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Electroplating Connector Ends on Tape-Processed Slapper Detonator Cables: Improvements on Plating Head Design

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Abstract

A prototype spot plater was built to meet Mound's product requirements in the Tape Process Laboratory. This plating system enables Mound to selectively plate connector ends on a flexible printed circuit cable.

Introduction

Early in 1981, a project was initiated at Mound to establish a tape processing facility for fabricating flexible, printed-circuit slapper detonators and related items. Since that time, a line of reel-to-reel processing equipment has been developed to fabricate an integral detonator cable assembly.

Reel-to-reel equipment and processes are routinely used at Mound to slit, inspect, laminate photoresist, expose, develop, etch, strip, punch, and laminate the components required for a slapper detonator assembly. Figure 1 shows the typical process flow and the major processing operations required to fabricate a slapper detonator.

Figure 1 - Typical process flow for tape-processed slapper detonators.

As the in-house flexible circuit manufacturing capability developed, the need to plate specific areas on these cables became apparent. To accomplish this, a plater that would permit the process solution to contact only the cable areas to be plated was needed, and the process would have to be automated to allow consistent plating. To meet this need, a reel-to-reel spot plater was developed.

Discussion

No commercially available industrial or electronic plating equipment could fulfill Mound's plating requirements. However, "speed" or "jet" plating systems in use in the electronics industry showed potential for meeting these requirements. Using available information on these systems, a prototype reel-to-reel spot plater was developed onsite.

Some of the problems encountered while developing the electroplater involved the many variables inherent in electroplating. These include such things as plating solution parameters, plating current, fluid flow dynamics, and anode/cathode parameters.

This report is a continuance of a previously published report [1]. It covers the attempted upgrade of current equipment with a different plating head and selection of a plating head from several designs.

Modification of Current Plater

Based on experimental data previously reported [1], a production plater was modified to improve plating efficiency. This modification involved adding a higher volume pump for the plating solution and installing development-type plating fixtures in series. These are shown in Figures 2, 3, and 4. The increased solution flow provided increased nickel ion concentration per unit time, enabling a higher plating current to be used to shorten the plating time. The plating heads were designed to reduce the drag-out (carry over) volume from one process solution to another. The heads were also designed to present a specific platinum anode surface area at a discrete distance from the circuit to improve the plating efficiency and nickel thickness uniformity across the copper.

Figure 2 - Development plating fixture. Because double plating heads are used, both sides of a cable can be plated simultaneously.

A third modification involved installing pulse timers that caused the plating current to pulse on and off to improve the thickness uniformity of the nickel. Figure 5 shows the concave plating obtained with a constant direct current. Earlier experimental data had indicated that pulsing the current would reduce the concave effect. Figure 6 depicts the more uniform nickel plating that resulted from a pulsing current. A significant amount of production time can be saved by plating more uniformly.

The newly modified plater was to operate using updated parameters based on previous experimental data. These parameters are compared to the present parameters in Table 1.

Figure 3 - Installation of two plating figures in series for a total of four plating heads.

Figure 4 - Development plating heads.

Figure 5 - Concave nickel plating resulting from a constant current.

Figure 6 - Uniform nickel plating resulting from a pulsing current.

TABLE 1 - PRODUCTION PARAMETERS FOR MODIFIED PLATER

	<u>Present Parameters</u>	<u>Updated Parameters</u>
Nickel ion concentration, g/L	67-82	110
Boron acid g/L	33-41	33-41
pH	3.6-4.4	3.6-4.4
Plating temperature, °C	55 ± 5	55 ± 5
Anode/copper distance, in.	0.5	0.2
Solution flow rate, gal/min	0.17-0.24	0.65
Anode	All metal titanium	PVC with platinum cap
Amp/ft ²	35-39	139, pulsed
Plating time, min (based on minimum of 150 μin.)	12	2

Results Using Modified Plater

After the plater modifications were implemented, the updated plating parameters were not achieved. Several reasons for this setback are listed below.

- The maximum achievable flow rate was 0.45 gal/min instead of 0.65. Substantial flow loss was caused by flow through the several solenoid valves before and after the plating fixtures. These valves caused considerable frictional losses and could not be operated above 12 psi (fluid pressure).
- The reduced flow resulted in a preferential flow pattern and did not allow a uniform flow across the cable. This resulted in a wedge-shaped thickness profile with the maximum thickness near the solution outlet, as shown in Figure 7.

Figure 7 - Thickness profile resulting from preferential fluid flow.

- Earlier experimental data indicated that a higher nickel ion concentration (110 g/L versus 80 g/L) in the plating solution could provide additional nickel to increase the plating efficiency. Because the more viscous solution, at the lower flow rate, could not sweep gas (generated by the plating process) from the plating surface, pitted nickel resulted. A dull nickel finish was also produced under these conditions. Adjusting the concentration to 80 g/L of nickel ion, which lowered the viscosity, and maintaining a pH of 3.6 to 4.0 were required to produce the desired bright nickel finish.
- Using a pulsed current and higher plating current did not produce the desired results. Reduced nickel ion concentration and flow rate did not allow quality nickel plating at higher plating currents. Only a slight advantage was gained by pulsing the current.

This developmental work revealed that the reduced solution flow rate increased the problem of poor flow within the plating head; therefore, several new heads were designed to regulate the flow pattern. One design (Figure 8) incorporates replaceable anode disks. The inlet and outlet solution flow in the head should move through the anode as shown in the figure. Different inlet and outlet hole sizes were evaluated to develop a uniform flow pattern within the plating head.

This work also provided additional information regarding the effects of the plating solution chemistry on the quality of nickel plating.

Improved Plating Head Design

Plating head design A, Figure 9, was the head used to obtain the experimental data discussed in the previous section. Based on these data, two new plating heads were designed and tested. These heads, designed to correct preferential solution flow patterns within the plating head, are shown in Figures 10 and 11. Data were generated from these heads and from the earlier plating head shown in Figure 9.

Figure 8 - Plating head design with replaceable anode disks.

Head Designs

Head design B (Figure 10) was constructed to permit different anodes to be installed. The anodes have different inlet/outlet hole sizes. The head was designed for maximum anode surface area. (The anode in design A occupies only 70% of the maximum possible anode surface area.) Five different anodes were tested in head design B (four are shown in Figure 12). One of the anodes, detail 77 (Figure 13), was machined to have a surface resembling a pyramid with a flat top to distribute electrons more uniformly across the anode surface. This anode did not improve the uniformity of the nickel plating.

Design C, Figure 11, was constructed to test a simplified version of design B.

Figure 9a - Plating head design A: anode.

Figure 9b - Plating head design A: internal view.

Figure 9c - Plating head design A: plating fixture.

Figure 10a - Plating head design B: anode.

Figure 10b - Plating head design B: internal view.

Figure 10c - Plating head design B: plating fixture.

Figure 11a - Plating head design C: anode.

Figure 11b - Plating head design C: discoloration showing preferential fluid flow across anode.

Figure 11c - Plating head design C: internal view.

Figure 11d - Plating head design C: plating fixture.

Anode Detail 77

Anode Detail 76

Anode Detail 69

Anode Detail 75

Figure 12 - Anode designs tested in plating head B.

Figure 13 - Anode, detail 77, machined to have a flat-topped pyramid surface.

Experimental Variables

An experiment was developed to determine the best head and anode design for plating. The plated samples were compared using nickel brightness, plating quality, and thickness uniformity as test criteria. The experimental plating variables were as follows:

- The chemical variables were fixed throughout the test. Nickel sulfamate concentration was 100 g/L of nickel ion, pH was 3.8, boric acid concentration was 35 to 37 g/L, and solution temperature was 53 to 56°C.
- The solution flow rate thorough the heads was 0.9 gal/min.
- The current to plate the samples was pulsed in a forward and reverse direction. This involved six experimental variables (see Figure 14).
- The anode/cathode distance was maintained at 0.15 to 0.17 in. This distance was selected based on data presented in a previous report [1].

Figure 14 - Pulsed forward/reverse plating current (two possible variations).

- The same product cable was used throughout the testing and is shown in Figure 15. This cable consists of a disk and hoop opposite each other on a double-sided flex cable.

The pulsing forward/reverse power supply was used to improve the nickel thickness uniformity (see Figure 16). Nickel accumulated at the corners, resulting in concave plating. This is the reason one anode (detail 77) was machined with a pyramid surface to improve the distribution of the electrons. Deplating will preferentially remove nickel in the same areas. The current was varied as follows: forward current, forward on, forward off, reverse current, reverse on, and reverse off. The forward-to-reverse cycle ratio was 1:1. Eleven trial samples were plated using each plating head/anode design. Some plating voltage data are given in Appendix A.

Evaluation of Data

Plating heads A and C, based on sample brightness and plating quality, plated samples that, overall, were of poorer quality than those plated using head B; therefore, heads A and C were not further evaluated.

Figure 15 - Product cable used for testing.

Figure 16 - Nickel plating resulting from the pulsed forward/reverse power supply.

Figure 17 shows examples of plated samples. Figure 18 shows the preferential flow characteristics within the heads as determined from the data. Photo b, Figure 11, shows the preferential titanium oxidation caused by the solution flow within head design C. The smaller anode surface area also affected the plating quality for head design A. A large percentage of plated samples from design A had poor quality plating near the head outlet, as shown in Figure 19.

Samples from the five anodes used in plating head B (Figure 17) were ranked by quality on a scale of -2 to +2 for entering into the mathematical model. Thickness uniformity data were also entered. The information discussed below was indicated by the data. These data are not conclusive since all plating variables were not included in the study to select the best plating head/anode design.

Figure 17 - Plated samples.

Figure 18 - Solution flow characteristics within the plating heads.

Figure 19 - Poor quality plating near the head outlet obtained using head design A.

The configuration and surface area of a connector influence the forward/reverse, on/off pulse requirements. The pulse requirements for disk and hoop connectors vary. The disk and hoop from one product may have a different pulse requirement than the connectors of a second product. This seems to be an effect of the ratio of edge length to surface area (see Figure 20). Table 2 shows the data that gave the best quality and highest uniformity values.

Figure 20 - Effect of surface area and configuration on current pulsing requirements.

Table 2 - DATA GIVING BEST QUALITY AND UNIFORMITY VALUES

<u>Pulse/Current</u>	<u>Disk</u>	<u>O-Ring</u>
Forward pulse/current on	10 ms @ 475 MA	1-2 ms @ 400-425 MA
Forward pulse/current off	2-3 ms	6 ms
Reverse pulse/current on	3-5 ms @ 350 MA	1-2 ms @ 475 MA
Reverse pulse/current off	2-3 ms	5 ms

The data also support earlier work showing that pulsing the plating current plates at a faster rate and results in a brighter finish than using a constant current. The data also indicate strong effects from most of the forward/reverse pulse current variables. No interaction terms were seen. The reliability of the data is not known, since all plating variables were not used in the experiment.

Summary

Mound has improved upon an earlier plating head design. A plating head/anode design that gave wider latitude in process variables for higher quality plating was selected. Data indicated connector configuration has a strong effect on plating current pulsing variables. Further experimentation with process variables is expected to improve the quality, speed, cost-effectiveness, and efficiency of the plating process.

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Reference

1. Bruns, R. J., *Nickel Plating Connector Ends on Tape Processed Slapper Detonator Cables*, MLM-3575, EG&G Mound Applied Technologies (February 1989).

Appendix A - Plating Voltage Data

Plating Head Design B with Platinum-Coated Titanium Anode (Nickel Sulfamate = 100 g/L, Boric Acid = 35-37 g/L, pH = 3.8)

Data on constant current power supply with forward pulse timer^a:

<u>Dialed (amp)</u>	<u>On/Off Pulse (ms)</u>	<u>Dialed^b (Maximum Voltage)</u>	<u>Actual Plating Voltage</u>	<u>Peak (amp)</u>	<u>Ave (amp)</u>
0.25	3/1	20		0.3	0.170
0.25	1/1	20		0.3	0.130
0.50	1/1	20		0.7	0.250
0.50	3/1	20		0.7	0.33
0.50	0.1/0.1	20		0.65	0.27
1.0	0.1/0.1	20			0.54
1.0	3/1	20			0.67
1.0	20/3	20	Poorly plated part		0.84
1.0	3/1	30	15		0.66
1.0	3/1	20	11		0.66
1.0	3/1	10	8		0.63

^a All parts plated between 0.25 to 1.0 amp looked good, with the exception of 1 amp @ 87% duty cycle. Maximum voltage on power supply of 20 volts appears satisfactory.

^b Voltage limit switch.

Plating Head Design A, Gold Sulfite Solution

(1 oz. Gold per Gallon, Platinum Anode)

<u>Dialed (amp)</u>	<u>On/Off Pulse (ms)</u>	<u>Actual Plating Voltage</u>
1.0	30/70	6.3
0.5	30/70	4.9
0.17	10/90	3.3
0.08	constant current	2.5
0.08	30/70	3.0
0.08	50/50	2.8

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