Additive Processing

by Jerry Murray, West Coast Editor

Additive plus subtractive equals positive positioning.

Some say that additive processing is the wave of the future,' some say 10% of the future is already here, and some say improvements in subtractive processing can satisfy today's and tomorrow's high-circuit-density needs. Still others—perhaps the wise ones—suggest that the board maker go both ways at once.

As the most active U.S. proponent of additive processing, AMP-AKZO PCK Technology (Melville, NY) cites two basic advantages of using additive processing: more uniform metallization across a panel and better copper deposition within deep, high-aspect-ratio-holes. The first advantage helps meet SMT assembly requirements, the second increases PCB reliability.[2] AMP-AKZO offers two new products for fully additive and partially additive processing. Both processes involve full-build electroless plating solutions that are chemically similar to the electroless copper solutions used in subtractive processing prior to acid copper electroplating.

These similarities, shared by virtually all electroless copper baths, lie in electroless copper solutions' four basic ingredients-dissolved copper, formaldehyde as a copper-reducing agent, a chelating agent, and caustic. While the proportions of these four ingredients may vary slightly, it is the electroless solutions' additives that account for the differences between vendors' products in terms of deposition rate and the all-important properties of the deposited copper.

Frank Nuzzi, group manager of chemical research and development at AMP-AKZO, said PCK600 is a full-build electroless bath, licensed from Hitachi Ltd., that deposits copper with an elongation of 10 to 15% and a tensile strength of 40,000 to 50,000 psi. The product's unusually high deposition rate of 0.25 roils per hour directly addresses additive critics' claims that chemically deposited copper takes much longer than electrolytic. This is an invalid criticism because the full-build tank, without electrodes, can be more heavily loaded with panels. Anyway, PCK600 works at three times the speed of its competitors, Hitachi has been using it in production for over two years, and U.S. beta site testing is well underway. PCK600 is meant to be used for partially additive board fabrication, where standard but nonelectrolytic panel plating processes are used on standard copper-clad laminates.

In addition, AMP-AKZO offers CC-4 Fully Additive chemistries for use on unclad laminate precoated with adhesive and impregnated with the necessary palladium catalyst. In line with the times, several laminate manufacturers offer such base materials. The special laminate is drilled, imaged with a permanent plating resist, and then plated up with electroless copper. In addition to the advantage of uniform surface and hole plating, the CC-4 process, used in production at AMP-AKZO Additive Circuits (Aquobegue, NY) since 1983, is said to produce fine lines with precise geometries. The CC-4 Fully Additive chemistry is commercially available i premixed concentrates as PCK570, a full-build solution that isn't as fast as PCK600 but has the same copper deposit quality. The concentrate has been marketed since 1987.

MACDERMID

MacDermid (Waterbury, CT) has been researching and developing full-build processing for a long time. Legend h s it that MacDermid was responsible for an additive process at IBM Endicott that turned out some truly remarkable boards. While that rumored process remains shrouded in Big Blue secrecy, MacDermid makes no secret f its Prism full-build electroless co per process. Joe D'Ambrisi, coauthor of definitive papers on the subject [3,4] and product manager at MacDermid, said that all of the company's full-build chemistries involved with the Prism process were internally developed. A home-grown process comes as a refreshing change from the predominantly Japanese licensing situations under which some of the U.S. companies market their full-build chemistries.

On the Prism process, MacDermid's literature reports, "There is only one way to uniformly plate high-aspect-ratio holes and create perfect surface mount pads. " To substantiate this seeming immodesty, MacDermid's literature quotes IPC Technical Report #579, "For high-reliability applications in severe use environments, standard electrolytic plating processes become inadequate for higher PTH aspect ratios, even with opti-

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mum process controls." The IPC report goes on to say, "The full-build electroless copper fabricated holes performed extremely well in all board constructions submitted. "

A polyethylene or Teflon tankful of Prism, or XD-6157-T, is made of four MacDermid ingredients and 80% DI water. At 153" to 160" F with air agitation and proper control, the bath deposits 85 to 90 microinches of copper on 0.25 to 0.5 square feet of circuit board panels for each gallon of 6157 in the tank. Automatic analyzers and replenishers can be used to keep the solution in control. Manual titrations can also be used to analyze for copper, chelator, free caustic, and formaldehyde. From eight to 30 turnovers per hour through 10-micron filters keep the bath clean. When the solution's specific gravity reaches 1.08, the bath should be either partially or completely returned to MacDermid for reclamation, or it can be treated on-site with MacDermid's Piranha copper recovery unit. The copper that Prism deposits on PCB panels is 99.7% pure, with an elongation greater than 6% and a tensile strength of more than 55,000 psi.

D'Ambrisi said that most of MacDermid's production installations of Prism have been in panel plate, tent-and-etch processing. Other full-build applications such as semi-or partially additive processing have not yet been realized because the industry lacks an aqueous resist that will withstand the rigors of a highly alkaline full-build bath. This resist, when it comes, will permit the full-build fabricator to use solder mask as a permanent plating resist and subsequently plate only the pads and the holes. With large captives interested in the additive process for *use* on their most difficult boards, polymer chemists are undoubtedly working nights to come up with a more resistant resist.

Other than starting with precatalyzed laminate—which can cost two to six times more than standard laminate—MacDermid recommends no fully additive process. But, D'Ambrisi suggested, standard laminate can be completely stripped of its copper cladding, conventionally catalyzed, and then additively processed. Stripping the copper provides an optimal microtopography, thereby overcoming another historical additive shortcoming, poor adhesion.

In discussing MacDermid's Prism solution, D'Ambrisi mentioned colligative properties. This catch-all phrase refers to maintaining small hydrogen bubble formation within holes as they are plated. If proper surfactants are selected and solution viscosity is kept low, small bubbles flow out of holes instead of coalescing and blocking them. Once again, the secrets are in the additives.

Colligative properties are very important during processing but not as important as the properties of the deposited copper at the end of the line. Also dependent on MacDermid's patented additives, the physical properties of Prism full-build copper approach those of the electrolytically plated metal and are in some cases better. Thermal cycling tests show that Prismed boards stand up as well as subtractively made boards. However, since full-build work is not addressed in mil specs, formal testing methods for additively made boards have not ye been settled on by the IPC or the military. D'Ambrisi said that driven y large captive OEMs, military acceptance of the full-build product is currently in the works.

ENTHONE-OMI

As mentioned, one fault found with classical additive techniques that involve the us of full-build copper has been the copper's adhesion to the base substrate. An early surface preparation step used mineral acids etching an epoxy-rich, adhesive or "butter-coated" laminate for subsequent copper adhesion. It was a dicey process, highly dependent on the state of the epoxy coating, and it produced peel strengths of 6 pounds per inch and often considerably less. While this peel strength level might have been adequate for disposable boards often associated with the electronics entertainment segment of yesteryear, it didn't approach U.S. military specifications standards. A result of this shortcoming was a generally negative association with additive techniques for U.S.-built boards. Better copper adhesion was a primary goal at Enthone-OMI (New Haven, CT) when developing the Envision SMT Full Build process. According to Kathy Nargi-Toth, manager of PC fabrication products at Enthone-OMI, because the Envision process begins with standard copper-clad laminates,

ADDITIVE AND SUBTRACTIVE PROCESSING

PANEL PLATE ADDITIVE

Copper-clad laminate is drilled, deburred, catalyzed, and full-build plated with electroless copper to a thickness of over 1 mil. Panels are coated and holes are tented with dry-film resist or with a screened liquid resist that plugs the holes. After imaging, the resist is stripped, leaving the bare copper circuit pattern. Solder mask is applied, and the panel is solder leveled or organic lacquer coated.

PATTERN PLATE ADDITIVE

Copper-clad laminate is drilled, deburred, catalyzed, and struck with conventional electroless copper to 0.1-mil thickness. A resist is applied, imaged and developed, and holes and surface features are plated to 1 mil in a full-build electroless copper bath. Immersion tin is applied as an etch resist, photoresist is stripped, and the background copper is etched away, leaving uniformly plated holes and surface features.

PARTIALLY ADDITIVE

In one of several variations, 1-oz. copper-clad laminate is drilled, deburred, catalyzed, and plated with 0.1 mil of electroless copper. Holes are tented and features defined with a dry-film resist, followed by etching and stripping. A combination solder mask and plating resist is applied, protecting fine-line conductors during the subsequent full-build electroless plating of through-holes.

SEMI-ADDITIVE

Unclad copper, precoated with an adhesive, is drilled, treated with catalyst, and electrolessly plated with copper. Photoimageable resist is applied and developed, the panel is electroplated with copper, and resist stripping followed by copper etching produces the final features.

SUBTRACTIVE

Copper-clad laminate is drilled, deburred, catalyzed, and struck with a thin layer of electroless copper as a conductive base for subsequent through-hole electroplating. In panel plating, the full panel is electroplated prior to imaging; in pattern plating, a negative image is made prior to copper electroplating. In either case, tin and lead etch resist plating follows copper plating, and extensive copper etching produces the final features.

copper adhesion is just as good as the copper cladding supplied by the laminate vendor. The starting laminate can be polyimide or any of the other more exotic low Z-axis expansion materials as well as the FR-4s.

The process is built around Envision SMT's Enplate CU-9011, a noncyanide bath that deposits copper with unique properties. Copper deposited from CU-9011 exhibits moderate elongation, typically measured at 6 to 10%, and is very dependent on the substrate used as a base. The tensile strength of the deposit is exceptionally high, over 110,000 psi, more than double that seen with electrodeposited foils or other electroless copper chemistries. The net result of these properties is a copper deposit that was shown in testing to be more resilient to thermal cycling than its higher-elongation and lower-tensile-strength counterparts.

A user of Enthone's process begins by drilling a standard copper-clad laminate whose cladding weight (copper thickness) corresponds to that of the desired features of the final board. Rather than acid desmear, Enthone-OMI's permanganate treatment follows drilling to increase dielectric microtopography while cleaning the holes. A conditioning neutralizer establishes the proper polar charges before the catalyzation sequence. The dried panels are coated with a tenting photo resist, and the circuitry is generated by tent-and-etch techniques. Etching in cupric chloride or ammoniacal solutions is followed by resist stripping. For increased yields at decreased cost, the in-process panels can be electrically tested at this point. After cleaning and drying, boards are then coated with Envision DSR-5057. This is a a liquid-photoimageable solder mask that is aqueously processable. This material serves as the final solder mask and a permanent plating resist during processing. After imaging, development, and curing, the boards are cleaned, reactivated, and electrolessly plated in a two-step operation consisting of a 20-microinch strike and full-build plating in the Envision SMT Enplate CU-9011 bath. Final fabrication processes, such as gold tab plating, hot-air solder leveling, or organic protective coating, follow.

Typical full-build immersion time to build up to 1 ounce of copper is 14 to 16 hours, which, as Nargi-Toth points out, is deceptive from a productivity standpoint. As mentioned, full-build processing can be more productive than electrolytic because the full-build tank will hold many more panels in the same floor space occupied by an electrolytic tank. Outside lab tests on Envision-processed boards show improved small-hole reliability in thermal cycling as compared to electrodeposition processing. Tying up any loose ends, Enthone-OMI offers the modular OSCER (On-Site Copper and EDTA Regeneration), an equipment package that recovers dissolved copper and EDTA (ethylene diamine tetra-acetic acid, an ingredient common to most electroless copper baths) as reuseable solids.

The company claims several advantages attributable to its Envision SMT process:

- Since exposed pads and SMD attachment areas are plated after solder mask application, finished boards have a level surface ideal for SMD mounting.
- Because traces are etched, not plated, there are no resist residues under overhang that will interfere with uniform etching, no thickly plated areas due to uneven current density, and generally greater control of circuit geometries for controlled impedance designs.
- Circuits can be electrically tested prior to plating.
- The elimination of rectifiers, solder plating, and solder stripping to generate an SMOBC product results in a reduction of tank floor space and capital equipment costs.
- Gallon for gallon, full build is twice as productive as electrolytic copper.
- Copper is deposited uniformly within small, high-aspect-ratio holes,

While some of these advantages can be found in the variations of full-build processing, their listing sums up features of additive processing that board builders and assemblers find attractive. Attributes unique to the Envision process are the absence of cyanide in the electroless copper solution, the high tensile strength of the deposit, OSCER, and the liquid-photoimageable solder mask that also acts as a plating resist.

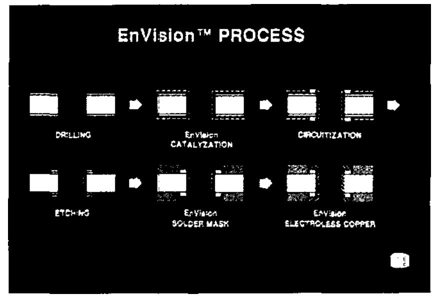
SHIPLEY CO.

Probably every supplier of processing chemicals to the PCB industry has some sort of full-build research going on. After hearing all the licensing agreements and considering the patents involved, we realize getting additive chemistry to market isn't an easy task. Shipley Co. (Newton, MA), however, is on the way. According to technical marketing manager Marlin Marsh, Shipley's full-build electroless copper is an emerging technology geared at the manufacturing of high-density boards. A related Shipley technology, fully emerged, is the Solderposit Process that deposits SnPb through a nonelectrolytic, nonelectroless chemical displacement reaction. The solder plates onto only copper surfaces to a very uniform thickness of 0.02 to 0.03 roils, providing a base for SMDs. It is said to be an ideal replacement not only for electrolytic solder but also for hot-air leveling where solder thickness can't be controlled at the knees of the holes. A potential drawback to the Solderposit Process lies in increased treatment volume of tin and lead wastes. Shipley has the rights to Hitachi's TAFII full-build copper process, and a marriage with Solderposit could provide something of an ultimate in SMT boards.

PROS AND CONS

If PCB makers believed all they read and heard, they'd all be involved with full-build processing now. But some past full-build processes proved to be disappointing. And the IPC report #579, which implicitly extolled the virtues of additive processing, was published in 1988; since that time subtractive as well as additive processing has seen some advances.

A few years ago, when florid predictions were being made about molded boards, LeaRonal (Freeport, NY) came out with Adron, a specialized



The Envision process, a partially additive methodology, includes full-build electroless copper, liquid-photoimageable solder mask, and OSCER, a modular waste treatment system. (Photo courtesy of Enthone-OMI.)

full-build process that went on the shelf with the demise of molded circuits. Having thus been singed in the past, LeaRonal is now concentrating on subtractive chemistry. The company's Bill Brasch said, "No question full build is a great idea, but it's got a lot of negatives—like big capital investment, long plating times, and a whole new way of production, Additive may come, but not today. Meantime, there are still improvements to be made in subtractive processing."

The folks at Herco Technology (San Diego, CA) say they see no current need for additive processing. The Herring family experimented extensively with full build in its existance as Industrial Circuits and later gave up on it for technical reasons. More important, by availing themselves of every frill and furbelow offered on the new PAL/ MacDermid electrolytic copper line, with the LeaRonal chemistry, the family corporation is now subtractively making high-aspect-ratio boards with copper thicknesses that vary less than 10% across a panel. This is just about as good as you can expect.

OTHER OPTIONS

PAL (Dallas, TX) is part of AIL/ PAL/MacDermid. AIL builds tanks and imports machinery, MacDermid supplies chemistries, and PAL distributes electroplating lines made in Hong Kong by Process Automation Ltd. PAL's electroplating extras include double rectification, floating shields and overflow weirs used for maintaining uniform current density, ramping rectification plus variable frequency vibrators and ultrasonics to dislodge gas bubbles from holes, and a computer monitoring system to ensure that all goes well in customers' tanks. PAL's electroplating equipment certainly seems to do the job, and MacDermid's alliance with PAL allows MacDermid to provide the latest technology in subtractive and additive chemistries.

Du Pont offers super-electroplating equipment in the form of an Impingement Plating Module (IPM- 1400), a plating cell system of pumps and manifolds with control cabinet by which constantly replenished acid copper solution is forced against panels, through holes, and immediately sucked away. High throw chemistry can be used with the optimally designed plating cell system. The rather elaborate equipment is being used in the production of very difficult (and classified) boards, but as Du Pont's Tim Henry said, it takes more than equipment to get really good plating of any kind. "Excellent plating entails every aspect of the whole line, including materials, processes, and SPC. Let's not forget that the leading-edge, higher-density boards are more dependent on innerlayer fine lines and spaces rather than outers. This is where primary imaging processes and etching techniques are key. Putting it all together isn't easy, but the technology is either available or rapidly approaching the point where 2- and 3-mil lines can be done in production."

With home-built equipment of his own design, Larry Velie of Velie Circuits (Costa Mesa, CA) is subtractively making boards with 3.5-mil lines and spaces, blind and buried vias, and high-aspect-ratio holes. He remains impressed with the additive boards he saw coming out of IBM Endicott a few years back, but he points out that many other companies have tried additive processing and failed, often because of control problems. Judging only from the Japanese and the IBM experience, Velie said additive processing is certainly viable.

USERS' VIEWS

Several of the interviewees blame the once bitten, twice shy syndrome for the dearth of additive processing in the U.S. They recall the late 1970s, when chemical suppliers were vigorously touting additive processing as the only way to go. The state of the process at the time made their enthusiasm premature, and conservative types take a long time to forget. But Cliff Ames of Unisys said, "To reach six-sigma quality, you have to get away from conventional plating techniques. Additive is the way to make blind vias in the future, and buried vias lead straight to additive processing. The anomalies in subtractive processing are going to drive us to something different. The next step I see is additive. We've got to challenge the electroless copper people to move into the forefront and work with us."

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Dalton Stelmak of Tyco Corp. is currently evaluating two vendors' additive chemistries. "Additive processing will cut down a lot of processing steps," he said, "For instance, if you made blind vias subtractively, you'd have to use sequential lamination. But if you made blind vias by controlled depth drilling and additive plating, you'd only have to go through one laminating step, and the savings would be tremendous. We're stretching the process as much as we can to evaluate its limitations."

When critics of additive processing point to capital equipment costs as a major deterrent, they're often talking about the costs of ripping out all the subtractive equipment and starting anew with additive. The purveyors of additive chemistries do not recommend this. They point out that only 10% of today's boards are of the density and complexity to merit full-build additive processing, They suggest that the board maker install an additive detour in the subtractive line or a full-build electroless tank at the end of the line, and then use additive with discretion. The board maker does not have to go all the way with the process all at once. Check out its variations, the additive purveyors say. Give it a try. And keep in mind that the 10% figure can do nothing but rise. ■

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