Korea's New Electronics Waste Law, p. 18


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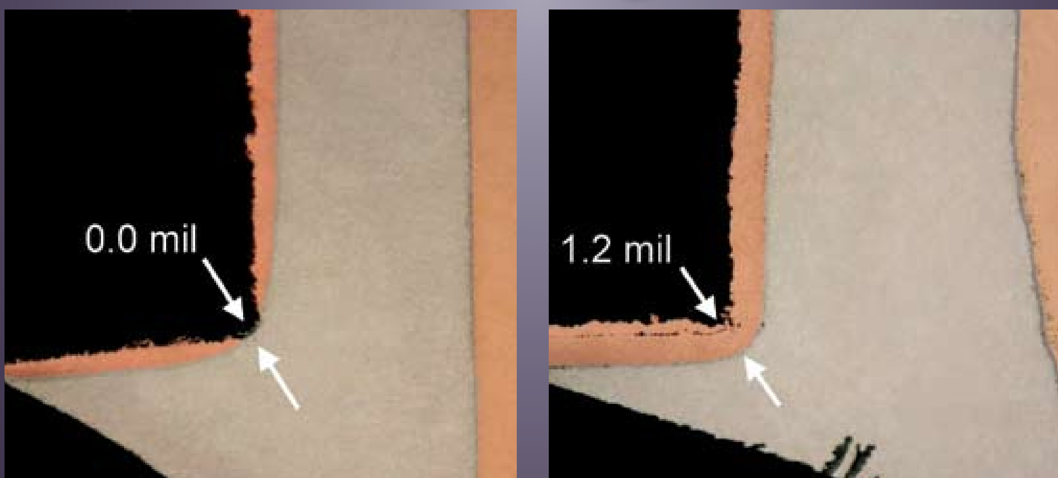
# Copper Dissolution: Just Say No!




Connector after conventional SAC 305 rework showing copper dissolution (left), and minimal copper dissolution (right) using new SAC 305 rework method.

Nondestructive Cuts

Preheating and Pb-free

SMT Fasteners

与锡/铅焊料喷泉相同的返工工艺相比，在含SAC 305焊料的无铅焊料喷泉上移去并更换通孔元件，会大幅增加铜在孔壁和定位焊盘溶解的风险。带OSP或ImAg表面涂层的厚而重的印刷电路板风险最大。一张厚而重的印刷电路板抽取更多热能，在焊料喷泉上的接触时间更长，增加铜溶解的风险。本文研究多种通孔元件返工技术，并指出成功减低铜溶解风险的技术。

# Pb-free PTH Rework on a Thick, Heavy Assembly

Robert Farrell, Paul Bodmer, Bruce Tostevin, Richard Russo and Gregory Morose

## A forced convection platform with a solder fountain showed a dramatic impact on copper dissolution.

Benchmark Electronics conducted a Pb-free implementation for a customer in January 2006 that included documentation of the process and findings by the Toxic Use Reduction Institute.[1,2] This customer designs and manufactures computer systems based on open industry standards. The Pb-free conversion was done on a limited number of an existing SnPb high-reliability medical product. This product is referred to as the Maverick Card and is 7.5" by 9.2", 16 layers with seven layers being power or ground, 0.084" thick, and populated with a total 1,694 SMT and PTH components on both sides. The SnPb version has been in production for an extended period of time.

The Pb-free version included three surface finishes: OSP, ENIG and ImAg; all chemistry was organic acid (OA). The assembly required four reflow cycles because select BGAs could only be obtained as SnPb. The four assembly profiles were, in order, Pb-free bottomside, Pb-free topside, SnPb bottomside and SnPb topside.

All PTH components were soldered during the original assembly on a SAC 305 solder fountain with the molten solder at 285°C. The solder fountain included complete board preheat to a topside laminate temperature of 132°C prior to component soldering. The average contact time on the solder fountain was 9 sec. for each PTH component, and the objective was to obtain IPC-A-610 Class 3 joints during the original assembly and subsequent forced rework. Class 3 joints require a minimum of 75% flow solder fill in the z-axis.

**Table 1. PWB Copper Thickness, Practice Board 1**

| | Site 1 Single Rework Stagnant Flow | Site 2 Single Rework Full Flow | Site 3 Double Rework Full Flow | Site 4 Double Rework Stagnant Flow |
|---|---|---|---|---|
| Top layer pad copper | 2.279 | 2.071 | 2.071 | 2.138 |
| Bottom layer trace copper | 2.306 | 2.216 | 2.257 | 2.104 |
| Bottom pad copper | 1.996 | 1.688 | 1.620 | 1.564 |
| Knee copper | 1.575 | 1.379 | 1.350 | 1.238 |

### PTH Forced Rework

Practice Boards 1 and 2 were selected for development work prior to reworking a PTH component on the Maverick Card. The objective: Identify the optimum rework method to achieve IPC Class 3 through-hole joints with minimal copper dissolution, pad lifting and laminate thermal degradation. Single, double and triple reworks were evaluated. A single rework is defined as removal and replacement of a PTH component; a double rework is the second removal and replacement of the component at the same site. The board is permitted to cool to room temperature between rework cycles, and a triple rework follows similarly. Double and triple reworks on the same site would be rare in practice, but a successful double rework may be necessary and also provides a higher confidence level for the integrity of a single rework.

Practice boards 1 and 2 were identical and selected because they had an OSP surface finish, which has a significant risk of copper dissolution. Moreover, the boards had 10 sites for the same PTH component, which permitted different techniques to be assessed at various board locations. The sites were sufficiently apart to minimize the thermal impact of rework from adjacent sites. The board was 14.5" by 16.5", 0.074" thick, and four of the 10 layers were power or ground. **Figures 1** and **2** show the practice board and respective component.

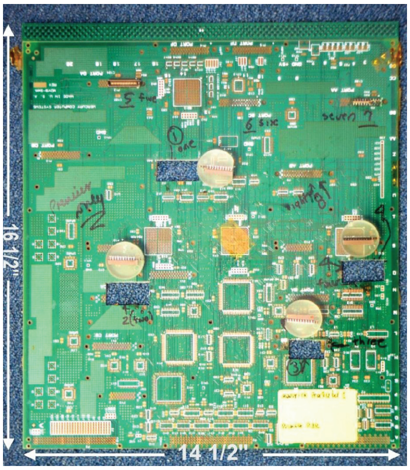



**Figure 1.** Practice board.

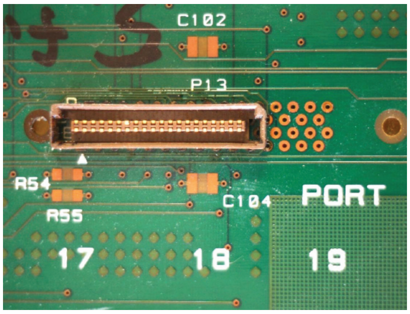



**Figure 2.** Close-up of the PTH component and rework site on the practice board (10 sites per board).

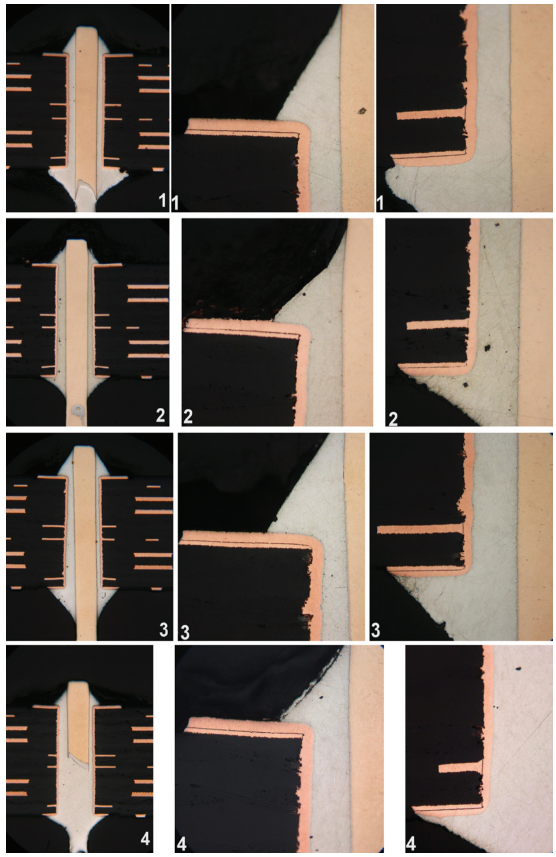


**Figure 3**. Topside section and process summary for sites 1, 2, 3 and 4 on practice board 1.

**Practice board 1.** Sites 1 through 4 on practice board 1 were reworked completely on a SAC 305 fountain set at 280°C. The original component installation was performed on the same solder fountain. All reworked boards were preheated to a topside temperature of 150°C and subjected to single or double rework. The rework nozzle style was varied to provide a "stagnant" or "full flow." Stagnant flow is defined as solder making intimate contact with the board's bottomside, but not overflowing the sides of the nozzle. Full flow is defined as solder making intimate contact with the board's bottom and overflowing the sides of the nozzle. The objective was to determine if stagnant flow reduced copper dissolution as compared with full flow. The rework contact time is defined as the period the solder makes intimate contact with the board bottom. The flux used was Vendor A OA flux paste.

**Figure 3** shows a summary of the results. The digit in the lower corner of each cross-section corresponds to the applicable site, and each site includes three cross-sections: the complete, top and bottom view. The process summary appears in the right column.

PCB copper thickness measurements on Sites 1 through 4 were taken (**Figure 4** and **Table 1**). The top layer pad copper is on the board's topside, and masking covers the bottom layer trace copper. Both locations have negligible risk of copper dissolution and can be considered baselines for the original copper thickness. All measurements in Figure 4 are mils.

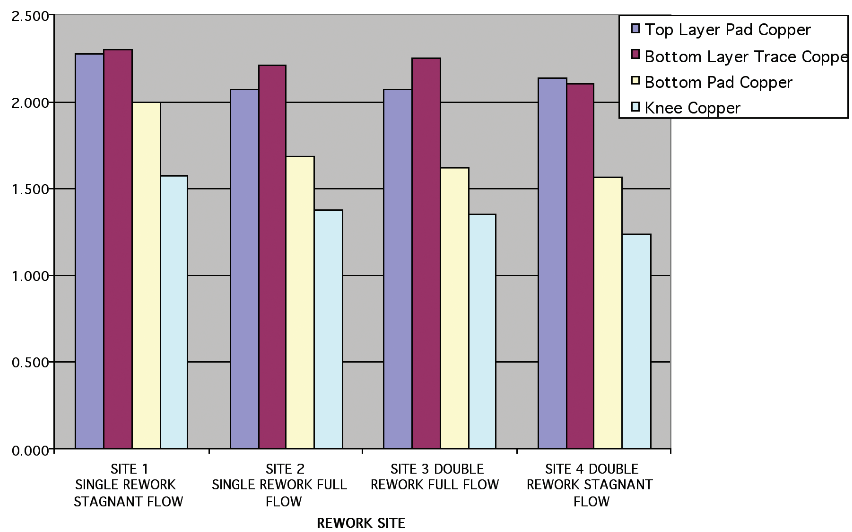



**Figure 4.** Copper thickness measurements for sites 1-4 on practice board 1 (OSP).

Some observations from the data:

- All four sites were acceptable. There was no evidence of excessively thin or fractured knees, nor was there any significant via wall thinning near the surface. Copper thickness was above the IPC Class 3 minimum of 0.001".
- Copper dissolution increased for the double rework as compared with the single rework, which was expected, but the increase was smaller than anticipated.
- The difference in copper dissolution between the stagnant and full flow was not significant.
- By the end of the double rework process, the bottomside pads lost approximately one-quarter their original copper thickness, regardless of the method used.

| Table 2. PWB Copper Thickness, Practice Board 2 | | |
|---|---|---|
| | 2X | 3X |
| Top layer pad copper | 1.872 | 1.764 |
| Bottom layer trace copper | NA | 2.103 |
| Bottom pad copper | 1.357 | 1.364 |
| Knee copper | 1.001 | 1.035 |

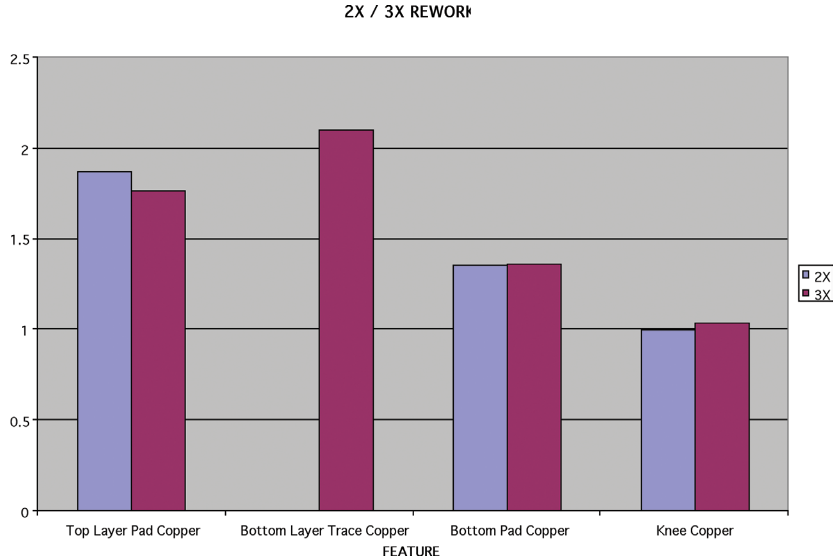



**Figure 5.** Copper thickness for practice board 2 (OSP) 2X and 3 sites. (Note: The 2x thickness for the bottom layer trace copper was not available.)

**Practice board 2.** Practice board 2 was used to assess a different rework process in which forced convection was used to remove the connector and vacuum solder from the through-holes. The solder fountain was only used to install the component. This process significantly reduced the contact time on the solder fountain; it was hypothesized this would minimize copper dissolution. One connector location was subjected to a double rework; another connector was subjected to a triple rework; the two sites were referred to as 2X and 3X, respectively.

Hot air component removal and hole cleaning parameters were:

- Board topside preheat for component removal and hole cleaning: 160°C.
- Peak temperature of the component plastic body: 245°C.
- Peak temperature of solder in barrel: 225° - 235°C.

Component installation on the solder fountain parameters were:

- Board topside preheat: 150°C.
- Temperature of the solder: 280°C.
- Contact time: 8 - 9 sec.

PWB copper thickness was measured (**Figure 5** and **Table 2**). The top layer pad copper is on the board top; masking covers the bottom pad copper. Both have negligible risk of copper dissolution and can be considered baselines for the original copper PWB thickness. All measurements are in mils.

The measured results were acceptable for 2X and 3X reworks per IPC Class 3 criteria. The copper thickness at the knees did not go below 0.001", and the amount of copper dissolution on 2X and 3X reworks was equivalent, which was somewhat surprising. It was anticipated the dissolution would increase on the 3X rework as compared with the 2X. The final copper thickness on the bottom pad copper and knee copper were less on practice board 1 as compared with practice board 2, which was not anticipated because the solder fountain contact time on practice board 2 was lower. However, based on the copper thickness of the top layer pad copper and bottom layer trace copper, it appears practice board 1 had more copper prior to the start of the rework as compared with practice board 2, and this would explain the results. **Figure 6** shows cross-sections of the 2X and 3X rework. The 2X or 3X figure in the lower part of the image denotes the respective rework.

The 2X and 3X rework cross-sections were acceptable per IPC Class 3 criteria. Copper dissolution was acceptable, and the small amount of pad lifting is consistent with SnPb through-hole rework. Solder flow-through to the topside was 100%; there was minimal voiding; wetting was good, and there was no laminate thermal degradation.

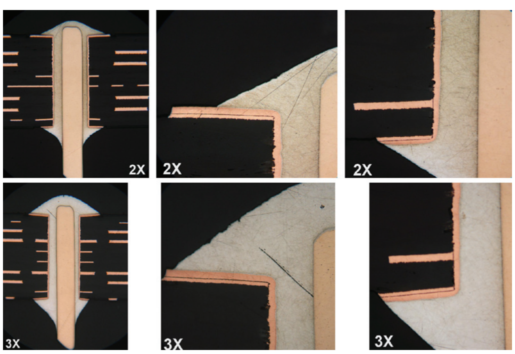



**Figure 6.** Topside sections of practice board 2 2X and 3X rework.

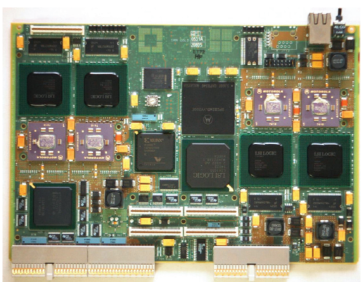


**Figure 7.** Maverick Card topside.

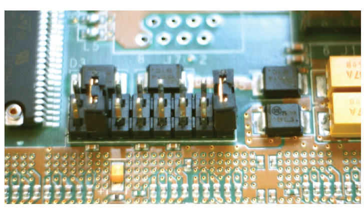


**Figure 8.** Close-up of 16-pin header reworked at Location J6. The arrow references Location J6 on the board.

## Maverick Card PTH Rework

The Maverick Card is 0.084" thick, 16 layers with 7 ground/power planes. Compared to practice boards 1 and 2, it represents a significantly more difficult rework challenge in terms of thermal load. The component selected for rework on the Maverick Card was the 16-pin header at Location J6. The Maverick Card and the header at Location J6 appear in **Figures 7** and **8**.

**Maverick Card 3 – OSP surface finish, double rework on the solder fountain.** Practice boards 1 and 2 results indicated a double rework done completely on the solder fountain would be successful. It was decided to employ this process on Maverick Card 3, which had an OSP surface finish. This process is faster as compared with the alternative forced convection process because it takes less time to remove a component on the solder fountain as compared with the forced convection platform.

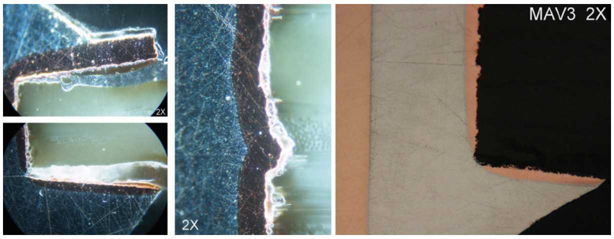



**Figure 9.** Cross-sections of 16-pin header on Maverick Card 3 after double rework on the solder fountain.

The solder fountain parameters for the rework of the 16-pin/header at Location J6 on Maverick Card 3 were:

- Topside board preheat temperature: 150°C.
- SAC 305 solder temperature: 280°C.
- Contact time for each rework: 20 sec.
- Total contact time for both reworks: 40 sec.
- Flux: Vendor B flux paste.

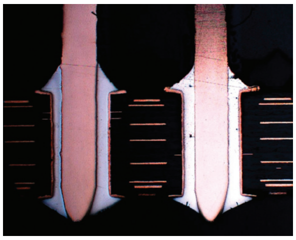


**Figure 11.** Cross-section of 16-pin header on Maverick Card 9 after double rework using forced convection in conjunction with the solder fountain (full view).

**Figure 12.** Cross-section of 16-pin header on Maverick Card 9 after double rework using forced convection in conjunction with the solder fountain (top view).

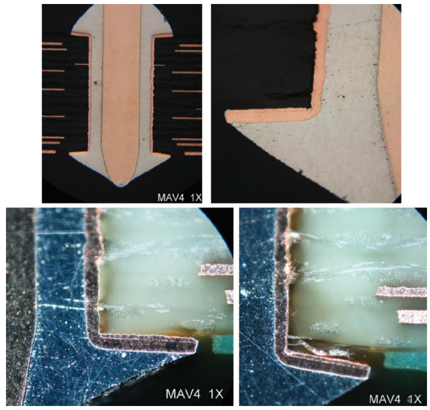



**Figure 10.** Cross-section of 16-pin header on Maverick Card 4 after single rework using forced convection in conjunction with the solder fountain.

Contact time for each rework is defined as the total time required to remove a component and install a new one while the solder is making continuous contact with the board bottom. The contact time for the original assembly was 9 sec., which means the total contact time for assembly and rework was 49 sec. Cross-section results are shown in **Figure 9.**

The double rework was not acceptable because of the fractured knee caused by copper dissolution because of excessive contact with the molten SAC 305 solder. This is a known risk with Pb-free SAC 305 rework and has been documented.[3,4] This board would have to be scrapped, which could have significant cost and delivery implications. It should be noted that the fractured knee could not be detected with visual inspection and required destructive cross-sections to see it. The board also exhibited through-hole pull away, which is not acceptable and exhibited undesirable pad lifting.

The Maverick Card is a more thermally massive card as compared with the practice boards and required longer contact times on the solder fountain, which likely caused the unacceptable copper dissolution.

**Maverick Card 4 – ImAg surface finish, single rework using forced convection in conjunction with the solder fountain.** Based on the unacceptable results for the double rework of Maverick Card 3 on the solder fountain, it was decided to perform a single rework incorporating the forced convection platform for component removal and through-hole cleaning in conjunction with the solder fountain. The solder fountain was used only to install the new component, which significantly reduced contact time on the fountain, which in turn minimized the copper dissolution risk. Initially, the forced convection parameters were identical to practice board 2, but the plastic body of the 16-pin header melted, and it was determined that the plastic was only rated to 220°C, which made it difficult to remove the component. The topside preheat of the board was increased to 180°C from 160°C; the peak temperature on the plastic component body was lowered to 220°-230°C, and the component was removed from the board just before the plastic body melted. The PTH solder temperature was 220°-225°C. The solder fountain was used to install the new component with the following parameters:

- Topside board preheat temperature: 150°C.
- SAC 305 temperature: 280°C.
- Contact time for installation: 9 sec.

Cross-section results are shown in **Figure 10.**

The single rework was successful in minimizing copper dissolution, but induced some PCB thermal degradation, as manifested by pad lifting and hole pull away. The pad lifting varied from none to a maximum of 0.002", as seen in the two bottom images of Figure 10. The hole pull away was less than 10% along the entire length. It was believed the thermal degradation was most likely caused by the high topside preheat (180°C) in conjunction with the time required at this temperature to reflow the component, remove the component and vacuum the holes. The high PCB preheat temperature was required to minimize melting of the plastic PTH component body; a lower preheat would have been used had the PTH component been rated to a higher temperature. A contributing factor was likely the four reflow cycles required during the original assembly, which, in order, were bottomside Pb-free, topside Pb-free, bottomside SnPb and topside SnPb.

**Maverick Card 9 – OSP surface finish, double rework with forced convection in conjunction with the solder fountain.** Based on the generally positive results with Maverick Card 4, it was decided to conduct a double rework using the same technique on an OSP Maverick Card. The forced convection and solder fountain parameters were identical to Maverick Card 4, and the total contact time on the solder fountain was 18 sec. (two installations). The card selected was Maverick Card 9. Cross-section results appear in **Figures 11, 12, 13** and **14**.

The process dramatically reduced copper dissolution as compared with the process used for Maverick Card 3. The solder fill was greater than 75% as required for IPC-610 Class 3; wetting was good and voiding was minimal. Slight pad lifting was detected, likely related to the high PCB preheat temperature required to compensate for the low temperature rating of the 16-pin header. Also, this card was subjected to a double BGA rework prior to through-hole rework, and the card was reflowed four times during the original assembly. The increased number of thermal cycles was likely a factor in thermal degradation. Standard Pb-free boards would be reflowed only twice during the original assembly; it is unlikely four reworks would be performed on the same board.

**Maverick Card 8 – ENIG surface finish, double rework with forced convection in conjunction with the solder fountain.** The double rework technique used for Maverick Card 9 was used for Maverick Card 8, which had an ENIG surface finish. **Figure 15** shows the cross-section. The joint meets IPC Class 3 Criteria, but there is evidence of slight pad lifting, which is not preferred. The thermal degradation was likely caused by factors similar to those in Maverick Card 9. Copper dissolution on Maverick Card 8 was not an issue, as anticipated given the ENIG PCB surface finish.

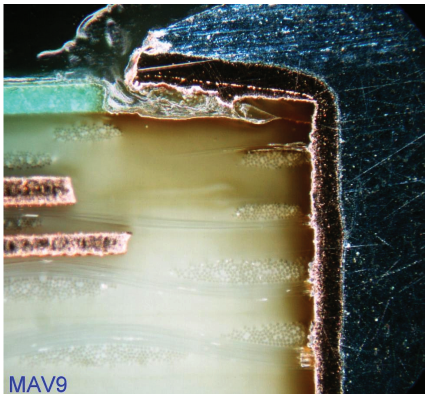



**Figure 13.** Cross-section of 16-pin header on Maverick Card 9 after double rework using forced convection in conjunction with the solder fountain (top view showing pad lift).

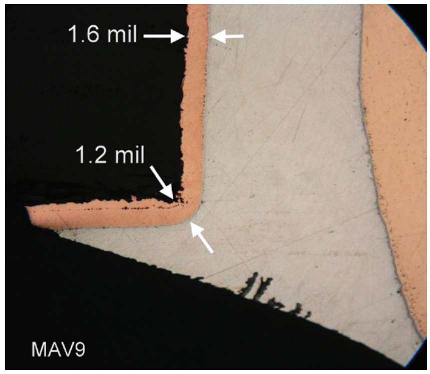



**Figure 14.** Cross-section of 16-pin header on Maverick Card 9 after double rework using forced convection in conjunction with the solder fountain (bottom view showing copper thickness at the knee).

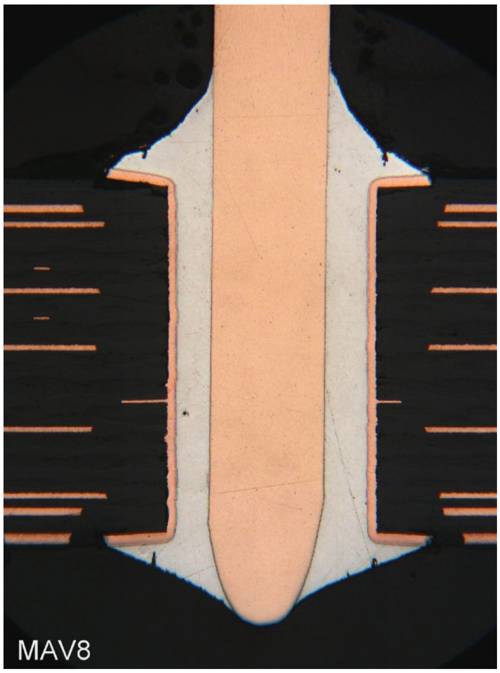



**Figure 15.** Cross-section of 16-header on Maverick Card 8 after double rework using forced convection in conjunction with the solder fountain (full view).

## Conclusions

The forced convection platform, in conjunction with the solder fountain, dramatically reduced the copper dissolution observed on the Maverick Card as compared with the rework done completely on the solder fountain. The former is the recommended rework process for thermally massive cards such as the Maverick Card.

Overall, the Pb-free through-hole rework processes evaluated were successful. The solder fountain, or a combination of forced convection and solder fountain, is a viable process; optimum rework process selection should be predicated on board design and construction.

Additional optimization is required to minimize pad lifting.

All components should be rated for the higher temperatures associated with Pb-free assembly and rework. The 16-pin PTH header reworked on the Maverick Card was rated to 220°C and melted during forced convection removal. A 260°C temperature rating is recommended for all Pb-free components. ■

## References

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4. L. Ma, A. Donaldson, S. Walwadkar and I. Hsu, "Reliability Challenges of Lead Free (LF) Plated-Through-Hole (PTH) Minipot Rework," IPC\Jedec Global Conference on Lead Free Reliability and Reliability Testing for RoHS Lead Free Electronics, April 2007.

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