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IMPROVED METHODS OF
FABRICATING MULTILAYER
PRINTED WIRING BOARDS

Final Report

J. L. Wilson, Project Leader

Project Team:

C. L. Long
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Published January 1978

Prepared for the United States Department of Energy
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**Kansas City
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IMPROVED METHODS OF FABRICATING MULTILAYER PRINTED WIRING BOARDS

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Prepared by J. L. Wilson, D/821

A reliable process for the fabrication of multilayer printed wiring boards has been further improved by implementing a solder-dip-and-level process in place of the conventional pattern-tin-lead-plate process. A commercial chromic acid etchant has proven to be superior to the previously used sulfuric acid etchback solution. An economical, disposable polyvinyl-fluoride-film release sheet has been adopted, and a nuclear static-electricity eliminator has proven effective in providing lint-free panels.

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A prime contractor with the United
States Department of Energy under
Contract Number EY-76-C-04-0613

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SUMMARY

Previous work has produced a reliable process for the fabrication of multilayer printed wiring boards (MLBs). Additional development work has resulted in further improvements being made to the basic process.

The solder-dip-and-level process now used at Bendix Kansas City for the production of double-sided printed wiring boards has proved to be an equally valuable process for the fabrication of MLBs. Studies have shown that MLBs have the capability for tolerating the thermal shock that is inherent with the solder-dip-and-level process.

A proprietary chromic acid etchant has proven to be superior to the previously used sulfuric acid etchback solution. It provides a uniform rate of epoxy removal, and the solution is easier to control than the sulfuric acid solution. As before, hydrofluoric acid is used for etching the glass fibers within the laminate.

Tedlar, a disposable polyvinyl-fluoride-film release sheet, was found to be a satisfactory and economical replacement for the Teflon sheet material formerly used.

A nuclear static-electricity eliminator proved to be an effective aid in providing lint-free panels prior to lamination of the MLBs.

DISCUSSION

SCOPE AND PURPOSE

The need for denser packaging of electronic assemblies has dictated the use of multilayer printed wiring boards (MLBs) in ERDA products. Initial work resulted in the establishment of a reliable MLB fabrication process.¹ Subsequent work, reported herein, was directed toward the improvement and refinement of the developed process.

PRIOR WORK

The following described work on related process development orders has consisted of studies pertaining to the solder-dip-and-level process, the effects of thermal cycling, and the rework of MLB assemblies.

An initial investigation of solder dipping and leveling revealed that the solder-leveling process improved solderability and eliminated solder slivers, solder splatter, and bridged conductors without damaging the printed wiring boards.² Another study determined that the process made visual inspection easier and reduced the time required to manufacture the assembly.³

In a study to determine the effects of thermal expansion on epoxy-glass laminates used in the manufacture of solder-dipped-and-leveled printed wiring boards, gradual or instant shock encountered during the normal manufacturing and rework process cycles were found to have no adverse effects on circuit board quality.⁴

A study of the rework techniques that were used on approximately 16,000 connections within MLBs involved the use of heat which caused thermal cycling similar to that encountered during solder dipping and leveling. A significant conclusion drawn from the study was that the internal connections of MLBs generally are not degraded by rework of the assembly.⁵

ACTIVITY

Solder Dipping and Leveling of MLBs

MLBs which had been produced according to the SC/BX Standard Process were used in tests to determine whether these boards could benefit from adoption of the solder-dip-and-level process. Except for the fact that the plated-through holes (PTH) were etched back prior to plating, the process was not changed.

The solder-dip-and-level process that is employed at Bendix Kansas City consists of first baking the boards for 2 hours at 110°C (230°F) prior to hand-dipping the prefluxed boards in a solder pot at a temperature of 246°C (475°F). The boards then are cleaned in a flux remover, cleaned in trichloroethylene, liquid-leveled in a Hydro-Squeegee leveling machine which utilizes ethylene glycol at a temperature of 246°C, rinsed in water, and again cleaned in trichloroethylene. Table 1 provides a comparison between the solder-dip-and-level process and the pattern-tin-lead-plate process.

Ten units each of Boards 230219 and 230776 and 20 units of Board 230585 were fabricated according to the described process. All were made from Type GE laminate material. Board 230219 consists of six layers, 230776 of eight layers, and 230585 of four layers. Boards 230219 and 230776 (Figures 1 and 2, respectively) both contain ground planes.

Evaluation Procedure

Electrical testing of internal-circuit continuity and insulation resistance was performed on the PT2200 tester using the same inspection tapes as those used for testing the MLBs now produced by the pattern-tin-lead-plate process. No discrepancies were found in any of the six boards of each part tested.

Microhm resistance readings were recorded from selected holes on each of three boards of Parts 230219 and 230776. These boards then were baked at a temperature of 82 to 93°C (180 to 200°F) for a minimum of 1 hour and subjected to three consecutive solder-dip-and-level cycles. Microhm readings again were recorded from the original holes selected, and any changes in board appearance were noted. This same procedure was repeated after the completion of each total of six, eight, ten, and thirteen solder-dip-and-level cycles. The baking operation was performed before each set of consecutive cycles.

Test Results After Liquid Leveling

Resistance readings proved to be consistent through seven solder-dip-and-level cycles (Figure 3). A definite increase in resistance can be seen after the completion of ten cycles, and even higher readings with one open circuit occurred after thirteen cycles.

These boards were visually unacceptable after six to ten cycles. Boards 230776 developed blisters up to 25.4 mm (1 inch) in diameter after six cycles, while Boards 230219 did not blister until after ten cycles. The following descriptions of the appearance of the MLBs were noted after the completion of each group of consecutive solder-dip-and-level cycles.

Table 1. Comparison Between Pattern-Tin-Lead-Plate and Solder-Dip-And-Level Processes

Steps in Pattern-Tin-Lead-Plate Process	Steps in Solder-Dip-and-Level Process
Etchback PTHs	Etchback PTHs
Plate With Electroless Copper	Plate With Electroless Copper
Panel-Plate 15 Minutes With Copper	Panel-Plate 70 Minutes With Copper
Laminate Resist	Laminate Resist
Expose Circuitry	Expose Circuitry
Develop Circuitry	Develop Circuitry
Pattern-Plate 80 Minutes With Copper	Etch
Pattern-Plate With Tin-Lead	Remove Resist
Remove Resist	Bake
Etch	Solder-Dip
Drill Nonplated-Through Holes	Solder-Level
	Drill Nonplated-Through Holes

- After four cycles, Boards 230219 showed no apparent degradation. Boards 230776 showed a slight measling between closely spaced plated-through holes.
- After six cycles, the laminate of Boards 230219 had darkened slightly. Boards 230776 displayed blisters up to 25.4 mm (1 inch) in diameter, measling, and darkening of the laminate; if they had been production parts, these boards would have been scrapped because of their appearance.
- After eight cycles, the laminate of Boards 230219 had become slightly darker; although no measles or blisters had appeared, terminal areas were slightly cupped. Boards 230776 showed a small increase in the number and size of both measles and blisters, and the terminal areas were cupped.
- After ten cycles, Boards 230219 exhibited blisters up to 32 mm (1.25 inches) in diameter, while Boards 230776 had blisters up to 50 mm (2 inches) in diameter.
- After thirteen cycles, both groups of boards showed severe delaminations. One Board 230219 had one partially missing terminal area, and Boards 230776 had many loose or missing terminal areas.

Figure 1. Multilayer Printed Wiring Board 230219

The fact should be noted that visually observable degradation occurred in all samples before there was a significant increase in the resistance of the plated-through holes.

Metallurgical mounts of cross sections of the plated-through holes which were made after the completion of thirteen solder-dip-and-level cycles clearly show the effect of the repeated thermal shocks (Figure 4). More than half of the holes that were sectioned were either cracked or showed evidence of cracking at the intersection of the terminal area and the hole wall. The holes that did not show evidence of cracking were all severely cupped, thus indicating that the epoxy-glass laminate was permanently swollen by the repeated thermal cycling. There was no indication of any degradation of the internal connections.

Test Results After Hot-Gas Leveling

Two each of Boards 230219 and 230776 were solder-dipped-and-leveled twelve additional times (for a total of thirteen cycles)

Figure 2. Multilayer Printed Wiring Board 230776

at Sandia Laboratories, Albuquerque, in the hot-gas leveling machine. This machine utilizes heated air instead of ethylene glycol to achieve the leveling effect.

By comparison with the liquid-leveled boards, this group of boards fared much better. There was no visible degradation, and the resistance readings obtained after the twelve additional cycles were of the same magnitude as those obtained from boards that had been liquid-leveled only once (Table 2). Cross sections of the hot-gas-leveled plated-through holes show no evidence of cracking or any other type of defect (Figure 5).

Figure 3. Changes in the Average Resistance Values of 1.32-mm-Diameter (0.052 Inch) and Smaller Plated-Through Holes After the Initial Solder-Dip-And-Level Cycle of Parts 230219 (Above) and 230776 (Below)

Figure 4. Cross Sections of Plated-Through Holes Showing the Effect of Thermal Shock After Thirteen Solder-Dip-And-Level Cycles

When comparing the two solder-dip-and-level methods, the fact should be noted that 12 cycles through the solder-dipping-and-liquid-leveling process constitute 24 thermal shocks (one each for dipping and leveling), whereas 12 hot-gas-leveling cycles produce only 12 thermal shocks. This is because the hot-gas-leveling equipment is arranged in such a manner that the leveling is accomplished immediately after solder-dipping; thus the boards are not allowed to cool between the dipping and leveling portions of the process.

Another important consideration when evaluating the two methods is that the 12 hot-gas cycles were consecutive, and thus the boards did not cool to room temperature between cycles. (Although the boards were dipped in flux between cycles, the flux became heated to such an extent that the thermal shock was greatly reduced.)

Despite the special considerations described, the evidence indicates that hot-gas leveling is the more desirable of the two methods studied.

Table 2. Resistance of Selected Plated-Through Holes After Thirteen Cycles of Solder Dipping and Hot-Gas Leveling

Part Number	Hole Number	Hole Diameter		Resistance ($\mu\Omega$)	
		(mm)	(Inch)	Board 4	Board 5
230219	10	0.81	0.032	82	76
	23	0.81	0.032	69	82
	66	0.81	0.032	79	65
	90	0.81	0.032	70	66
	107	1.07	0.042	36	34
	118	1.07	0.042	24	22
	151	1.07	0.042	34	36
	214	1.07	0.042	34	36
	234	1.22	0.048	26	37
	238	1.22	0.048	29	26
	254	1.52	0.060	17	17
	256	1.52	0.060	18	17
230776	10	1.32	0.052	51	50
	22	1.32	0.052	54	51
	35	1.32	0.052	46	54
	92	1.32	0.052	58	45
	103	1.32	0.052	57	59
	119	1.32	0.052	49	52
	178	1.32	0.052	56	47
	191	1.32	0.052	46	43
	207	1.52	0.060	20	22

MLB Thermal-Shock Tests

Further tests to determine the effects of thermal shock on MLBs also were performed on boards that originally had been produced by the conventional pattern-tin-lead-plate process. Thermal shock was induced by dipping rosin-fluxed MLBs in a solder pot at

Figure 5. Left and Right Cross Sections of Hot-Gas-Leveled Plated-Through Hole

a temperature of 243°C (470°F). Electrical resistance was measured periodically by a Micro-Ohm Meter Model 143D, and a graph was made for each sample to show the electrical resistance versus the number of dipping cycles (Figures 6 through 14). The resulting data, compiled in Table 3, indicate that little or no change occurred in plated-through-hole resistance through five cycles of dipping in molten solder, even though some delamination did occur as early as the third cycle. All MLBs survived at least ten cycles before fractured terminal areas became evident. Four of the nine boards completed eighteen cycles before fracturing. Cross sections revealed that all fractures had occurred at the intersection of the hole wall with the outside terminal area. This condition was produced by fatigue caused by repeated bending as the laminate expanded and contracted. No fractures were observed in the hole walls, and no internal connections appeared to have been degraded.

Solder-dipping the boards with flux was found to produce more severe results than either leveling or fusing. One four-layer sample board was fused twenty times in peanut oil with only a slight increase in resistance becoming apparent, although delamination was present. The board then was solder-leveled ten times,

Figure 6. Average Plated-Through-Hole Resistance After Solder-Dipping Part 229188

Figure 7. Average Plated-Through-Hole Resistance After Solder-Dipping Board 1 of Part 229192

Figure 8. Average Plated-Through-Hole Resistance After Solder-Dipping Board 2 of Part 229192

and it showed some increase in resistance. For the last twenty cycles, it was solder-dipped with flux. At the completion of the fifty cycles, many terminals had become loose. Apparently, fluxing caused a gradual loss of copper which was evidenced by rounded breaks in the cross-sectional mounts and a measured 0.13-percent increase of copper in the solder bath.

Plated-through holes tended to hold delaminated areas of the boards together until the holes broke under fatigue after ten or more solder-dipping cycles. Most board delaminations occurred at the interior copper ground planes rather than within the bond between the glass substrates.

Thermal Properties of MLBs

The thermal properties of five different MLBs were studied using the DuPont 941 Thermomechanical Analyzer (TMA). The TMA was used to graph the expansion and contraction of the plated-through holes and laminates; the coefficient of expansion was determined by the slope of the plotted curve. The laminates consisted of one four-layer, one six-layer, and three eight-layer MLBs. All were of Type GE laminate, but each of the eight-layer MLBs was of a different thickness.

Figure 9. Average Plated-Through-Hole Resistance After Solder-Dipping Board 3 of Part 229192

Figure 10. Average Plated-Through-Hole Resistance After Solder-Dipping Board 1 of Part 229193

Figure 11. Average Plated-Through-Hole Resistance After Solder-Dipping Board 2 of Part 229193

Figure 12. Average Plated-Through-Hole Resistance After Solder-Dipping Board 1 of Part 231275

Figure 13. Average Plated-Through-Hole Resistance
After Solder-Dipping Board 2 of
Part 231275

The properties of the laminates that were determined consisted of measurements of the dimensional changes that occurred during one heating-cooling cycle from ambient to 260°C (500°F) and back to ambient. The coefficient of linear thermal expansion (CLTE) was measured above the glass-transition point of the epoxy resin.

All of the MLB laminates that were analyzed contracted during one heating-cooling cycle (Figures 15 through 19). The amount of contraction ranged from 1.27 percent for the four-layer board to 2.16 percent for the six-layer board. The CLTE values for the three eight-layer laminates decreased as the board thickness decreased.

The thermal properties of all the MLB laminates are shown in Table 4. Although the TMA data shows different CLTE values for the laminates, the TMA profiles are very similar in shape, thus indicating a similarity in the resin systems and curing conditions employed.

The plated-copper holes through the MLBs with the laminate intact also were analyzed by the TMA (Figures 20 through 24). One heating-cooling cycle of the board showed that the length of the

Figure 14. Average Plated-Through-Hole Resistance After Solder-Dipping Part 231295

copper hole expanded along with the laminate surrounding the hole. Upon cooling from 260°C (500°F) to ambient, all of the plated-through holes surrounded by laminate except the plated hole in the six-layer board were found to have stretched during the heating-cooling cycle. The plated-through holes in the four remaining MLBs had stretched from 0.50 percent (Board 231275) to 0.77 percent (Board 229192). The stretching effect of the laminates on the plated holes is shown in Table 4.

Etchback Evaluation

The use of Niklad 233P-MLB (a chromic-acid plastic etchant manufactured by the Allied-Kelite Division of The Richardson Company, Des Plaines, Illinois) followed by the use of Niklad 220 Chrome Neutralizer (manufactured by the same company) have proven to constitute a successful etchback process which is superior to the previously used process employing a sulfuric acid solution. The complete process includes the use of hydrochloric and hydrofluoric acids. The latter acid is used for etching the glass fibers within the laminate.

The etching rate of the 233P-MLB etchant was found to depend mostly upon the temperature of the solution. To determine optimum time-temperature parameters, tests were conducted in which the

Text continued on page 26.

Table 3. Plated-Through-Hole Resistance Data

Solder-Dipping Cycles	Hole Number and Resistance for Part and Board Number Shown												
	Hole ($\mu\Omega$)		Hole ($\mu\Omega$)		Hole ($\mu\Omega$)		Hole ($\mu\Omega$)		Hole ($\mu\Omega$)		Hole ($\mu\Omega$)		Average ($\mu\Omega$)
Part 229188 (Figure 6)													
0	1	54	2	64	3	39	4	44	5	76	6	80	59.5
4		74		64		34		36		62		80	58.3
6		61		73		36		36		55		65	54.3
8		65		73		37		39		56		65	55.8
10		71		70		38		35		58		72	57.5
12		94		95		43		36		74		81	70.5
14		67		95		40		40		72		82	65.6
16		76		100		44		38		70		83	68.5
18		87		89		51		42		80		80	71.5
20		81		90		48		43		81		87	71.6
Part 229192, Board 1 (Figure 7)													
0	1	156	2	167	3	104	4	116	5	92	6	230	144.2
4		164		164		104		116		100		230	146.3
6		198		210		110		118		108		247	165.2
8		193		201		120		123		114		243	165.6
10		176		187		118		118		95		246	156.6
12		205		207		123		131		92		260	169.6
14		225		211		136		149		110		310	190.2
16		229		208		142		152		110		312	192.2

Table 3 Continued. Plated-Through-Hole Resistance Data

Solder-Dipping Cycles	Hole Number and Resistance for Part and Board Number Shown												
	Hole ($\mu\Omega$)		Hole ($\mu\Omega$)		Hole ($\mu\Omega$)		Hole ($\mu\Omega$)		Hole ($\mu\Omega$)		Average ($\mu\Omega$)		
Part 229192, Board 1 Continued													
18	1	181	2	197	3	140	4	146	5	110	6	502	212.2
20		221		210		142		145		135		653	251.0
Part 229192, Board 2 (Figure 8)													
0	94	72	23	132	305	84	277	92					95.0
5		90		160		103		109					115.5
10		119		213		174		171					169.3
Part 229192, Board 3 (Figure 9)													
0	94	84	23	156	305	90	277	89					104.8
1		86		147		84		91					102.0
20		240		128				252					206.7
Part 229193, Board 1 (Figure 10)													
0	174	102	191	133	31	92	39	91					104.5
1		94		131		100		100					106.3
10		94		145		111		105					113.8
15		114		149		124		145					133.0
20		198		165		224		154					185.3
Part 229193, Board 2 (Figure 11)													
0	174	91	191	127	31	136	39	108					115.5
5		109		130		98		108					111.3
10		197		163		141		142					160.8

Table 3 Continued. Plated-Through-Hole Resistance Data

Solder-Dipping Cycles	Hole Number and Resistance for Part and Board Number Shown												
	Hole ($\mu\Omega$)		Hole ($\mu\Omega$)		Hole ($\mu\Omega$)		Hole ($\mu\Omega$)		Hole ($\mu\Omega$)		Average ($\mu\Omega$)		
Part 231275, Board 1 (Figure 12)													
0	182	80	174	76	153	80	13	149				96.3	
1		77		84		82		149				98.0	
20								174				174.0	
Part 231275, Board 2 (Figure 13)													
0	182	73	174	79	153	102	13	163				104.3	
5		85		85		100		206				199.0	
10		116		129		147		213				151.3	
Part 231295 (Figure 14)													
0	1	49	2	60	3	65	4	62	5	59	6	42	56.2
4		49		60		65		73		69		42	59.6
6		54		62		80		68		77		46	64.5
8		58		66		67		80		88		46	67.5
10		56		73		96		82		105		51	77.2
12		57		84		560		221		158		370	241.6

Figure 15. Displacement of Laminate During One Heating-Cooling Cycle of Four-Layer Board 229147

time was varied from 30 to 240 seconds and the temperature was varied from 44.2 to 112.3°C (110 to 190°F). Each of 56 panels containing 0.762- and 1.524-mm-diameter (0.030 and 0.060 inch) holes was etched at a different time-temperature combination.

Cross sections were made of four 0.762- and four 1.524-mm holes from each panel. Four etchback readings were taken from each hole that was sectioned, thus making a total of 16 measurements per panel for each hole-size and a total of 32 measurements for each time-temperature combination. The 16 readings obtained from each hole-size from each panel were averaged to obtain single values for comparison. The graphs shown in Figures 25 and 26 were derived from the acquired data.

Figure 16. Displacement of Laminate During One Heating-Cooling Cycle of Eight-Layer Board 229147

Table 5 defines each step in the final etchback process that has been derived as a result of the tests performed at Bendix Kansas City. The use of Niklad 233P-MLB etchant provides a uniform rate of epoxy removal, and the solution is easier to control than the previously used sulfuric acid solution.

Release-Sheet Evaluation

Earlier procedures for processing MLBs at Bendix Kansas City incorporated the use of Teflon and various other materials as release sheets for the laminating process. Testing of DuPont's polyvinyl fluoride film *Tedlar* proved it to be acceptable and more economical than the release-sheet materials previously used.

Figure 17. Displacement of Laminate During One Heating-Cooling Cycle of Eight-Layer Board 229192

Nuclear-Static-Eliminator Evaluation

To obtain lint-free panels prior to laminating MLBs, a 3M-Company Nuclear Static Eliminator was acquired. This device eliminates static electricity by emitting alpha particles from Polonium 210. It is attached to a compressed-dry-nitrogen supply line and is used to blow off the panels and prepreg sheets prior to making the lay-up for laminating the boards.

Figure 18. Displacement of Laminate During One Heating-Cooling Cycle of Six-Layer Board 229193

ACCOMPLISHMENTS

A reliable process for manufacturing high-quality MLBs has been established as a result of this development effort. MLBs made from Type GE laminate material have been shown capable of tolerating the thermal shock that is inherent in the solder-dip-and-level process. Specifications have been incorporated for the solder-dip-and-level process and the pattern-copper and pattern-tin-lead-plate processes. A design guide and standard also have been adopted.

Niklad 233P-MLB etchant has proven to be superior to the previously used sulfuric acid etchback solution.

Figure 19. Displacement of Laminate During One Heating-Cooling Cycle of Eight-Layer Board 231275

Tedlar, a disposable polyvinyl-fluoride-film release sheet, has been found to be a satisfactory and economical replacement for the Teflon sheet material formerly used.

A nuclear static-electricity eliminator has proven to be an effective aid in providing lint-free panels prior to lamination of the MLBs.

Table 4. Thermal Properties of Multilayer Laminates With Plated-Through Holes

Part Number	Layers	Original Thickness		CLTE* (X10 ⁻⁶)	Contraction of Laminate (Percent)	Elongation Copper Hole (Percent)
		(mm)	(Inch)			
229147	8	2.16	0.085	307	1.90	0.70
229192	8	1.80	0.071	220	1.71	0.77
231275	8	1.75	0.069	196	1.96	0.50
229193	6	1.47	0.058	225	2.16	
229147	4	0.99	0.039	289	1.27	0.55

*Coefficient of linear thermal expansion.

Figure 20. Displacement of Plated-Through Hole During One Heating-Cooling Cycle of Four-Layer Board 229147

FUTURE WORK

A process for the fabrication of MLBs from polyimide materials to meet high-temperature requirements will be investigated.

Figure 21. Displacement of Plated-Through Hole During One Heating-Cooling Cycle of Eight-Layer Board 229147

Figure 22. Displacement of Plated-Through Hole During One Heating-Cooling Cycle of Eight-Layer Board 229192

Figure 23. Displacement of Plated-Through Hole During One Heating-Cooling Cycle of Six-Layer Board 229193

Figure 24. Displacement of Plated-Through Hole During One Heating-Cooling Cycle of Eight-Layer Board 231275

Figure 25. Etchback Test Results From 0.762-mm-Diameter (0.030 Inch) Holes

Figure 26. Etchback Test Results From 1.524-mm-Diameter (0.060 Inch) Holes

Table 5. Etchback Process Used at Bendix Kansas City

Process Operation	Time (s)
Dip in ammonium persulfate	45 to 60
Rinse in tap water	30 to 60
Dip in hydrochloric acid	60 to 70
Rinse in tap water	30 to 60
Blow dry with filtered air	
Bake at 71 to 88°C (160 to 190°F)	600
Dip in Niklad 233P-MLB* at 77 to 82°C (170 to 180°F)	88 to 92
Rinse in tap water	30 to 60
Dip in Niklad 220	60 to 90
Rinse in tap water	30 to 60
Blow dry with filtered air	
Dip in hydrofluoric acid	30 to 35
Rinse in tap water	30 to 60
Dip in hydrochloric acid	45 to 60
Rinse in tap water	30 to 60
Blow dry with filtered air	

*The specific gravity of Niklad 233P-MLB is maintained from 1.52 to 1.65 at a temperature of 77°C (170°F); the solution is analyzed periodically for chromic acid content.

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