

Electroplated Copper Filling of Through Holes on Varying Substrate Thickness

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Abstract

This paper discusses a through hole copper filling process for application to high density interconnects constructions and IC substrates. The process consists two acid copper plating cycles. The first cycle uses periodic pulse reverse electroplating to form a bridge in the middle of the hole, followed by direct current electroplating to fill the resultant vias formed during the bridge cycle. This process can provide defect-free filled holes with total plated copper on the surface below 25 μm , with dimple less than 5 μm for boards with core thickness of 0.2 mm and 0.25 mm. This process was designed to be deployed in specially constructed vertical continuous platers (VCP), thus reducing capital equipment compared to horizontal conveyerized electroplaters.

The chemical components, copper, acid and additive, for periodic pulse reverse plating cycle, are optimized via experimental conditions selected from DOE (design of experiments) software. Critical parameters are identified and the impact on cavity formation during the bridging step is quantified. The additive and copper concentrations play key roles in reducing defects during bridge formation and on the resultant via formation.

A high performance via-filling process is used to fill the formed vias, with less than 5 micron dimple depth, while depositing approximately 12 microns on the surface. The thin surface copper enables fine line resolution without the need for planarization or grinding. The mechanical properties of the plated deposit meet or exceed all IPC standards.

This process is applicable to both laser-drilled X shape through holes and mechanically drilled straight holes. Laser-drilled through holes are bridged faster than mechanically drilled holes. However, mechanically drilled holes show a lower tendency for drilling induced defects, especially at the smaller hole diameters of 0.1mm. This process has shown capability to fill through-holes in thicker cores of 0.4 mm to 0.8 mm, where further investigation continues.

1. Introduction

Resin or paste plugging of through holes in cores has been part of build up technology, especially in IC substrate for many years. However, increasing circuit density and stacked via constructions coupled with higher power devices have added an extra dimension of thermal management. Solid copper filling of these through holes offers many advantages, such as reducing the CTE mismatch, providing a stable platform for stacking microvias and offering thermal management properties for high power devices. New technologies started to develop in order to completely fill through holes and vias in build-up core layers in HDI and IC with solid copper. One of the approaches for filling through holes with copper is via DC plating technology, for thin core board with laser-drilled X holes as shown below (Figure 1).

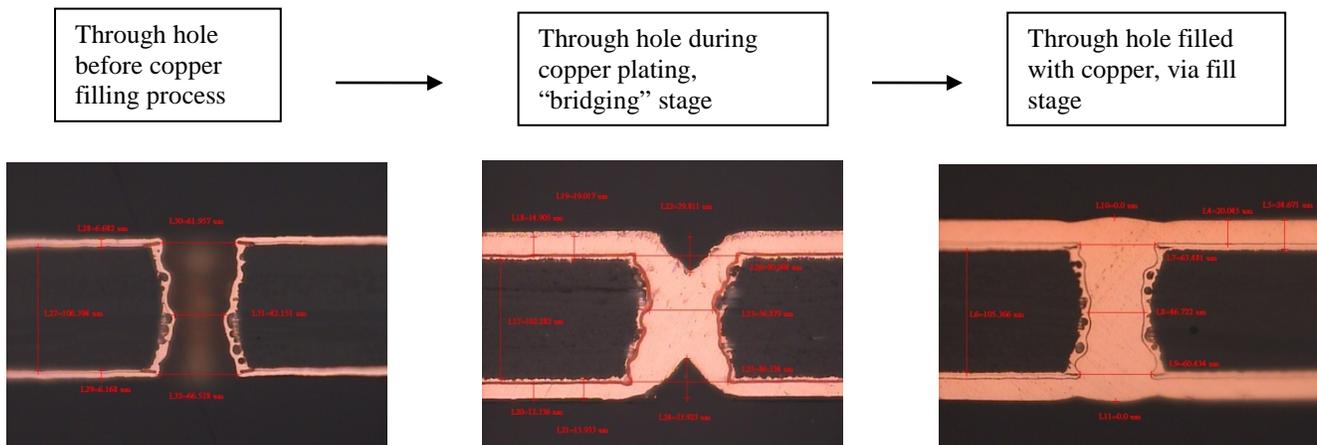


FIGURE 1. COPPER FILLING STAGES VIA DC PLATING TECHNOLOGY

The plated copper on the surface can be controlled below 25 μm , with core thickness around 100 μm , and diameter around 100 μm (50-70 μm in the middle).

The filling process consists of two stages. During the initial stage, copper is preferentially deposited in the middle of the through holes until the hole wall in the center of the hole meets, resulting in the formation of two blind microvias. This stage is called “bridging”. The second stage consists of filling, the resultant double blind via. A single chemistry and one step plating process are ideal for filling through holes with solid copper.

However, DC plating is limited by the thickness of the substrate. Once the substrate thickness is above 200 μm , the propensity for inclusions/cavities grows (Figure 2) and the plated surface copper thickness increases beyond the 25 μm limit. Higher incidence of cavities may reduce reliability while the increased surface copper thickness reduces the ability to resolve fine line and space requirements. These limitations are exacerbated for the boards with mechanical drilled through holes.

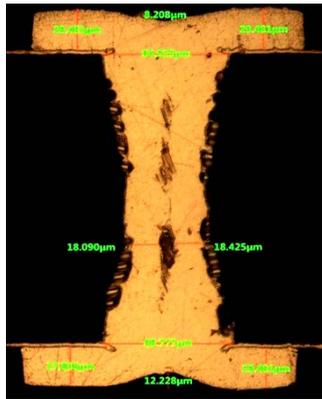


FIGURE 2. CAVITY DEFECTS IN DC PLATING PROCESS WHEN THE BOARD THICKNESS IS ABOVE 200 μm .

2. Two step through hole fill technology

The two-stage concept is adopted into two-step plating, the first step consists of “bridging” with periodic pulse reverse plating, then filling the resultant double blind via by a via-fill plating process. The combined processes offer defect-free solid copper filling technology for the boards with through holes, both laser-drilled and mechanically drilled.

Through holes were processed through standard primary metallization processes, including permanganate desmear or plasma desmear, an electroless copper plating or a direct metallization process, such as Blackhole, to make the holes conductive. To obtain a conductive copper layer inside the through hole, flash plating can be used to make sure the through holes have good conductivity across entire wall. The pre-plate chemistries and process cycles were not changed to accommodate the acid copper plating process.

2.1 Bridging Step by Periodic Pulse Reverse Plating, Via Formation

Periodic pulse reverse plating is a widely used electrolytic copper plating process. Over the past decade, this technology has gained widespread adaptation in the conformal plating of high aspect ratio through holes. The practice of periodic pulse reverse plating has continued to develop. New rectifiers and software now offer greater flexibility for wave forms, including asynchronous pulse wave formations to accelerate the plating rate in the center of the through holes, i.e. up to 5 times the rate compared to conventional pulse waves. The plated copper merged together in the middle of the hole to form two opposing vias as shown in Figure 3. This process is called the “bridging” step. A standardized vertical plating cell was designed to achieve this new type of plating capability inside through holes. A vertical plating cell, installed with insoluble IrO mesh anodes, offers the widest operating range of current density plating for bridging through holes. Additional considerations for the vertical plating cell include anode shielding, anode/cathode spacing, area ratio, panel agitation, solution movement, flow rate and the panel clamping system.

After the bridging step, the two opposing vias are filled with an efficient via fill acid copper plating solution to complete the through hole copper filling process as shown in Figure 4

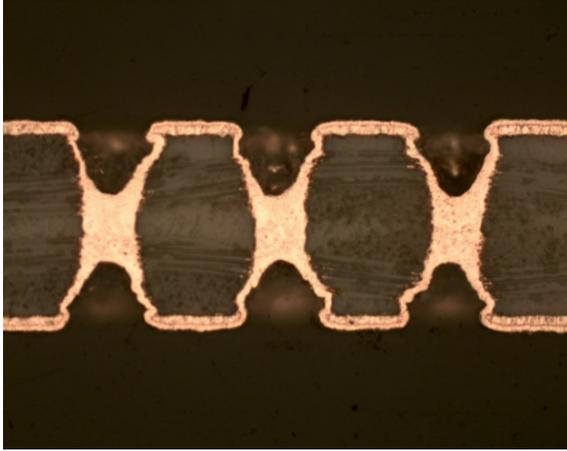


FIGURE 3. CROSS-SECTION AFTER BRIDGING STEP.

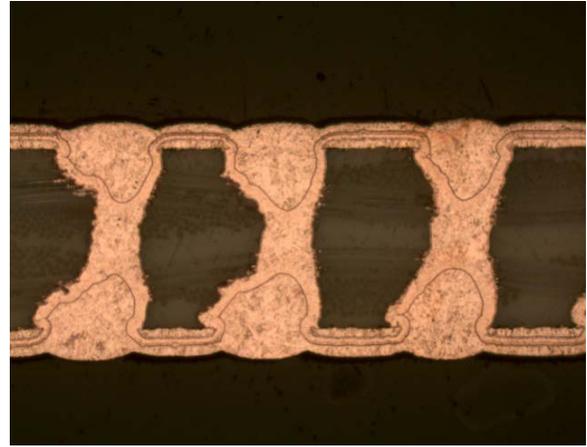


FIGURE 4. CROSS-SECTION AFTER BRIDGING AND VIA FILLING STEP

2.2 Chemistry for Bridging Step

The chemistry for the periodic pulse reverse acid copper plating process, used during bridge step, is a production chemistry material. This process contains a specifically designed organic additive system for pulse plating applications. The electrolyte components, copper sulfate, sulfuric acid, and chloride ion, are typical of standard acid copper plating solutions. To study the interaction among the chemical components, the concentrations of copper sulfate, sulfuric acid and additive are optimized with experimental conditions selected from DOE (design of experiments) software to achieve good hole bridging/filling performance, and cavity-free in the middle of the through holes. As a DOE constraint, the combined copper sulfate and sulfuric acid concentrations were kept below 350 g/L, to keep the plating solution from forming copper sulfate crystals. The boards with through-holes used for the DOE were laser drilled boards with core thickness of 200 μm , hole diameter of 100 μm . After the bridging step, 10 through holes were inspected, for each tested condition, by cross-section to determine if any cavity were present in the copper filled through holes, as shown in Figure 3 above.

2.3 Chemistry Optimization

CHART 1. DOE RESULTS ON ADDITIVE CONCENTRATION AFFECTING ON CAVITY DURING BRIDGING STEP

Design-Expert® Software
 Factor Coding: Actual
 Bridging Cavity

-- CI Bands

X1 = C: Additive

Actual Factors
 A: Copper sulfate = 240.00
 B: Sulfuric acid = 109.46

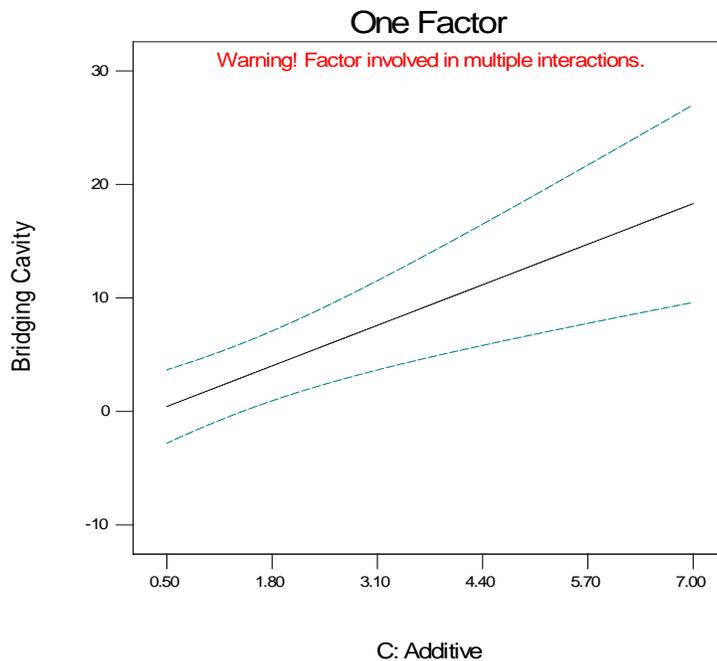
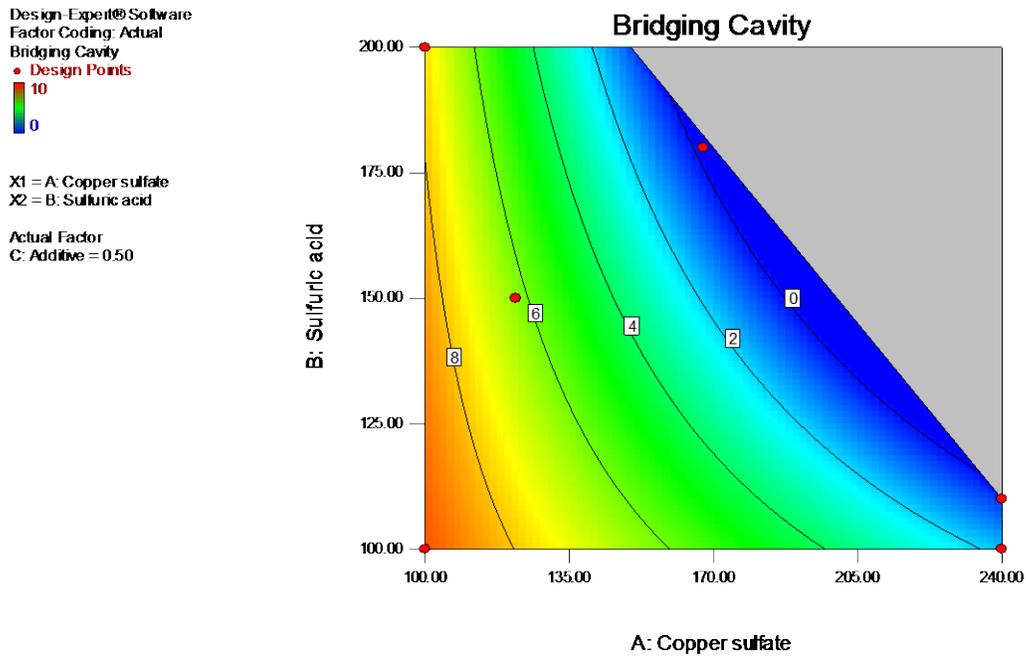


CHART 2. DOE RESULTS ON CAVITY INFLUENCED BY COPPER SULFATE AND SULFURIC ACID CONCENTRATIONS WHEN ADDITIVE WAS AT 0.5 ML/L



DOE experiments indicated that additive and copper concentrations play important roles in obtaining cavity-free copper plating during the bridging step, it is essential to have lower additive and higher copper sulfate concentration, as shown in the Chart 1 and 2. One of the best combinations of each component is copper sulfate at 240 g/L, sulfuric acid at 110 g/L, and additive at 0.5 ml/L.

2.4 Via Filling Step by DC Plating

Electrolytic copper microvia filling technology has been widely used in manufacturing HDI and packaging substrates. A new production copper plating process is used to fill the resultant blind via after bridging step. This offers thin plated copper on the panel surface with minimum dimple depth, as demonstrated in Figure 5 below.

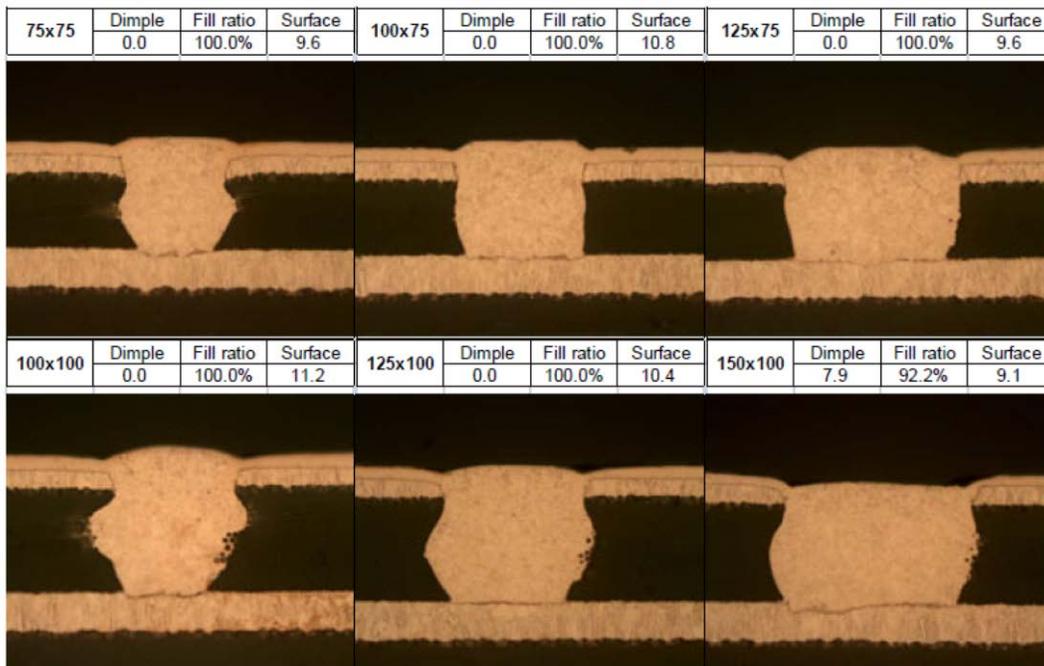


FIGURE 5. COPPER PLATING PROCESS VIA FILLING CAPABILITY (UNIT IN μM)

The combined plating processes from the bridging and via filling steps offer copper filling technology on thicker boards with different diameter through holes.

3. Solid copper filling boards with varying core thickness

This hole filling technology with solid copper can be applied to the boards with the varying core thickness and hole geometry.

3.1 Boards with core thickness of 200 μm , containing laser drilled through holes with a 100 μm diameter at the surface and 50-70 μm diameter in the middle of the hole

Laser-drilled through holes require less bridge plating time than mechanically drilled straight holes. Complete bridging of laser-drilled X through holes is achieved in approximately 30 minutes with the core thickness of 200 μm . When the laser-drilled holes showed inconsistency in the diameter of the middle of holes as shown in the Figure 3, cavity-free copper filled through holes can still be obtained. The plating time for via filling was about 50 minutes. Total plated copper on the surface was approximately 20 μm as shown in Figure 3.

3.2 Boards with core thickness of 200 μm and 250 μm , containing mechanically drilled 100 μm diameter holes

The plating time for mechanically drilled through hole is approximately 60 minutes for the bridging step, and approximately 50 minutes for the via filling step. Plated surface copper is about 25 μm , as shown in Figure 6.

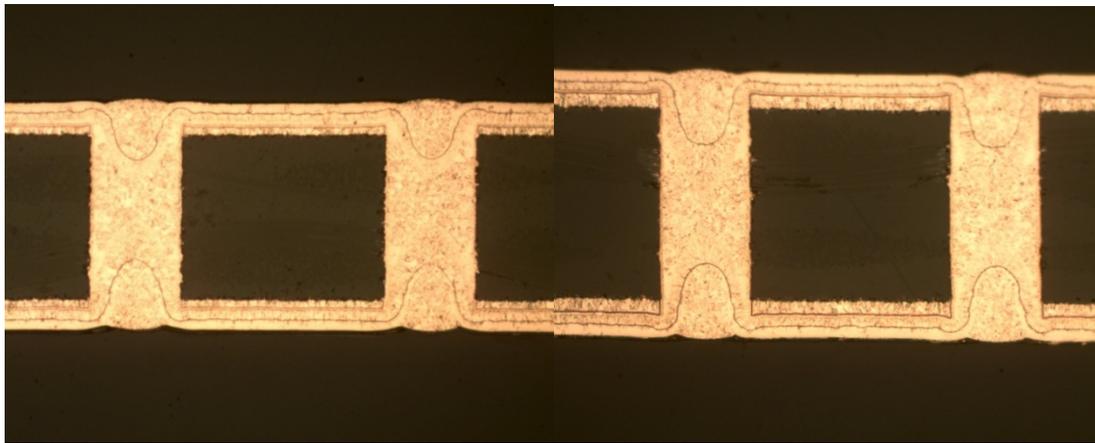


FIGURE 6. MECHANICAL DRILLED THROUGH HOLE, CORE THICKNESS OF 200 μm

3.3 Boards with core thickness of 400 μm , containing mechanically drilled 100 μm diameter holes

Longer bridge plating time is required for thicker panels with core thickness of 400 μm , mechanically drilled 100 μm diameter holes. The plating time on the bridging step was approximately 120 minutes, while the via filling time remained at 50 minutes. Plated surface copper thickness is about 35 μm total.

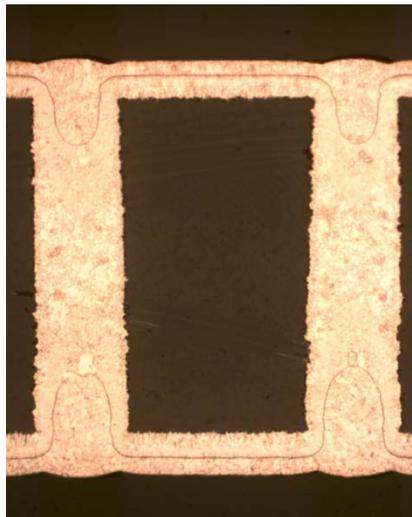


FIGURE 7. MECHANICALLY DRILLED THROUGH HOLE, CORE THICKNESS OF 400 μm , DIAMETER OF 100 μm

3.4 Board with core thickness of 800 μm , mechanically drilled through holes

It becomes challenging to bridge the panels with core thickness of 800 μm . In holes with diameters below 250 μm , cavities were observed.

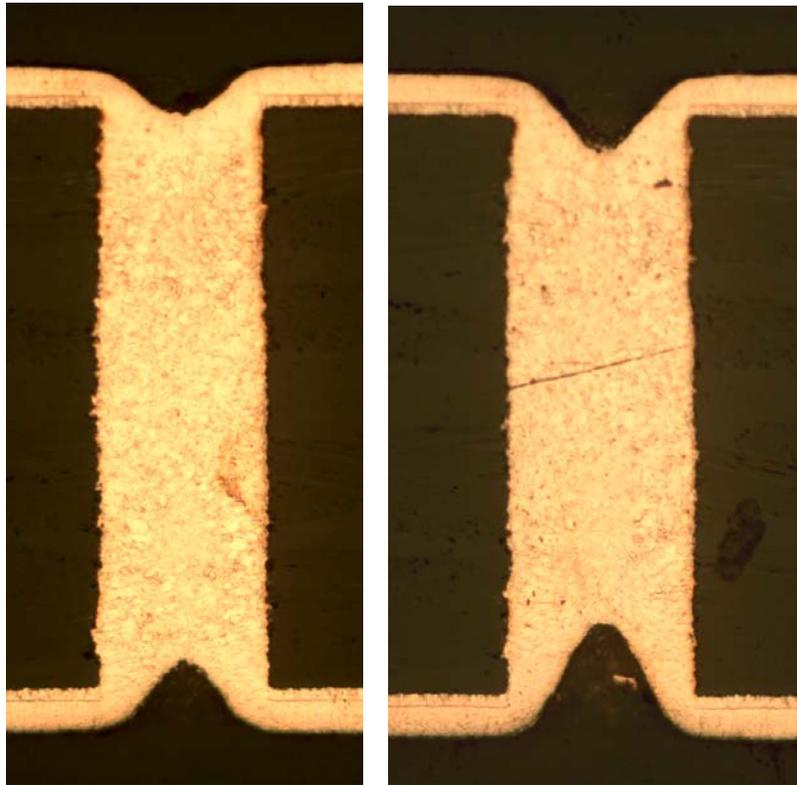
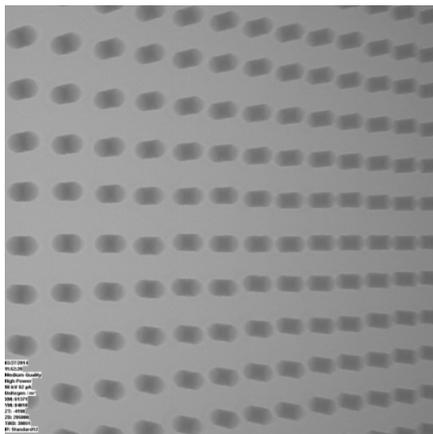


FIGURE 8. MECHANICALLY DRILLED THROUGH HOLE, CORE THICKNESS OF 800 μm , DIAMETER OF 250 AND 300 μm , AFTER BRIDGING STEP, 240 MINUTES.

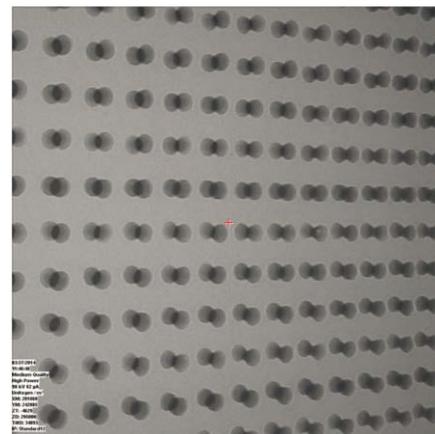
For the larger diameter through holes, it took longer time to fill the resultant vias, which leads to thicker plated copper on panel surface.

4. X-ray Inspection

Most of the evaluation was done under microscope with cross-sections. X-ray inspection was used to inspect boards with a core thickness of 200 μm , with both mechanically drilled through hole and laser-drilled through hole. X-ray inspection, after two step plating process, showed that the filled copper in the through holes were defect-free as seen in Figure 9.



COPPER FILLED MECHANICALLY DRILLED THROUGH HOLE



COPPER FILLED LASER-DRILLED THROUGH HOLE

FIGURE 9. X-RAY IMAGE ON THE BOARD WITH CORE THICKNESS OF 200 μm

5. Physical Properties

The physical properties of the deposit are critical to insure acceptable quality of the finished board. Tensile strength and percent elongation were measured by a production pull tester, -with the copper plated in bridging bath, and the via fill bath. The results are listed in Table 1.

TABLE 1. RESULTS ON ELONGATION AND TENSILE STRENGTH

Plating cycle	Sample #	Plated copper Thickness (mil)	Break Force (lbf)	Weight (g)	Elongation (%)	Tensile Strength (PSI)
Copper plated with bridging plus via fill process	1	2.82	62.75	0.9726	21.92	47098.0
	2	3.23	72.83	1.1146	21.19	47699.5
	3	2.71	60.21	0.9348	20.79	47018.9
	4	2.87	62.89	0.9901	19.46	46368.8
	5	3.05	68.12	1.0510	22.47	47314.6
	Mean	3.94	65.36	1.0126	21.17	47100.0

A board with a core thickness of 250 μm , with hole diameters from 100 to 300 μm , was bridged and filled with copper. This panels was subjected to thermal stress evaluation, according to IPC TM-650 2.6.8 6X solder floats for 10 seconds at 288 $^{\circ}\text{C}$. The deposit integrity was excellent, as neither crack nor separation was observed in any tested through holes, as seen in Figure 10.

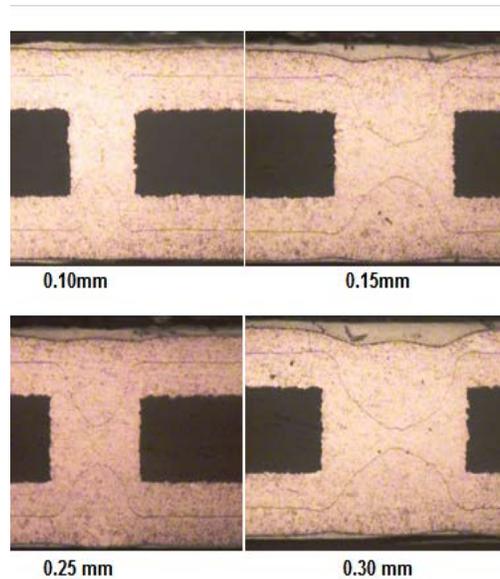


FIGURE 10 CROSS-SECTION AFTER 6 X OF SOLDER SHOCK

6. Conclusions

A through-hole copper filling technology for application to high density interconnect constructions and IC substrates was demonstrated. The process consists of two acid copper plating cycles. The first cycle is periodic pulse reverse electroplating to form a bridge in the middle of the hole, followed by direct current electroplating to fill the resultant double vias formed during the bridge cycle. This process can provide defect-free filled through hole with solid copper. The mechanical properties of the plated deposit meet or exceed all IPC standards.



Electroplated Copper Filling of Through Holes on Varying Substrate Thickness

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OUTLINE

1 INTRODUCTION

2 TWO STEP THROUGH HOLE FILL (THF) TECHNOLOGY

- Bridge formation in through hole
- Chemical optimization
- Via fill chemistry

3 APPLICATION TO DIFFERENT BOARDS

4 PLATED COPPER PHYSICAL PROPERTIES

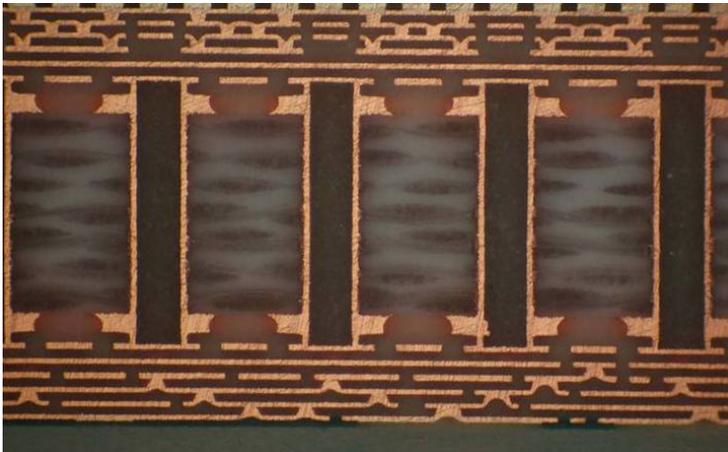
5 CONCLUSIONS



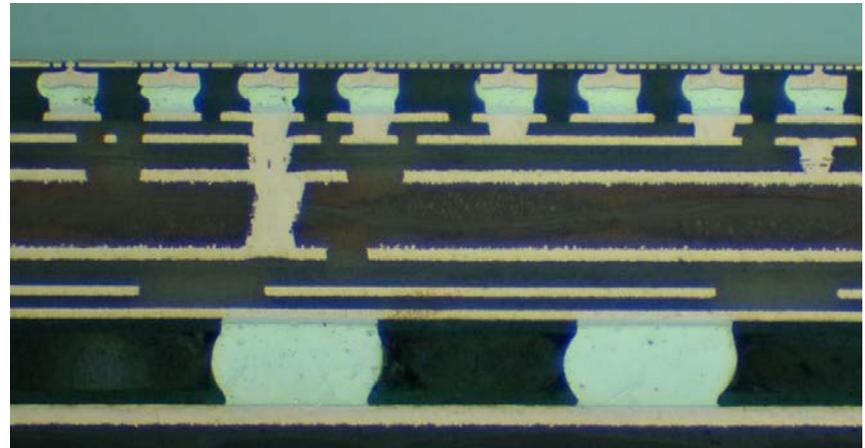
Introduction

Industry trend, increased Circuit Density/Miniaturization

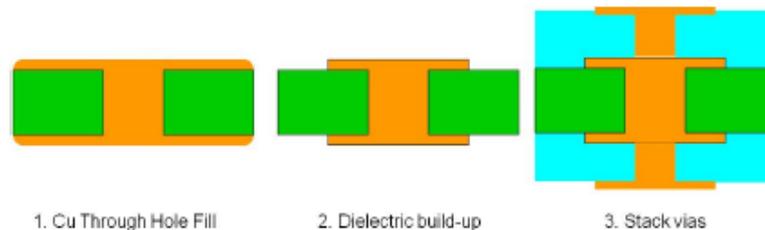
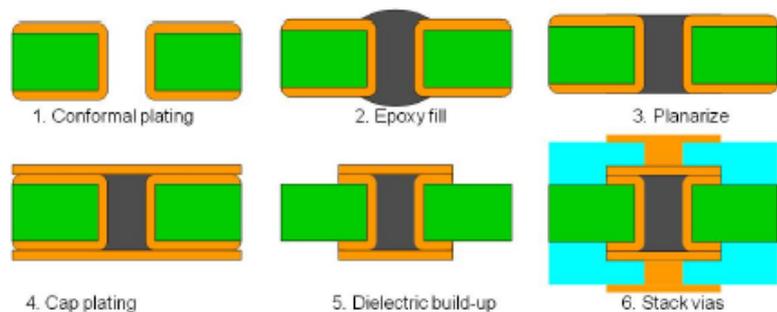
- Filled vias enable stacking
- Partial filled vias
- Copper filled through-hole as a more reliable process



Paste plugged through hole



Copper filled through hole



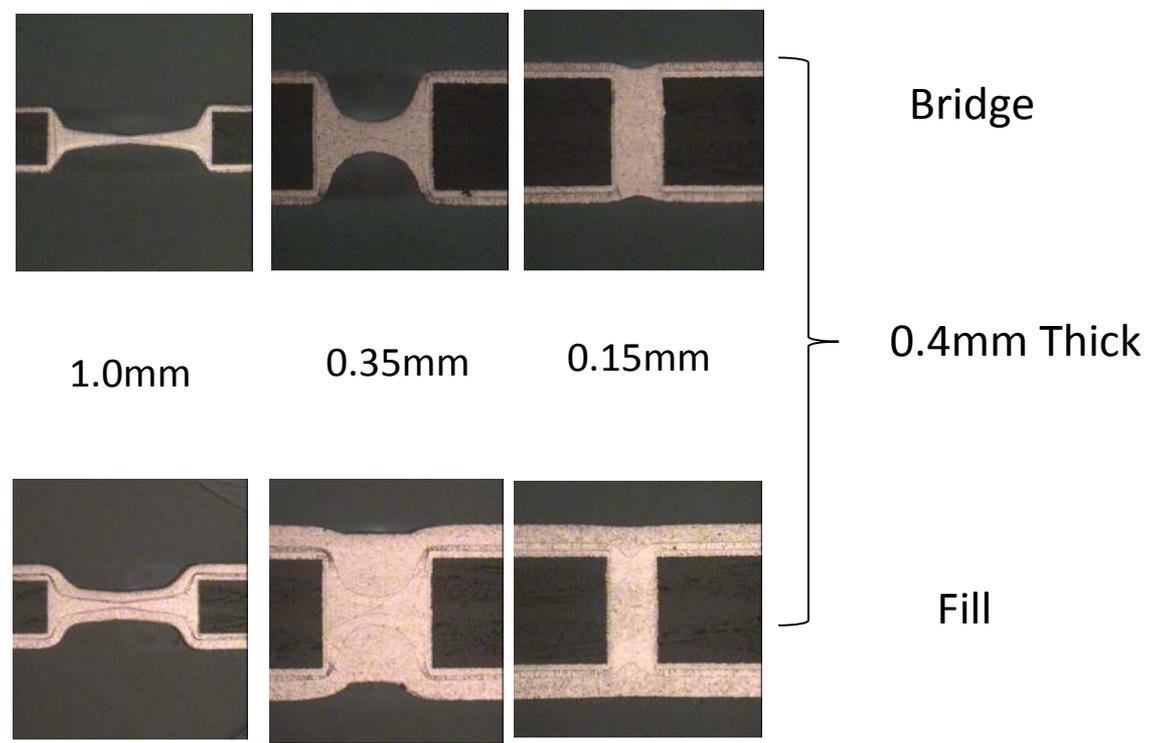
Copper fill Process

- Improved reliability
- Enhanced Thermal management
- Fewer Process steps
- Increased productivity while reducing costs



2 Step Process

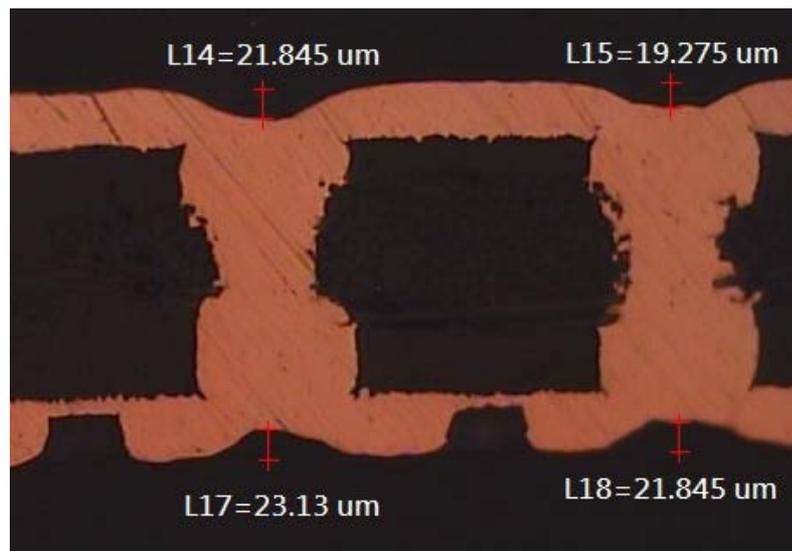
- Bridge the holes – close the hole in the center, forming two vias one on either side of the board
- Fill the two vias with electroplated copper (Via Fill Technology)





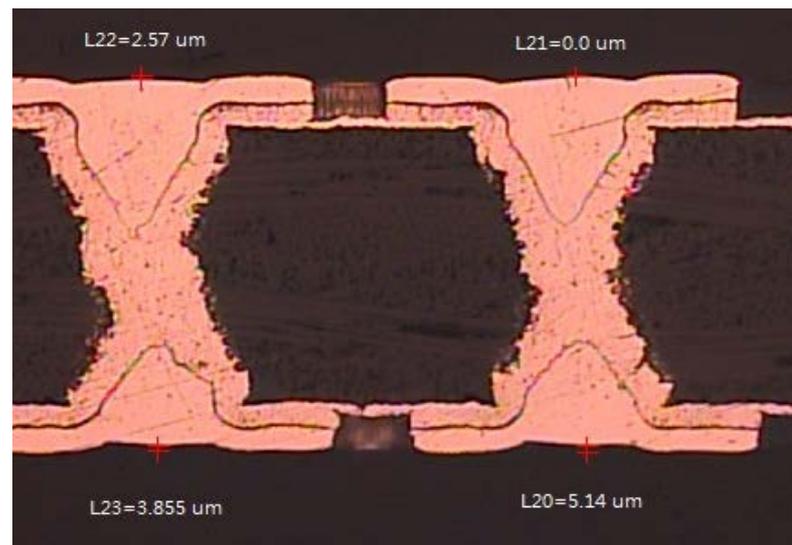
Why a 2 step Process?

- Enables filling of a wider range of hole diameters
- Fills mechanically drilled holes well
- Enables thicker substrates to be used(0.2-0.6mm)and developing for thicker
- PPR reduces the surface copper



DC only

(0.2 mm thickness)

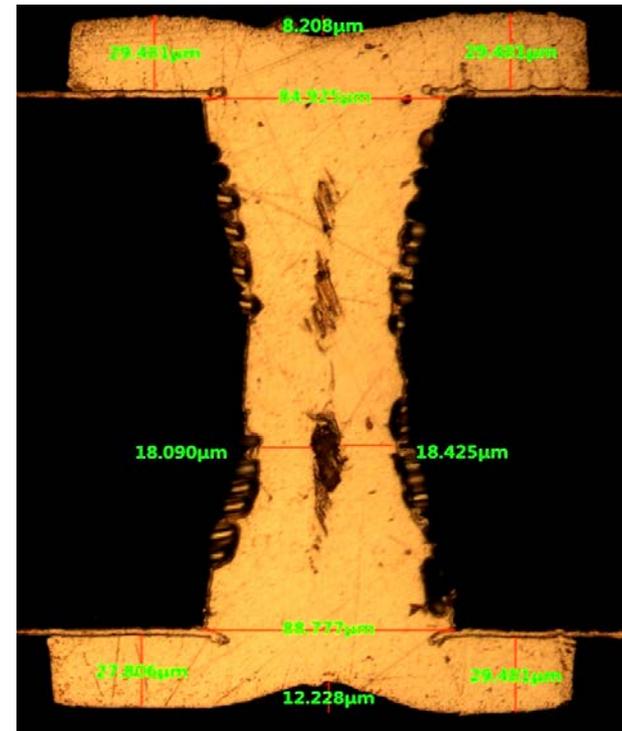
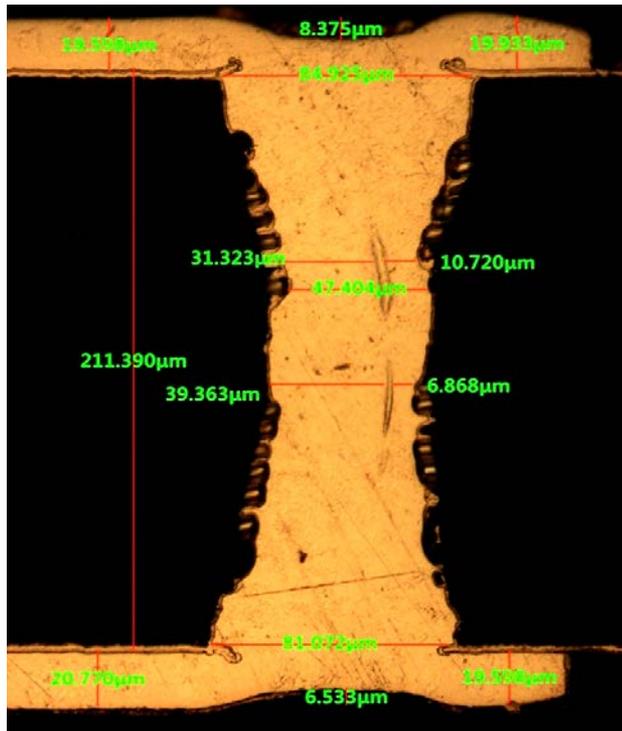


PPR bridge+VF (DC)



Through-hole filling technology via DC copper plating

Limited by board thickness to obtain defect-free plating, > 200 μm





Two step through hole fill technology

1. Periodic Pulse Reverse (PPR) Plating
2. Via fill plating

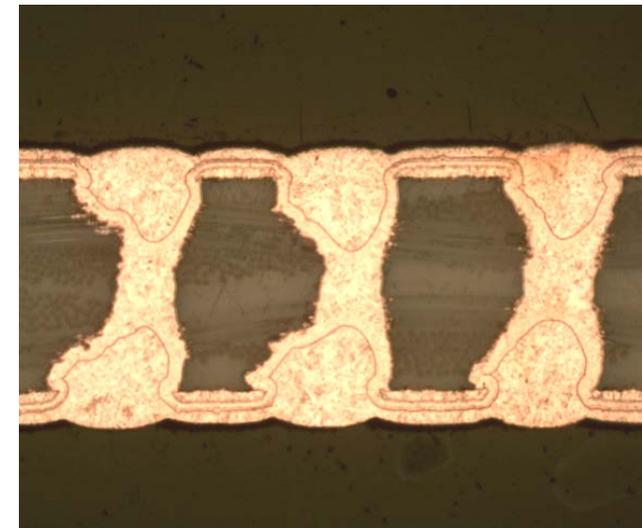
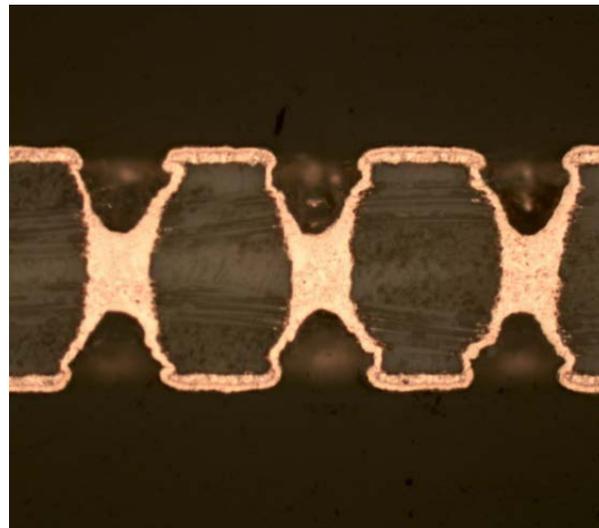
Through hole
before copper
filling process



PPR bridging step,
copper plated in the
middle of through hole



Via fill step, the formed
vias were filled to finish
through hole fill process





Bridging Step

- Vertical process utilizing insoluble anodes
- Special rectifiers that produce unique wave forms
- Equipment design employing high solution impingement
- Adaptable to VCPs

Acid Cleaner

Rinse

Etch (if Flashed)

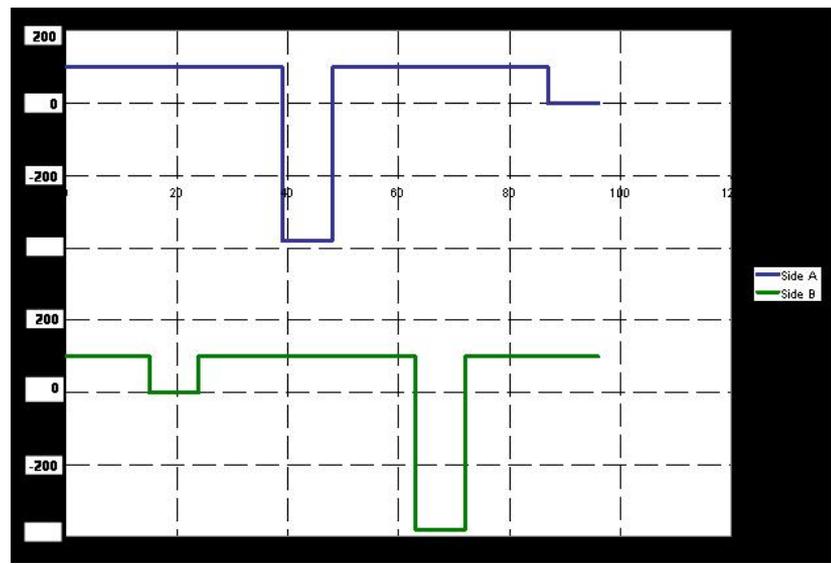
Acid Dip

PPR

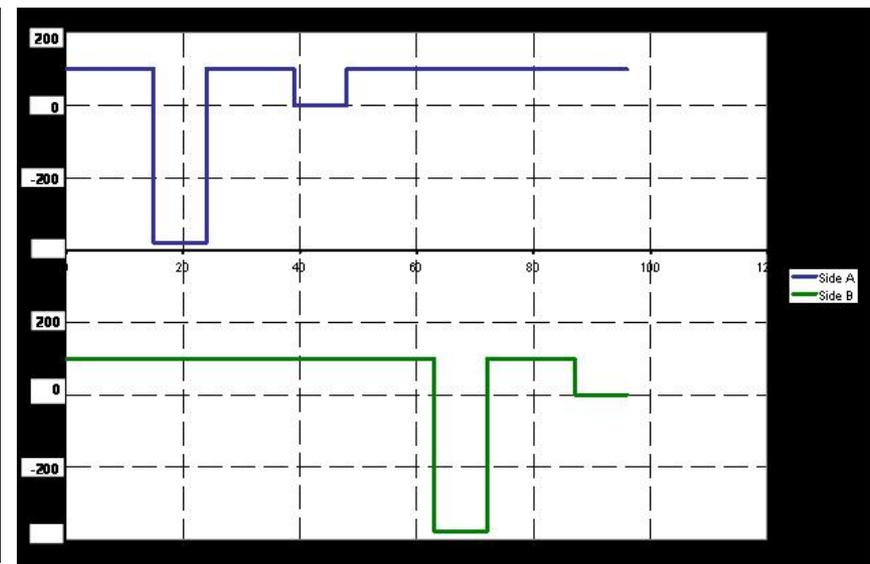




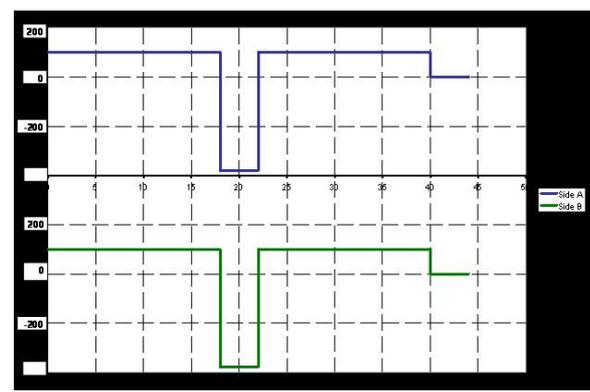
Phase Shifting



90 deg. shift



180 deg. shift



Std 0 deg. shift



Bridge Optimization

Design-Expert® Software
 Factor Coding: Actual
 Bridging Cavity

-- CI Bands

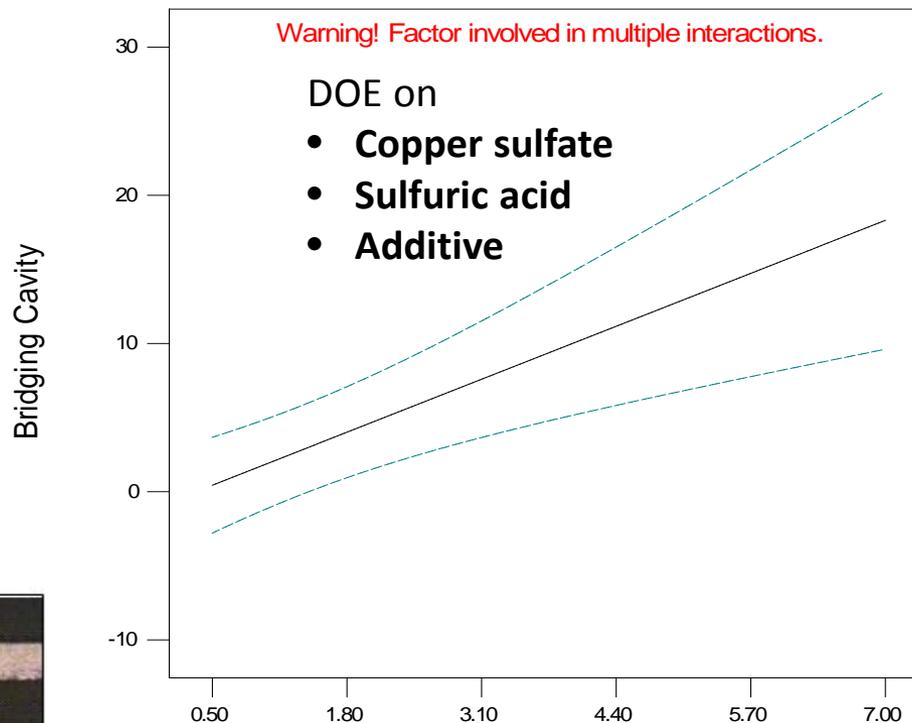
X1 = C: Additive

Actual Factors

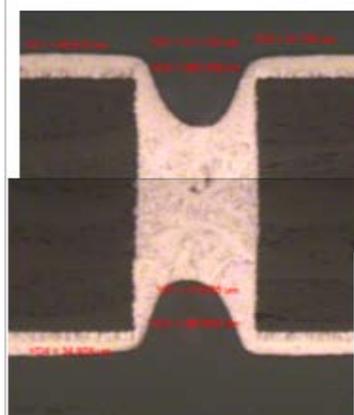
A: Copper sulfate = 240.00

B: Sulfuric acid = 109.46

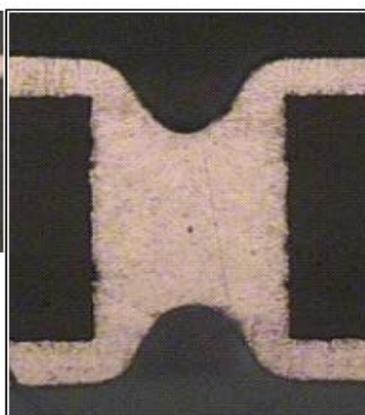
One Factor



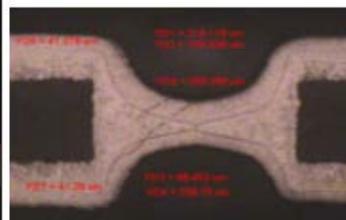
0.3mm Hole



0.8 mm



0.4 mm



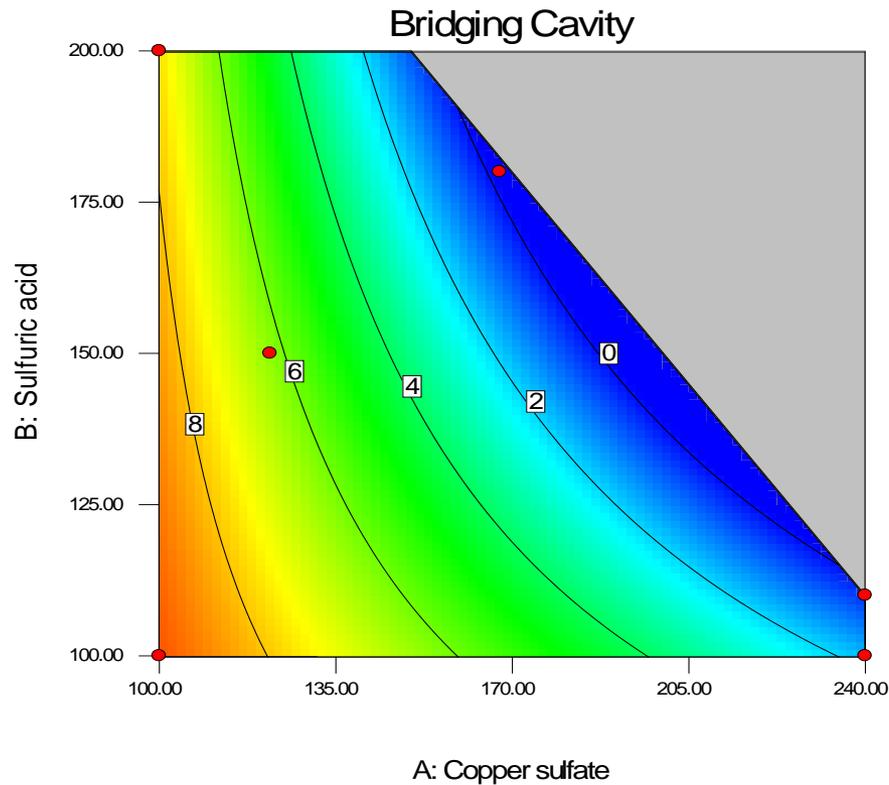
0.2 mm

C: Additive



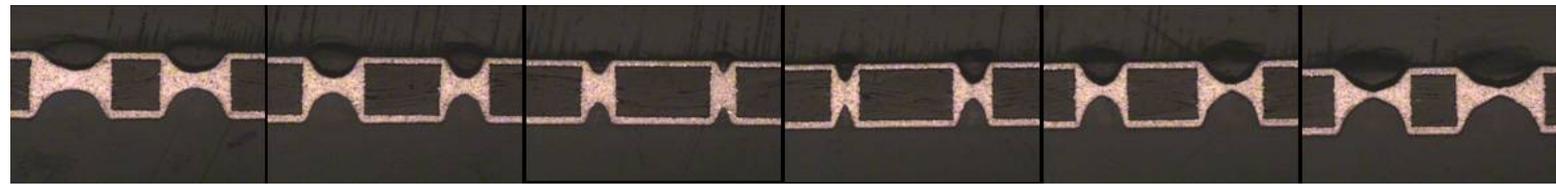
Bridge Optimization

Design-Expert® Software
Factor Coding: Actual
Bridging Cavity
● Design Points
10
0
X1 = A: Copper sulfate
X2 = B: Sulfuric acid
Actual Factor
C: Additive = 0.50



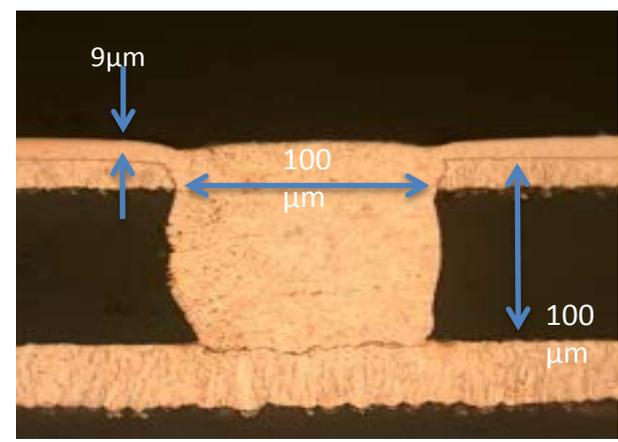
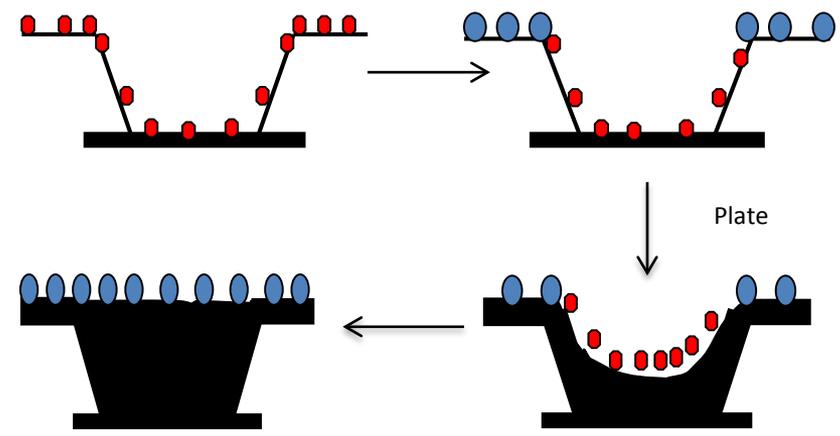
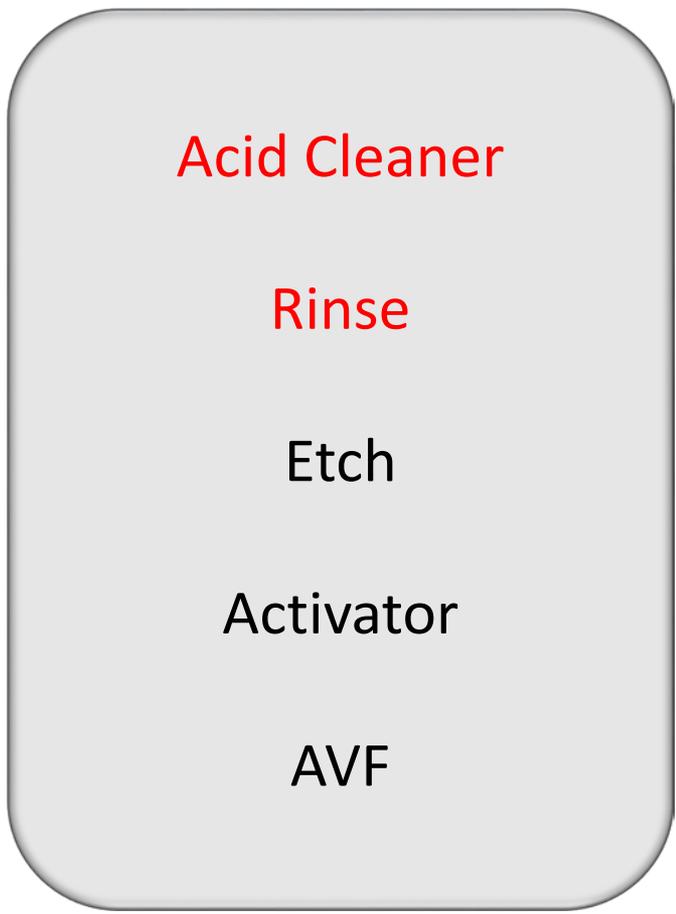
One of the best condition

- Copper sulfate at 240 g/L
- Sulfuric acid at 110 g/L
- Additive at 0.5 ml/L





Advanced Viafilling -Proprietary activator is key for bottom up filling consistency, thin surface copper and elimination of cavities



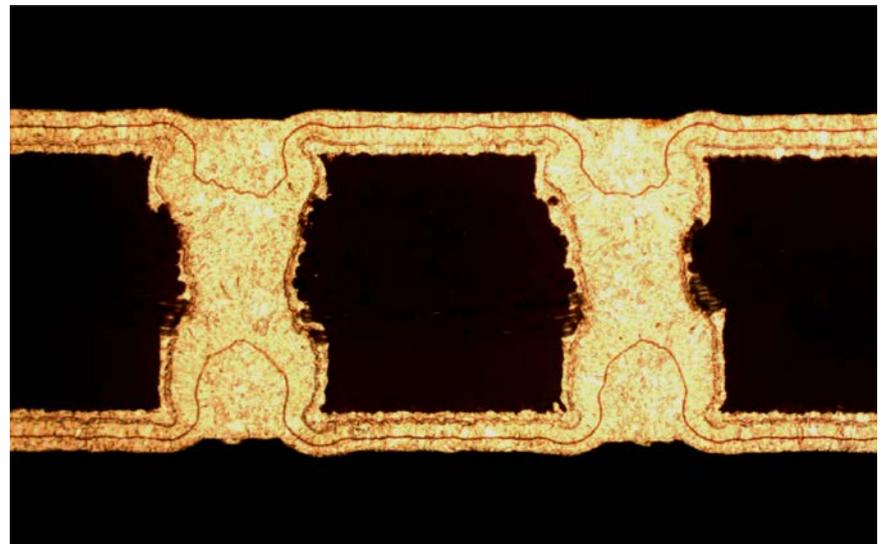
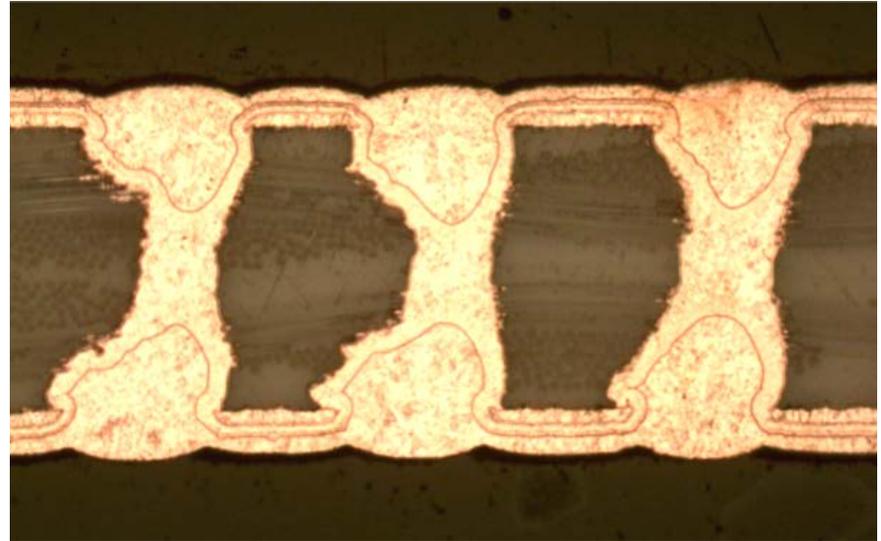
Denotes required for dry panels



Board thickness and
hole geometry
variations

**Laser drilled X shape
through hole,
thickness at 200 μm ,
diameter at 100 μm .**

- **PPR bridging 30 min, Via fill 50 min.**
- **Copper thickness below 20 μm .**
- **Dimple below 5 μm**

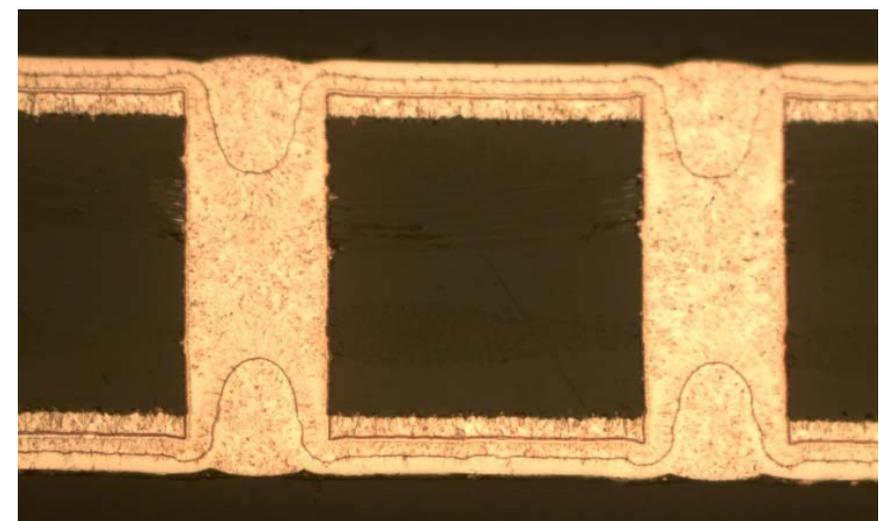
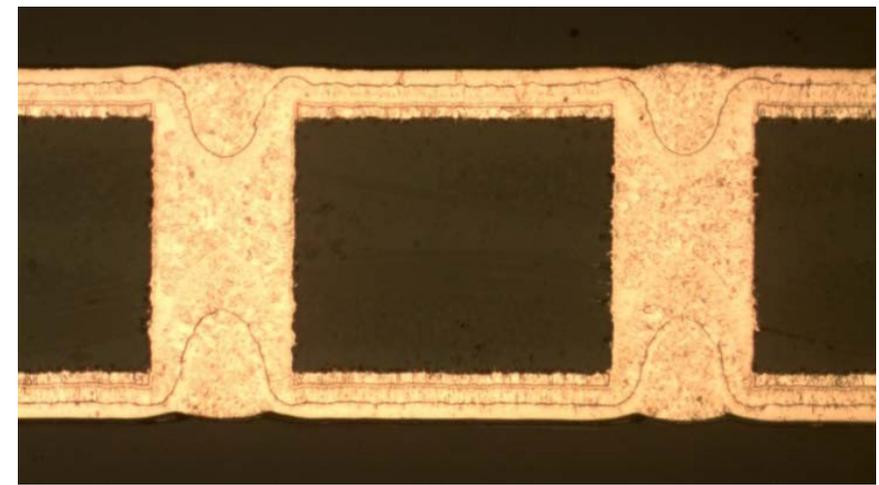


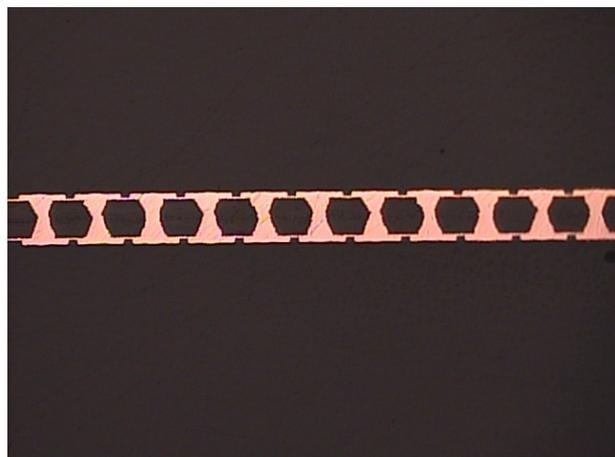


Board thickness and hole geometry variations

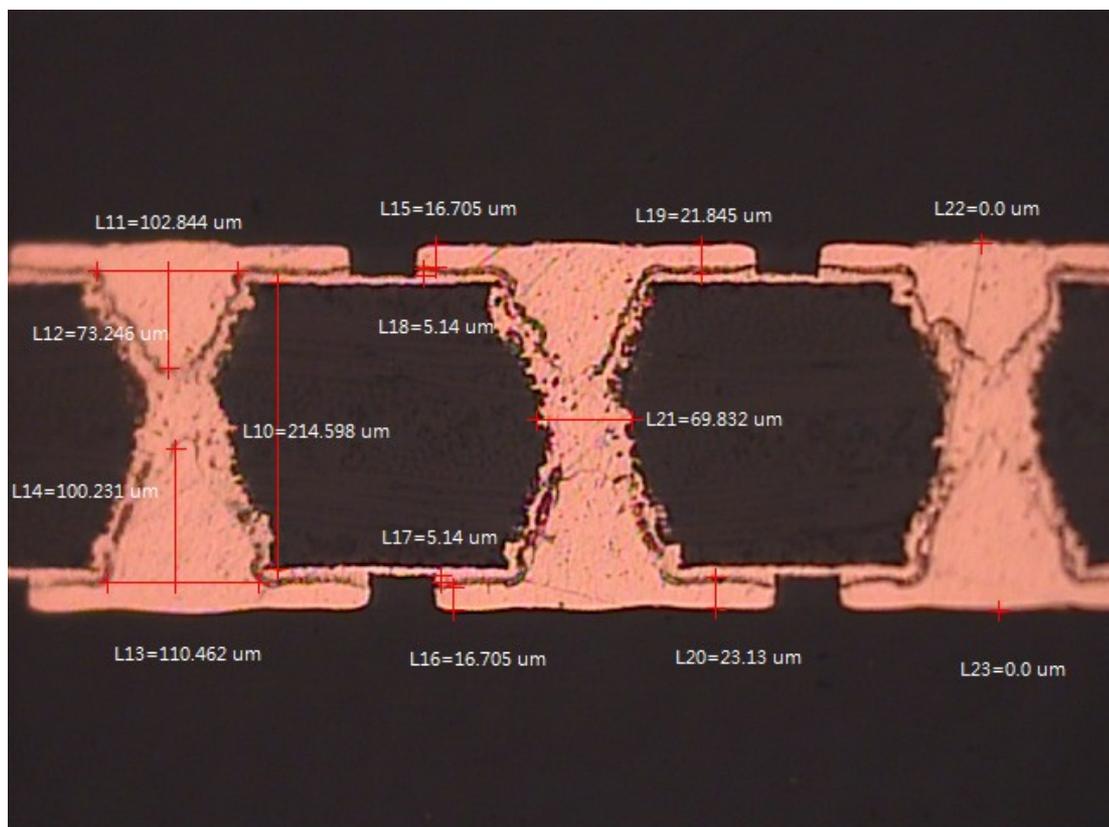
Mechanical drilled through hole, thickness at 200 and 250 μm , diameter at 100 μm .

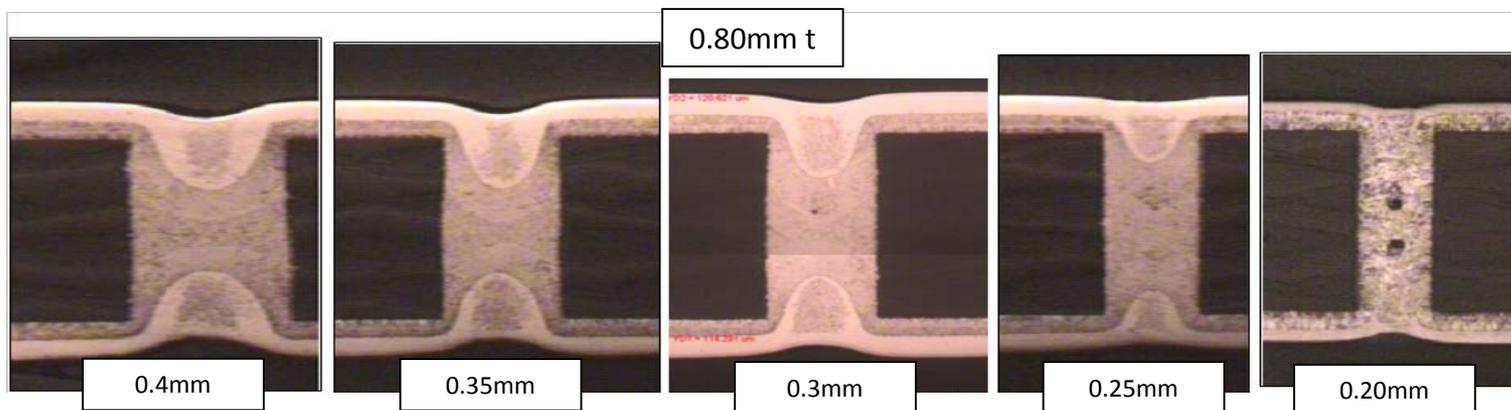
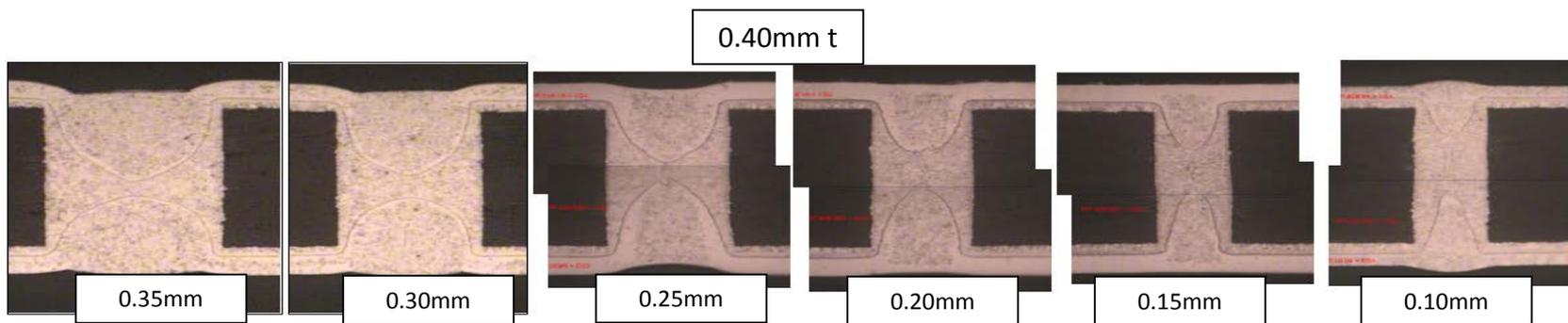
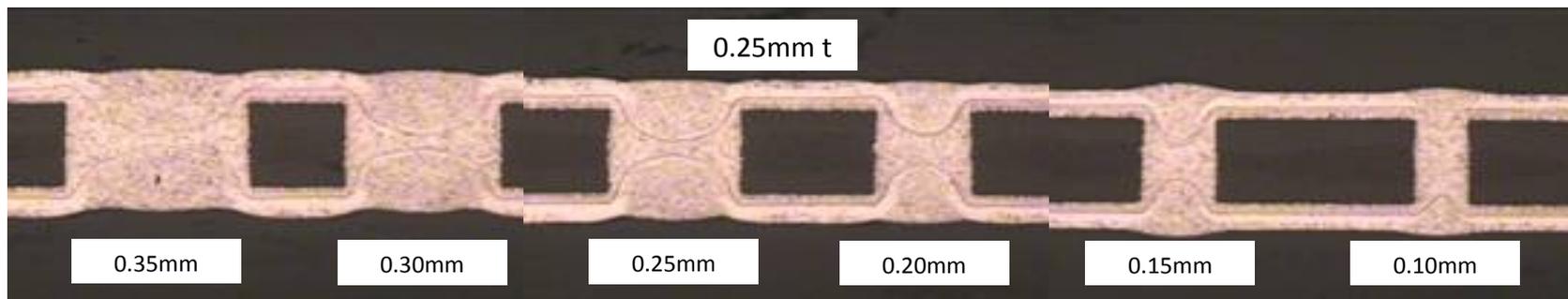
- PPR bridging 60 min, Via fill 50 min.
- Copper thickness below 25 μm .
- Dimple below 5 μm





0.15mm holes in .2mm thick
Pattern plate
Dimple = 0 μ m
Surface copper = 21 μ m
Cycle time = 75 minutes



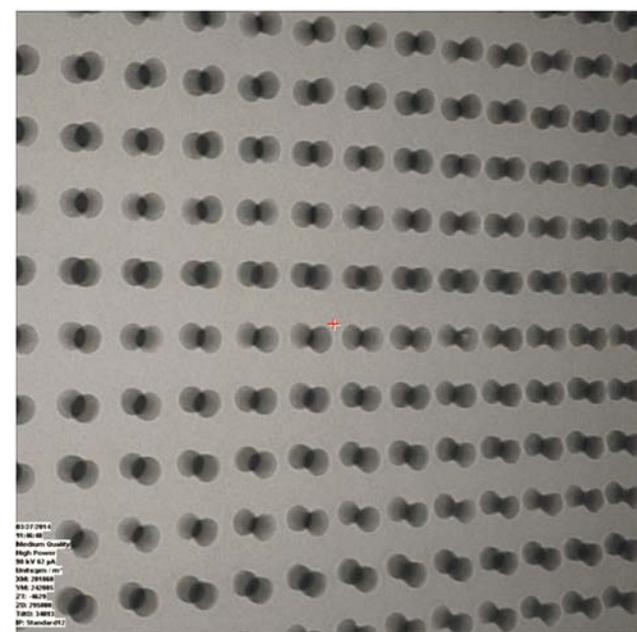
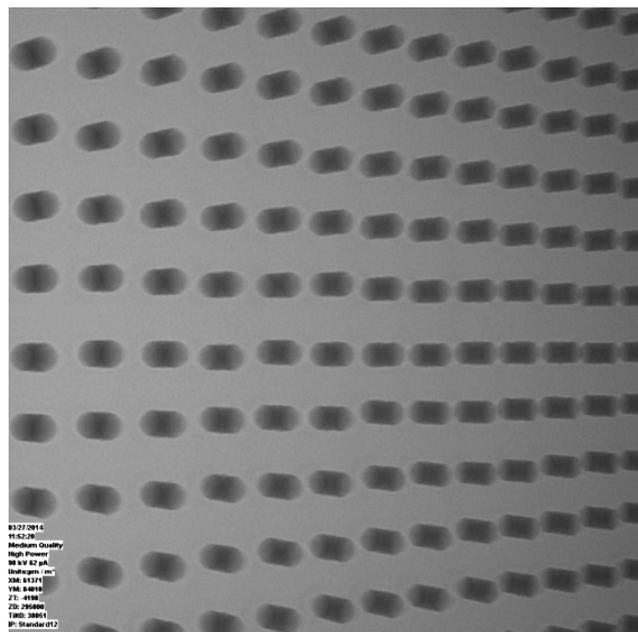




X-ray inspection on copper filled through holes, both laser-drilled and mechanically drilled

- Thickness at 200 μm , diameter at 100 μm .

Tube		Detector		Manipulator	
Mode	High Power	Mode	Medium Quality Standard12	Magnification	41.99
Voltage	98 kV	IP		ZT	-4478 μm
Current	62.0 μA			ZD	295000 μm
				TiltD	39543 m°
				Tray-Offset	0.8 mm





Filled copper properties

- Copper plated with bridging plus via fill process
- Measured by a production pull tester

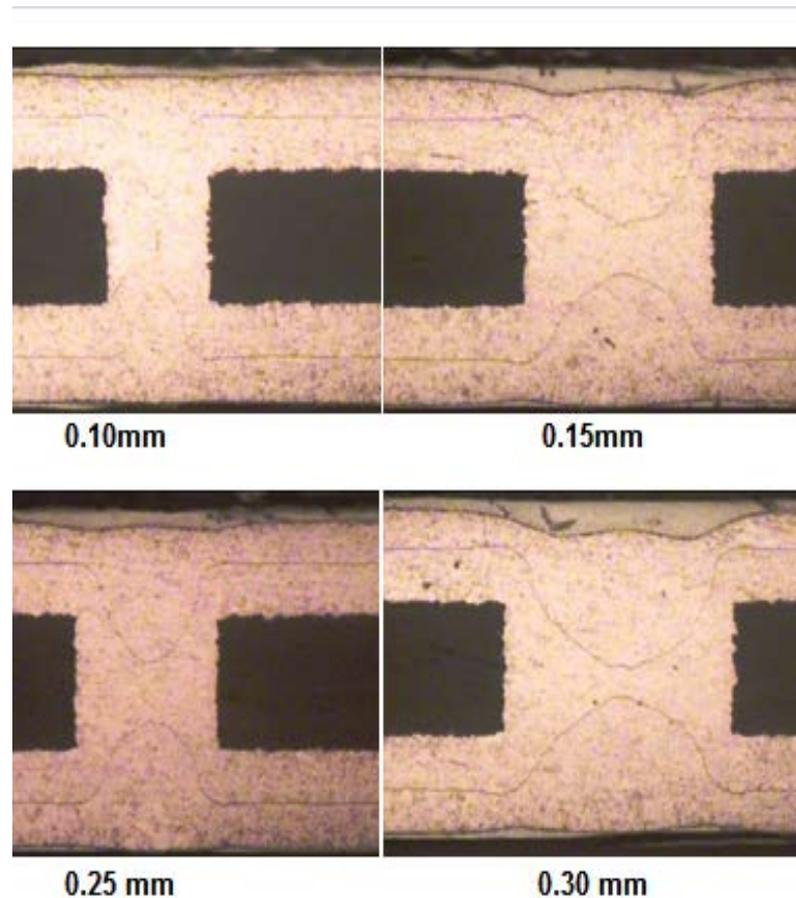
Plating cycle	Sample #	Plated copper thickness (mil)	Break Force (lbf)	Weight (g)	Elongation (%)	Tensile Strength (PSI)
Copper plated with bridging plus via fill process	1	2.82	62.75	0.9726	21.92	47098.0
	2	3.23	72.83	1.1146	21.19	47699.5
	3	2.71	60.21	0.9348	20.79	47018.9
	4	2.87	62.89	0.9901	19.46	46368.8
	5	3.05	68.12	1.0510	22.47	47314.6
	Mean	3.94	65.36	1.0126	21.17	47100.0



Filled copper properties

- Core thickness at 250 μm , diameter was varied from 100 to 300 μm .
- 6 times of solder floats for 10 s at 288 ° C

Neither crack nor separation were observed in the copper filled through holes





Conclusion

- **A through-hole copper filling technology can be applied to high density interconnect construction and IC substrates.**
- **The combination of PPR bridging and high efficient via fill offers defect-free filled copper in various boards with different geometry of through holes.**
- **The mechanical properties of the plated deposit meet or exceed all IPC standards.**



Thank You

Questions?

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