

# Electroplated Copper Filling of Through Holes on Varying Substrate Thickness

Kesheng Feng<sup>a</sup>, Bill DeCesare<sup>a</sup>, Mike Yu<sup>b</sup>, Don DeSalvo<sup>c</sup>, Jim Watkowski<sup>a</sup>

<sup>a</sup>MacDermid, 227 Freight Street, Waterbury, CT 06702

<sup>b</sup>MacDermid Taiwan Technical Center

<sup>c</sup>MacDermid Suzhou Technical Center

## 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  $\mu\text{m}$ , with dimple less than 5  $\mu\text{m}$  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).

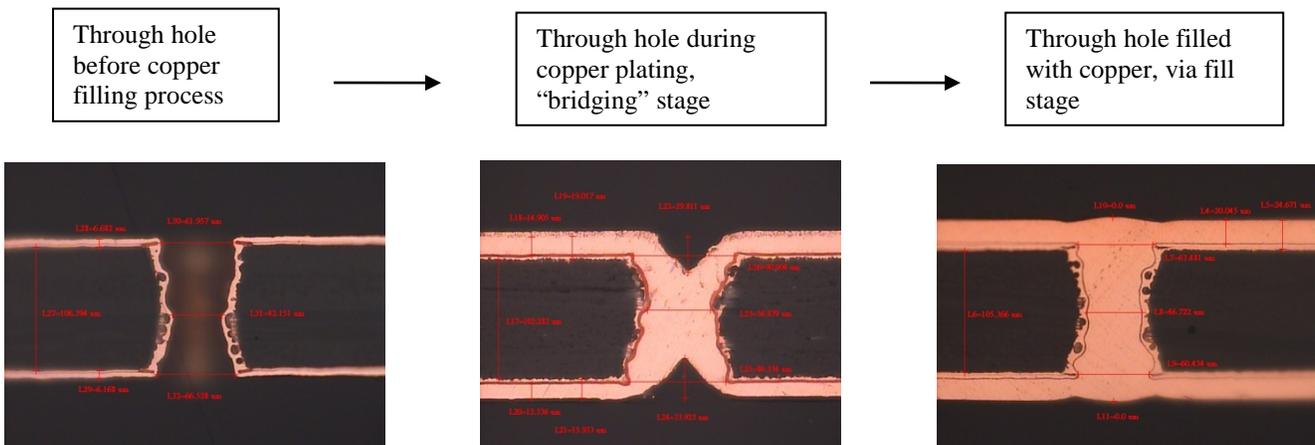
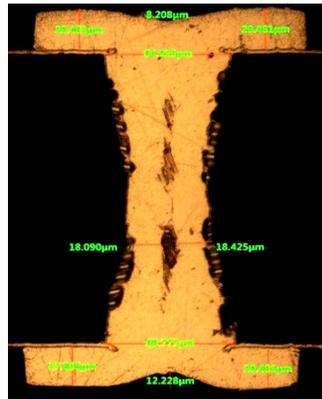


FIGURE 1. COPPER FILLING STAGES VIA DC PLATING TECHNOLOGY

The plated copper on the surface can be controlled below 25  $\mu\text{m}$ , with core thickness around 100  $\mu\text{m}$ , and diameter around 100  $\mu\text{m}$  (50-70  $\mu\text{m}$  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  $\mu\text{m}$ , the propensity for inclusions/cavities grows (Figure 2) and the plated surface copper thickness increases beyond the 25  $\mu\text{m}$  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  $\mu\text{m}$ .**

## 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

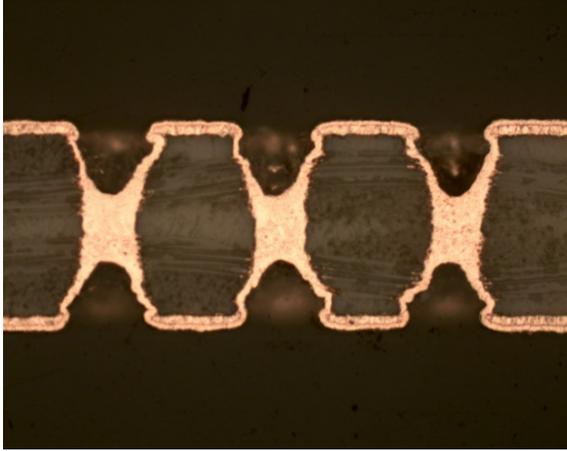


FIGURE 3. CROSS-SECTION AFTER BRIDGING STEP.

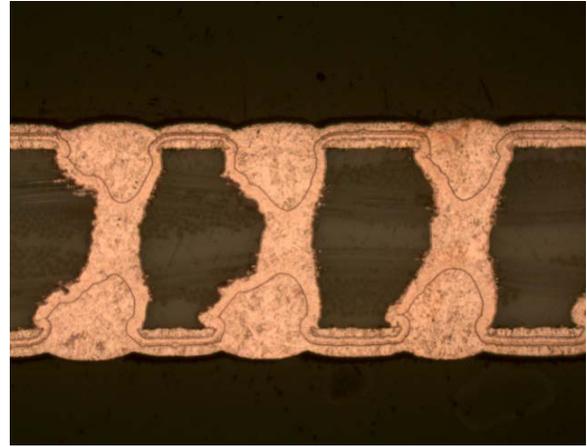


FIGURE 4. CROSS-SECTION AFTER BRIDGING AND VIA FILLING STEP

### 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  $\mu\text{m}$ , hole diameter of 100  $\mu\text{m}$ . 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

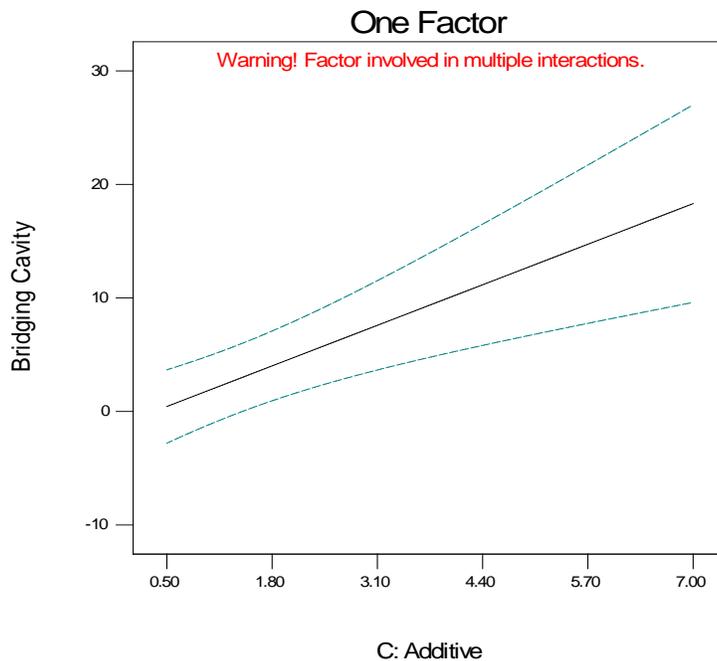
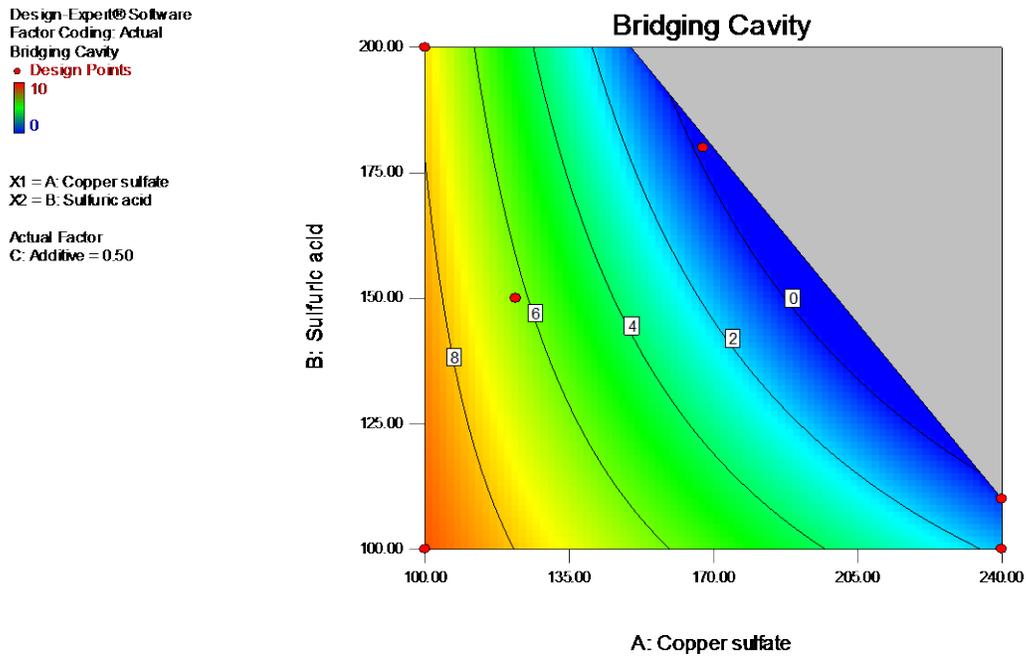


CHART 2. DOE RESULTS ON CAVITY INFLUENCED BY COPPER SULFATE AND SULFURIC ACID CONCENTRATIONS WHEN ADDITIVE WAS AT 0.5 ML/L



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.

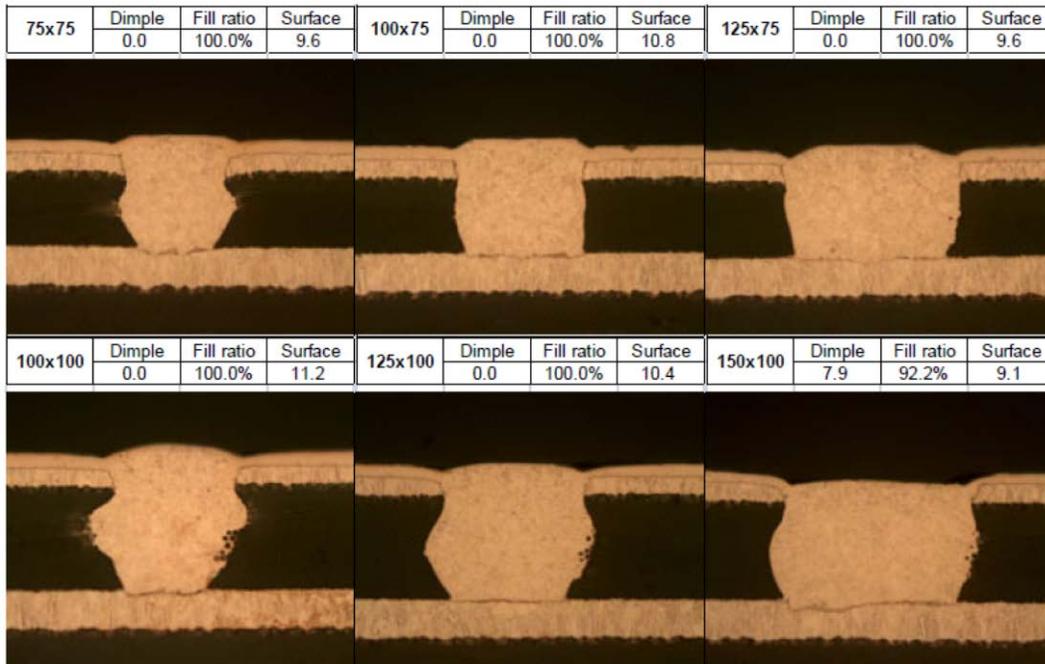


FIGURE 5. COPPER PLATING PROCESS VIA FILLING CAPABILITY (UNIT IN  $\mu\text{M}$ )

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 $\mu\text{m}$ , containing laser drilled through holes with a 100 $\mu\text{m}$ diameter at the surface and 50-70 $\mu\text{m}$ 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  $\mu\text{m}$ . 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  $\mu\text{m}$  as shown in Figure 3.

#### 3.2 Boards with core thickness of 200 $\mu\text{m}$ and 250 $\mu\text{m}$ , containing mechanically drilled 100 $\mu\text{m}$ 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  $\mu\text{m}$ , as shown in Figure 6.

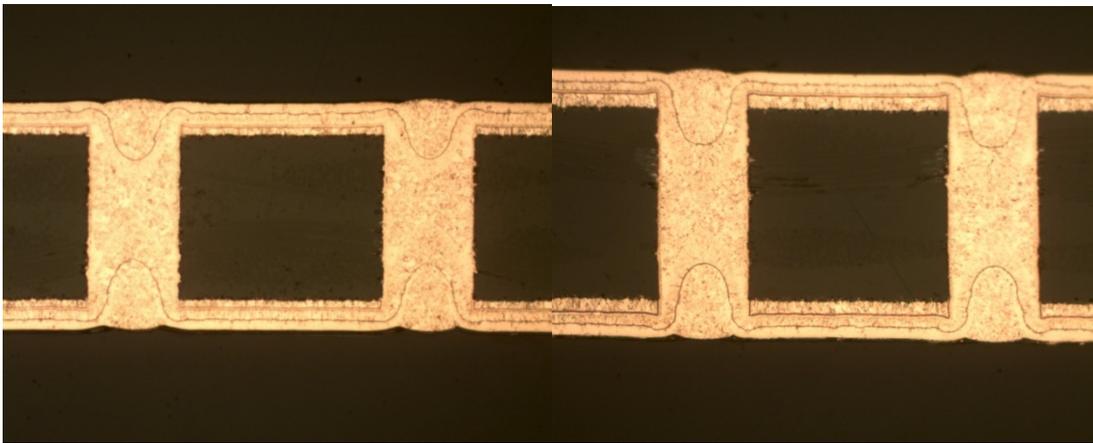


FIGURE 6. MECHANICAL DRILLED THROUGH HOLE, CORE THICKNESS OF 200  $\mu\text{m}$

#### 3.3 Boards with core thickness of 400 $\mu\text{m}$ , containing mechanically drilled 100 $\mu\text{m}$ diameter holes

Longer bridge plating time is required for thicker panels with core thickness of 400  $\mu\text{m}$ , mechanically drilled 100  $\mu\text{m}$  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  $\mu\text{m}$  total.

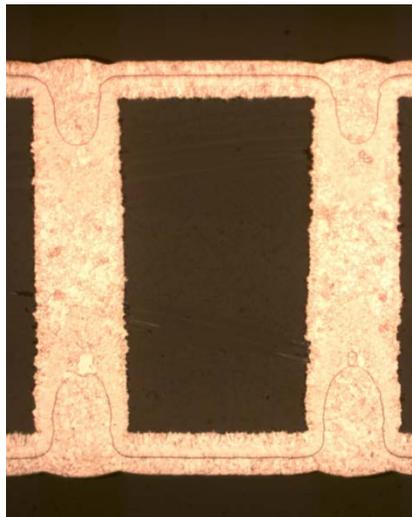
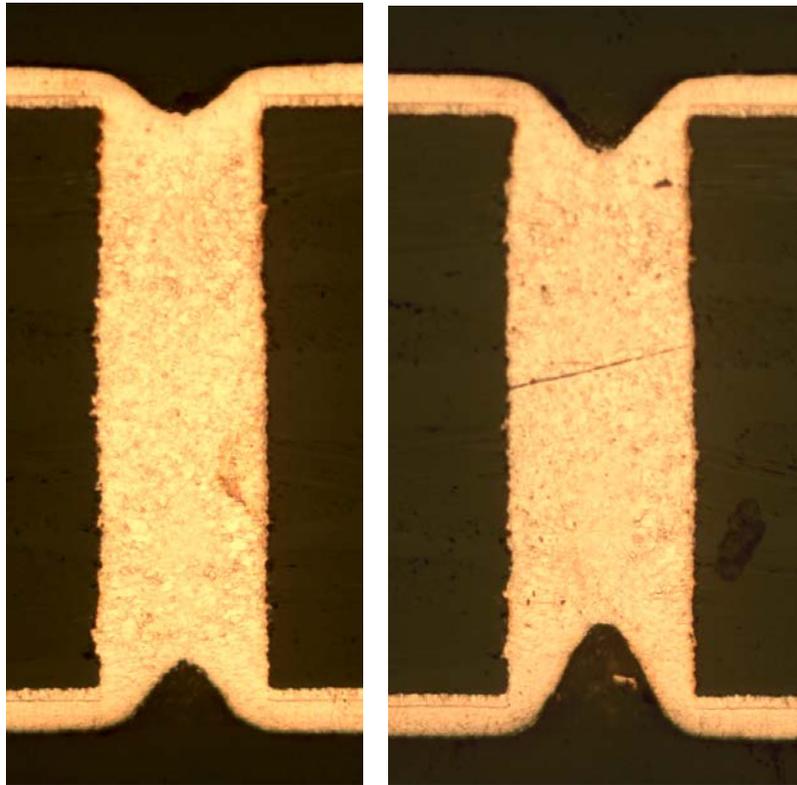


FIGURE 7. MECHANICALLY DRILLED THROUGH HOLE, CORE THICKNESS OF 400  $\mu\text{m}$ , DIAMETER OF 100  $\mu\text{m}$

#### 3.4 Board with core thickness of 800 $\mu\text{m}$ , mechanically drilled through holes

It becomes challenging to bridge the panels with core thickness of 800  $\mu\text{m}$ . In holes with diameters below 250  $\mu\text{m}$ , cavities were observed.

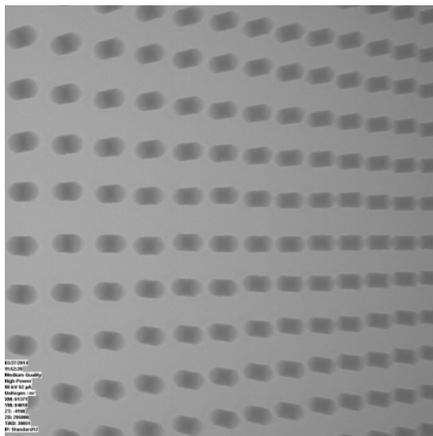


**FIGURE 8. MECHANICALLY DRILLED THROUGH HOLE, CORE THICKNESS OF 800  $\mu\text{m}$ , DIAMETER OF 250 AND 300  $\mu\text{m}$ , AFTER BRIDGING STEP, 240 MINUTES.**

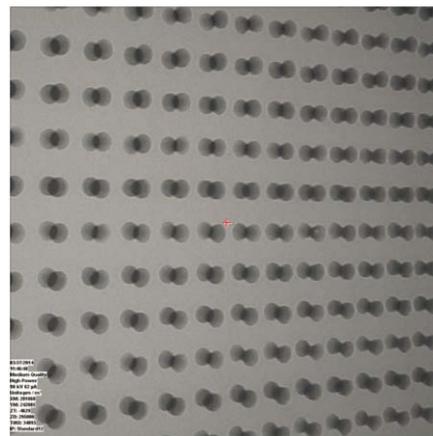
For the larger diameter through holes, it took longer time to fill the resultant vias, which leads to thicker plated copper on panel surface.

#### 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  $\mu\text{m}$ , 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  $\mu\text{m}$**

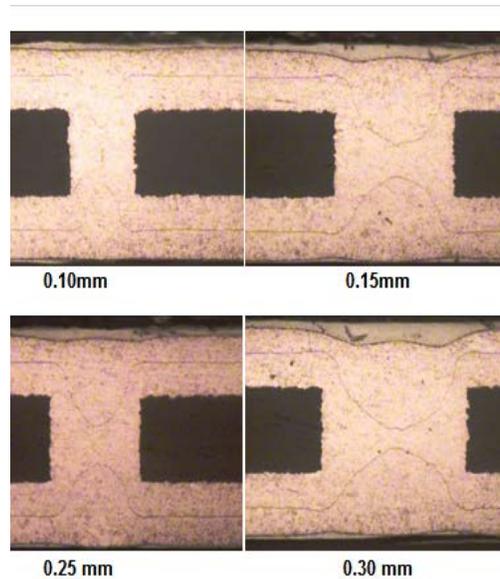
## 5. Physical Properties

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	<b>3.94</b>	<b>65.36</b>	<b>1.0126</b>	<b>21.17</b>	<b>47100.0</b>

A board with a core thickness of 250  $\mu\text{m}$ , with hole diameters from 100 to 300  $\mu\text{m}$ , 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.