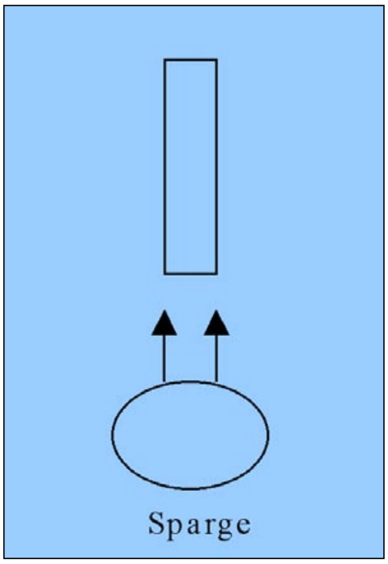
Uniformity Of Ni Plating Thickness in High Aspect Ratio PTH

by David M. Lee, Frank L. Collins, Ann E. Dietrich, John T. Folkerts, Walter A. Johnston, Richard J Saunders,
Johns Hopkins Applied Physics Laboratory

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. We take a look at the effect of various plating parameters and chemical additives on through hole plating uniformity.

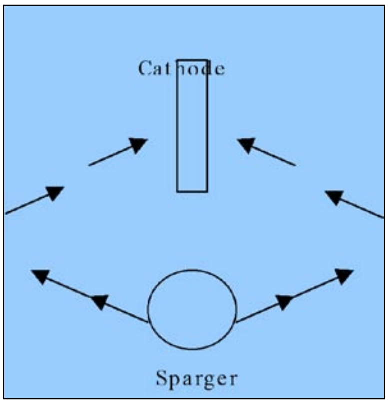
As advanced printed wiring board (PWB) designs become more complex, the thickness of the board has increased due to the greater number of layers. The plated through hole (PTH) diameters have become much smaller to accommodate the greater density of advanced designs. As the PTH aspect ratio (board thickness 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 PTHs is to keep this ratio as low as possible.

PWB designs that require selective PTHs 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 centre of the hole.

Figure 1 – Direct agitation (left)
Figure 2 – Indirect agitation (below)



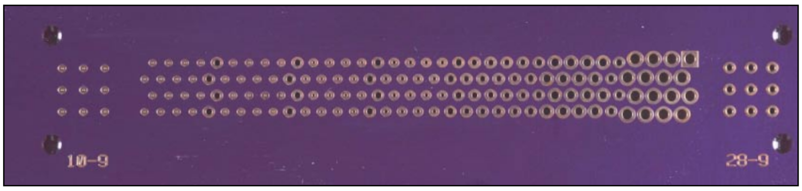
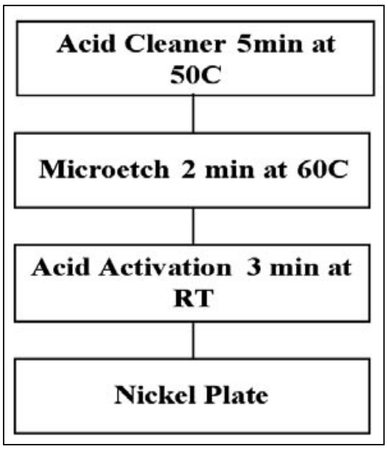


Figure 3 – Test coupon
Figure 4 – Pre plate process flow



If the plating on the surface layer becomes too thick while trying to obtain the minimum thickness in the centre 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, levellers) in their chemistry to obtain the higher throwing power.

Current Density	Sulfamate Bath DC Direct Agitation	DC Indirect Agitation	Pulse Direct Agitation	Pulse Indirect Agitation	Bromide Bath 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

Tables 1 and 2 – Experiment matrix – surface to hole thickness ratio: 28 mil hole

Current Density	Sulfamate Bath with Additive DC Direct Agitation	DC Indirect Agitation	Pulse Direct Agitation	Pulse Indirect Agitation	Bromide Bath with Additive 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

Therefore when utilising 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 centre 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.

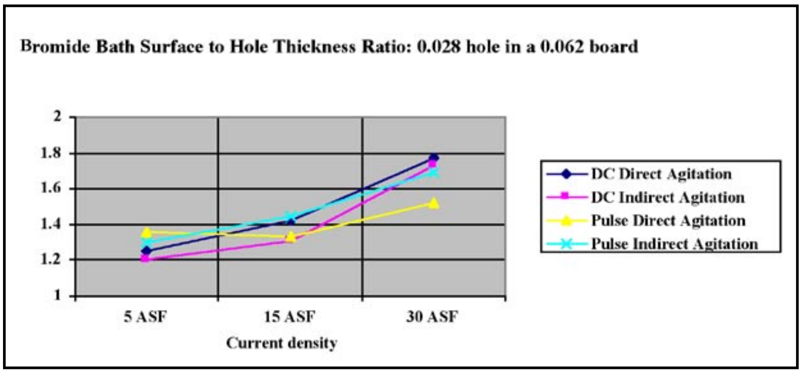
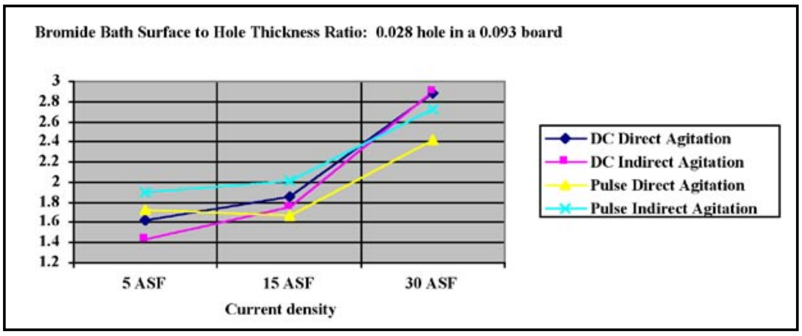


Figure 5 – Bromide bath SHTR with a 28 mil hole in a 62 mil board
Figure 6 – Bromide bath SHTR with a 28 mil hole in a 93 mil board



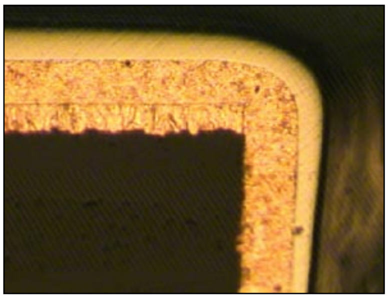
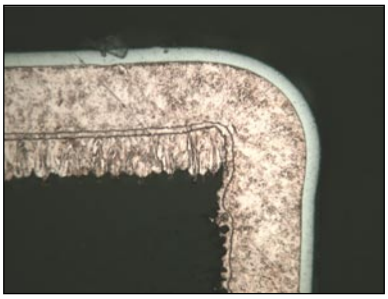



Figure 7 – 28 mil hole in a 62 mil board plated in the sulfamate bath with DC at 5 ASF using indirect agitation (left, 20 x magnification)
Figure 8 – 28 mil hole in a 62 mil board plated in the bromide bath with DC at 5 ASF using indirect agitation (right, 20 x magnification)

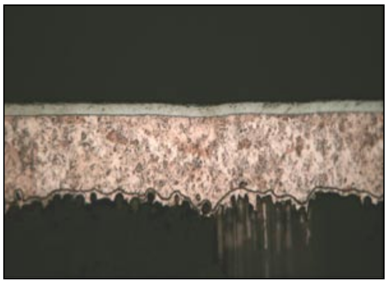
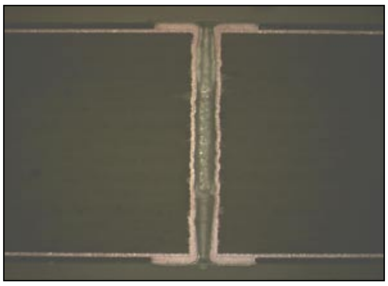



Figure 9 – 6 micron thick nickel deposit in the center of a 28 mil hole in a 62 mil board (left, 20 x magnification)
Figure 10 – 10 mil hole in a 93 mil board pulse plated in the bromide bath at 15 ASF with direct agitation (right, 5 x magnification)

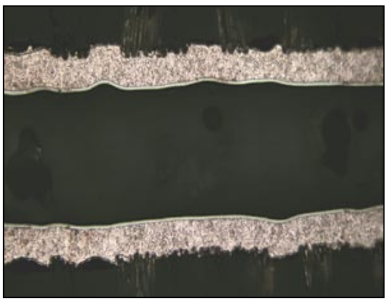
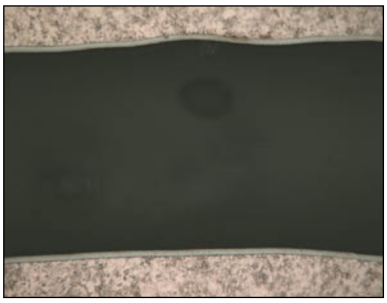
Experiment details

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).

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 (0.1 sec. on-0.9 sec. off) was compared to direct current. The solution flow was varied utilising 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, micro-etch and an acid activation with a 2 min. deionised water rinse between each step (Figure 4).

Figure 11 – 10 mil hole in a 93 mil board pulse plated in the bromide bath at 15 ASF with direct agitation (left, 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)

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 Table 1 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.

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

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

Table 3 – Plated thru hole SHTR
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

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 centre 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

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

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.

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.

Deposit analysis

Sample coupons were prepared from 3 inch silicon wafers that were metallised 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.

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.

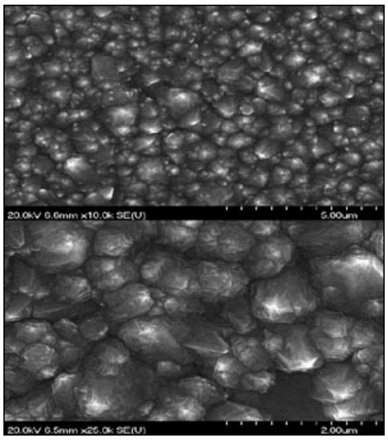
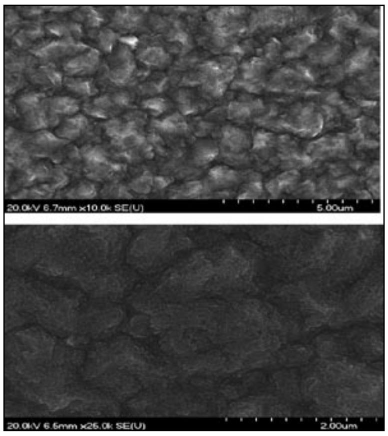


Figure 13 – DC plated in the bromide bath at 5ASF with indirect agitation
Figure 14 – Pulse plated in the bromide bath at 15 ASF with direct agitation



Scanning Electron Microscopy (SEM) was used to determine the deposit morphology. Figure 13 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 levellers) in the bath.

Figure 14 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.

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

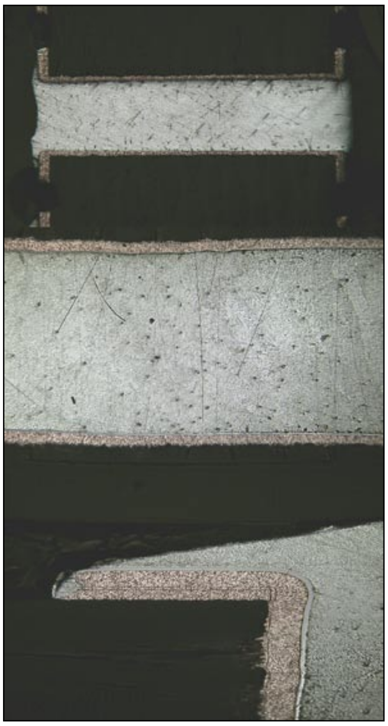


Figure 15 – 28 mil hole in a 62 mil board after thermal shock and thermal stress test

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 15 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.

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.

Figure 16 – 62 mil board with a press fit connector pin after the thermal shock test
Figure 17 – 93 mil board with a press fit connector pin after the thermal shock test

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 16 shows the 62 mil board and Figure 17 shows the 93 mil board after the thermal shock test.

This article is based on a paper originally presented at the IPC Printed Circuits Expo, APEX and the Designer's Summit 2008

Placing LEDs On Flex Circuits

The future, from a lighting prospective, will look drastically different thanks to LED technology, which is being used in more and more applications all over the world. In the last few years, Essemtec has delivered production equipment to the LED industry for various applications. Most of this production equipment was custom design. For example, a customer producing sensor strips began with screen printing of the solder paste on a high end SP200 printer then dispensing with a jet dispenser, pick & place of the LED and UV curing of the adhesive on a FLX 2010 based module. Next step was laser soldering of the pads on a 3rd party laser soldering system. The sensor strips were based on a foil substrate consisting of up to 56 strips with 3 LEDs each and the target cycle time was 5.4 seconds per sensor strip. Essemtec delivered a system with a cycle time of 4.1 seconds per strip, achieving 34% higher production capacity.

The concept of the solution was based on the FLX 2010, equipped with a movable vacuum table, UV chamber and dispensing unit with jet valve. The foil is placed on a carrier. This carrier can be used for the previous and the following processes. The vacuum table and the carrier are pressurised permanently. The movement of the table is software controlled. The GUI was customized for this application. The head unit is equipped with a jet valve and the pick & place Z axis. The vacuum pump was located outside of the machine and runs constantly. The customisation was based on feasibility and cost considerations. The system is flexible and can be upgraded easily.

Essemtec
Mosenstrasse 20, CH-6287 Aesch/LU – Schweiz
Tel. +41 41 919 60 60, Fax +41 41 919 60 50
info@essemtec.com
www.essemtec.com