# IPC Midwest 2011

## A Review of Issues and Next Steps in Moving From Sn3Ag0.5Cu to Low Silver Solder Alloys

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**Executive Summary:**

The implementation of the European Restriction of Hazardous Substances (RoHS) Directive has initiated an electronics industry materials evolution. Printed wiring board laminate suppliers, component fabricators, and printed wiring assembly operations are engaged in numerous investigations to determine what lead-free (Pbfree) material choices best fit their needs. The complexities of Pbfree soldering process implementation insures a transition period in which Pbfree and tin/lead solder finishes will be present on printed wiring assemblies for many electronic product segments. One of the component surface finishes being offered by electronics industry component fabricators is 98% tin - 2% bismuth (98Sn2Bi) as a Pbfree component finish option. This presentation documents an investigation of a solder joint integrity assessment of tin/bismuth component surface finishes in both tin/lead and Pbfree soldering processes under thermal cycle conditions. The investigation results are also compared/contrasted with other industry published data sets.

# A Review of the Issues and Next Steps in Moving From Sn3Ag0.5Cu To Low Silver Lead-Free Alloys

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# Agenda

- Introduction/ Background
- Reliability tests for low Ag lead-free alloys
- Processing tests for low Ag lead-free alloys
- Updates needed to component and board standards
- Conclusions
- Future Work

# Background

- The electronics industry has been transitioning from Sn37Pb to lead-free Sn3Ag0.5Cu over the last ten years.
- More recently there has been activity and interest in transitioning to low silver(≤1.2wt%) lead-free solder alloys in BGA/CSP component spheres, wave solder and rework alloys and now solder paste.

# Background (cont.)

- Presentation will review:
  - the current situation and usage of low silver alloys
  - pricing pressures to use low silver alloys based on global solder usage and the high costs of silver metal
  - Alternative low silver lead-free solder alloys in relation to their affect on board and component temperature, warpage and solderability standards.
  - Test development by consortia such as IPC SPVC and INEMI.

# Current Lead-free Alloys Uses

SMT solder pastes:

Mainly Sn3-4Ag0.5Cu

Some Sn1Ag0.5Cu and Sn0.7Cu based alloys

Wave Alloys: Sn3-4Ag0.5Cu and Sn0.7Cu based alloys

Rework Wave and Wire Alloys: Sn3-4Ag0.5Cu, Sn3.5Ag, Sn0.7Cu based alloys

BGA/CSP Sphere Alloys: Sn3-4Ag0.5Cu and Sn3.5Ag (for ATC reliability); Sn1Ag0.5Cu (for Mechanical/Drop reliability)

Transition to lead-free low Ag lead-free solder generally based on cost considerations for high silver based alloys(3 to 4wt% Ag).

# Annual World Solder Market

Global Solder Market per year (Approximate)

60,000 tonnes solder

Solder paste: 10,000- 15,000 tonnes

Wave solder: 45,000 tonnes

Global Silver Metal Usage per year (Approximate)

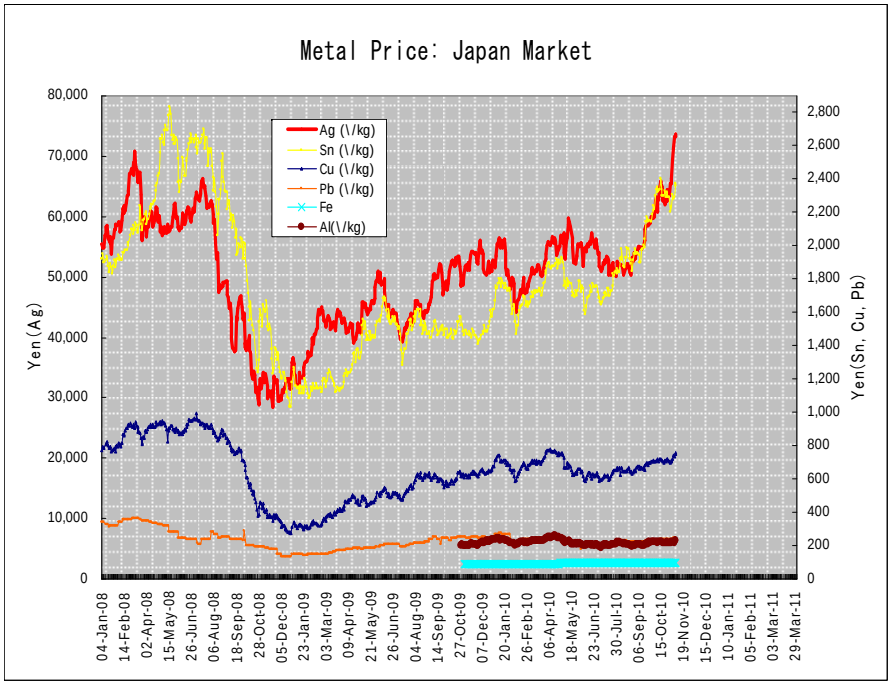
Global silver usage: 13,500 tonnes

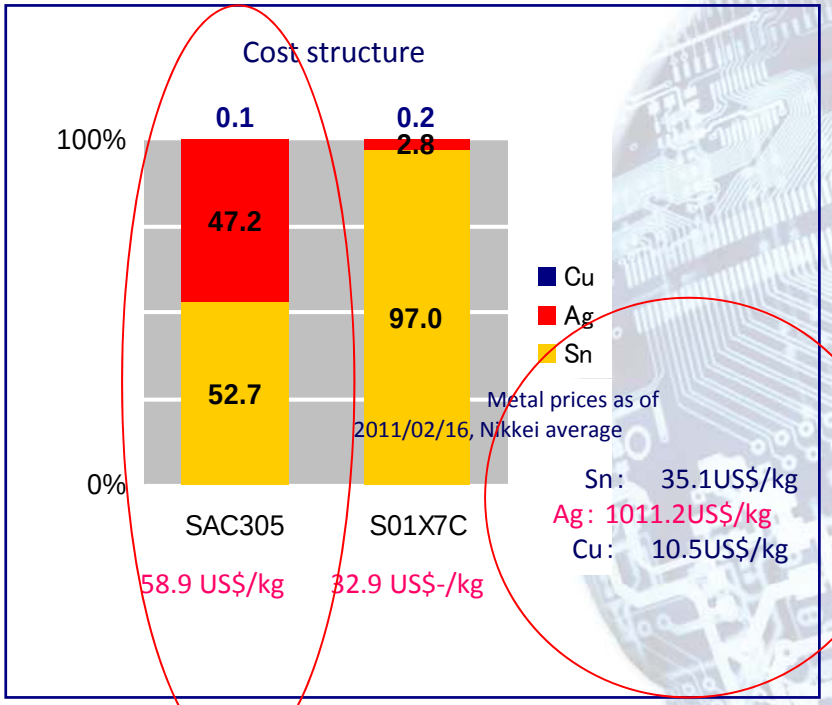
World capacity: 15,000 tonnes

Spare capacity: 1,500 tonnes

Enough silver for a lead-free solder alloy up to about 2wt% Ag.

# World Silver Price affecting Sn3Ag0.5Cu solder



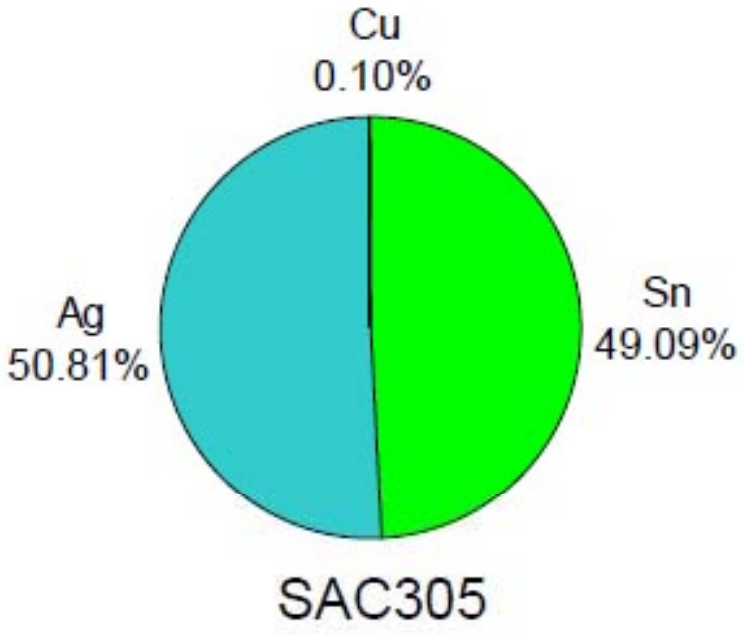



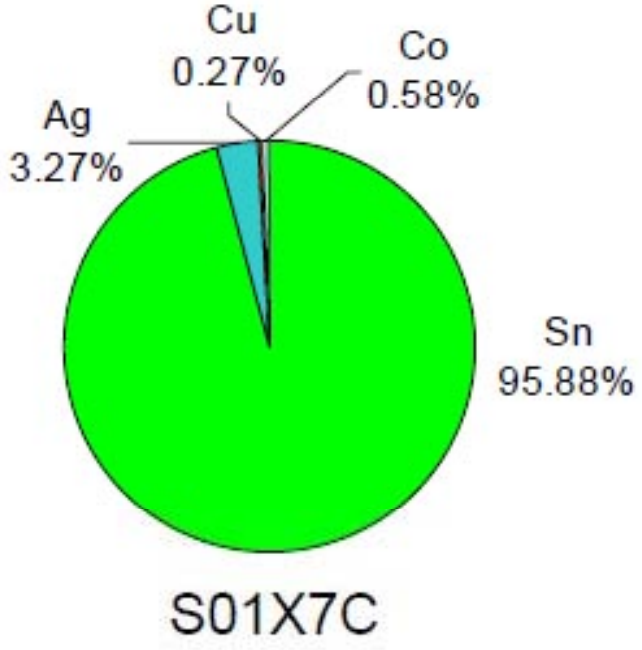

SAC305 (Sn / 3.0Ag / 0.5Cu), a mainstream composition of lead free solder alloy of today, contains 3% of Ag.

As precious metals can easily be a target of investment/speculative buying, the cost of Ag has increased considerably in recent years.

Numerous requests from customers for a low Ag solution.

# Example Cost analysis for Sn3Ag0.5Cu versus Low Ag solder pastes

- 


Low Silver alloy (Koki S01X7C- Sn0.1Ag0.7Cu0.03Co) reduces cost compared with Sn3Ag0.5Cu

Sn0.1Ag0.7Cu0.03Co has lower cost than Sn0.3Ag0.7Cu

# Some Lead-free Low Silver (Ag) Alloys to Sn3Ag0.5Cu

SMT solder pastes:

Sn1Ag0.5Cu, Sn0.3Ag0.7Cu, Sn0.1Ag0.7Cu,

Sn0.7Cu,

Sn0.7Cu0.05Ni,

Sn0.7Cu (+ X)

Wave Alloys: Sn0.7Cu based alloys

Wave Rework and Rework Wire Alloys: Sn0.7Cu based alloys

BGA/CSP spheres: Sn1Ag0.5Cu and Sn0.7Cu (+ X) alloys

# Issues transitioning to Low Silver Alloys for SMT

Higher melting temperature

– SnAgCu alloys

Sn3-4Ag0.5Cu (MP: 217°C)

⟹ Sn1Ag0.5Cu (MP:225°C) to Sn0.7Cu (MP: 227°C)

Increased soldering temperatures, more likelihood of component and board temperature issues

# Issues Transitioning to Low Ag alloys for Wave

Increased solder usage in Wave machines versus SMT

Sn0.7CuNi, Sn0.7CuAg and Sn0.7CuAgNi (JEITA) alloys

Lower Ag amount, lower cost: MP 227°C vs Sn3-4Ag0.5Cu MP 217°C

- JEITA alloys: Sn1Ag0.7Cu, Sn0.3Ag0.7Cu, Sn0.3Ag0.7Cu0.03Ni
- Sn0.7Cu based alloys
- Thicker boards: Higher pot temperatures- potential component and board issues and reduced wave holefill.

# Issues Transitioning to Low Ag Lead-free Rework Alloys

Hand soldering:

Sn0.7Cu based alloys (lower cost)

Potentially higher soldering iron tip temperatures especially for thicker more thermally demanding board

BGA/CSP rework

Sn0.7Cu based alloys (lower cost)

Higher board and component temperatures

Mini-pot/solder fountain: Good holefill/ low copper dissolution

Sn0.7Cu+Ni

Sn0.7Cu0.3Ag0.03Ni(JEITA alloy)

Higher board and component temperatures

# Component temperature rating (SMT)

- J-STD-020 standard for Sn3-4Ag0.5Cu (MP: 217°C):
  - 3X 245°C to 3X 260°C peak (based on package thickness/ volume)
  - Additional 1X 260°C for area array rework (BGA/CSP) parts not rated to 260°C
  - Time above 217°C : 60-150 sec

For low silver lead-free alloys such as Sn0.3Ag0.7Cu (MP: 227°C) this could be changed to:

- 3X 255°C to 3X 270°C peak
- Additional 1X 270°C for area array rework
- Time above 227°C: 60 – 150 sec

# Non-IC component temperature rating standards

- J-STD-075 (SMT and Wave): Assembly Classification for Chip components, Aluminium capacitors, Crystals, Oscillators, etc
- Reflow components:
  - R4: Classified to 3X 260°C peak temperature for Sn3-4Ag0.5Cu
  - For Sn0.3Ag0.7Cu could use the following:
    - RX: Classified to 3X 270°C peak temperature for Sn0.3Ag0.7Cu
- Wave components:
  - W1: Classified to 2X 275°C wave temperature for Sn3-4Ag0.5Cu
  - For Sn0.3Ag0.7Cu could use the following:
    - WX: Classified to 2X 285°C wave temperature for Sn0.3Ag0.7Cu

# Component temperature rating standards (Wave)

- JEDEC JESD-B106-D (Wave soldered TH components):
  - SnPb 1st pass : 260°C for 10 sec.
  - Sn3-4Ag0.5Cu 1st pass: 270°C for 7 sec.
  - Optional lead-free TH rework: 270°C for 15 sec
  - For Sn0.3Ag0.7Cu could use the following:
    - 1st pass: 280°C for 7 sec
    - Optional lead-free Sn0.3Ag0.7Cu TH rework: 280°C for 15 sec
- JEDEC JESD22-A111 (Wave soldered Immersed bottom-side SMT components) [2004]:
  - 260°C for 10 sec (SnPb)
  - For Sn3-4Ag0.5Cu and Sn0.3Ag0.7Cu could use the following:
  - 270°C for 10sec (Sn3-4Ag0.5Cu)
  - 280°C for 10sec (Sn0.3Ag0.7Cu)

# Bare board testing standards (IPC 4101)

- Base Materials Specification for PCBs (IPC4101) includes:
  - Time to delamination at 288°C (T288): At least 5 mins(for lead-free Sn3-4Ag0.5Cu)
  - For Sn0.3g0.7Cu could use the following:
    - 10 mins at 288°C for Sn0.3Ag0.7Cu or higher temperature than 288°C for 5 mins
  - Laminate decomposition temp.(Td):at least 325°C(for lead-free Sn3Ag0.5Cu)
  - For Sn0.3Ag0.7Cu could use the following:
    - 335°C for Sn0.3Ag0.7Cu

# Component Warpage Standards

- Work by JEITA and JEDEC to update component coplanarity specifications to include coplanarity requirements during SMT reflow
  - Max. Package Warpage during Lead-free Sn3-4Ag0.5Cu Reflow up to 260$^{o}$C : 3-6 mils (dependent on ball pitch: 0.4-1.27mm)

  For Sn0.3Ag0.7Cu could use the following:

  - 3-6mils Warpage for Sn0.3Ag0.7Cu up to 270$^{o}$C

# Board Flatness Standards

- IPC standards refer to maximum board flatness of 7.5mils/inch for SnPb or Sn3-4Ag0.5Cu at room and reflow temperatures.
- Is this the same for Sn0.3Ag0.7Cu
- The current board standards do not scale correctly at this time with package size and I/O count so:
  - Board flatness specifications need to be adjusted
  - Lead-free Sn3-4Ag0.5Cu and Sn0.3Ag0.7Cu solder updates need to be incorporated into the IPC standards.

# Physical Property tests for low Ag lead-free alloys

- Test low Ag lead-free alloy against Sn3Ag0.5Cu and in certain cases Sn37Pb solder.

<u>Testing data to include:</u>

- Melting point
- Wetting balance/ Solderability/ Holefill
- Copper dissolution
- Tensile and Creep Testing
- Coefficient of Thermal Expansion

- IPC SPVC, INEMI alternative alloy group documents to be combined to address this area.

# IPC SPVC (Solder Products Value Council)

IPC SPVC members include:

- AIM, Amtech, Inc., Cookson Electronics, Henkel Corporation
- Heraeus, Inc., Indium Corp., Inventec Performance Chemicals,
- Kester, Koki Company Ltd., Matsumura Metal Co., Ltd.,
- Metallic Resources, Inc., Nihon Superior Company Ltd.,
- Nordson EFD LLC, P. Kay Metal Inc., Qualitek, Redring Solder,
- Senju Metal Industry, Shenmao Technology, Inc.
- Sigma Ming GOA Electronics, Yik Shing Tat industrial Co.

# IPC SPVC Alternatives Alloy Test Proceedure for Basic Material Properties (May 2010)

Test data needed for:

- Alloy Composition
- Differential Scanning Calorimetry (Melting Point)
- Wetting Balance (Solderability)
- Copper Dissolution Test
- Coefficient of Thermal Expansion (CTE)
- Tensile Testing (Ultimate Tensile Stress, etc)
- Dynamic Modulus Testing (Elastic Modulus, etc)

# INEMI Alternative Alloy Group

INEMI members include:

- HP, Intel, Agilent, Alcatel-Lucent, Amkor,
- BTC, Celestica, Cisco, Cookson, Delphi,
- DfR Solutions, Flextronics, Henkel, Huawei,
- Indium, IST, Nihon Superior, Plexus,
- Rohm & Haas, Senju

* also members of IPC SPVC

# INEMI Alternative Alloy Group Recommendations for a Joint IPC SPVC/ INEMI document on Basic Material Property Testing

- Release the Basic Material Property Testing document without a copper dissolution test at this time.
- Note in the document that a copper dissolution test method is being developed and will be included in a future revision.
- INEMI recommend working with the IPC SPVC to establish a group to develop a standard test for copper dissolution.

# INEMI Alternative Alloy Group Recommendations for a Joint IPC SPVC/ INEMI Basic Material Property document

- Release the Basic Material Property Testing document without a creep test at this time.
- Recommend noting in the document that a creep test method is being developed and will be included in a future revision.
- INEMI recommend working with the IPC SPVC to establish a group to develop a standard creep test.

# INEMI Recommendations

- Finalize the joint IPC SPVC- INEMI Basic Material Properties document as soon as possible and submit it to the appropriate committee within IPC for development of a formal industry standard.
- iNEMI recommends that this document be developed by IPC into a binding standard (preferred) or a guideline (if necessary).

# Example of mechanical property tests conducted in the industry

| | Koki S01X7C (Sn0.1Ag0.7Cu0.03Co) | Sn3Ag0.5Cu | Sn0.3Ag0.7Cu | Sn0.7Cu0.05Ni |
|---|---|---|---|---|
| Melting Point (°C) | 217-227 | 217-219 | 217-227 | 227 |
| Specific gravity ($g/cm^3$) | 7.3 | 7.4 | 7.3 | 7.4 |
| Tensile strength ($N/mm^2$) *1 | 36 | 46 | 34 | 32 |
| Hardness (Hv) | 13.6 | 18.2 | 14.7 | - |
| Lapped Solder Joint Shear Strength($N/mm^2$) | **52** | 50 | 42 | - |
| Impact strength ($J/cm^2$) | 66.3 | 64.0 | 62.5 | - |
| Creep test (hours) | 35.3 | 23.8 | 16.2 | - |
| Copper erosion (g) | **0.14** | 0.32 | 0.30 | - |

*1 – JIS (Japan Industrial Standard) JIS Z 3198-2 standard used - Test Methods for Lead-free Solders – Part 2: Methods for Testing of Mechanical Characteristics – Tensile Test, 2003.

Sn0.1Ag0.7Cu0.03Co is a lead free solder alloy with low Ag content but it has similar shear strength and improved copper erosion versus Sn3Ag0.5Cu solder.

# Reliability tests for low Ag lead-free alloys

- Test low Ag lead-free alloy against Sn3Ag0.5Cu and in certain cases Sn37Pb solder.

<u>Testing data to include:</u>

- ATC testing
- Mechanical Testing
- etc

- INEMI alternative alloy group working on a document to address this.

# INEMI Recommendations for Reliability testing of alloys

The recommended tests address the need for standard data regarding:

- Thermal fatigue of SMT Joints
- Mechanical shock of SMT Joints
- Through hole (TH) joints – preconditioned pull tests only

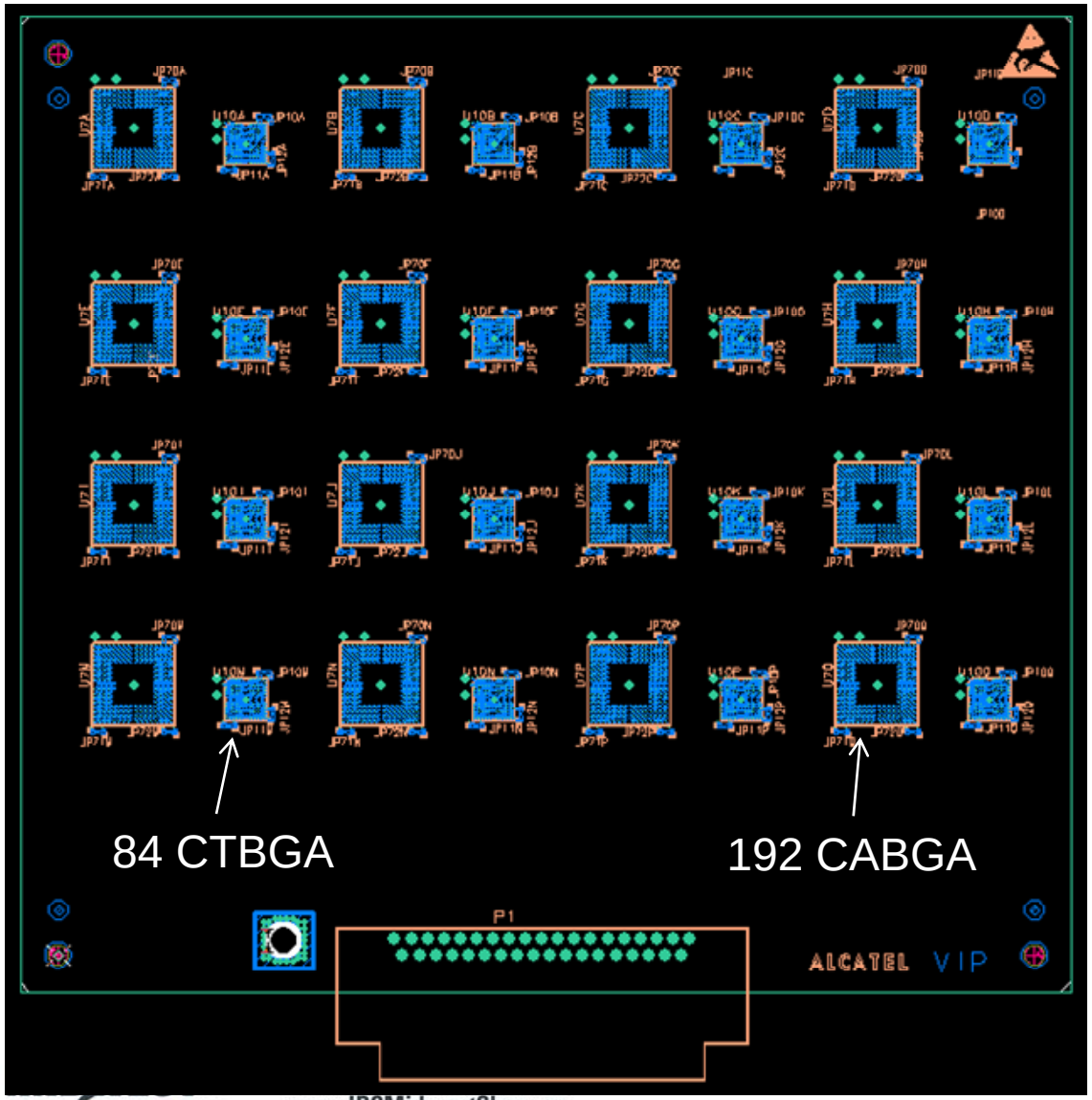
# INEMI Recommendations for Reliability testing of alloys

- ATC: 0ºC to 100ºC, -40ºC to 125ºC according to IPC 9701 standard.
- Mechanical Shock: according to JEDEC standard JESD22-B111.
- Pin Pull testing: Pin pull testing of conditioned/aged TH soldered components (Pin pull force measured versus pin wetted length).

# iNEMI Recommendations for Reliability Testing of Solder Alloys

- The testing described in the INEMI document is for general alloy reliability assessments.
- These tests do not replace those performed by alloy producers and their customers to qualify alloys for specific product use.
- Electronics manufacturers are encouraged to perform application-specific testing and further engineering, as appropriate, prior to the use of any solder alloy for a given product.

# INEMI ATC test vehicle




- 16 of each part per board
- 16 parts per test leg
- One daisy chain per part
- In-situ monitoring
- Over 3000 parts under test

Reference: Greg Henshall, HP

# INEMI Assessment of impact of alloy composition on thermal fatigue – test alloys

Alloys Under Test

| Cell No. | BGA Ball Alloy | Trade Name | Solder Paste | Comments |
|---|---|---|---|---|
| 1 | Sn-37Pb | Eutectic Sn-Pb | **Sn-37Pb** | Control |
| 2 | Sn-0.7Cu+0.05Ni+Ge | SN100C | **SN100C** | 0% Ag joint |
| 3 | Sn-0.7Cu+0.05Ni+Ge | SN100C | SAC305 | Impact of [Ag] |
| 4 | Sn-0.3Ag-0.7Cu | SAC0307 | SAC305 | Impact of [Ag] |
| 5 | Sn-1.0Ag-0.5Cu | SAC105 | SAC305 | Impact of [Ag] |
| 6 | Sn-2.0Ag-0.5Cu | SAC205 | SAC305 | Impact of [Ag] |
| 7 | Sn-3.0Ag-0.5Cu | SAC305 | SAC305 | Impact of [Ag] |
| 8 | Sn-4.0Ag-0.5cu | SAC405 | SAC305 | Impact of [Ag] |
| 9 | Sn-1.0Ag-0.5Cu+0.05Ni | SAC105+Ni | SAC305 | Impact of dopant |
| 10 | Sn-2.0Ag-0.5Cu+0.05Ni | SAC205+Ni | SAC305 | Impact of dopant |
| 11 | Sn-1.0Ag-0.5Cu+0.03Mn | SAC105+Mn | SAC305 | Impact of dopant |
| 12 | Sn-0.3Ag-0.7Cu + Bi + X | SACX0307 | SAC305 | Doped commercial alloy |
| 13 | Sn-1.0Ag-0.5Cu | SAC105 aged | SAC305 | Effect of aging |
| 14 | Sn-3.0Ag-0.5Cu | SAC305 aged | SAC305 | Effect of aging |
| 15 | Sn-1.0Ag-0.7Cu | SAC107 | SAC305 | Impact of [Cu] |
| 16 | TBA | SACi | SAC305 | Doped commercial alloy |

- 12 Pb-free alloys plus Sn-Pb control
- Systematically investigate the impact of Ag content
- Impact of common dopants, such as Ni
- Low Silver Alloys becoming fairly common in practice for wave and BGA/CSP and increasingly solder paste
- Impact of aging

Reference: Greg Henshall, HP

# Processing tests for low Ag lead-free alloys

Tests to include:

- SMT Assembly
- Wave Assembly
- Rework: BGA/CSP, Mini-pot/Solder Fountain, Hand Soldering evaluations

- INEMI alternative alloy group working on a document to address this.

# INEMI Recommendations on Manufacturing Impact of Alternative Lead-free Alloys

- Impact on manufacturing process
  - Industry needs to understand the impact of alloy composition on the process window, not just whether or not a board can be built under a narrow set of specific conditions.
  - Consider the sensitivity of results to equipment used, PCBA characteristics (thermal mass, etc.), and process materials (e.g. fluxes).

  – Next steps to draft recommended tests for assessing the impact of alloy composition on manufacturing process window (in progress)

# Status of alloy testing industry standards development

| | Basic Material Properties | Board-Level Reliability | Impact on Mfg. Process |
|---|---|---|---|
| iNEMI Recommendations | Complete | Complete | Started |
| Alignment of iNEMI and SPVC/IPC Recommendations | Nearly Complete | Pending | Not Started |
| IPC Standards Development | Pending | IPC Draft Available | Not Started |

Reference: Greg Henshall, HP

# Reflow Profile and Cooling Rate for Tin-Lead and Lead-free Sn3-4Ag0.5Cu and Sn0.3Ag0.7Cu Solders

Preheat and Soak

Reflow:

- Tin-Lead: Time over 183°C: 30-90 sec, Peak: 205- 215°C
- Lead-free (Sn3-4Ag0.5Cu): Time over 217°C: 30-90 sec, Peak: 235- 260°C
- Lead-free (Sn0.3Ag0.7Cu): Time over 227°C: 30-90sec, Peak: 240C-270°C

Cooling:

- Tin-Lead: Peak temperature down to 183°C, 1-4°C/sec
- Lead-free (Sn3-4Ag0.5Cu): Peak temperature down to 217°C, 1 – 4°C/sec
- Lead-free (Sn0.3Ag0.7Cu): Peak temperature down to 227°C, 1-4°C/sec

# Solderability testing of components (IPC J-STD-002 standard)

Test components according to IPC J-STD-002 standard (with either SnPb or Sn3-4Ag0.5Cu solder)

Need to incorporate testing with Sn0.3Ag0.7Cu

# Solderability testing of boards (IPC J-STD-003 standard)

- Test boards according to IPC J-STD-003 standard
  - Testing with Sn37Pb and Sn3Ag0.5Cu

    Need to incorporate testing with Sn0.3Ag0.7Cu

# Conclusions

Apart from physical property, manufacturing and reliability testing of low Ag solders, need to consider updating industry component and board temperature rating and solderability standards including:

IPC JEDEC J-STD-020 (SMT Components)
J-STD-075 (SMT and Wave Components)
JEDEC JESD B-106D (Wave and Wave Rework Components)
JEDEC JESD22-A111 (Immersion Waved Components)
IPC 4101 (Board Laminate Rating)
JEDEC and JEITA (Component Warpage Standards During Reflow)
IPC (Board Warpage Standards During Reflow)
IPC J-STD-002 (Component Solderability Standard)
IPC J-STD-003 (Board Solderability Standard)

# Future work

Industry needs to work on developing and updating test methods and standards for low silver solders including:

1. Physical property
2. Reliability
3. Manufacturing tests
4. Temperature related standards for board and components previously mentioned