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Implementing Cleaner Technologies in the Printed Wiring Board Industry: Making Holes Conductive

Design for the Environment Program
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1. INTRODUCTION

Direct metallization has been gaining attention in the printed wiring board (PWB) industry as an environmentally preferable alternative to electroless copper. Even though many PWB manufacturers are currently using these alternatives, there is still a lack of available information on successfully implementing them. Some of the best sources of information about alternative technologies for Making Holes Conductive (MHC) are those PWB manufacturers who have actually installed and used the direct metallization systems under real-world operating conditions. By sharing information, PWB manufacturers can benefit from others' experiences with the relatively new technologies. This report details the specific experiences of these companies, along with their recommendations for successful implementation.

This guide presents first-hand accounts of the problems, solutions, time, and effort involved in implementing alternative MHC technologies. The information presented is based on telephone interviews with PWB manufacturers currently using these technologies, manufacturers who have used and discontinued these technologies, and the vendors of these alternative technologies. When a respondent is directly cited, their comments appear in quotes. With the information from these interviews, manufacturers considering a switch to an alternative technology can benefit from the lessons learned by those who have already made the change.

Twenty PWB manufacturers and seven vendors were interviewed. Appendix A provides background information on these facilities, such as annual production, types of boards produced, highest aspect ratio normally run, and conveyorized (horizontal) or non-conveyorized (vertical) configuration.

Carbon, graphite (two types), palladium (five types), and conductive polymer technologies are discussed in this guide. Each section begins with a description of the technology, presents a flow chart of the technology's typical process steps, and provides a summary of the interviews.

This document was developed as part of the Design for the Environment (DfE) Printed Wiring Board Project. The DfE PWB Project is a voluntary, cooperative partnership which identifies and assesses environmentally beneficial technologies and practices for the PWB industry. Project partners include the U.S. Environmental Protection Agency (U.S. EPA), the printed wiring board industry, Microelectronics and Computer Technology Corporation (MCC), the University of Tennessee Center for Clean Products and Clean Technologies, the Institute for Interconnecting and Packaging Electronic Circuits (IPC), and other stakeholders. The primary focus of the project has been the evaluation of environmentally preferable MHC technologies. Quantitative performance testing (both electrical and mechanical), risk characterizations, and cost analyses were conducted on a comparative basis for several MHC technologies, including electroless copper. The results of these analyses will be presented in a *Cleaner Technologies Substitute Assessment* (CTSA) report.

Throughout the document, the facilities interviewed are not mentioned by name. Instead, each company has been given a code, Facility A, Facility B, etc. It was the opinion of the project participants that using the actual facility names might distract the reader from the information presented on the technologies. However, the information in Appendix A will assist the reader in understanding some of the circumstances governing production at each of the facilities interviewed. This information includes the surface square feet produced annually, the types of PWBs produced, and the highest aspect ratio run for each facility.

It should be noted that mention of trade names in this report does not constitute endorsement or recommendation for use. Instead, the reader is encouraged to contact the individual companies for more information on their products.

2. Carbon Method

In carbon processes, a conductive layer of carbon black particles is deposited onto the substrate surface and the through-holes. A pre-treatment conditioner solution removes oil and debris from the substrate and creates a positive charge on the glass and epoxy walls of the vias. After conditioning, the substrate is placed in a carbon black dispersion. A noncrystalline structure of carbon black particles is adsorbed onto the positively charged surfaces, creating a conductive layer coating the entire panel. A copper microetch then removes the carbon from the copper surface while cleaning the surface for plating. Because the microetch does not attack the glass and epoxy surfaces of the through-holes, a conductive carbon layer remains only on the through-hole surfaces.

A typical carbon process has six chemical process steps (cleaner, carbon black, conditioner, carbon black, microetch, and anti-tarnish) and two air knife/oven drying steps, as shown in Figure 1. The system is configured as an enclosed, conveyorized (horizontal) process. The specific number and location of rinses and air knife stations depends on the type of product run at a facility and the condition of the rinse water used.

Information is presented on the following carbon method:

- Blackhole® (MacDermid, Inc.)

Blackhole® (MacDermid, Inc.)

Background

To date, approximately 135 Blackhole® systems, distributed by MacDermid, Inc., have been installed worldwide. Blackhole® customers run a variety of substrates including Teflon®,

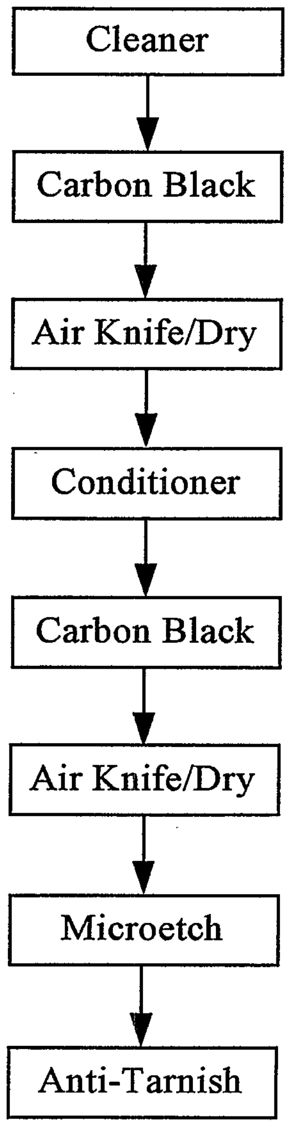

Figure 1. Typical Carbon Process Steps

polyimide, and rigid flex, with holes as small as 0.008 inches in diameter. Most Blackhole® customers run multi-layer boards. MacDermid has not identified any limitations in the types of boards that can be run through the Blackhole® system.

Implementation at Specific Facilities

For this implementation guide, two facilities in the U.S. were interviewed about their experiences with their Blackhole® systems. Both facilities process primarily multi-layer boards. Facilities A and B both run boards with up to sixteen layers and boards with aspect ratios of 8:1. Facility B has also successfully processed boards with a 10:1 aspect ratio, and runs a wide range of thicknesses from 0.001-inch thick flex to 0.250-inch thick back panels. When processing high aspect ratio boards, Facility B runs them through the Blackhole® system twice, as "insurance," although the facility engineer thinks this step is probably unnecessary. Both of these facilities are quick-turn shops, so reducing cycle time was the primary factor in their decisions to switch from electroless copper to the Blackhole® system. Both, however, noted other potential benefits, including reduced time and expenses for waste treatment system maintenance.

> **REASONS WHY FACILITIES SWITCHED TO BLACKHOLE®**
>
> - Reduced cycle time
> - Reduced waste treatment
> - Decreased maintenance requirements
> - Wider process window

Experiences with the Blackhole® Process

Both facilities interviewed completed their Blackhole® installations within the last few months and had very different experiences. Facility A installed Hollmuller equipment. After an installation period of two to three weeks, the facility put product on the line and ran the system for one month to qualify it. There were very few problems during the installation and debug period at Facility A, other than some rollers that were redepositing carbon on the panel surface. The type of roller used was changed and the problem was eliminated.

Facility A may have avoided other problems for two reasons. First, this facility uses deionized water for the Blackhole® line. According to MacDermid, there have been problems at other facilities where the water is very high in salts, which may contaminate the Blackhole® dispersion. In these cases, the incoming water may need to be deionized. Second, the engineer at Facility A noted that the capacity of their Blackhole® system far exceeds their throughput. This excess capacity makes it easy for the facility to keep the process controls tight and within MacDermid's parameters.

The installation at Facility B did not go as smoothly. The facility installed the first MacDermid brand equipment manufactured in the U.S. Both "minor irritations" and "major problems" occurred during the installation, all of which were equipment-related. MacDermid made all the on-site modifications necessary to get the system working well, including changing the microetch pumps, the cooling coils, the chiller, and the air knives. The engineer at Facility B believes that the MacDermid equipment manufactured in Germany is superior, since manufacturers there have had much more experience. Facility B's installation spanned several months, followed by one month of running boards to qualify the system. Once all equipment-related problems were solved (there were no issues with the chemistry), the facility was pleased with the system performance.

Facility B has made one equipment modification and one change in the process chemistry. The facility found that propagation improved by running a lower microetch rate. The facility adjusts the microetch daily to 35 to 40 microinches (μin), instead of the 30 to 50 μin given in MacDermid's specification sheet. The facility has also modified the first air knife section. The system had holes in the lid for heat exhaust; however, the carbon solution was blowing off of the boards and out of the holes in the cover. The facility mounted a piece of standard fiberglass door screen to the lid, which let the heat out but kept the carbon in.

As a quick turn-around shop, Facility A deals primarily with engineers. Because of this relationship, the facility did not have any problems obtaining customer acceptance of the new system. The process engineer at Facility A noted that there may be additional hurdles to acceptance for those companies that process a higher volume of boards. Facility B, also a quick turn-around shop, had no problem gaining customer acceptance of the new technology. Facility B invited its major customers (including NASA, the nuclear industry, and the military) to review the data, look at the process, and evaluate the product. These two facilities advise others going through this process to "let your customers tell you what they need to see" and then to supply it.

Comparisons to Electroless Copper

The two facilities interviewed experienced similar benefits of the Blackhole® system over electroless copper. Both saw notable reductions in cycle time ("dramatically reduced" and "significant decrease"). For example, the electroless copper line at Facility B took 1.5 hours to get the first product through after running a load of dummies. After start-up, the line could process approximately 60 panels per hour. Using the Blackhole® system, it takes only six minutes to get the first panel through, dummies are not required, and product can be processed at an average speed of 75 panels per hour.

Although quantitative data are not yet available on changes in board failure rates at either facility, engineers from both facilities have noticed improvements. Facility A noted that the boards are "far superior in terms of hole wall reliability." Facility B has seen increased capability in addition to improved board quality. For example, Facility B's engineer noted that the facility can process smaller holes with the Blackhole® system than with electroless copper. Also, when running electroless, the Facility B operator had to visually scan every panel for problems. Because of the improved quality of the Blackhole® system, this time-consuming step is no longer necessary.

Both facilities made changes to other parts of their process after the Blackhole® line was installed. Facility A has benefited from a more consistent surface than on panels processed with electroless copper. This has enabled the facility to eliminate one of the two acid cleaners from its pre-clean line in the plating process. At Facility B, a downstream change was needed in electrolytic plating operations. When using electroless copper, the facility would start with a low current density and ramp up. With Blackhole®, this facility starts with a high current density for fifteen minutes to get propagation through the hole, and then reduces the density to the lower level. Facility B was able to eliminate the scrubbing process it previously used with the electroless copper line. This has improved the facility's processing efficiency as the panels travel automatically from the Blackhole® line into imaging. It should be noted that the Blackhole® line is a "no-scrub" system; that is, scrubbing is not needed and should not be done after Blackhole® processing.

Although cost was not a primary motivation for installing the Blackhole® system, Facility A estimates that its production cost per square foot has decreased with the new system. The cost savings are the result of reduced chemical and labor costs. The labor savings come from a reduction in the time required for lab testing and maintenance. The electroless system at Facility A required from two to three hours per day of testing and maintenance, compared to two to three hours per *week* for the Blackhole® line. Facility B has seen similar reductions. The facility now spends about thirty minutes daily on lab analysis with the Blackhole® system, instead of over 2.5 hours per day with the old electroless copper system.

The two facilities have also realized cost savings through reduced maintenance requirements. Weekly maintenance tasks include approximately two hours per week for chemistry changes and four hours per week for equipment maintenance such as cleaning rollers and strainers, and inspecting filters, nozzles, and air knives. As part of their system maintenance, the operator at Facility B completes a 10-minute equipment check list and cleans the pinch rollers every morning. Without cleaning, the carbon can get baked onto the pinch rollers over time, so the rollers are removed daily and cleaned with water. MacDermid also stresses the importance of equipment maintenance. The vendor recommends performing preventive maintenance for two to three hours per week, including cleaning the carbon from the rollers and the nozzles twice a week.

Both facilities have also seen improvements in their waste treatment. Facility A has eliminated batch treatment of chelated wastewater at 700 to 800 gallons a month. There was also a "significant simplification" of waste treatment at Facility B. With the electroless copper line, Facility B's wastewater discharge contained 2.5 parts per million (ppm) copper and "it was a job to keep it there." With the Blackhole® system, the only treatment concern is the copper in the microetch, which is less than 1 ppm with less treatment. Facility B also no longer has to treat the manganese, several forms of copper, palladium, and chelated copper that were in the electroless copper wastestream. Total water use at Facility A appears to be about the same for Blackhole® as it was for its electroless system, whereas Facility B has seen a "considerable decrease" in its water use.

Keys to Success

> *"Don't skimp on the equipment...It will end up costing a lot more for a lot less quality."*
>
> *-Facility A*

Both the facilities and the supplier emphasized the importance of quality equipment. The process engineer at Facility A advises other facilities, "Don't skimp on the equipment. You'll end up with a sub-standard system that will require all kinds of on-site modifications. It will end up costing a lot more for a lot less quality." Facility B experienced such a string of on-site modifications. After several difficult months, the engineer at Facility B now considers the system to be a "surprisingly pleasant experience." Having used and removed a palladium system prior to Blackhole®, he advises facilities considering a change to talk to as many current customers as possible and to run some product at a Blackhole® customer's facility. He believes that Blackhole® has significant advantages over palladium processes, including a wider process window and a shorter cycle time. According to the engineer interviewed, Blackhole® may have a wider operating window than electroless.

Facility A also advises that facilities changing to direct metallization need to identify and understand the current and anticipated problems in all parts of their production process. This is because quality problems in other parts of the process can surface when a facility switches to direct metallization. It may be that these problems always existed, but could not be detected until direct metallization was installed. For example, it is important that problems in drilling or desmear operations are corrected prior to installing the Blackhole® process. "Electroless copper can be a band-aid over problems in other parts of the manufacturing process," according to Facility A. His advice is to know where your problems lie and don't be "too quick to point the finger at direct metallization."

MacDermid concurred with these observations, stressing the importance of working with the vendor to evaluate the application before implementing any changes. Most vendors will help a facility to determine if its line is suitable for direct metallization.

For more information on the Blackhole® process, contact Bill Sullivan of MacDermid, Inc. at 203-575-5659.

3. GRAPHITE METHODS

Graphite methods disperse graphite (another form of carbon) onto the substrate surface. Similar to the carbon method, a conditioner solution creates a positive charge on the substrate surface, including the through-holes. Graphite particles are then adsorbed onto the exposed surfaces. In contrast to the amorphous structure of the carbon black crystallites, graphite is a three-dimensional, crystalline polymer. This crystalline structure creates a conductive layer covering both the copper and the nonconductive surfaces of the outside layer and interconnects. A copper microetch removes the unwanted graphite from the copper surfaces, leaving a conductive, graphite layer on the glass and epoxy surfaces in the vias.

A typical graphite process has three or four chemical process steps (cleaner/conditioner, graphite, fixer [optional], and microetch) and one air knife/oven drying step, as shown in Figure 2. The number and location of rinses needed between process steps will vary by facility.

Information is presented on the following graphite methods:

- Graphite 2000™ (Shipley Company)
- Shadow™ (Electrochemicals, Inc.)

Graphite 2000™ (Shipley Company)

Background

The Graphite 2000™ process uses a patented shear pump to keep the graphite suspended in solution. The Graphite 2000™ process is run on conveyorized (horizontal) equipment. Customers

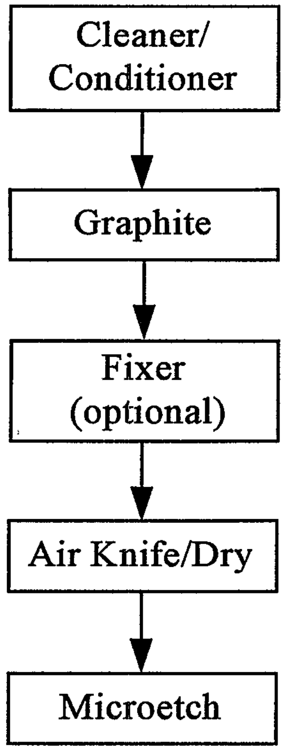

Figure 2. Typical Graphite Process Steps

using this process run predominantly double-sided boards (approximately 65 to 90 percent double-sided and 10 to 35 percent multi-layer). Most of the customers run between 2,000 and 5,000 surface square feet per day. According to the vendor, the Graphite 2000™ system is limited to boards that are 0.125 inches thick or less, holes that are 0.013 inches in diameter or greater, and aspect ratios of 8:1 or less.

Implementation at Specific Facilities

Two facilities (Facilities C and D) that have successfully implemented the Graphite 2000™ process were interviewed for this report. Primary motivations for switching to the Graphite 2000™ system in both cases included the elimination of formaldehyde, hydrazine, and cyanide; reduced operating costs; and improved worker safety. The facilities chose the Graphite 2000™ system for several reasons: the vendor had a strong reputation in the industry, a good relationship had been established with the vendor, and both facilities were beta sites for the technology.

REASONS WHY FACILITIES SWITCHED TO GRAPHITE 2000™

- Elimination of formaldehyde
- Lower operating costs
- Improved worker safety
- Less water consumption
- Reduced cycle time

Facility C was the alpha-beta site; it was the first facility to install the Graphite 2000™ system. Facility C took three months to install and debug the Graphite 2000™ system; Facility D took six weeks. Both facilities installed new equipment from Finishing Services Limited (FSL), one of the vendors recommended by Shipley. To reduce water usage, Facility C installed a chiller to provide a closed-loop cooling system for the conveyorized unit. Facility D modified its equipment by removing the scrubbing unit and adding an anti-tarnish module and a high-pressure (125 pounds per square inch) water blast at the end of the graphite line. According to Shipley, equipment installation requires a week, chemistry evaluation takes another week, and then the system needs a trial month before a facility can go to full production on all substrates and work types.

Experiences with the Graphite 2000™ Process

During debugging, equipment problems outnumbered chemistry problems. For example, Facility C experienced problems with plugged nozzles that caused weak coverage on the board. By replacing the spray manifolds with fluid wedges, the facility improved the coverage and solved the problem. Occasionally, the squeegee rollers do not remove enough water from the board (after the graphite tank) during full production. Daily preventive maintenance helps minimize equipment problems. "Sometimes," reported Facility C, "small holes can be an issue. In these cases, we run the boards through three times." The facility believes that Shipley is improving the process so that smaller hole sizes can be run. Approximately 97 percent of Facility C's customers accepted the new technology immediately; the remaining 3 percent needed more data, testing, and in-house inspections before accepting it. Customers of Facility D had no problems with the new technology.

With its previous electroless copper line, Facility D contracted out its multi-layer production so that the facility would not need a permanganate desmear operation in-house. When Facility D installed its new Graphite 2000™ line, the facility decided to continue to contract out its multi-layer production

Comparisons to Electroless Copper

Facility C spends more time on equipment maintenance for the Graphite 2000™ process than for the electroless copper process, but less time on lab analysis. Facility D has not experienced any major changes in time spent on maintenance or lab analysis. Both facilities report reduced cycle time and water usage with the new system.

Keys to Success

Both the vendor and the manufacturers thought that commitment and dedication at all levels, from management down to the line operators, is vital for the successful implementation of the Graphite 2000™ system. According to Facility D, "The selection of high-quality equipment, and its daily maintenance, are extremely important. Also, management must be patient. It takes four to six weeks to get everything working smoothly." Shipley believes that a company needs to view the Graphite 2000™ process as part of the bigger picture. "Often, changes need to be made upstream or downstream to optimize the graphite process. A company needs a willingness and commitment to change their process and to maintain better control of the process." For example, a facility switching to the Graphite 2000™ process might need to adjust and optimize the process window in the electrolytic plating step downstream from the graphite step.

> *"The selection of high-quality equipment, and its daily maintenance, are extremely important."*
>
> *-Facility D*

For more information on the Graphite 2000™ system, contact Hal Thrasher of Shipley Company at 508-229-7594.

Shadow™ (Electrochemicals, Inc.)

Background

The Shadow™ process uses a patented binder system in the graphite mixture to promote hole wall adhesion and colloid stability. The process also includes a fixer step immediately following the graphite bath; the patented fixer promotes a uniform graphite coating of the hole wall. Almost all Shadow™ systems are conveyorized (horizontal). The Shadow™ process has successfully run multi-layer boards and exotic substrates (e.g., Teflon®, rigid flex). According to the vendor, the limitations of the system are related to the quality of the incoming boards; drilling quality is especially important. According to one facility interviewed (Facility E), boards that are thicker than 0.093 inches are run at a slower conveyor speed, and Teflon® boards go through two passes at the slower conveyor speed.

Implementation at Specific Facilities

Three facilities (Facilities E, F, and G) were interviewed for this report--two that have successfully implemented Shadow™ and one that has switched back to electroless copper. Primary motivations for switching to the new process included the elimination of formaldehyde, reduced cycle time, and decreased water usage. One facility interviewed chose the Shadow™ system because it was the most affordable conveyorized system available at the time (March 1995). A second facility interviewed helped the supplier develop and test the Shadow™ system. Installation of the system took approximately two to five days (not counting delays due to missing equipment parts), and the debugging period ranged from one to two months. All three facilities purchased new, conveyorized (horizontal) equipment for the system.

> **REASONS WHY FACILITIES SWITCHED TO SHADOW™**
>
> - Elimination of formaldehyde
> - Reduced cycle time
> - Less water consumption
> - Affordable for a conveyorized system

Experiences with the Shadow™ Process

All the facilities encountered some problems during debugging and/or full operation, most of which were equipment-related. Facility E now experiences only occasional mechanical problems during full production; "there are always little problems." For example, if one roller is out of place, it creates dragout which could contaminate the other tanks. Another problem occurs when the squeegee rollers sometimes develop hard spots where solids collect. "We are thinking of having a second set of rollers immersed at all times, so that changeover is more efficient," the facility reported. Most equipment problems can be minimized by aggressive preventive maintenance.

During debugging, Facility F found that graphite left on the board surface due to excessive dragout created drying problems. To reduce dragout from the graphite tank, the facility increased the tension of the squeegee rollers. This facility also had graphite build-up at the "knee" of the holes during drying. To solve this problem, the facility installed a bigger blower motor in the dryer to create sufficient air flow through the holes. Facilities E and F have not had any issues with customers accepting the Shadow™ process.

Facility G switched back to electroless copper after running the Shadow™ line for less than one year. During debugging, Facility G switched from a sulfuric peroxide microetch to a sodium persulfate microetch, which increased the copper discharge concentration. In addition, the facility had problems maintaining the agitation needed to keep the graphite in suspension. This resulted in unexpected sludge generation and plugged nozzles. During full production, the facility's customers found that solder joints would fail during circuit board assembly.

According to the vendor, Electrochemicals, Inc., almost all of the companies that have pulled out of the Shadow™ process had problems with equipment. The vendor stated that it is critical for manufacturers to follow the vendor's equipment recommendations.

Comparisons to Electroless Copper

Facility F spent less time maintaining the Shadow™ line than maintaining their previous electroless system, and spent a lot less time on lab analysis. Facility F reduced cycle time from 90 minutes to approximately 10 to 15 minutes, while significantly reducing water consumption. Chelated copper was eliminated from the wastestream, and the copper concentration in the discharged wastewater was reduced.

Keys to Success

Electrochemicals, Inc. emphasizes the importance of quality production practices. "If a facility has quality problems with electroless copper, it will still have those problems with direct metallization." The vendor believes it is important that facilities

> *"If a facility has quality problems with electroless copper, it will still have those problems with direct metallization."*
>
> *-Electrochemicals, Inc.*

follow the vendor's recommendations for equipment purchases. The facilities report that daily chemical analysis, preventive equipment maintenance, and a commitment to eliminating formaldehyde are necessary to successfully implement the Shadow™ process.

For more information on the Shadow™ system, contact John Myers of Electrochemicals, Inc. at 612-479-2008.

4. PALLADIUM METHODS

Palladium systems use palladium particles to catalyze nonconductive surfaces of the through-holes. Palladium particles tend to agglomerate (cluster) unless they are stabilized through the formation of a colloid, which surrounds the individual palladium particles with a protective layer. The two main categories of stabilizers are organic polymer and tin.

Initially, a conditioner solution creates a positive charge on the substrate surface. For organic-polymer/palladium colloids, a predip solution conditions the surfaces of the vias with a polymer film that acts as an adhesion promoter for the colloids. When the substrate is introduced to colloidal suspension, the tin/palladium colloids adsorb onto the slightly charged surfaces, and the organic-polymer/palladium colloids adsorb onto the film-covered through-hole walls. The adsorbed colloidal particles form a nonconductive coating on the through-hole walls. The substrates are then placed in an accelerator solution (for tin) or a postdip solution (for organic polymer) which removes the stabilizers, exposing a conductive layer of palladium particles in the through-holes.

A typical palladium process has six chemical process steps (cleaner/conditioner, microetch, predip, catalyst/conductor, accelerator/postdip, and acid dip), as shown in Figure 3.

Information is presented on the following palladium methods:

Organic-stabilized method:

- Neopact (Atotech U.S.A., Inc.)

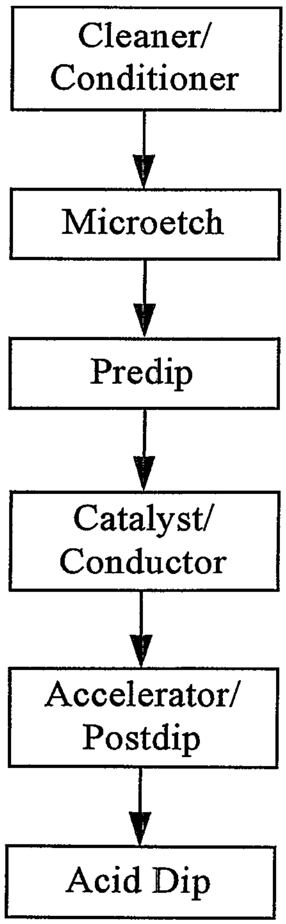

Figure 3. Typical Palladium Process Steps

Tin-stabilized methods:

- Conductron DP (LeaRonal Inc.)
- Crimson 1® (Shipley Company)
- Envision DPS™ (Enthone-OMI, Inc.)
- HN504™ (Solution Technology Systems)

Neopact (Atotech U.S.A., Inc.)

Background

Neopact is an organic-stabilized palladium-based technology available in both non-conveyorized (vertical) and conveyorized (horizontal) configurations. The Neopact system is quite versatile, working on a wide variety of substrates, boards with many layers, and boards with very small holes. Many Neopact customers produce complex boards, typically with ten or more layers. Although electroless copper is likely to be more effective than direct plate for extremely thick boards, the difference in quality is narrowing with experience, according to the vendor, Atotech U.S.A., Inc. Hole diameter sizes of 0.008, 0.010, 0.013 inches, and some as small as 0.006 inches have been through the qualification process. Neopact users work with a wide variety of substrates, including FR-4, Teflon®, polyimide, acrylic flex, non-acrylic flex, and epoxy.

Implementation at Specific Facilities

Two facilities (Facilities H and I) that have successfully implemented the Neopact process were interviewed for this report. Their primary motivations for switching to the new process included the elimination of formaldehyde, lower costs for labor and support materials, and decreased water use.

REASONS WHY A FACILITY SWITCHED TO NEOPACT

- Elimination of formaldehyde
- Reduced labor and material costs
- Decreased water use
- Ability to run a variety of substrates

Facility H chose the Neopact process because it was capable of running the wide variety of substrates that the facility uses. In addition, some systems offered by other vendors utilize a permanganate desmear, which only works on epoxy. The use of permanganate would not have been compatible with Facility H's plasma desmear operation. Facility I switched to the Neopact system in January 1996 after nine months of experiencing problems with voids using a palladium process supplied by a different vendor.

Both facilities used an existing, computer-controlled, non-conveyorized (vertical) rack system for the Neopact process. Installation at Facility H took four days, and there were no unexpected expenses. Facility H's only equipment modification was the addition of a heating and cooling coil to one of the process tanks. This facility first ran a prototype system, which underwent a two-week debugging process followed by eight months of end-user qualification testing. The company had to qualify the new process to meet military qualifications and other customer requirements. At that point, the Neopact system was incorporated into the main production line.

Installation at Facility I took approximately two to three days. During this period, however, the facility discovered additional equipment needs that were not anticipated. These unexpected expenses for line set-up included heating coils on one tank and a flash-plate step to allow for void detection.

The vendor, Atotech U.S.A., Inc., noted that when a Neopact system is installed in a conveyorized (horizontal) configuration, the debugging timeline is much longer due to the complex nature of the installation and start-up of automated equipment. It usually takes three to five months to install and debug the chemistry and equipment. The vendor strongly recommends using its own equipment (sold under the trade name Uniplate) to minimize debugging and control problems.

Experiences with the Neopact Process

In Atotech's experience, "facilities retrofitting existing tanks for the Neopact system usually go through a phase of four to six weeks during which a facility discovers unique qualities of its process that require adjustments" (e.g., analytical frequency, dumping schedules, and interactions with other equipment). This was true for Facility H, although its debugging period was shorter. Other than minor fine-tuning, Facility H did not encounter any problems during debugging.

After the Neopact system was in full production at Facility H, problems began to occur with the oxidation-reduction potential (ORP) controller on the palladium bath. Over time, the controller and probe failed, yet the operator could not immediately detect its failure. The facility eventually replaced the controller and probe with a more reliable one.

In contrast to Facility H, Facility I experienced problems with voids during the debugging process. On the advice of the vendor, the facility solved the problem by adding an extra step to the process (a "wetter" step), which required an additional tank and chemistry. A recycling pump was also added to allow for better circulation of the chemistry through the holes. At Facility I, it took about three months to get the system working properly. With the system fully operation, Facility I periodically experiences voids on all types of boards. When this occurs, the facility works with the local Atotech service representative to adjust the process chemistry. Inner and outer layer separation on multi-layer boards is another problem that occasionally happens, the solution to which the company is still investigating.

According to Atotech, voids have not been a commonly cited problem with the Neopact system. To inspect through-holes for voids, customers use the backlighting technique after flash or panel plating. If the customer pattern plates after direct plating, a backlight test coupon is used along with a microsection of the finished product. It is not possible to perform backlight inspection of the product unless it has been flash-plated. Regardless of the effective methods of inspecting for voids, some PWB manufacturers may have customer specifications (e.g., military) to use the solder float test followed by cross-sectioning. This is the case for Facility H. Neither company had significant problems with customer acceptance, although Facility H noted that some companies may be reluctant to accept the process because it is new.

Comparisons to Electroless Copper

Facility H found that cycle time and labor time required for preventive maintenance on the Neopact system are roughly the same as for electroless copper. However, the labor time necessary for process control has decreased by 50%, and the time spent on lab analysis has also been reduced. In addition, board quality is reported to be superior, and the board failure rate has been halved. Facility H noted no differences in copper discharge, sludge generation, or water usage. However, chelated wastestreams are not generated by the Neopact system.

The switch to the Neopact process at Facility I has resulted in a cycle time 50% faster than for electroless copper. The facility notes no differences in board failure rate and the amount of time spent on maintenance. Some changes in waste treatment have been required as a result of implementing the new process. Palladium-containing wastewater cannot be treated in the facility's resin-based treatment system, so it must be shipped off-site. On the other hand, some process wastes do not require treatment at all before discharge. With regard to environmental impact, Facility I has achieved reduced copper discharge, and savings in water usage, but sludge volume remains unchanged.

Keys to Success

Facility H emphasizes that close support from the supplier during start-up is critical to the success of this technology. PWB manufacturers who choose to implement this technology should request that the vendor supply a technician who has substantial experience setting up the system to work in the facility during the start-up period. Facility

> *Atotech U.S.A., Inc. emphasized that management must support all phases of the implementation, from installation to debugging to full production.*

H attributes its success to a thorough evaluation of the process (e.g., plating distribution, post-separation resistance, chemical usage) prior to full production in order to facilitate customer approval.

For companies to be successful with the Neopact system, Facility I stresses that "training is very important because you are working with very sensitive chemistry." Operators must maintain process baths according to vendor specifications. "You can't stretch it when it's time to change [the chemistry] or else you'll have problems." Facility I also considers flash plating (to facilitate void detection) a necessary step "in order to have 100% confidence" that proper plating in through-holes is achieved.

Atotech emphasized that management needs to make a firm commitment to the alternative technology. Management must support all phases of the implementation, from installation to debugging to full production.

For more information on the Neopact system, contact Mike Boyle of Atotech U.S.A., Inc. at 803-817-3561.

Conductron DP (LeaRonal Inc.)

Background

The Conductron DP process accelerates the tin from the tin/palladium colloid, and at the same time reduces the copper back onto the palladium. The resulting layer of conductive palladium/copper is electroplated with copper. The Conductron process can be run for both non-conveyorized (vertical) systems (Conductron DP) and conveyorized (horizontal) systems (Conductron DP-H). According to the vendor, LeaRonal Inc., there are no substrate limitations, and a maximum aspect ratio of 26:1 has been run on a conveyorized (horizontal) system. Most of the facilities that run the Conductron process produce less than 500,000 surface square feet per year, but some large facilities have successfully installed the system as well.

Implementation at Specific Facilities

Two facilities (Facilities J and K) that have successfully implemented the Conductron system were interviewed for this report. Primary motivations for switching to the new process included lower operating costs, reduced water use, quicker throughput, increased worker safety, and ease of waste treatment. One facility chose LeaRonal's Conductron system because the vendor had a lot of experience in the industry, the initial test results for Conductron were better than those for carbon and graphite systems, and the palladium technology is similar to that of electroless copper, making it easier to sell to customers.

> **REASONS WHY FACILITIES SWITCHED TO CONDUCTRON DP**
>
> - Lower operating costs
> - Less water use
> - Quicker throughput
> - Increased worker safety
> - Ease of waste treatment

Installation and debugging of the non-conveyorized (vertical) system at Facility J took approximately six months. Facility J did not purchase any new equipment and had no unexpected expenses during this time. Other facilities, according to LeaRonal, had typical equipment issues with the conveyorized systems during debugging. "With these complex systems, there is bound to be a problem with pumps, wiring, etc." Also, tap water contaminated baths at some facilities. In these cases, the facilities switched to deionized water.

Experiences with the Conductron Process

Facility J stated that "any printed wiring board manufacturer will experience intermittent problems" with plating through-holes. During full operation, the facility occasionally experiences variations in bath temperatures and contaminated chemistries caused by human error. The facility encounters about the same number of problems as it did with the previous electroless copper line. One customer--a military account--decided to take its business elsewhere, because it wanted a technology backed by many years of test data on performance. Nevertheless, Facility J meets military qualifications and can run Teflon®, FR-4, and polyimide substrates.

Facility K primarily uses an electroless copper line, but recently installed a conveyorized (horizontal) Conductron DP-H line to help with smaller orders that require quick turn-around time (e.g., prototype boards). The facility encountered some problems during debugging and testing of the Conductron line. There was excess dragout due to the squeegee rollers. This was solved by resurfacing the rollers. While there was no problem with epoxy coverage, there was inconsistent coverage for glass surfaces in the through-holes. Tin was also oxidizing out because of poor machine design. The equipment would aerate the solution, resulting in tin precipitating out. There were also problems with liquid level controls. To solve these problems, Facility K is planning to install a new conveyorized Conductron system. The new Conductron line is not meant to replace the existing electroless line.

Comparisons to Electroless Copper

Facility J spends more operator time on bath maintenance and lab analysis with the Conductron system than it did with electroless copper, while Facility K predicts its new system will need less time for analysis and chemistry bath maintenance. Facility J's Conductron line has a cycle time that is 60 to 75 percent faster than the previous electroless line; Facility K predicts the Conductron line's cycle time will be approximately 65 percent faster than electroless copper. The Conductron systems at both facilities generate less sludge and less copper waste.

Keys to Success

Facility J believes it is very important to have excellent, well-established vendor support to successfully implement a new direct metallization system. The facility believes that LeaRonal has provided good technical support and is "very knowledgeable about the chemistry." Also, the facility emphasized the need for line operators who are willing to learn about the new technology. Facility K stated that the equipment is very important, and that

Facility J believes it is very important to have excellent, well-established vendor support to successfully implement a new direct metallization system.

the vendor's equipment recommendations should be followed. The Conductron system, according to both facilities, is "not as forgiving as electroless copper and requires more operator attention."

For more information on the Conductron DP system, contact David Schram of LeaRonal Inc. at 516-868-8800.

Crimson 1® (Shipley Company)

Background

The Crimson 1® system is a tin-stabilized palladium process. Crimson 1® differs from other tin-stabilized palladium processes in that it uses a sulfide step to stabilize the surface of the accelerated substrate. After the sulfidization of the palladium sites, some sulfide adsorbs to the exposed copper of the inner layers. This coating tints the boards a crimson color (and thus gives the technology its name). A microetch step then removes the adsorbed sulfide from the interconnects. The final step of the process, a high-pressure water rinse, removes any remaining microetch from the board surface.

According to Shipley, 30 of 70 Crimson 1® facilities use a conveyorized (horizontal) configuration. In a non-conveyorized (vertical) orientation, Shipley recommends that only double-sided boards be processed, but a conveyorized (horizontal) system can process both multi-layer and double-sided boards. This difference is due to the difference in the fluid dynamics. In a horizontal (conveyorized) system, there is more control of the flow of the solution going through the holes. This increased control is important in successfully running multi-layer boards. Most new systems are conveyorized (horizontal) lines, according to the vendor, "now that more shops are doing multi-layers." The typical Crimson 1® customer manufactures 60 percent multi-layered boards in volumes that range from 500 to 2,000 panels per day, with hole diameters of 0.008 inches and larger. The vendor notes, however, that 20 of these facilities process many more per day (for example, one processes 40,000 square feet per day of primarily double-sided boards, while another handles 30,000 square feet per day, 90 percent of which are multi-layer). According to the vendor, the current standard product mixes are being used successfully with the Crimson 1® process, customers are successfully running exotic substrates through the system, and, in some cases, aspect ratios as high as 20:1 have been plated successfully.

Implementation at Specific Facilities

Three facilities (Facilities L, M, and N) that have successfully implemented the Crimson 1® process were interviewed. All three facilities run the process horizontally, with production volumes ranging from 1.44 to 9.6 million surface square feet per year. Their primary motives for switching to Crimson 1® from electroless copper were decreases in chemistry costs, cycle time, water consumption, maintenance, and waste treatment costs, as well as improved worker health and safety. Debugging required the longest time at Facility M, the first U.S. manufacturer to use the Crimson 1® process for multi-layer boards. This line, which was installed in the summer of 1993, took one month for physical installation and nine months for debugging. Facility L also installed its line that year, taking six months due to the large size of the line. Debugging required four months. Facility N installed its Crimson 1® line in only two weeks in June 1996, with debugging requiring three months.

REASONS WHY FACILITIES SWITCHED TO CRIMSON 1®

- Decreased chemistry costs
- Faster cycle time
- Less water consumption
- Lower waste treatment costs
- Improved worker health and safety

All three facilities had researched or experimented with other technologies before adopting the Crimson 1® process. One facility experimented with carbon technology, and another facility experimented with graphite technology, but both experienced defect problems and overall process sensitivity. With the Crimson 1® system, however, one facility said "we couldn't get it to fail." Another facility remarked that "the Crimson process appeared to be more robust than other direct metallization systems." The third facility selected Crimson 1® based on its own research on the costs and voiding frequencies of alternative technologies.

Experiences with the Crimson 1® Process

Since Facility M's original persulfate microetch also etched the palladium, the facility switched to a peroxide microetch. This change necessitated other downstream process changes. First, different waste treatment chemicals were needed due to peroxide gassing; they now use sodium metabisulfite to help suppress gas formation. Also, the sodium peroxide evaporated and needed refreshing if the Crimson system was not in use. Lastly, Facility M noted that the sulfide waste from the Crimson 1® process requires special handling--the waste should be added directly to the batch treater to obviate hydrogen sulfide formation. The other two facilities interviewed also made adjustments to the process once it was operational.

All facilities experienced some minor process defects. Facility M reported negative etchback with Crimson 1® that was "noticeable" but within customer tolerances. This facility noted that military or three-point connections (and thus military-specification boards) are not a possibility due to etchback. Facility N experienced slight hole-wall separation. Facility L found that microetch must be maintained within proper limits to insure consistent film removal. In addition, Facility L found that a board scrubber was necessary to remove a thin film layer from the board surface before sending boards to the lamination room. According to Facility N, Shipley now recommends board scrubbing to manufacturers installing their lines.

Facility N had some conveyor jamming problems when running thin-core materials (e.g., 0.006 inches). Jams would occur when improperly adjusted water pressures knocked panels out of clips. These problems were eliminated after spray pressures were adjusted and stronger clips were added.

Manufacturers did not report major hole size or board thickness limitations with the Crimson 1® technology. Facility N experienced some failures with hole diameters of 0.008 inches, but solved the problem by experimenting with operating parameters. Newer versions of the Crimson 1® system have improved filtration and spray bar configurations, according to Facility M. A Florida facility with a Crimson 1® line is reportedly plating hole diameters as small as 0.008 inches and up to a 12:1 aspect ratio on "every material you can think of." According to Facility M, "Crimson 1® can do everything, once properly configured."

Comparisons to Electroless Copper

All three facilities increased production throughput with the Crimson 1® system. Facility M switched from a "typical electroless dip-and-dunk batch system" to the conveyorized (horizontal) Crimson 1® process and saw large throughput increases. Facilities L and N doubled and tripled their productivity by switching from electroless copper to the Crimson 1® system.

Manufacturers saw void frequency either decrease or stay the same. For Facility M, the Crimson 1® process "reduced voids by 90 percent, at least." The manufacturer at Facility M "used to tilt boards, bang them, vibrate them, but still had a problem with voids" due to hydrogen bubbles in the holes of the vertically-hanging boards. Facility N noted that the "failure rate is one-third of electroless" and "more a function of drilling and drill debris than a failure of Crimson."

Time required for lab analysis decreased at all facilities. Facility M now conducts one analysis a shift (eight hours) instead of once an hour. Facilities L and M report that continuous monitoring is now not necessary and fewer parameters need to be analyzed overall.

Changes in maintenance requirements varied by facility. Facility M noted "We used to have to use a colorimeter to calibrate baths and pumps and were constantly fighting the metering pumps, but now we don't have to worry about it at all." Facilities M and N caution that "there is a lot of preventive maintenance on the [Crimson 1®] line because it is so complicated." At Facility N, time spent on maintenance increased because of an extensive preventive maintenance schedule.

Facilities M and N saw water usage decrease. Facility M's water usage with the electroless system was 10 to 14 gallons per minute. Water use is 3 to 4 gallons per minute with Crimson 1® because the "rinsing tanks on the Crimson line have a far lower rating than the electroless." Facility L did not track water usage.

For Facility M, the switch from electroless copper to the Crimson 1® process did not appreciably change the concentration of copper in facility wastewater or the amount of sludge generated. However, Facility N saw a decrease in both. Facility L did not know if these factors had changed. All facilities reported lower air emissions (such as formaldehyde).

All three facilities reporting saving money with the Crimson 1® system. Facility N reported saving 50 to 60 percent overall compared to the costs of an electroless system. Facility M stated that the Crimson 1® process itself cost the same as electroless, but savings were possible in other areas such waste treatment, chemical maintenance, and lab analysis. This facility reported saving at least 30 percent overall. Facility L reported saving roughly 50 percent on chemical costs, but did not track other cost changes.

Keys to Success

Preventive maintenance is crucial to the success of a Crimson 1® line, according to all three manufacturers and the vendor. Facility M recommended paying special attention to keeping the fluid delivery systems free of clogs and debris. Other issues included profiling thin-core transport through the system and avoiding variations in water pressure (which can burn out pumps).

> *"You need to look at how the manufacturing process overall will change. A total process mentality is crucial."*
>
> *-Shipley Company*

Facilities and the vendor also recommended re-evaluating the entire process when adopting the

Crimson 1® system. According to the vendor, "you can't just drop out electroless out and drop in 'Crimson.' You need to look at how the manufacturing process overall will change. A total process mentality is crucial."

For more information on the Crimson 1® system, contact Hal Thrasher of Shipley Company at 508-229-7594.

Envision DPS™ (Enthone-OMI, Inc.)

Background

The Envision DPS™ method deposits a palladium-tin colloid on the hole during the activation step. A highly alkaline (pH of >12) copper-containing solution at an elevated temperature is used to substitute copper for tin through disproportionation (US patent 5,376,248). Electroplating takes place on the resulting palladium-tin-copper film.

According to the vendor, Enthone-OMI Inc., all but one of the 25 manufacturers using the Envision DPS™ operate it vertically, many in existing electroless copper equipment. Envision DPS™ customers process a variety of board types and dielectric materials ranging from double-sided FR-4 material to multi-layers, Teflon® and high T_g dielectrics.

Hole diameters of 0.018 inches in multi-layers which are 0.125 inches thick are successfully processed using non-conveyorized (vertical) process configuration. The operation of the Envision DPS™ process in conveyorized (horizontal) configuration improves solution exchange and increases the operating window. Smaller hole sizes and thicker boards are possible.

Implementation at Specific Facilities

Three facilities (Facilities O, P, and Q) that have successfully implemented the Envision DPS™ process were interviewed for this report. Their motivating factors for switching to the process from electroless copper were environmental compliance, decreased waste treatment and disposal costs, improved throughput, and decreased use of toxic chemicals (e.g., formaldehyde and cyanide).

REASONS WHY FACILITIES SWITCHED TO ENVISION DPS™

- Decreased waste treatment
- Better hole wall integrity
- Increased throughput
- Less use of toxic chemicals
- Compatible with electroless equipment

Facilities O and Q explored carbon and graphite technologies (one facility tested them side-by-side) before adopting the Envision DPS™ system. These facilities mentioned wider operating parameters and improved hole wall integrity as the primary reasons they chose Envision DPS™.

Facility Q also explored a different palladium system, but was discouraged by the up-front investment required to implement the technology.

Installation and debug time ranged from one day for the retrofit of an old line to one month for installation of an entirely new line. All three facilities use the non-conveyorized (vertical) process for all of their board production. Facility Q noted that the Envision DPS™ line was "very compatible" with the old electroless tanks, line set-up, and process. All three manufacturers reported that existing tanks from an electroless copper line were used to some degree, minimizing the need for new equipment purchases and extensive operator training. Additional expenses for line set-up were minor, including an extra filter pump in the catalyst bath, multi-meters, heating element adjustments, and modified pump capabilities.

Experiences with the Envision DPS™ Process

All three facilities encountered minor problems during debugging. At Facility O, hole wall adhesion problems on double sided PWBs were traced back to the drilling step. This manufacturer changed drilling parameters[1] and installed a water blast in their deburring operation to remove loose hole debris. This resulted in improved hole wall quality and eliminated hole wall adhesion failures.

Facility P noted that very large hole sizes tended to void slightly more often than would be expected with an electroless bath. These voids were not seen as a function of poor bath chemistry, but, according to the manufacturer, may have been a result of smears from the drilling process. Manufacturers did not encounter other hole size, board type, or board thickness limitations for Envision DPS™.

Reworked Envision DPS™ panels needed to be treated with slightly more care than reworked electroless panels at Facility Q. When the stripper bath was used to remove dry film, the bath also occasionally removed the palladium from the holes. The manufacturer reran the panels when this occurred.

The vendor cautioned that the alkaline nature of some of the steps in the Envision DPS™ process may cause problems with alkaline-sensitive adhesives. These issues are similar to those that facilities may experience with electroless copper, but with more pronounced adhesive swelling. According to the vendor, adhesive swelling issues are not a problem in the conveyorized (horizontal) mode due to reduced contact time with the alkaline solutions.

[1]This manufacturer changed drill bits, cut the number of hits per drill bit from 2,500 to 1,000, and switched from four panel to three panel stacks.

Comparisons to Electroless Copper

All three manufacturers found the Envision DPS™ system more cost-effective than the electroless system they had used previously. They reported spending less time on maintenance and lab analysis while reducing overall cycle time. When asked to compare Envision DPS™ to electroless copper, Facility Q stated: "I know I'm going to save a considerable amount of money." Facility P, noting significant savings in labor and waste treatment costs, called the technology "very cost-effective." The Envision DPS™ system also simplified waste treatment for all three manufacturers. The facilities reported reductions in sludge generation and copper discharge, although overall usage remained constant. Since chelating agents are not used, chelated copper does not enter the wastestream.

Keys to Success

Each of the manufacturers offered advice for the successful implementation of Envision DPS™. Facility O stressed the importance of drilling quality and consistent copper deposition during plating. Facility Q emphasized line control, lab analysis, and operator training as the most important components of success. Facility P noted that the DPS system is slightly more sensitive than electroless to dirty rinse water and to temperature. This facility found it needed to keep rinses cleaner and to monitor temperature more closely than it had with electroless.

> *Facility Q emphasized that line control, lab analysis, and operator training are the most important components of success.*

For more information on the Envision DPS™ system, contact Kathy Nargi-Toth of Enthone-OMI, Inc. at 203-932-8635.

HN504™ (Solution Technology Systems)

Background

Solution Technology Systems's HN504™ patented process uses vanillin in the formation of its tin-palladium colloid. Since the vanillin will attach to most surfaces except the surface of other vanillin molecules, the vanillin on the surface of the colloids prevents them from agglomerating. The vanillin also promotes colloid adsorption on the substrate surface, resulting in a conductive layer of palladium. Subsequent treatment in an alkaline accelerator containing copper ions forms a palladium-copper complex with greatly enhanced plating potential.

The HN504™ method can be run as either a non-conveyorized (vertical) or conveyorized (horizontal) system. Approximately 70 percent of the customers using this process run multi-layer boards to some extent. According to the vendor, the HN504™ process has plated hole diameters as small as 0.001 inches, has run an aspect ratio as high as 21:1, and has successfully processed Teflon®, polyimide, and FR-4 substrates. At one facility interviewed, Teflon® and certain types of polyimide were processed twice to ensure complete void-free coverage.

Implementation at Specific Facilities

Two facilities (Facilities R and S) that have successfully implemented the HN504™ process were interviewed for this report. Their primary motivations for switching to the new process included the elimination of formaldehyde from the process, waste treatment simplification, and the relatively low cost of the new system. Facility R had originally implemented a palladium system licensed from Solution Technology Systems. After running the system for one year and encountering some stability problems with the bath chemistries, the facility decided to "go to the

> **REASONS WHY FACILITIES SWITCHED TO HN504™**
>
> - Elimination of formaldehyde
> - Ease of waste treatment
> - Relatively low system cost
> - Ease of conversion

source" of the technology and implemented the HN504™ system. This facility had already tried a carbon system and is currently researching and testing a graphite system to complement the existing HN504™ line. Facility S chose the HN504™ system because of the system's ease of conversion and competitive price. At the time of installation (1990), Facility S believed that the HN504™ process required the fewest equipment changes when converting from an electroless copper line.

Both facilities took one to two days to install the non-conveyorized (vertical) process, with debugging taking up to six months before the system was put into full production. Existing tanks from an electroless copper line were used, which minimized the new equipment purchases required. Heaters, pumps, and filters were installed in the conditioner and accelerator tanks. Also, the conditioner tank needed a stainless steel liner, and the catalyst tank required a water jacket for indirect heating. One facility had unexpected expenses: an electrolytic regeneration unit was needed for the permanganate desmear bath to better control the buildup of manganese, and a dryer was added at the end of the line to ensure that the boards were completely dry. Solution Technology Systems also mentioned that rack agitation and a liner in the accelerator tank to prevent acid leaching from the tank walls may be required at some facilities.

Experiences with the HN504™ Process

Neither facility encountered any problems during debugging, and both thought that the process was very simple. There have been no customer acceptance issues for either facility. Solution Technology Systems stated that some subtle problems can be encountered with the HN504™ process. For example, adding too much conditioner can result in hole wall pull-away. Currently, one facility occasionally observes "smutting" -- an oxide film on the surface of the board -- after the flash-plate as a result of poor rinsing.

Comparisons to Electroless Copper

Both facilities noted that they spend a lot less time on lab analysis compared to electroless copper, since the baths are easier to analyze and need much less attention. In addition, they found that their board failure rates were much lower with the HN504™ process. After switching to the HN504™ process, both facilities simplified their waste treatment because there was much less copper and no chelated wastestreams. Also, both facilities reported a decrease in sludge generation and a slight decrease in water usage with the HN504™ process.

Keys to Success

Both the facilities and the vendor stressed the importance of training for successful use of the HN504™ system. The supplier stated that operators need to have the desire and willingness to make the new system work. Both facilities feel that educating operators is very important. They should understand the lab analyses and know what to look for to keep the system operating properly. The facilities also emphasized that operators need to maintain the baths to vendor specifications. The manufacturers noted that this system is fairly simple and does not require special equipment.

> *Both the facilities and Solution Technology Systems stressed the importance of training for successful use of the HN504™ system.*

For more information on the HN504™ system, contact Eric Harnden of Solution Technology Systems at 909-193-9493 .

5. Conductive Polymer Method

This process deposits a conductive polymer layer on the substrate surface of the via. A cleaner/conditioner step coats the glass and epoxy surfaces in the through-holes with a water-soluble organic film. A permanganate catalyst solution then deposits manganese dioxide (MnO_2) on the organic film (through oxidation). This only occurs on the film-coated glass and epoxy surfaces. Polymerization takes place when a conductive polymer solution containing the pyrrole monomer is applied to the surfaces coated with MnO_2. The polymerization continues until all of the MnO_2 oxidant is consumed, resulting in a layer of conductive polymer (polypyrrole) that coats the through-holes. The through-holes are then flash-plated with copper.

A typical conductive polymer process has six chemical process steps (microetch, cleaner/ conditioner, catalyst, conductive polymer, microetch, and copper flash-plate), as shown in Figure 4.

Information is presented on the following conductive polymer method:

- Compact CP (Atotech U.S.A., Inc.)

Compact CP (Atotech U.S.A., Inc.)

Background

The Compact CP process was introduced in 1988 and is used primarily in Europe. Eleven units are currently in full production, but only one unit, which is still in its trial phase, has been installed in the U.S. Compact CP is available only as a conveyorized (horizontal) plating unit. The volatility of the conductive polymer precludes its use in an open system, because it would deposit a black coating on the surrounding area. Facilities using Compact CP typically produce high

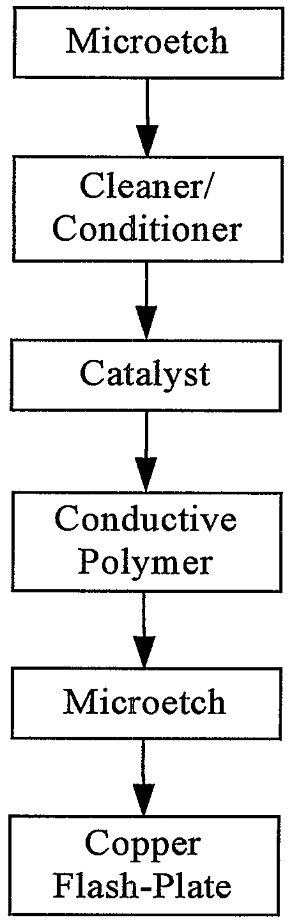

Figure 4. Typical Conductive Polymer Process Steps

volumes of FR-4 boards with four, six, or eight layers for the consumer electronic and communications industries. According to Atotech, "the buyers of these boards are demanding about product quality, have high technology demands, and typically require small holes." Companies that purchase or evaluate Compact CP are usually looking for a fully integrated system that can handle higher technology demands.

No limitations have been identified in terms of number of layers or hole size. The substrates, however, are limited to those that react well with permanganate. FR-4 is best suited for the Compact CP process. Polyimide also works but is not commonly used. Teflon® does not work with this technology.

Implementation at Specific Facilities

One facility (Facility T) that is experiencing success during the trial phase of implementing Compact CP was interviewed for this report. According to the Vice President of Process and Quality Control, the facility was motivated to make a switch to direct metallization because the company "looked at where the industry was going in the next five years or so, and it was not electroless." The company wanted a conveyorized (horizontal) process line to reduce handling and cycle time. The company anticipated spending less money on waste treatment with the Compact CP system. In addition, the company was concerned that the colloidal dispersions utilized in graphite and palladium systems would not move well through the holes. The company felt that a conductive polymer method would work well with 0.010 inch drilled (0.006 to 0.007 inch finished) holes. Atotech U.S.A., Inc. provided the advantage of supplying the chemistry and equipment as a package. Atotech is the only supplier in the U.S. offering a complete system.

REASONS WHY A FACILITY SWITCHED TO COMPACT CP

- Faster cycle time
- Less handling
- Lower waste treatment costs
- Works well with small holes
- Chemistry and equipment are available as a package

Facility T recently opened a new facility and installed the Compact CP process in a fully automated, conveyorized (horizontal) configuration. Acid copper plating is done in-line with Compact CP using an equipment package developed and sold by Atotech under the trade name Uniplate. An Atotech employee from Germany worked on-site full-time for six weeks to assist with the start-up phase. Installation took nearly three months to complete. At the time of the interview, the system had been running for approximately two months. Currently, the majority of boards running through the system are double-sided, but it is anticipated that this proportion will change primarily to four, six, and eight-layer boards over the next six months.

Experiences with the Compact CP Process

In the vendor's experience, integrating equipment, especially equipment from different suppliers, in an automated line with the conveyorized (horizontal) Compact CP system is often the greatest challenge during the debugging process. In general, it often takes three to five months to get the system running at desired levels. Autoloaders bringing boards into the system from deburring and unloaders moving boards to in-line copper plating are computer-controlled, and it can be a time-consuming process to integrate these positioners into the system.

Facility T experienced minor problems during installation of the system. One problem the facility faced after start-up was the sensitivity of the system's ventilation. Vapor from one tank was mixing with vapor from another tank within the enclosed unit. Engineers had to alter the air balance within the system by changing the belts on the blower on the roof to reduce air flow in the entire building. The facility also had to add and re-route plumbing, which had not been anticipated. In addition, the facility thought rinse water after the cleaning step would not require treatment for metals, but it did.

Comparisons to Electroless Copper

There is no direct basis of comparison to a previous system because the Compact CP system was installed at a new facility. The following comparisons between electroless copper and Compact CP were made based on experience at a sister facility employing electroless copper. The amount of time spent on preventive maintenance with Compact CP is a little more demanding because of additional cleaning requirements and other tasks such as changing filter cartridges. The process engineer at Facility T commented that "working with permanganate tends to be pretty messy. We have to be very conscious of cleanliness." Less time is spent on lab analysis and bath maintenance because tank pump-outs, chemical additions, and most other bath maintenance tasks are automated. Some analysis continues to be done manually for verification.

It is too early for Facility T to tell if there is a change in board failure rates, but they stated that "there is no indication that defect rates are any higher (with the new system)." The cycle time is about two-thirds faster than for the electroless line at the other facility. Whereas it takes two hours for the electroless line alone at the other facility, the new system takes only sixty minutes from deburring through electroplating. Water usage is greatly reduced with Compact CP. At the other facility water is used at a rate of 30 gallons per minute (gpm). For the same level of production, the new facility uses just 8 to 10 gpm. Facility T has not tracked copper discharge from the Compact CP line, but it plans to do this in the near future. Overall, Facility T feels that Compact CP will be very cost-effective, but it does not yet have adequate cost data to draw definitive conclusions.

Keys to Success

"Getting customer buy-in" is key to successfully implementing the Compact CP system, according to Facility T. A company considering using this system also "needs workers to commit to being on the line for installation, start-up, and debugging to understand changes that have been made along the way." This is essential because it is not possible to simply hire someone with experience setting up this system; conductive

> *"[A company] needs workers to commit to being on the line for installation, start-up, and debugging to understand changes that have been made along the way."*
>
> *-Facility T*

polymer technology is new in the U.S., and the learning curve is considerable. Facility T recommends that other PWB manufacturers implementing the system "take time to become familiar with the process, and take care of mechanical issues before running product at full production level." Finally, start-up each day is a complex process, so a facility needs to run enough product to make it cost-effective. For Facility T, the system "runs a lot better at 400 panels a day than 100."

Atotech stressed that management needs to make a firm decision and commit to switching to the alternative technology. Management must support all phases of the implementation, from installation to debugging to full production. Also, a substrate type appropriate for the Compact CP system must be used.

For more information on the Compact CP system, contact Mike Boyle of Atotech U.S.A., Inc. at 803-817-3561.

6. OTHER ALTERNATIVE TECHNOLOGIES

Two additional alternative technologies for making holes conductive were evaluated in the overall DfE project's *Cleaner Technologies Substitutes Assessment*. These were the non-formaldehyde electroless copper process and the conductive ink process. The non-formaldehyde process is currently in use at two facilities, one in the U.S. and one in Singapore, but neither facility was available for an interview. The conductive ink process is currently in the developmental phase for multi-layer applications.

7. Lessons Learned

No matter what the technology, some common suggestions emerged from company and vendor experience for successfully implementing an alternative MHC technology:

- Many facilities and vendors stressed the importance of high-quality equipment for conveyorized (horizontal) systems.

- Since there can be major differences between direct metallization and electroless copper processes, line operators need to be willing to accept changes and retraining.

- Some vendors and manufacturers emphasized that facilities should take a "whole-process" view of the MHC technology installation. Process changes upstream and/or downstream may be necessary to optimize the alternative MHC process.

- Perhaps the most important factor in successfully implementing an alternative technology is a strong commitment from management and line operators to the new technology.

As shown in the CTSA and in these facilities' experiences, alternative technologies are successfully "making holes conductive." According to the manufacturers interviewed for this report, alternative technologies offer benefits, but facilities may first have to overcome the problems encountered during installation.[2] After installing these systems, the most successful facilities improved their production efficiency and their worker safety, while decreasing environmental impacts. Hopefully, the experiences of these manufacturers will help others considering a switch to an alternative MHC technology.

[2] For a description of the experiences of PWB manufacturers in northern California with direct metallization, see the report, *Direct Metallization Report*, completed by the City of San José's Environmental Services Department. For a copy, contact John Mukhar at 408-945-3036.

Appendix A. Facility Information

Facility	Surface square feet produced annually	Types of PWBs produced	Highest aspect ratio normally run	Conveyorized or non-conveyorized system
Carbon Method: Blackhole® (MacDermid, Inc.)				
Facility A	750,000 ssf/yr	15% double-sided 85% multi-layer	8:1	conveyorized
Facility B	420,000 ssf/yr	30% double-sided 70% multi-layer	10:1	conveyorized
Graphite Method: Graphite 2000™ (Shipley Company)				
Facility C	1,000,000 ssf/yr	65% double-sided 35% multi-layer	8:1	conveyorized
Facility D	600,000 ssf/yr	2% single-sided 70% double-sided 27% multi-layer 1% flex	3:1	conveyorized
Graphite Method: Shadow™ (Electrochemicals, Inc.)				
Facility E	350,000 ssf/yr	70-75% double-sided 25-30% multi-layer	12:1	conveyorized
Facility F	800,000 ssf/yr	10-15% double-sided 85-90% multi-layer	8:1	conveyorized
Facility G	360,000 ssf/yr	70% double-sided 30% multi-layer		see below[a]

[a] Facility G switched from the Shadow™ process back to electroless copper.

Facility	Surface square feet produced annually	Types of PWBs produced	Highest aspect ratio normally run	Conveyorized or non-conveyorized system
Palladium Method: Neopact (Atotech U.S.A., Inc.)				
Facility H	26,000 ssf/yr	70% multi-layer 10% flex 10% rigid flex 10% microwave (Teflon®)	9:1	non-conveyorized
Facility I	250,000 ssf/yr	40% single-sided 40% double-sided 20% multi-layer		non-conveyorized
Palladium Method: Conductron DP (LeaRonal Inc.)				
Facility J	520,000 ssf/yr	5% double-sided 95% multi-layer	9:1	non-conveyorized
Facility K	700,000 ssf/yr	99.9% multi-layer	10:1	conveyorized[b]
[b] Facility K is currently running electroless copper while installing a new Conductron DP-H line.				
Palladium Method: Crimson 1® (Shipley Company)				
Facility L	9,600,000 ssf/yr	30% single-sided 60% double-sided 10% multi-layer	6:1	conveyorized
Facility M	1,500,000 ssf/yr	25% single-sided 75% double-sided	6:1	conveyorized
Facility N	1,440,000 ssf/yr	33% multi-layer 33% double blind via 33% PCMCIA	6:1	conveyorized

Facility	Surface square feet produced annually	Types of PWBs produced	Highest aspect ratio normally run	Conveyorized or non-conveyorized system
Palladium Method: Envision DPS™ (Enthone-OMI, Inc.)				
Facility O	600,000 ssf/yr	10% single-sided 70% double-sided 20% multi-layer	4:1	non-conveyorized
Facility P	250,000 ssf/yr	5% single-sided 80% double-sided 15% multi-layer		non-conveyorized
Facility Q	240,000 ssf/yr	20% double-sided 80% multi-layer	7:1	non-conveyorized
Palladium Method: HN504™ (Solution Technology Systems)				
Facility R	36,000 ssf/yr	10% double-sided 90% multi-layer	11:1	non-conveyorized
Facility S	300,000 ssf/yr	5% single-sided 35% double-sided 60% multi-layer	7:1	non-conveyorized
Conductive Polymer Method: Compact CP (Atotech U.S.A., Inc.)				
Facility T	960,000 ssf/yr[c]	80% double-sided[d] 20% multi-layer	5.5:1[e]	conveyorized

[c]Facility T's projected production.
[d]Facility T predicts a transition to 30-40% double-sided, 60-70% multi-layer.
[e]Facility T predicts an increase to a 7:1 aspect ratio.