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Using Periodic Pulse Reverse (PPR) for Plating Thick Panel Applications

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Abstract

There is increased interest in the printed wiring board (PWB) industry with regards to the use of periodic pulse reverse (PPR) plating to electroplate printed circuit boards. PPR plating offers several advantages over DC plating including improved throwing power, reliability, and surface distribution, leading to decreased product cycle times, and increased throughput. The use of widescale PPR plating in acid copper; however, has been hampered by disadvantages such as short bath life and a limited ability to plate high aspect ratio (HAR) thick panels. To that end, an acid copper PPR chemistry has been developed to address these issues. Scale-up, production testing, and the analytical techniques used to control the process are discussed herein. The process capability with respect to high aspect ratio panels as well as mixed technology boards is also presented.

Introduction

As technology advances, new challenges arise in the process of electroplating circuit boards in the printed wiring board industry[1]. One of the biggest challenges proves to be electroplating high aspect ratio thick panels[2]. Aspect ratio is defined as the thickness of the board divided by the diameter of the through hole. As aspect ratio and board thickness increases, the more difficult it becomes to plate copper into the through hole. Printed wiring boards for some applications, specifically backplane, can reach thicknesses in the 8 mm or thicker range, with through holes approaching 0.5 mm in diameter. Typical plating times utilizing DC plating for these types of boards can run upwards of 12 or more hours. The electroplating step for these types of circuit boards can be a significant bottleneck in the assembly process. Another emerging challenge in the PWB industry is the electroplating of printed circuit boards that contain multiple features on the same board[3]. These boards, known as mixed technology boards, may contain any or all of the following features: an imaged pattern with dense lines and isolated traces, blind vias, and through holes. In this case, the electroplating engineer must have a process to simultaneously plate through holes, blind vias, and the imaged pattern of the board with acceptable quality and thickness distribution. In extreme cases, multiple plating baths and cycles need to be utilized to electroplate these types of boards.

Both of these situations present significant difficulties to the electroplating engineer. In order to achieve high throwing power (average plated copper thickness in the center of the hole divided by the average thickness of the plated copper on the surface of the board, typically expressed as a percentage) and acceptable surface distribution, plating needs to occur at similar rates on all areas of the board. The copper plating rate is related to the potential at which plating will occur, and differences in the plating potential will affect the amount of copper that deposits in a certain area. Differences in the plating potential for different areas on a circuit board are affected by three factors, as seen in equation:[1] kinetics, (or charge transfer), mass transfer, and iR drop[4].

$$\Delta E_t = \Delta\eta_{ct} + \Delta\eta_{mt} + E_{ir} \qquad (1)$$

Mass transfer differences at different areas on the printed circuit board are due mainly to solution flow disparities between the surface of the board and recessed areas of the board, *i.e.*, through holes and blind vias. Employing high air agitation rates, eductors, or jets can minimize these differences; however, solution flow differences will always occur to some extent between the surface of the board and the recessed areas of the board. Potential drop (iR) differences between different areas are dependent upon the board thickness, the diameter of the hole, and the conductivity of solution. As the aspect ratio and thickness of printed circuit boards gets larger, the potential drop and mass transfer differences between the surface and recesses become more pronounced, leading to higher plating rates on the surface and lower plating rates in the recesses.

To counter these inherent mass transfer and iR drop differences, formulation chemists affect the remaining factor, kinetics, by changing the chemical ingredients of the plating bath. The ingredients of an acid copper bath can be broken down into two main areas: inorganic components and organic components. The inorganic portion of a copper plating bath consists of three main components: a copper salt, a supporting electrolyte, and a chloride ion source. Copper sulfate is usually the copper salt of choice due to its high solubility and acid stability. Sulfuric acid is the most common supporting electrolyte due to its low-cost, high conductivity, convenience, and readily handled waste. Chloride ions, though present only in trace amounts, work in tandem with the organic additives to refine the deposit.

The organic components, which are usually proprietary combinations, refine the copper deposit resulting in a bright surface, smooth deposit, and improved physical properties[5-12]. There are three major types of organic additives used in copper plating: carriers, brighteners, and levelers. Carriers, or suppressors, are typically polyethers of varying molecular weights. Carriers adsorb on the cathode, and work in conjunction with the chloride ions to suppress the plating rate. Brighteners, or accelerators, tend to be sulfur-bearing compounds that increase the plating rate by displacing the carrier. The active form of brightener at the copper surface is debatable, and it may not be the same as the actual material that is added to the plating bath. Levelers are usually nitrogen-containing heterocycles that displace brightener at high current density areas, and act locally to suppress the plating rate. The organic additives combine to increase the plating rate in the low current density regions, *i.e.*, through holes, and decrease the plating rate at the high current density regions, *i.e.*, the surface.

In PPR plating, the effects of these additives are further enhanced by the modulation of the applied current[13,14]. DC current provides a continuous current at a constant current density, where the circuit board is always the cathode. PPR current involves the periodic application of an anodic current to the circuit board itself, wherein the board temporarily becomes an anode. A typical PPR waveform used to plate through holes is schematically represented in Figure 1. This example involves a cathodic, or forward, current of 20 ms followed by an anodic, or reverse, pulse current of 1 ms, typically at three times the current density, or amplitude, of the forward current density. The forward to reverse frequency is expressed as (forward period:reverse period), or (20:1) in the prior case. The forward to reverse current density ratio is expressed as (forward:reverse ratio), or (1:3) in the previous case. In plating through holes, it is common using PPR to employ short, but powerful reverse current pulses. Other types of waveforms may be used for other applications.

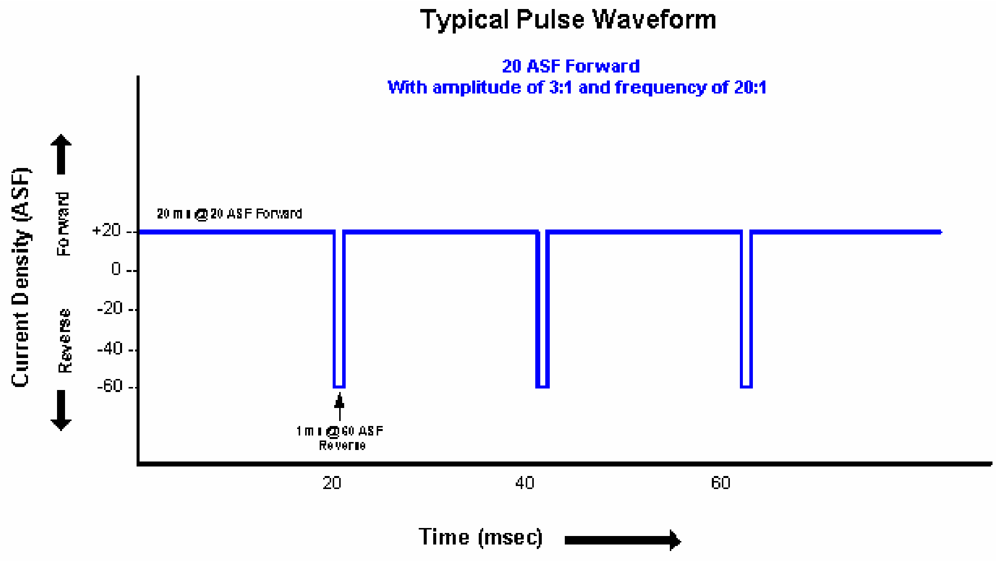
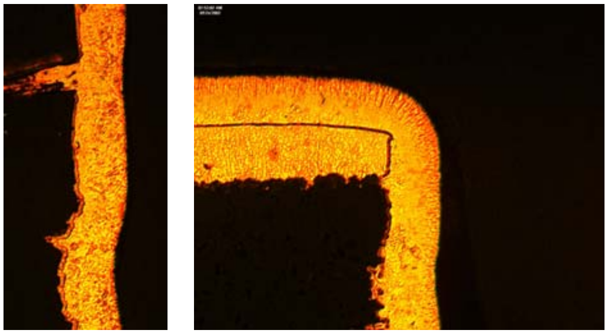


Figure 1 - Schematic of a Typical Pulse Waveform used in PPR Plating

The effect of this reverse current is extraordinary. Initially, the carrier, or suppressor is uniformly adsorbed on the surface of the cathode. During the forward portion of the current, brightener adsorbs on both the surface of the board and in the through holes, and the adsorption is proportional to the current density. During the reverse pulse, brightener desorbs from both the surface and the hole. Brightener desorbs more at the high current density region, *i.e.*, the surface of the board where the iR drop is limited. Therefore, more brightener desorbs from the surface of the board than in the holes of the board. Further, due to the high mass transfer rate at the surface of the board, the desorbed brightener can be easily washed away from the surface, but relatively more remains in the stagnant hole. Ultimately, this leads to a higher concentration of brightener adsorbed inside the holes, and a brightener deficiency on the surface of the board. Pulse plating, in effect, exploits the two main factors (mass transfer and iR drop) that cause lower throwing power in DC baths. Due to these significant differences in the surface chemistry of the different areas of the board, two dissimilar plating environments are created. Thus, PPR enables multiple plating environments on a single substrate.

These two distinct environments are evident in the appearance of the electroplated board. The surface of a panel plated in pulse mode appears matte or satiny (suppressed), while the holes have a bright appearance. This effect is also evident in the grain structure of the panels, as demonstrated in Figure 2. The surface exhibits an ordered, or striated, grain structure where the brightener is deficient, while the center of the hole displays equiax or amorphous grain more typical of a brightener-rich environment.



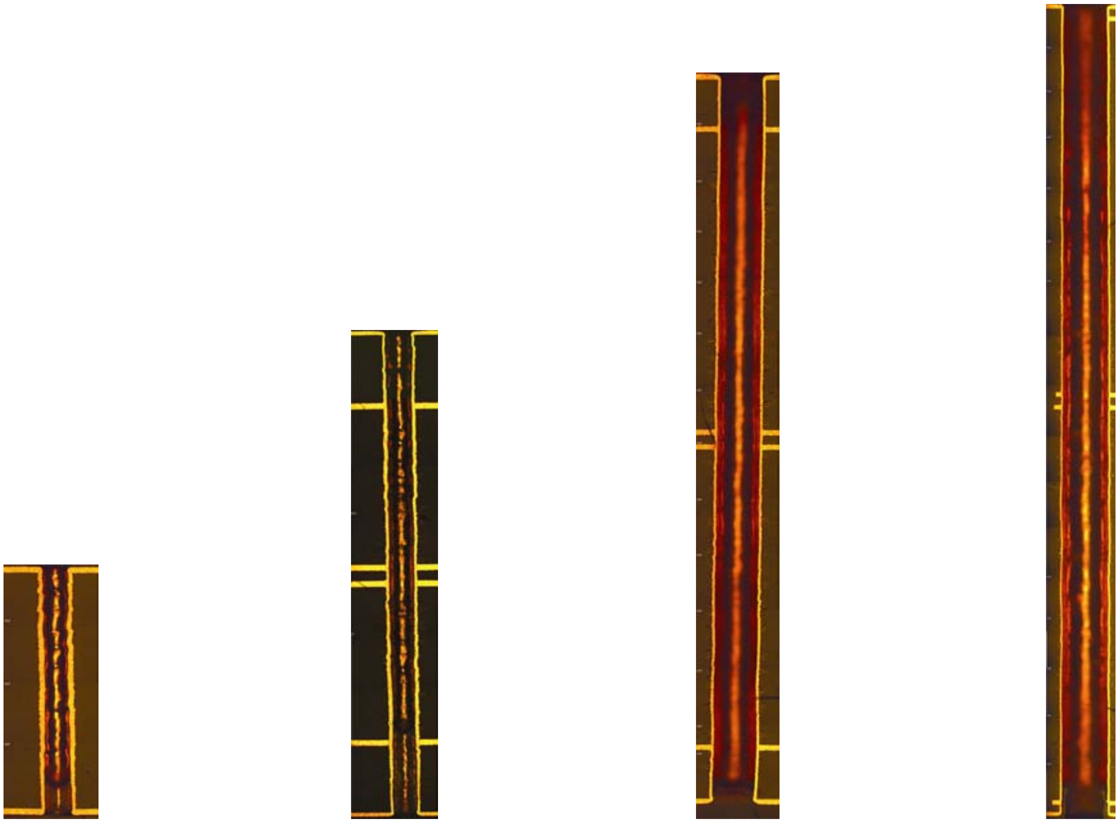
Center Hole Knee

Figure 2 - The Knee and Center of a 0.6 mm Through Hole in an 8.1 mm Thick Test Panel, Plated using PPR Chemistry. The Waveform Employed a forward Pulse Length of 50 ms and a Reverse Pulse Length of 2.6 ms (50:2.6), with a Reverse Pulse Amplitude of 3 Times the Forward Pulse (1:3)

Capability

Extensive screening of various organic additive formulations was conducted for throwing power efficacy. Candidate formulations were further optimized with inorganic chemistry concentration adjustments. This optimization was also done in conjunction with waveform adjustments, resulting in a process optimized for thick panel applications. The optimized inorganic concentrations were found to be 80 g/l $CuSO_4$ pentahydrate, 220 g/l H_2SO_4 and 35 ppm Cl^-. Lower copper concentrations had minimal effect on throwing power. The organic components and concentrations are proprietary. The optimized waveform utilizes a longer forward (50 ms) and reverse wave (varies depending on board design between 2 ms and 3 ms) than the common wave shown in Figure 1. The optimized reverse amplitude ratio was found to be 3:1 for panel plate mode, and 2:1 for pattern boards. This type of waveform was found to be the most effective in curtailing surface anomalies, such as whiskering.

Various results of panels plated in PPR chemistry are presented in Figure 3. Included in Figure 3 are the calculated difficulty factors (DF), which is defined as the board thickness squared divided by the through hole diameter in inches. This measurement better quantifies through hole difficulty than aspect ratio and emphasizes the detrimental impact of board thickness on throwing power. PPR chemistry can be used to effectively plate boards with a difficulty factor of greater than 4 in six hours or less.



DF = 0.64 in 2.4 mm thick 0.34 mm dia 20 ASF TP = 97%

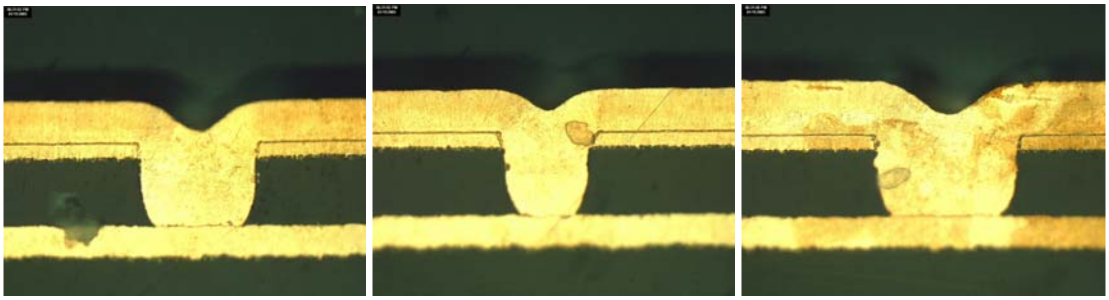
DF = 2.9 in 4.8 mm thick 0.30 mm dia 20 ASF TP = 92%

DF = 4.5 in 7.6 mm thick 0.5 mm dia 10 ASF TP = 73%

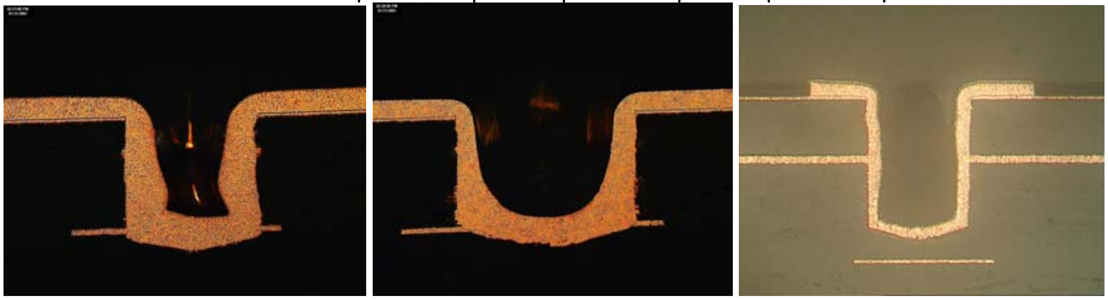
DF= 6.2 in 10.2 mm thick 0.6 mm dia 10 ASF TP = 73%

Figure 3 - Representative Sample of Different Sized Through Holes and Board Thicknesses as Plated using PPR Chemistry

Results from plating blind vias reveal that PPR chemistry is also capable of simultaneously plating blind vias and through holes on the same board, as presented in Figure 4. Small diameter, laser-ablated microvias show a strong degree of via filling (“superfilling”), and large mechanically drilled vias display excellent conformal plating.



100 µm X 125 µm 125 µm X 125 µm 150 µm X 125 µm



350 µm X 350 µm 450 µm X 350 µm 400 µm X 500µm

Figure 4 - Representative Sample of Blind Vias Plated at 10 ASF using PPR Chemistry. Notation above refers to Width Measurement X Depth Measurement. The Waveform Employed a Forward Pulse Length of 50 ms and a Reverse Pulse Length of 2.5 ms (50:2.5), with a Reverse Pulse Amplitude of 2 Times the Forward Pulse (1:2). The Vias in the Top Row were Laser Ablated, while the Vias in the Bottom Row were Mechanically Drilled

Although the surface of the board and the through holes have different grain structures, there has been no correlation with thermal reliability issues. To confirm this, a series of test coupons of varying board thicknesses and hole sizes plated with PPR chemistry have been subjected to 6X-solder floats at 288 ºC. After cross sectioning the coupons, the holes were inspected for both barrel and corner cracks, and the results are displayed in Table 1. No barrel cracks were detected in any of the solder floated samples, nor were any complete corner cracks detected. The only defect that was evident was a small percentage of starter cracks (<3%) that were present in the corners, as shown in **Figure 5**.

Table 1- Thermal Reliability Results from Various Samples Plated using PPR Chemistry

		Corner Cracks			**Barrel Cracks**		
Panel Thickness	**Hole Diameter**	**Number of Holes**	**% Partial**	**% Complete**	**Number of holes**	**% Partial**	**% Complete**
0.093”	0.036”	480	0.2%	0%	48	0%	0%
0.093”	0.0135”	520	1.2%	0%	52	0%	0%
0.187”	0.036”	640	2.2%	0%	64	0%	0%
0.187”	0.0125”	640	1.3%	0%	64	0%	0%
0.300”	0.036”	480	0.6%	0%	48	0%	0%
0.300”	0.020”	480	0.6%	0%	48	0%	0%

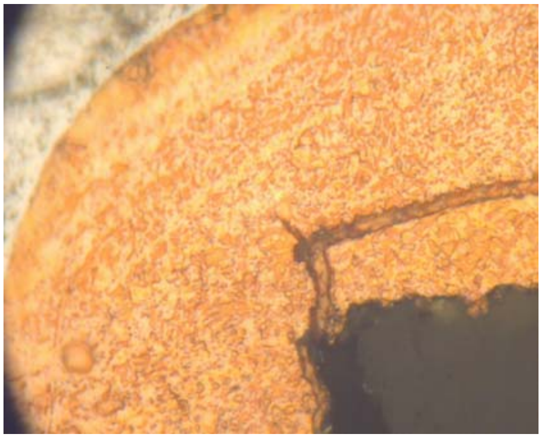


Figure 5 - Worst Case Starter Corner Crack seen in the Samples after 6X-Solder Floats at 288 °C

Further thermal cycling data involved liquid-to-liquid and air-to-air cycling comparing DC to pulse plating with different board materials. In the liquid-to-liquid cycling, the samples were held at –35 °C for 10 minutes, and then held at 125 °C for 10 minutes. In the air-to-air cycling, the samples were held at –35 °C for 15 minutes with a 5 second transfer time, then held at 125 °C for 15 minutes with a 5 second transfer time. Samples were pulled after 100, 200, 300, and 400 cycles in each case. After cycling, the samples were microsectioned and evaluated for thermally induced anomalies per IPC-6012A, Class 2. The PPR plated samples displayed superior performance compared to the DC plated samples. Representative data from the liquid-to-liquid cycling experiments are shown in Figure 6.

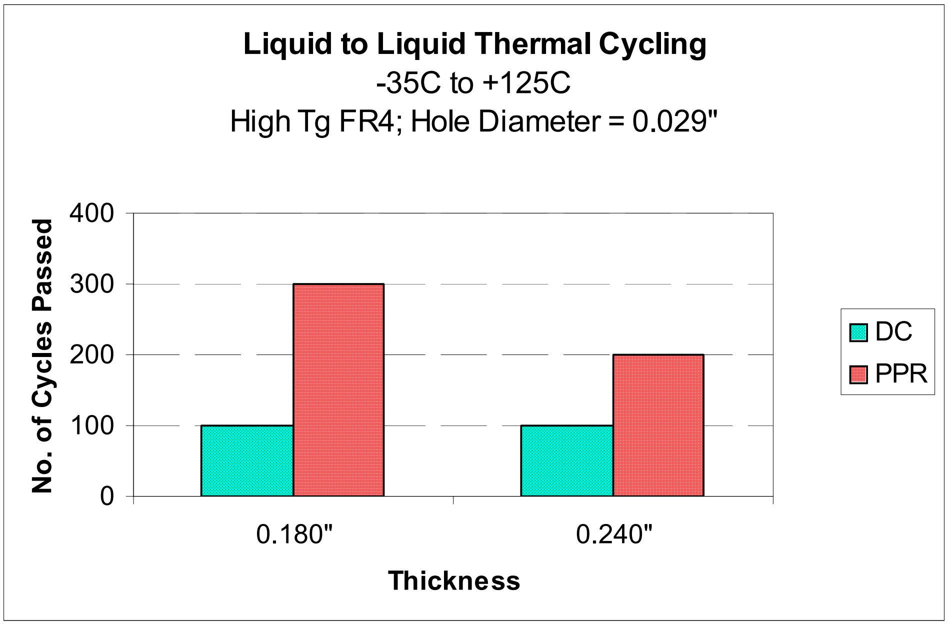


Figure 6 - Number of Cycles Passed by DC and PPR Plated Samples after Liquid-to-Liquid Thermal Cycling for different Board Thicknesses

New Analytical Techniques

Two analytical methodologies have been developed to monitor the PPR chemistry: a brightener analysis and a by-product detection technique. Brightener analysis for most plating baths is presently performed using cyclic voltammetric stripping voltammetry (CVS). CVS analysis involves performing a cyclic voltammogram with a dilute bath sample. A typical voltammogram is performed with a voltage sweep from an anodic potential to a cathodic potential, which then returns to the first anodic potential. Copper is plated onto the electrode during the cathodic sweep, and is then stripped off the electrode during the anodic sweep. The charge under the stripping wave is measured, which corresponds to the amount of copper that is plated during the plating step. The more brightener that is present in the plating bath, the more copper that plates during the cathodic sweep. Two subsequent additions of additive are made to the sample, and the attendant CVS sweeps are performed. A calibration curve is prepared, and the amount of additive in the original sample is then measured by extrapolation. The drawbacks to this method include the 15-20 minute time period to obtain a measurement, and that a dilute bath sample is used – perhaps changing the equilibrium of the brightener species.

The technique developed for PPR chemistry takes less than one minute for the analysis, uses a different electrochemical algorithm, takes a direct measurement of a bath sample with no dilution, and offers a ten-fold increase in sensitivity. The algorithm involves the use of cyclic pulse voltammetric stripping (CPVS) voltammetry, which includes a cleaning step, a constant voltage plating step, and a stripping step. This algorithm allows for direct measurement of the plating bath with no dilution. After generating a calibration curve from samples with known brightener concentrations, the brightener level of the bath sample can be determined. This new technique also uses new hardware that allows an even more sensitive response than a previous CPVS technique. When comparing the previous CPVS package (including both the algorithm and hardware) to the new CPVS package, the difference in instrument response is dramatic, as shown in Figure 7. A ten-fold increase in sensitivity is measured using the modified package.

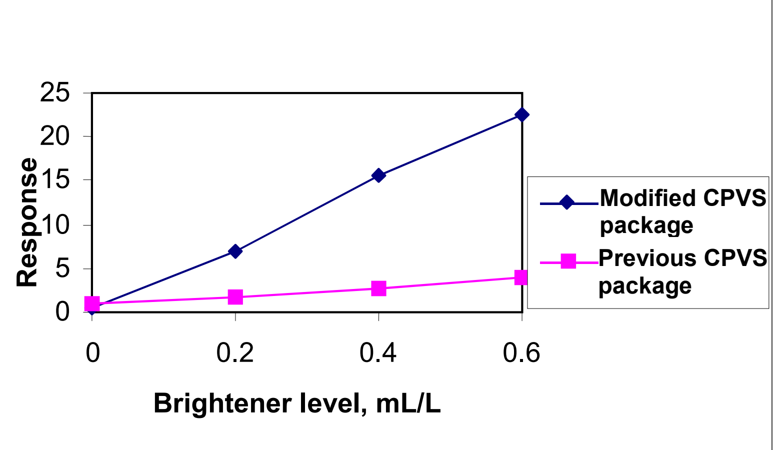


Figure 7 - Response of the Modified CPVS Package Compared to the Response of the Previous CPVS Package on a Shipley Bath Analyzer. Analysis was performed on Freshly Prepared Bath Samples of PPR Chemistry with Differing Amounts of Brightener

One of the main drivers for the development of the new PPR chemistry was to develop a pulse plating bath that would maintain its stability over a long period of time. In response to this, an analytical tool for measuring the amount of bath by-product was invented, called the “Stability Index.” Using the Stability Index method, the electrochemical response of an electrode immersed in a bath sample is monitored over time. Initially, the suppressor will adsorb on the surface of the electrode resulting in a response that is characteristic of a suppressed plating bath. If no by-product is present, that response will remain nearly constant for the full length of the ten minute scan. If there is by-product present in the bath; however, the by-product will adsorb onto the electrode. The electrode response will then change significantly with time during the scan, as the electrode surface becomes contaminated with by-product, see Figure 8. This curve can then be compared to standard curves that have been measured with varying amounts of a known brightener by-product. A relative amount of by-product in the bath can then be determined in “units.” If the amount of by-product is too high, then the level must be brought back in range before production continues. The by-product can be controlled by continuous carbon filtration with appropriately timed filter change-outs, dummy plating, and by diligent anode maintenance.

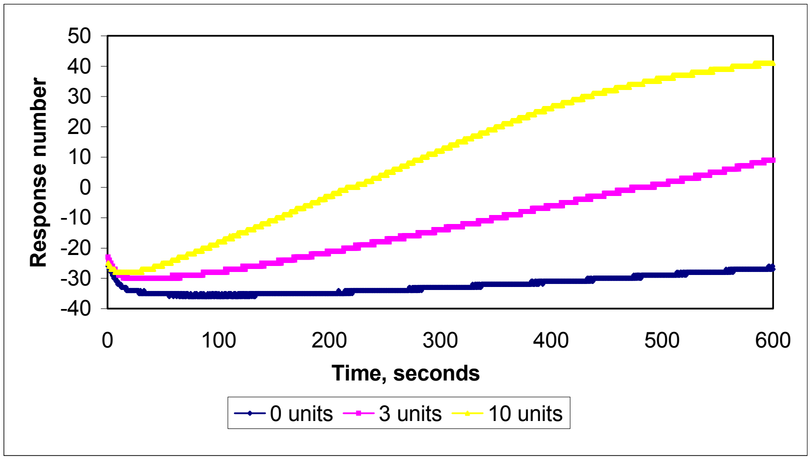


Figure 8 - Stability Index Measurements Performed on fresh PPR Chemistry Samples Spiked with Varying Amounts of Known By-Product. The Number of Units Refers to the Relative Amount of By-product Present in Each Sample

Correlation of Stability Index and PPR Performance

The performance of PPR chemistry deteriorates as the brightener by-product concentration increases. With the development of the Stability Index measurement, the relative amount of by-product present in the bath, and how the by-product affects plated through holes and blind vias can be correlated. For a series of plating experiments, a five-gallon tank was filled with fresh PPR chemistry, and panels of various hole sizes and thicknesses were electroplated at 10 ASF. The Stability Index of the bath was measured, and maintained at zero units. The tank was then spiked with a known bath by-product to bring the Stability Index value to 5. More panels with the same hole sizes and thicknesses were plated at 10 ASF, while maintaining the Stability Index at 5. This process was repeated for Stability Index measurements of 10 and 30. The bath was then dummy plated, the carbon filters were changed out, and the Stability Index was brought back down to zero units again. One final set of panels was plated in the bath. The plated samples were cross-sectioned and the throwing power was measured in each case, as shown in Figure 9. This clearly demonstrates that throwing power is directly related to the amount of by-product present in the bath. The throwing power decreases for all hole sizes and board thicknesses as the Stability Index increases (with one anomaly). The throwing power is effectively restored in all cases after the by-product level is returned to zero. It is significant to note that until by-product levels reach 50 units or more, traditional brightener analysis techniques are unaffected by the amount of by-product in the bath. As seen in Figure 9, the by-product affects throwing power even at 5-10 units. The Stability Index measurement therefore empowers bath operators by detecting by-product issues *before* the by-product begins to affect throwing power.

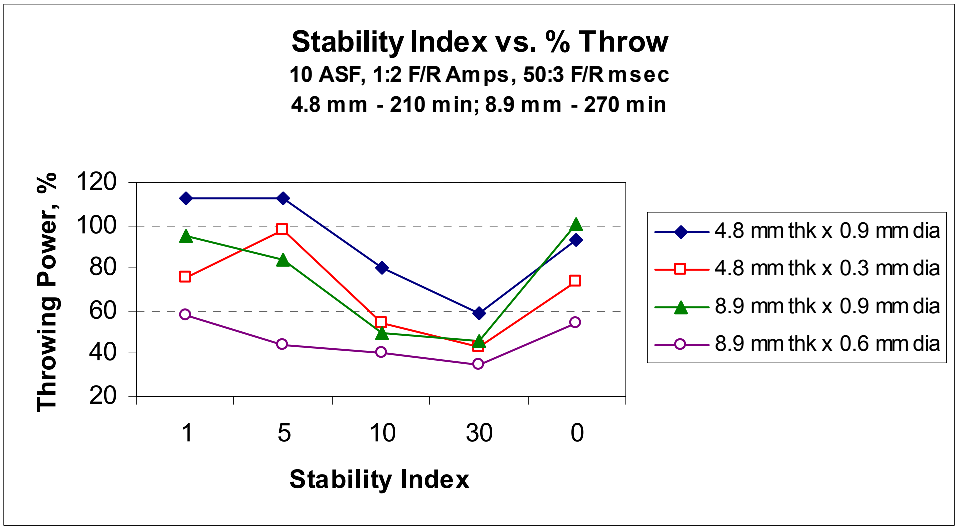
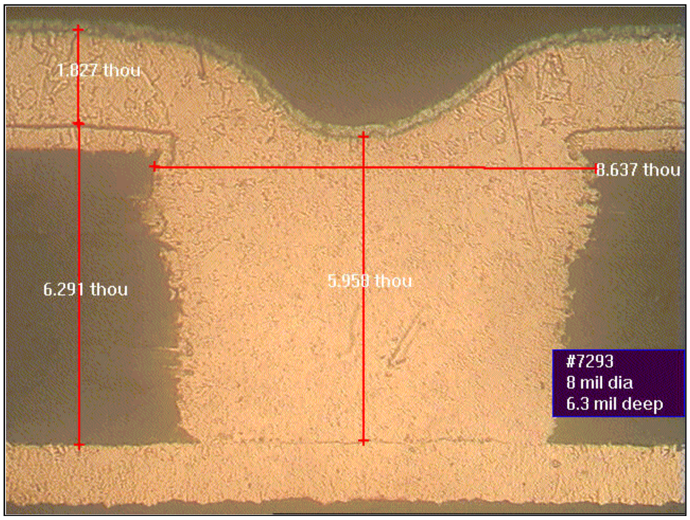


Figure 9 - Throwing Power versus Stability Index Measured for a Number of Board Thicknesses and Hole Sizes

The detrimental effect of the by-product is also evident in blind vias. In blind vias that are 200 microns wide and 150 microns deep, PPR chemistry with a low Stability Index (3) allows for near filling of the via. As the Stability Index of the PPR chemistry increases to 10, the plating rate inside the via decreases, and only conformal filling is possible, see Figure 10. Both situations in this case may be acceptable to a customer, but this demonstrates the effect that the excess by-product has on plating in different environments. The photographs in Figure 10 were obtained with vias from live boards in an operating bath, *i.e.*, the by-product was not added to the bath, but was generated with usage over time.



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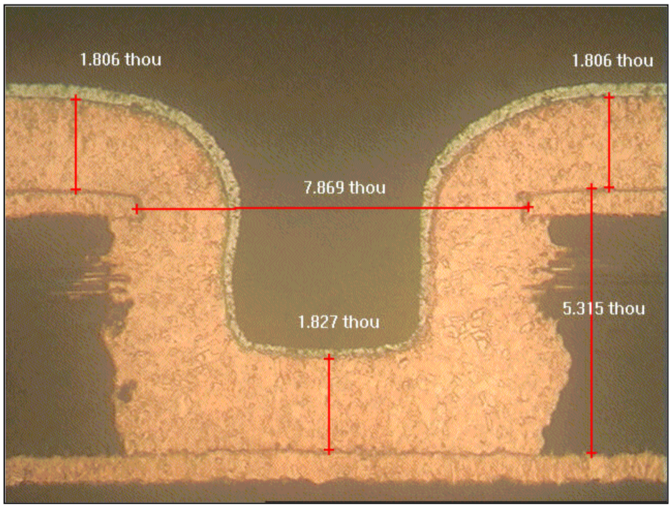

SI = 10

Figure 10 - PPR Performance in Blind Vias Measured as a Function of Bath Stability Index. Both Blind Vias were Plated Under the Same Bath Conditions using the Same PPR Wave

Conclusions

The PWB industry is looking for PPR to provide improved throughput, reliability, and surface distribution for the electroplating of copper onto printed circuit boards. Existing copper PPR systems suffer from short bath life, inability to plate high aspect ratio thick panels, and lack the capability to successfully plate mixed technology panels. A new copper PPR system, including chemistry, waveform, and analysis technique, was developed to address all of these issues.

This technology is enabling. Utilization of the new PPR chemistry and waveform gives the following capabilities over existing PPR systems:

- Ability to fill through holes in backplanes with a difficulty factor of 6 in and higher
- Ability to simultaneously plate through holes and microvias
- Improved throwing power with acceptable physical properties and high thermal reliability

In addition to the expanded process capabilities, analytical techniques have been developed for greater control of the plating bath. These techniques allow for:

- Rapid direct measurement of the brightener level
- Ability to track the relative concentration of by-product in the bath

- Selective removal of by-product to ensure product quality
- Predictable and consistent bath performance over time

At present, this technology is being used to produce both high aspect ratio panels and mixed technology boards for commercial applications.

Acknowledgements
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Using Periodic Pulse Reverse (PPR) for Plating Thick Panel Applications

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Agenda Topics

- Basic PPR Mechanism
- Product Objectives
- Product Development Approach
- Analytical Methods
- Performance
- Reliability
- Product Features Benefits

Total Potential Difference

Surface vs. Hole

$$\Delta E_t = \Delta\eta_{ct} + \Delta\eta_{mt} + E_{ir}$$

Where:

$\Delta\eta_{ct}$ = charge transfer overvoltage difference.
- governed by kinetics
- affected by additive chemistry

$\Delta\eta_{mt}$ = mass transfer overvoltage difference.
- governed by molecular motion
- affected by ion concentrations and agitation

E_{ir} = potential drop in the hole.
- governed by geometry of the hole
- affected by conductivity of the solution (eventual limit)

Throwing Power Considerations

- **For throwing power to equal 100%…**

  Surface current density = Hole current density

  $\Delta E_t = \Delta\eta_{ct} + \Delta\eta_{mt} + E_{ir} = 0$

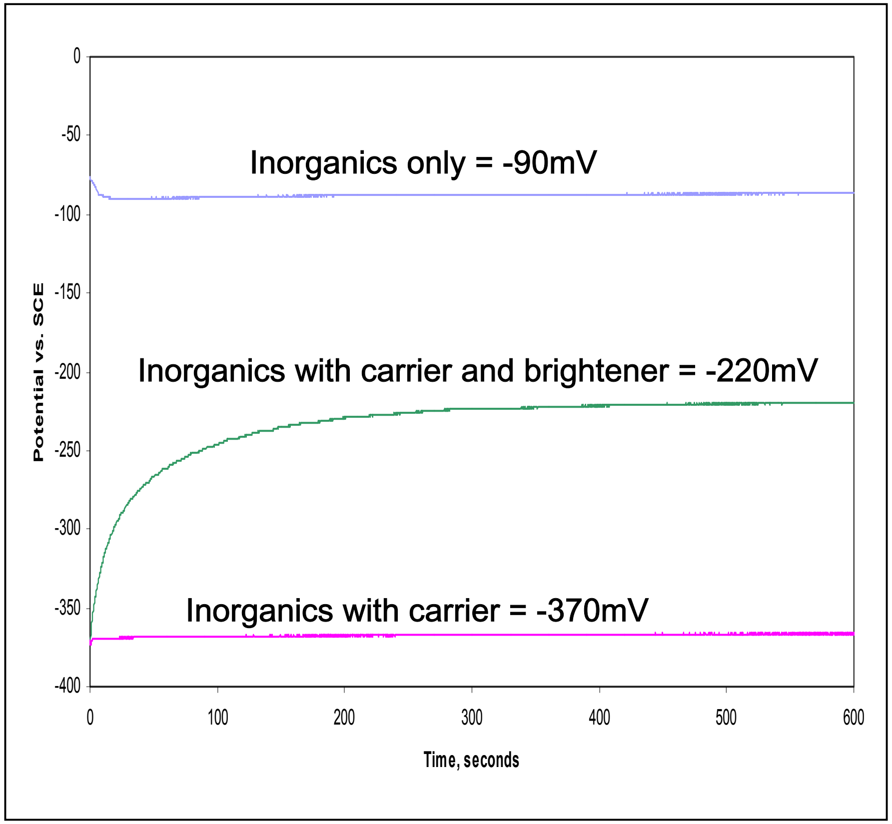
- **For throwing power to *exceed* 100%…**

  Surface current density < Hole current density

  $\Delta E_t = \Delta\eta_{ct} + \Delta\eta_{mt} + E_{ir} < 0$

Plating Potentials

Different Plating Environments

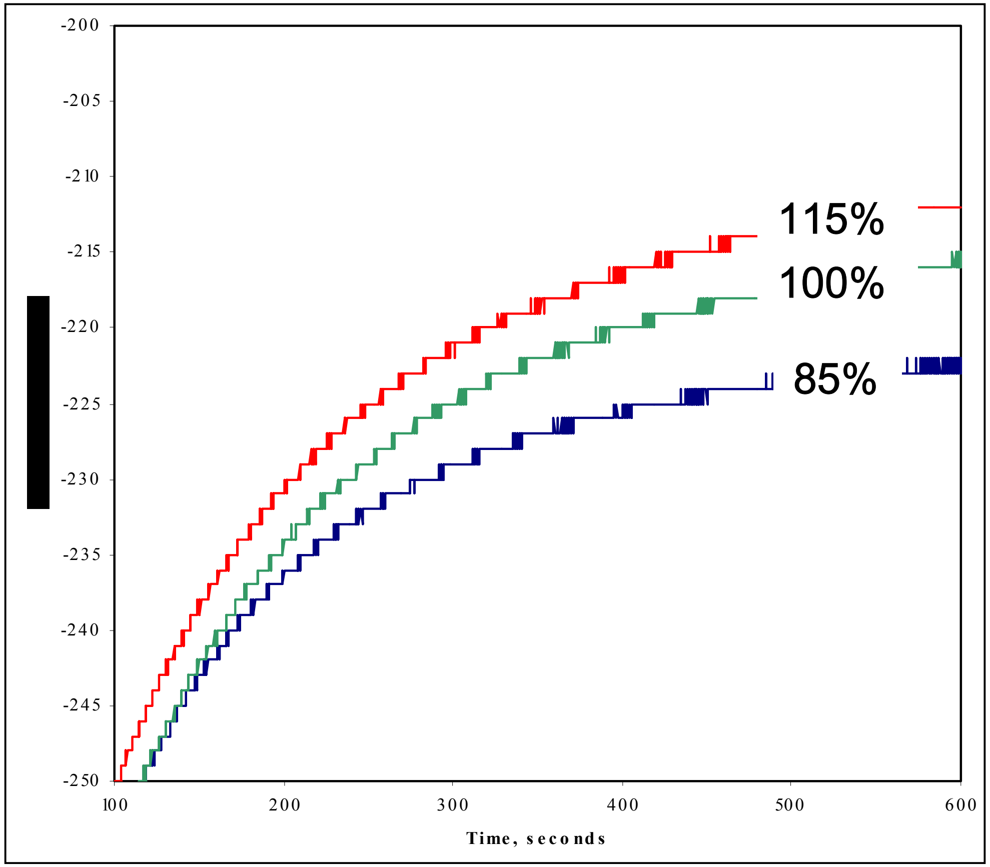


Increasing overpotential

- Inorganics has the lowest overpotential for copper plating
- Carrier suppresses the plating reaction
- Brightener accelerates the plating reaction

Plating Potentials

Different Brightener Concentrations



Increasing overpotential

- Increased brightener concentration decreases the overpotential for copper plating
- Optimum brightener concentration is a balance of rate enhancement and other plating attributes

Why Pulse for Increased Product Difficulty?

PPR technology enables multiple plating environments on a single substrate:

PPR Surface

- Brightener-deficient environment
- Increases η_{ct} on surface

PPR Hole

- Brightener-rich environment
- Minimizes η_{ct} in the hole

DC technology has homogeneous plating environments on the substrate:

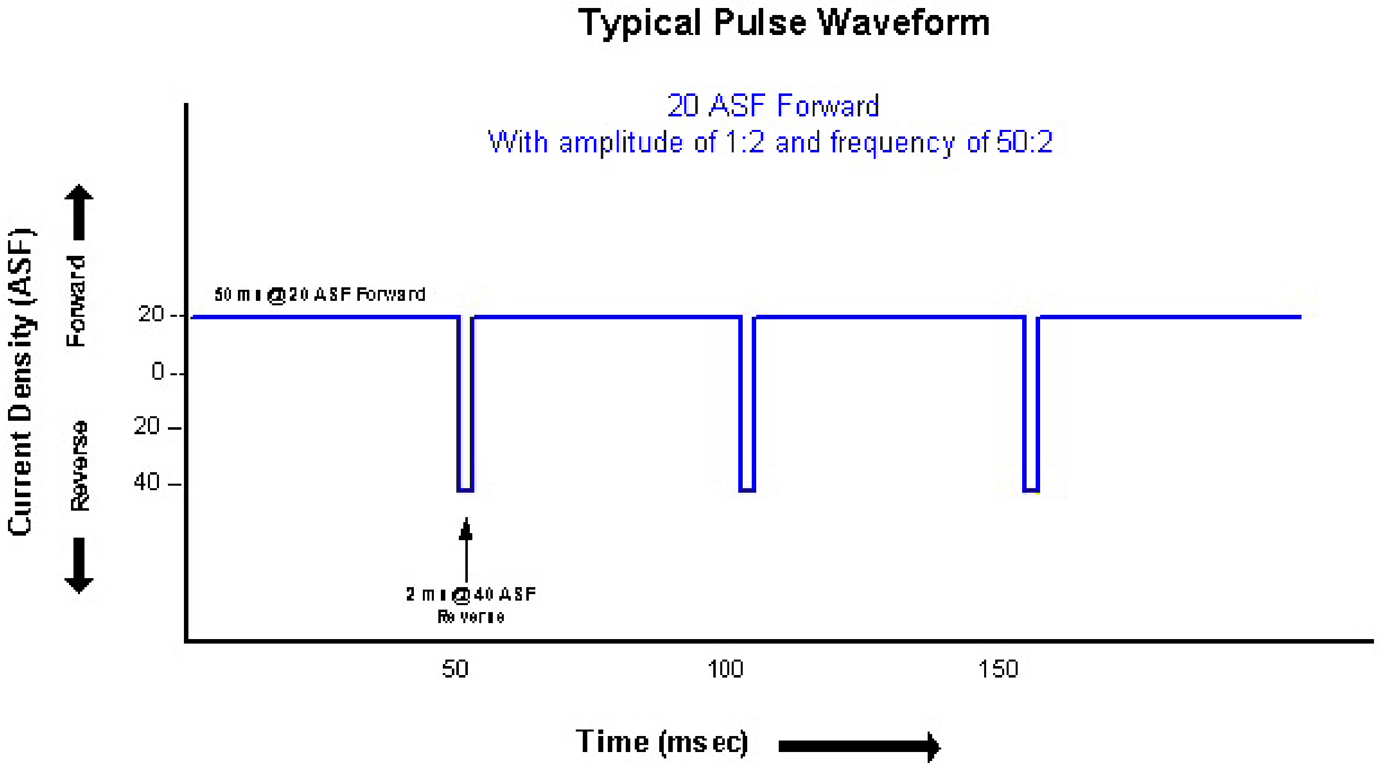
DC Surface

- Carrier/brightener mix
- Similar η_{ct} as the hole

DC Hole

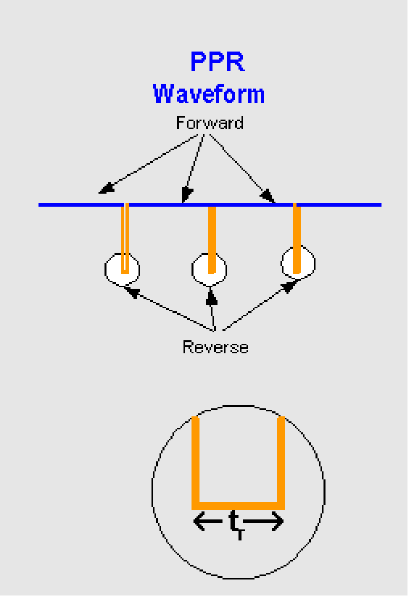
- Carrier/brightener mix
- Similar η_{ct} as the surface
- E_{ir} and η_{mt} become overriding factors

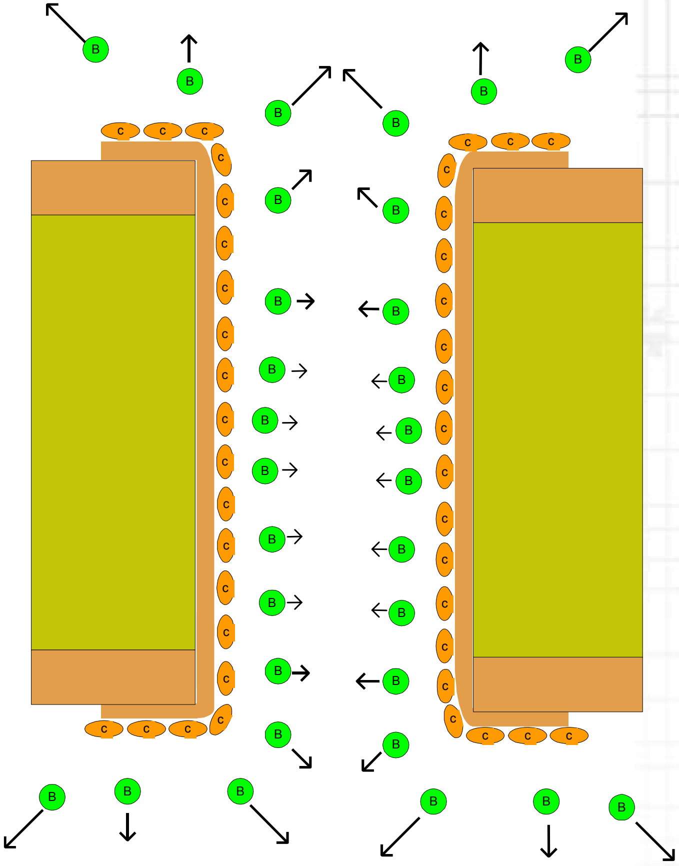
Typical Pulse Waveform



During the Reverse…t_R

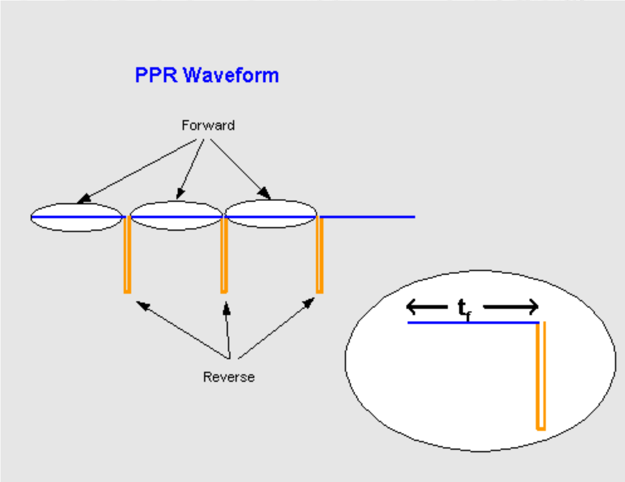
- Brightener desorbs from the cathode during reverse
- Brightener desorption is proportional to reverse CD
- Stronger brightener desorption in high reverse CD surface
- Weaker brightener desorption in low reverse CD hole
- Result is a brightener-rich PTH center, brightener-deficient surface

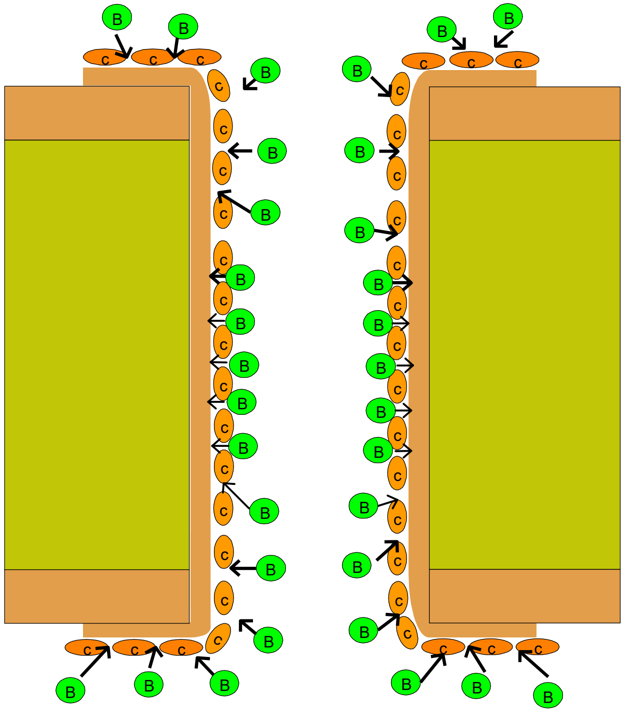




During the Forward…t_F

- Carrier is uniformly adsorbed on cathode surface
- Brightener is adsorbed on the cathode during the forward pulse
- Strong desorption of Brightener occurs in HCD areas during reverse pulse, slower to re-adsorb in forward pulse resulting in a carrier rich surface
- Only partially desorbed in LCD areas, the brightener readsorbs quicker in the hole during forward current resulting in a brightener rich surface





Model for PPR Throwing Power Performance

- **Brightener-deficient surface**
  - Matte/Satin deposit
  - Slower plating rate - desired

- **Brightener-rich hole**
  - Bright deposit
  - Fast plating rate – desired

- **Combination**
  - High throwing power
  - Excellent physical properties

Next Generation PPR

Primary Product Objectives

- **Improve PPR bath stability**
  - Idle time
  - Reduce and manage byproduct generation
- **Improve thick panel throwing power**
  - 0.187” (4.7mm) and greater, up to 0.320” (8.1mm)

Product Development Approach

Thick Panel Throwing Power Improvement

- X **Standard process with modified additive package**
  - X Throwing power
  - ✓ Physical properties

- X **Modified additive + new waveform**
  - ✓ Throwing power
  - X Physical properties

- ✓ **Modified additive + waveform + new inorganic matrix**
  - ✓ Throwing power
  - ✓ Physical properties

Product Development Approach

Stability Improvement

- Modified Additive Package
  - Chosen to generate less byproduct
- Bath Analysis
  - Stability Index
    - Leading indicator for taking action
  - Improved Brightener analysis procedure
    - More sensitive for modified additive package
- Byproduct Management
  - Controlled byproduct removal via carbon filtration and dummy plating
  - Done in conjunction w/ Stability Index

Novel Analytical Techniques

Old Method

Brightener Analysis

- CVS
- Copper Plating on Pt
- Byproduct detection limit above concentration where problems occur

New Methods

Brightener Analysis

- CPVS
- Faster than CVS
- 10X more sensitive than CVS

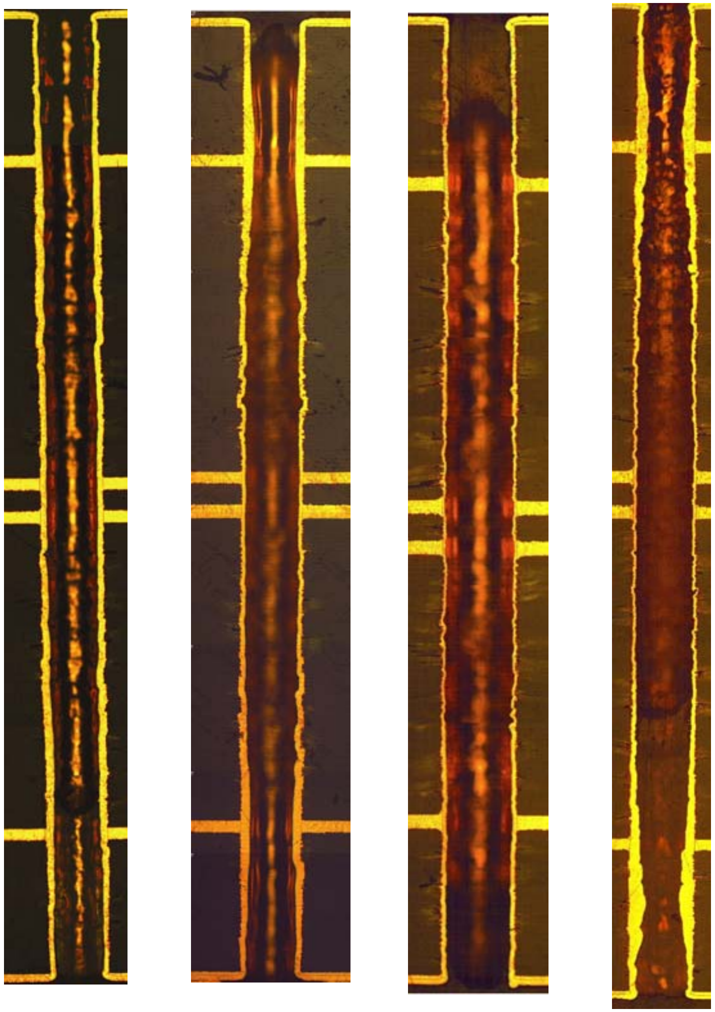
Stability Index

- Adsorption on Cu
- Ultra-sensitive detection allows action before problems arise
- IP in progress

Improved analysis = better process control

PPR
Byproduct Effects

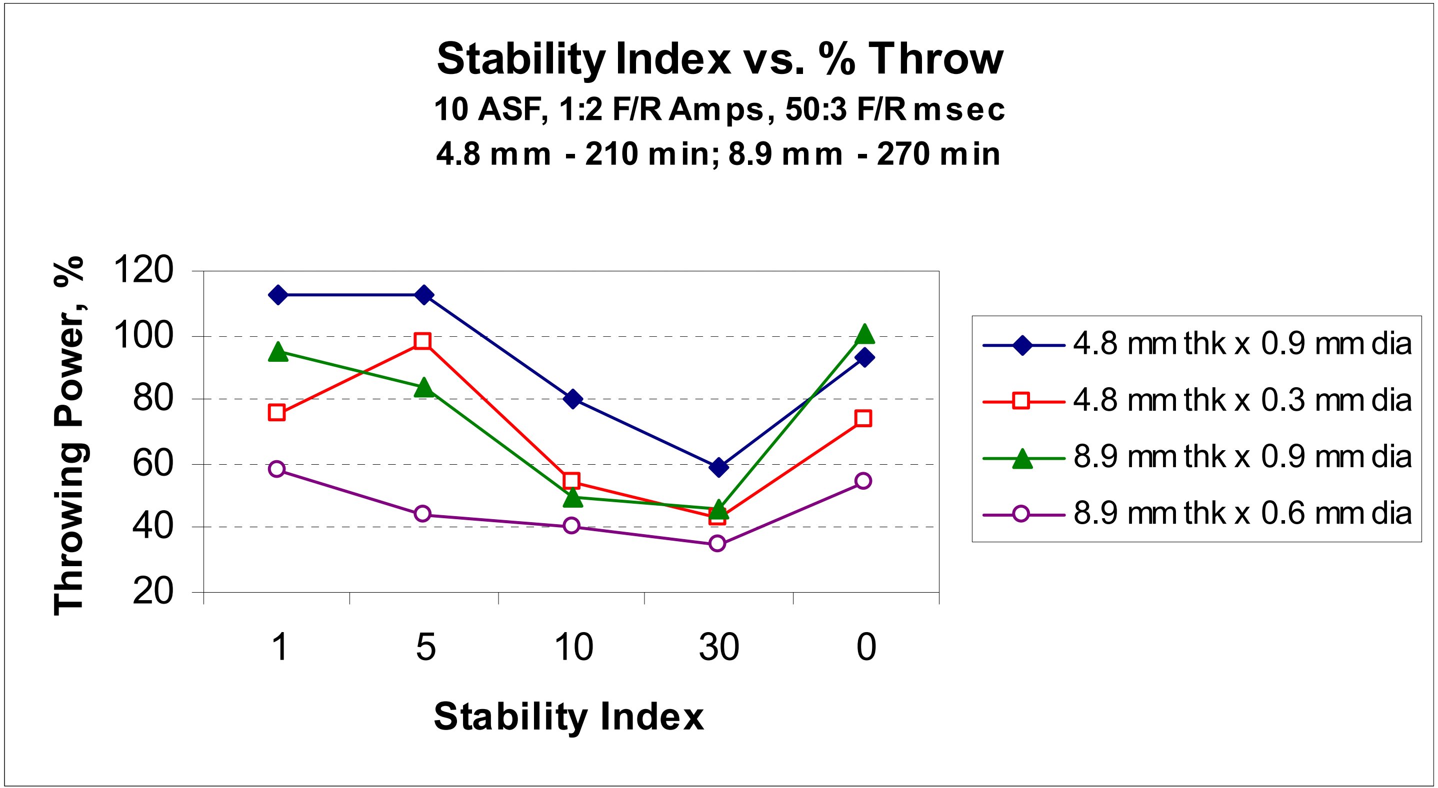
20 ASF
4.8mm thick x 0.3mm dia



SI = 1	SI = 10	SI < 5	SI > 10
TP = 92%	TP = 61%		
0.5 ml/L A	0.5 ml/L A	0 ml/L A	0 ml/L A

Stability Index

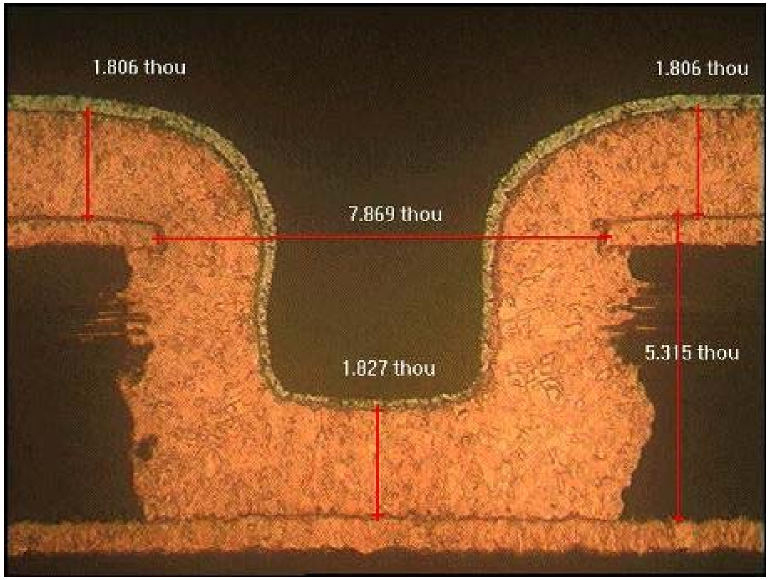
Backplane Throwing Power



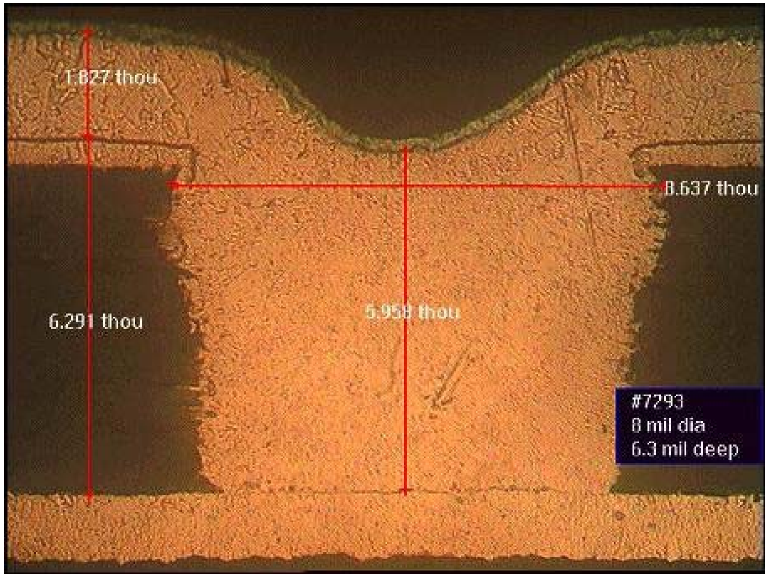
Stability Index

HDI Microvia

Stability Index = 10



Stability Index = 3

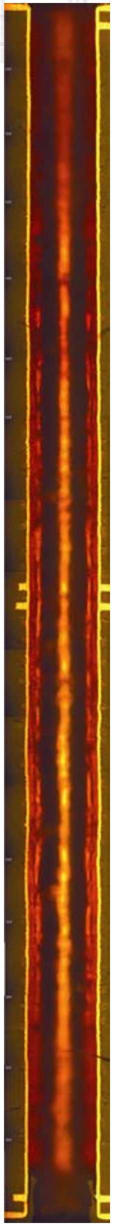


Microvia Dimension: 200 x 140um deep

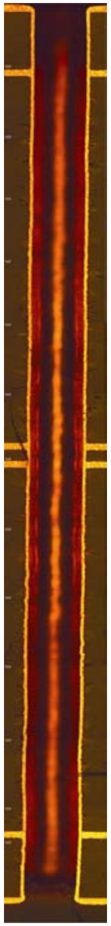
Next Generation PPR

Difficulty Factor Comparison

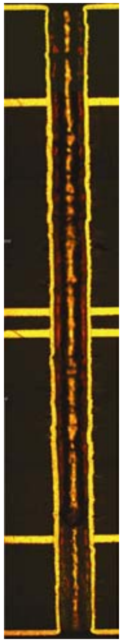
DF = 6.2
0.400” (10.2mm) Thick
0.026” (0.66mm) Dia
6 hr @ 10 ASF
TP = 73%



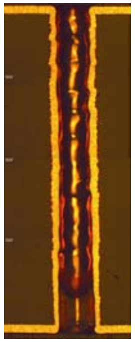
DF = 4.5
0.300” (7.6mm) Thick
0.020” (0.5mm) Dia
6 hr @ 10 ASF
TP = 73%



DF = 2.9
0.187” (4.8mm) Thick
0.012” (0.3mm) Dia
90 min @ 20 ASF
TP = 92%

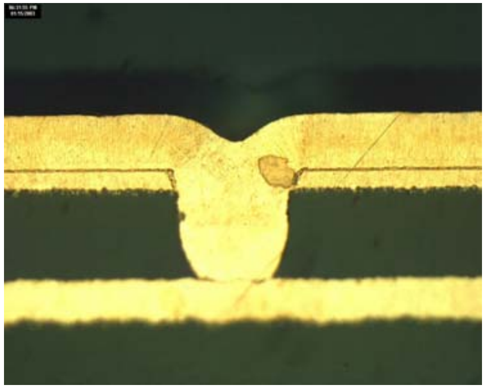


DF = 0.64
0.093” (2.4mm) Thick
0.0135” (0.34mm) Dia
90 min @ 20 ASF
TP = 97%

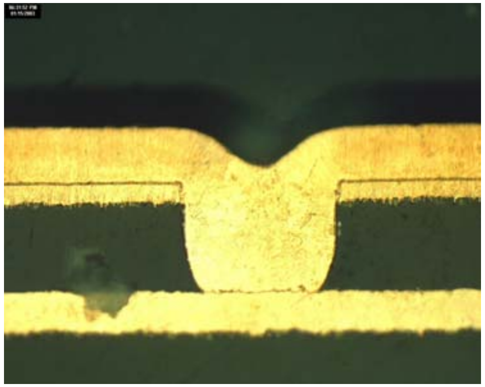


Next Generation PPR

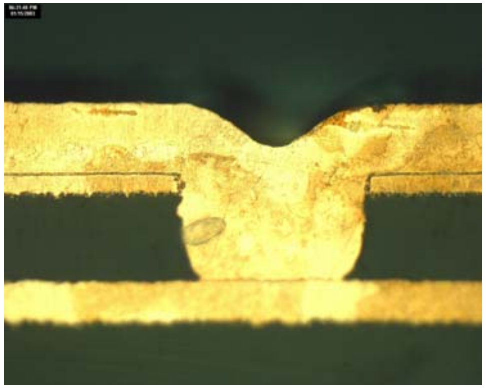
HDI Product



100 x 125um

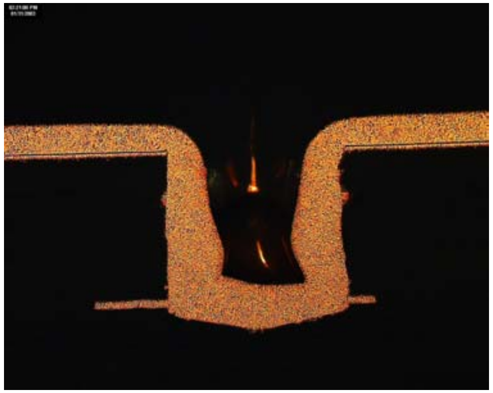


125 x 125um mil



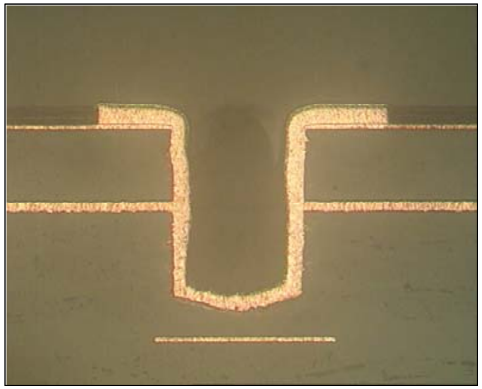
150 x 125um

Laser Ablated



350 x 350um

450 x 350um



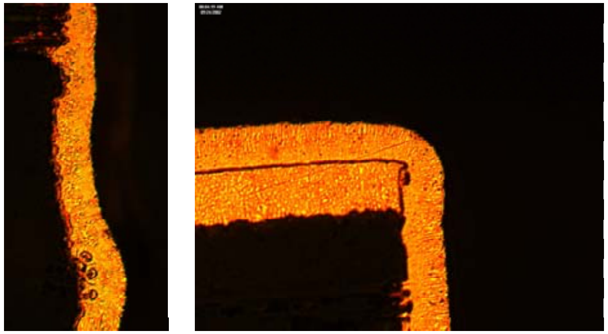
400 x 500um

Mechanical Drilled

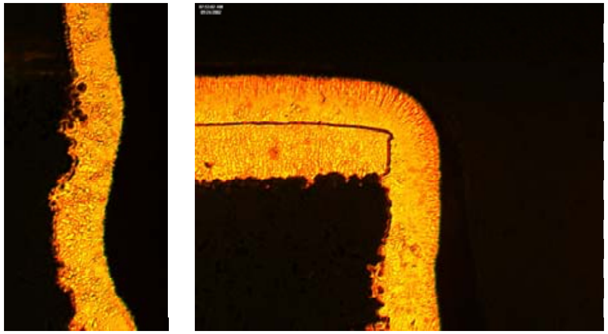
Next Generation PPR

Grain Morphology

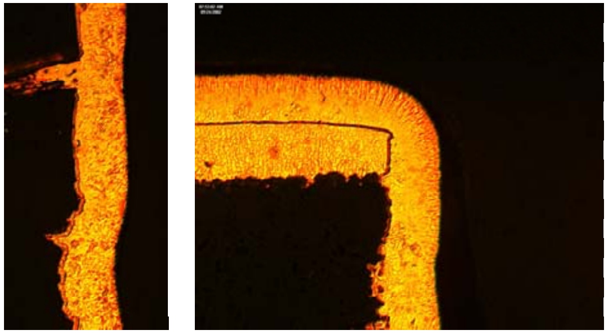
8.1 mm Thick
0.66 mm Dia



50:1.8 F/R msec
1:3 F/R current

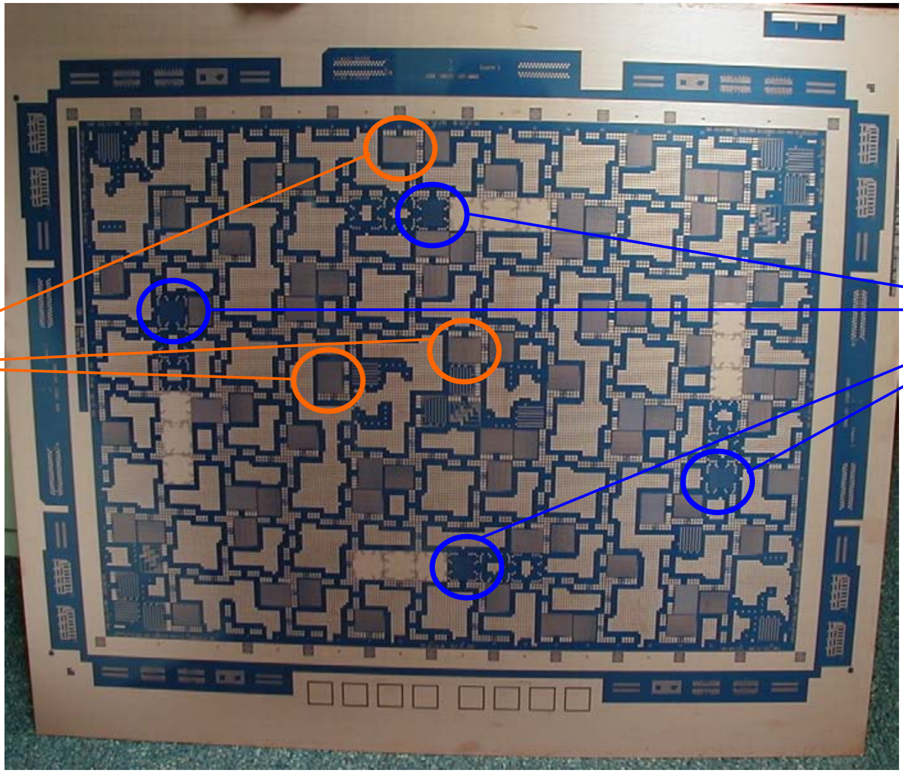


50:2.2 F/R msec
1:3 F/R current



50:2.6 F/R msec
1:3 F/R current

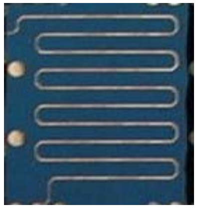
Test Detail – Pattern Plate Test Board

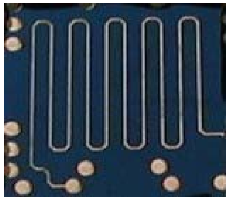


Dense line

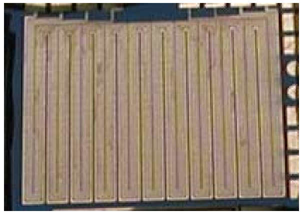
Isolated line

Isolated line



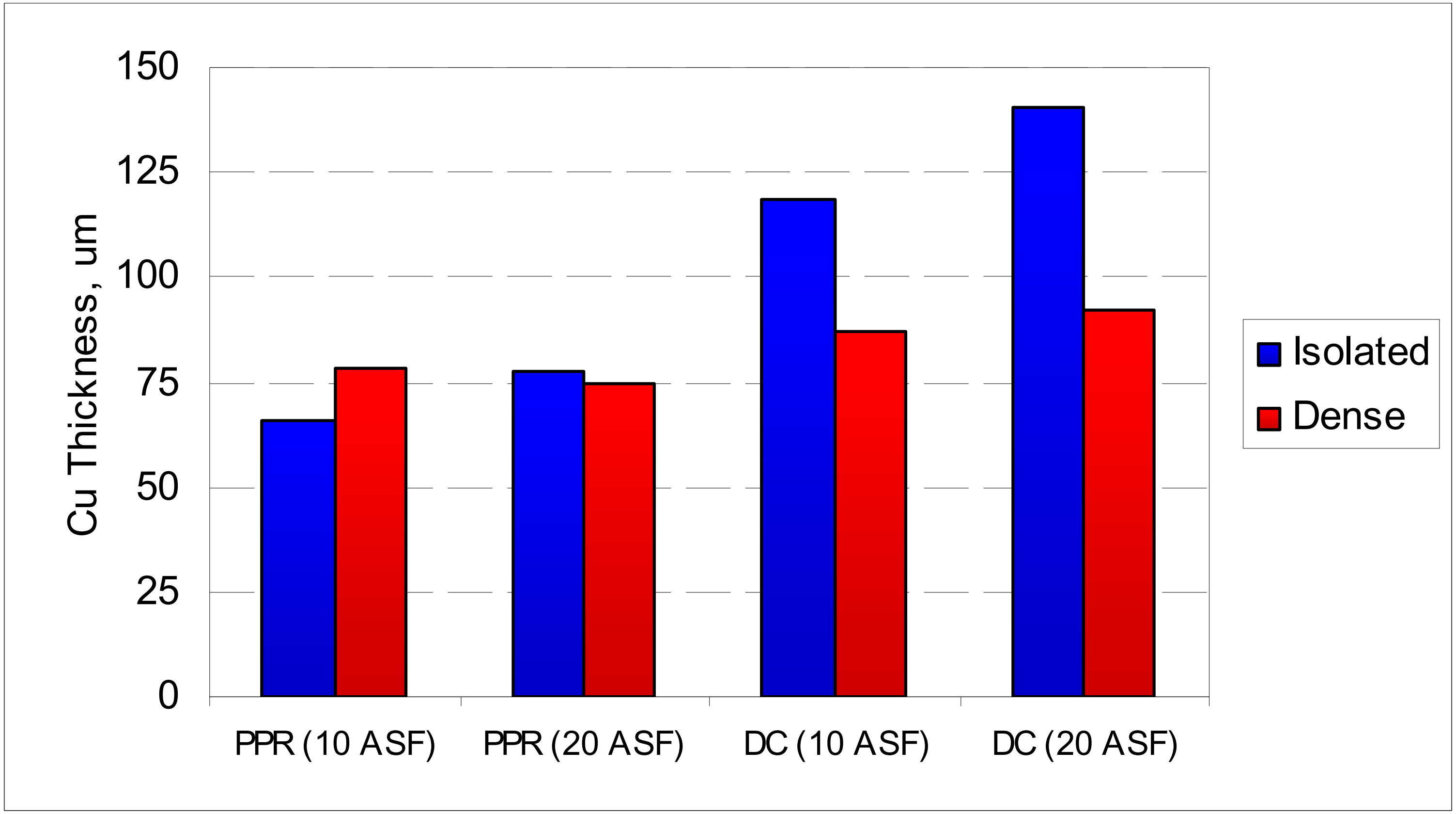


Dense line



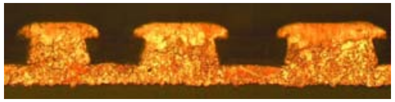
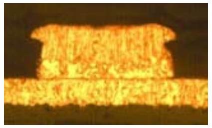
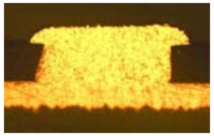
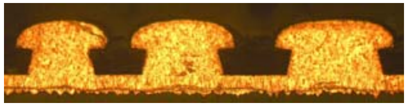
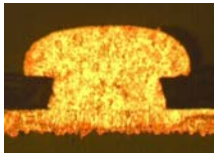
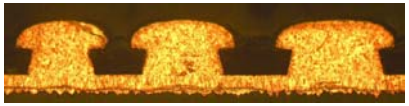
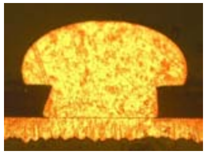
Comparison of DC and PPR

Pattern surface thickness distribution



Comparison of DC and PPR

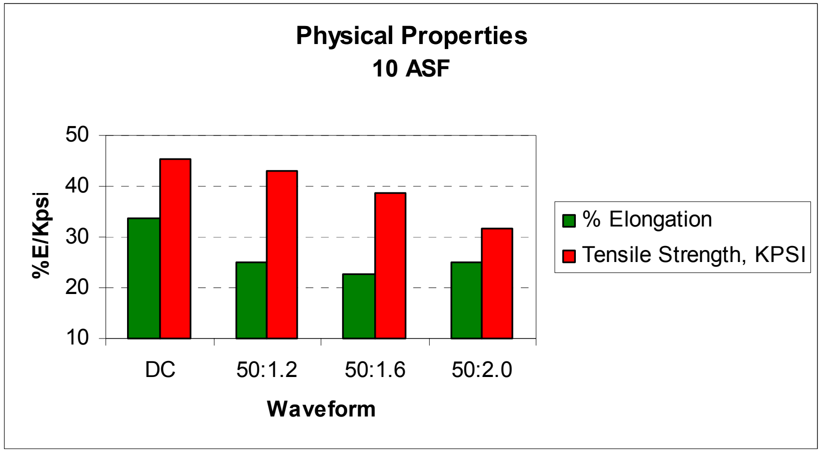
Trace profile

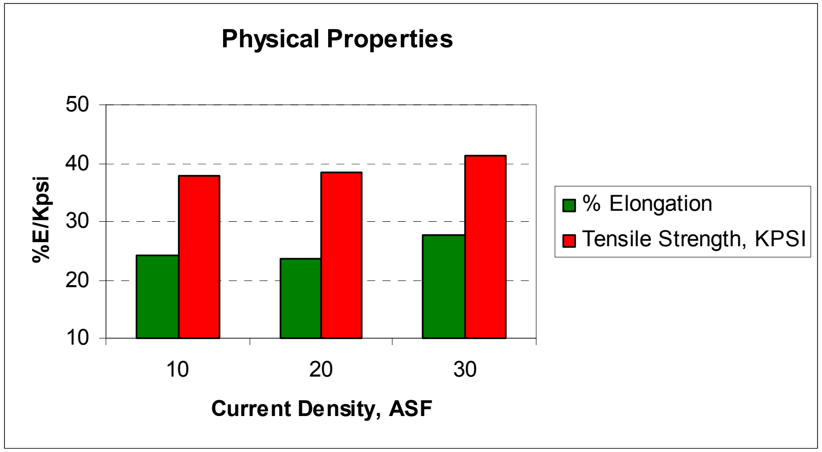
Rectification/CD	Dense	Isolated
PPR – 10 ASF		
PPR – 20 ASF		
DC – 10 ASF		
DC – 20 ASF		

Next Generation PPR

Physical Properties

- Measured tensile strength for PPR is typically lower than DC process
- Several factors influence PPR tensile strength
  - Reverse current time ratio
  - Reverse current ratio
  - Current Density (marginal effect)





Next Generation PPR

Physical Properties

- Due to mechanism of PPR and the different plating environments between surface and hole, T&E foils plated with production PPR waveforms are not representative of actual PTH physical properties
- Typical PPR foil physical properties
  - Elongation: 20 – 35 %
  - Tensile Strength: 35 – 45 Kpsi
- PPR exhibits excellent thermal shock and cycling performance

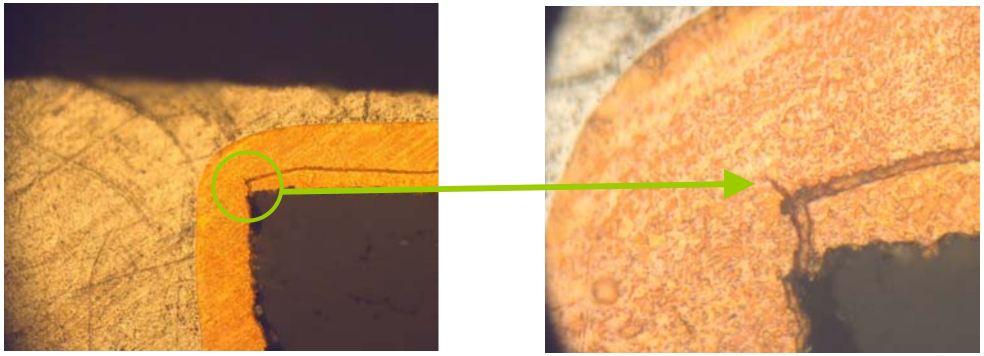
Next Generation PPR

Reliability – 6 X 10 sec, 288C Solder Float

- Customer Qualification
  - 90 days operation
  - >120 test panels processed and solder stressed

		Corner Cracks			Barrel Cracks		
Panel Thickness	**Hole Dia**	**No. Corners**	**% Partial**	**% Complete**	**No. Holes**	**% Partial**	**% Complete**
2.4 mm	0.9 mm	480	0.2%	0.0%	48	0.0%	0.0%
2.4 mm	0.34 mm	520	1.2%	0.0%	52	0.0%	0.0%
4.8 mm	0.9 mm	640	2.2%	0.0%	64	0.0%	0.0%
4.8 mm	0.32 mm	640	1.3%	0.0%	64	0.0%	0.0%
7.6 mm	0.9 mm	480	0.6%	0.0%	48	0.0%	0.0%
7.6 mm	0.5 mm	480	0.6%	0.0%	48	0.0%	0.0%

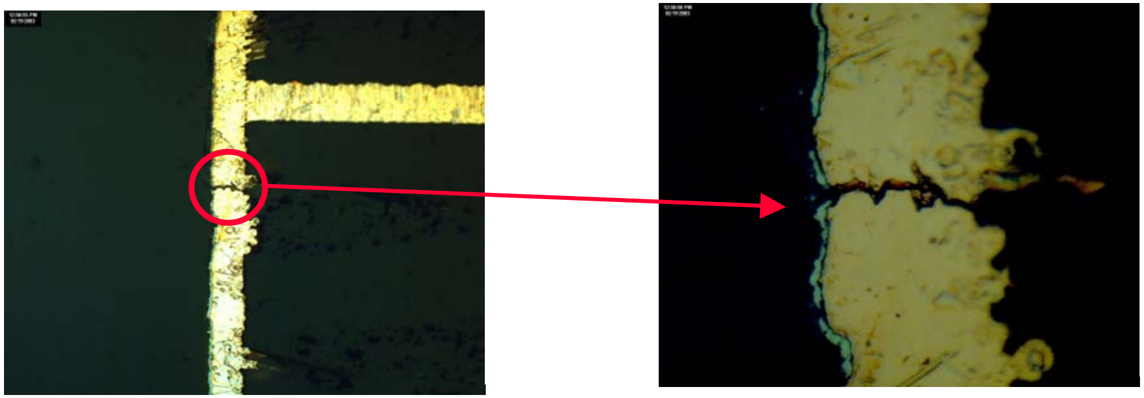
Typical Partial Corner Crack



Next Generation PPR

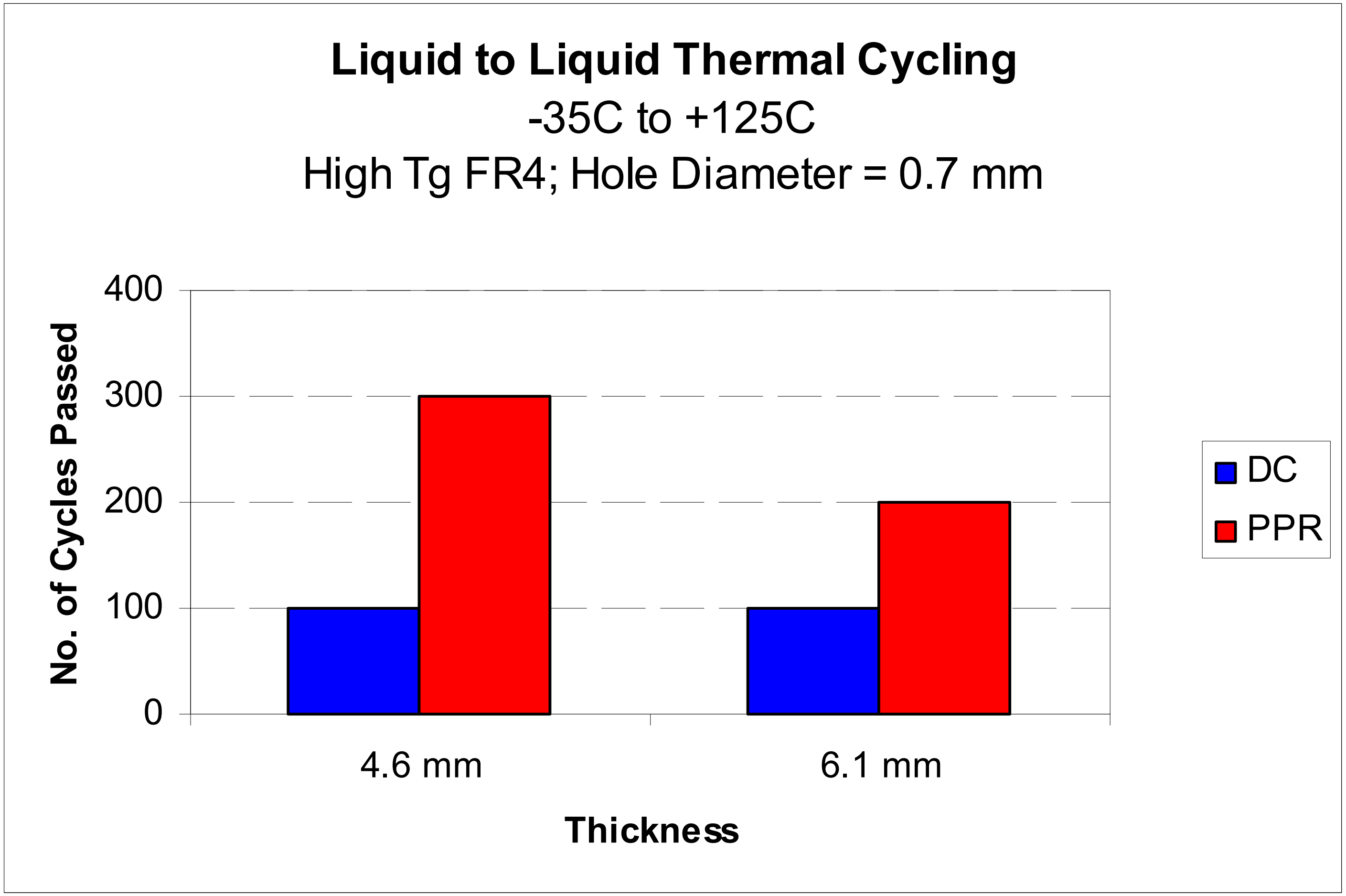
Reliability - IST

Board Thickness	4.0 mm
Hole Diameter	0.66 mm
Forward Current Density	10 ASF
Waveform	50:1.6 (3:1)
Selected bath parameters	0.4 ml/L A, 20.9 ml/L B, 32 ppm Cl
IST test mode	66° C/ no compensation/precond
Historical Mean Baseline (DC)	675 +/- 192
Cycles to Failure – CuPulse	1683
Failure mode	Barrel cracks



Thermal Cycling Reliability

DC vs. PPR



Next Generation PPR Parameters

Parameter	Target	Range
$CuSO_4.5H_2O$	80 g/L	70 – 90 g/L
H_2SO_4	225 g/L	215 – 235 g/L
Cl^-	32 ppm	30 – 35 ppm
PPR-A	0.22 ml/L	0.18 – 0.26 ml/L
PPR-C	15 ml/L	10 – 20 ml/L
Current Density		10 – 20 ASF
F/R Current		1:2 – 1:3 A
F/R Time		50:1.4 – 50:3.0 msec
Temperature	25°C	22 – 29°C

Next Generation PPR

Features and Benefits

Features

- New Organic Package
  - New Brightener & Carrier package
- Optimized Inorganic Matrix
  - Matched to the new organic package

Benefits

- Enhanced plating performance on HAR product
  - Improved grain structure and brightness in the hole
- Mixed technology capable (PTH & BVH)
- Improved stability & process consistency
- Improved PTH leveling
- Improved reliability
- New/improved analytical methods

Acknowledgements

- Mark Kapeckas, Project Leader
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- Frank Oberholtzer from Teradyne (Nashua, NH)