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Accelerating Plating Cycles and Reducing Costs:
Improving the Plating of High Aspect Ratio Holes & Blind Vias

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Abstract
This paper describes a new technology for speeding the initiation and uniformity of electroplating deposits that does not depend on modifying the chemistry or physical environment of the plating bath. Rather, it involves the treatment of conductive surfaces *outside of the plating environment* and is therefore not dependant on any particular type of bath, the pH of the bath, or the chemical agents contained in the bath. Process improvements include a more rapid initiation of plating; an increase in "throwing power" into low current density areas; and improved metal-to-metal bonding such that very thin deposits exhibit unusual resistance to corrosive testing environments.

Introduction
While the focus of this discussion is on circuit manufacture, the applicable technology applies to other types of plating and some of the relevant test data that has been generated will be described in order that the reader have a better understanding of its application to the plating process in general.

Accepted theory and practice mandates *activation* of metal substrates to achieve good plating results. The technology that is the subject of this paper requires *passivation* of substrate metals, causing them to become extremely receptive to electroplated deposits. This, in turn, causes deposits to initiate in low as well as high current density areas, in some cases, very nearly simultaneously. Passivated metals can allow uniform deposits to occur at current flows so low that electroplating would not otherwise proceed at all.

How It Is Applied
In applying the passivation step to metallic substrates, all testing to date has been in the form of one or more acidic cleaning solutions capable of removing oxidation and other contaminates from substrate surfaces. The passivated surface resulting from this contact renders the metal hydrophobic, shedding rinse water like the proverbial ducks back, and preventing the formation of oxides that normally accompany the final acidic activation step before plating.

Why It Works
The hydrophobic layer that forms on metallic surfaces is an extremely dense polymeric structure, probably not more than two or three molecules thick, that is more conductive than the base metal or alloy upon which it is deposited. Therefore, the speed of plating initiation and the ability of the plating bath to "throw" into low current density areas will be greater on metals with higher resistance, and will be less on metals with lower resistance. The polymeric layer does not inhibit metal-to-metal bonding, but enhances it as you will see.

Nickel Plating on Steel
The first field test was conducted at a large metal finishing company in North Carolina and is illustrative of the unusual effects possible with this technology. The plating bath was a low brightener Watts nickel bath made up as shown in Table 1.

Table 1 - Watts Nickel Bath

Nickel sulfate	40 oz./gal.(10 oz./gal. as Ni)
Nickel chloride	5.5 oz./gallon
Boric acid	5.0 oz./gallon
Quest 1 B & L	0.02% (by MacDermid)
pH - adjusted	3.5 - 4.5 with boric acid

Test parts were industrial door hinges made of mild steel. The plating racks carried 2.25 ft^2 of hinge parts which were plated at 80 amps (35.5 ASF) for a minimum of 6 to a maximum of 12 minutes depending on customer requirements. Preclean was an ultrasonic alkaline cleaner followed by a hydrochloric acid pickle, rinse and plate.

The test racks were cleaned in the test solution for one minute, rinsed, and plated. We found that the test racks could be plated at 25 amps (11 ASF) for three (3) minutes and achieve complete coverage, including better than normal coverage in the barrels where the hinge pin fits. The platers tried the same 25 amps for 3 minutes with their in-house cleaning system and found that all the plating went to the outside, high current edges of the hinge flats. What little plating occurred was amorphous and had no adhesion. A three minute cycle at 50 amps was also tried. The result was spotty, incomplete plating.

Cadmium on Steel
We next prevailed upon the head of the quality control lab of a large Santa Ana metal finishing company to have a look at our passivation treatment

and give us an opinion. This gentleman ran a standard cadmium bath test in a Hull Cell but used our test solution as the final pickle for his steel coupon. His report was that the cadmium plate was a measured 50% thicker than normal and exhibited a "significant" increase in throwing power. Interesting results, but still no hard, measurable data.

Cadmium Again

A controlled test was set up at AnaCon Laboratories in Riverside, an independent lab specializing in the analysis of plating chemistry, and willing and able to do the plating and evaluate the results against a control. The criteria sought was plating efficiency, throwing power, and adhesion of the electroplate. The medium chosen was an alkaline cadmium bath the make up of which is detailed in the report. The substrate metal was 1020 steel formed to make a recess with the walls angled at 78°. The depth of plating into this recess was the determinate of throwing power. The depth was 5 cm. The results are shown in Table 2.

Table 2 - Throwing Power Test Values

Test #1 30 Seconds @ 0.2 amps			
	Cleaning Process	**Depth of Coverage**	**Percent of Coverage**
	Conventional	3.6 cm	72 %
	Test Solution	5.0 cm	100 %
Test #2 10 Seconds @ 0.2 amps			
	Cleaning Process	**Depth of Coverage**	**Percent of Coverage**
	Conventional	2.9 cm	58 %
	Test Solution	5.0 cm	100 %

Based on Haring Cell data and thickness tests, the increase in cathode efficiency was not found to be valid. This was expected. But the lack of increased plating thickness was not. However, we had no reason to doubt the previous thickness data supplied by the Santa Ana metal finishing company, and in view of subsequent test data showing substantial increases in plating thickness during any number of tests on copper, the question of why this particular cadmium bath did not exhibit these effects is still open to question.

On the other hand, the case for increased throwing and adhesion of the electroplate was definitely found to be valid. Salt spray per ASTM-B-117 showed no significant difference between test panels and control. However, salt spray resistance of the low current density panels processed through the test solution showed a significant increase in salt spray resistance. The report speculated that the unusual corrosion resistance of this very thin electroplate was due to the exceptional receptivity of the surface after processing through the test solution. The report goes on to say the following: *"The covering power of 1020 steel, using the* (test solution) *as compared to conventional muriatic preprocess is, however, impressive. As you can see from the numbers, the speed at which the low current density is covered is 50% greater than conventional preprocess".* And finally the report ends with this: "*The speed of low current coverage would allow for shorter plating time for thin deposits, give better coverage in low current* (areas) *for improved corrosion resistance and, in some cases, allow for a reduced dog bone effect".*

Copper Circuit Boards

Every circuit board manufacturer knows that fabricating multilayer boards with high aspect ratio holes and blind vias can present some very interesting challenges to the plater. Plating cycles of 4 to 8 hours and even longer are not unheard of where cutting edge work is being done. Some problems are being met within the plating solution itself through the use of eductors to improve solution flow through the holes; strategic placement of anodes; and pulsed rectifiers to help even out deposits, eliminate dog boning, and speed the plating process. On the chemical side are companies at the leading edge of plating bath technology who work to alleviate problems through the magic of chemical additives and bath component ratios.

With all this very much in mind, we decided it was time to find out what this surface phenomenon could do for high aspect ratio holes in multilayer boards. We had a single, 0.20" thick, 20 layer multilayer board made up and precision drilled so that when cut into Hull Cell sized rectangles, each small multilayer panel contained 4 rows of parallel holes sized 22, 20, 18, and 16 mils. The aspect ratios of these holes was 12.5, 11, 10, and 9 to 1.

First Copper Plating Test

This first test was structured simply to determine what differences would occur between test and control panels plated in the same bath under identical conditions. The bath was a basic acid copper made up as shown in Table 3.

Table 3 - Copper Plating Bath

Copper sulfate pentahydrate	10 oz/gal.
Sulfuric acid, 66 degrees Baumé	28 oz/gal.
Chloride	60 mg/L
McGean 339 Brightener	0.5% v/v

In order to magnify whatever effects the passivating test treatment could provide, we opted to have the laboratory double the amperage normally used to plate holes in the aspect ranges we had provided. Thus the panels were plated at 20 amps/ft^2 instead of 10 amps/ft^2 or less which would have been a more normal range for these high aspect ratio holes.

Control and test panels were plated for 5, 15, 20, and 30 minutes. Unfortunately, specific measurements of cross sections were not saved and recorded, and the final report deals only with relative thickness between test and control panels for each time cycle. However, the information is still quite revealing. Boiled down to essentials, the 20 minute control panel showed severe "dog boning" such that the opening of the holes were plated approximately four times thicker than the deposit inside the bore.

The test panel, on the other hand, was nearly uniform with only a very slight differential between the bore and the openings. Also, there was considerably more copper deposited in the bore of the test panel holes than in those of the control because of the continuous drop in current density as the control panel openings plated to a smaller diameter.

At 30 minutes the test panel showed a much thicker deposit in the bore over that of the control, but also showed a substantial buildup forming at the hole openings. The obvious conclusion is that the passivating treatment, being a surface phenomenon, has a finite life and no longer has plating effects after 20 to 25 minutes. This was not unexpected, and explains many of the results we saw later on.

The crude data from these tests, though lacking in specifics, still gave us additional insight into how the phenomenon works, and helped us structure test criteria from which we could derive the maximum amount of information.

Copper Plating Test #2

Though we were beginning to get a feel for what this passivating treatment could do for plating metal on metal, we still had a great deal to learn. What we wanted most at this point was some hard numbers derived from plating high aspect thru-holes, and we did some interesting experiments to obtain the data we needed.

A good example was a high aspect ratio test plated in a Gornall Cell. This is a "V" shaped Cell that holds 1500 ml of plating solution and is designed specifically for plating Hull Cell sized thru-hole boards. There are two anodes placed at the ends of each leg of the "V", with the panel placed in a slot in the middle where the two legs of the "V" converge. Because of the placement of the panel at a steep angle to the anodes, there is a considerable difference in current density from one end of the panel to the other. The test panels were 0.2" thick with four rows of holes 16, 18, 20, and 22 mils. Plating was for 20 minutes. Bath make-up is shown in Table 3.

The cross sections were prepared by Microtek Laboratories in Anaheim, CA, and were taken from the 20, 50, and 70 amp/ft^2 sections of the test and control panels. The really interesting results were from the 20 and 50 amp sections. The 20 amp section showed an average of +85.4% thicker deposit on the surface compared to control, and +92.9% in the holes (see Table 4).

Table 4

Surface Thickness Avgs. - 20 min. @ 20 amps/ft^2			
	Control	**Test**	**% Thickness ±**
16 mils	.00032	.00060	+87.5
18 mils	.00032	.00052	+62.5
20 mils	.00032	.00056	+75.0
22 mils	.00030	.00065	+116.6
Avgs.	**.000315**	**.000583**	**+ 85.4 %**

Hole Thickness Avgs. - 20 min. @ 20 amps/ft^2			
	Control	**Test**	**% Thickness ±**
16 mils	.00022	.00046	+109.0
18 mils	.00022	.00048	+118.0
20 mils	.00026	.00048	+ 84.6
22 mils	.00030	.00048	+ 60.0
Avgs.	**.00025**	**.000475**	**+ 92.9 %**

The 50 amp test panel, however, plated an average of +23.5% on the surface compared to control, and +28% in the holes (see Table 5).

Table 5

Surface Thickness Avgs. - 20 min. @ 50 amps/ft^2			
	Control	**Test**	**% Thickness ±**
16 mils	.00032	.00039	+22.0
18 mils	.00032	.00033	+03.0
20 mils	.00031	.00046	+48.0
22 mils	.00038	.00045	+18.5
Avgs.	**.00033**	**.00041**	**+23.5 %**

Hole Thickness Avgs. - 20 min. @ 50 amps/ft^2			
	Control	**Test**	**% Thickness ±**
16 mils	.000124	.000149	+20.0
18 mils	.000132	.000157	+19.0
20 mils	.000149	.000198	+32.8
22 mils	.000165	.000231	+40.0
Avgs.	**.000143**	**.000184**	**+28.0 %**

The 70 amp section showed a 40% surface increase and a thicker surface deposit than the 50 amp section, but had about the same deposit in the hole for a truly dismal surface-to-hole ratio. Perhaps the most unusual aspect of this data is that the 20 and 70 amp sections had the same surface deposit thickness which was almost double the thickness of the 50 amp section.

Certainly the results shown in Tables 4 and 5 are interesting. They clearly show the ability to throw into low current density areas as evidenced by the

fact that plating inside the test panel holes is building faster than it is on the surface. It also clearly shows that there can be to much of a good thing. There are limits to what can be done by increasing amperage and these tests give some clues to what may be expected by raising the amperage to high.

Copper Plating Test #3

This test was done in a production bath and the luxury of experimenting with different amperages was not available. We wanted to get away from Hull Cell testing and into real world production plating and were therefore limited to what was going on at the time in the bath we had access to. We were able to modify time cycles in the bath by removing panels at set intervals, the purpose being to verify our Hull Cell experience that indicated loss of activity after 20 to 25 minutes.

The electroplating bath was a Shipley EP-1100 bath designed for plating high aspect ratio holes, a function our cross sectioned control panels indicated that it does very well. This particular bath was not chosen for any specific reason, but because it was available. Nevertheless, the results were interesting and indicated that the way a bath functions has definite effects on results with respect to the tests we were running.

The panels used in the test were 0.113" thick Hull Cell sized multilayer panels 3.75" x 2.9375" with 4 rows of 28 holes sized 16, 18, 20, and 22 mils. The aspect ratios were 5, 5.6, 6.27, and 7 to 1.

The test was set up to plate sets of panels at 20, 40, and 60 minutes. This was done by attaching our small panels to the large carriers of an automated production line and then removing one set every 20 minutes. Control panels went down the normal preclean line; test panels were processed off line and attached to the carrier just before the final sulfuric acid dip before plating.

Unfortunately, something went wrong with the 40 minute panels so they are not included. The results from the 20 and 60 minute tests are quite interesting, however, especially as they relate to this particular electroplating bath.

Initially, in the first 20 minute plating segment, the average test panel disparity in surface deposit over those in the hole are substantial. However, after 60 minutes of plating the situation has changed and even though there is still a differential in terms of percentages as compared to control, the actual differences in terms of the end results are ahead by an average of +10 % in the holes of the test panel vs. the surface plating. See Tables 6 and 7.

Table 6 -

Surface Thickness Avgs. - 20 min. @ 12 amps/ft^2			
	Control	**Test**	**% Thickness ±**
16 mils	.00022	.00039	+ 77
18 mils	.00022	.00039	+ 77
20 mils	.00022	.00041	+ 86
22 mils	.00024	.00041	+ 71
Avgs.	**.000225**	**.000400**	**+ 77.7 %**

Hole Thickness Avgs. - 20 min. @ 12 amps/ft^2			
	Control	**Test**	**% Thickness ±**
16 mils	.00028	.00032	+ 14
18 mils	.00028	.00035	+ 25
20 mils	.00026	.00035	+ 35
22 mils	.00028	.00037	+ 32
Avgs.	**.000275**	**.000347**	**+ 26 %**

Below are the tables representing results obtained after 60 minutes of plating. Again, Table 7 has been separated for purposes of clarity. You will note a marked difference between hole and surface plating thickness compared to those in Table 6. Also see Figures 1 and 2.

Table 7

Surface Thickness Avgs. - 60 min. @ 12 amps/ft^2			
	Control	**Test**	**% Thickness ±**
16 mils	.00045	.00065	+ 44
18 mils	.00047	.00069	+ 47
20 mils	.00045	.00065	+ 44
22 mils	.00045	.00063	+ 40
Avgs.	**.000455**	**.000655**	**+ 44 %**

Hole Thickness Avgs. - 60 min. @ 12 amps/ft^2			
	Control	**Test**	**% Thickness ±**
16 mils	.00056	.00067	+ 20
18 mils	.00058	.00069	+ 19
20 mils	.00058	.00069	+ 19
22 mils	.00058	.00084	+ 45
Avgs.	**.000575**	**.000723**	**+ 26 %**

As you can see by comparing the control panel averages in Table 7 after one hour of plating, the EP1100 bath has deposited 26% more copper in the hole than it has on the surface. The test panel has ended up with an increase of 10% more copper in the hole than on the surface, but it has an overall gain of 26% in thickness of deposit in the hole vs. control.

It should be understood that the gain in plating thickness is a function of the passivating surface treatment. The finding of thicker deposits in the holes than on the panel surface is a function of the EP 1100 bath, not the test solution, as can readily be seen by comparing Table 6 and Table 7.

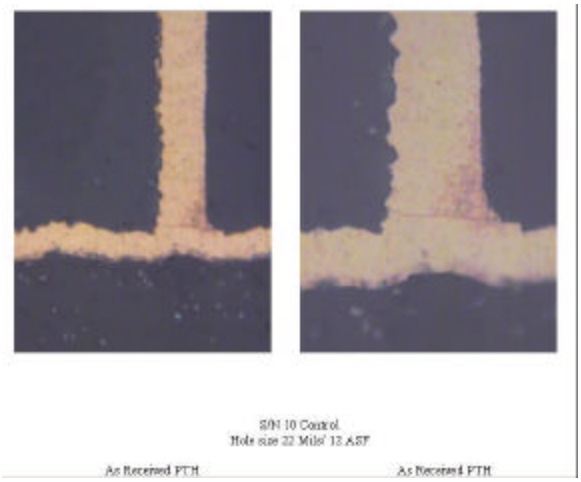

Figure 1 - Plating Thickness of a 22 mil Hole as Reflected in Table 7 – Test

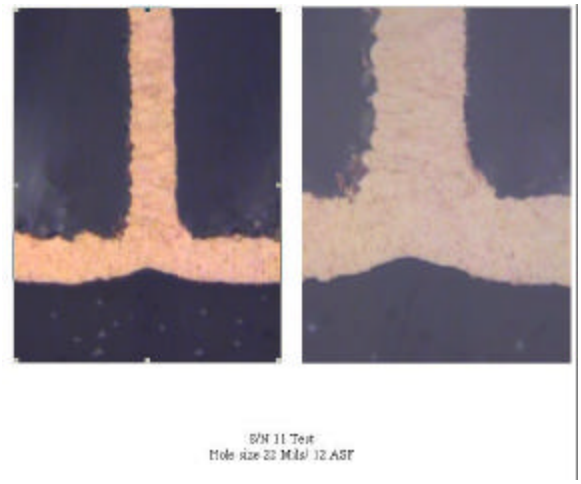

Figure 2 - Plating Thickness of a 22 mil Hole as Reflected in Table 7 - Control

Copper Plating Test #4

Test number four was a repeat of the Shipley EP 1100 bath except that it was run for the entire plating cycle of 175 minutes at 12 amps/ft^2. As with the first production bath plating test, the amperage and total plating time was adjusted for whatever the production board requirements were, having nothing to do with our tests. Our panels were just along for the ride.

The results of this nearly three hour plating cycle are shown in Table 8. They are very different from the 20 minute and one hour cycles shown in Tables 6 and 7. As with other Tables in the series, Table 8 has been separated for added clarity.

Table 8

Surface Thickness Avgs - 175 min. @ 12 amps/ft^2			
	Control	**Test**	**% Thickness ±**
16 mils	.00128	.00144	+ 12.5
18 mils	.00132	.00144	+ 9.1
20 mils	.00124	.00153	+ 23.4
22 mils	.00132	.00153	+ 15.9
Avgs.	**.00129**	**.00149**	**+ 15.5 %**

Hole Thickness Avgs - 175 min. @ 12 amps/ft^2			
	Control	**Test**	**% Thickness ±**
16 mils	.00111	.00124	+ 11.7
18 mils	.00128	.00132	+ 3.1
20 mils	.00124	.00140	+ 12.9
22 mils	.00132	.00144	+ 9.1
Avgs.	**.00124**	**.00135**	**+ 9.2 %**

As you can see, a long plating cycle with high aspect holes is not nearly as impressive as earlier tests with shorter time cycles. Here the control is only + 4 % on the surface compared to hole thickness, whereas the test panel averages are + 10 % thicker on the surface and increased hole thickness over control is only an average of + 9.2 %. The question of why we lost ground in the surface to hole ratio when our one hour testing showed us ahead 10 % is a puzzle without a solution pending further testing.

One thing that appears evident to us is that to derive the benefit inherent in this surface phenomenon it will be necessary to change some plating parameters when using it to plate high aspect multilayer boards. One approach would be to double the amperage for the first 20 to 30 minutes of operation, and then lower it back to normal amperage for the remainder of the cycle The second approach would be to increase amperage, plate for 20 to 60 minutes, remove panels and rinse, passivate, rinse, and plate at the same increased amperage for another 20 to 60 minutes. Even accounting for the time to re-process, the increased production rate should make it more than worthwhile. Of course this remains to be proven. I'm convinced it will be in the not to distant future.

Copper Plating Test #5

Test number five was done by a company that does plating as a service for other circuit manufacturers. The testing was for panel plating 0.5 mil of copper on .062 board material drilled with 35 to 40 mil holes. This was a straight forward test with no surprises.

The manufacturer made up eight test panels configured as shown in Figure 31.

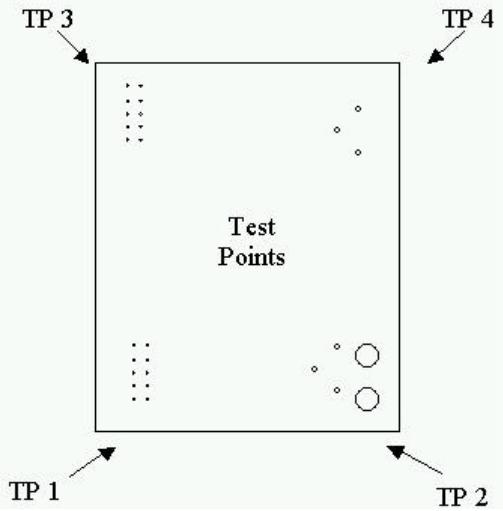

Figure 3 – Test Panel

All panels were run through electroless copper per standard procedures. Panels 1 through 4 were precleaned and panel plated using procedures normal to the company doing the tests. Panels 5 through 8 were cleaned in the test solution, rinsed, and panel plated using the same plating time and current as the control.

The plating cycle to plate these boards was 40 minutes. Start up was 10 minutes at 5 amps/ft^2 followed by 30 minutes at 15 amps/ft^2. We do not know the maker of the electroplating bath or anything about its characteristics

Thickness measurements were taken in the holes represented by the four areas shown in Figure 1 as TP 1, 2, 3, and 4. The results of these thickness measurements are shown in Tables 9 and 10. The averages for all test and control panels as well as the average increase in plating thickness for each of the four test areas is shown in Table 11.

Table 9 - Control Panels - Plating Thickness

	TP 1	TP 2	TP 3	TP 4
Pnl. 1	.00050	.00058	.00055	.00047
Pnl. 2	.00056	.00057	.00048	.00057
Pnl. 3	.00057	.00062	.00068	.00062
Pnl. 4	.00055	.00050	.00063	.00053

Table 10 - Test Panels - Plating Thickness

	TP 1	TP 2	TP 3	TP 4
Pnl. 5	.00085	.00082	.00080	.00072
Pnl. 6	.00075	.00065	.00069	.00077
Pnl. 7	.00062	.00066	.00066	.00066
Pnl. 8	.00075	.00062	.00062	.00065

Table 11 - Control & Test Panel Averages

	TP 1	TP 2	TP 3	TP 4
Control	.00054	.00057	.00059	.00055
Test	.00074	.00069	.00069	.00071
Increase	**+ 37%**	**+ 21%**	**+ 17%**	**+ 29%**

The engineer who did the testing on these panel plated test boards calculated that he could reduce plating time per load from 40 minutes to 30, a savings of 25%. He also determined that at his current volume he could plate two (2) extra loads per eight hour shift, not an inconsequential improvement.

Actually, he could do much better, and may in the future run the necessary tests. By increasing the amperage, the plating time on these low aspect ratio boards could probably be reduced by as much as 50% which would, in effect, double capacity in the plating line.

Is this really possible? The numbers seem to indicate that it is, at least in cases where the plating cycle is relatively short and board configuration not to demanding. Where high technology is being fabricated, the savings in plating time may be less. However, it would make sense to plate with this technology in timed segments as previously discussed. Even without raising amperages, the time savings could be dramatic. The same applies to initiating high amps and ramping down to normal after 30 minutes. These concepts are in testing now.

Cost Cutting In The Copper Plating Line

An immediate and obvious benefit of this technology is a reduction in plating time. In some cases this may be substantial, in others less so. There are too many unknowns yet. But speeding the initiation of electroplating is not all that this technology can do. What it can also do is bring about the elimination of the microetch as a preplate cleaning tool.

In 1981 a Southern California company introduced a system that eliminated copper strike and allowed the lamination of dry film directly over the thin 20 to 30 microinch electroless copper deposits used in those days. The system was dependant on the ability to reactivate the copper after developing the dry film, but reactivating meant removing more than just post development photo resist residues. Just as important was removing the antioxidant that made the whole process work. The system worked then and is still used on the much thicker electroless coppers of today. The difference is that today microetches are routinely used to ensure removal of antioxidants.

To get around the need to microetch requires three things: (1.) an antioxidant that supports resist adhesion; (2) an antioxidant that allows cleaner development of the dry film; and (3) an antioxidant that *does not have to be removed*.

The technology that is the subject of this paper does all these things and, as we have seen, supports the plating process as well.
As you may imagine, much of this is experimental. Only one field trial has been undertaken using a form of this developmental technology in the role of an antioxidant for electroless copper. It has worked well in this capacity for over ten months at a large facility on the East Coast The next step is a preplate cleaner based on this same technology to clean and prepare surfaces for plating without the necessity of a microetch. Some of the test results described in this paper were from panels cleaned with a prototype of just such a cleaner.

Other Uses In The Circuit Manufacturing World
The plating uses of this metal passivation technology extends to nickel and cadmium as you know, and probably to gold, though we have not tried it yet. It may be useful in tip plating; and may even be useful in high speed automated plating of lead frames. There are many areas that remain to be explored. Options are limited only by the imagination.

For instance, we have yet to explore the use of this material with the several different types of direct plate electroless copper substitutes. Generally speaking, these conductive materials have higher electrical resistance than does electroless copper, and therefore it takes longer to initiate plating on these surfaces. We had occasion to field test with one of these products, and measurement of resistance values side-to-side through the holes before and after the passivation treatment showed a resistance drop of around ten to one . That is a significant drop and indicates the test treatment would probably work extremely well in this application. But so far we haven't plated any of these materials, so this is pure speculation until a plating test is actually done.

Speculating about things is what research is all about, and every now and then leads to the development of something new and useful. Our hope is that the surface passivation treatment described here will prove to be useful to the electroplating of copper into the ever smaller thru-holes and blind vias the circuit fabricator must contend with every day.