Uniformity of Nickel Plating Thickness in High Aspect Ratio Plated Through Holes

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Abstract
Nickel plating is often used on PWBs to increase wear resistance and to prevent diffusion between copper and other plated metals. The nickel plating is often present in through holes as well as on the surface, such as when the entire PWB panel is nickel/gold plated or when press fit pins are used for assembly. When the plated through holes are evaluated by microsectioning, it often becomes apparent that the nickel plating is not uniform. It tends to be much thinner in the middle of the hole than on the surface of the board, and may not meet minimum thickness requirements. This paper will evaluate the effect of various plating parameters and chemical additives on through hole plating uniformity. Data will be presented comparing direct current and pulse plating. This paper will also evaluate how the addition of chemical additives to increase throwing power affects the intrinsic stress and grain structure of the nickel. Tests include plating PWBs having through holes of varying diameters and aspect ratios with nickel in thicknesses up to 100 mils. Nickel thickness and uniformity are evaluated both by microsection and X-ray fluorescence measurement techniques.

Introduction
As advanced printed wiring board (PWB) designs become more complex, the thickness of the board has increased due to the greater number of layers. The plated through hole (PTH) diameters have become much smaller to accommodate the greater density of advanced designs. As the PTH aspect ratio (board thickness divided by hole diameter) increases, it becomes more difficult to obtain a uniform plating in the hole.

The performance specifications of MIL-PRF-55110G for high reliability PTH nickel deposits requires a minimum plating thickness of 5 microns in the hole. This minimum thickness is difficult to obtain when plating high aspect ratio holes without resulting in excessive plating on the board surface. The difference in the plating thickness in the hole and the board surface is referred to as the surface-to-hole thickness ratio (SHTR). The SHTR is determined by dividing the deposit thickness on the surface by the deposit thickness in the hole. The goal when fabricating high reliability PTH's is to keep this ratio as low as possible.

PWB designs that require selective PTH's are particularly challenging to obtain a low SHTR because of the high current density on the surface of the board around the hole. As a result of the increased current density on the holes annular ring, the plating is much thicker on the surface then in the center of the hole. If the plating on the surface layer becomes too thick while trying to obtain the minimum thickness in the center of the hole a number of problems can arise such as: a decrease in the hole diameter so components won't fit, increased stress between the plated layers, and mushroom plating on surface pads that can trap photo resist.

Plating formulas with high throwing power are designed to overcome the limitations of conventional plating formulas. High throw plating baths distribute the current more evenly, resulting in a uniform plating layer in the hole. Some high throw plating baths reduce the amount of organic additives (carriers, brighteners, levelers) in their chemistry to obtain the higher throwing power. Therefore when utilizing these types of plating baths, a complete analysis of the deposit must be performed to ensure that it meets all the performance and specification requirements.

A number of plating experiments were conducted with the goal of achieving the lowest possible SHTR while meeting the plating specifications required for flight qualified PWBs. Also, tests were conducted to determine the highest aspect ratio through hole that can be reliably plated.

Two plating formulas were compared in these experiments. A sulfamate bath was selected because of the low stress deposits it produces and a bromide bath specifically designed for high throw plating. Each bath was also compared with the addition of a grain refiner additive. The plating parameters that were varied for these experiments were: rectification, direct current (DC) vs pulse current, solution agitation and current density.

Analysis of the nickel deposit included, stress measurements of the as plated nickel and after a thermal cycle, surface roughness, thermal shock and thermal stress tests were performed.

Plating Equipment
All experiments were conducted in a 5 gallon tank. Agitation was supplied by a recirculation filter pump with a center tank sparger. The sparger can be adjusted for direct agitation (Figure 1) or indirect agitation (Figure 2) to the substrate.

The nickel anodes were sulfur free and anode bags were used. Kraft Dynatronix models DUP10-1-3 and DP20-5-10 power supplies were used.

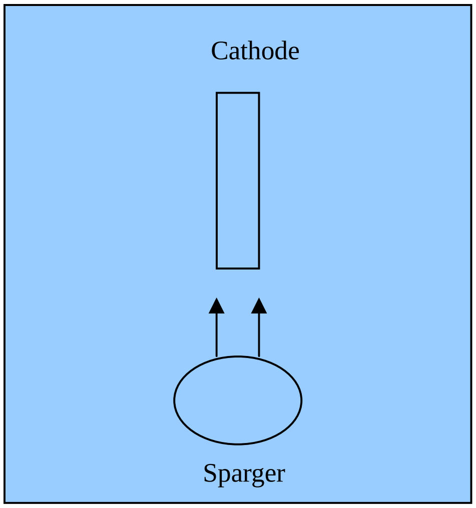

Figure 1 - Direct Agitation

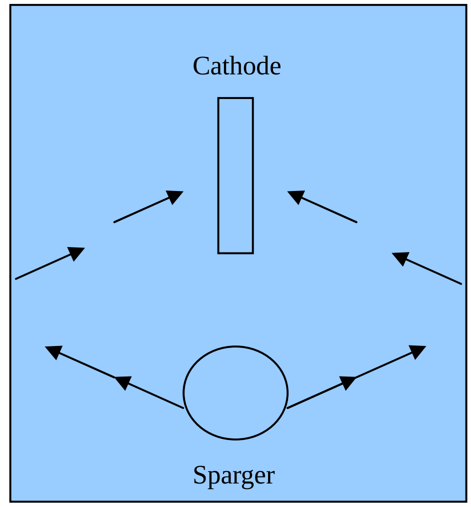

Figure 2 – Indirect Agitation

Experiment Details

This study used polyimide boards of two thicknesses 62 mils and 93mils. The board design variables included seven hole sizes of 8, 10, 15,20,28,40, and 50 mils representing aspect ratios from 1.25:1 up to 11.37:1. The boards were drilled, electroless copper plated, patterned, electrolytically copper plated as a 12”x18” panel. The panels were then routed to 2”x 4” test coupons. The test coupons were patterned with dry film photoresist for selective plating (Figure 3).

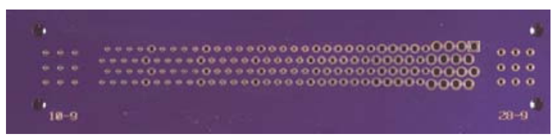

Figure 3 -Test Coupon

Plating experiments were conducted with sulfamate and a bromide plating formulas. Current densities of 5, 15, and 30 amps per square foot (ASF) were compared. Pulse plating with a 10% duty cycle (0.1sec.on-0.9sec.off) was compared to direct current. The solution flow was varied utilizing direct and indirect agitation as shown in Figures 1 and 2. Tests were conducted with the addition of a grain refiner in each bath as well.

Pre plate preparation consisted of a standard acid cleaner, microetch and an acid activation with a 2 min. deionized water rinse between each step (Figure 4).

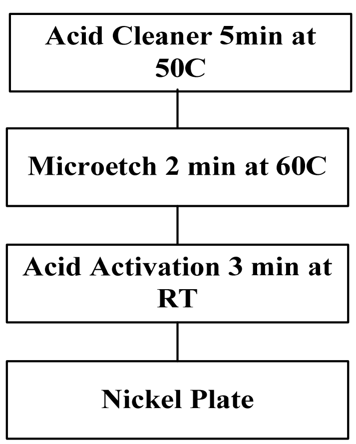

Figure 4 - Pre plate process flow

The plating thickness on the surface of the coupon was measured with a Fischerscope XDLM x-ray fluorescence system. The test coupons were then microsectioned and optical microscopy was used to determine the nickel deposit thickness in the through hole. The 28 mil hole was used as the control.

Test Results

The experimental matrix listed in Table1 shows the SHTR measured from a 28 mil hole in the test coupon. The results in Table1 clearly show that the SHTR is much lower with the bromide bath compared to the sulfamate bath. The best results were obtained in the bromide bath with DC plating and a current density of 5 ASF with indirect agitation. Pulse plating at 15 ASF with direct agitation also resulted in a low SHTR.

Indirect agitation appears to increase the throwing power when DC plating at a low current density. Conversely, direct agitation improved the throwing power when pulse plating. This could be attributed to the fact that when pulse plating, the metal ions are replaced at the cathode film during the off cycle. Therefore the increased solution flow would increase the plating efficiency. When DC plating, too much solution flow actually reduces the throwing power.

Table 2 shows the experimental matrix with the grain refiner additive. The addition of the grain refiner did not improve the SHTR in either of the plating baths. Further studies will be performed with different additives.

Table 1- Experiment matrix – Surface to Hole Thickness Ratio: 28 mil hole

	Sulfamate Bath				Bromide Bath			
Current Density	DC Direct Agitation	DC Indirect Agitation	Pulse Direct Agitation	Pulse Indirect Agitation	DC Direct Agitation	DC Indirect Agitation	Pulse Direct Agitation	Pulse Indirect Agitation
	.062 /.093	.062 /.093	.062 /.093	.062 /.093	.062 /.093	.062 /.093	.062 /.093	.062 /.093
5 ASF	4.13 / 5.34	4.32 /5.26	4..35 /5.20	4.33 / 5.44	1.25 / 1.62	1.20 / 1.43	1.36 / 1.72	1.30 / 1.89
15 ASF	4.50 /5.62	4.75 / 5.75	4.28 / 5.10	4.19 / 5.07	1.42 / 1.85	1.31 / 1.75	1.33 / 1.67	1.45 / 2.01
30 ASF	4.84 /5.85	5.02 / 5.81	4.21 / 4.98	4.00 / 4.95	1.77 / 2.89	1.73 / 2.90	1.52 / 2.42	1.69 / 2.73

Table 2 -Experiment matrix – Surface to Hole Thickness Ratio: 28 mil hole

	Sulfamate Bath with Additive				Bromide Bath with Additive			
Current Density	DC Direct Agitation	DC Indirect Agitation	Pulse Direct Agitation	Pulse Indirect Agitation	DC Direct Agitation	DC Indirect Agitation	Pulse Direct Agitation	Pulse Indirect Agitation
	.062 /.093	.062 /.093	.062 /.093	.062 /.093	.062 /.093	.062 /.093	.062 /.093	.062 /.093
5 ASF	4.38 / 5.01	4.29 / 4.98	4.10 / 5.10	4.02 / 5.05	1.35 / 1.72	1.39 / 1.44	1.50 / 2.09	1.40 / 2.11
15 ASF	4.42 / 5.45	4.55 / 4.95	4.12 / 5.25	4.11 / 4.98	1.82 / 2.10	1.42 / 1.69	1.67 / 2.22	1.49 / 2.20
30 ASF	4.70 / 5.38	4.89 / 4.78	4.15 / 5.23	4.22 / 5.17	1.89 /2.42	1.95 / 2.85	1.60 / 2.57	1.59 / 2.69

Figures 5 and 6 show the bromide bath SHTR with a 28 mil hole in a 62 mil and a 93 mil board.

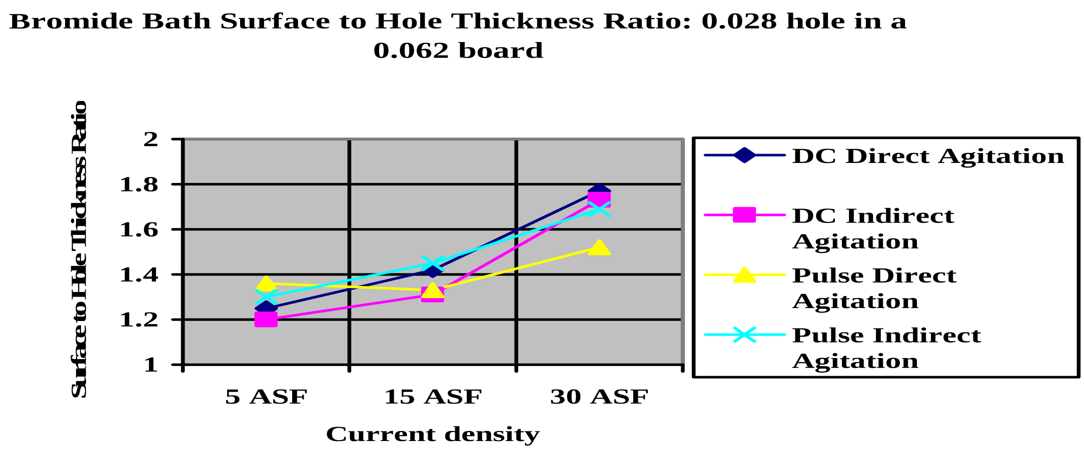

Figure 5 - Bromide Bath SHTR with a 28 mil hole in a 62 mil board.

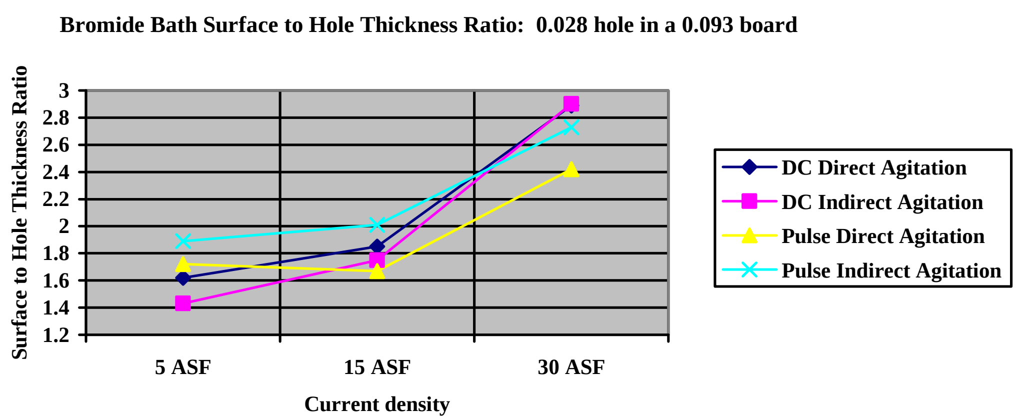

Figure 6- Bromide Bath SHTR with a 28 mil hole in a 93 mil board.

Figures 7 and 8 compare a 28 mil hole in a 62 mil board plated under the same conditions (DC at 5 ASF using indirect agitation) in the sulfamate bath and in the bromide bath. It can be seen that the nickel deposit from the bromide bath is much more uniform than the sulfamate bath. The SHTR of the sample in Figure 7 is over 4.3 compared to the SHTR of 1.25 in Figure 8. Figure 9 shows a 6 micron thick nickel deposit in the center of a 28 mil hole in a 62 mil board plated with the same conditions as the sample in figure 8.

As noted in the experimental matrix listed in Table 1, pulse plating in the bromide bath at 15 ASF with direct agitation also resulted in a low SHTR. The uniformity of the nickel deposit in the high aspect ratio PTH plated with these conditions was comparable to the DC plating at a current density of 5 ASF with indirect agitation. Figures 10, 11 and 12 show a 10 mil hole in a 93 mil board, pulse plated in the bromide bath at 15 ASF with direct agitation.

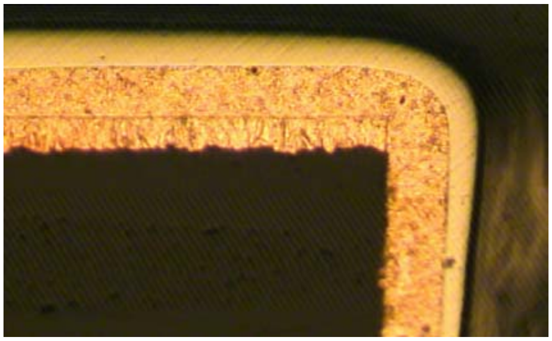

Figure 7- 28 mil hole in a 62 mil board plated in the sulfamate bath with DC at 5 ASF using indirect agitation. 20 x magnification

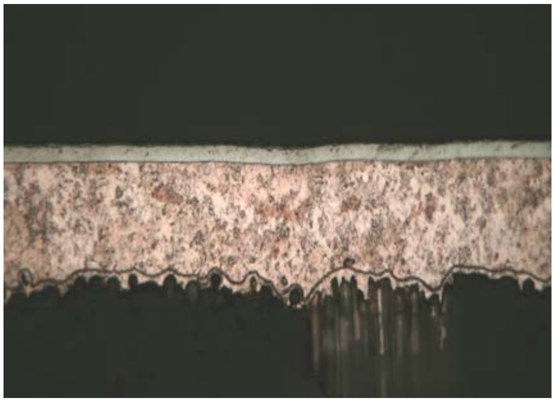

Figure 8 - 28 mil hole in a 62 mil board plated in the bromide bath with DC at 5 ASF using indirect agitation. 20 x magnification

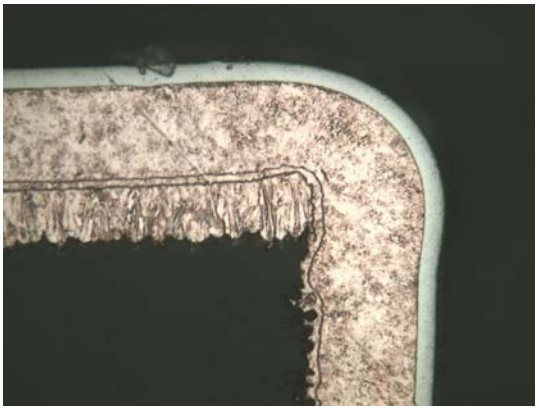

Figure 9- 6 micron thick nickel deposit in the center of a 28 mil hole in a 62 mil board. 20 x magnifications

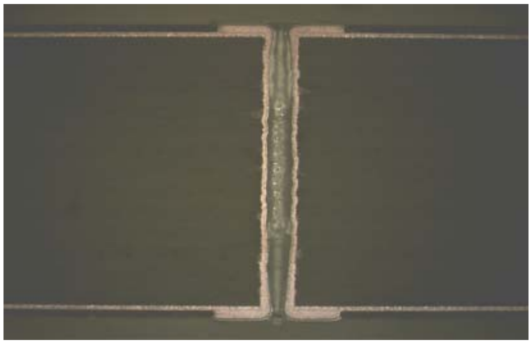

Figure 10 - 10 mil hole in a 93 mil board pulse plated in the bromide bath at 15 ASF with direct agitation. 5 x magnification

Figure 11 - 10 mil hole in a 93 mil board pulse plated in the bromide bath at 15 ASF with direct agitation. 10 x magnification

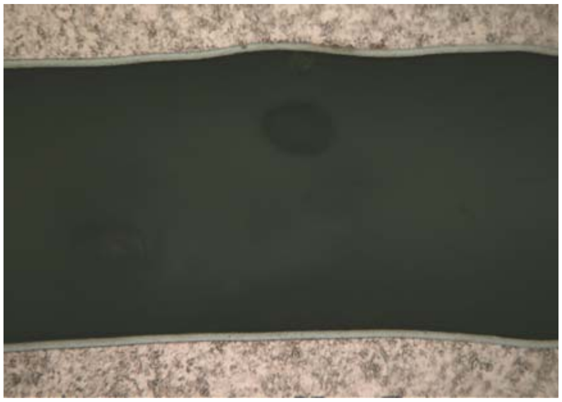

Figure 12 - 10 mil hole in a 93 mil board pulse plated in the bromide bath at 15 ASF with direct agitation. 20 x magnification

All of the holes in the test coupons from the DC plating at 5 ASF with indirect agitation and pulse plating at 15 ASF with direct agitation were evaluated to determine the greatest aspect ratio that these processes were capable of plating.

Table 3 shows that both plating conditions were capable of depositing a uniform nickel layer in holes with an aspect ratio as great as 9.1:1. Reliable plating results could not be obtained from the 8 mil holes with an aspect ratio of 11.37:1.

Although, the SHTR increased as the aspect ratio became greater, the values are still well within acceptable limits.

Table 3 Plated Thru Hole SHTR

Plated Through Hole SHTR		
Aspect Ratio	5 ASF / D.C	15 ASF / Pulse
1.82:1	1.52	1.59
2.27:1	1.55	1.61
3.25:1	1.75	1.67
4.55:1	1.88	1.79
6.06:1	2.12	1.98
9.1:1	2.67	2.5

Deposit Analysis

Sample coupons were prepared from 3 inch silicon wafers that were metalized with 3 microns of copper. The wafers were plated in the bromide bath with DC and pulse current at 5 and 15 ASF. The stress in the nickel deposit was measured with a KLA Tencor FLX Film Stress Measurement System. The stress was first measured as plated. The samples were then annealed at 125°C for 150 hours and remeasured.

Although results in Table 4 show an increase in the tensile stress after the anneal, the stress values are well within the acceptable range for each of the plating conditions. The nickel deposit should exhibit good thermal shock properties.

Table 4- Nickel Deposit Stress Measurements

Tensile Stress Measurement (MPa)		
Current Density	As Plated	After Anneal
5 ASF / DC	110.3	190.7
5 ASF / Pulse	102	176
15 ASF / DC	154.2	249.1
15 ASF / Pulse	121.8	220.1

The surface roughness was measured with a DEKTAT 6M Stylus Profilometer.

A 1000 micron scan was taken in 5 areas of each wafer. The results in Table 5 show that the surface roughness was greater at the lower current density irrespective of the rectification used.

Table 5 -Surface Roughness Measurements

Surface Roughness (RA)		
Current Density	As Plated	After Anneal
5 ASF / DC	856	832
5 ASF / Pulse	663	630
15 ASF / DC	374	380
15 ASF / Pulse	303	311

Scanning Electron Microscopy (SEM) was used to determine the deposit morphology. Figure 12 shows a SEM of a sample plated in the bromide bath using DC at 5ASF with indirect agitation. The deposit has a grain size of about 1 micron. The rough surface can be attributed to the lack of additives (brighteners and levelers) in the bath.

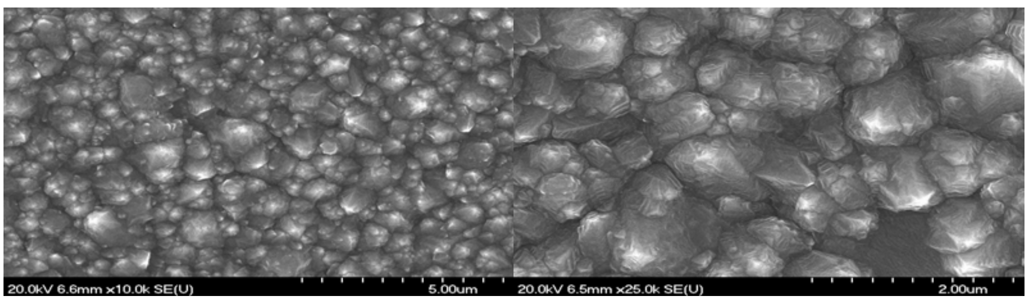

Figure 12 - DC plated in the bromide bath at 5ASF with indirect agitation.

Figure 13 shows a sample that was pulse plated in the bromide bath at 15 ASF with direct agitation. The grain size is about 0.5 micron at the higher current density with pulse plating.

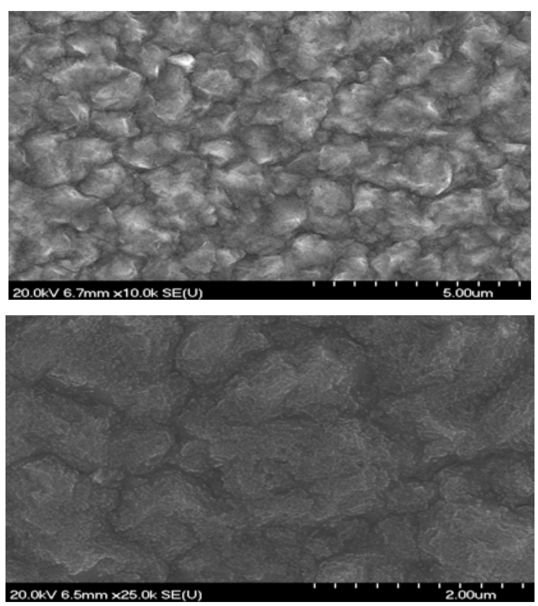

Figure 13- Pulse plated in the bromide bath at 15 ASF with direct agitation.

Reliability

Sample coupons were subjected to thermal shock and thermal stress tests. The thermal shock test consisted of a temperature cycle of + 125 °C to – 65°C for 100 cycles with a 15 min dwell time. The thermal stress test conducted per IPC-TM-650 consisted of a 6 hour bake at 120°C, then a solder float at 290°C for 10 seconds.

Evaluation of the coupon microsections showed no signs of cracking or delamination. Figure 14 shows a 28 mil hole in a 62 mil board plated using DC at 5 ASF with indirect agitation after thermal shock and thermal stress tests.

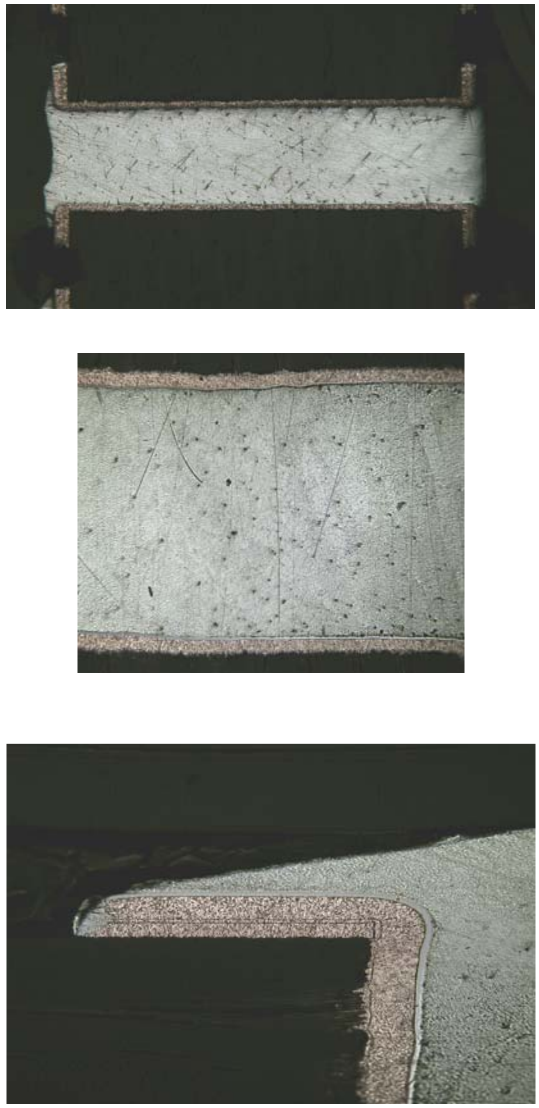

Figure 14- 28 mil hole in a 62 mil board after thermal shock and thermal stress test.

Sample boards of 62mils and 91mils were fabricated and selective nickel and gold plated for a press fit connector. The boards consisted of one hundred 28 mil holes for an Airborne press fit connector. The nickel plating was from the bromide bath using DC at 5 ASF with indirect agitation. The nickel plating thickness was 6 microns. Hard gold was plated over the nickel.

The press fit connector was inserted into the boards. Each board was subjected to the thermal shock test. Evaluation of the microsections showed no signs of cracking or delamination.

Figure 15 shows the 62 mil board and Figure 16 shows the 93 mil board after the thermal shock test.

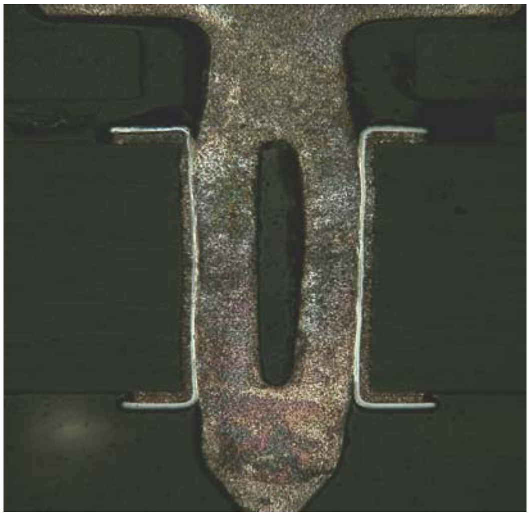

Figure 15 - 62 mil board with a press fit connector pin after the thermal shock test

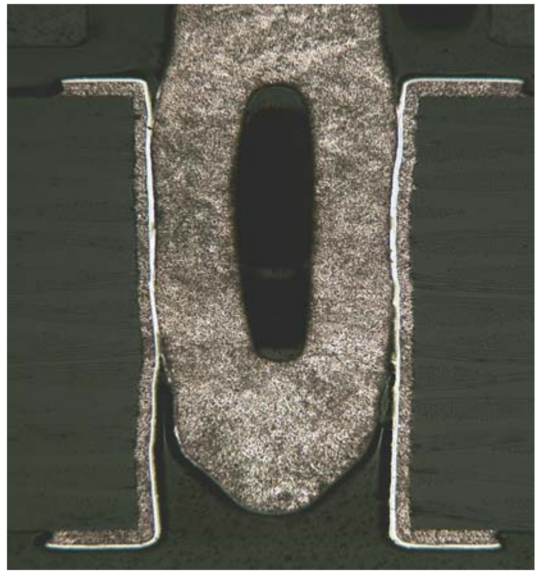

Figure 16 - 93 mil board with a press fit connector pin after the thermal shock test.

Conclusion

A plating process has been developed that reliably deposits a uniform nickel layer on high aspect ratio through holes. Superior surface to hole thickness ratios were obtained with direct current and pulse plating. The results from the physical property and thermal stress evaluations meet the performance specifications for flight qualified printed wiring boards.

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Introduction

- As advanced printed wiring board (PWB) designs become more complex, the thickness of the board has increased due to the greater number of layers.

- Plated through hole (PTH) diameters have become much smaller to accommodate the greater density of advanced designs.

- As the PTH aspect ratio (board thickness divided by hole diameter) increases, it becomes more difficult to obtain a uniform plating in the hole.

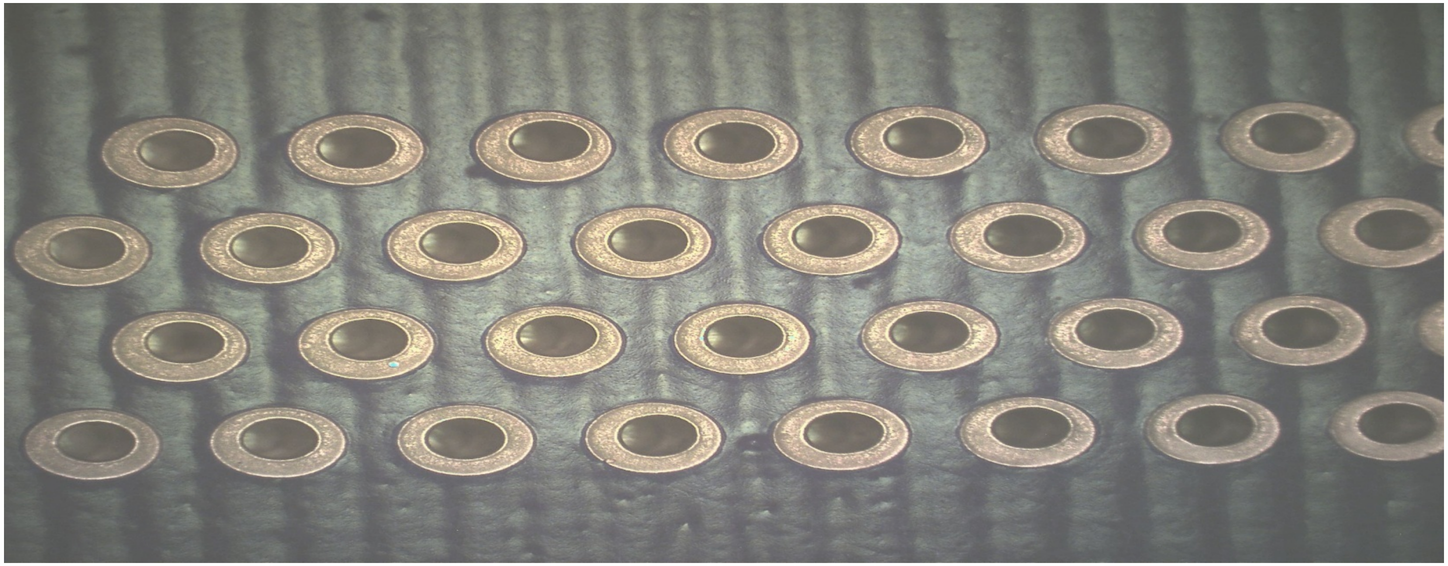
Performance Specifications

- MIL-PRF-55110G for high reliability PTH nickel deposits requires a minimum plating thickness of 5 microns in the hole.
- Low tensile stress deposit. Below 400 MPa is recommended.
- Pass Thermal Shock and Thermal Stress test.

Surface to Hole Thickness Ratio

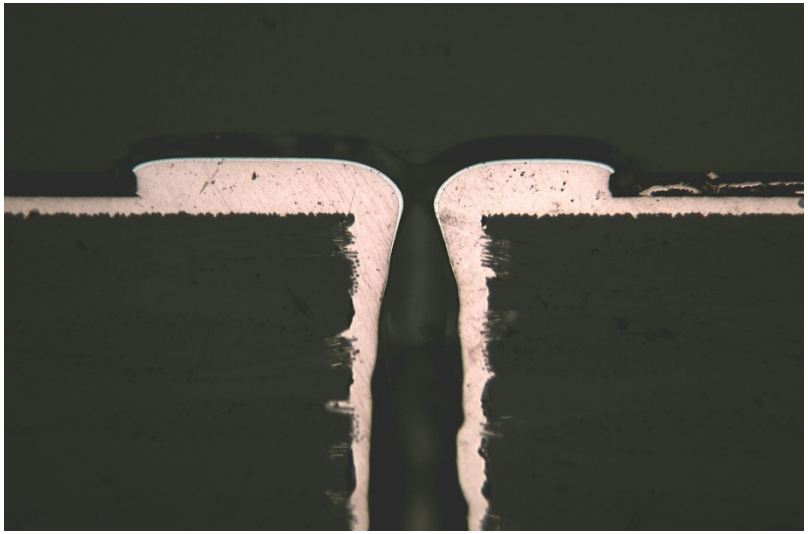
- The difference in the plating thickness in the hole and the board surface is referred to as the surface-to-hole thickness ratio (SHTR).
- The SHTR is determined by dividing the deposit thickness on the surface by the deposit thickness in the hole.
- The goal when fabricating high reliability PTH's is to keep this ratio as low as possible.

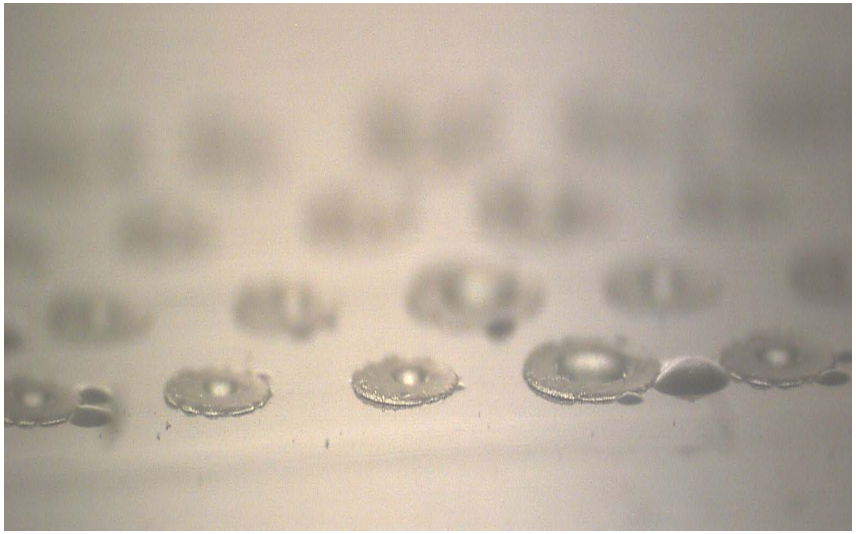
Selective Plating of Through Holes



- Only the hole and the annular ring is exposed to the plating solution.
- Difficult to plate because of the high current density on the surface of the board around the hole.
- The plating is much thicker on the surface then in the center of the hole.

Plating Through Hole Problems





- Decrease in the hole diameter so components won't fit.
- Increased stress between the plated layers.
- Mushroom plating on surface pads that can trap photo resist.

High Throw Plating Process

- High throw plating baths distribute the current more evenly.
- High throw plating baths reduce the amount of organic additives (carriers, brighteners, levelers) in their chemistry.
- Uniform deposit on the surface and in the PTH.

Experiment Details

- **Plating Formulas**

- Sulfamate bath produces low stress deposits. Wide current density range.

- Bromide bath specifically designed for high throw plating.

- Each bath was compared with the addition of a grain refiner additive.

Experiment Details

- **Plating Parameters**

- **Rectification: direct current (DC) vs pulse current 10% duty cycle (0.1sec.on-0.9sec.off) .**

- **Solution agitation: direct agitation vs indirect agitation.**

- **Current density: 5, 15, and 30 amps per square foot (ASF).**

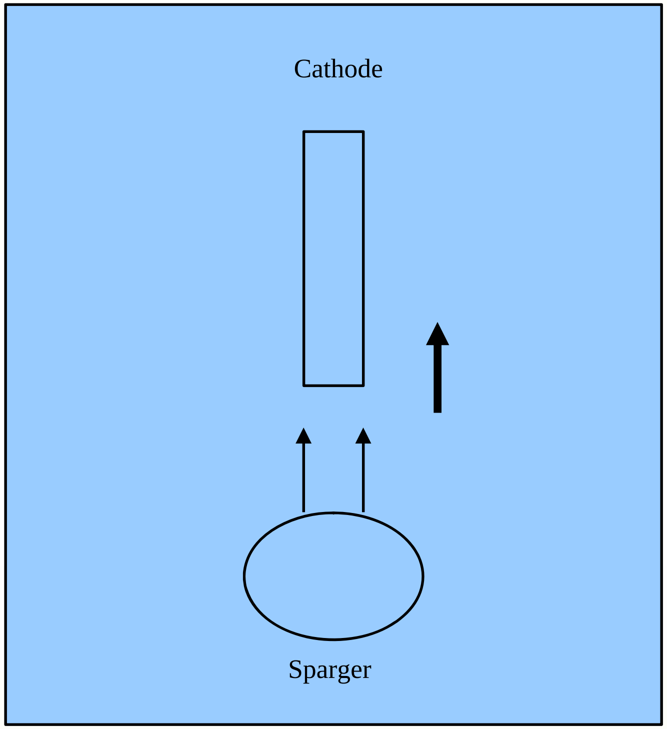
Experiment Details

- **Plating Equipment**

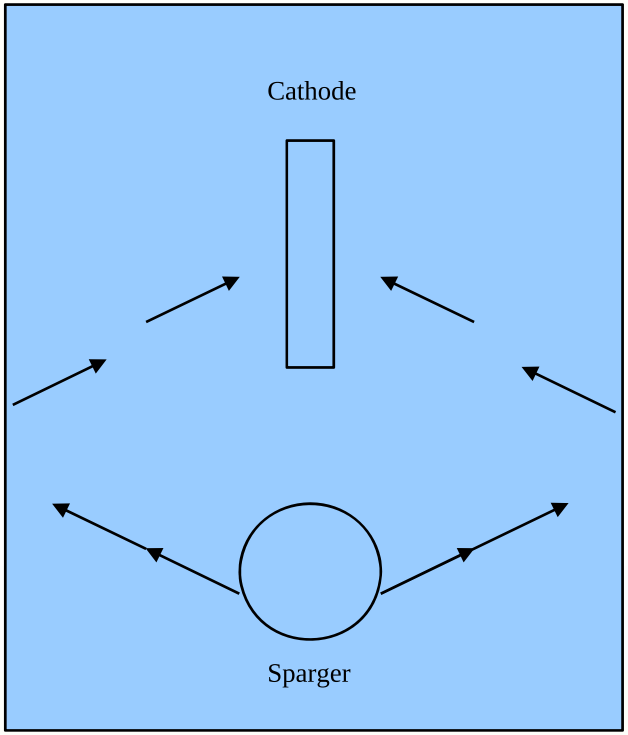
- **All experiments were conducted in a 5 gallon tank.**
- **Agitation was supplied by a recirculation filter pump with a center tank sparger.**
- **The nickel anodes were sulfur free and anode bags were used.**
- **Kraft Dynatronix models DUP10-1-3 and DP20-5-10 power supplies were used.**

Solution Agitation

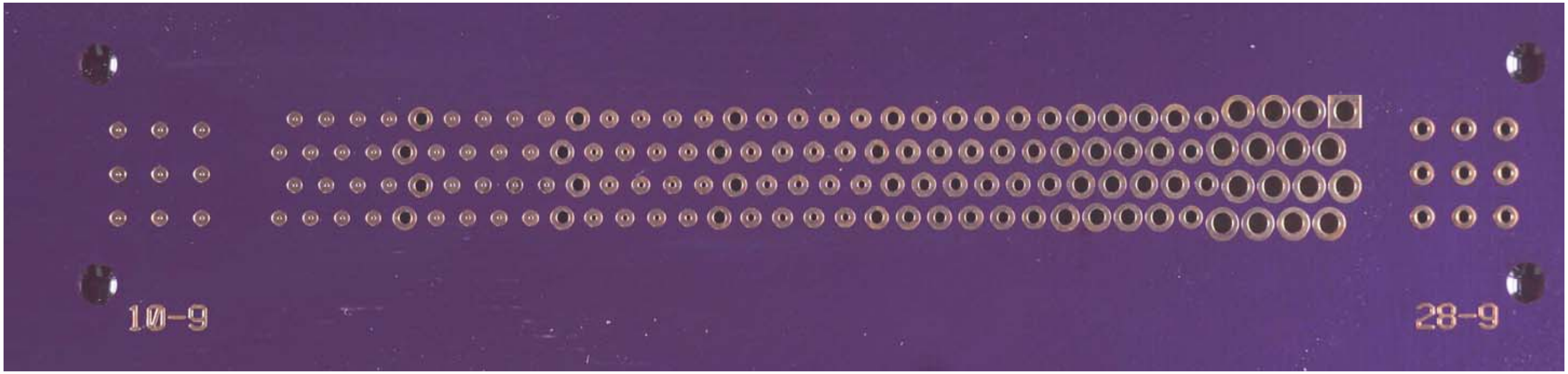
- **Direct Agitation**



- **Indirect Agitation**



Test Vehicle



- Polyimide boards of two thicknesses: 62 mils and 93mils.
- Seven hole sizes of 8, 10,15,20,28,40, and 50 mils representing aspect ratios from 1.25:1 up to 11.37:1.

Pre Plate Process Flow

Acid Cleaner 5min at 50C

↓

Microetch 2 min at 60C

↓

Acid Activation 3 min at RT

↓

Nickel Plate

Test Results

- Plating thickness on the surface of the coupon was measured with a Fischerscope XDLM x-ray fluorescence system.

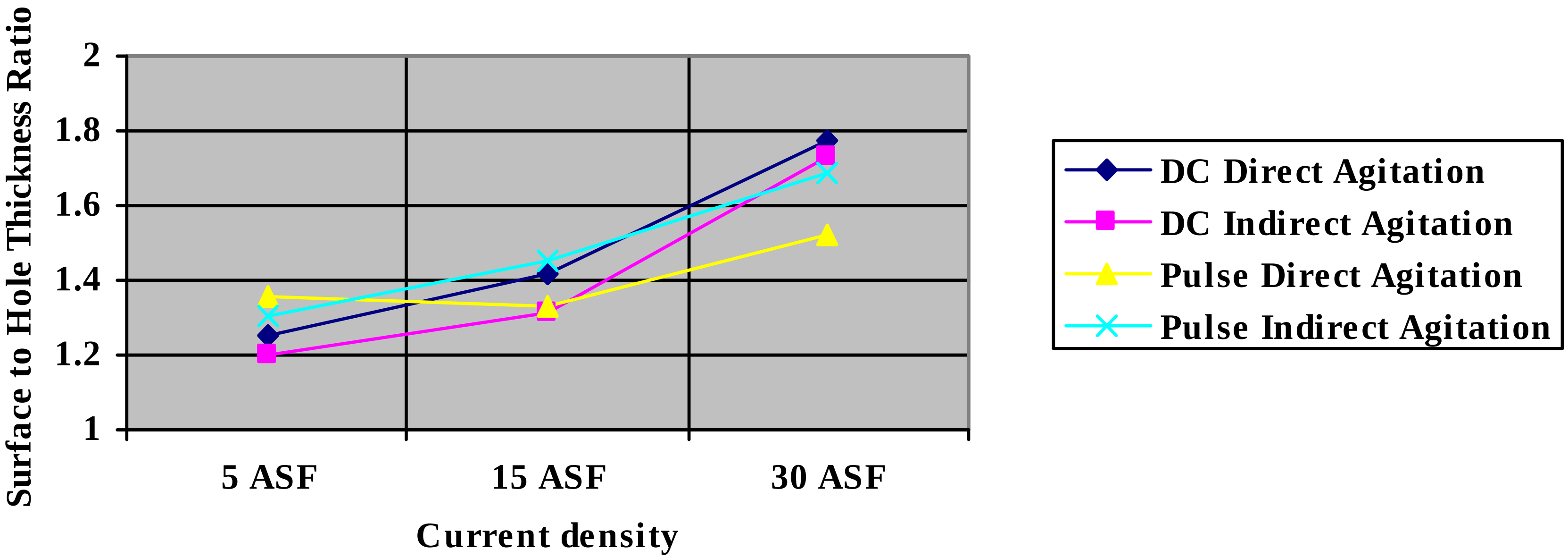
- Test coupons were microsectioned and optical microscopy was used to determine the nickel deposit thickness in the through hole.

- The 28 mil hole was used as the control.

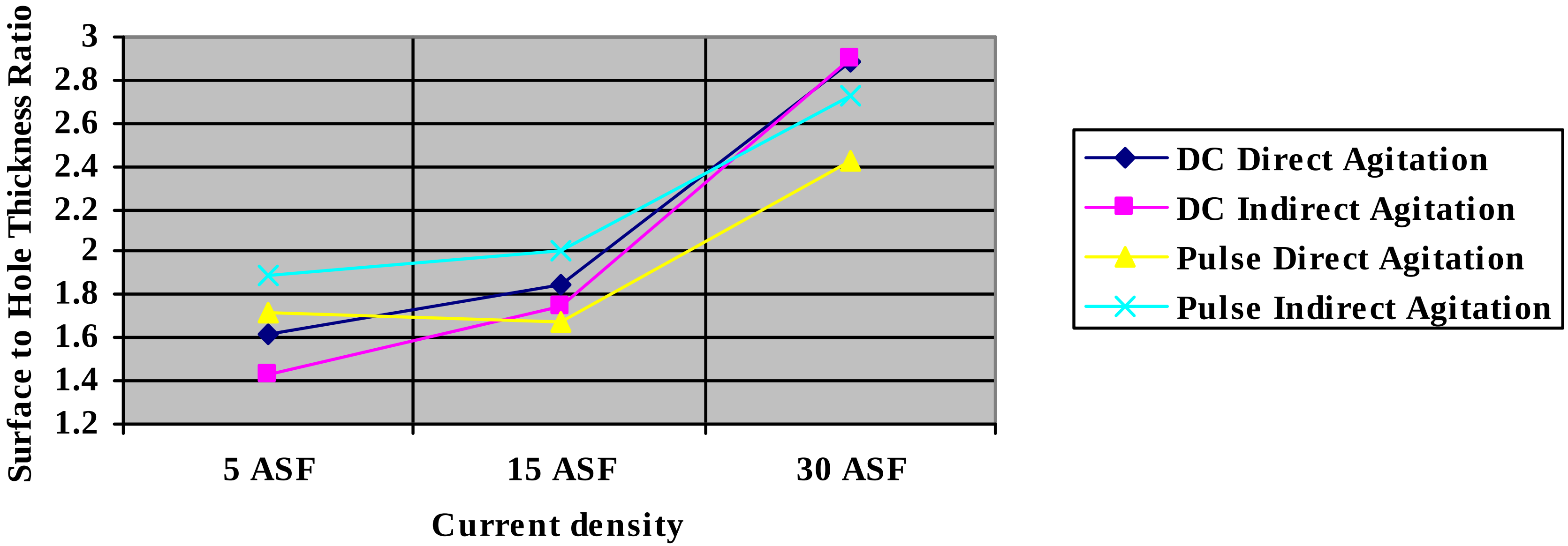
Experiment Matrix
Surface to Hole Thickness Ratio:
28 mil hole

Current Density	Sulfamate Bath				Bromide Bath			
	DC Direct Agitation	DC Indirect Agitation	Pulse Direct Agitation	Pulse Indirect Agitation	DC Direct Agitation	DC Indirect Agitation	Pulse Direct Agitation	Pulse Indirect Agitation
	.062 /.093	.062 /.093	.062 /.093	.062 /.093	.062 /.093	.062 /.093	.062 /.093	.062 /.093
5 ASF	4.13 / 5.34	4.32 /5.26	4..35 /5.20	4.33 / 5.44	1.25 / 1.62	<u>1.20 / 1.43</u>	1.36 / 1.72	1.30 / 1.89
15 ASF	4.50 /5.62	4.75 / 5.75	4.28 / 5.10	4.19 / 5.07	1.42 / 1.85	1.31 / 1.75	<u>1.33 / 1.67</u>	1.45 / 2.01
30 ASF	4.84 /5.85	5.02 / 5.81	4.21 / 4.98	4.00 / 4.95	1.77 / 2.89	1.73 / 2.90	1.52 / 2.42	1.69 / 2.73

Bromide Bath SHTR with a 28 mil hole in a 62 mil board



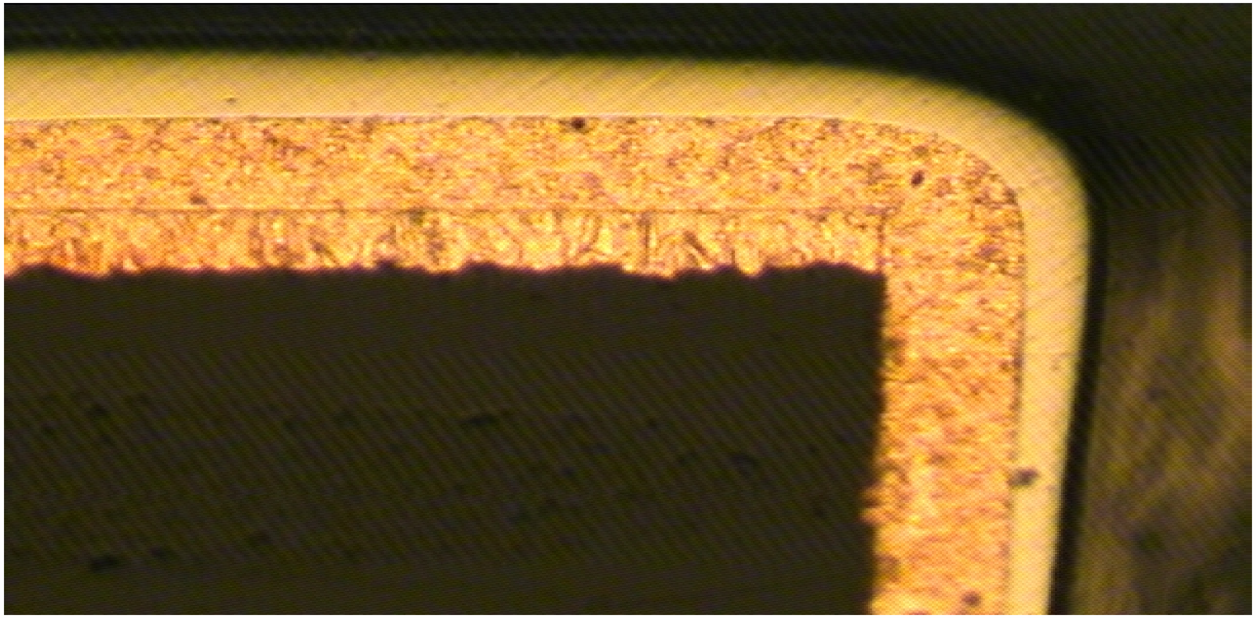
Bromide Bath SHTR with a 28 mil hole in a 93 mil board



Test Results

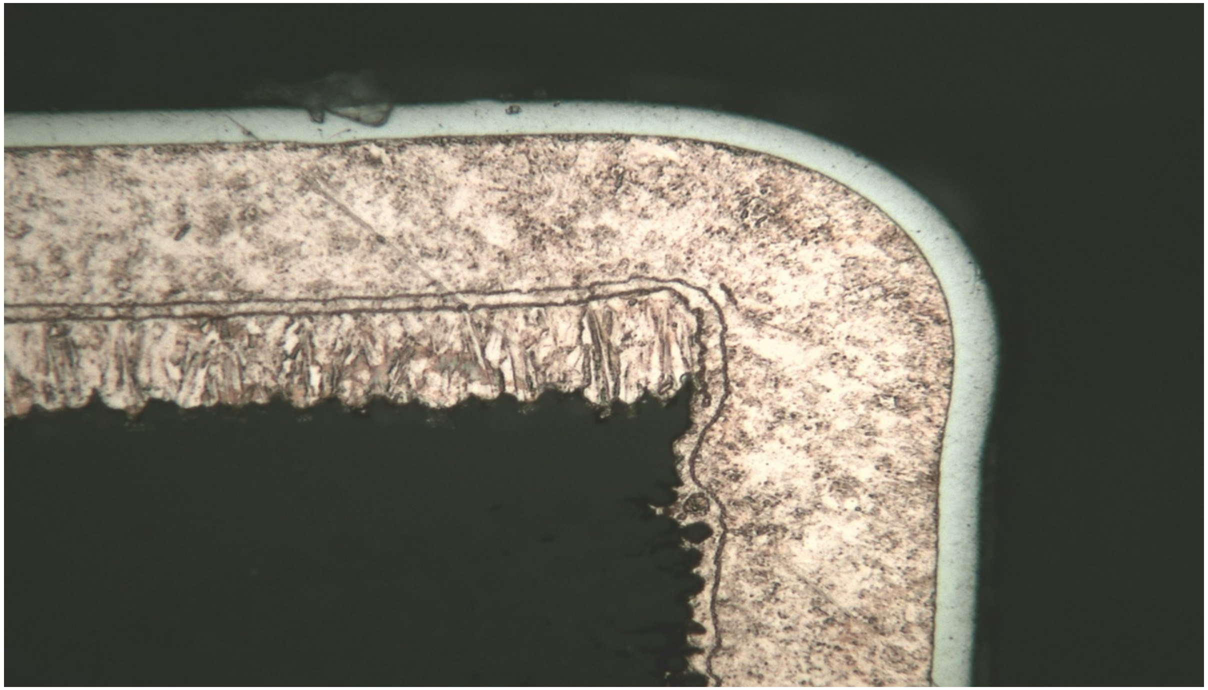
- The best results were obtained in the bromide bath with DC plating and a current density of 5 ASF with indirect agitation.
- Indirect agitation increases the throwing power when DC plating at a low current density.
- Pulse plating at 15 ASF with direct agitation also resulted in a low SHTR .
- Direct agitation improved the throwing power when pulse plating.
- When pulse plating, the metal ions are replaced at the cathode film during the off cycle.

Sulfamate Process



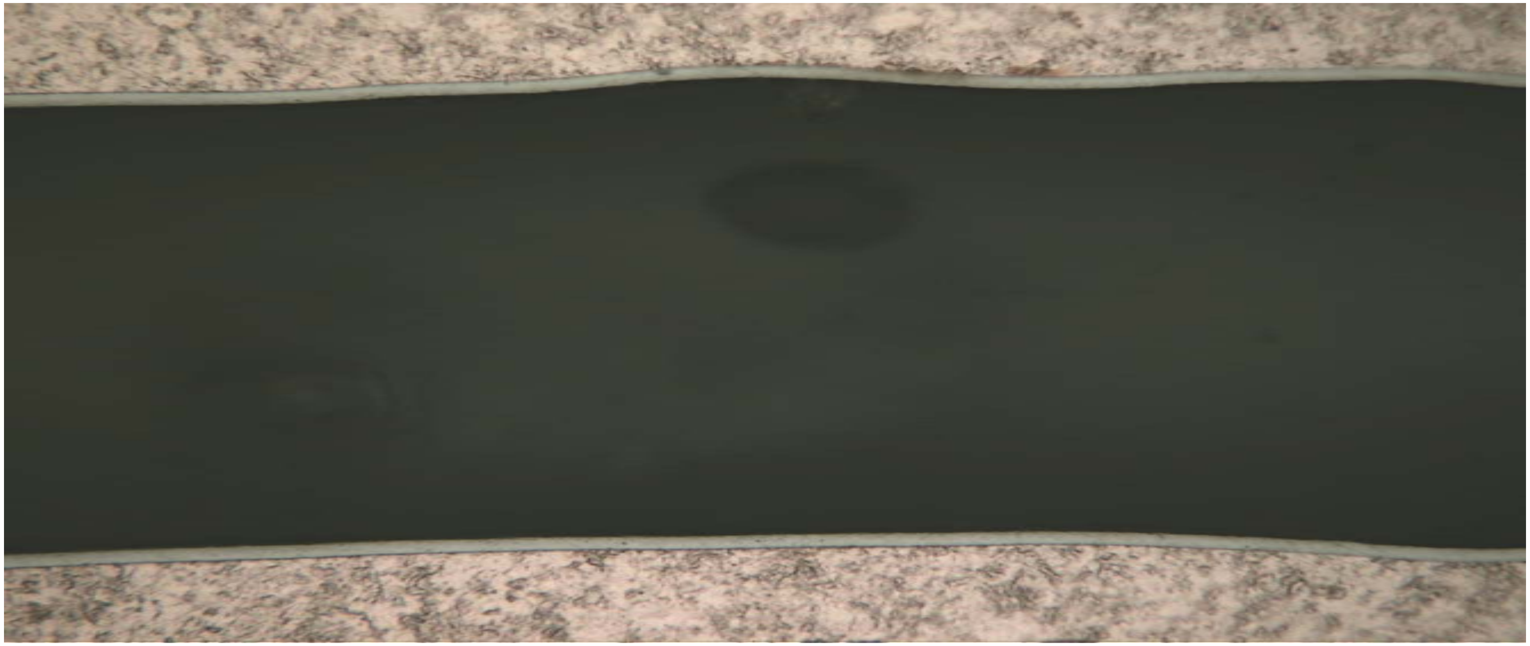
- **28 mil hole in a 62 mil board plated in the sulfamate bath with DC at 5 ASF using indirect agitation. 20 x magnification.**

High Throw Process



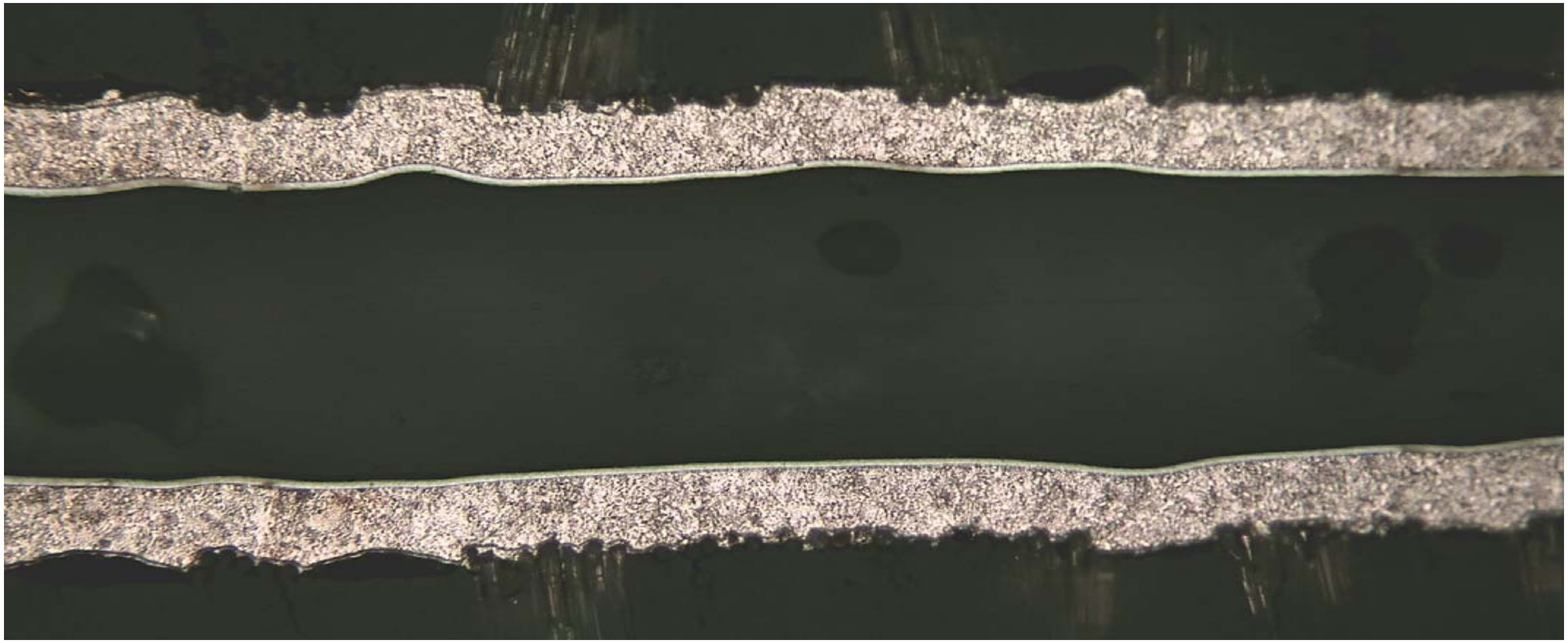
- **28 mil hole in a 62 mil board plated in the bromide bath with DC at 5 ASF using indirect agitation. 20 x magnification.**

Uniformity of Nickel Deposit



- **10 mil hole in a 93 mil board pulse plated in the bromide bath at 15 ASF with direct agitation. 20 x magnification.**

Uniformity of Nickel Deposit



- **10 mil hole in a 93 mil board plated in the bromide bath with DC at 5 ASF using indirect agitation. 20 x magnification.**

Aspect Ratio Matrix

Bromide Bath Plated Through Hole SHTR		
Aspect Ratio	5 ASF / D.C	15 ASF / Pulse
1.82:1	1.52	1.59
2.27:1	1.55	1.61
3.25:1	1.75	1.67
4.55:1	1.88	1.79
6.06:1	2.12	1.98
9.1:1	2.67	2.5

Deposit Analysis

- **Stress Measurements**

- **Sample coupons were prepared from 3 inch silicon wafers that were metalized with 3 microns of copper, then plated in the bromide bath with DC and pulse current at 5 and 15 ASF.**
- **Stress in the nickel deposit was measured with a KLA Tencor FLX Film Stress Measurement System.**
- **The stress was first measured as plated, then the samples were then annealed at 125° C for 150 hours and remeasured.**

Nickel Deposit Stress Measurements

-

Tensile Stress Measurement (MPa)		
Current Density	As Plated	After Anneal
5 ASF / DC	110.3	190.7
5 ASF / Pulse	102	176
15 ASF / DC	154.2	249.1
15 ASF / Pulse	121.8	220.1

Deposit Analysis

- **Surface Roughness Measurements**

- **The surface roughness was measured with a DEKTAT 6M Stylus Profilometer.**

- **A 1000 micron scan was taken in 5 areas of each wafer.**

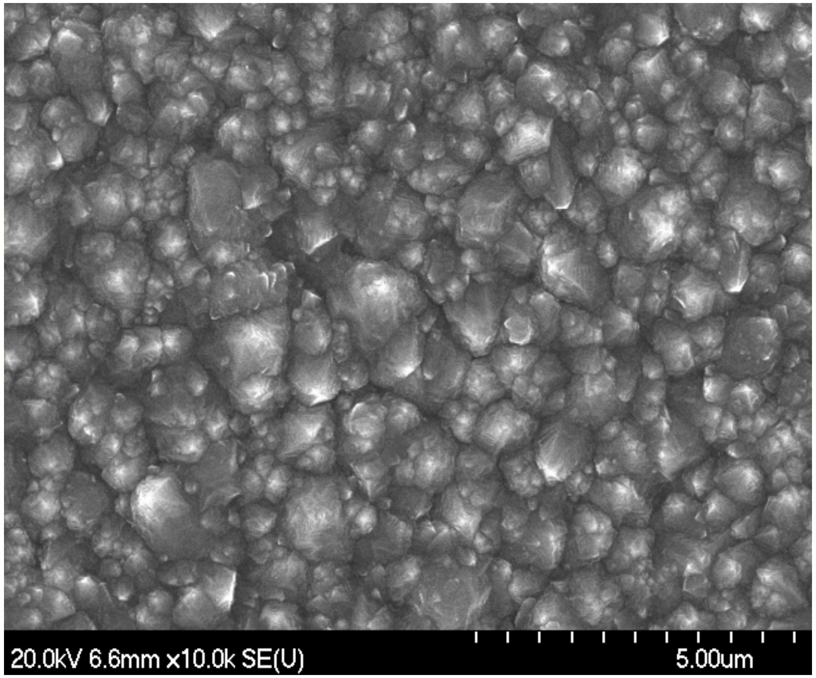
- **Surface roughness was greater at the lower current density irrespective of the rectification used.**

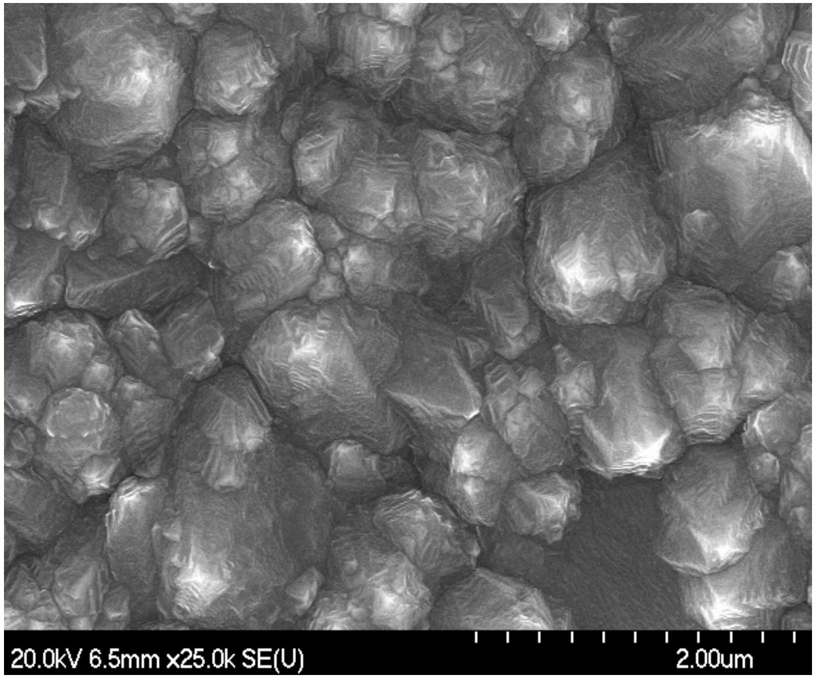
Surface Roughness Measurements

-

Surface Roughness (RA)		
Current Density	As Plated	After Anneal
5 ASF / DC	856	832
5 ASF / Pulse	663	630
15 ASF / DC	374	380
15 ASF / Pulse	303	311

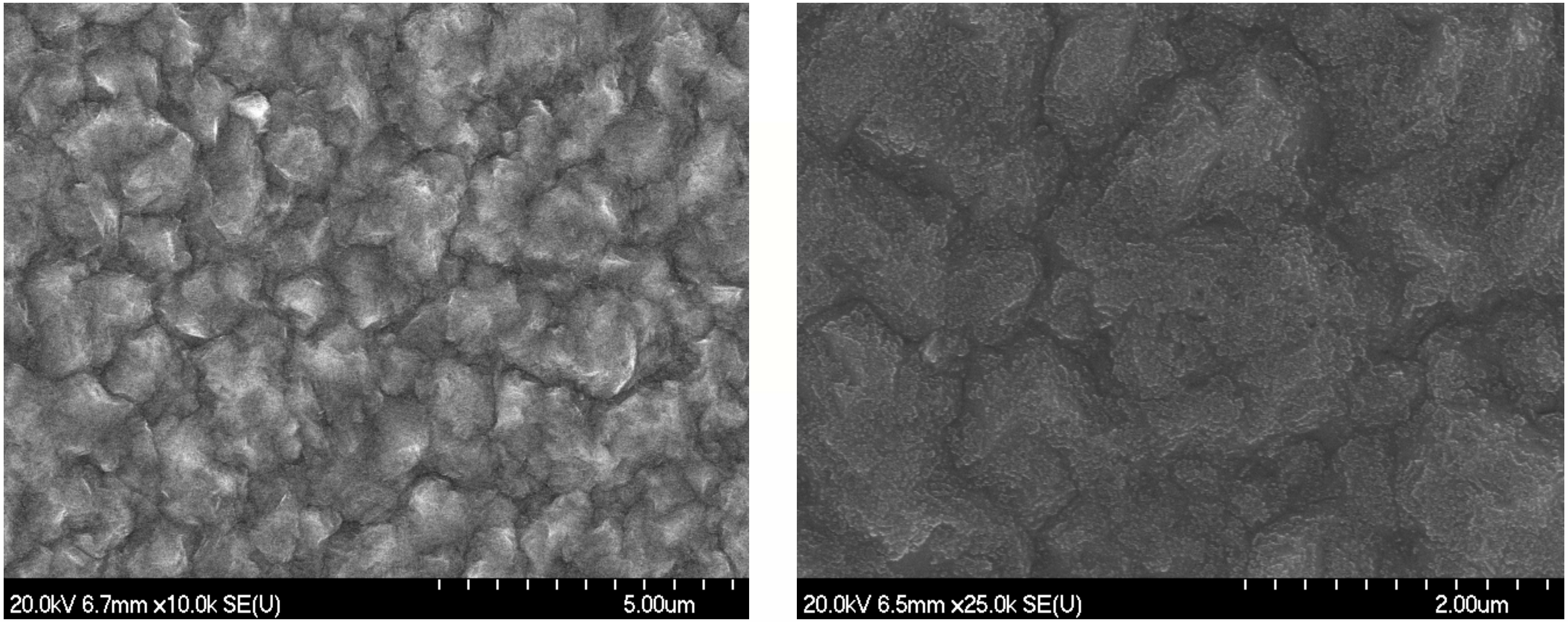
Surface Morphology





- **SEMs of a sample DC plated in the bromide bath at 5 ASF with indirect agitation.**
- **Deposit has a grain size of about 1 micron.**

Surface Morphology



- SEMs of a sample pulse plated in the bromide bath at 15 ASF with direct agitation.
- Deposit has a grain size of about 0.5 micron.

Reliability

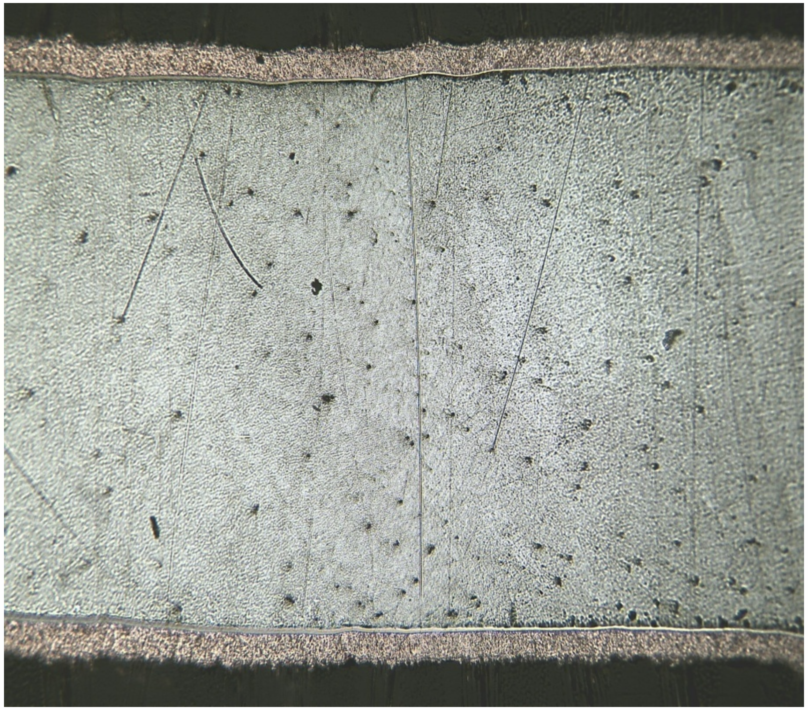
- Sample coupons were subjected to thermal shock and thermal stress tests.

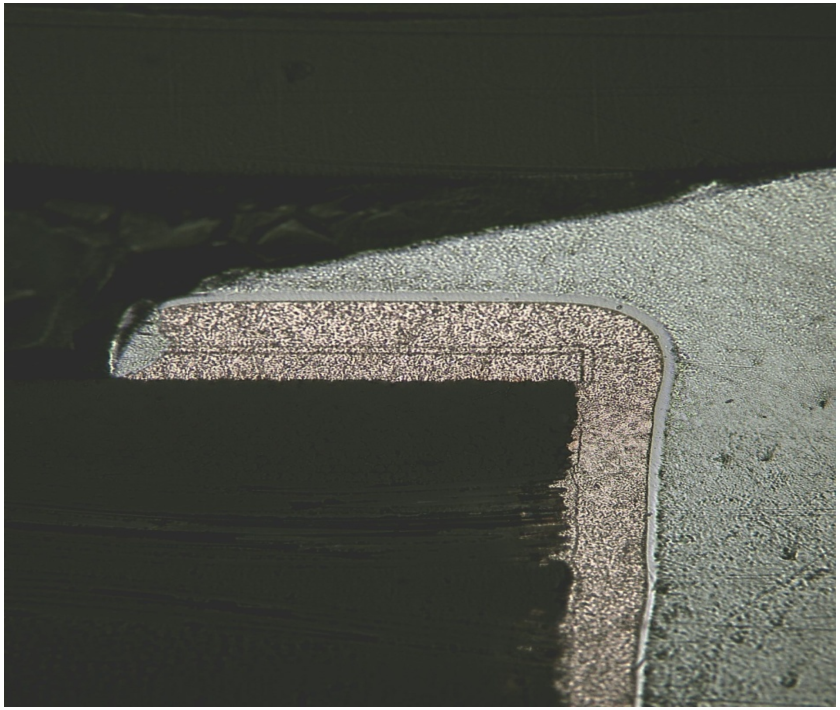
- The thermal shock test consisted of a temperature cycle of + 125 ° C to – 65° C for 100 cycles with a 15 min dwell time.

- The thermal stress test conducted per IPC-TM-650 consisted of a 6 hour bake at 120° C, then a solder float at 290° C for 10 seconds.

- Evaluation of the coupon microsections showed no signs of cracking or delamination.

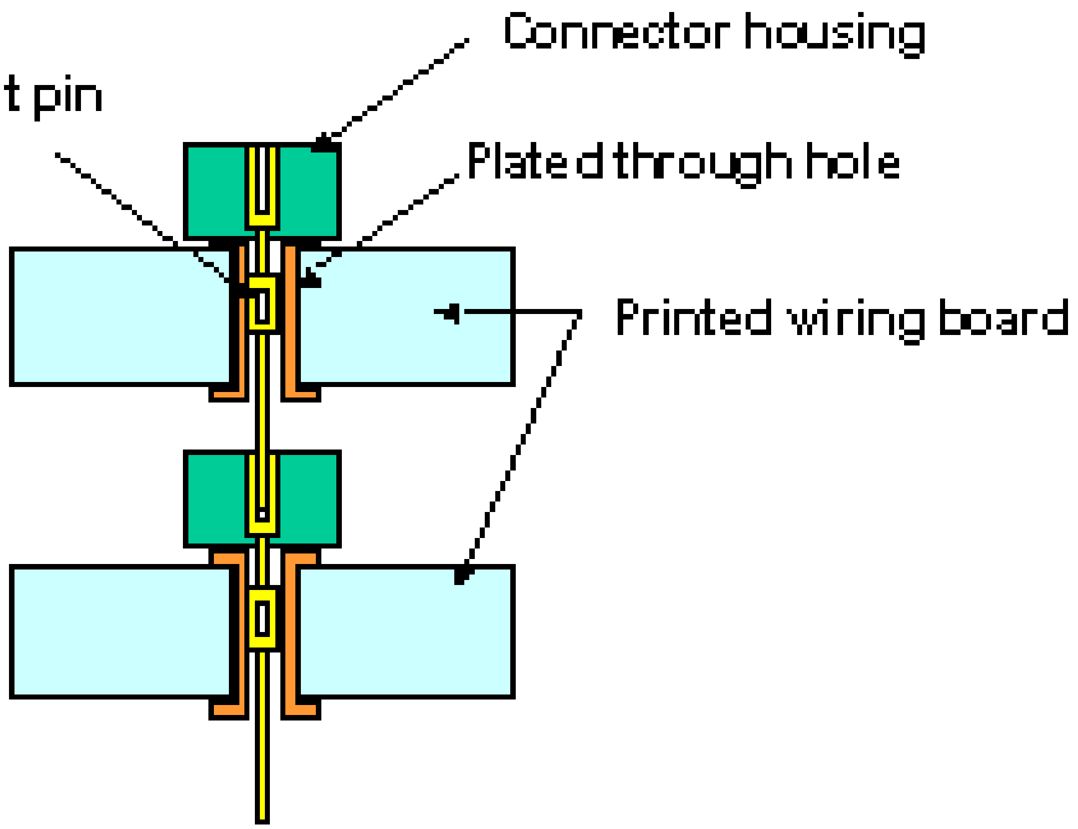
Thermal Shock / Thermal Stress Test



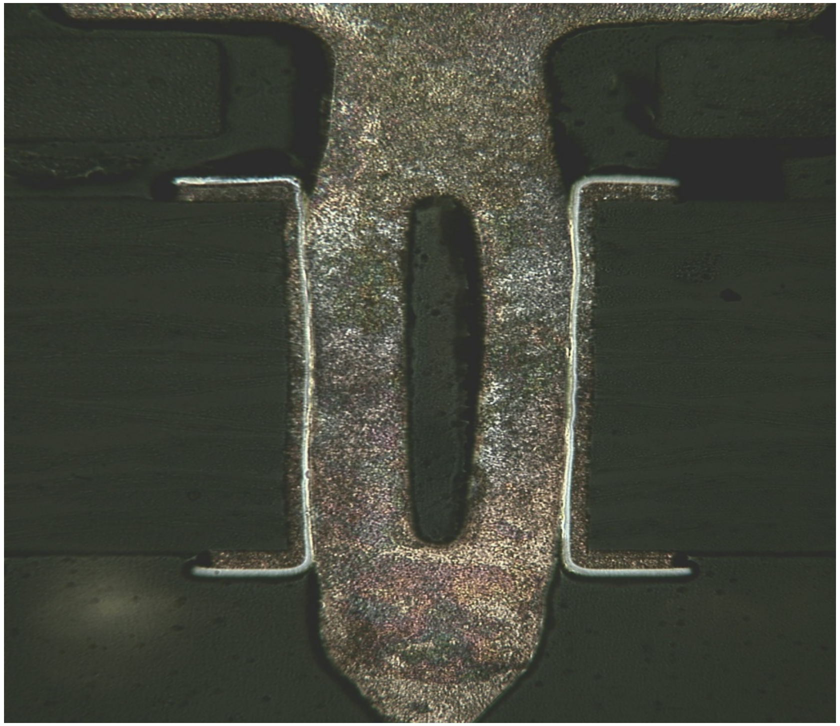


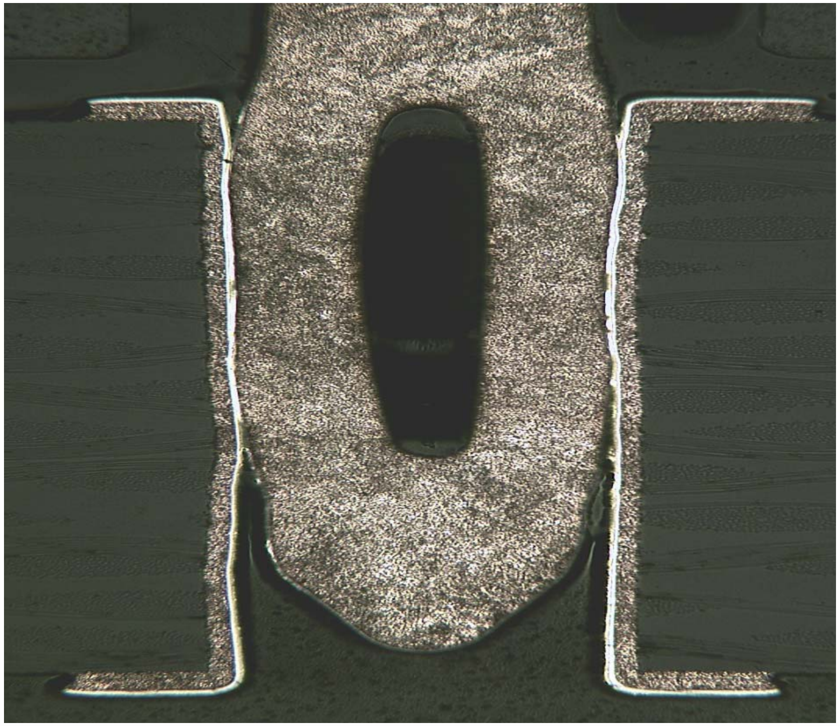
- **28 mil hole in a 62 mil board after thermal shock and thermal stress test.**

Airborne Press Fit Connector



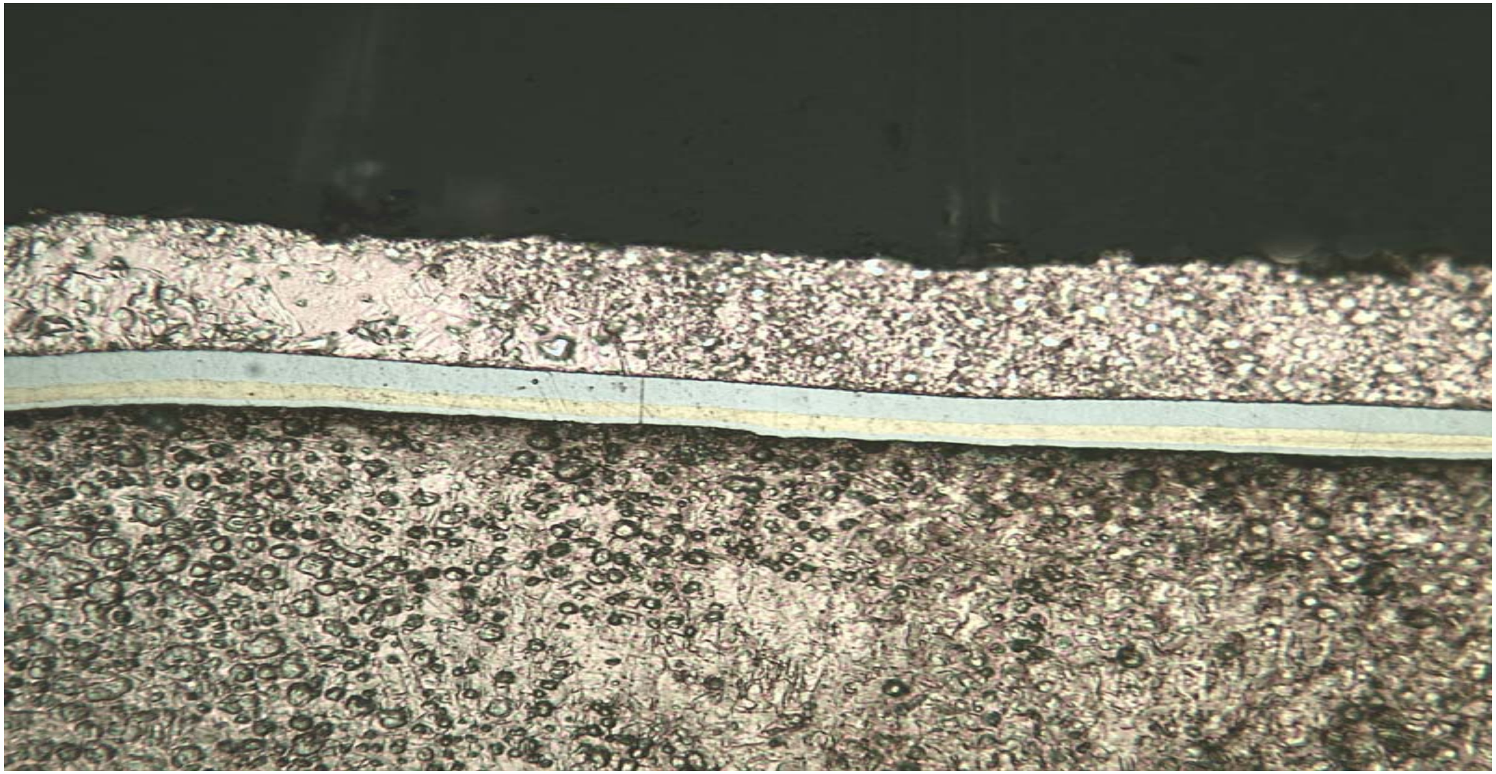
Airborne Press Fit Connector





- 62 mil and 93 mil board with a press fit connector pin after the thermal shock test

Airborne Press Fit Connector



- **Crossection of a press fit connector pin in a 62 mil board after the thermal shock test.**

Conclusion

- **A plating process has been developed that reliably deposits a uniform nickel layer on high aspect ratio through holes.**
- **Superior surface to hole thickness ratios were obtained with direct current and pulse plating.**
- **Results from the physical property and thermal stress evaluations meet the performance specifications for flight qualified printed wiring boards.**