

ALTERNATIVE METALLIC FINISHES FOR PWB AN ITRI/OCTOBER PROJECT

F.D.Bruce Houghton
Celestica, Inc.
North York, Ontario , Canada, M3C-1V7

ABSTRACT

The ITRI / October Project on (Metallic) Surface Finishes was started to investigate the use of Palladium (Pd) as a PWB finish that would withstand multiple passes through SMT and Wave Soldering as well as support Aluminum and Gold Wire Bonding operations. The project was expanded to include Bismuth, Silver and Tin finishes. A test vehicle was designed. To determine if different PWB processes would affect the assembly process, the Test Vehicle would be built a second time to verify repeatability. Different Palladium chemistries would also be used for the same finishes. Electroless Nickel / Immersion Gold finish would be used as a reference. Different companies would perform various assembly and test operations on a number of boards.

The following describes some of the activities that Celestica, Inc. (formerly IBM Canada Ltd., Toronto Mfg.) performed during the various assembly, aluminum wire bonding and testing operations on the ITRI / October Project Test Vehicles with the different metallic finishes.

INTRODUCTION

As the technologies such as BGA (Ball Grid Array), CSP (Chip Scale Packaging), Flip Chip and COB (Chip on Board) have progressed, creating smaller component leads and smaller component pads on the printed boards, there has been a desire to obtain a finish for the circuit board which would meet the needs of each of these technologies through the entire assembly process. The finish should be as flat as an OSP coating, as solderable as a good HASL finish, withstand multiple thermal excursions, without the use of nitrogen, be compatible with a variety of cleanable and no-clean fluxes, be wire bondable and cost similar to a HASL finish.

From this base, an investigation was started to design experiments to evaluate some surface finishes. The experiments were defined between the participating companies, (Atotech, Altron, Delco, Lucent, Auburn University, Celestica, Hadco, IBM, MacDermid, Merix, Motorola and Sematech), in which Celestica, Inc. would conduct some assembly and aluminum wire bond testing.

The ITRI / October Project focused on electroless palladium from two suppliers with different metallurgy's, one a 'pure' palladium and the second a phosphorus palladium, as the finishes to begin the investigation. They would be applied over bare copper and over electroless nickel. Immersion gold would be applied over the palladium, since we had already experimented with bare palladium and had unsatisfactory results.

BACKGROUND

Celestica has used mainly OSP finishes for SMT printed boards since we started SMT assembly in 1986. We also use a variety of tin/lead finishes but

they generally are not our preference. We started to use electroless nickel / immersion gold (ENi/IAu) in 1993, for a product which required an electrical contact to the finished board surface. ENi/IAu added to our use of a variety of nickel/gold surface finishes, whose volume continues to grow. However, Ni/Au is often the most expensive finish. We are continually looking for that "ideal surface finish", at the right cost.

Ideally there would be one surface finish for all applications, but most likely, several will be required to be: a) the ideal surface finish which will work for all SMT, compression contact, PTH and wire bond applications; b) the ideal surface finish for SMT, compression contact and wire bonding or c) the ideal surface finish for SMT, compression contact and PTH. The finish should work with ambient air versus requiring nitrogen and work with a variety of no-clean and cleanable fluxes. The cost of the finish must be no more than its comparable current alternative. (ENi/IAu or OSP). This led to the investigation of alternative finishes. Since ITRI / October Project Surface Finishes Task Group were just about to embark on investigation of alternative finishes, the two activities coincided.

During the last part of 1995, we had conducted some preliminary tests on bare palladium over copper and bismuth finishes. Based on these results, we refined our test matrix for this project.

TEST PLAN

Test Vehicle

A test vehicle was developed, which contains the basic SMT, PTH and wire bond features in a double sided board 10" x 7.5", 0.062" thick.. (Figure 1)

- 16 mil QFP (512 lead)
- 25 mil QFP (132 lead)
- 50 mil QFP (84 lead)
- 50 mil BGA (256 I/O)
- 50 mil SOIC (20 lead x 4)
- 100 mil DIP (20 lead x 2)
- 1200 PTH area with 3 via sizes
- 4 Solder Spread coupons
- 4 chip sites for aluminum wire bonding
- 4 chip sites for gold wire bonding

Although the board design included solder mask, none was used for the initial builds, so that there would be no interaction or contamination implications between the solder mask and any of the finishes.

Test plans were developed among the different participating companies to evaluate a number of surface finishes and what each participant would perform. This paper will discuss just the activities performed at Celestica. A more detailed report will be produced by ITRI, with results from all of the participants.

Celestica performed SMT, wave soldering and aluminum wire bonding (where applicable) on their sample boards. The following finishes were investigated:

Suppliers	Finishes	Thickness
2	ENi/IAu	Ni:50-75u"; Ni:125-150; Ni:225-250u"
2	ENi/EPd/IAu	Pd:10-15u" Pd: 25-30u" Ni:125-150u"
2	EPd/IAu	Pd:10-15u" Pd: 25-30u"
2	EPd	n/a
1	Bi	3-8u"
1	Ag	4-6u"
2	Sn	30-50u"

Table 1 - Surface Finishes

- ENi/IAu - electroless nickel / immersion gold
- ENi/EPd/IAu - electroless nickel / electroless palladium / immersion gold
- EPd/IAu - electroless palladium / immersion gold
- Bi - immersion bismuth
- Au - immersion silver with an organic preservative
- Sn - immersion tin with an organic preservative

SMT and PTH Activity

Celestica sectioned the test vehicle into different parts to permit the build of the SMT and wire bonding as separate activities.

For SMT and wave soldering, test vehicles were put through a variety of processes to simulate boards being built as single pass wave, SMT plus wave, second side SMT and wave, and additional thermal excursions to simulate rework (component replacement) to adjacent components. All of the SMT preconditioning, reflow and post conditioning was done in a convection IR oven with regular air. Nitrogen was not used in order to create a worst case condition for surface oxidation. SMT was done with a no-clean solder paste. Wave solder was done with a no-clean, alcohol based spray flux.

Board #	Processes
1	W
2	SMT + W
3	IR + SMT + W
4	2IR + SMT + W + IR
5	3IR + SMT + W + 2IR

Table 2 - SMT and Wave Process Steps

- W - Wave solder
- SMT - Screen paste, component place and reflow
- IR - reflow without any screen paste or parts

The following items were assessed after the above processes were finished:

- Surface wetting
- PTH and via hole fill
- Lead pull on some of the 50 mil SOIC leads

Wire Bond Activity

For aluminum wire bonding, some boards were bonded as received. Others were put through two passes of simulated SMT, then cleaned and wire bonded. Our normal wire bond activity occurs to COB (Chip on Board) after SMT build. The wire bond yield was assessed. Wires were then pulled to assess the strength of the wire bonds. Celestica uses ultrasonic wedge bonders which clamp and tear the wire to break the wire at the end of the bond.

RESULTS

SMT Wettability

Bismuth samples were tested more than a year ago. Hole fill degraded after successive passes. The color of the finish gradually darkened making it difficult to set up a vision system. The product has since been discontinued.

Palladium samples were also tested over a year ago. Hole fill and SMT wetting degraded quickly after the first pass through SMT (using air). We needed a finish which would withstand multiple assembly processes. It was decided that a flash of gold over the palladium should solve this problem.

Visual Inspection after SMT:

The SMT pads were inspected for solder wetting. There was no solder mask on the boards, so the wettability of each of the surfaces was evident by the amount of solder spread on the SMT pads plus the amount of wicking of solder along traces connected to the SMT pads.

ENi/IAu Finish:

Wettability did not vary significantly from supplier A or B. Wettability did not vary significantly from nickel thickness of 50 - 75 microinches to 225 - 250 microinches. Wettability did not vary significantly from the first pass board to those preconditioned (5th board). Wettability was best on the nickel/gold finishes, compared to all of the other finishes, based on how far the solder spread across the SMT pad and along the traces from the SMT pads. (Figure 2)

ENi/EPd/IAu Finish:

Wettability did not vary significantly from supplier A or B. Wettability did not vary significantly from thin (10 - 15 u”) palladium to thick (25 - 30 u”) palladium. Wettability did not vary significantly from the first pass boards to those preconditioned. Solder spread across the SMT pads and just started down the traces. (Figure 3) The solder joints looked grainy on the thicker Pd finish. The grainy appearance intensified with additional thermal cycles. The grainy appearance was more evident on supplier B than supplier A. (Figure 4)

EPd/IAu Finish:

Wettability did not vary significantly from supplier A or B. Wettability did not vary significantly from thin to thick palladium. Wettability did not vary significantly from the first pass board to those preconditioned. The solder joints looked grainy on the thicker Pd finish. The grainy appearance intensified with additional thermal cycles. The grainy appearance was more evident on supplier B than supplier A.

IAG Finish:

Wettability did not vary significantly from the first pass SMT board to those preconditioned. Wettability was second best on the silver, compared to the nickel/gold finishes, based on how far the solder spread across the SMT pads and along the traces from the SMT pads. (Figure 5)

ISn Finishes:

Wettability varied from supplier A to B. Wettability decreased from the first pass board to the preconditioned boards. There was good wetting on the first pass board. By the 5th board, the solder was tending to ball up on the SMT pads. (Figure 6)

Visual Inspection after Wave:

Hole fill was inspected after wave soldering to compare hole fill.

ENi/IAu Finish:

Hole fill decreased slightly from first pass to the preconditioned 5th board. The amount may not be significant. No significant difference between supplier A or B. No significant difference between thicknesses of nickel.

ENi/EPd/IAu Finish:

Good hole fill on all boards. No significant difference between first pass and the preconditioned 5th board. No significant difference between supplier A or B. No significant difference between thicknesses of palladium.

EPd/IAu Finish:

Good hole fill on all boards. No significant difference between first pass and the preconditioned 5th board. No significant difference between supplier A or B. No significant difference between thicknesses of palladium.

IAG Finish:

Good hole fill on all boards. No significant difference between first pass and the preconditioned 5th board.

ISn Finishes:

Hole fill varied from supplier A to B. Hole fill decreased significantly from the first pass board to the 5th preconditioned boards.

Results of Lead Pulls:

Samples of the SOIC modules were cut and the leads pulled to compare the strength of the solder joints on the different finishes. Sometimes the pad was pulled off of the board. Most of the time, the lead pulled out of the solder fillet. Numbers shown are mean value and standard deviation (lbs) of the pull strength for the board 2 (1 pass SMT plus wave) and board 5 (the board through 2xIR + SMT + 2xIR).

ENi/IAu Finish:

Lead pull strength did not vary significantly from first pass SMT to the preconditioned 5th board. No significant difference between supplier A or B. No significant difference between thicknesses of nickel. The leads pulled out of the solder joints, if the pad didn't lift first.. (Figure 7)

Supplier	Nickel	Board 2	Board 5
A	Low	4.6 - 0.32	4.7 - 0.16
A	Med	4.0 - 0.35	4.1 - 0.15
A	High	4.7 - 0.11	5.0 - 0.23
B	Low	5.6 - 0.14	4.5 - 0.44
B	Med	4.2 - 0.21	4.3 - 0.28
B	High	4.8 - 0.87	5.1 - 0.63

Table 3 - Pull Strength on Ni/Au Boards

ENi/EPd/IAu Finish:

Lead pull strength increased slightly from first pass SMT to the preconditioned 5th board. No significant difference between supplier A or B. No significant difference between thicknesses of palladium. The leads pulled out of the solder joints, if the pad didn't lift first.. (same as Figure 7)

Supplier	Palladium	Board 2	Board 5
A	Low	4.2 - 0.23	4.8 - 0.35
A	High	4.1 - 0.27	4.4 - 0.19
B	Low	4.4 - 0.18	5.7 - 0.23
B	High	4.3 - 0.30	4.9 - 0.44

Table 4 - Pull Strength on ENi/EPd/IAu

EPd/IAu Finish:

Lead pull strength decreased from first pass SMT to the preconditioned 5th board on thick Palladium. Significant difference between supplier A and B. Significant decrease in lead pull strength with thick palladium from supplier B compared to supplier A. Wider fluctuation in results. Some of the solder joints fractured along an intermetallic layer. This situation increased with increased number of thermal excursions. (Figure 8)

Supplier	Palladium	Board 2	Board 5
A	Low	3.8 - 0.20	4.8 - 0.62
A	High	4.5 - 0.47	3.7 - 0.31
B	Low	4.4 - 0.53	4.4 - 0.32
B	High	5.2 - 0.27	1.1 - 0.01

Table 5 - Pull Strength on EPd/IAu Boards

IAg Finish:

Lead pull strength was highest on the silver finished boards.. It did not vary significantly from first pass SMT to the preconditioned 5th board. The leads pulled out of the solder joints, if the pad didn't lift first.. (Figure 9)

ISn Finish:

Lead strength did not vary significantly from first pass SMT to the preconditioned 5th board, in spite of the fact that the solder tended to ball up on unused pads by the 5th board. Lead pulls were only done on the first suppliers parts, which showed the worst wetting. The second suppliers boards were not ready when lead pulls were done. (same appearance as Figure 7 or 9)

Supplier	Finish	Board 2	Board 5
C	Ag - Silver	5.1 - 0.82	5.3 - 0.55
D	Sn - Tin 1	4.6 - 0.22	4.9 - 0.42
E	Sn - Tin 2	n/a	n/a

Table 6 - Pull Strength on Ag and Sn Boards

Results of Aluminum Wire Bonding:

2184 aluminum wires were attempted to be ultrasonically wedge bonded to each of the finishes that would accept the bonds, using two different processes.

Process 1: The boards were washed before entering the clean room then they were wire bonded.. This represents an ideal finish.

Process 2: The boards were put through 2 passes of SMT and wash, then wire bonded.

Process 2 is a closer representation of our process. SMT must be done before wire bonding on our product. If there is a defective SMT component, the board would have to go through a rework before wire bonding. Therefore, we used 2 passes of SMT preconditioning.

Some boards exhibited very poor bond yields. Therefore, 2184 bonds were not attempted.. Silver sample size was smaller than Ni/Au and Pd.

Supplier and Finish	Thick-ness	Process 1 Wash & Bond		Process 2 Age - Bond	
		Wires	No-Sticks	Wires	No-Sticks
A-1c	Ni-H	2184	0	2184	1
B-1c	Ni-H	2184	1	2184	0
A-2a	Pd-L	1130	4	2184	3
B-2a	Pd-L	2184	0	1638	1
A-2b	Pd-H	2184	1	1905	6
B-2b	Pd-H	2184	0	2184	2
A-3a	Pd-L	474	26*	138	11*
B-3a	Pd-L	130	39*	0	**
A-3b	Pd-H	655	17*	1911	27
B-3b	Pd-H	426	17*	1164	11*
C	Ag	1212	21*	1673	14

Table 7 - Wire Bond Yields

Table Legend:

- A-1c Ni-H: Supplier A of Ni/Au with (High) thick Ni
- B-1c Ni-H: Supplier B of Ni/Au with (High) thick Ni
- A-2a Pd-L: Supplier A of Ni/Pd/Au with thin Pd
- A-2b Pd-H: Supplier A of Ni/Pd/Au with thick Pd
- A-3a Pd-L: Supplier A of Pd/Au with thin (Low) Pd
- A-3b Pd-H: Supplier A of Pd/Au with thick (High)Pd
- C Ag: Supplier C of Ag - Silver (smaller sample)

* - All bonds could not be done - bad yield

** - Board would not bond

Supplier and Finish	Thick-ness	Process 1 Wash & Bond		Process 2 Age - Bond	
		Pull Stren.	s.d.	Pull Stren.	s.d.
A-1c	Ni-H	33.0	1.2	24.8	4.6
B-1c	Ni-H	25.8	1.2	25.7	1.6

A-2a	Pd-L	18.1	1.9	19.0	2.0
B-2a	Pd-L	35.8	3.4	26.1	1.6
A-2b	Pd-H	17.1	1.5	18.8	1.5
B-2b	Pd-H	24.2	1.4	28.3	2.7
A-3a	Pd-L	n/a	n/a	n/a	n/a
B-3a	Pd-L	n/a	n/a	n/a	n/a
A-3b	Pd-H	n/a	n/a	n/a	n/a
B-3b	Pd-H	n/a	n/a	n/a	n/a
C	Ag	35.0	1.9	33.2	2.1

Table 8 - Wire Bond Pull Strength (lbs)

Table Legend:

Same as Table 7, plus

s.d. - Standard deviation

n/a - finishes with very poor yield

Wire Bond Results:

- ENi/IAu is aluminum wire bondable
- ENi/EPd/IAu is aluminum wire bondable
- EPd/IAu is not wire bondable
- Ag is aluminum wire bondable sometimes.

Where the wire bonds to silver, there are very strong bonds. The yield was too low during this test. There were fewer samples of silver boards than the others.

CONCLUSIONS

Based on the above results and the work that has been done by Dave Hillman etal [1] investigating different thicknesses of palladium and the other finishes, also the work of Jim Reed [2] and the NCMS Consortium [3], plus the other activity on palladium [4], [5] and [6], silver [7] and [8] and tin [9], on these same finishes confirms that these are worth pursuing. The EPA is also embarking on a study of alternative finishes to HASL, to see if HASL can be eliminated from the PWB shops.

The ITRI/October Project for Surface Finishes has already defined additional rounds of testing of surface finishes. Modifications will be made to the thickness of the palladium finish. Modifications will be made to the test vehicle, to add a reliability coupon for thermal stressing of the solder joints. Supplier D of the tin finish stated that their bath was out of control and should be able to provide a better finish. Supplier E of the second tin finish is also investigating changes to their chemistry. I am not aware of any changes planned for the silver

chemistry. Our results were very favorable to warrant continuing with this finish as well.

ACKNOWLEDGMENTS

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REFERENCES

- [1] Hillman, David, Bratin, Peter and Pavlov, Michael. "Wirebondability and Solderability of Various Metallic Finishes for use in Printed Circuit Assembly" SMI Proceedings, pp. 687-701, Fall 1996.
- [2] Reed, Jim. "NCMS Surface Finish Testing" SMI Proceedings, pp. 797-805, Fall 1996
- [3] Kokas, J., DeSantis, C., etal, "NCMS PWB Surface Finishes Team Project Summary" IPC EXPO Proceedings, pp. S17-1-1 - S17-1-21, March 1996.
- [4] Toben, Mike and Kanzler, Miriana, "Palladium's Niche", Printed Circuit Fabrication, pp. 24-27, July 1996.
- [5] Milad, George and Roberts, Hugh, "Electroless Palladium Finish for Bonding Fine-Pitch Devices", Nepon West Proceedings, pp. 1333-1341, Fall 1996
- [6] Milad, George, "Surface Finishes: Metallic Coatings over Nickel Over Copper", SMI Proceedings, pp. 794-796, Fall 1996.
- [7] Beigle, Steve, "Alternate Metal Finishes for Wire Bond and Soldering Applications", IPC Expo Proceedings, pp. S9-2-1 - S9-2-6, March 1996.
- [8] Beigle, Steve, "Non-Precious Metal Coatings for Fine Pitch Assembly and Direct Chip Attachment", SMI Proceedings, pp. 780-785, Fall 1996.
- [9] Hinton, Phillip, "Tin-Plating, Tin-Nickel Electroplate and Tin-Plating over Nickel as Final Finishes over Copper", SMI Proceedings, pp. 806-810, Fall 1996

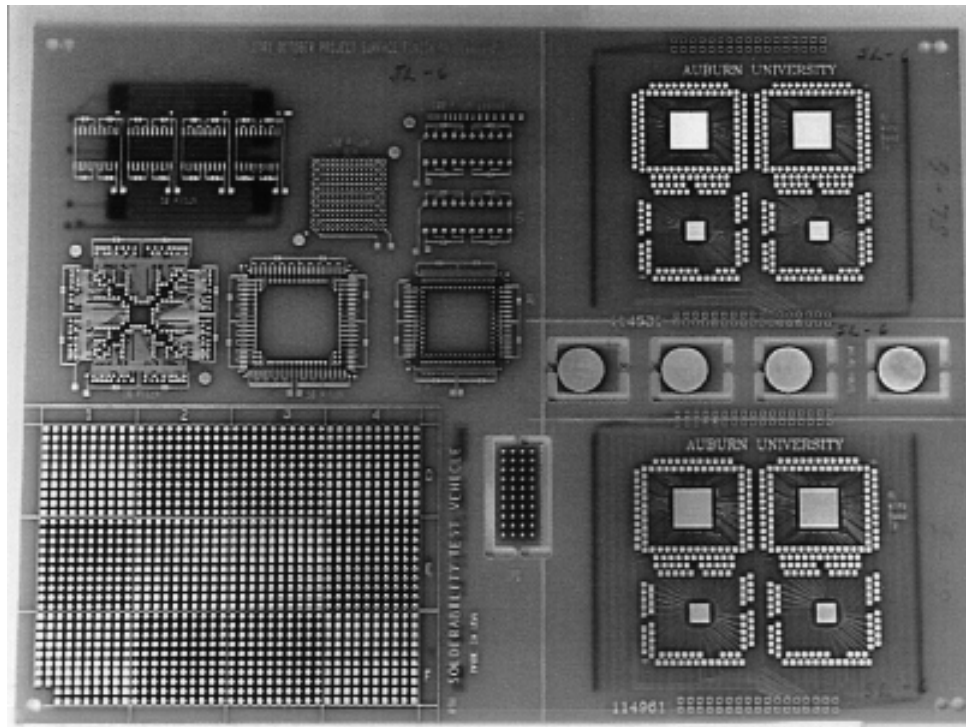


Figure 1 – ITRI/October Project Surface Finishes TV

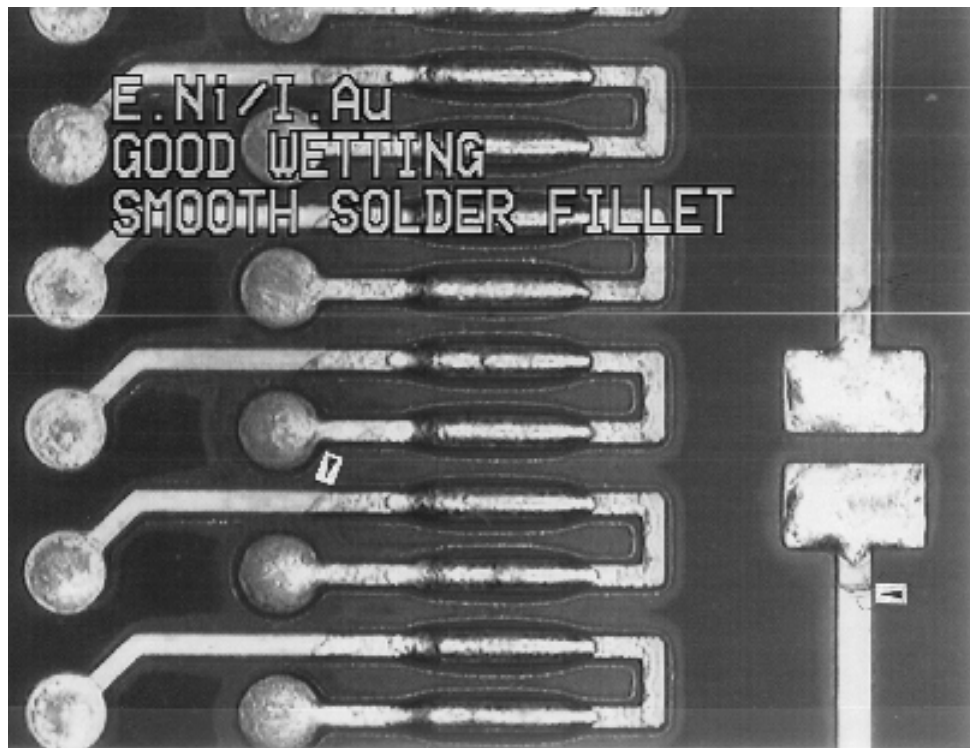


Figure 2 - Solder Wetting on Electroless Nickel / Immersion Gold

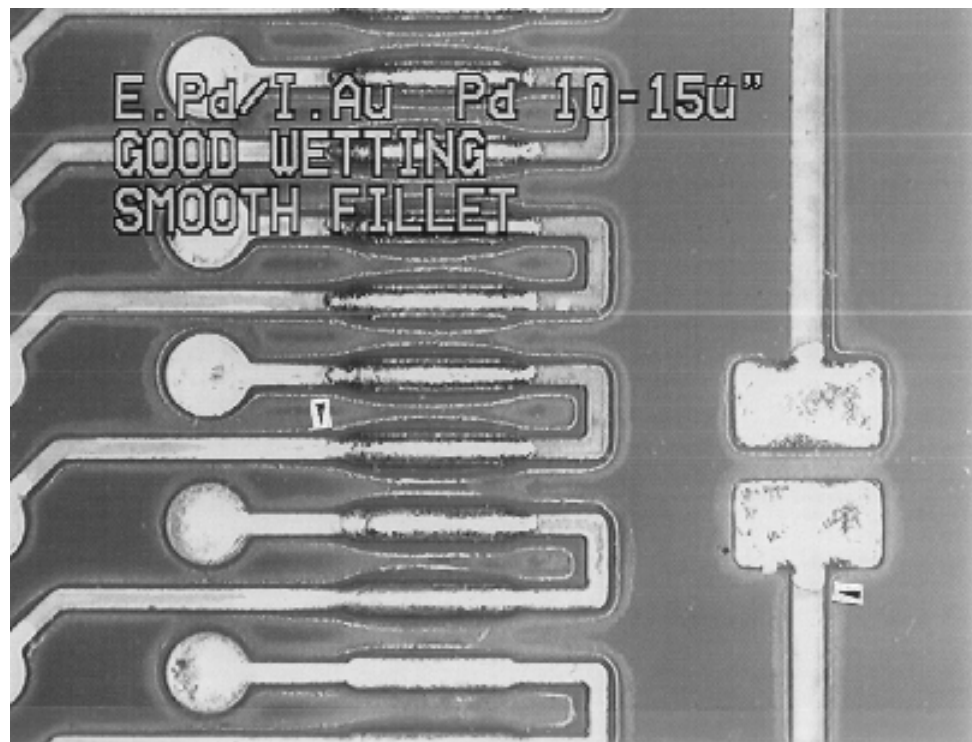


Figure 3 - Solder Wetting on Electroless Palladium / Immersion Gold



Figure 4 - Grainy Solder on Thick Palladium after Thermal Cycles

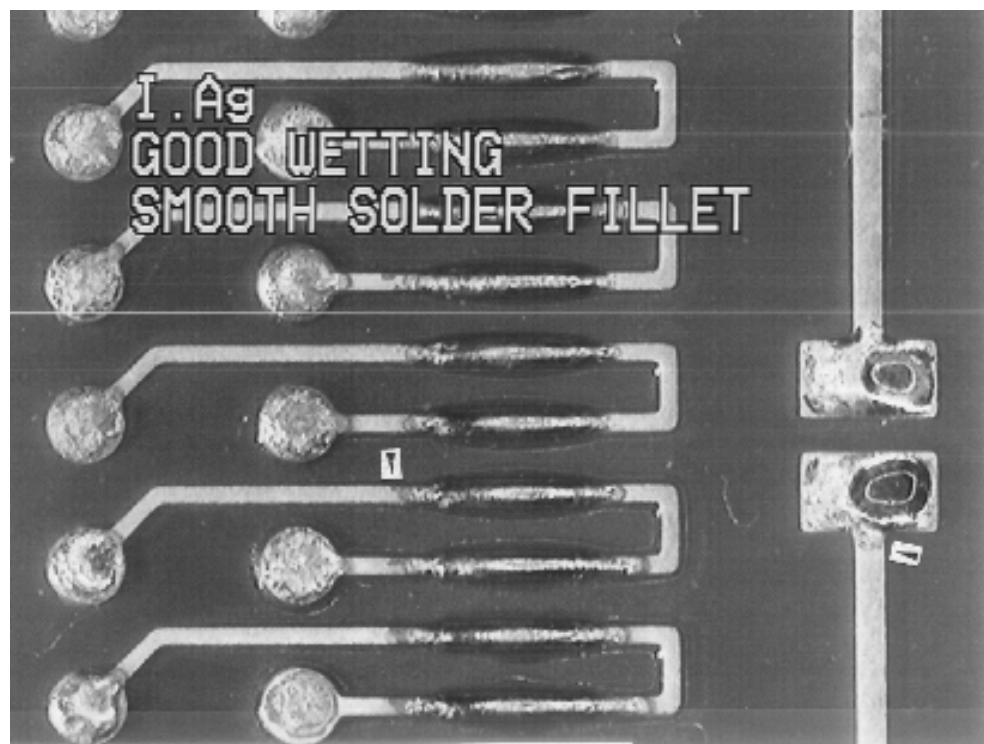


Figure 5 - Solder Wetting on Silver

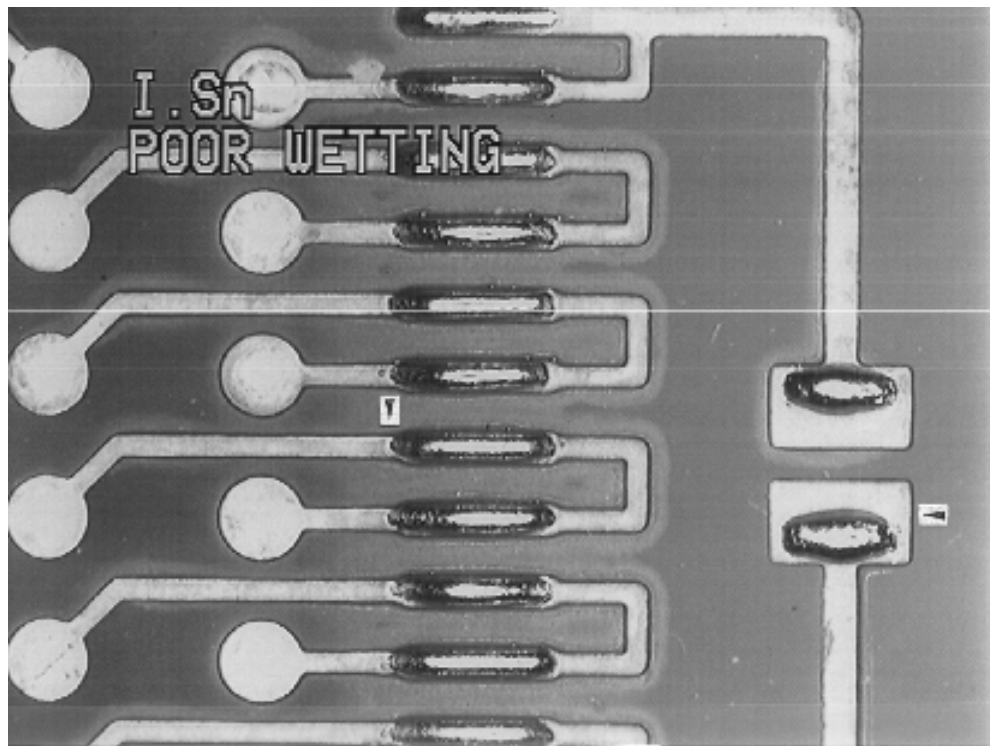


Figure 6 - Solder Wetting on Tin

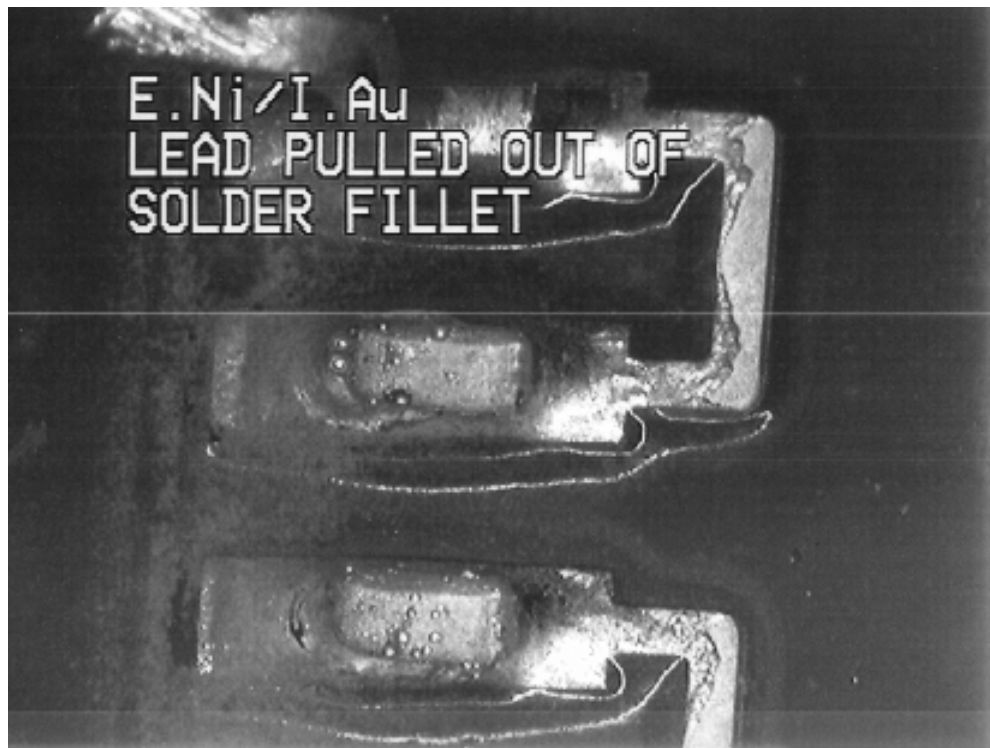


Figure 7 - Lead Pull from Nickel / Gold Finish

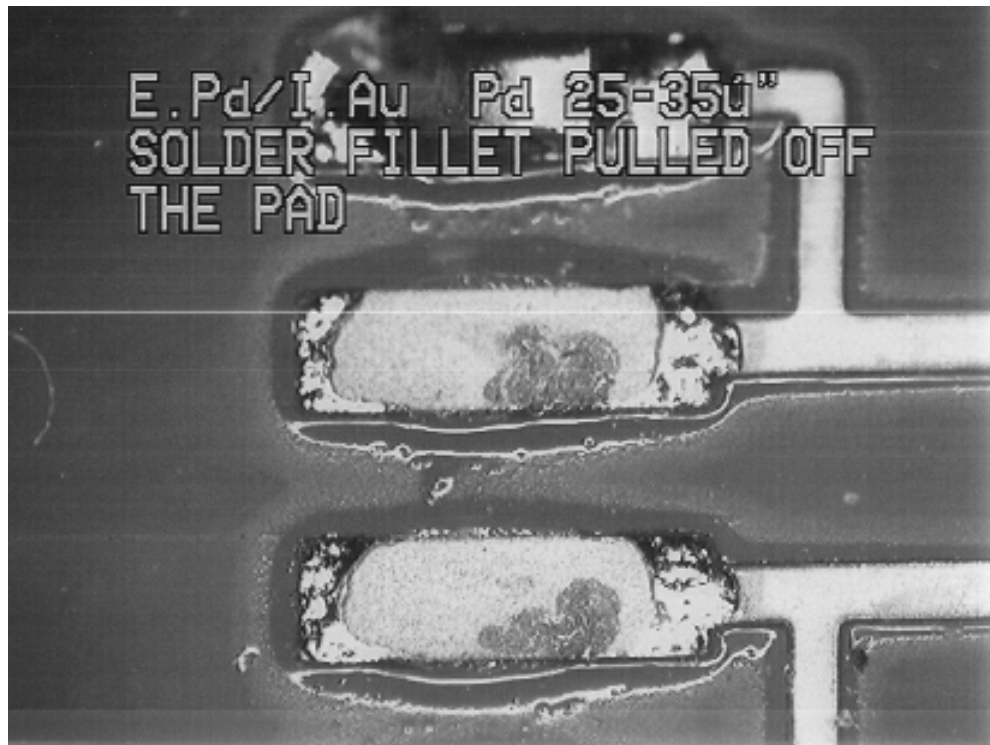


Figure 8 - Lead Pull from Thick Palladium / Gold Finish

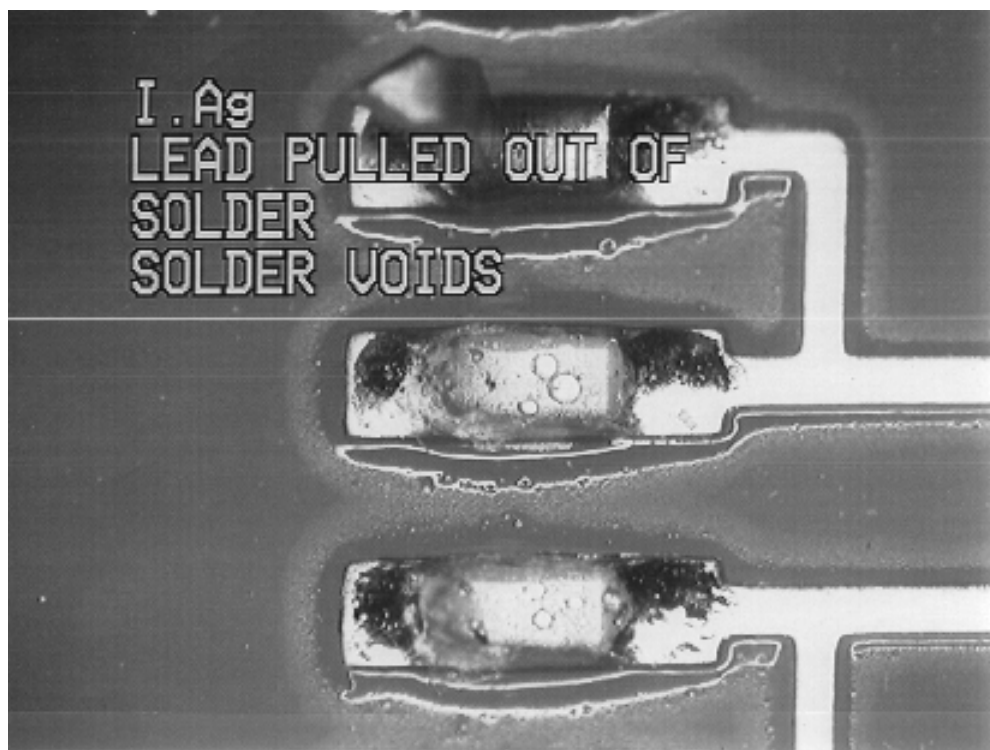


Figure 9 - Lead Pull from Silver Finish