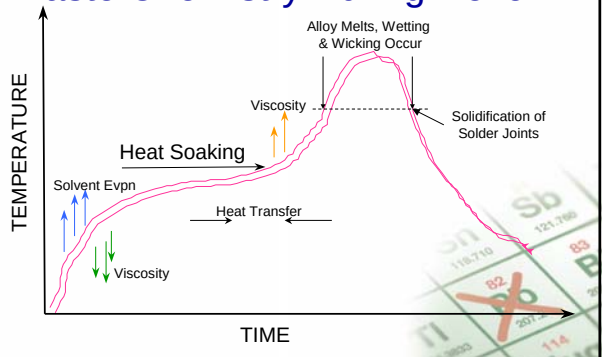
Paste Chemistry During Reflow



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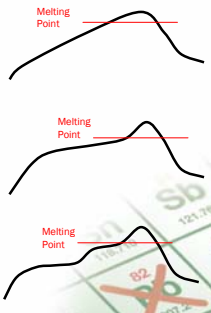
Reflow Profile Types

- Linear
  - Small components, rapid cycles
  - More popular profile
- High Hold
  - Higher mass product
  - Ensure component heat distribution
- Double soak
  - Flux activity management (wetting management)
  - Not in large use



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The Pb-free Reflow Process Challenge

- Achieve good wetting on the coldest part of the circuit board
  - 235°C for 10 seconds is the accepted minimum – reports we can achieve good wetting at 229°C
- Minimize the temperature of the hottest part of the circuit board
- Keep the process stable
- Monitor the process accurately

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Alloy Contact Angle vs. Substrate

Solder paste contact angles all in the range 20 - 25° for the same flux system

SUBSTRATE	REFLOWED ALLOY PELLET (Sn +)					
	0.5Cu	3.5Ag	3.8Ag0.7Cu	3.5Ag0.5Sb	3.8Ag0.7Cu0.5Sb	37Pb
Cu	42	43	43	41	43	12
Ag	19	26	24	30	33	13
Sn37Pb	19	19	22	20	22	5
Sn0.7Cu	15	11	18	11	10	17
Au over Ni	9	6	10	14	5	4

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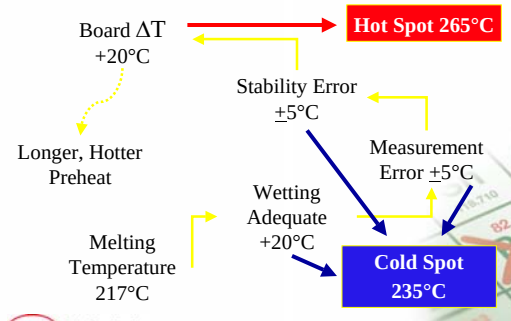
Worst Case Scenario for Pb-Free Solder Paste



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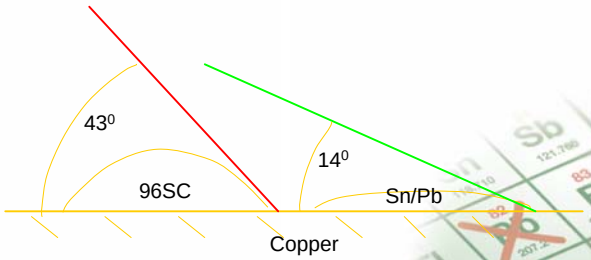
Wetting Angle on Copper



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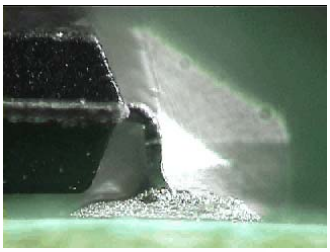
Example of Wetting



- Solder Melting
- Wetting up the lead

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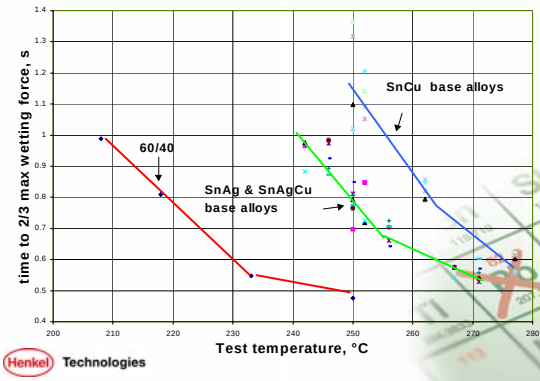
Summary wetting speed vs temp.



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Pb-free Alloy Wetting Behaviour

- Higher melting temperature
  - expect to need higher soldering temperatures
  - higher soldering temperature increases need for flux activity
- Wetting Balance Tests
  - quantify the ***wetting rate*** behaviour
- Spread Tests
  - quantify the ***equilibrium wetting*** behaviour

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Can Wetting Rate be Enhanced?

- Flux activity is the main parameter
- Alloying changes
  - Sb, Bi have been proposed as wetting rate enhancers
  - Observations show the same effect of minor and impurity elements as known for Sn/Pb alloys

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Wetting Rate and Ability

- Wetting rate effects:
  - Degree of tombstoning
  - Ability of component to self center
- Both are also related to surface tension

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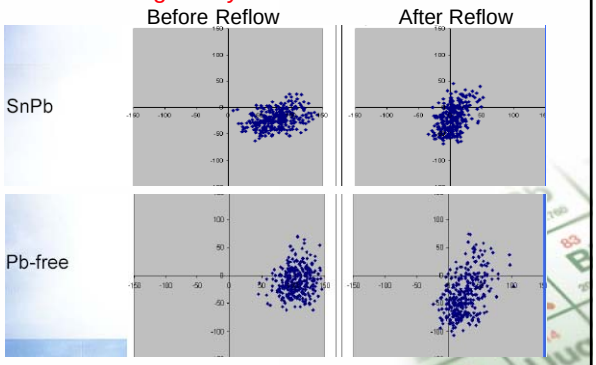
Self-Centering Ability



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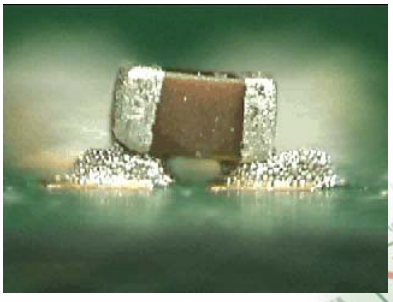
Tombstoning



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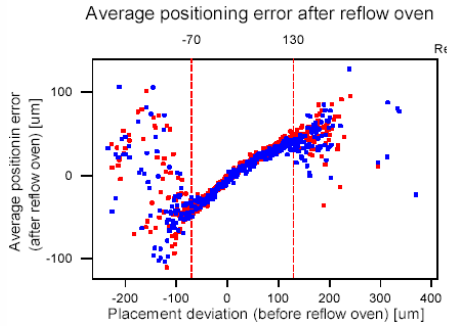
Component Self-Centering Process Window



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Wetting Test Conclusions

- Wetting rates and spread for Pb-free alloys render assembly processes viable
- Surface tension of lead free alloys is higher than SnPb
  - spread is lower
- Maximum wetting force is largely independent of the alloy
- Wetting speed for SnAg and SnAgCu alloys is acceptable at lower superheat temperatures than SnCu alloys

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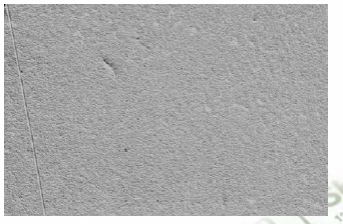
Pb-free Solder Joints



- Lead-free:
  - Sn / Ag / Cu / Au / Ni
  - More variation in surface finishes
  - OSP, IAg, ISn, ENIG
  - Needs more investigation

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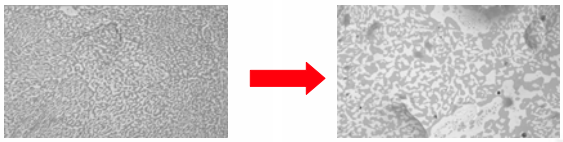
"Traditional" SnPb Solder Joints



- **Currently:**
  - **Sn / Pb / Cu**
  - **Sn / Pb / Au / Ni**
  - **Still has lamellar structure**

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Materials Used in This Study

- Solder Alloy
  - Sn 95.5 Ag 3.8 Cu 0.7
- Board Finishes
  - OSP
  - Immersion Tin
  - ENIG
- QFPs
  - Tin / Bismuth
  - 100% Tin
  - Tin / Copper
- Discrete Components
  - Tin/Nickel
  - 100% Tin
- µBGA
  - SAC 305 bumps

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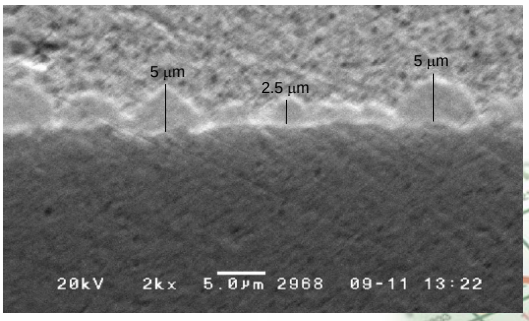
QFP Sn/Bi + Sn / Ag / Cu + IAg



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Beyond Engineering

Even if you choose the best solder paste, components and process…it is not enough

Others Involved in the Process:

- Quality
  - Need to know the differences
- Logistics
  - Transition time period / multiple lines
- Purchasing
  - Sourcing the correct materials
- Operators
  - Need to be trained to understand the differences with Pb-free

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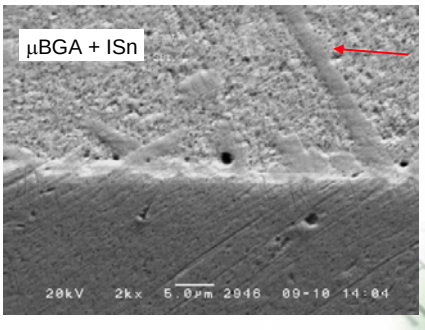
MicroBGA (Sn/Ag/Cu) + SAC + ISn



Large IM Fingers Present

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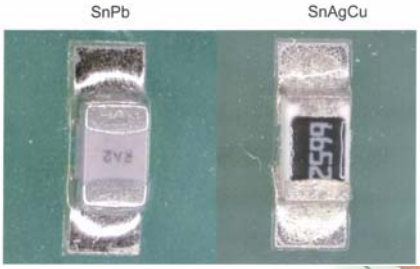
Key Inspection Differences



SAC – Rougher, dull, appearance
Less bright and shiny
THIS IS OK!

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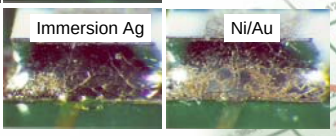
Key Inspection Differences

All Pb-free

Different surface finishes



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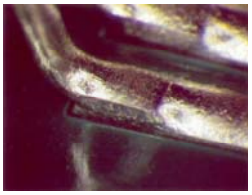
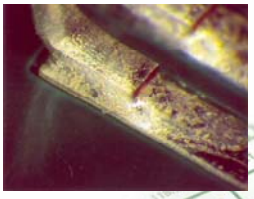
Wetting on cut terminations



Weaker flux reflowed in nitrogen



Stronger flux reflowed in air

Generally poorer than Sn/Pb pastes but can be improved using flux changes and/or nitrogen

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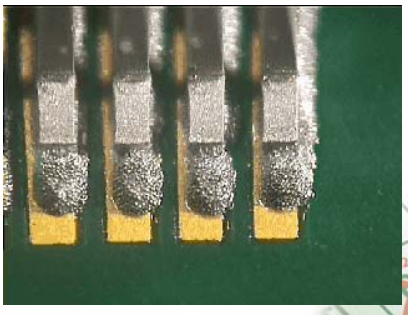
Solder Wetting on Pad



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Operator Training

- Manufacturer B working with us conducted operator training
- Review of characteristics of Pb-free Paste
  - Wetting Performance
  - Wetting Angle
  - Solder Joint Appearance
- All Operators went through 2 training courses
- 32 hours total over 2 months

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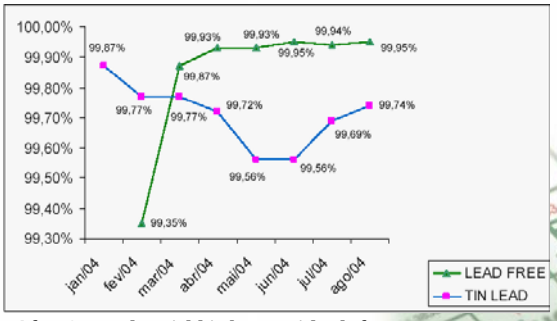
Yield Performance – Full Time Manufacturing



After 2 months, yield is *better* with Pb-free!!

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"Mixed Metal" Systems

- Even with exemptions full Sn/Pb may not be possible
- Mistakes will happen
- Availability of components

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Pb-free Manufacturing

- Pb-free Cell Phones have been in production for over 2 years
- Choosing the right materials is critical
- With the right training and implementation you can do as well as with Sn/Pb

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"Mixed Metal" Systems
Pb-free "leaded" component finishes

- Pure Sn
  - Most common
  - Whiskers(?)
- Sn/Bi
  - More popular in Japan
  - Reliability Questions
- Ni/Pd/Au
  - Vendor Specific
  - Questions about wettability
- Sn/Pb + Pure Sn
  - Wetting issues
  - Reflow Profile
- Sn/Pb + Sn/Bi
  - Sn/Bi/Pb – low melt temp
- Sn/Pb + Ni/Pd/Au
  - Least affected

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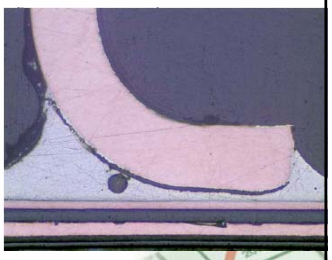
"Mixed Metal" Systems
"leaded" component finishes

- Failed SOIC lead
  - SAC 387 Paste
  - Pure-Sn Lead
  - ENIG Surface Finish
  - Components Fail after burn-in



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"Mixed Metal" Systems
Pb-free bumped component finishes

- SAC Alloy
  - SAC 305
  - SAC 405
- All SACs appear to be equal
  - IPC Solder Value Council
- Many, Many, Many Questions

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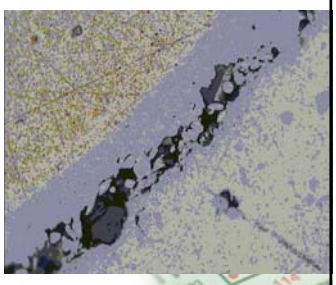
"Mixed Metal" Systems
"leaded" component finishes

- Failed SOIC lead
  - Lead 80/20 Sn/Pb
  - Failure at component lead
  - Quat eutectic (Sn/Pb/Cu/Ag) melts at 172
  - Failed in high-temp burn-in



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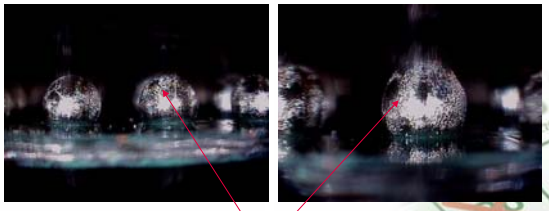
"Mixed Metal" Systems
Pb-free bumped component finishes

- Outer Appearance – BGA bumps



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"Mixed Metal" Systems
Pb-free bumped component finishes

- Outer Appearance – BGA bumps

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"Mixed Metal" Systems
Pb-free bumped component finishes

- Pb-free BGA bumps / Sn/Pb Paste
- Metals in the solder joint:
  - Sn (bulk)
  - Ag
  - Cu
  - Pb
  - Ni
  - Au
- Not evenly distributed

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"Mixed Metal" Systems
Pb-free bumped component finishes

- Pb-free BGA bumps / Sn/Pb Paste & Profile
  - Bump doesn't melt/collapse
  - Component at a higher standoff
  - Component tilt
  - Impact to reliability
- Pb-free BGA bumps & Profile / Sn/Pb Paste
  - Flux exhaustion of the Sn/Pb Paste
  - Increased voiding/blowholes
  - Poorer wetting

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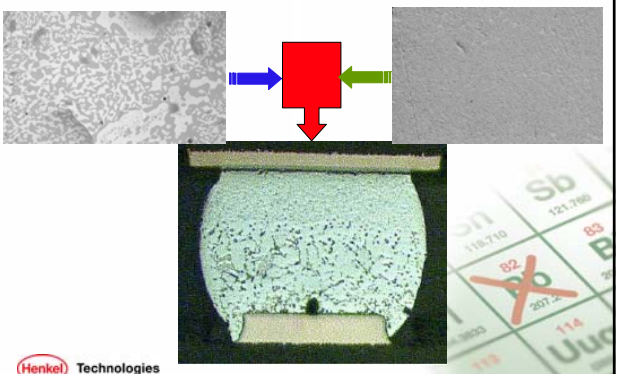
"Mixed Metal" Systems
Pb-free bumped component finishes



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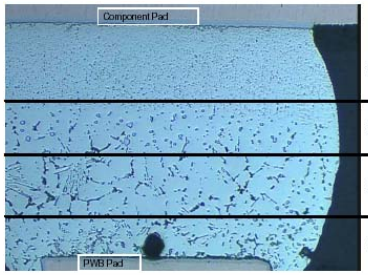
Mixed Metal Reflowed BGA



Zone	Microstructure Observed
A	Original SAC solderball - Tin Matrix, Fine Blocky & Platelet Intermetallic Phases
B	Tin Matrix, Large Blocky & Platelet Intermetallic Phases
C	Tin Dendrite Matrix, Interdendritic Phases, Fine Blocky & Platelet Intermetallic Phases
D	Tin Dendrite Matrix, Interdendritic Phases, Blocky & Platelet Intermetallic Phases, Solder Joint Crack

Henkel Technologies Hillman, et al., CMAP Pb-free Conference, May 2005.

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Final Joint Compositions and Liquidus Temp. with Sn3Ag0.5Cu Ball and Sn37Pb Paste

Pitch (mm)	Aperture Size (mil)	Stencil Thickness (mil)	Transfer Ratio (%)	Ball Dia. (mil)	% of Pb	% of Ag	% of Cu	Liquidus temp. (C)
1.27	21 (Ro)	6	100	28	3.4	2.7	0.5	**216**
		5	100	28	2.9	2.8	0.5	216
1.0	18 (Sq)	5	90	22	4.9	2.6	0.4	215
0.8	16 (Sq)	5	85	14	11.1	2.2	0.4	209
0.65	14 (Sq)	5	80	10	17.0	1.6	0.3	203 (200*)
0.5	11 (Sq)	4	90	10	11.9	2.1	0.3	**208**

* Calculated by Dr. Ursula R. Kattner of NIST from NIST thermodynamic database

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J. Pan, et al., IPC/JEDEC Pb-free Conference, March 2006

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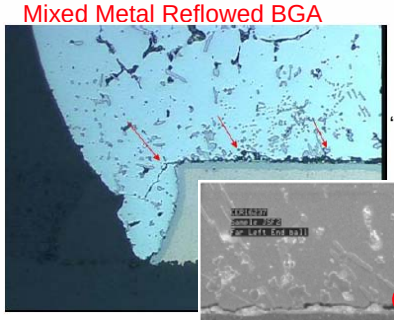
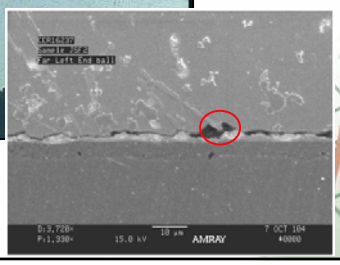
Mixed Metal Reflowed BGA



Thermal Cycling
-55 / +125
10C/min, 11 min dwell
"Normal" Sn/Pb= 1000+
Mixed Metal = 267



Hillman, et al., CMAP Pb-free Conference, May 2005.

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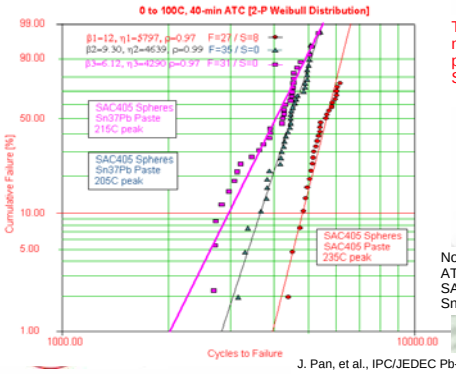
Solectron Lead-free Working Group Project



The fatigue life of mixed assembly is poorer than that of SAC/SAC

No significant differences in ATC reliability between SAC/SAC and previous SnPb/SnPb work

J. Pan, et al., IPC/JEDEC Pb-free Conference, March 2006

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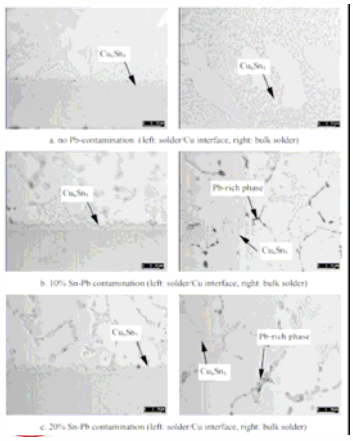

Effect of Pb Content

Study showed that the amount of Pb-rich phase increases and becomes coarser as the Pb impurity increases.
The Pb-rich phase is the weakest region in the bulk solder, and the crack may propagate along the Pb-rich phase interface during reliability testing.

Ref. Zhu, et al., "The effect of Pb contamination on the microstructure and mechanical properties of SnAg/Cu and SnSb/Cu solder joints in SMT," *Soldering and Surface Mount Technology*, Vol. 12, No. 3, 2000, pp. 19-23.

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Environmental Health and Safety Issues

- Solder still contains metals
- Heavy metal systems are toxic to humans
- Silver is a significant aquatic toxin
- Handle as the same as Pb-containing materials
- Good laboratory practices
  - Separate waste containers
  - Gloves, hand washing after shift/before break
- No need to report EPA/TRI

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Conclusions

- There are success with mixed metal systems
- Reliability window is more narrow
- More work needs to be done
- iNEMI committee looking into mixed metal BGA/CSP assembly
- Other companies also investigating
- Avoid it if possible, understand the risks if required
- Purchasing needs to understand differences in components
- Incoming quality inspection?

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Lead-Free Impact on SMT – Board Finishes

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Requirements for a Pb Free surface Finish

- Solderable surface for Pb free alloys.
- Planar surface.
- Good shelf life.
- Can withstand 3 reflows.
- Good contact for pin probing.

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ENIG Surface Finish

Advantages	Disadvantages
• Established finish • Planar surface • Good shelf life • Good solderability • Compatible with 3 reflows	• Cost • Complex process • Black pad • Gold embritlement

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Candidate Surface Finishes

- Electroless Nickel Immersion Gold (ENIG)
- Immersion Tin (IT)
- Immersion Silver (IAg)
- OSP Copper
- Pb Free HASL (Sn/Cu/Ag)
- Electroless Nickel Electroless Paladium, Immersion Gold (ENEPIG)

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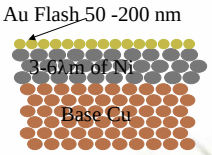
Gold Embritlement

Theoretical Average Au Content of Filet

	Stencil Thickness		
Au Thickness	4 Mil	5 Mil	6 Mil
50 nm	0.19%	0.16%	0.13%
100 nm	0.38%	0.32%	0.26%
200 nm	0.76%	0.63%	0.52%
500 nm	1.89%	1.58%	1.31%



1 µinch = 25 nm

Assumes 88% SAC 305 Paste

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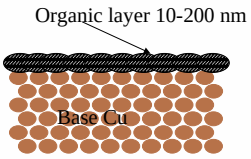
OSP Surface Finish



- Poor spread of Pb free alloys.
- Pb free OSP versions available.
- Thermally degraded
- Chemically degraded by flux.

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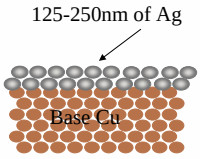
Immersion Ag Surface Finish



- New surface finish
  (Less than 5 years)
- Ag stabilized with organic preservative
- UL electromigration concerns being addressed.

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OSP Surface Finish

Advantages	Disadvantages
• Low cost • Planar surface • Established finish • Simple intermetalics • Robust manufacturing process	• Low cost • Poor Pb free spread • Easily removed • Fragile

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Immersion Ag Surface Finish

Advantages	Disadvantages
• Planar Surface • Can take multiple reflows • Drop in replacement for HASL • Reasonable cost • Good wetting characteristics	• Limited supply base • (should change) • Long term storage unknown • UL issues unresolved

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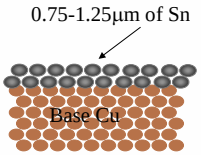
Immersion Sn Surface Finish



- Relatively thick coating of Sn.
- Compatible with Pb free alloys.
- Gained limited acceptance in Europe

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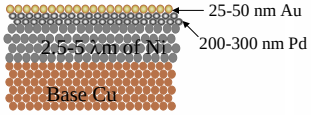
Other Possible Surface Finishes

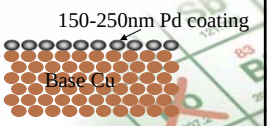
ENEPIG

- Most expensive complex process
- Very stable highly solderable surface
  (no black Pad)



Electroless Pd

- Costly
- Good solderability and shelf life



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Immersion Sn Surface Finish

Advantages

- Planar Surface
- Easy to rework
- Drop in replacement for HASL
- Reasonable cost
- Good wetting characteristics

Disadvantages

- Potential tin whisker problem
- limited shelf life
- Still limited supply

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Comparison of finishes

- There is no one finish “fits all”
- Assemblers need to evaluate surface finish pros and cons
- Things to consider:
  - Cost
  - Planarity
  - Availability
  - Storage
  - Process

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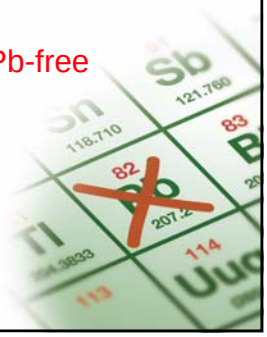
Manufacturing with a Pb-free Process

Material Compatibility



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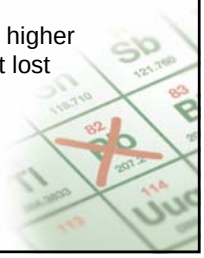
Adhesion versus Temperature

- Adhesion decreases with increasing temperature
- Pb free wave requires higher pot temperatures.
- It is necessary to verify adhesion at higher temperatures is sufficient to prevent lost components



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Beyond Solder Alloy

- Other materials in the process also affected by the change to Pb-free
  - Surface Mount Adhesive
  - Conformal Coating
  - Underfill
  - Substrate
  - Board Finish

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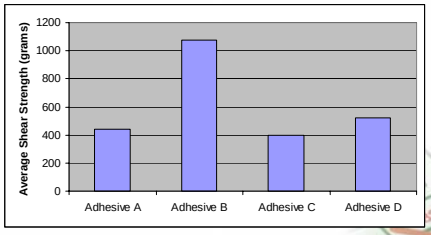
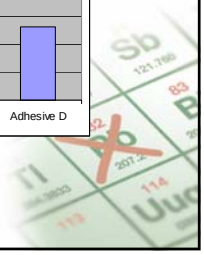
0805 Shear Strength at 260C





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SMA Failure

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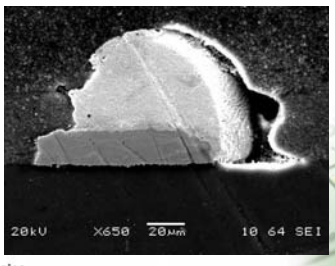
Poor Underfill Adhesion

- Example of poor underfill adhesion to flux residue



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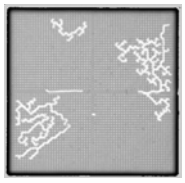
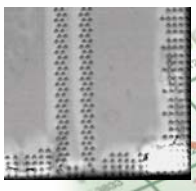
Poor Performance

Flux Compatibility Issues

- **Poor adhesion when first applied and cured**
- **Delamination after stress is applied**





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Conformal Coating Reliability

- Need to retest with new flux systems
  - SIR
  - Adhesion testing
  - Corrosion testing

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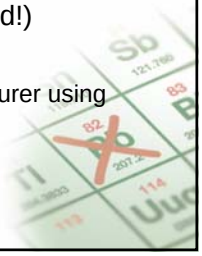
Other Considerations

- Wave Soldering
- Rework
- Logistics
- Mixed Alloys (Transition Period!)
- Voids in Solder Joints
  - One handheld device manufacturer using underfill to meet reliability



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Thank You

Questions?