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An OEM's perspective on copper dissolution in lead free assembly and rework

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Outline

- Brief review of copper dissolution
- Copper dissolution impact on HP
- Preferred approach: process control
- Issues with alternative alloys
- HP's alternative alloy approach
- Conclusions

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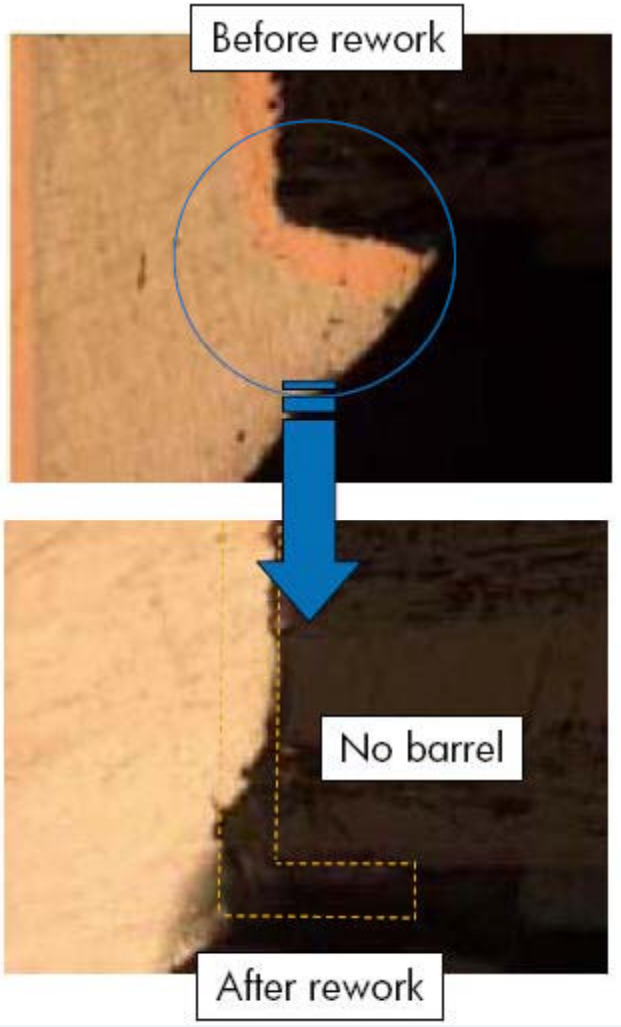
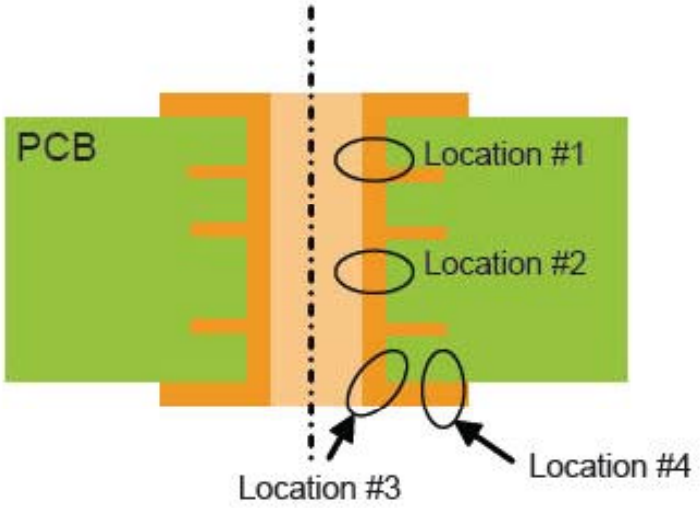
Copper dissolution

- Dissolution of Cu into molten solder from PCB land and/or PTH during:
  - Rework
  - Wave solder
  - Reflow
- HP internal test results confirm these observations

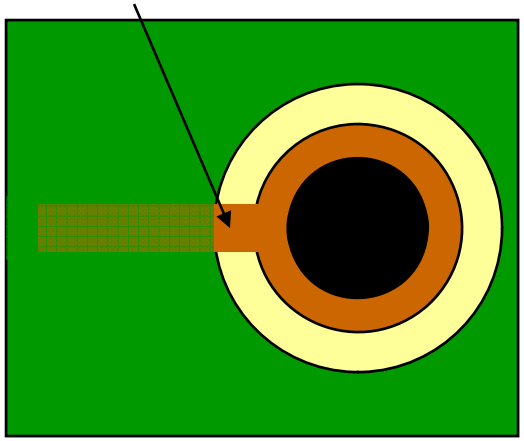


Copper dissolution

- Extensive industry and academic publications and presentations on copper dissolution
- We know a lot about the phenomenon
  - Rework is the highest risk process
    - Longer exposure
    - Lower degree of process control
  - Locations 3 and 4 are highest risk
    - Knee
    - Pad to trace transition
  - NSMD pads can be high risk, especially if traces aren't protected
  - Factors influencing dissolution rate include:
    - Contact time
    - Temperature
    - Solder flow velocity
    - Alloy
    - Copper and surface finish

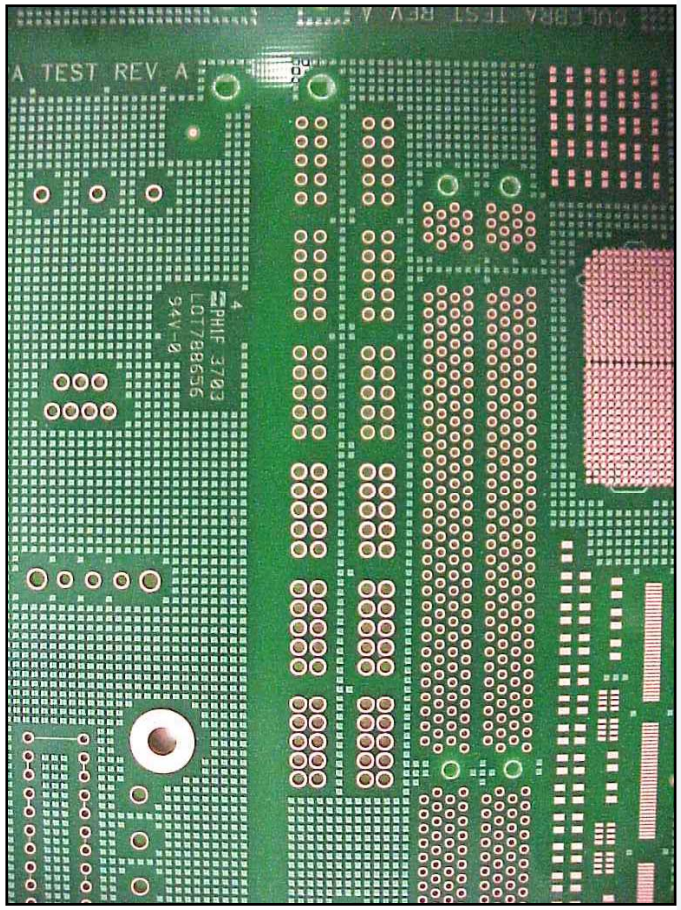


High risk



Copper dissolution can affect HP

- HP is a heavy user of surface finishes, like OSP, that allow the creation of the Cu_6Sn_5 IMC during soldering
  - These finishes expose copper during soldering and rework processes
- HP requires SAC305 for wave and rework
  - Product-specific waivers for other alloys only after engineering review
- HP uses NSMD
- HP uses thick boards in some products (>120 mils) which require longer exposure times for TH rework processes



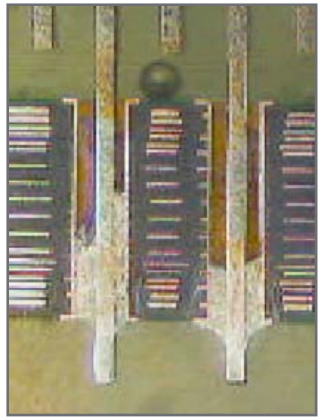
Is copper dissolution a major concern for HP?

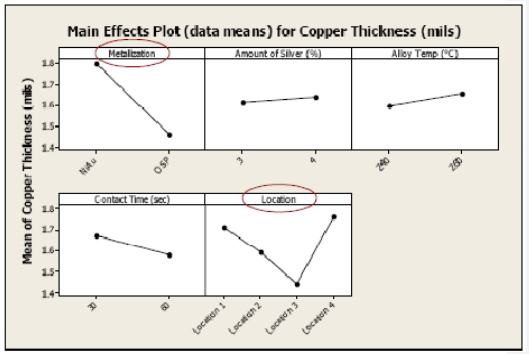
- When severe dissolution occurs, it can be a reliability problem
  - Trace removal at NSMD pad
  - Complete Cu removal at knee
- Minimum copper thicknesses specs exist for as-received PCBs, but not after soldering
- No non-destructive inspection techniques
  - Dissolution does not necessarily affect yield so normal process controls may not be invoked until field reliability is already impacted
- In HP's experience, severe dissolution is not common now
  - Hasn't been a major contributor to field return
  - Small number of boards subjected to minipot rework
  - Dissolution incidents have primarily been associated with out-of-control processes
  - Seeing more incidents as we build more large thick boards in lead-free processes

HP's preferred approach: process control

HP's preferred solutions are to:

1. Minimize TH minipot rework
   - Use good wave process control to improve yield and eliminate rework
   - Only rework with minipot for bent pins, wrong connector, significant problems
   - Don't do unnecessary minipot rework (e.g. TH fill on a DIMM lead)
   - Use soldering iron for point rework
2. Practice good process control with minipot rework
   - Assign BEST engineers to rework
   - Treat as a real process
     - Process development
     - Process monitoring
   - Use best available equipment
     - Maintain and characterize
3. Investigate solutions like alternative alloys **<u>as a last resort for reducing minipot copper dissolution</u>**
   - Even if alloy is changed, still need to do #1 and #2





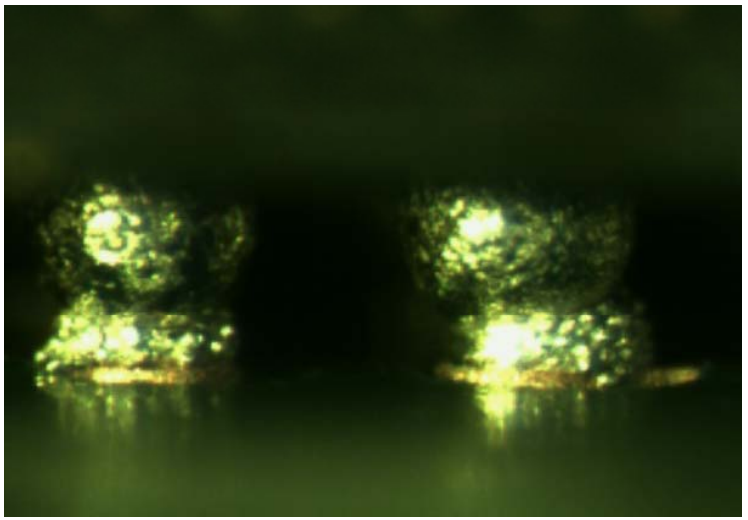
Concerns with alternative alloys

In addition to copper dissolution, there are many concerns with alternative alloys:

- Technical issues with alternative alloys
  - Manufacturing and rework
  - Reliability
  - Inspection
- Non-technical issues with alternative alloys
  - HP concerns
  - Industry concerns

Technical issues with alternative alloys: Manufacturing and rework

- The change to low Ag alloys may require a change to PCA manufacturing processes
- For some alloys, the silver (Ag) content is reduced from 3% to 1-2% or lower
  - Such a change can increase the melting point of the solder ball by as much as 10° C
- Improperly soldered low Ag joints are a significant reliability risk because they may pass electrical test but still have unacceptable solder joints and unmelted regions
- Assembly and repair facilities can have unexpected yield losses due to low Ag alloys if they are not aware of their presence



Partially melted paste and unmelted solder balls

Technical issues with alternative alloys: Reliability

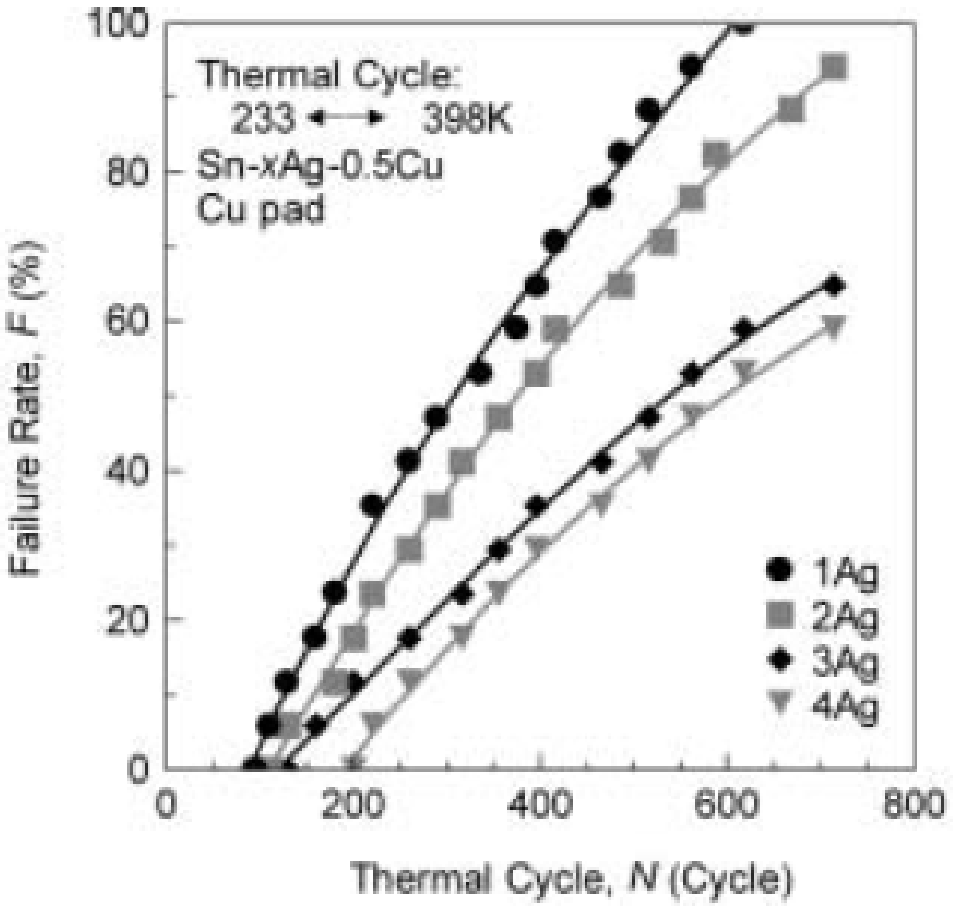


Fig. 6. Effect of thermal cycles on the failure rate of Sn-xAg-0.5Cu (x = 1, 2, 3, and 4) solder joints on the Cu pads.

- Changes in Ag content can have significant impact on thermal fatigue reliability
- Terashima et al. found that a decrease of Ag content from 4% to 1% decreases the thermal fatigue life (first failure) by a factor of about 2
  - -40/125° C, 10 min dwell.
  - All alloys had 0.5% Cu
  - Performance relative to eutectic Sn-Pb not reported
- Addition of other alloying elements which affect undercooling, formation of various IMCs, matrix properties & microstructure not well understood

S. Terashima, et al., J. Elec. Mater., Vol. 32, No. 12, p.1527 (2003).

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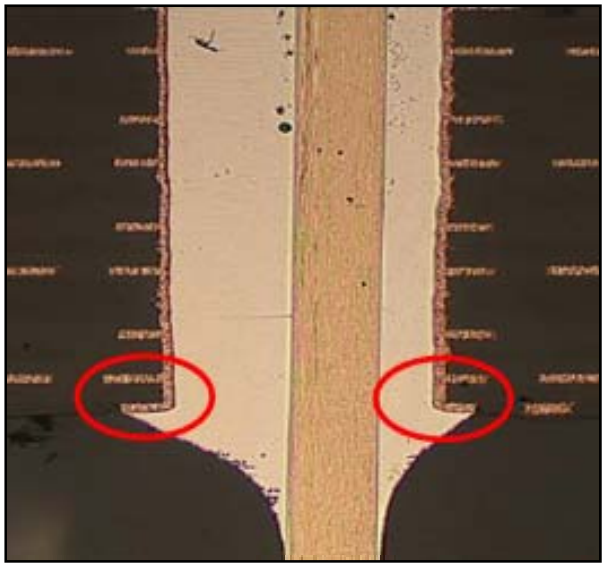
Technical issues with alternative alloys: Appearance vs material properties and reliability

- One of the many benefits claimed by alloy suppliers is that these materials have a better appearance and IPC-A-610 compliance in wave soldering and rework
- Even if joints meet the visible criteria of IPC-A-610, alternate solders may not be reliable enough
- IPC-A-610 does not address differences in solder material properties
  - For example, the eutectic 52.2In-46.0Sn-1.8Zn could form an acceptably shaped joint with the right flux and process
  - With a melting point of 108C, it wouldn't meet reliability requirements for most electronics



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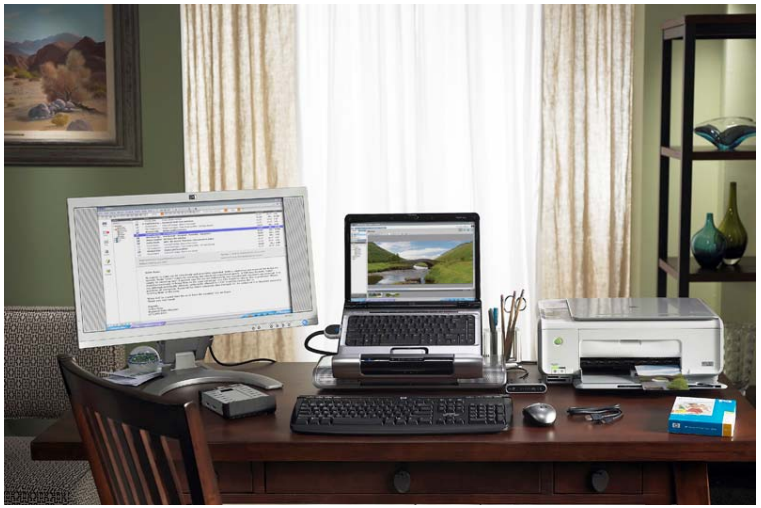
Non-technical issues with alternative alloys

- Our product portfolio is very broad
  - Reliability in one product line can impact sales in others
- Our supply chain is very complicated
  - Business models range from no-touch to in-house design
  - Assurance of supply concern if only one patented material with limited licensees
  - Standardization is generally better for HP even if a special alloy might be okay for one product
  - Management of multiple alloys, even at a single factory site, is complicated
- The product support and repair implications of alternate alloys are very significant
  - Third party repair facilities



Beyond HP

- There is growing concern about the proliferation of alternate alloys
- Consortia and other research occurring on SAC alloys
- Some OEMs want to keep SAC305
- Some OEMs want to re-converge on something better
- Some OEMs aren't concerned about what "the industry" does as long as they have a solution

Beyond HP

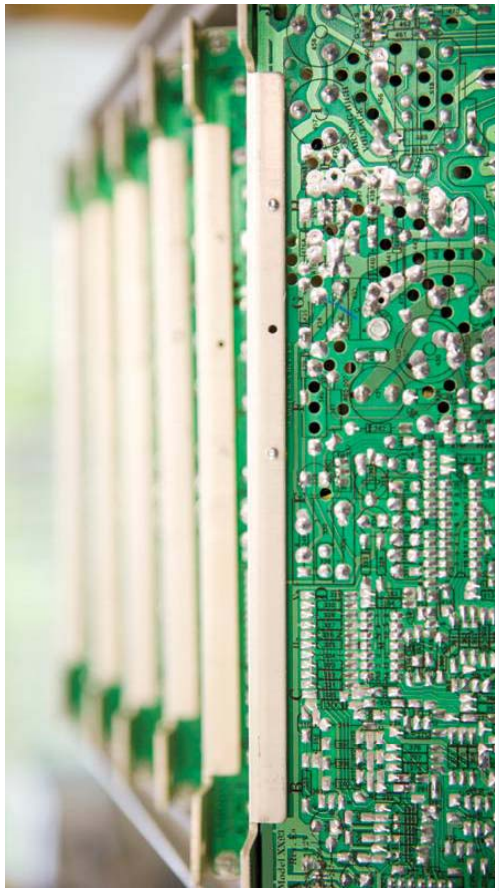
- iNEMI statement from May 2007 calling for "Unique Part Numbers to Differentiate Ball Metallurgies on Pb-Free BGA Components"
  - In it, Mike Davisson, RoHS technical program manager for Agilent Technologies is quoted as saying:
    "The proliferation of solder ball metallurgies only makes it more difficult to close the remaining knowledge gaps for Pb-free conversion of mission-critical applications. Reliability experts are still working to fully understand the long-life performance of SAC 305/405 and have limited data on some of the alternate ball formulations. A change in metallurgy without the ability to track the change through MPNs will only make Pb-free conversion more difficult and could delay the process."
  - iNEMI members supporting this position include: 3M, Agilent Technologies Inc., Alcatel-Lucent, Analogic, Celestica Inc., Delphi Electronics & Safety, Hewlett-Packard Company, Huawei Technologies Co. Ltd., Intel Corporation, Jabil Circuit Inc., Microsoft Corp., Micro Systems Engineering Inc., Plexus Corp., Sanmina-SCI Corporation, Solectron Corporation and Tyco Electronics Corporation.
- Although this statement is about BGA ball alloys, proliferation of alternate process alloys could create even more confusion if not managed properly
- Change in alloy is a change in fit to process (form, fit or function)

HP and alternate alloys to SAC305

Using alternate alloys are not HP's preferred solution for copper dissolution in minipot rework

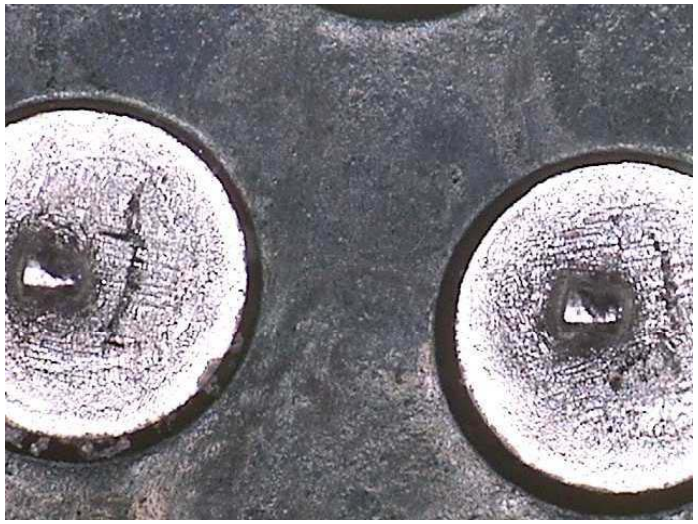
BUT

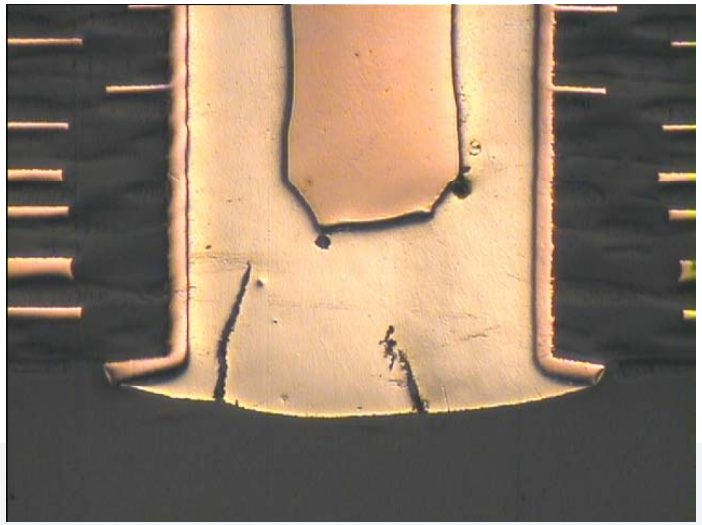
- SAC305 is not necessarily the optimal Pb-free solution
- Beyond copper dissolution, problems with SAC305 include:
  - Poor shock/drop performance
  - Sporadic brittle fracture on Ni
  - Unpredictable material properties due to crystal orientations having different modulii and CTE
  - Expense of Ag
  - Poor TH fill
  - Hot tearing and other surface phenomena



HP's situation with respect to alternate alloys

- HP has received many requests for alternate alloys
  - Rework and wave
  - BGA and CSP ball alloys
  - Solder paste
- Many different reasons for the requests to change alloys
- HP has been reviewing each case separately
- We don't want to keep having to repeat full engineering evaluations for each request
- Also if there is something truly better than SAC305, we want to use it





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HP's approach to managing alternative alloys

- HP is creating a process for reviewing alternative alloys for use in our products
  - Beta-testing on current requests
  - Expected formal release APEX 2008

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What the HP alternative alloy approval process would look like (still being drafted)

- HP would consider requests to use alternatives to SAC305 in products
  - Wave soldering and minipot rework
  - BGA and CSP balls
  - Solder paste
- HP would consider extending broader approval than product-level, if data support it
  - Cross-compatibility with SAC305 will be critical to wider approval
- HP would rely on external groups for data, but would specify tests to ensure data will meet HP's needs
  - Much information about current alternative alloys is inconsistent or missing

The burden of proof is on suppliers to prove alternatives meet our requirements, not on us to prove that they don't.

What the HP alternative alloy approval process would look like (still being drafted)

- There would be two documents containing HP's test requirements for alloys (one for process and one for BGA balls)
  - Being drafted by the top HP solder and reliability experts
  - Generalized requirements for alloys
- Central submission point at HP for proposed alloys
- Expert team from across HP to review materials for use in products
  - No guaranteed approval, even with complete data
  - Review may take some time, so allow enough time between submission and target implementation date

What the HP alternative alloy approval process would look like (still being drafted)

- Collaboration expected between different external groups to generate complete data package
  - Material properties from solder supplier
  - Manufacturing data from CM/ODM
  - Reliability from component or solder supplier

- May be possible to evaluate some materials “by similarity” to others, with a subset of the required data
  - Notify HP of intent to submit
    - To find out if any tests can be waived
    - To find out who else may be working on the same alloy to coordinate the submission
  - HP may use results from individual alloys to determine acceptable composition ranges and dopants (generalized)

Draft of alternate alloy

- General requirements
- Information from suppliers
  - Non-technical
  - Material properties
  - Reliability
  - Manufacturing
  - Component

General requirements (draft)

To be considered for use in HP products, solders would need to meet the following requirements:

- Solders must have the following base alloy composition:

  Sn - [0.0 to 4.0] Ag - [0.0 to 1.2 Cu]

- Must conform to HP General Specification for the Environment
  - Component elements and dopants must meet EH&S requirements

- Solidus ≥ 183C

- Liquidus ≤ 228C

General requirements (draft)

- Must meet the requirements of J-STD-006, including contamination levels, EXCEPT if intentionally microalloyed with additions of elements at or below 0.1% weight.
  - If alloy contains component elements in amounts < 0.1%, the manufacturing tolerance for the alloy components must be at least as good as ± 50% of the smallest weight percent addition, and sufficient to ensure the microalloy component benefits are uniform across the entire range of compositions.
  - Alternately, show the effective range and set tolerances appropriately

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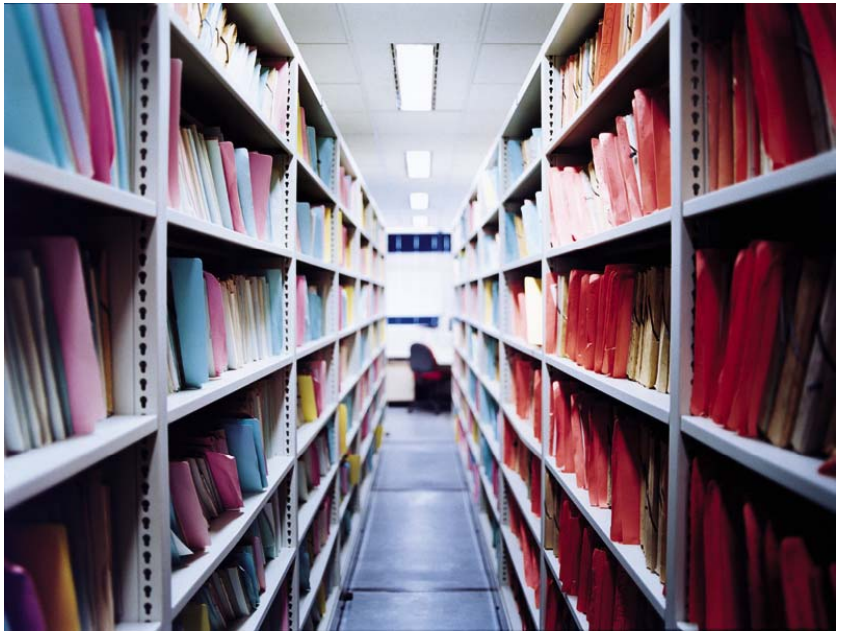
Non-technical requirements (draft)

- Submitters' info*
- Complete nominal alloy composition*e.g. Sn-3.0Ag-0.5Cu-0.01Ni-0.005Ce
- Range in which the benefit of each microalloy is demonstrable*
- Trade names*
- Test labs*
- Patent status
- Submitter's licensing status
- Approximate cost of one kg of alloy at current market rate
- Applications and/or processes in which the alloy will be used
- Target implementation date or when alloy will be commercially available
- Advantages over SAC305



* (required)

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Material properties requirements (draft)

- Data must be submitted for the actual alloy, not the generic SAC family (except by waiver from HP)
- Each test must be accompanied by contamination report
- Literature review containing citations of existing papers and phase diagrams that directly pertain to this composition

Solidus temperature* (required)	Young's modulus (dynamic)
Liquidus temperature* (required)	Yield strength (0.2%)
DSC or DMA curve* (required)	UTS
Electrical conductivity	Elongation
Thermal conductivity	Stress strain curves
Density	Poisson's ratio
Expansion vs temperature, TCE	Hardness

Reliability requirements (draft)

HP will provide **test method** (in most cases standard) and sample requirements:

- Thermal cycling*
- Mechanical shock*
- Vibration*
- Four-point bend*
- Physical samples of soldered assemblies for inspection and further analysis*
- Alloy cross-compatibility - require a mix with SAC305 in DOE*
- Data from any other reliability tests

* (required)

Manufacturing (draft)

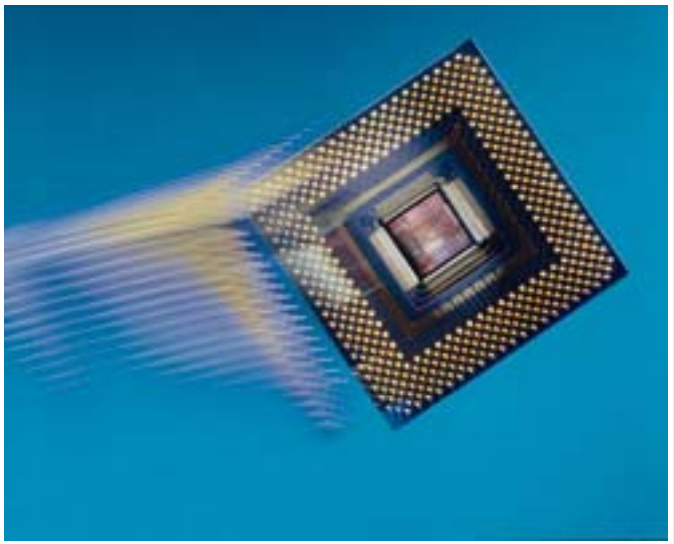
HP will provide test method and sample requirements:

- HP DOE for wave pot temperatures, including copper dissolution (* required for wave and rework alloys)
- HP DOE for reflow profiles*
- Laminate damage assessment (if temp > 5C over SAC305)*
- Pastes must meet HP Solder Paste Specification (* required for pastes only)
- Wetting balance

* (required)

Components requirements (draft)

- No additional “component only” tests
- Tests already specified in other sections are sufficient:
  - Non-technical*
  - Material properties*
  - Reliability*
  - Manufacturing*
- Test boards will select various component finish combinations (e.g. NiAu/OSP) and be consistent with actual finishes used in HP products
- Any other available component data, including fast ball pull or ball shear



* (required)

Conclusion: copper dissolution

- HP internal test results confirm copper dissolution as observed in industry
- Copper dissolution can affect HP because of the surface finishes, board thicknesses, features, and alloys used in our products
- When severe dissolution occurs, it can be a reliability risk
- In HP's experience, severe dissolution is does not affect a large number of our products
  - Dissolution incidents have primarily been associated with out-of-control processes
- HP's preferred approach to minimizing copper dissolution is **process control**

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Conclusion: alternative alloys to SAC305

- HP has received several requests for the use of alternate alloys, including as a solution for copper dissolution
- There are many technical and non-technical issues with using alloys other than SAC305
  - But, if there is something truly better than SAC305, we want to use it
- HP is creating a process for reviewing alternative alloys for use in our products
  - Beta-testing process on current requests
  - Other OEMs may have different approaches
  - HP will share requirements docs with outside groups, including iNEMI
  - Expected formal release APEX 2008
- Remember: alternative alloys are a last resort for reducing minipot copper dissolution
  - **Even if alloy is changed, still need to minimize rework and practice good process control**

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Questions?