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An EMS's Experience with Copper Dissolution

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The 7 Stages of Change Implementation …as it Applies to Cu Dissolution

- Stage 1: **Shock**
  - "What do you mean there are no barrels left on the board?"
  - Cu Dissolution 101
- Stage 2: **Denial**
  - Run some Test Vehicles… Flow rate matters!
  - Control the process, modify the machine!
- Stage 3: **Fight or Flight**
  - Just add more copper!
- Stage 4: **Tolerance**
  - A ray of hope… the Ni resistance.
  - How about a different alloy?
- Stage 5: **Embrace Change**
  - We need reliability Data!
  - Sn0.7Cu0.05Ni for PTH rework
- Stage 6: **Involvement**
  - The potential influence of PCB plating
  - Copper Plating Work to date
- Stage 7: **Commitment**
  - A Call to Arms

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…as it Applies to Cu Dissolution

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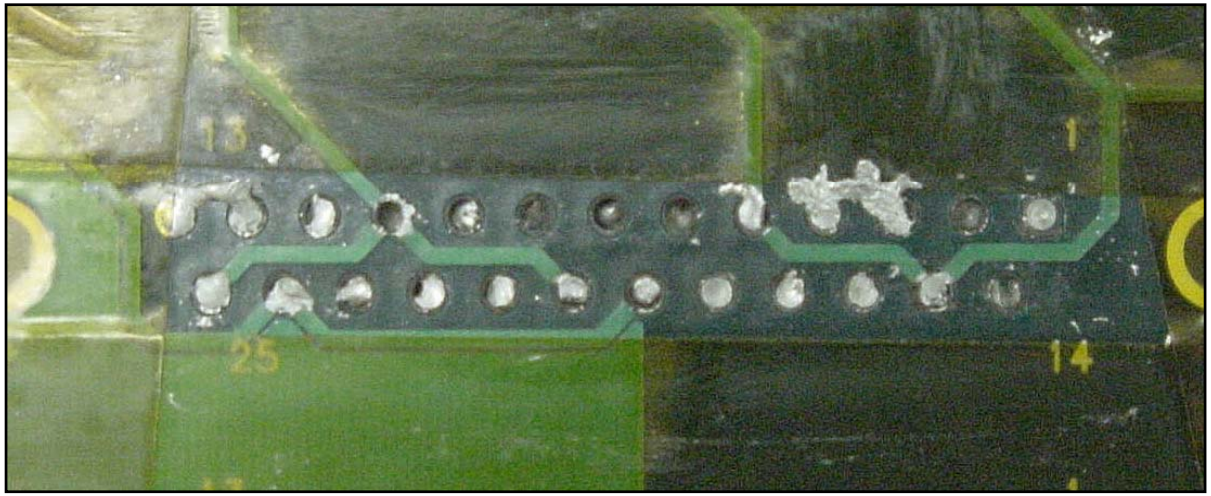
Stage 1: SHOCK
"There are no barrels left on the board?!"

Pb-free test vehicles & customer qualification frequently include forced PTH rework cells. The initial PTH rework process was based on the existing infrastructure, equipment and processes used for SnPb PTH rework.

In the case shown below, a single assembly was reworked using a 'one step' remove and replace mini-pot process (SAC305) at 520F / 271C the bottomside annular rings were *completely dissolved*.

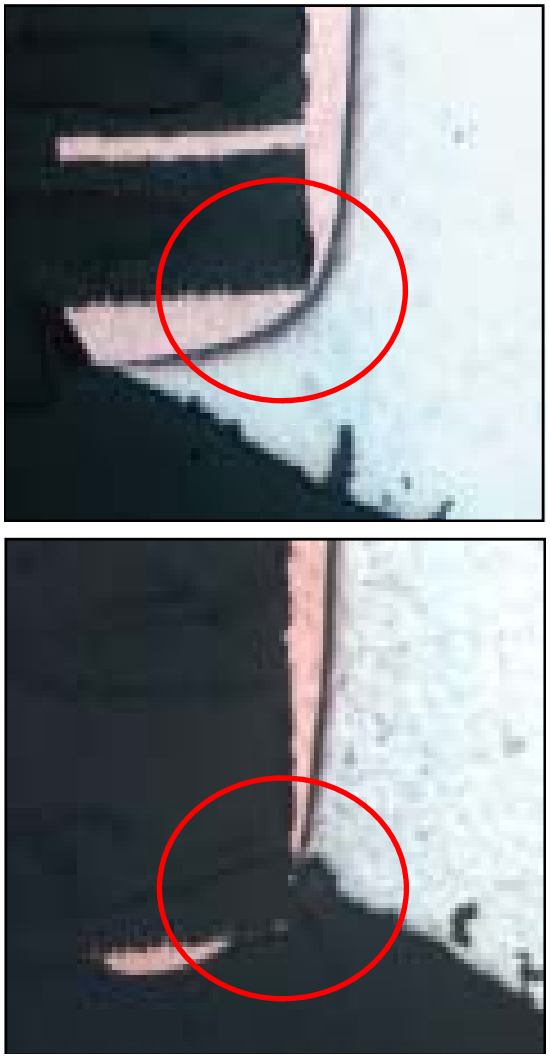


RS232 Connector
0.093" thick PCB
6 layer, FR4 Laminate

Notice the delamination of the FR4 material and the complete absence of annular rings!

iNEMI Payette reports also indicated severe dissolution of PTH barrels & traces during all PTH rework attempts with SAC305… (SMTAi 2005)

Cu Dissolution 101



Cu dissolution after PTH rework (SAC305)

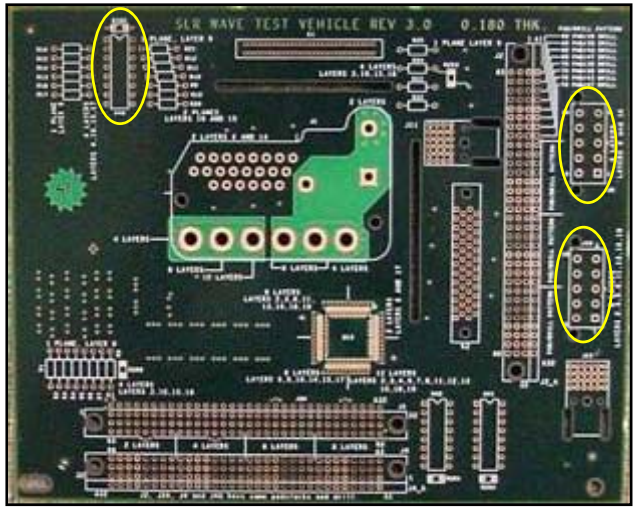
- Cu dissolution is a metallurgical reaction where the copper (Cu) dissolves into a tin-rich liquid (SAC305).
  - This reaction occurs at wave solder & PTH rework, however dissolution at wave solder seems to be less pronounced.
- Cu dissolution can vary between adjacent PTHs.
- Cu dissolution is a function of:
  - Solder temperature & alloy (Tin%)
    (lower temperature = less dissolution)
  - Solder dwell / contact time
    (less contact time = less dissolution)
  - Solder flow rate & direction
    (lower flow = less dissolution)

Stage 2: DENIAL
Pb-free PTH Test Vehicles

PTH rework validation run.

- 0.093” OSP-HT PTH test vehicles
- SAC305 assembly
- Simulated rework – applied to the fountain (without pre-heat) for a series of 5sec, 10 sec, 15 sec, and 20 sec at a ‘low’ flow rate.

These samples were cross-sectioned to assess post rework barrel thickness as a function of solder pot dwell time.



PTH Test Vehicle - Topside

PCB Size:

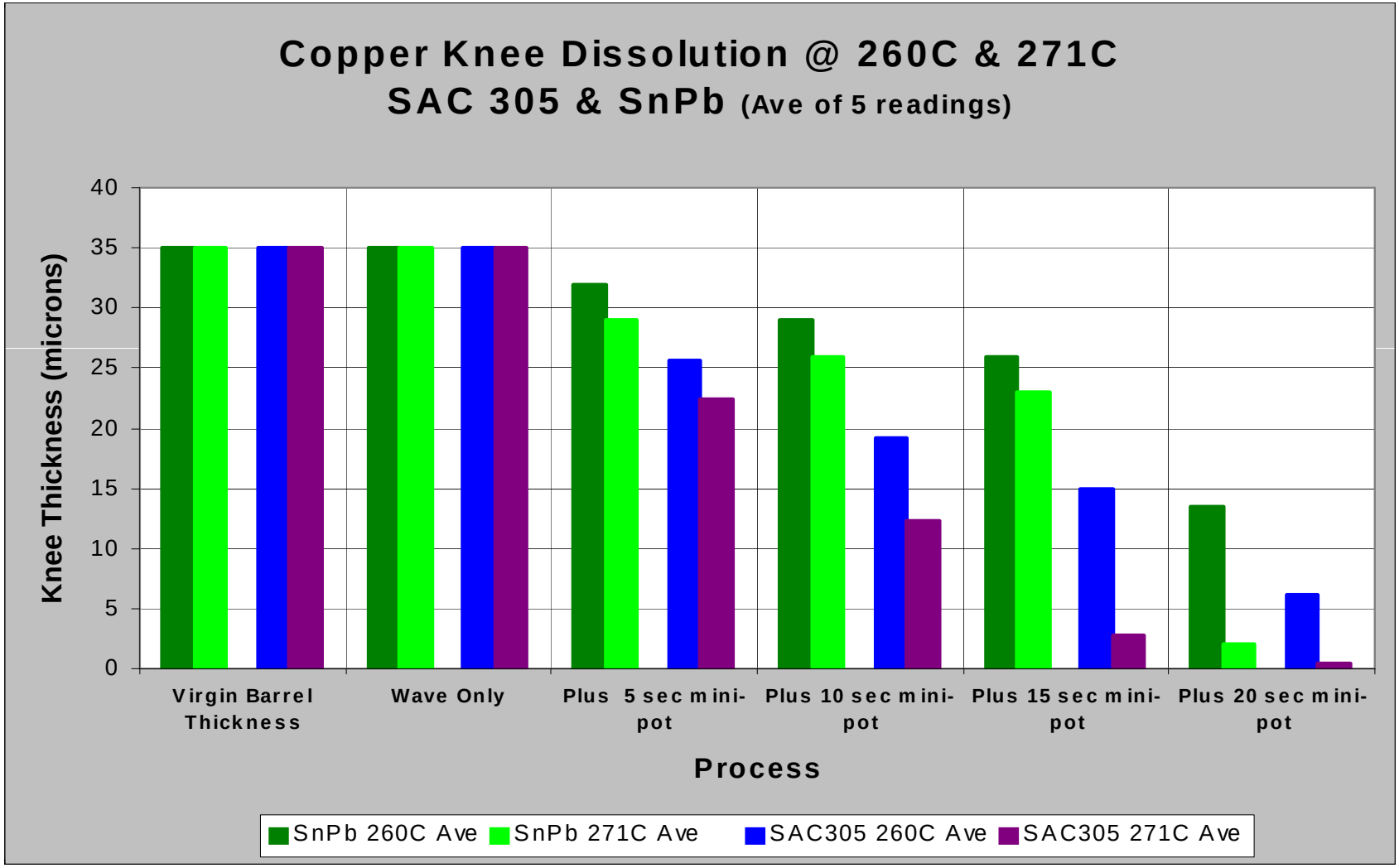
- **Single (5.5” x7.0”)**
- **Panel (4UP, 12” x 15”)**

Board Thickness:
62, 93, 125, & 180 mils

Surface Finish: OSP-HT or Imm. Ag

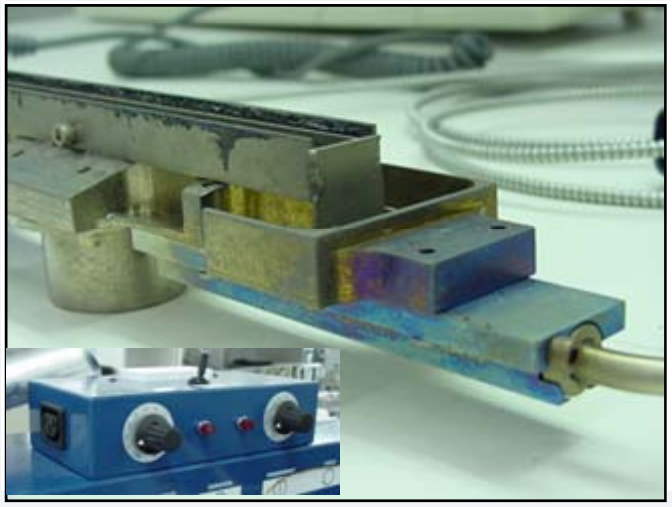
- **Various pad and hole diameters**
- **Various copper layers: 1, 2, 4, 6, 8 (up to 12 layers for 0.180” board)**
- **Various SMT & PTH pad spacing**
- **Includes thermal relief design (for power brick design)**

Copper Dissolution SnPb vs SAC305



PTH TV 0.093" OSP-HT, DIP16 Location

Just Control the Rework Process…



PTH Rework Equipment:

Production Mini-pot configuration

- IR Preheaters
- Digital Temperature Controls
- Secondary Nozzle Heater Controls
- Offline Hotplate

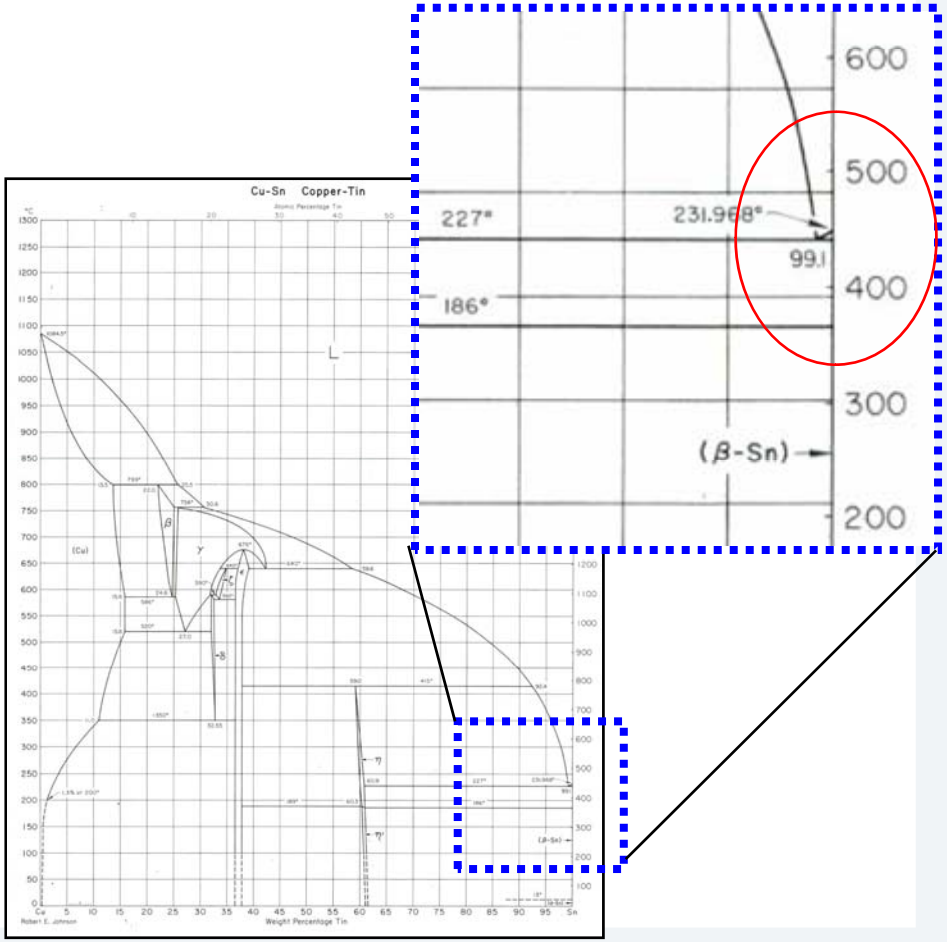
Pb-free PTH Rework Set-up:

- **Alloy:** SAC305
- **Flux Type:** NC VOC-free Low Solids
- **Pot Temp:** 520F / 270C
- **Nozzle Flow:** Low flow / turbulence
- **Remove**
  - Target PWB preheat temperature*: 250F / 121C *thermocoupled*
  - Target removal time: <20 seconds
- **Replace**
  - Target PWB temperature*: 250F / 121C *thermocoupled*
  - Target installation time: <20 seconds

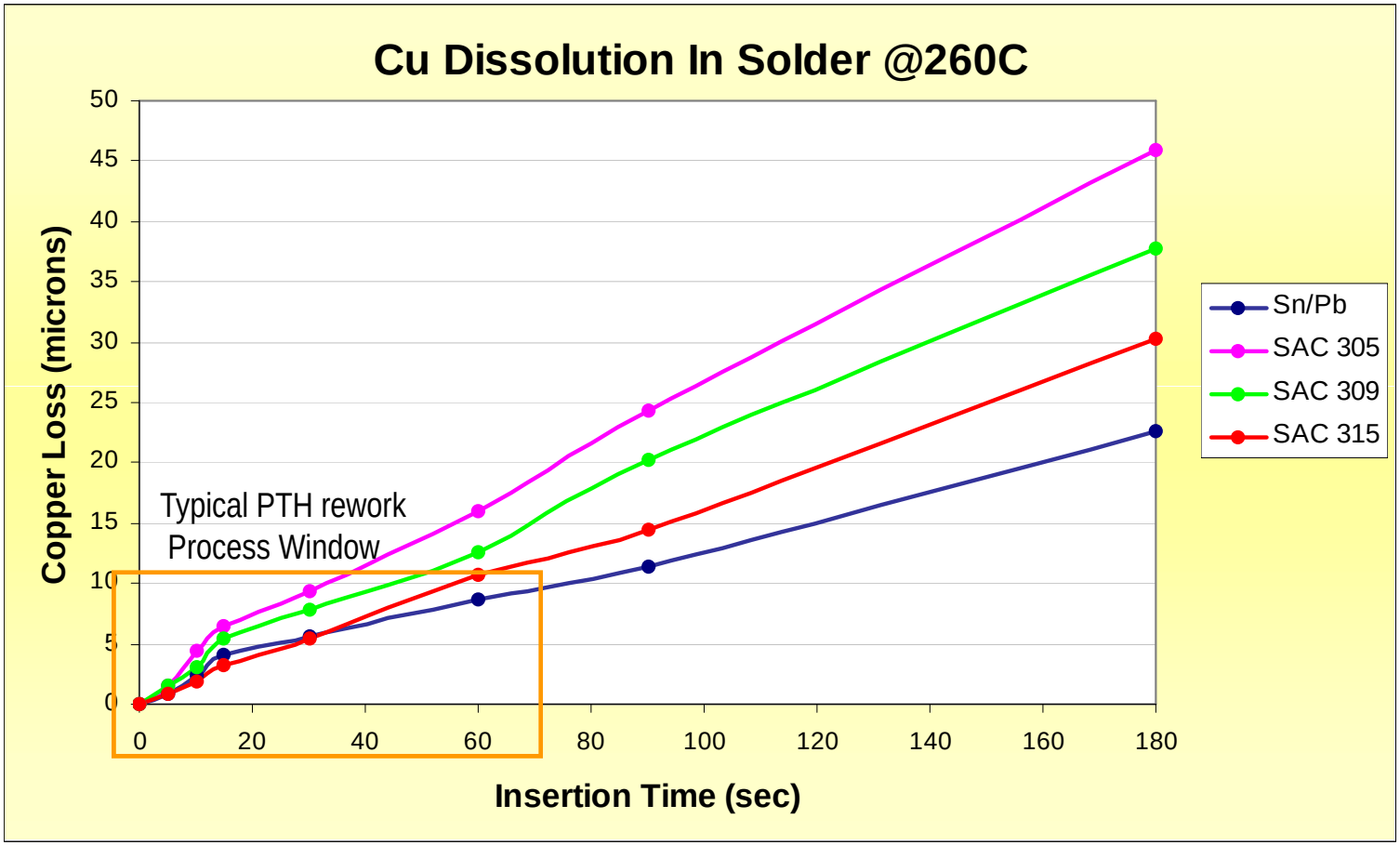
Stage 3: FIGHT or FLIGHT?
Cu Dissolution – Just add copper…

- It is well known that increasing the concentration of a solute within a solvent, that the dissolution rate of the solute will decrease.
- Following this logic, an increase in Cu levels in solder should decrease the Cu dissolution rate.
- By observing the Sn-Cu phase diagram, we see that increased Cu levels can quickly lead to saturation within the rework process window (500F / 260C).
- Saturation of solder with Cu can lead to excess intermetallic formation, with the SnCu IMC sinking to the bottom of the pot leading to increased maintenance issues.
  - Note: J-STD-006B Requirements for Electronic Grade Solder Alloys… do not specify elemental limits for active solder baths. (as received only)

At 520F / 270C the Sn becomes saturated as the Cu % approaches ~1.2% wt.…



Cu content & dissolution rates (static pot)



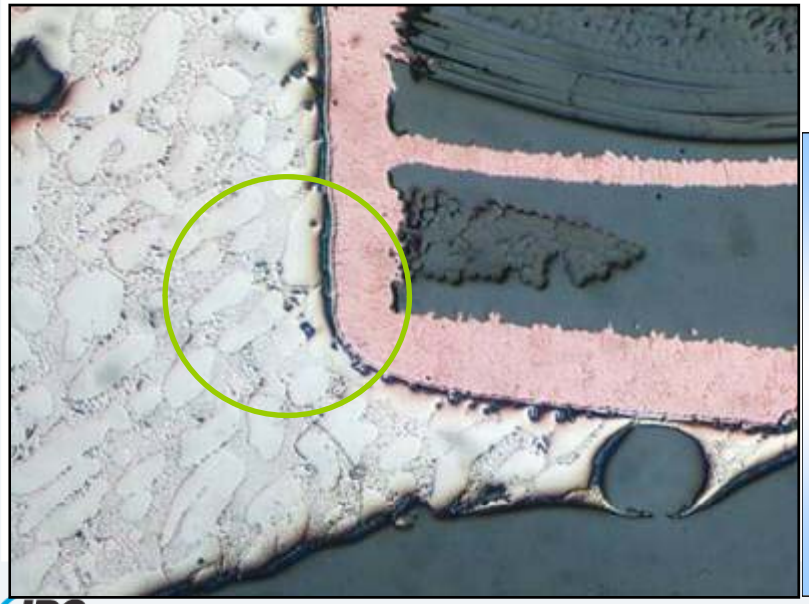
Increased content of Cu does decrease the overall rate of dissolution.

Previously published data indicates that a Cu wt % of >1.0% will have a negative effect on PTH soldering performance (vertical fill).

STAGE 4: TOLERANCE
Ni PCB finishes demonstrate resistance!

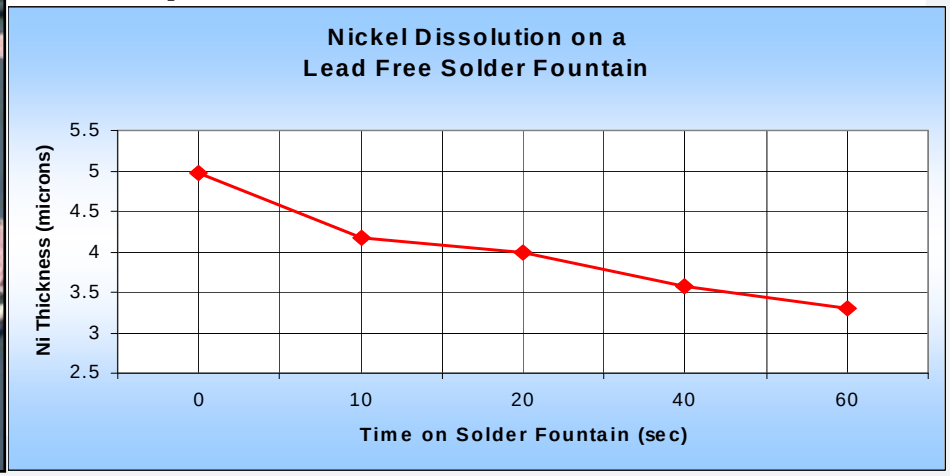
Example of rework PTH joints on a ENIG .093” thick assembly:

Dwell time:
60 sec

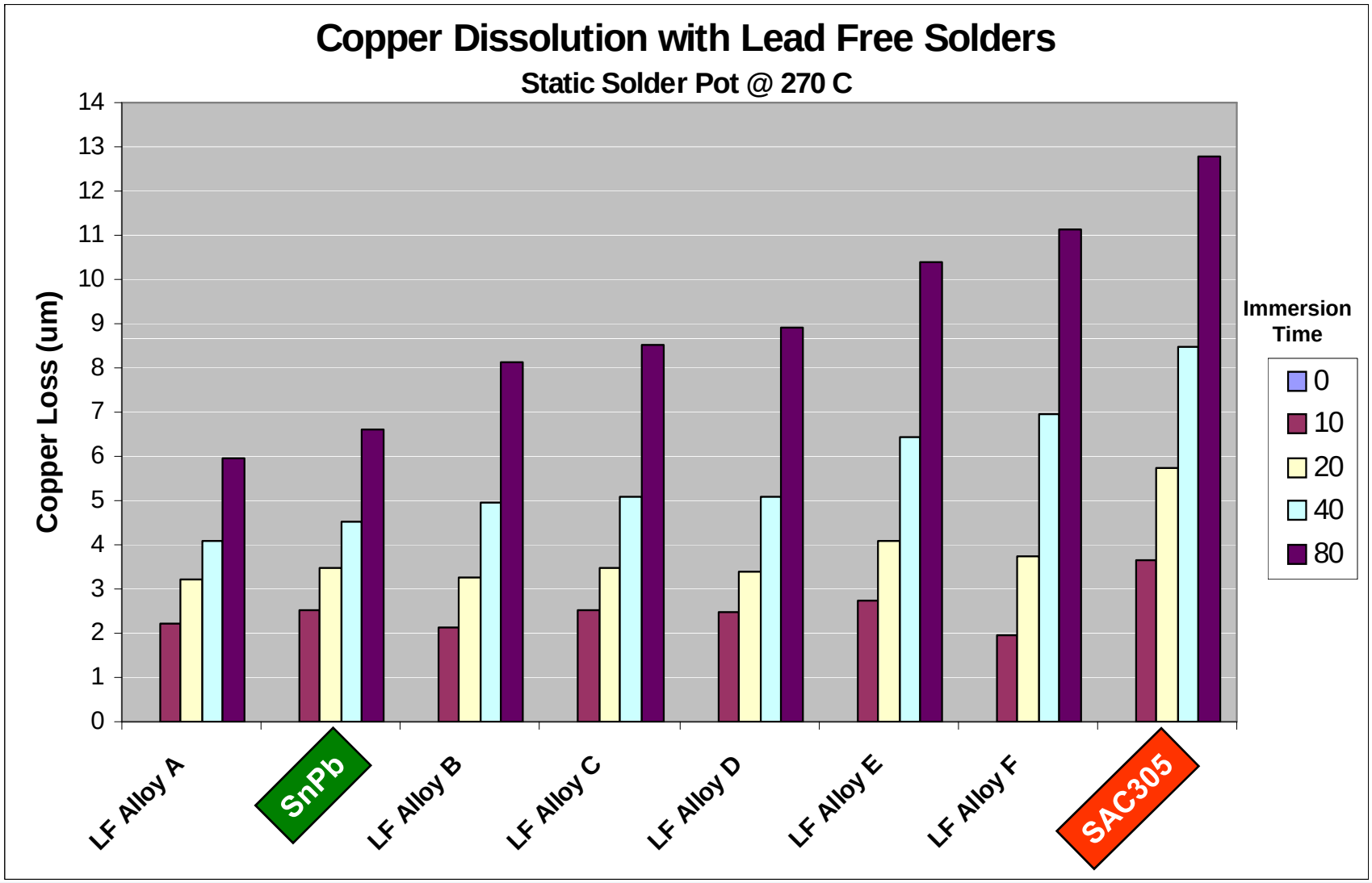


Pb-free rework & Cu dissolution:

- The Ni layer plated during the application of the ENIG surface finish appears to provide a barrier that resists the effects of Cu dissolution into the SAC305 alloy.
- **However, ENIG Samples have had knees completely dissolve after ~60 seconds on a static SAC305 pot and Ni-Au PWB finishes are not always accepted.**



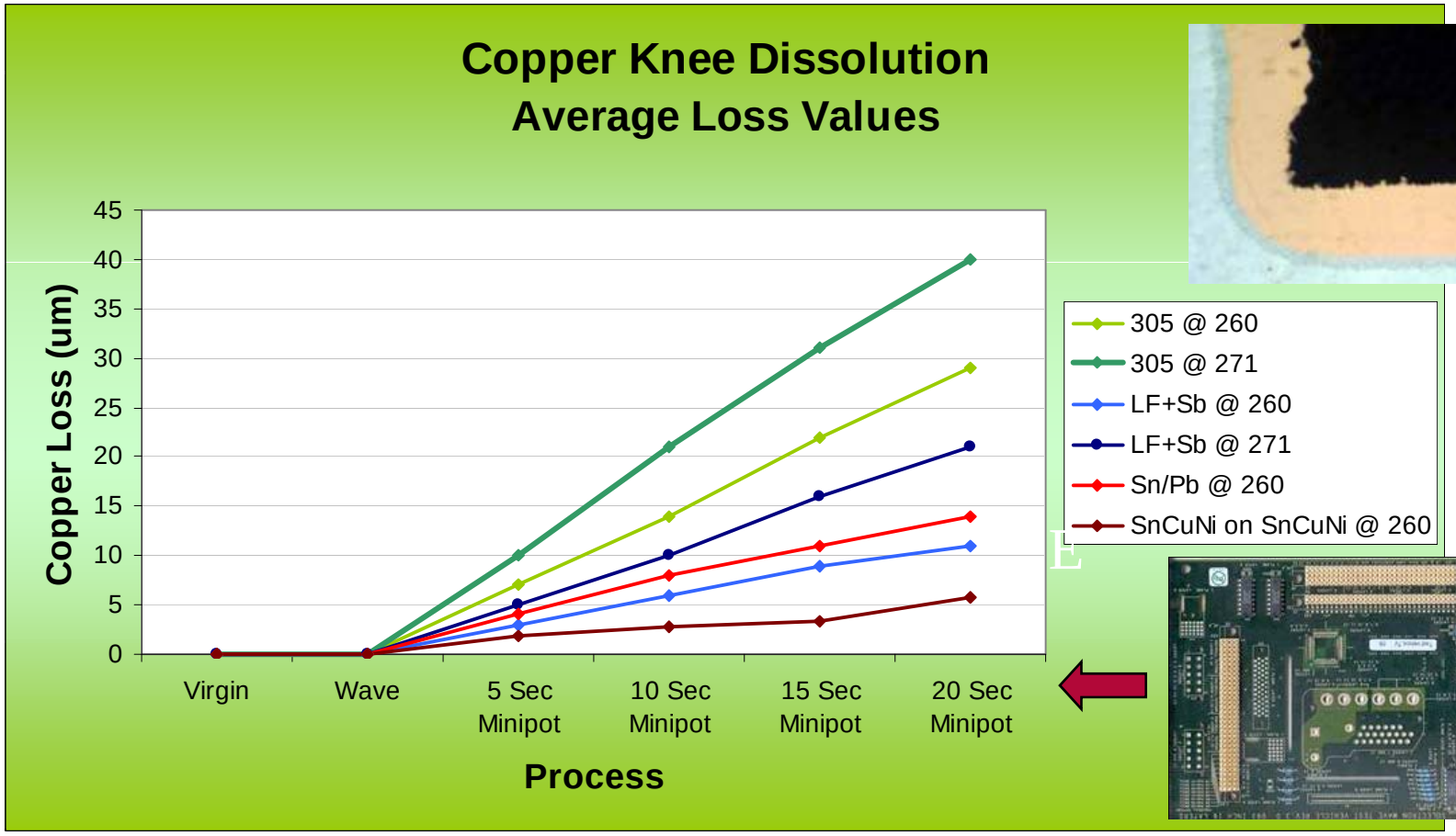
Perhaps use an Alternative Alloy?
Dissolution Rates of No / Low Ag Alloys



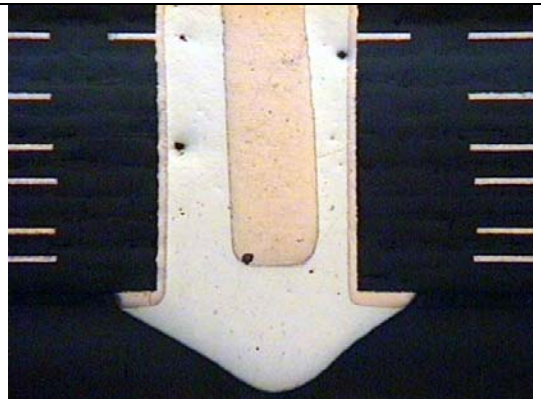
Dissolution difference between alloys would only be more severe on a dynamic pot.

Copper Dissolution during PTH Rework – Comparison of Alloys

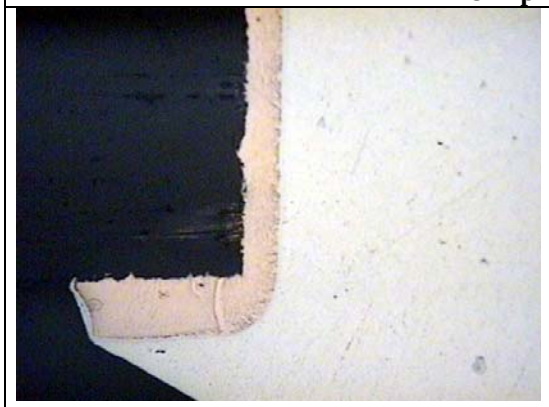
Sn0.7Cu0.05Ni alloy has much lower copper dissolution rates than many other solders while retaining other desirable attributes (wetting & vertical-fill).



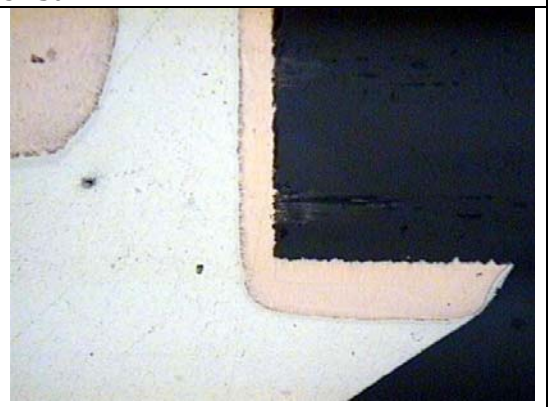
Verification of Sn0.7Cu0.05Ni PTH Rework



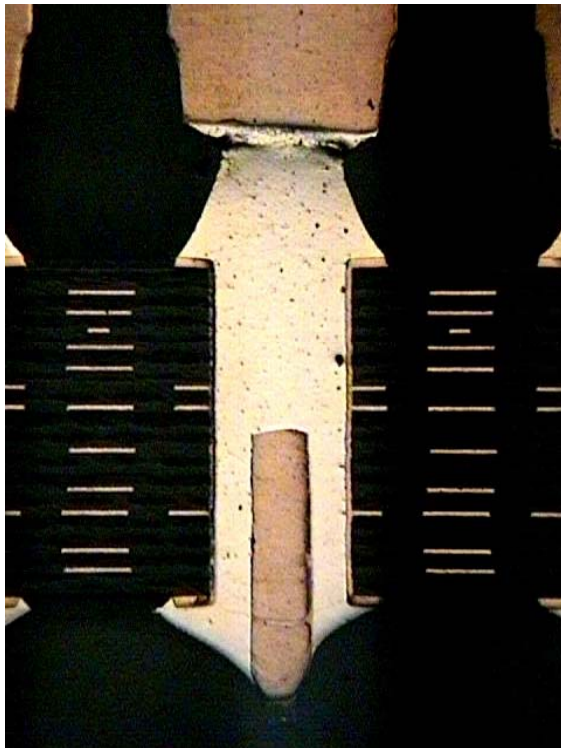
U41 pin9 50X



U41 pin9, 200X



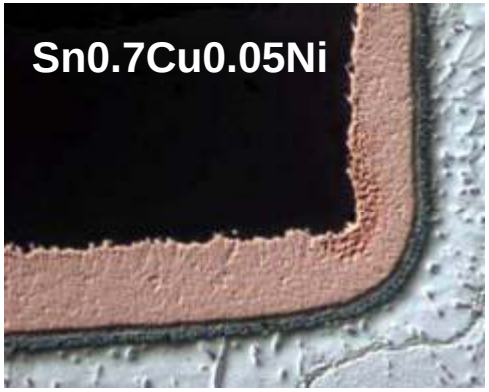
U41 pin9, 200X

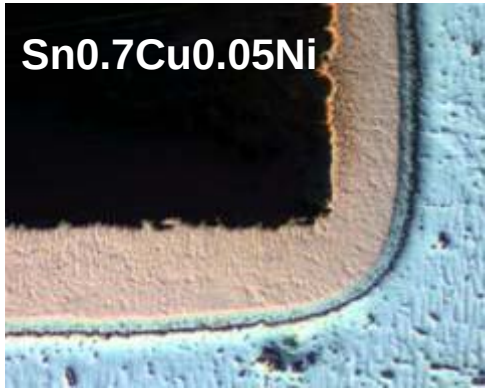


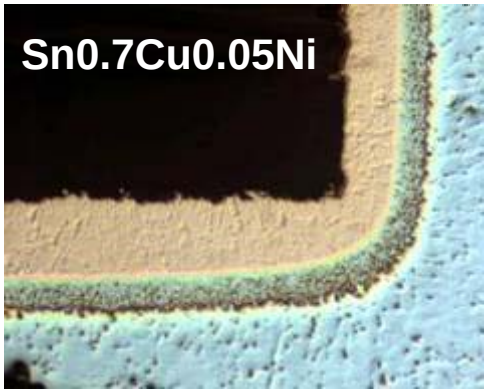
Results: Solder joint cross sections showed acceptable conditions for hole fill and copper dissolution (including 0.125” thick PCBs).

(Solectron Mat Lab Report #: 1944)

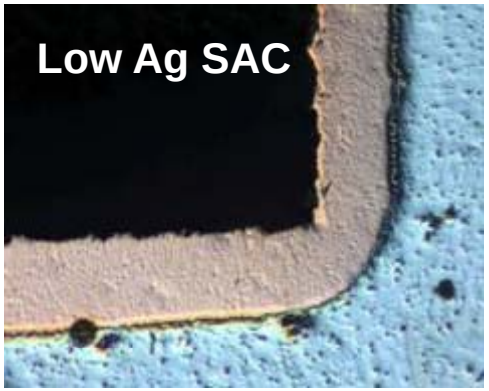
Alternative Alloy Rework Comparison: Simulated Mini-pot

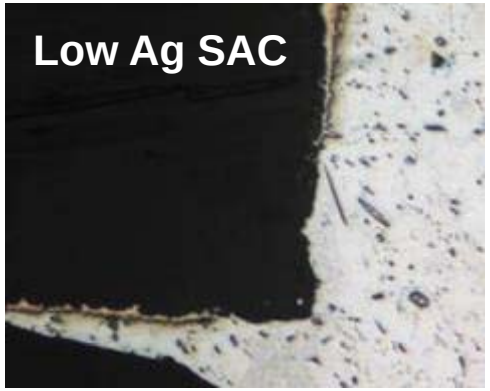






15 sec contact | **40 sec contact** | **120 sec contact**



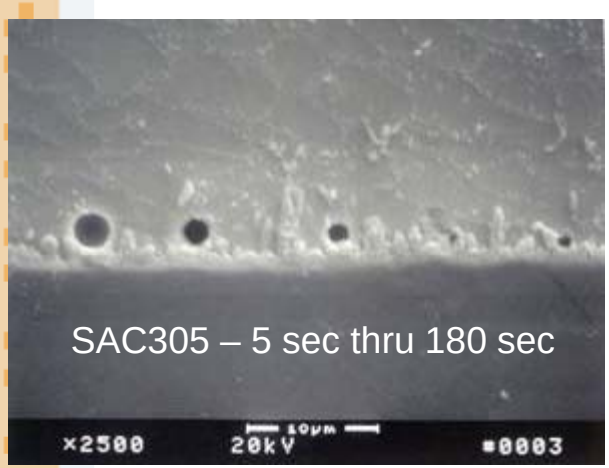


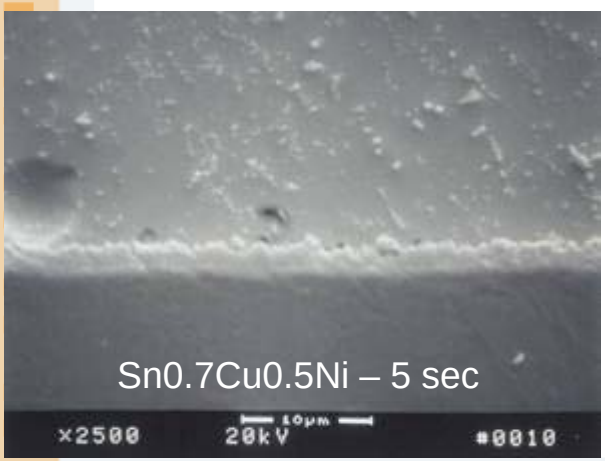
Boards were waved and reworked with the respective alloys. Simulated mini-pot rework (no component removal) was performed from 0 – 120 second exposure. Samples were cross-sectioned and knees measured. Samples shown above indicate minimum knee thickness at each exposure time (8 through-holes; 16 knees per time).

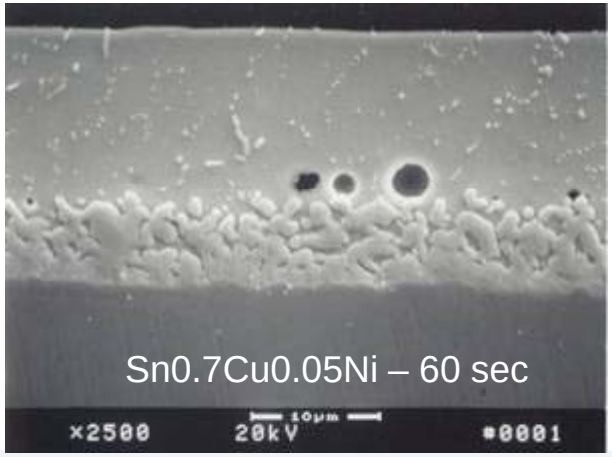
Intermetallic Growth of Sn0.7Cu0.05Ni

Another unusual observation with Sn0.7Cu0.05Ni was its IMC growth. All other alloys including Sn/Pb, SAC305, and other alternative alloys tested, reached a steady state IMC thickness of about 2-3 um regardless of contact duration. Sn0.7Cu0.05Ni however, appeared to have continuing IMC growth with increasing contact time during static pot experiments.

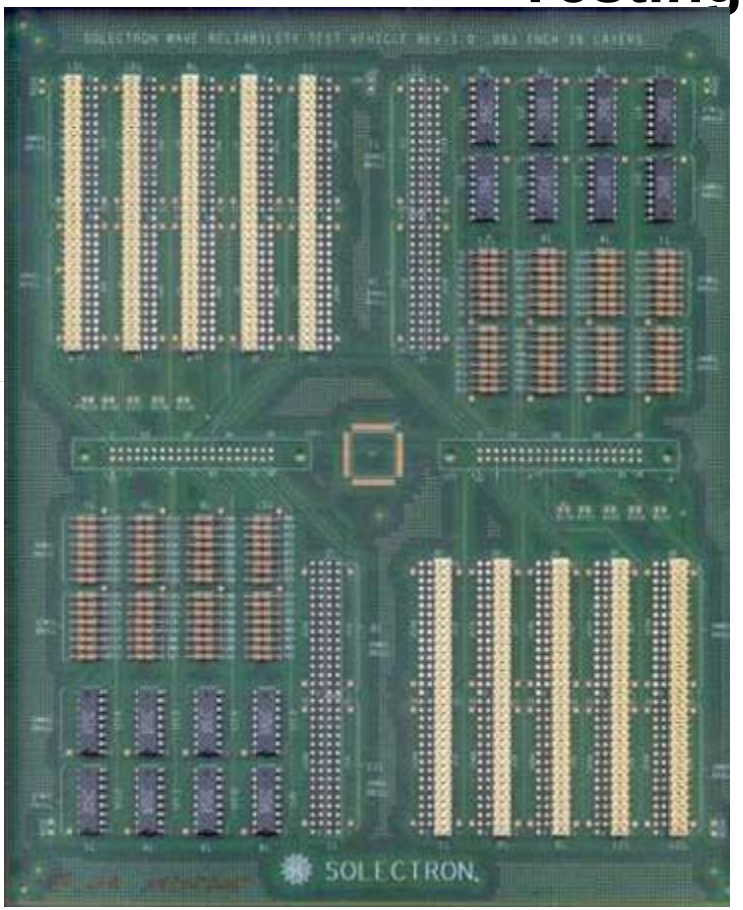
Although this has been documented previously, the impact of the IMC on solder joint reliability was assessed.







Stage 5: EMBRACE CHANGE
Sn0.7Cu0.05Ni Alloy ATC Reliability Testing



PTH Reliability TV: 0.093”
ATC: -40˚ C to +125˚ C
4˚ C/sec Ramp Rate

PTH Reliability Test Vehicle Assembly:

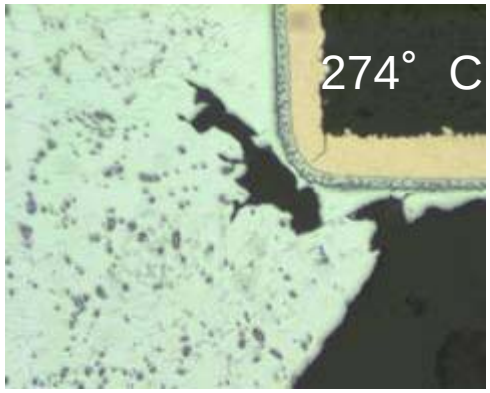
- 2x SMT Pb-free reflow profile conditioning
- Wave solder assembly
  - SnPb baseline
  - SAC305
  - Sn0.7Cu0.05Ni
  - SAC387
- Forced PTH rework on a sub-set of boards including Sn0.7Cu0.05Ni / Sn0.7Cu0.05Ni (best case dissolution) combination.
- Forced rework was performed at 274˚ C and 285˚ C from 30-80 seconds and boards were thermally cycled from -40˚ C to 125˚ C for 1500 cycles.

ATC test range: -40˚ C to +125˚ C for 1500 cycles.

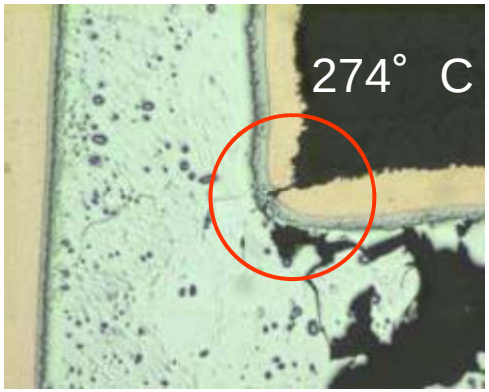
Results: No solder joint failures

All non-reworked samples continued for 3000 cycles with no solder joint failures.

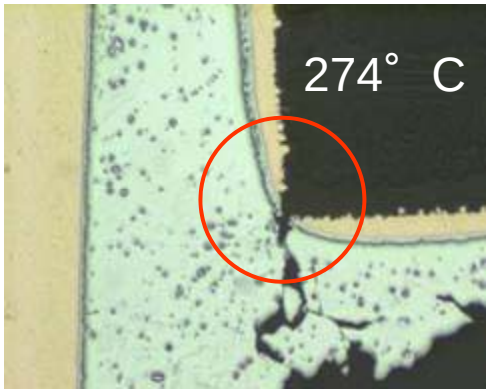
Sn0.7Cu0.05Ni / Sn0.7Cu0.05Ni PTH Rework Samples After 1500 ATC Cycles



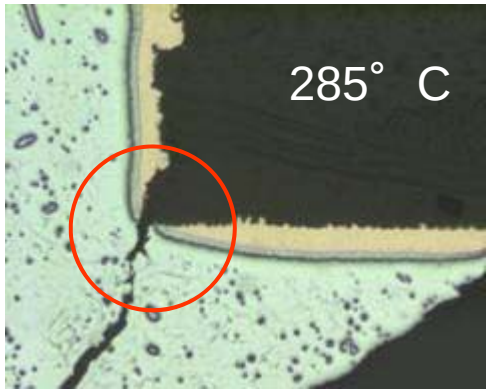
45 sec contact

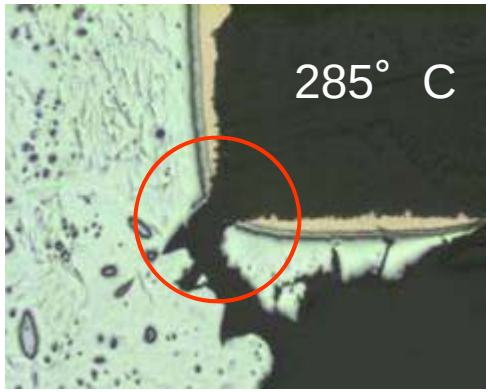


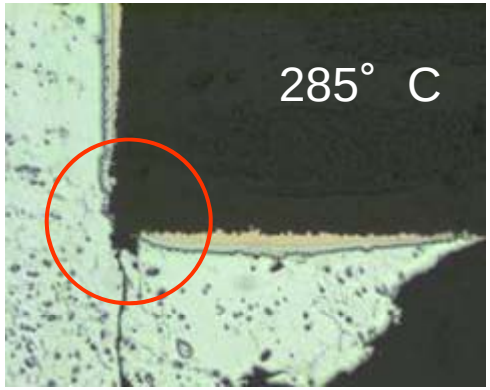
60 sec contact



80 sec contact







Notice the occurrence of higher than expected Cu dissolution…
Is there another HIDDEN VARIABLE?

Resulting PCBA Process Development Activities

Observations:

- High dissolution rates seen with SAC305 are unacceptable in a rework process. Artificially increasing Cu content results in unacceptable bath maintenance.
- ENIG finishes can slow the effect of dissolution, but ENIG knee failures have been seen.
- LF alloys with Ni and Sb additions show promise in dissolution reduction.
- Ni containing alloys do not reach a steady state IMC thickness, but continue to grow with time. Based on the ATC testing highlighted in this study, the thickening of the Sn0.7Cu0.05Ni IMC has not been shown to be a reliability concern.
- SnCuNi alloys have gained a wide acceptance in the industry as an alloy for PCBA assembly.

Resulting PCBA Process Development Activities

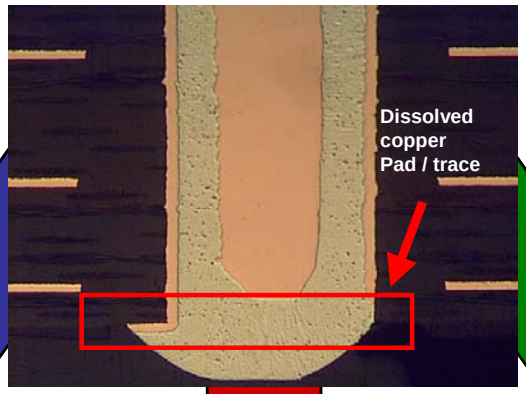
Actions:

1. Drive Industry Commonality
   - Continue to work with industry groups to identify mitigation strategies.

2. Optimize the Manufacturing Process
   - Prepare, optimize and deploy a process for PTH soldering using Sn0.7Cu0.05Ni alloy.
   - Continue to investigate alternative solder alloys and processes to reduce dissolution.

3. Investigate Root Cause
   - Further characterize Cu dissolution and investigate the effects of Cu plating processes/chemistries on dissolution

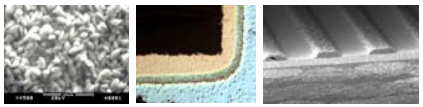
Stage 6: BECOME INVOLVED
Cu Dissolution Mitigation Strategy



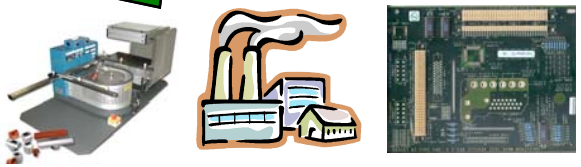
Courtesy of iNEMI

iNEMI
International Electronics Manufacturing Initiative

Drive Industry Commonality
- ❑ iNEMI Pb-Free Rework Project
- ❑ Alloy Alternatives
- ❑ PTH Rework Process Characterization & Control



Investigate Root Cause
- ❑ Material Analysis
- ❑ Alloy Comparisons
- ❑ Process Temperatures
- ❑ Influence of Cu Plating

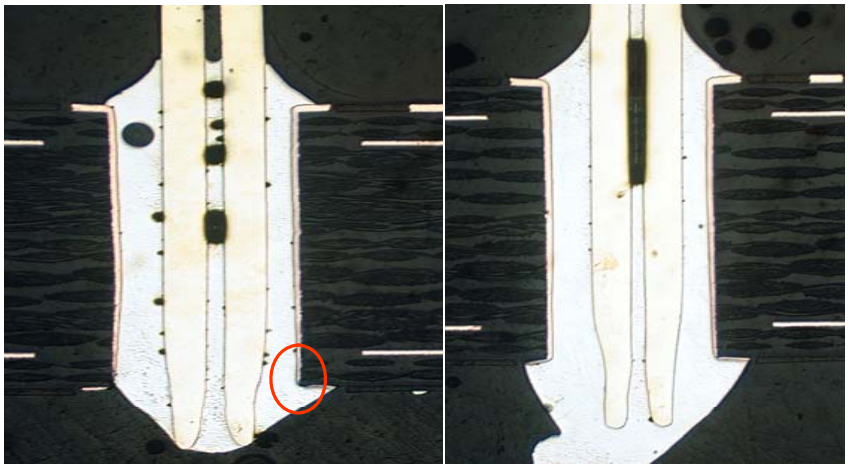


Optimize Mfg. Processes
- ❑ Rework Equipment & Methods
- ❑ Flow Rate Control
- ❑ Contact Time
- ❑ Reliability Testing

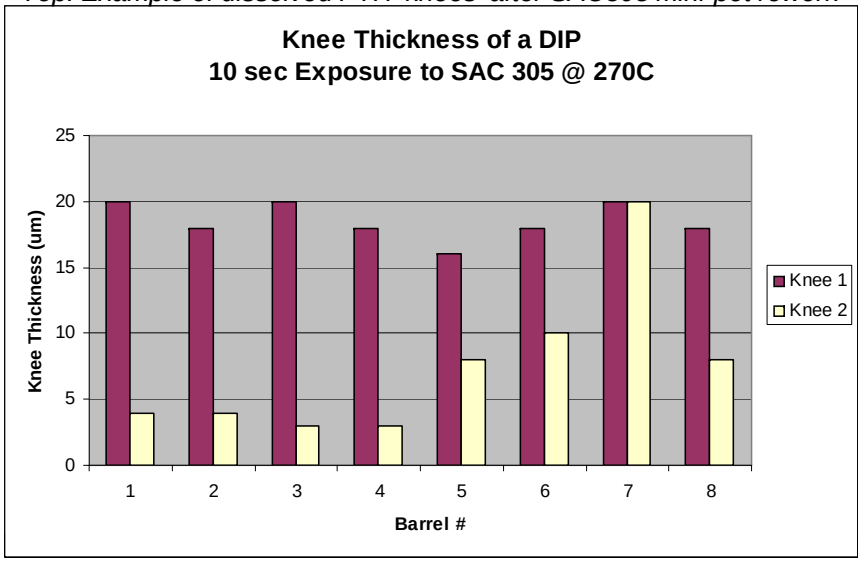
Cu Dissolution – Another Variable?

To date, all published attempts to address Cu dissolution has focused on enhancing rework process controls and deployment of alternative alloys.

However, our experience indicates that the rate and effect of Cu dissolution depends on at least one additional factor…
Copper Plating.



Top: Example of dissolved PTH 'knees' after SAC305 mini-pot rework



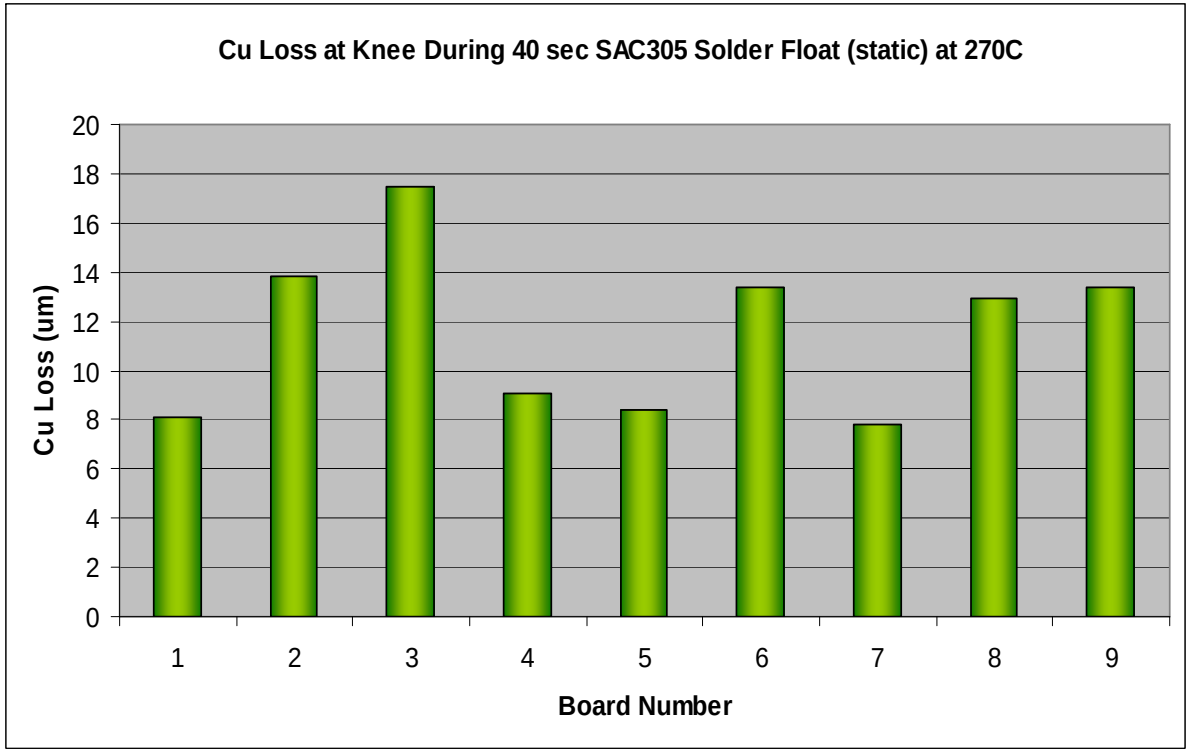
Bot: Dissolution variation found on a DIP after SAC305 mini-pot rework

Copper Plating

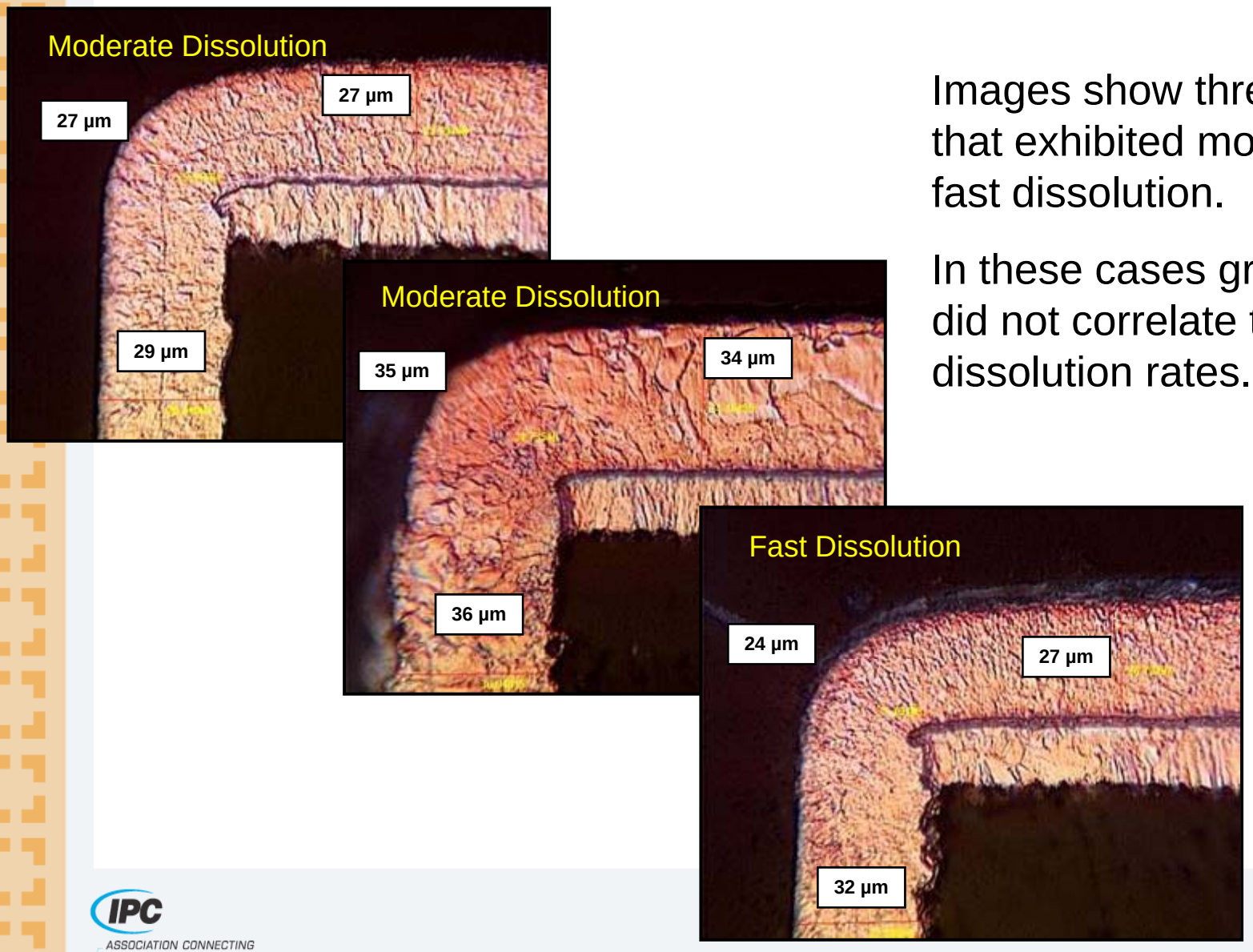
- Throughout all of the rework trials and experiments, it became clear that there was another contributor to Cu dissolution besides solder alloy and process parameters. Naturally, greater Cu thickness helps survivability of the PCB, however, other differences were apparent.
- We have experienced PCBs with nominal Cu thickness exhibit total knee dissolution in under 10 seconds, yet other PCBs survive 45 seconds or longer.
- There appears to be a significant difference in dissolution rates between test vehicles as well as PCB suppliers of the same test vehicle… regardless of alloy used.
- Clearly, there must be differences in the copper plating that have an effect on dissolution… We are working to identify this difference.

Copper Plating

As further evidence of copper plating having varying rates of dissolution, nine random raw boards were obtained and excised samples were evaluated using a static solder float test. The plot below show Cu loss for each board. Note the variations, even from the same supplier and location.



What is the effect of Cu grain size on dissolution?



Images show three boards that exhibited moderate or fast dissolution.

In these cases grain size did not correlate to copper dissolution rates.

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Copper Plating

Copper plating comes in many varieties, using several processes and many different chemistries.

- Copper Direct Current, Copper pulse, Copper reverse pulse, Direct Current/Pulse Combo, etc.

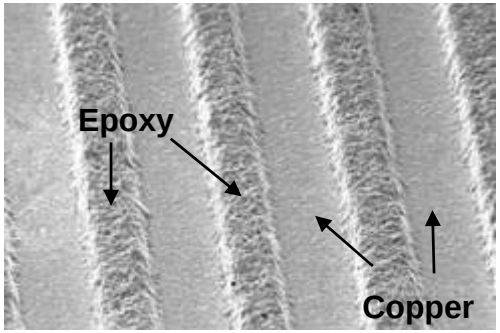
Solectron is currently working with industry chemistry suppliers to evaluate Cu plating and its effect on dissolution. Variations include plating chemistry, plating processes, new solutions, used solutions and used/filtered solutions.

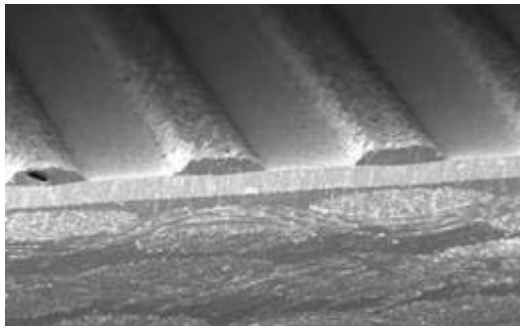
<u>Work is ongoing and initial results appear to show some differences.</u>

Copper Plating Investigation: Stenciled Dissolution Coupon (SDC)

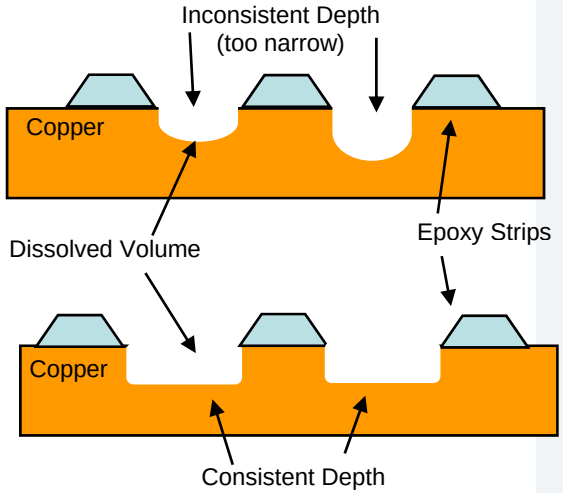
Stenciled Dissolution Coupon – SDC

- Dissolution results often show scatter in data due to variations in virgin Cu thickness.
- A test coupon was developed to minimize thickness variation effects.
- Epoxy is stenciled on a Cu plated panel with optimum spacing to allow proper solder/Cu interaction.
- This coupon allows direct measurement of dissolved Cu rather than determining dissolution by comparing differences between a virgin area vs a dipped area.





SEM images of epoxy strips on Cu plated panel



Cross-Sectional View

Executive Summary – Cu Dissolution (1)

- Significant work has been published on the effects of alloy selection, solder flow characteristics, contact time and process controls as a means to mitigate severe Cu dissolution.
- Alternative Pb-free rework alloys (other than SAC305) have been shown to reduce the rate of Cu Dissolution in static flow and dynamic flow experiments.
- Studies have shown that the presence of nickel reduces the rate of Cu dissolution. (i) Nickel plating in a PCB surface finish (ii) Nickel additive in a Pb-free alloy
- Sn0.7Cu0.05Ni alloys appear to have positive PCBA rework attributes but the higher melting point will limit the available processing window until the JEDEC Wave & Rework component temperature restrictions are lifted or revised. (JESD22-B106)

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Executive Summary – Cu Dissolution (2)

- Based on the results of our investigation the PTH rework process could change with the PCB changes (supplier, plating chemistry, technique).
- Work performed by Solectron and our suppliers have often produced confounding or contradictory results, leading to the suspicion that PCB copper structure may have influence over the rate of Cu dissolution.
- Industry specifications do not exist that defines PTH Cu thickness for finished assemblies (remaining barrel thickness). IPC-6012B only addresses PCB fabrication requirements.
- Currently the PCB solder float tests are performed to the 288° C standard typically using the 63Sn37Pb alloy… but only laminate survivability is assessed. Suggest Pb-free laminates are tested using Pb-free alloys to check for dissolution (SnAgCu etc...).

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Stage 7: COMMITMENT

To combat this metallurgical menace the industry should work along multiple fronts… participate in industrial groups & consortia, collaborate with technology driving OEMs & EMS providers and suppliers.

- END -

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References & Acknowledgements

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