Reliable Acid Copper Plating for Metallization of PCB

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Abstract
Copper plating is widely used in the electronic industry for fabrication of electronic devices. It is particularly useful for fabrication of printed circuit boards and semiconductors. Copper is electroplated over the surface of a printed circuit board and onto the walls of the through holes. The mass PCB production requires intensification of and at the same time simplification of the metallization process without sacrificing but instead improving the reliability. Various approaches have been studied in order to plate high aspect ratio (AR) through holes with improved micro-distribution and improved mechanical properties of the plated copper such as Tensile Strength and Elongation. Direct current acid copper PTH (plating through holes) at low current densities as well as PPR plating for high AR (>12) were explored. The parameters of a new high throw acid copper plating process are described in this paper. The mechanical properties and the thermal characteristics of the plated copper are presented. The results from the throwing power measurements are provided.

A high temperature acid copper process has been also studied. For a large number of PCB fabrication facilities in areas with hotter climates, plating at elevated temperature presents difficulties. Reduced brightness, increased grain size, and increased roughness lead to a decrease in reliability performance. A new process for plating smooth, bright, and planar copper layers at temperatures up to 40^{o}C is described. Tensile strength and elongation measurements as well as the thermal characteristics of copper layers deposited at room temperature and at elevated temperatures are given.

Introduction
Copper plating is widely used in the electronic industry for manufacturing of electronic devices. It is particularly useful for fabrication of printed circuit boards (PCBs) and semiconductors. During circuit fabrication, copper is electroplated over selected portions of the surface of the printed circuit board and onto the walls of through holes passing between the surfaces of the circuit board base material. The walls of the through holes are metallized to provide conductivity between the circuit layers of the printed circuit board. The conductive pathway should be of a uniform plating thickness. Thus in many printed circuit board and semiconductor fabrication processes, electroplating has been adopted by industry as the primary deposition means for copper metallization. [1-2].

The tendency for portability along with increased functionality of electronic devices has driven the miniaturization of PCBs. The mass PCBs production requires intensification of and at the same time simplifying of the metallization process without sacrificing but instead improving the reliability. A challenge exists for fabrication of reliable PCBs.

It is desirable to obtain good throwing power in the electrodeposition processes. Particularly in the through hole plating of PCBs a uniform distribution of deposited copper is demanded. In general, copper plating processes that provide better leveling of the deposit across the substrate surface and inside the through holes tend to worsen the throwing power of the electroplating bath. Plating through holes (PTHs) with various aspect ratios, including those with high AR presents a challenge for the PCB manufactures. High throwing power electrolytes are becoming increasingly important, due to the electronic industry requirements of manufacturing high aspect ratio circuit boards.

In this paper a Hi Throw acid copper plating process with various plating parameters was studied in order to plate through holes with improved micro-distribution and improved mechanical properties of the plated metal such as tensile strength and elongation. The structure of the deposits was examined. The thermal characteristics of plated copper meet the IPC standards and ensure that no failure occurs during the subsequent soldering operations.

A high temperature acid copper process has also been explored. Because the copper plating electrolytes are designed for use at room temperature, they are not generally suited for plating through holes at elevated temperatures. Reduced brightness, increased grain size, and increased roughness lead to a decrease in the reliability performance.
Printed circuit board fabrication has dramatically increased over the past few years in geographic areas with hotter climates. In order to maintain the desired temperature in these areas, chillers or other cooling means are needed.

Thus, it is desirable to simplify the process in these areas, to eliminate the need for chillers or other cooling means and still obtain a desired plating deposit. A new direct current process for plating smooth, bright, and planar copper layers at temperatures up to 40^{o}C is described in this paper.

High Throw Acid Copper Plating Process

A typical copper plating solution contains copper sulfate, sulfuric acid, chloride ions, and organic additives that control the deposition process and the quality of the plated coatings [3-6]. The throwing power of an electroplating bath depends on solution conductivity, electrodeposition kinetics (the slope of the polarization curve), cell geometry, and temperature. The purpose of this work was to determine the effect of various organic additive species and their concentration on the throwing power. The effect of the basic solution composition was also studied. A series of copper electroplating solutions were evaluated.

Test Vehicles

Throwing Power Test Vehicle

The test vehicles that were used in the process evaluation were 1.6 mm and 3.2 mm thick boards with various sized through holes. The through holes diameters for 1.6 mm boards were 0.2mm, 0.25mm, 0.35mm, and 0.5mm. The through holes diameters for 3.2 mm boards were 0.2mm, 0.25mm, 0.35mm and 0.5mm, and 0.8 mm. The through holes AR varied from 3.2 to 16. All the geometries incorporated in the test vehicles were simultaneously plated.

Microdistribution

The Microdistribution is defined as the ratio of the deposit copper thickness in the center of the through hole to its thickness at the surface. It is calculated according to the equation:

$$\text{Microdistribution in \%} = \frac{(C+D)*100 / 2}{(A+B+E+F) / 4}$$

Figure 1 shows a cross section of a through hole indicating the points of thickness measurements.

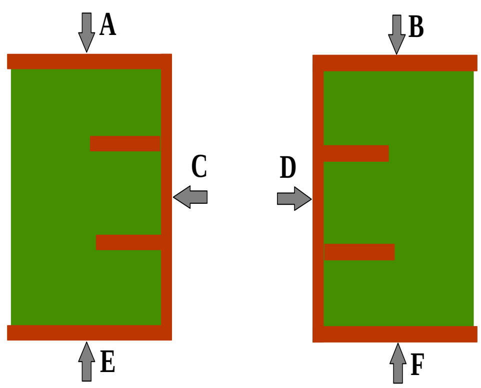


Figure 1 – Cross Section of Plated Panel

Bath constituents
The optimized bath constituents and the plating parameters are given in Table 1. The best results were achieved with a low copper, high acid concentration solution. Plating at low current densities (CDs) allowed us to reliably plate higher AR through holes.

Table 1 – High Throw Process Parameters

Component	Target	Range
$CuSO_4x5H_2O$	50 g/l	45 – 80 g/l
Sulfuric Acid	250 g/l	220 – 300 g/l
Chloride	75ppm	60ppm – 85ppm
Wetter	10 ml/l	8 - 15 ml/l
Brightener	4 ml/l	2 – 6 ml/l
Temperature	22°C	20 – 24°C
Current Density	1.0 ASD	0.5 – 3.0 ASD

Results from Microdistribution Measurements
The measured microdistribution values for the current density tested are shown on Figures 2 and 3. An excellent microdistribution was achieved. Depending on the board design an appropriate current density and plating time could be chosen to achieve the required copper thickness inside the through hole on the walls.

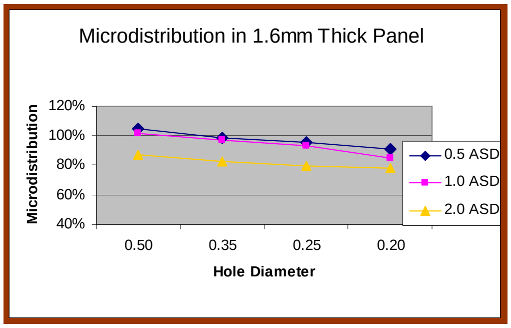


Figure 2 – Microdistribution for 1.6mm Thick Panel

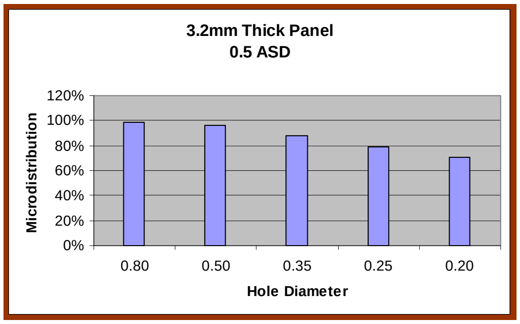
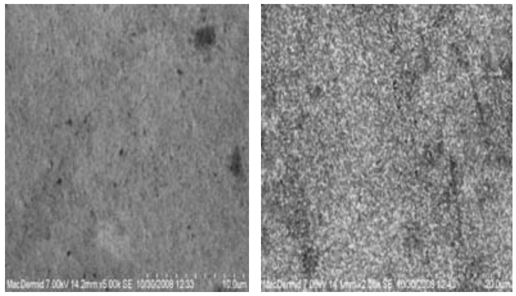


Figure 3 – Microdistribution for 3.2 mm Thick Panel

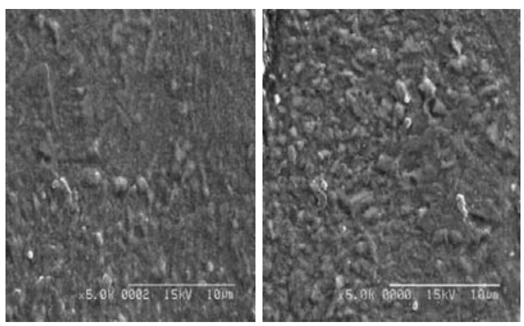
Process Features
Structure, Surface Appearance
Bright leveled deposits were plated from this electrolyte. SEM pictures were taken from copper surface before and after etching to examine the surface morphology. Figure 4 shows copper deposited on the surface of the panel from a perpendicular view. It reveals small equiaxial grain size structure. No particular texture was determined.



(a) 5000x (b)

Figure 4 - SEM of (a) Board surface (b) Board Surface after Etching

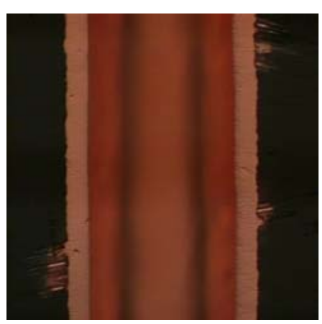
SEM pictures were taken from cross sections of the panel surface (higher current density) and from the inside of the through holes (lower current density). An etch solution was used to expose the crystal structure of the deposit. Pictures of the cross sections are shown in Figure 5. They show a uniform grain orientation. Small grain structure is observed.



(a) 5000x (b)

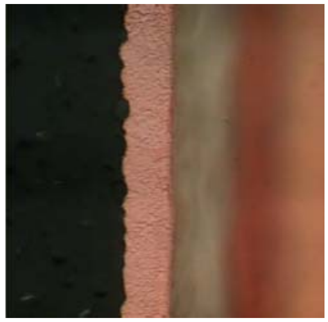
Figure 5 - SEM Cross Sections of 1.6mm Panel Plated at 0.5 ASD (a) Surface (b) 0.35mm Through Holes

Copper plated inside the through hole on the through hole walls was smooth and leveled. Figures 6 and 7 show pictures of cross sections from boards plated under various plating conditions.



500x

Figure 6 - Cross section of 0.2mmThrough Hole in 3.2mm Panel Plated at 0.5 ASD



1000x

Figure 7 - Cross section of 0.2mmThrough Hole in 1.6 mm Panel Plated at 1.0 ASD

Properties of Plated Copper Coatings

Tensile Strength and Elongation

Tensile Strength and Elongation of plated copper were measured in accordance with IPC TM-650 2.4.18.1. Vertical and horizontal pulls were measured. The results from the Tensile Strength evaluation are given in Figures 8. Increasing plating over-potential increases the nucleation rate and leads to formation of deposits with higher Tensile Strength. This is shown in Figure 8: increasing the deposition CDs from 0.5 ASD up to 2.0 ASD increases the values of the Tensile Strength measured. The Elongation was up to 19%. Plating at all conditions met or exceeded IPC specifications.

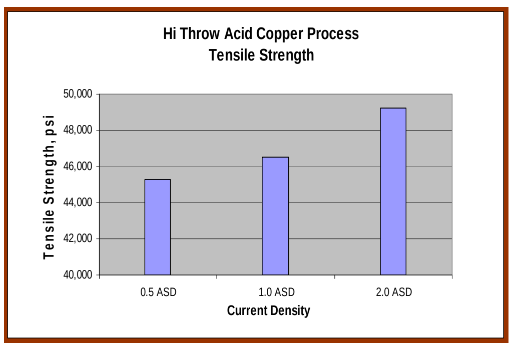


Figure 8 - Tensile Strength versus Current Density

Through-Hole Reliability

Solder shock resistance testing per IPC TM-650 2.6.8 was used to study the thermal characteristics of plated boards. Solder shock conditions were 10 second float at 288ºC for 6 times. Tests were performed for copper foils plated at 0.5, 1.0 and 2.0 ASD. The thermal integrity was excellent for all of the through hole sizes plated. Neither corner cracks nor barrel cracks were observed as shown in Figure 9 across the current densities range studied.

Figure 9 – Hi Throw DC Process, Plating at 1.0 ASD; Cross Section of 0.5 mm through hole after 6x Solder Shock

Summary
A Hi Throw acid copper process was developed for reliably plating of various aspect ratios through holes with an excellent microdistribution. Direct Current mode was used. Plating at low current densities was explored in order to plate higher aspect ratio through holes with the desired microdstribution. Bright, smooth copper was deposited. Good leveling was achieved inside the through holes and on the board surface. Plated copper deposits meet or exceed industry standards for Tensile strength, Elongation and Solder shock resistance.

High Temperature Acid Copper Process
Significant printed circuit board fabrication has migrated to areas of hotter climate. A DC acid copper process for tropical use without cooling was formulated. It was developed in order to meet the requirements for high volume rigid PWB production. The plating bath contains organic additives that are stable at elevated temperatures thus allowing for utilizing the process within the temperature range 22°C - 40°C. The plating parameters are shown in Table 2.

Table 2 – High Temperature Process Parameters

Component	***Target***	***Range***
$CuSO_4x5H_2O$	75 g/l	65 – 85 g/l
Sulfuric Acid	200 g/l	190 – 220 g/l
Chloride	75ppm	60 – 90ppm
Make up	8 ml/l	6 – 10 ml/l
Wetter	Dosing during the plating	
Brightener	0.8 ml/l	0.6 – 1 ml/l
Temperature		22 – 40°C
Current Density	2.0 – 2.5 ASD	1.0 – 4.0 ASD

Process Features
Fine grained deposits were obtained from this electrolyte up to 40°C. Plated copper was smooth and leveled inside the through hole. No thin copper at the knee of the holes was observed. No plating folds and no thin areas inside the hole were measured. Plating thickness was consistent throughout the barrel of the hole.

Microdistribution
Good microdistribution values were measured across a wide current density range, 1.0 ASD - 3.0 ASD, as shown on Figures 10 and 11. Bath performance was consistent for the temperature range studied.

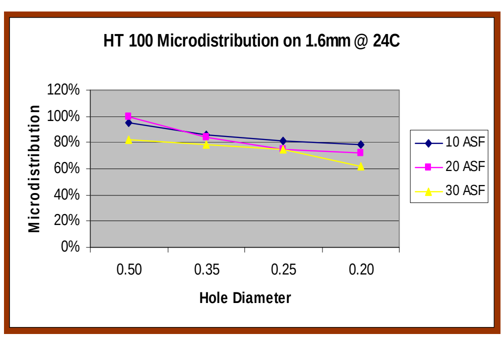


Figure 10 – Microdistribution for 1.6mm Thick Panel Plated 24°C

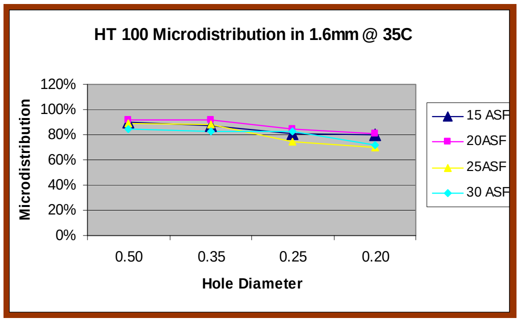


Figure 11 – Microdistribution for 1.6mm Thick Panel Plated 35°C

Properties

Tensile Strength and Elongation

Tensile strength more than 40,000 psi and Elongation in the range 17% - 22% were measured for copper plated from the bath at various temperatures and various current densities. CD's tested were 1.0, 2.0, and 3.0 ASD. Temperature was 24°C and 35°C. Increasing CD and lowering plating temperatures increases tensile strength. Decreasing CD and increasing plating temperatures increases elongation.

Thermal characteristics

For through hole reliability, sections were taken and solder floated 6 times at 288°C. The holes were examined for any defects. No cracks or starter cracks were present, Figure 12.

Figure 12 – HT Process, Plating at 35°C, 2.0 ASD; Cross Section of 0.5 mm through hole after 6x Solder Shock

Equipment and Control

Air and no air solution agitation were studied. Eductor nozzles were used. There was no difference in either the appearance or in the properties of the plated copper between air agitation and the eductor nozzles.
The electrolyte was easy to maintain. The organic additives, the wetter and the brightener were CVS analyzable. Hull cell tests could be used to control the process. The additive consumption changed insignificantly with the temperature change.

Summary

A new DC process was formulated for high volume rigid PWB production. The process yield consistent results over a wide temperature range up to 40ºC. Bright, leveled copper deposits were obtained. Plated copper has excellent physical mechanical properties that meet the IPC standards. The process could be used with air or with eductors nozzles in pattern or panel plate mode allowing for greater flexibility. It is CVS analyzable or Hull cell controllable.

References

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2. Dubin, V.M., "Copper Plating Techniques for ULSI Metallization," Advanced Metallization and Interconnect Systems for ULSI Application in 1997: Materials Research Society Symposium Proceedings, (Jan. 1998) 405-411, Materials Research Society, Warrendale.
3. Yung, Edward K., "Plating of Copper into Through-Holes and Vias," J. Electrochem. Soc., 136 (1989) 206-215
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6. J.P. Healy, D. Pletcher, M. Goodenouth , J. Electroanal. Chem., 338 (1992) 179.

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Acid Copper Plating for Electronic Devices

- Copper plating widely used in the electronic industry for fabrication of electronic devices.
- Copper is electroplated over the surface of a printed circuit board and onto the walls of the through holes.
- The mass PCB production requires intensification of and at the same time simplifying the metallization process without scarifying and even further more improving the reliability.

Benefits of Electroplated Copper

- Copper is a highly conductive metal (low electrical resistivity, high current carrying capacity)
- Copper improves thermal conductivity and heat dissipation in PWB’ s.
- High deposition rate
- Low cost process
- Electro-deposition of copper has been the interconnection technology for the PCB fabrication for fifty years.

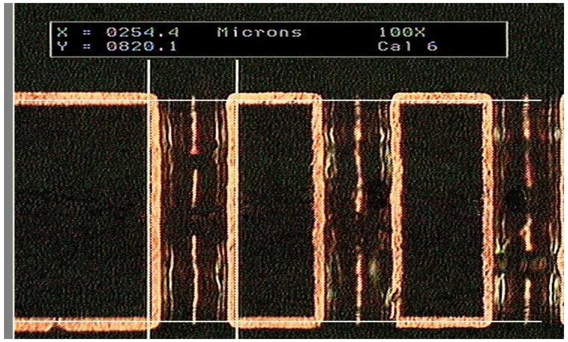
Plating Through Holes

PTH

- Increase Aspect Ratio (AR)
  - High AR = > 12
- Decreasing hole diameters
  - 250 microns   - 200 microns   - 100 microns
- Plate thick boards
- Physical Mechanical Properties of plated copper important
- Difficulties in reliably PTH of the latest designs

Attributes

- Products that plates reliably Through Holes
  - DC plating at low Current Densities
- Ability to plate AR of 8 with >=85% Microdistribution
- Choice of plating parameters depending on TH size
  - CD regime
    - 1.0 ASD for AR up to 8
    - 0.5 ASD for higher AR’s
  - Additive concentrations
- Physical mechanical properties that meet IPC specification
- Bright surface
- Smooth, leveled copper deposits in the range of CD’s used



Metrics

- Micro-distribution
  - Minimize the amount of copper deposited on the surface of the PWB
  - Maximize the amount of copper deposited on the TH walls
- PTH capabilities across a wide range of geometry utilized in production
- Meet thermal reliability criteria (IPC 2.6.8)
  - 6x Solder Shock

    288°C for 10 seconds float
- Tensile and Elongation that meet IPC spec
- Surface appearance

Hi Throw Process Flow

- Acid Cleaner
- Rinse
- Microetch
- Rinse
- Acid Dip
- Rinse
- Hi Throw Cu
- Rinse

- Micro-etch

  Etch undercuts and remaining debris and ensure excellent copper to copper adhesion

- Low CD's Direct Current plating

DC Hi Throw Bath Constituents

Component	Target	Range
$CuSO4x5H2O$	50 g/l	45 – 80 g/l
Acid	250 g/l	220 – 300 g/l
Chloride	75ppm	60 – 85ppm
Wetter	10 ml/l	8 - 12 ml/l
Brightener	4 ml/l	2.0 – 6.0 ml/l
Temperature	22°C	20 - 24°C
Current Density	1.0 ASD	0.5 – 3. 0 ASD
Agitaion	Air or Eductor nozzles	

Hi Throw Anodes

Options

- Copper Anodes
  - Easy to use
  - Low organic additives consumption
- Insoluble Anodes
  - Metal Oxide Coated Titanium anodes
  - Uniform surface distribution
  - Horizontal and vertical plating applications
  - Need copper replenishment
  - Higher organic additives consumption

Capability Test Vehicle

Throwing Power Test Vehicle

- 1.6 mm thick boards with various size through holes

  0.2mm, 0.25mm, 0.35mm, and 0.5mm.

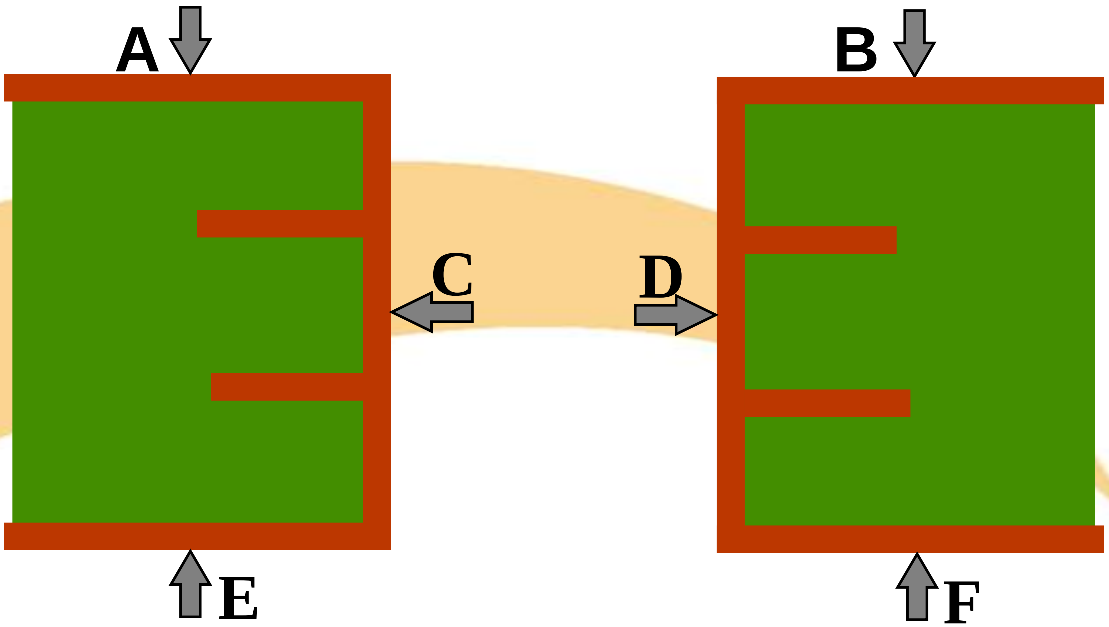
- 3.2 mm thick boards

  Through hole size

  0.2mm, 0.25mm, 0.35mm, 0.5mm, and 0.8 mm

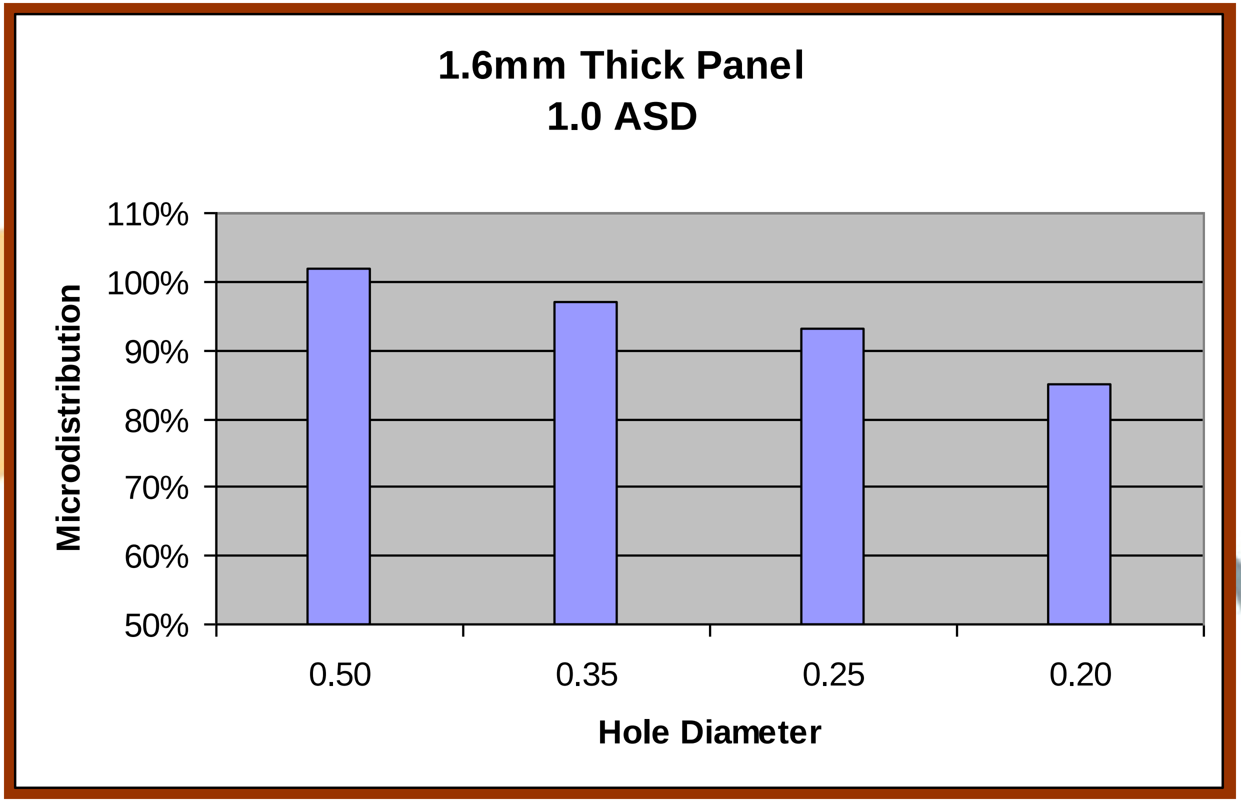
- Simultaneously plating of all geometry

Throwing Power

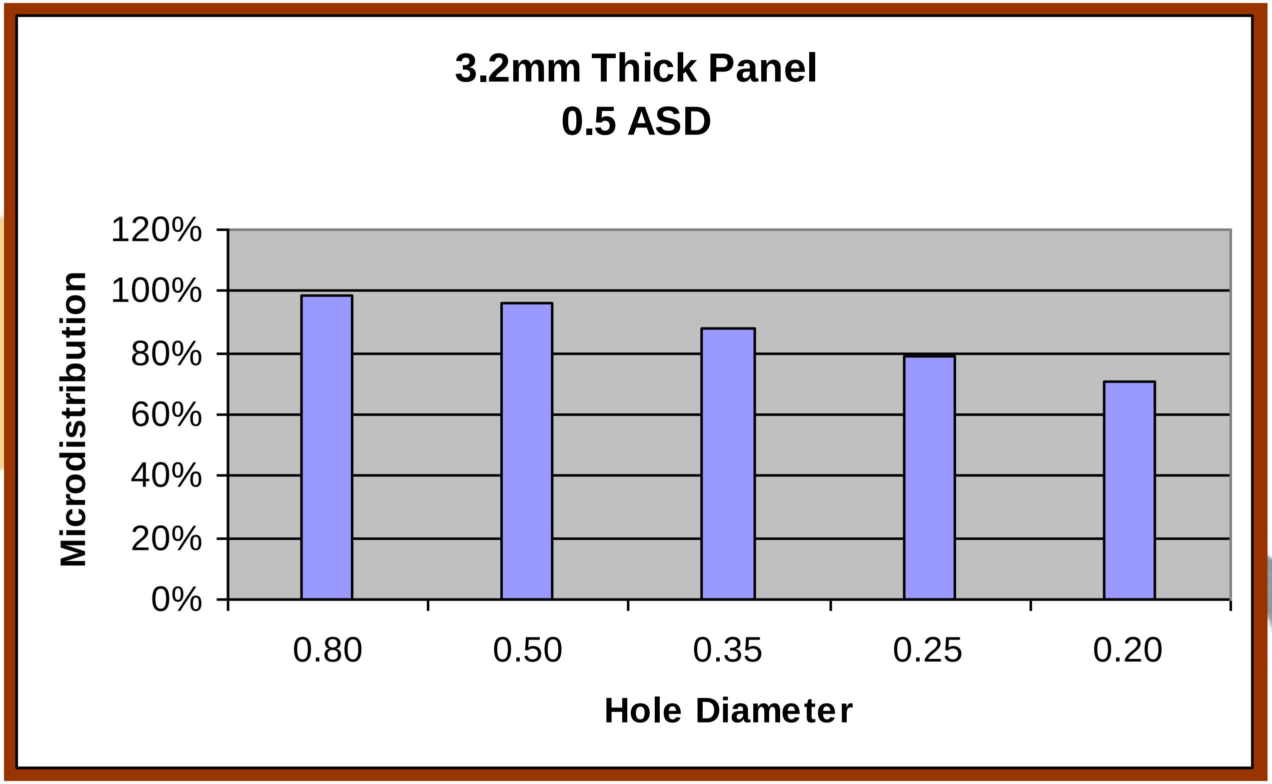


Microdistribution in % = $\frac{(C+D)/2}{(A+B+E+F)/4} \times 100$

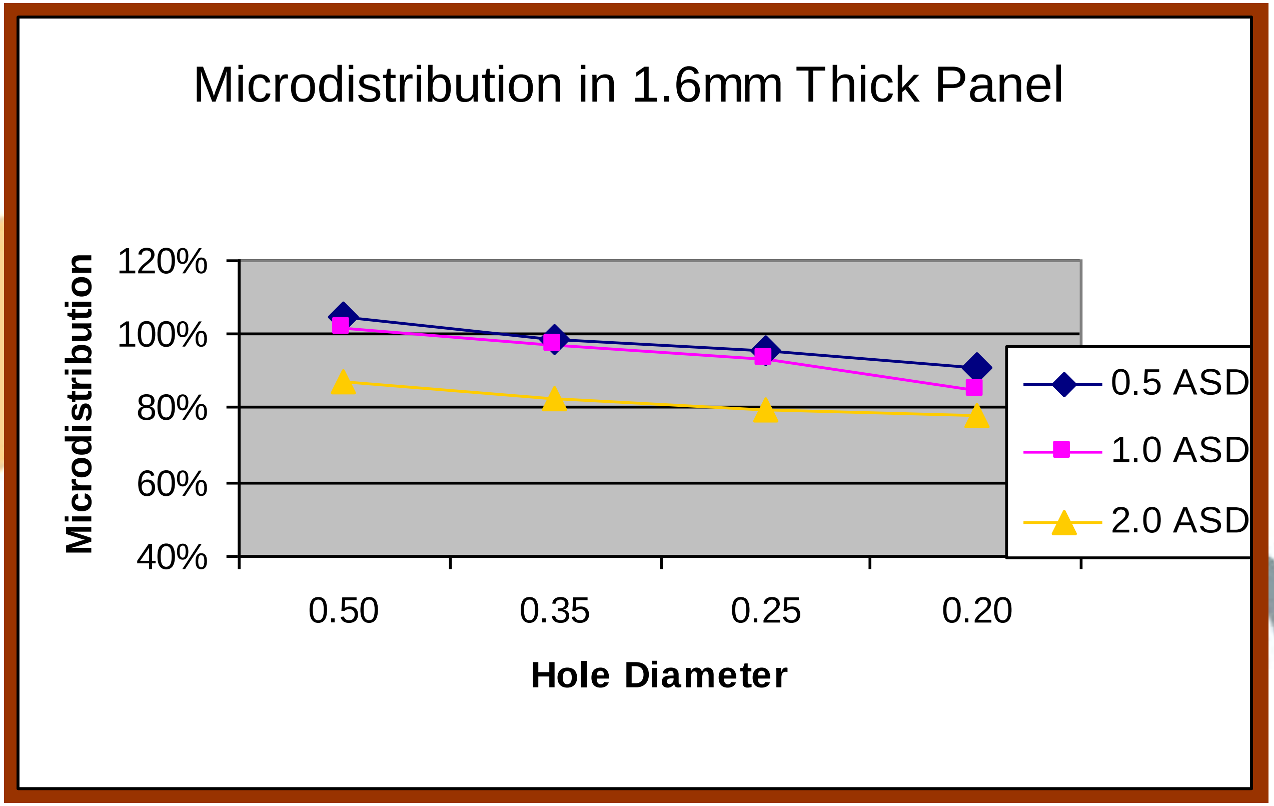
Microdistribution 1.6 mm



Microdistribution 3.2 mm



Microdistribution - CD



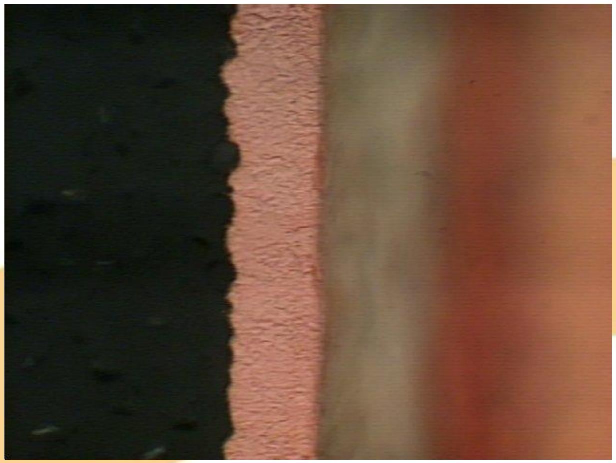
Uniform Panel Plate

Surface copper thickness

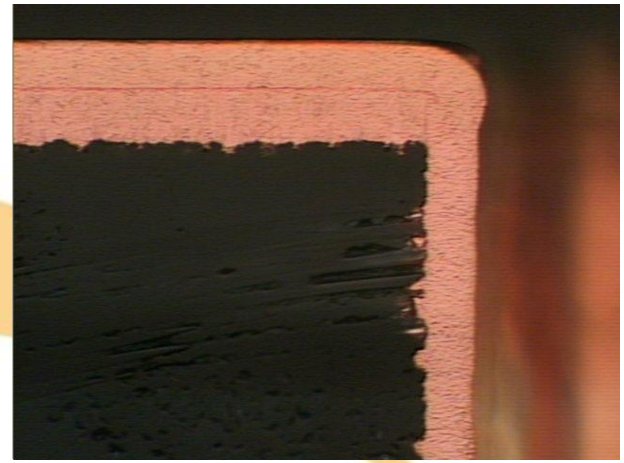
- Optimized plating parameters reduces surface copper thickness
- Uniform thickness across the panel
- Consistent results across the panel

Process Features

1.6 mm Thick Panel
Plating at 1.0 ASD

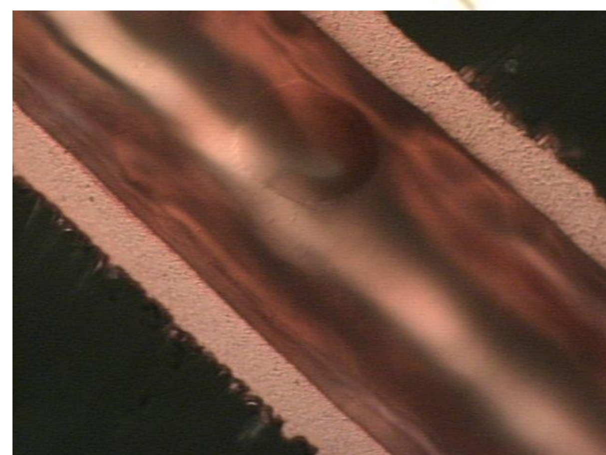


0.2 mm TH



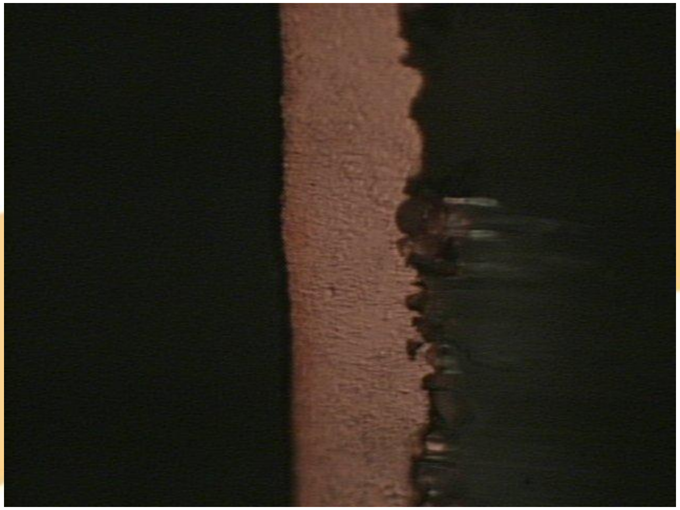
Surface Appearance

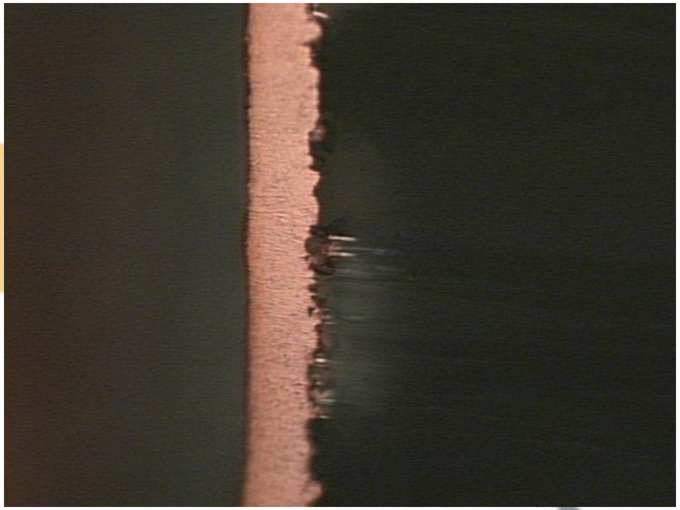
- Bright smooth surface
- Leveled copper inside the TH and on the surface



Cross Sections 1.0 ASD

1.6 mm Thick Panel
Plating at 1.0 ASD





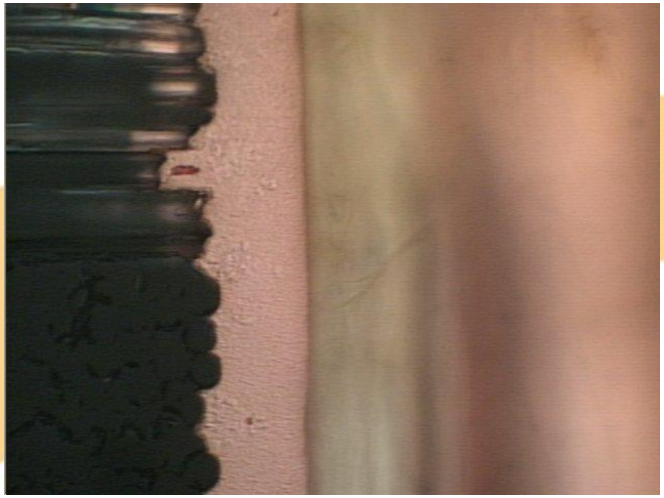
1000x

500x

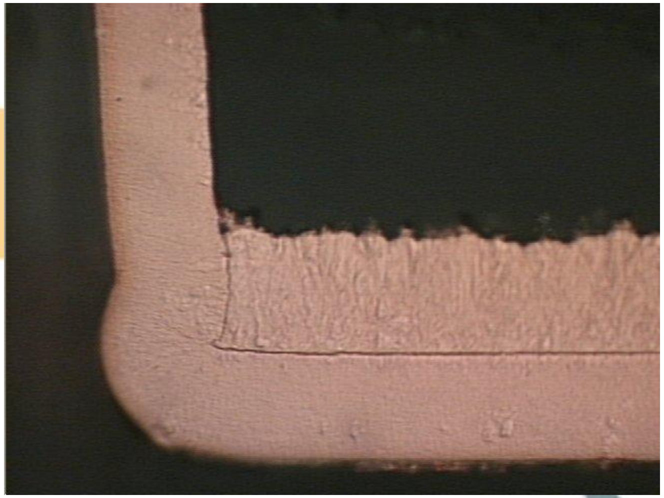
0.5 mm TH

Cross Sections 0.5 ASD

1.6 mm Thick Panel
Plating at 0.5 ASD



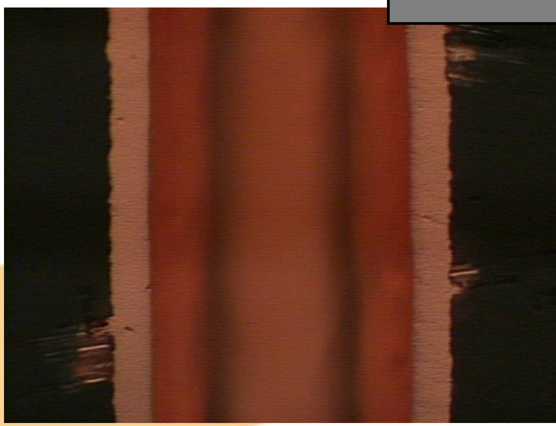
0.2 mm TH
Middle of the Barrel



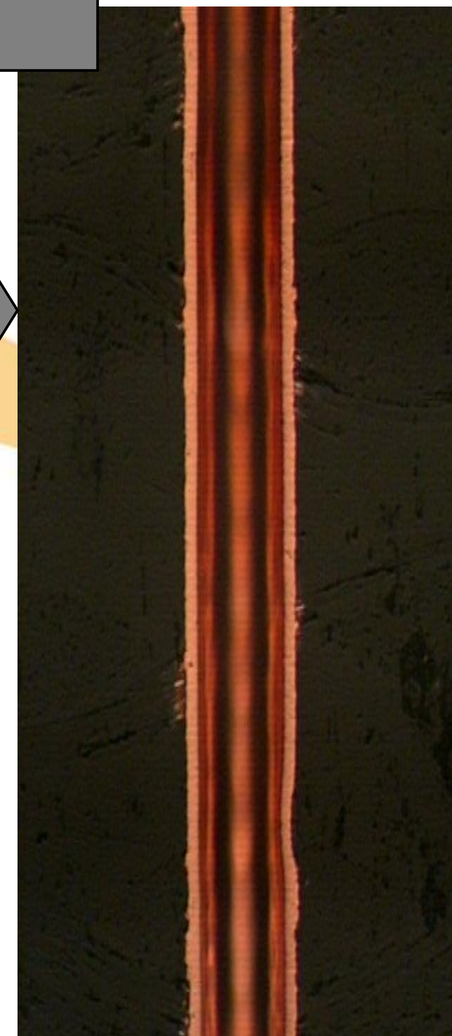
0.2 mm TH
Corner

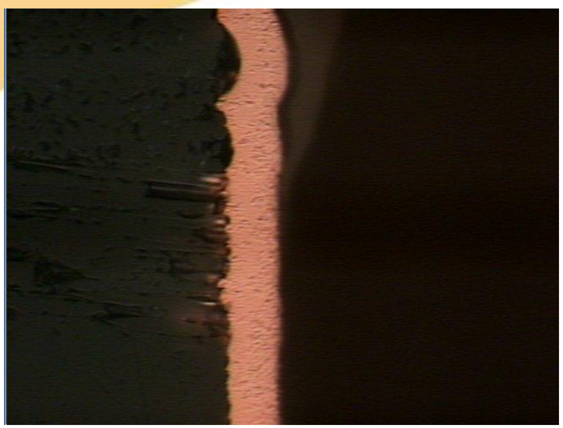
PTH with Good Leveling at low CD's

3.2 mm Thick Panel
Plating at 0.5 ASD



0.2 mm TH
AR = 16

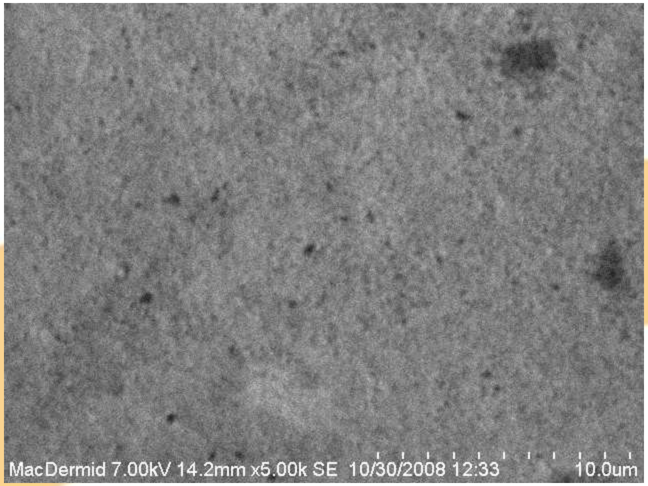




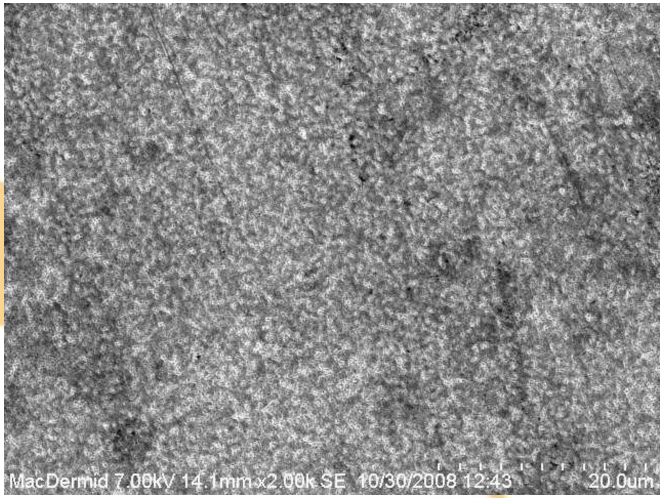
0.8 mm TH

Hi Throw Copper Structure

Surface



After Etching



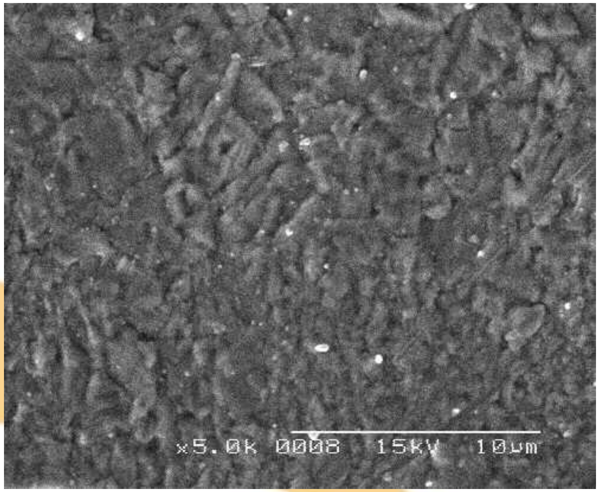
SEM

Structure of copper plated on the board surface

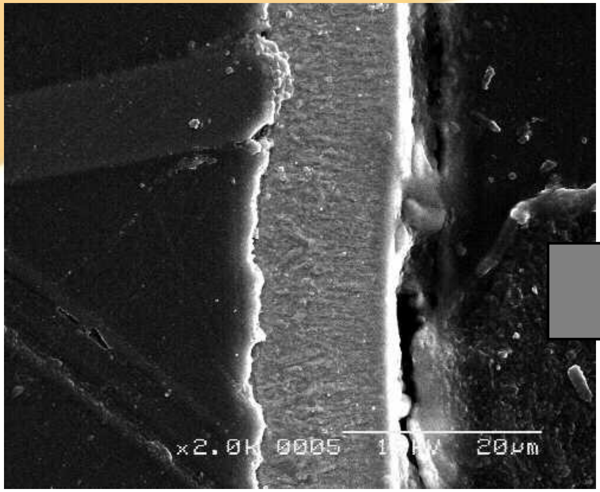
- Small grain size, equiaxeal
- Leveled deposit

SEM Study

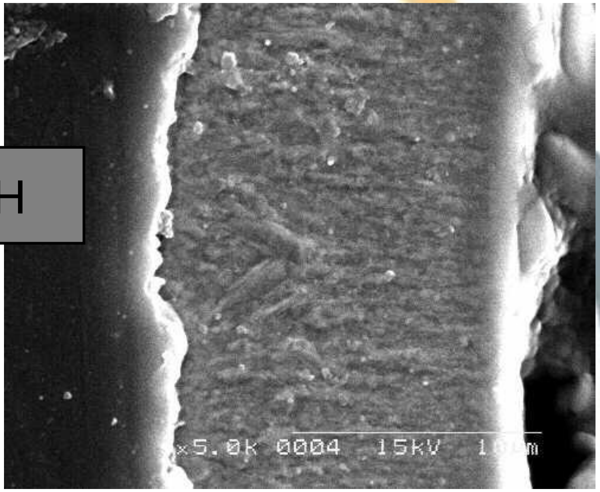
Cross Sections of 3.2 mm Thick Panel
Plating at 1.0 ASD



Surface

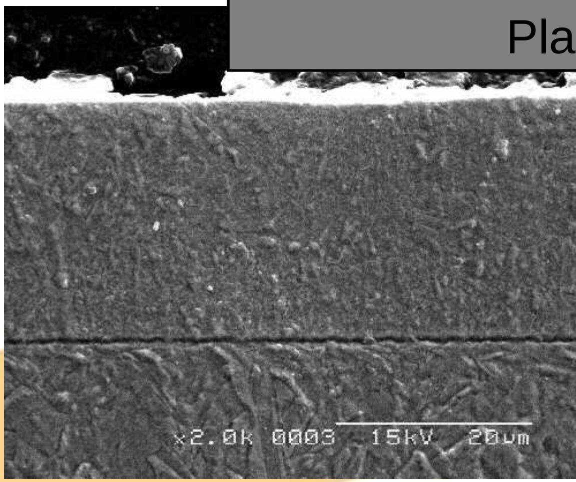


0.2 mm TH

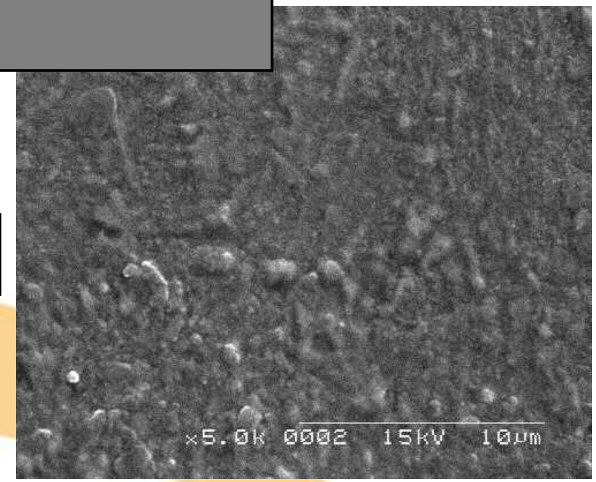


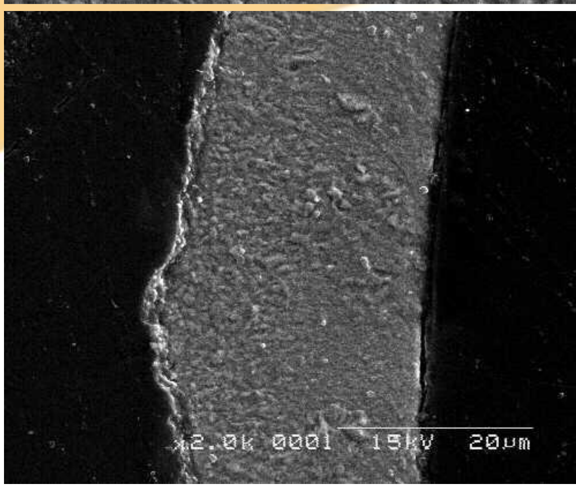
SEM

Cross Sections of 1.6 mm Thick Panel
Plating at 0.5 ASD

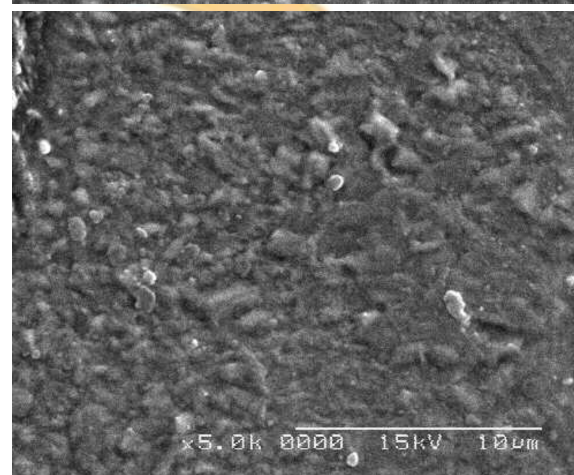


Surface

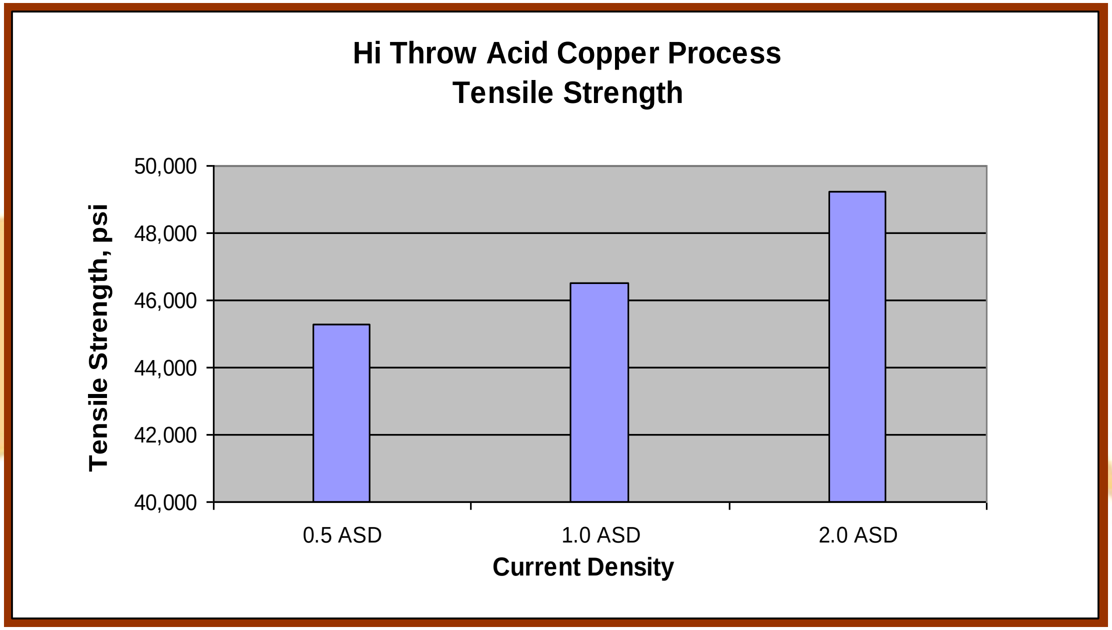




0.35 mm TH



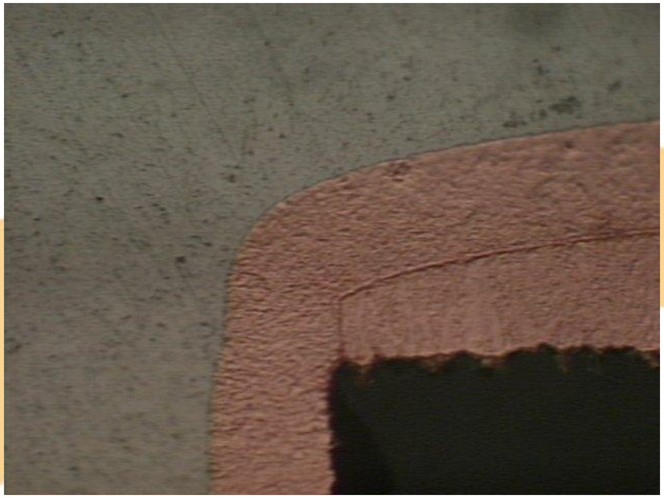
Properties

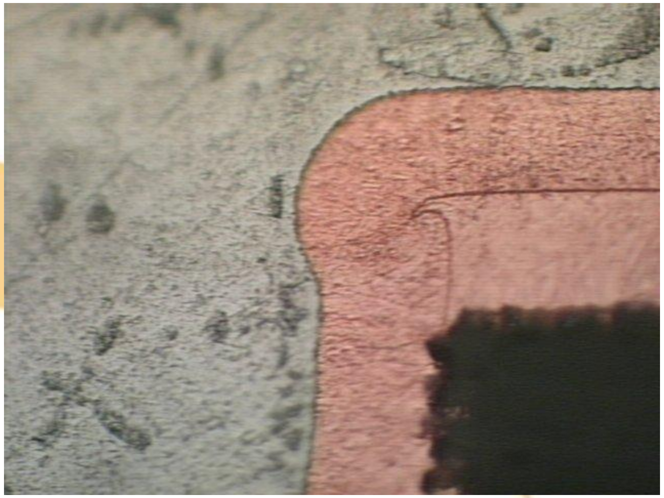


- High Tensile Strength
- Elongation up to 19%

Thermal Resistance

6x SS @ 288^{o}C

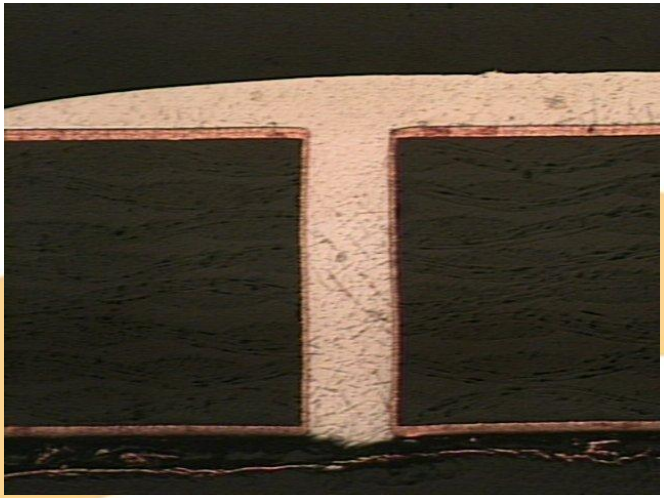




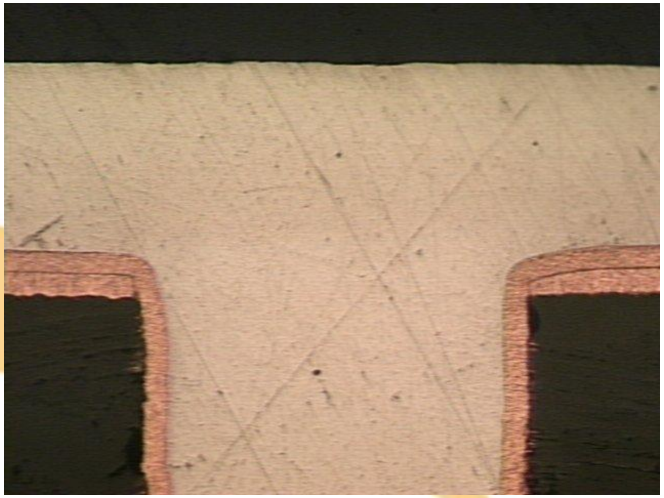
Through hole reliability

- No thin copper at the knee of the holes
- No cracks nor starter cracks after 6x solder shock

6x Solder Shock



50x



200x

0.5mm Through hole in 1.6mm Panel
No corner cracks
No barrel cracks

Hi Throw Summary

- Acid copper process that plates reliably various AR through holes
- Direct Current mode at low CD's
- Excellent Throwing Power of the plating solution
- Plated deposit exceeds industry standards
  - Tensile strength
  - Elongation
  - Solder shock resistance
- No extraordinary tank set up or agitation system required
- Long bath life
- Wide capability range for PTH

High Temperature Acid Copper Process

- DC acid copper process for high volume rigid PWB production
- Plating temperature up to 40^{o}C
- Tropical areas use without cooling
  - Significant printed circuit board fabrication migrated to areas of hotter climate

Description

- Temperature: 22°C - 40°C   71.6F - 104F
- Agitation: Air or Euductors
- CD: 1.0 ASD - 4.0 ASD
- High TOC tolerance (Low building TOC system)
- Bright appearance
- Tensile Strength >36,000 psi (>40,000 psi)
- Elongation >12% (>20%)
- Micro-distribution in 1.6 mm thick board
- Thermal Characteristics 6x Solder Shock resistance
- Good propagation for Black hole or Eclipse

Process Flow

Acid Cleaner

Microetch

Acid Dip

MacuSpec HT 100

- Cleaner wets the holes and removes light soils
- Etch ensures excellent copper to copper adhesion
- Acidifies copper surface prior to plating
- Electrolytic copper for high volume PWB production

HT 100 Components

- Make-up
  - High MW organic compounds having low solubility in the solution and low coefficient of diffusion
  - A mixture of wetter / suppressor to improve start up and decrease dummy plating time on new baths
  - Used only for new make-ups and after carbon treatments
- Brightener
  - Anti-suppressor, Sulfur - containing compounds
  - Responsible for copper grain refinement and internal stress reduction; has leveling effect
  - Has an effect on tensile strength and elongation

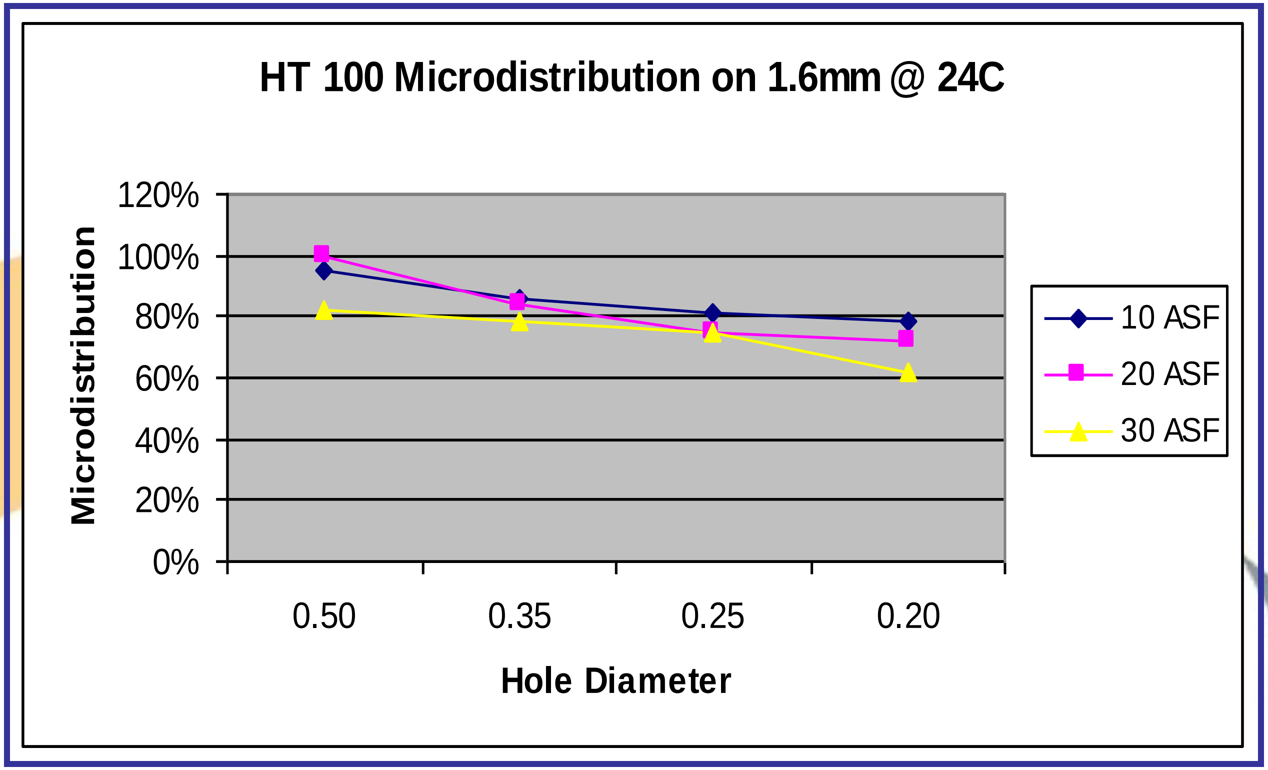
HT 100 Components

- Wetter
  - Suppressor that forms diffusion layer on the cathode to limit the transfer of additives
  - Increases activation energy and “slows “ plating down
  - Used for replenishment only
- Chloride
  - Enhance the adsorption and inhibition effect of the wetter
  - Assist in controlled dissolution of copper anodes

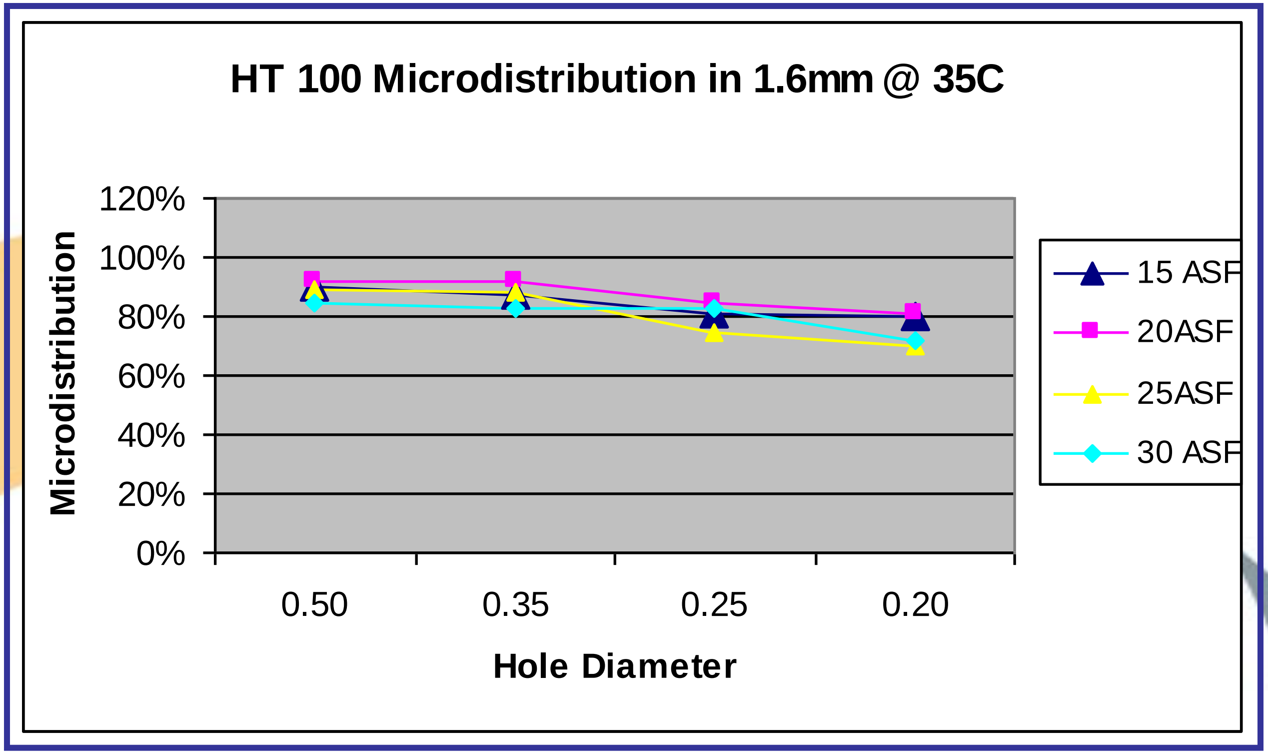
HT 100 Bath Constituents

Component	Target	Range
$CuSO_4 \times 5H_2O$	75 g/l	65 – 85 g/l
Sulfuric Acid	210 g/l	190 – 220 g/l
Chloride	75ppm	60ppm – 85ppm
HT 100 Make up	8 ml/l	6 ml/l – 10 ml/l
HT 100 Wetter	Dosing during the plating	
HT 100 Brightener	0.8 ml/l	0.6 – 1.2 ml/l
Temperature		22^{o}C - 40^{o}C
Current Density	2.0 ASD	1.0 – 4.0 ASD

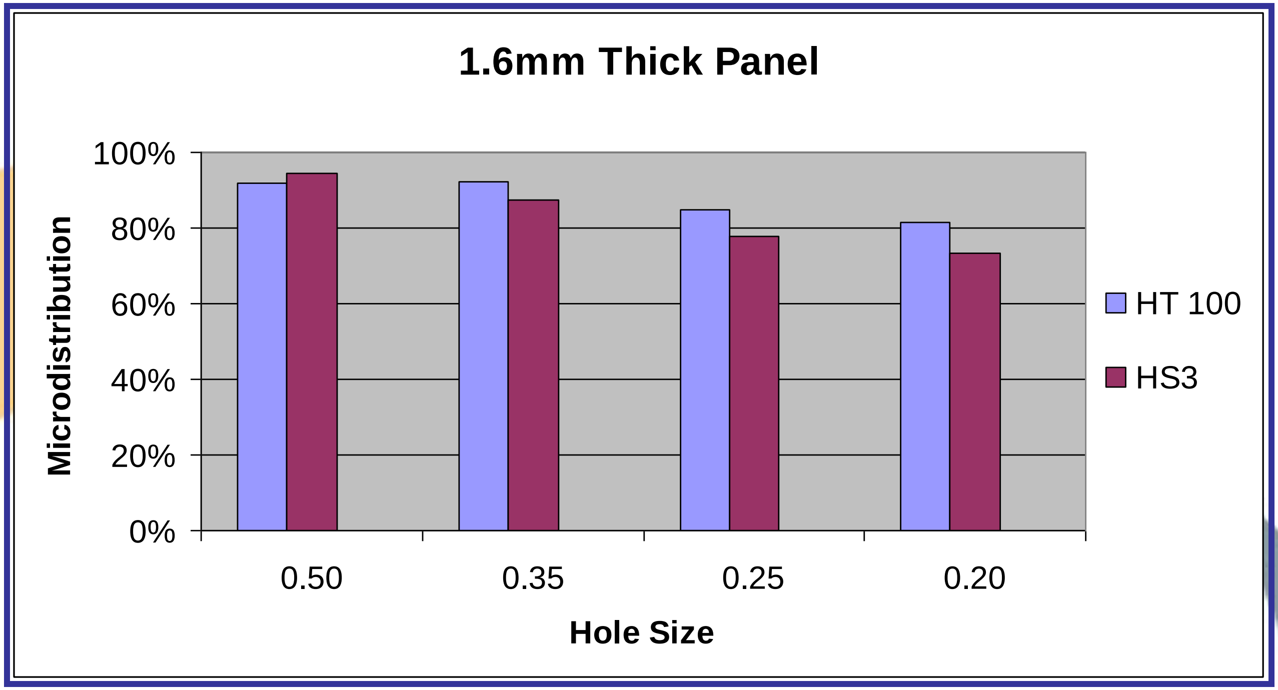
Microdistribution at 24^{o}C



Microdistribution at 35^{o}C



HT 100 and HiSpec 3



Microdistribution Summary

- Good Microdistribution across a wide current density range
- Bath performance is consistent across 24ºC or 35ºC
- Microdistribution is equivalent/better than MacDermid MacuSpec HiSpec3 acid copper process, designed for room temperature use only

Tensile Strength and Elongation

23^{o}C, 2 ASD

Sample	Break Force (lbf)	Weight (g)	Elongation (%)	Tensile Strength (PSI)	Approximate Thickness (mils)
1	74.59	1.2104	21.95	44,983.47	3.51
2	73.50	1.1952	23.18	44,893.39	3.47
3	72.41	1.1729	24.09	45,066.46	3.40
4	70.85	1.1498	25.26	44,981.70	3.33
5	70.24	1.1418	23.57	44,907.93	3.31
Mean	**72.32**	**1.1740**	**23.61**	**44,966.59**	**3.40**

36^{o}C, 2 ASD

Sample	Break Force (lbf)	Weight (g)	Elongation (%)	Tensile Strength (PSI)	Approximate Thickness (mils)
1	70.98	1.2300	25.65	42,127.51	3.57
2	69.00	1.1961	20.20	42,114.37	3.47
3	67.70	1.2039	13.99	41,048.64	3.49
4	68.35	1.1877	25.85	42,007.52	3.44
5	67.31	1.1785	25.76	41,694.50	3.42
Mean	**68.67**	**1.1992**	**22.29**	**41,798.51**	**3.48**

23^{o}C, 3 ASD

Sample	Break Force (lbf)	Weight (g)	Elongation (%)	Tensile Strength (PSI)	Approximate Thickness (mils)
1	67.56	1.1042	9.21	44,664.85	3.20
2	68.06	1.0784	22.39	46,074.26	3.13
3	68.21	1.0812	22.80	46,055.51	3.14
4	66.34	1.0582	15.71	45,762.99	3.07
5	64.49	1.0327	15.33	45,589.33	2.99
Mean	**66.93**	**1.0709**	**17.09**	**45,629.39**	**3.11**

36^{o}C, 3 ASD

Sample	Break Force (lbf)	Weight (g)	Elongation (%)	Tensile Strength (PSI)	Approximate Thickness (mils)
1	68.45	1.1917	21.00	41,930.84	3.46
2	68.74	1.1985	20.49	41,867.89	3.48
3	68.23	1.1830	21.69	42,105.24	3.43
4	68.55	1.2041	20.53	41,562.27	3.49
5	70.94	1.2311	21.25	42,062.04	3.57
Mean	**68.98**	**1.2017**	**20.99**	**41,905.66**	**3.49**

Mechanical Properties

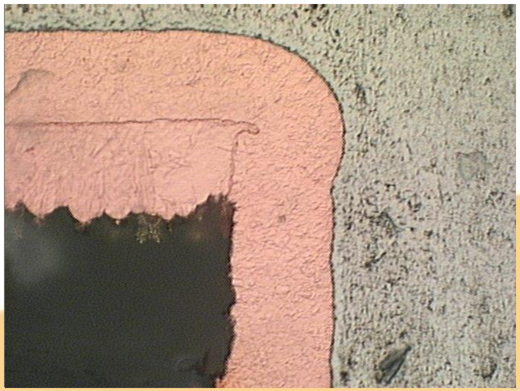
Mechanical Properties - All conditions meet IPC spec

- Increasing CD increases Tensile strength and lowers Elongation
- Increasing Temperature decreases Tensile strength and increases Elongation

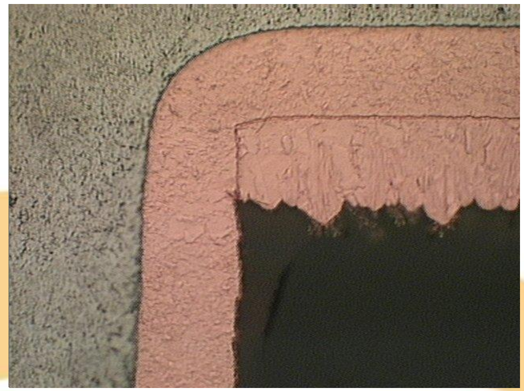
Deposition at higher over-potential (higher CD's and

lower T) decreases the grain size

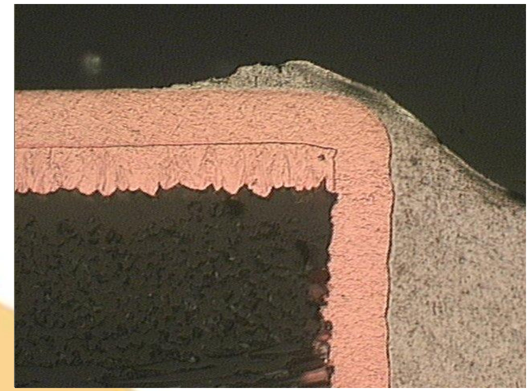
Thermal Resistance



24ºC



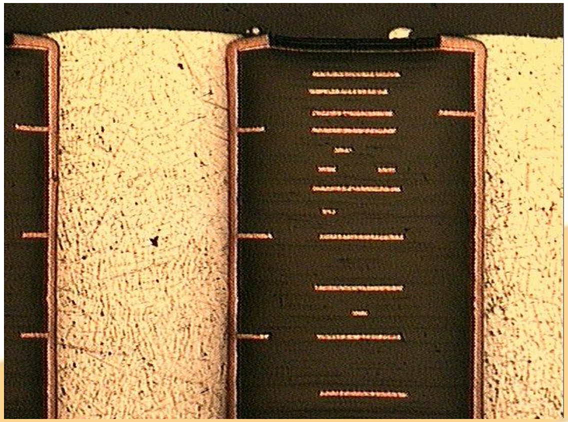
35ºC



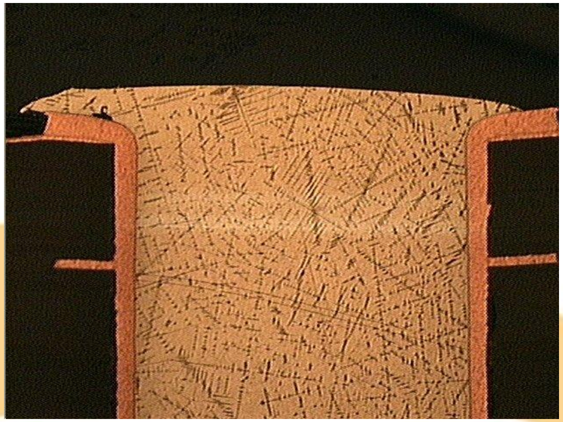
40ºC

Solder shock conditions – 10 second float @ 288ºC 6 times
No cracks, no starter cracks across the temperature range

Pattern Plate



50x



100x

200x

Pattern Plate mode

- 6x Solder Shock Test
- Meets IPC Specifications

HT 100 Details

- Additives are independently controlled
  - Separate components
  - Can be mixed together for auto-dosing

- CVS analyzable (preferred) or Hull cell controllable – wide operating window

- Good results achieved up to 40ºC, but runs very well at lower temperature

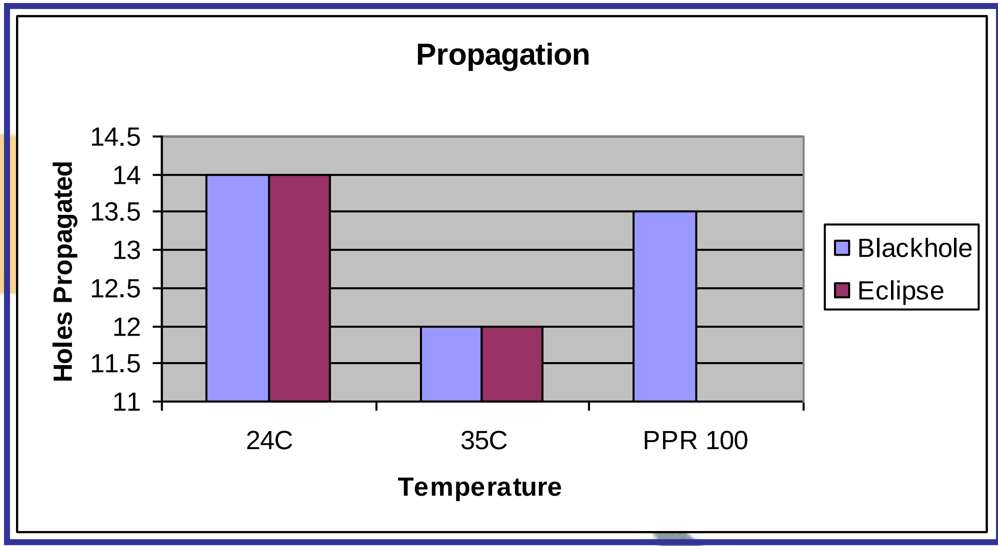
Direct Plate

Conductive layer prior to electroplating

- Electroless Copper
  - good coverage
  - requires close control
- Non Copper Conductors Black hole / Eclipse
  - easy to control
  - stable chemistry
  - low cost process
  - environmentally friendly
  - versatility

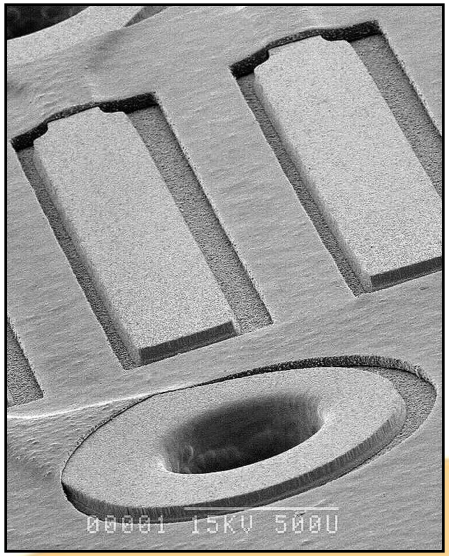
HT 100 Propagation

- Hull Chains were run 10 minutes@1 amp
- Holes propagated are out of a total 14 holes possible
- A slight decrease was noted at the elevated temperature
- The comparative control was Blackhole plated in PPR 100 @ 24ºC



HT 100 Summary

- A new process is formulated for high volume rigid PWB production
- Process that yields consistent results over a wide temperature range up to 40ºC
- Bright, leveled copper deposits
- Excellent Physical Mechanical properties that meet the IPC standards.
- The process can be used with air or with eductors nozzles in pattern or panel plate mode allowing for greater flexibility
- The electrolyte is CVS analyzable or Hull cell controllable
- Excellent propagation for use after direct plate



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