Characterization of DuPont 9015, Aqueous Processable Dry Film Photoresist for Printed Wiring Boards

Kansas City Division

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KCP-613-5537

Published April 1995

Topical Report

David Fogleman, Project Leader

Prepared Under Contract Number DE-ACO4-76-DP00613 for the
United States Department of Energy

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A prime contractor with the United States
Department of Energy under Contract Number
DE-ACO4-76-DP00613.

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Abstract

This report describes the evaluation of DuPont's Riston 9015, fully aqueous processable dry film photoresist as a mask for gold plating, tin/lead plating, and print and etch patterning for printed circuit board products.

Summary

DuPont's Riston 9015, a fully aqueous processable dry film photoresist, was characterized for use on printed circuit products as a mask for gold plated features. The characterization was performed to replace Dynachem's Laminar HY which was no longer manufactured by Morton Thiokol, Inc., Dynachem Division. Additional work was done to evaluate 9015 as a mask for tin/lead plated patterns and as a mask during alkaline copper etching.

The DuPont 9015 proved to be chemically resistant to the existing copper electroplate, tin-lead electroplate, gold electroplate and alkaline etch processes and produced an etched circuit maintaining 2 mil line and a 5 mil space patterns.

Discussion

Scope and Purpose

The purpose of this evaluation was two-fold:

1. To find a replacement for the Dynachem "HY" dry film photoresist used for selected gold plating on printed circuit board product. A replacement was necessary because Dynachem's HY was no longer going to be available.
2. To have the capability of defining 2-mil line and spaces on the final circuit. Additional work was done to determine if the DuPont 9000 series dry film photoresist could be used for tin-lead patterning or print and etch using alkaline etchant.

Prior Work

DuPont's 4615 and Dynachem's HY were originally compared for gold plating capability. The two performance criteria used were adhesion of the dry film photoresist to copper or nickel substrates during the gold plating process and the ability to resolve patterns of 5-mil lines and spaces.

Attributes of DuPont 4615 and Dynachem HY:

1. Sidewall integrity: This was analyzed by viewing Scanning Electron Microscope (SEM) photomicrographs of 4615 and HY to determine which photoresist had the straightest sidewall (see Figures 1 and 2).

Panel 9, Exposure Setting 80, Stouffer Step 9

Panel 3, Exposure Setting 80, Stouffer Step 9

Figure 1. SEM Photomicrographs of DuPont 4615 Photoresist

Panel 23, Exposure Setting 50, Stouffer Step 8

Panel 25, Exposure Setting 70, Stouffer Step 9

Figure 2. SEM Photomicrographs of Dynachem HY Photoresist

Results: The DuPont's 4615 shows a slightly straighter sidewall in the SEM micrographs

2. Path width: This was data generated by an inspector measuring the widest part of the 5- and 10-mil circuit paths under a microscope at 40X.

Results: The print and etch comparisons of the 5- and 10-mil photoresist paths measurements are shown in Figure 3. Path width measurements for both the DuPont's 4615 and the Dynachem's HY were acceptable.

3. Chemical resistance/adhesion: This evaluation was subjective, looking for resist breakdown, or changes in surface texture or color during all printed circuit board chemical processes. The ability to withstand nickel and gold plating were the most rigorous tests.

Results: The DuPont 4615 occasionally broke down during the nickel and gold plating process. Further evaluations also confirmed the results of the 4615 sporadic resist breakdown. The HY did not show signs of resist breakdown during the same evaluations. Consequently, HY was chosen as the photoresist to image gold plated patterns.

4. Process Latitude: This was a review of the process interactions for photoimaging both resists. The photoimaging parameters were varied during this characterization, which helped establish a processing window for future design reviews.

Results: DuPont's 4615 was more sensitive than the HY to temperature changes during lamination. The HY could be laminated using a wider temperature range which gave HY a larger processing window for manufacturing.

Process sequence used:

1. Pre-image conveyORIZED chemical cleaning
2. Hot roll laminating of photoresist on copper or nickel substrate (Table 1)
3. Exposing of photoresist (Table 2)
4. ConveyORIZED developing of photoresist (Table 3)
5. Pre-plate cleaning (acid detergent cleaner dip tank)
6. Water rinse
7. Ammonium persulfate (microetching of copper in dip tank)
8. Water rinse
9. Nickel strike
10. Water rinse
11. Gold plate
12. Water rinse

The specific photoimaging parameters for both resists are shown in Tables 1 - 3.

As a result of this evaluation, HY was chosen for gold patterning. DuPont 4615 was chosen for the print and alkaline etch process.

PRINT AND ETCH RESIST COMPARISON

DYNACHEM HY VS DUPONT 4615
CONDUCTOR WIDTH AFTER DEVELOPING

TYPE ——— HY 5

————— HY10

4615 5

461510

Table 1. Hot Roll Laminating of Photoresist

DuPont HRL Hot Roll Laminator CE# 54013/59225		
Parameters	HY	4615
Temperature °C	116	100
Exit Board Temperature °F	148	139
Pressure (psi)	30	30
Roll Speed (meters/min)	1.5	1.5

Table 2. Exposing of Photoresist

Optical Radiation Corporation Optibeam 6000, CE# 66483		
Stouffer Step Tablet Reading (bare copper)	Exposure Setting HY	Exposure Setting 4615
8	50	57
9	70	80
10	98	112

Table 3. Conveyorized Develop of Photoresist

Advanced Systems Inc. (ASI) Developer, CE# 64707		
Parameters	HY	4615
Temperature °F	100	85
Spray pressure (psi)	22/22	21/24
Conveyor Speed (ft/min)	1. 2.0 2. 3.0	1. 3.0 2. 3.75
Break Point(Dwell Time)		
1. 50% (3rd spray bar)	1. 1 min 50 s	1. 1 min 13 s
2. 75% (4th spray bar)	2. 1 min 14 s	2. 58 s

Activity

Background

The use of dry film photoresist for selective gold plating is conventional to the printed circuit board industry. DuPont's Riston 9000

series was relatively new to the commercial market when this study was done. Companies like AT&T, IBM, and TI were doing evaluations comparing this dry film photoresist to their existing photoresists and printed circuit board (PCB) fabrication processes. The Kansas City Division chose to evaluate the 9000 photoresist due to the prior information learned from these other companies. The 9000 series photoresists had many different thicknesses, and 9015 was chosen because of its 1.5-mil-thick photoresist. DuPont 9015 gave both good imaging resolution and chemical resistance during the build of copper and tin-lead plating.

DuPont 9015 is marketed as an all-purpose photoresist. This evaluation was expanded to determine the performance not only of gold plating but also copper, tin-lead plating, and alkaline etching. This evaluation was not designed to be a side-by-side comparison to Dynachem's HY photoresist. The remainder of this report concerns the 9015 study only. The data generated in this evaluation was to determine the 9015 capability in the existing processes.

Characterization

This study was focused on four specific qualifying areas to confirm the 9015 photoresist's adequacy for printed wiring board fabrication in the Kansas City facility.

Photoresist performance

The photoresist imaging process was characterized by varying the parameters of lamination, total exposure energy, and developing dwell time (as determined by conveyor speed), and evaluating the patterns by scanning electron micrographs. The performance of the photoresist processed at various parameters was evaluated by its ability to maintain a 2-mil path after electroplating or alkaline etching.

Tin-Lead Plating

The tin-lead plating process was a very good test to demonstrate the chemical resilience of the photoresist and minimum path width capability.

Gold plating

The nickel and gold plating process was a very rigorous test for photoresist. The chemistries and dwell times in the plating baths made it a very good visual test for photoresist adhesion and chemical resistance.

Alkaline etching

The alkaline etching solution is a very aggressive bath for most fully aqueous photoresists, such as DuPont's 9015. Alkaline solutions, in fact, are used to strip off aqueous photoresists. Resistance to the alkaline etchant also showed how well the photoresist was cured or polymerized during the exposure operation.

Photoresist Imaging Performance

To expedite the evaluation of the DuPont 9015, 16 panels were fabricated. The parameters chosen were lamination temperature, exposure energy, and developing dwell time. Based on past photoresist processing experience, these parameters have the greatest effect on photoresist performance.

Table 4 shows the specific parameters which were varied and the values selected for each.

Table 4. Designed Experiment for Maximum Line/Space Definition, DuPont 9015

Panel	1,2	3,4	5,6	7,8	9,10	11,12	13,14	15,16
Lamination (°C)	110	100	110	100	110	100	100	110
Expose (Setting/Step)	110 9	185 11	185 11	110 9	110 9	110 9	185 11	185 11
Develop (Ft/Min)	2.5	2.0	2.5	2.5	2.5	2.5	3.25	2.5

The test vehicle used to demonstrate the 9015 performance was the multilayer capability panel (1468622-105). Figure 13 shows the overall panel layout. This panel was designed to be used for multiple material evaluations and had test coupons and serpentine patterns containing 2-, 5-, 10-, 15-, and 25-mil lines and spaces as shown in Figure 4 and Table 5.

Table 5. Coupon C, Line/Space Snake Pattern

Coupon Indicator (C ₁)	1	2	3	4	5	6	7	8	9	10
Line (mil)	2	2	2	2	5	5	5	10	10	10
Space (mil)	2	5	10	15	5	10	15	5	10	15

Figure 4. Capability Panel Line/Space Snake Pattern (Coupon C)

The advantage of the serpentine pattern is that the multiple line and space widths give an immediate visual indication of the artwork reproduction capability immediately after developing. The particular coupon used was C₁ located in the bottom half of the panel.

A visual qualitative analysis was done to verify the photoresist integrity after developing. The photoresist was shiny (as an example, a matte finish is an indication of improper cure due to low exposure energy or excessive developing temperature), the path widths were sharply defined, and some 2-mil paths were defined. Panels 01, 07, 09, and 11 visually looked better after develop, which showed that the lower exposure setting (step 9) resulted in the best 2-mil line and space patterns. The conclusion from this information was that the pattern was visually acceptable after developing.

The developed path widths were then magnified and microphotographed at 100X, 500X and 1000X, using the scanning electron microscope (SEM), and are shown in Figures 5 through 12. The microphotographs by themselves show little difference in the magnified sidewall. Additional microphotographs were taken to show the final etched circuit which are later explained in this report.

Because plating and etching would impact the definition of the final pattern, the optimum parameters were selected following the plating and etching processes. The processing parameters providing the best results after plating and etching were lamination temperature of 110°C, exposure energy setting of 110 (step 9), and developing speed of 2.5.

The factorial designed experiment included two groups of panels processed through photoimaging with identical parameters and split after developing. One group of panels was copper/tin-lead plated and the second group of panels was gold plated.

Figure 5. SEM Photomicrographs of 9015, Panel 1
Hot Roll Lamination
Temperature 110°C
Exposure setting 110
Stouffer Step 9
Developed Conveyor
Speed 2.5 ft/min

Figure 6. SEM Photomicrographs of 9015, Panel 3
Hot Roll Lamination
Temperature 100°C
Exposure setting 185
Stouffer Step 11
Developed Conveyor
Speed 2.0 ft/min

**Figure 7. SEM Photomicrograph of
DuPont Riston 9015, Panel 5
Hot Roll Lamination
Temperature 110°C
Exposure Setting 185
Stouffer Step 11
Developed Conveyor
Speed 2.5 ft/min**

**Figure 8. SEM Photomicrograph of
DuPont Riston 9015, Panel 7
Hot Roll Lamination
Temperature 100°C
Exposure Setting 110
Stouffer Step 9
Developed Conveyor
Speed 2.5 ft/min**

**Figure 9. SEM Photomicrograph of
DuPont Riston 9015, Panel 9
Hot Roll Lamination
Temperature 110°C
Exposure Setting 110
Stouffer Step 9
Developed Conveyor
Speed 2.5 ft/min**

**Figure 10. SEM Photomicrograph of
DuPont Riston 9015, Panel 11
Hot Roll Lamination
Temperature 100°C
Exposure Setting 110
Stouffer Step 9
Developed Conveyor
Speed 2.5 ft/min**

Figure 11. SEM Photomicrograph of
DuPont Riston 9015, Panel 13
Hot Roll Lamination
Temperature 100°C
Exposure Setting 185
Stouffer Step 11
Developed Conveyor
Speed 3.25 ft/min

Figure 12. SEM Photomicrograph of
DuPont Riston 9015, Panel 15
Hot Roll Lamination
Temperature 110°C
Exposure Setting 185
Stouffer Step 11
Developed Conveyor
Speed 2.5 ft/min

Tin-Lead Plating

The tin-lead portion of the DuPont 9015 evaluation consisted of 8 panels taken from the original 16 panels discussed in the Photoresist Image Performance evaluation. Table 6 lists specific panel numbers and processing conditions.

Table 6. Copper/Tin-Lead Panels and Processing Conditions

Panel	1	3	5	7	9	11	13	15
Lamination (°C)	110	100	110	100	110	100	100	110
Expose (Setting/Step)	110 9	185 11	185 11	110 9	110 9	110 9	185 11	185 11
Develop (Ft/Min)	2.5	2.0	2.5	2.5	2.5	2.5	3.25	2.5

The processing sequence using DuPont 9015 for copper/tin-lead plating on the KCD capability panel was:

1. Copper Pre-image Cleaning - Conveyorized Chemical Cleaning (Table 7)
2. Photoresist Lamination - Hot Roll Laminating of photoresist
3. Photoresist Exposure - Exposing of photoresist to Ultra-violet (UV) light
4. Photoresist Develop - Conveyorized Developing of photoresist
5. Acid Copper Electroplate - Emersion tank
6. Tin-Lead Electroplate - Emersion tank
7. Photoresist Strip - Conveyorized Stripping of photoresist
8. Copper Etch - Conveyorized Alkaline Etching of copper
9. Tin-lead Strip - Emersion tank

Table 7. Pre-Image Cleaning (Chemcut 547, CE #55762)

Process Sequence	Material Name	Conc	Temp	Dwell Time	Belt Speed
Alkaline Clean	MacDermid Metex P-507	19 g/L	140°F (135-145)	42 Sec	42 lpm
Water Rinse	Di Water				
Micro-Etch	Sodium Persulfate	60-150 g/L	Ambient	30 Sec	
	SULFURIC ACID	10-15 ml/L			
Water Rinse	Di Water		Ambient	30 Sec	
Dry	Warm Air Dry			30 Sec	

Some combinations of processing variables resulted in patterns with insignificant differences. Panels were visually evaluated and ranked after tin-lead plating by three people. The visual ranking was based on resist adhesion, definition of the lines and spaces, overall appearance of the photoresist after tin-lead plating.

Ranking was similar by all individuals, for instance panels 01, 07, 09, and 11 were exposed to a step 9 and looked much better than the panels 03, 05, 13, and 15, which were exposed to a step 11 (a higher amount of exposure energy than step 9).

The following photographs, Figures 13 through 18, depict the tin-lead plated process as produced by the evaluation.

Figure 13 shows the overall panel front of the standard capability image used for the printed circuit board process characterization. This panel has two coupons removed, as they were used for the SEM microphotographs described earlier in the report.

Figure 13. DuPont's Riston 9015 Photoresist with Gold Plating, Front View

Figure 15 is a close-up of the panel prior to photoresist stripping. There are three 15-hole coupons and one land and line spacing coupon. The 15-hole coupon shows the definition of the coupons and one land and line spacing coupon. The 15-hole coupon shows the definition of the lands were used only for visual information and not for measurements. The land and line spacing coupon shows the 5-, 10-, and 15-mil paths with 0.050 and 0.062 inch diameter lands. This coupon was also used for visual information only.

Figure 14. DuPont's Riston 9015 Photoresist with Tin/Lead Plating, Back View

Figure 14 shows the overall panel back of the standard capability image used for the printed circuit board process characterization. This panel has two coupons removed, as they were used for the SEM microphotographs described earlier in the report.

Figure 15. Close Up of 15-Hole Test Coupons and Land/Spacing Coupon

Figure 16 is the serpentine pattern showing the photoresist pattern broken up into 10 different line and spacing combinations. (See Table 5 for specific line widths.) The combination labeled 1 shows some developed line resolution, but the developing was incomplete as shown by no evidence of copper or tin-lead plating. The combination labeled 2 shows complete definition of copper and tin-lead plating, which is the 2-mil line with a 5-mil space.

Figure 16. Close Up of Line/Space (Serpentine) Pattern

Figure 17 shows the overall panel front with the standard capability image similar to Figures 13 and 14, but with additional processing where the photoresist and the copper are chemically removed. Comparing this photo to Figure 13 shows that some of the serpentine pattern was removed after etching. Figures 18 and 19 will show a close-up of the coupons and serpentine patterns to illustrate the line width after etching.

Figure 17. Overall Pattern After Etch

Figure 18 is a close-up of the etched coupons. There are three 15-hole coupons and one land/line spacing coupon in this picture. The 15-hole coupon shows the etched definition of the 5- and 10-mil lines, but the 2-mil line was not maintained after etching. The land/line spacing coupon shows the etched 5-, 10-, and 15-mil lines.

Figure 18. Close-up of 15-Hole Coupon and Land/Line Spacing Coupon After Etch

Figure 19 shows the etched serpentine pattern. The area labeled 1 is mostly one continuous block of copper with some streaks of tin-lead plating, but no defined circuits. Area 2 has some resolution, but the tin-lead has bridged some of the circuits. Areas 3 and 4 have been etched and the line width is barely seen. Area 5 is not completely etched between the circuits. Area 6 is the first acceptable defined circuit pattern on this example, which is a 5-mil line and 10-mil space.

Figure 19. Line/Space Pattern After Etch

Figure 20 shows the tin-lead stripped off and is a SEM micrograph of the side wall.

Gold Plating

The gold plating portion of the DuPont 9015 evaluation consisted of 8 panels taken from the original 16 panels discussed earlier. Table 8 lists the specific panel numbers and the processing conditions.

Gold Plating Processing Sequence for the KCD Capability Panel using Dupont 9015

1. Copper pre-image cleaning - conveyorized chemical cleaning (Table 7)
2. Photoresist lamination - hot roll laminating of photoresist
3. Photoresist exposure - exposing of photoresist to UV light
4. Photoresist develop - conveyorized developing of photoresist
5. Nickel electroplate - emersion tank
6. Gold electroplate - emersion tank

Some combinations of processing variables resulted in patterns with insignificant differences. Panels were visually evaluated and ranked after gold plating by three people. The visual ranking was based on resist adhesion, definition of the lines and spaces, and overall appearance of the photoresist after gold plating.

Ranking split the panels in two groups: 02, 08, 10, 12 and 04, 06, 14, and 16. Panels 02, 08, 10, and 12 were exposed to a stouffer step guide 9, while panels 04, 06, 14, and 16 were exposed to a stouffer step guide 11 (exposure energy increases in proportion to the exposure step reading).

Figure 20. SEM Photomicrograph of Copper Circuit Sidewall, With the Tin-Lead Stripped After Etch

Table 8. Specific Panel Numbers and Processing Conditions for Gold

Panel	2	4	6	8	10	12	14	16
Lamination (°C)	110	100	110	100	110	100	100	110
Expose (Setting/Step)	110 9	185 11	185 11	110 9	110 9	110 9	185 11	185 11
Develop (ft/min)	2.5	2.0	2.5	2.5	2.5	2.5	3.25	2.5

Table 9. Nickel Sulfamate Electroplate (Barrett Sn, Tank BB-30)

Parameter	Actual (03-94)	Lower Limit	Upper Limit
Nickel (g/L)	84	70	90
Boric Acid (g/L)	33.7	0	3
pH	4.4	3.05	4.5
Temp. (°F)	130	120	140
Plating Amps (ASF)	20	20	50

Nickel Plating Calculation:

Ampere-minutes

per panel = (Area sq in) x (9314 plating factor) x (thickness desired)

Thickness = 0.0001 inch minimum

Ampere minutes per panel = target 0.0005 inch

Area = 226 sq in

Table 10. High-Purity Gold Bath (Soft Gold, PY-AU-Bond (DD-30))

Parameter	Actual (3-15-94)	Target Values	Lower Limit	Upper Limit
pH	6.77	6.8	6.0	7.5
Baume	17.8	20	15.0	25.0
Gold Concentration (g/L)	9.6	10.2	4.1	16.4

Gold plating calculation:

Ampere-minutes

per panel = (Area sq in) x (2840 plating factor) x (thickness desired)

Thickness = 0.0001 inch minimum

Ampere minutes per panel = target 0.0003 inch

Amps per panel = 1 ASF

thickness of gold is 0.0002 min generally 0.0002/0.0003

The SEM Micrograph shows the final circuit of panel 10. This panel shows some undercutting, caused by extended etching time.

Figures 21 and 22 show the overall front and back views of panel 10 with the standard capability image used for the printed circuit board process characterization. This panel was gold plated, but has not been stripped of the photoresist.

Figure 23 is a close-up of the coupons on the panel prior to photoresist stripping: there are three 15-hole coupons and one land and line spacing coupon. The 15-hole coupon shows the definition of the 2-, 5-, and 10-mil lines. The land and line spacing coupon shows the 5-, 10-, and 15-mil lines showing definition.

Figure 21. DuPont's Riston 9015 Photoresist with Gold Plating, Front View

Figure 24 shows the serpentine pattern broken up into 1 through 10 different line and spacing combinations (Table 5). The lines in the area labeled 1 are not completely defined. The lines were not completely defined at develop, and are gold plated as one large block. The combination labeled 2 has complete definition with a 2-mil line and a 5-mil space. (See Table 5 for specific line widths.)

Figure 22. DuPont's Riston 9015 Photoresist with Gold Plating, Back View

DUPONT'S RISTON 9015 PHOTORESIST
WITH GOLD PLATING

Figure 23. Close Up of 15-Hole Coupons and Land/Line Spacing Coupon

DUPONT'S RISTON 9015 PHOTORESIST
WITH GOLD PLATING

Figure 24. Close-Up of Line and Space Serpentine Pattern

Figure 26 is a close-up of the coupons as in Figure 23: there are three 15-hole coupons and one land and line spacing coupon. The 15-hole coupon shows the resolution of the 2-, 5- and 10-mil lines. The 2-mil line was not lost in etching. The land and line spacing coupon shows that etched 5-, 10-, and 15-mil lines are still well defined. Figure 27 shows the etched serpentine pattern broken up into 10 different line and spacing combinations. The area labeled 1 is mostly one continuous block of gold plating, although some spacing is present on the ends of the pattern. This can be attributed to the loss of adhesion after developing. Combinations 2 through 10 are defined after etching and show a big difference between the gold-plated samples and the tin-lead plated samples (Figures 13 and 14).

Figure 25. Overall Pattern After Etch

Figure 25 is similar to Figures 21 and 22, which show the overall panel but this panel has been stripped of photoresist and etched to remove the clad copper.

Figure 26. Close-Up of 15-Hole Coupon and Land and Line Spacing Coupon After Etch

Figure 27. Serpentine Pattern After Etch

Figure 28 shows the final circuit of panel 10 which shows very good definition of the circuit, but does show some undercutting caused by too long an etching dwell time.

Figure 28. SEM Microphotography of Circuit Processed With DuPont Riston 9015, 2-mil Line Cross Section (actual measurement approximately 1.3 mils)

Figure 29 shows a gold-plated circuit.

**Figure 29. SEM Photomicrographs of
Circuits Processed with
DuPont Riston 9015,
Gold-Plated Circuit After Etch**

Alkaline Etching

The alkaline etching part of the experiment used a different etch pattern than the KCD capability pattern. In this evaluation, the artwork was a UMPS 5-8 pattern created by the imaging team of the National Center for Manufacturing Sciences (NCMS). The conductor analysis technology artwork is a 10 by 10 array of one-inch-square serpentine patterns 90° out of phase to evaluate directional processing factors, such as effects of etching lines parallel to the direction of conveyor travel versus etching lines perpendicular to the direction of conveyor travel. This serpentine pattern contains artwork path width sizes of 5, 6, 7, and 8 mils. Two panels were processed at each condition and the electrical test data was combined and labeled in Table 10 as a group number (for example, panels 21 and 25 were electrically tested and the test data is combined as group 1).

Table 11. Processing Conditions and Yield Response

Alkaline Etch - NCMS Artwork, DuPont 9015 Parameters								
Panel No.	Group No.	Lam. Temp. °C	Exp. Set.	Develop	Conductor Yield %			
					5 mil	6 mil	7 mil	8 mil
21,25	1	110	110	2.0	100.0	100.0	100.0	100.0
22,23	2	110	80	2.0	97.00	98.00	99.50	99.50
24,28	3	110	80	2.5	99.75	99.50	99.50	99.50
26,27	4	110	110	2.5	99.75	99.75	99.50	100.0
30,31	5	110	110	3.25	99.25	99.25	99.25	99.50
29,32	6	110	80	3.25	99.50	99.25	99.25	99.50

Table 12. Defects for Various Processing Conditions (1-inch Module)

Alkaline Etch - NCMS Artwork DuPont 9015 Parameters					
Panel No.	Group No.	Defects per Million Inches of Conductor			
		5 mil	6 mil	7 mil	8 mil
21,25	1	0	0	0	0
22,23	2	2446	1640	411	415
24,28	3	201	407	411	415
26,27	4	201	203	411	0
30,31	5	403	611	617	415
29,32	6	403	611	617	415

A review of this data shows that panels 22 and 23 have significantly higher defects per million inches of conductor in the 5- and 6-mil conductor paths, but still has a conductor yield of 97% as shown in Table 11.

A review of the entire Processing Sequence for Alkaline etch using Dupont 9015 on the NCMS Conductor Analysis Panel.

1. Copper Pre-image Cleaning - Conveyorized Chemical Cleaning (Table 7)
2. Photoresist Lamination - Hot Roll Laminating of photoresist (Table 11)
3. Photoresist Exposure - Exposing of photoresist (Table 11)
4. Photoresist Develop - Conveyorized Developing of photoresist (Table 11)
5. Copper Etch - Conveyorized Alkaline Etching (Table 13) of copper
6. Photoresist Strip - Conveyorized Stripping of photoresist

Table 13. Alkaline Etch, Ammoniacal Copper Chloride (CE #54699)

PARAMETERS	Readings
Temperature	125
Pressure (psi)	10/30
Conveyor speed (in/min)	55
pH	7.7
Specific Gravity	1.195
Copper Thickness	0.0017

conductor analysis program, are published in a series of charts in Appendices A through F.

The summary of the alkaline etching evaluation using the NCMS pattern showed a consistent yield of 97% or better.

- Groups 2 and 3 did have a larger line loss (0.6 to 0.7 mils) than the other groups (0.5 mil line loss).
- Group 3 has a larger standard deviation (0.2) than the other groups (0.13 - 0.15 standard deviation).
- From this evaluation we can conclude that all of the panels were etched with less than 1 mil etch factor and consistent with 0.13 - 0.2 standard deviations.

Table 14. Alkaline Etch (Ammoniacal Copper Chloride Solution Limits)

Parameters	Limits Lower	Limits Upper	Actual (3/22/94)
Copper	145	165	145.4
Chloride	177	212	211.6
Ph	7.6	7.8	7.7
Conveyor Speed			55

The panels were fabricated in the KCD PWP manufacturing facility and then sent to Sandia National Laboratory, New Mexico, for electrical testing. The line width loss and yield response, as generated by the

Future Work

Additional work will be done evaluating the DuPont 9015 for processing chemically machined product etched in ferric chloride rather than the alkaline copper chloride used for PWB fabrication. This evaluation did not evaluate DuPont 9015 on non-copper surfaces — such as nickel alloys, stainless steels, or brass, which are materials etched in the ferric chloride etchant.

Appendix A
Group 1 Panels

GROUP 1

Conductor Yield vs Nominal Conductor Width TM1 & TM2 Sides

Artwork Feature Size (mils)	Total Number of						Conductor Yield (%)	DEMIS
	Lines	Spaces	Opens	Shorts	Good	Bad		
5	400	400	0	0	400	0	100.00	0
6	400	400	0	0	400	0	100.00	0
7	400	400	0	0	400	0	100.00	0
8	400	0	0	0	400	0	100.00	0

DEMIS = Defects per Million Inches of Conductor

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GROUP 1

Capability Performance Index for $\pm 20\%$ Controlled Conductor Width

Without Artwork Compensation

Conductor Width and Height Calculated from Electrical Resistance Measurements

Artwork Feature Size (mils)	Target Conductor Width (mils)	Number of Lines	Calculated Conductor Width (mils)						Control Indices	
			Min	Max	Mean	σ	LSL	USL	Cp	Cpk
5	5.0	398	4.16	4.89	4.48	0.130	4.00	6.00	2.56	1.22
6	6.0	398	5.12	5.94	5.45	0.149	4.80	7.20	2.69	1.45
7	7.0	398	6.10	7.03	6.47	0.152	5.60	8.40	3.07	1.90
8	8.0	398	7.17	7.92	7.47	0.130	6.40	9.60	4.09	2.73
Nominal Copper Thickness (mils)	Target Conductor Height (mils)	Number of Modules	Calculated Conductor Height (mils)						Control Indices	
			Min	Max	Mean	σ	LSL	USL	Cp	Cpk
1.40	1.20	398	1.12	1.34	1.24	0.031	0.96	1.44	2.58	2.10

LSL = Lower Specification Limit
 USL = Upper Specification Limit
 Cp = Capability Potential Index
 Cpk = Capability Performance Index

TM1 & TM2 Sides

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Cor=0.997

RHO=2.00

Appendix B
Group 2 Panels

GROUP 2

Conductor Yield vs Nominal Conductor Width TM1 & TM2 Sides

Artwork Feature Size (mils)	Total Number of						Conductor Yield (%)	DEMIS
	Lines	Spaces	Opens	Shorts	Good	Bad		
5	400	400	9	3	388	12	97.00	2446
6	400	400	4	1	392	8	98.00	1640
7	400	400	1	0	398	2	99.50	411
8	400	0	2	0	398	2	99.50	415

DEMIS = Defects per Million Inches of Conductor

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GROUP 2

Capability Performance Index for $\pm 20\%$ Controlled Conductor Width

Without Artwork Compensation

Conductor Width and Height Calculated from Electrical Resistance Measurements

Artwork Feature Size (mils)	Target Conductor Width (mils)	Number of Lines	Calculated Conductor Width (mils)						Control Indices	
			Min	Max	Mean	σ	LSL	USL	Cp	Cpk
5	5.0	386	3.88	4.74	4.28	0.140	4.00	6.00	2.38	0.66
6	6.0	391	4.80	5.72	5.24	0.153	4.80	7.20	2.62	0.95
7	7.0	393	5.78	6.74	6.26	0.158	5.60	8.40	2.96	1.39
8	8.0	393	6.89	7.71	7.27	0.141	6.40	9.60	3.79	2.06
Nominal Copper Thickness (mils)	Target Conductor Height (mils)	Number of Modules	Calculated Conductor Height (mils)						Control Indices	
			Min	Max	Mean	σ	LSL	USL	Cp	Cpk
1.40	1.20	393	1.14	1.35	1.26	0.030	0.96	1.44	2.71	2.04

LSL = Lower Specification Limit
 USL = Upper Specification Limit
 Cp = Capability Potential Index
 Cpk = Capability Performance Index

TM1 & TM2 Sides

CATS Version 2.3

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Cor=0.997

RHO=2.00

GROUP 2

Calculated Conductor Width & Control Indices vs
Target Feature Size with 20% Specification Limits
and no Artwork Compensation

TM1 & TM2 Sides

Appendix C
Group 3 Panels

GROUP 3

Conductor Yield vs Nominal Conductor Width
TM1 & TM2 Sides

Artwork Feature Size (mils)	Total Number of						Conductor Yield (%)	DEMIS
	Lines	Spaces	Opens	Shorts	Good	Bad		
5	400	400	0	1	399	1	99.75	201
6	400	400	0	2	398	2	99.50	407
7	400	400	0	2	398	2	99.50	411
8	400	0	0	0	398	2	99.50	415

DEMIS = Defects per Million Inches of Conductor

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GROUP 3

Capability Performance Index for $\pm 20\%$ Controlled Conductor Width

Without Artwork Compensation

Conductor Width and Height Calculated from Electrical Resistance Measurements

Artwork Feature Size (mils)	Target Conductor Width (mils)	Number of Lines	Calculated Conductor Width (mils)						Control Indices	
			Min	Max	Mean	σ	LSL	USL	Cp	Cpk
5	5.0	397	3.99	5.03	4.36	0.173	4.00	6.00	1.92	0.69
6	6.0	397	4.86	6.09	5.33	0.190	4.80	7.20	2.11	0.92
7	7.0	397	5.87	7.04	6.34	0.196	5.60	8.40	2.39	1.27
8	8.0	397	6.97	8.04	7.35	0.173	6.40	9.60	3.09	1.84
Nominal Copper Thickness (mils)	Target Conductor Height (mils)	Number of Modules	Calculated Conductor Height (mils)						Control Indices	
			Min	Max	Mean	σ	LSL	USL	Cp	Cpk
1.40	1.20	397	1.14	1.37	1.25	0.032	0.96	1.44	2.49	1.98

LSL = Lower Specification Limit
 USL = Upper Specification Limit
 Cp = Capability Potential Index
 Cpk = Capability Performance Index

TM1 & TM2 Sides

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Cor=0.997

RHO=2.00

GROUP 3

Calculated Conductor Width & Control Indices vs
Target Feature Size with 20% Specification Limits
and no Artwork Compensation

TM1 & TM2 Sides

Appendix D
Group 4 Panels

GROUP 4

Conductor Yield vs Nominal Conductor Width TM1 & TM2 Sides

Artwork Feature Size (mils)	Total Number of						Conductor Yield (%)	DEMIS
	Lines	Spaces	Opens	Shorts	Good	Bad		
5	400	400	1	0	399	1	99.75	201
6	400	400	1	0	399	1	99.75	203
7	400	400	2	0	398	2	99.50	411
8	400	0	0	0	400	0	100.00	0

DEMIS = Defects per Million Inches of Conductor

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GROUP 4

Capability Performance Index for $\pm 20\%$ Controlled Conductor Width

Without Artwork Compensation

Conductor Width and Height Calculated from Electrical Resistance Measurements

Artwork Feature Size (mils)	Target Conductor Width (mils)	Number of Lines	Calculated Conductor Width (mils)						Control Indices	
			Min	Max	Mean	σ	LSL	USL	Cp	Cpk
5	5.0	397	4.16	5.08	4.48	0.132	4.00	6.00	2.53	1.22
6	6.0	398	5.06	6.18	5.44	0.155	4.80	7.20	2.57	1.38
7	7.0	397	6.08	7.16	6.46	0.155	5.60	8.40	3.02	1.86
8	8.0	398	7.15	8.09	7.48	0.134	6.40	9.60	3.98	2.67
Nominal Copper Thickness (mils)	Target Conductor Height (mils)	Number of Modules	Calculated Conductor Height (mils)						Control Indices	
			Min	Max	Mean	σ	LSL	USL	Cp	Cpk
1.40	1.20	398	1.14	1.32	1.24	0.032	0.96	1.44	2.51	2.10

LSL = Lower Specification Limit
 USL = Upper Specification Limit
 Cp = Capability Potential Index
 Cpk = Capability Performance Index

TM1 & TM2 Sides

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Cor=0.997

RHO=2.00

GROUP 4

Calculated Conductor Width & Control Indices vs
Target Feature Size with 20% Specification Limits
and no Artwork Compensation

TM1 & TM2 Sides

Appendix E
Group 5 Panels

GROUP 5

Conductor Yield vs Nominal Conductor Width TM1 & TM2 Sides

Artwork Feature Size (mils)	Total Number of						Conductor Yield (%)	DEMIS
	Lines	Spaces	Opens	Shorts	Good	Bad		
5	400	400	0	2	398	2	99.50	403
6	400	400	0	2	397	3	99.25	611
7	400	400	0	2	397	3	99.25	617
8	400	0	0	0	398	2	99.50	415

DEMIS = Defects per Million Inches of Conductor

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GROUP 5

Capability Performance Index for $\pm 20\%$ Controlled Conductor Width

Without Artwork Compensation

Conductor Width and Height Calculated from Electrical Resistance Measurements

Artwork Feature Size (mils)	Target Conductor Width (mils)	Number of Lines	Calculated Conductor Width (mils)						Control Indices	
			Min	Max	Mean	σ	LSL	USL	Cp	Cpk
5	5.0	395	4.17	4.94	4.54	0.130	4.00	6.00	2.56	1.38
6	6.0	395	5.04	5.95	5.50	0.153	4.80	7.20	2.61	1.52
7	7.0	395	6.09	6.95	6.52	0.154	5.60	8.40	3.02	1.99
8	8.0	395	7.14	7.95	7.53	0.132	6.40	9.60	4.04	2.86
Nominal Copper Thickness (mils)	Target Conductor Height (mils)	Number of Modules	Calculated Conductor Height (mils)						Control Indices	
			Min	Max	Mean	σ	LSL	USL	Cp	Cpk
1.40	1.20	395	1.16	1.34	1.26	0.035	0.96	1.44	2.28	1.76

LSL = Lower Specification Limit
 USL = Upper Specification Limit
 Cp = Capability Potential Index
 Cpk = Capability Performance Index

TM1 & TM2 Sides

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Cor=0.997

RHO=2.00

GROUP 5

Calculated Conductor Width & Control Indices vs
Target Feature Size with 20% Specification Limits
and no Artwork Compensation

TM1 & TM2 Sides

Appendix F
Group 6 Panels

GROUP 6

Conductor Yield vs Nominal Conductor Width TM1 & TM2 Sides

Artwork Feature Size (mils)	Total Number of						Conductor Yield (%)	DEMIS
	Lines	Spaces	Opens	Shorts	Good	Bad		
5	400	400	0	2	398	2	99.50	403
6	400	400	0	2	397	3	99.25	611
7	400	400	0	2	397	3	99.25	617
8	400	0	0	0	398	2	99.50	415

DEMIS = Defects per Million Inches of Conductor

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GROUP 6

Capability Performance Index for $\pm 20\%$ Controlled Conductor Width

Without Artwork Compensation

Conductor Width and Height Calculated from Electrical Resistance Measurements

Artwork Feature Size (mils)	Target Conductor Width (mils)	Number of Lines	Calculated Conductor Width (mils)						Control Indices	
			Min	Max	Mean	σ	LSL	USL	Cp	Cpk
5	5.0	395	4.17	4.94	4.54	0.130	4.00	6.00	2.56	1.38
6	6.0	395	5.04	5.95	5.50	0.153	4.80	7.20	2.61	1.52
7	7.0	395	6.09	6.95	6.52	0.154	5.60	8.40	3.02	1.99
8	8.0	395	7.14	7.95	7.53	0.132	6.40	9.60	4.04	2.86
Nominal Copper Thickness (mils)	Target Conductor Height (mils)	Number of Modules	Calculated Conductor Height (mils)						Control Indices	
			Min	Max	Mean	σ	LSL	USL	Cp	Cpk
1.40	1.20	395	1.16	1.34	1.26	0.035	0.96	1.44	2.28	1.76

LSL = Lower Specification Limit
 USL = Upper Specification Limit
 Cp = Capability Potential Index
 Cpk = Capability Performance Index

TM1 & TM2 Sides

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Cor=0.997

RHO=2.00

GROUP 6

Calculated Conductor Width & Control Indices vs
Target Feature Size with 20% Specification Limits
and no Artwork Compensation

TM1 & TM2 Sides