Introducing The OSP Process as an Alternative to Hasl

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Abstract

Organic Solderability Preservatives (OSPs), also known as anti-tarnish, on bare copper printed circuit boards (PCBs) are becoming more prevalent in the electronics industry as the low-cost replacement to Hot Air Solder Leveling (HASL). Introducing the anti-tarnish alternative into the customer sites requires working closely with the coating supplier, assembler, and Original Equipment Manufacturer (OEM) to gain a mutual understanding of respective processing concerns and finished product requirements.

An operational cost comparison was completed at Merix Corporation (formerly Tektronix Circuit Board Division) detailing the annual expenses associated with the HASL process versus an in-line anti-tarnish organic protective coating line. The results of this study revealed that the OSP process is approximately one-third the cost of the HASL process. An implementation plan, designed jointly by the board shop and assembly customers, was used for the selection of the OSP chemistry supplier and introduction of the bare copper process into multiple customer sites.

Presented will be a PCB fabrication cost comparison of HASL versus OSP, a method of introducing the technology and products into the customer site, and managing the conversion through information sharing. The presented OSP technology is based on the newly introduced substituted benzimidazole-based compounds.

Background

Printed circuit boards requiring component attachment, whether leaded or surface mount technology (SMT), must have the exposed copper land areas coated with a protective finish. This protective coating must be solderable and, at the same time, act as a barrier for preventing the copper from oxidizing which causes assembly problems for the end user. In the United States, the predominant surface finish in the PCB industry is HASL. Driven by the push for Solder Mask Over Bare Copper (SMOBC), HASL was born as a reliable method to apply solder to the copper surfaces after solder mask. A thin layer of eutectic solder is deposited onto the exposed copper by passing the boards through a hot, molten wave (or pot) of solder and subsequently blasting the excess solder from the boards using high velocity hot air. This process is currently under scrutiny due to environmental and safety issues (hazardous waste/lead exposure), technological limitations (fine-pitch device assembly), and equipment maintenance expenses to name a few.

In contrast, the OSP process is environmentally friendly, provides a surface planarity equivalent to the plated copper finish, and requires very low equipment maintenance. Whereas HASL occurs in the panel form (i.e., prior to the boards being excised), the OSP coating is typically applied after rout and test. In terms of processing sequence, however, both technologies share many of the same steps (figure 1).

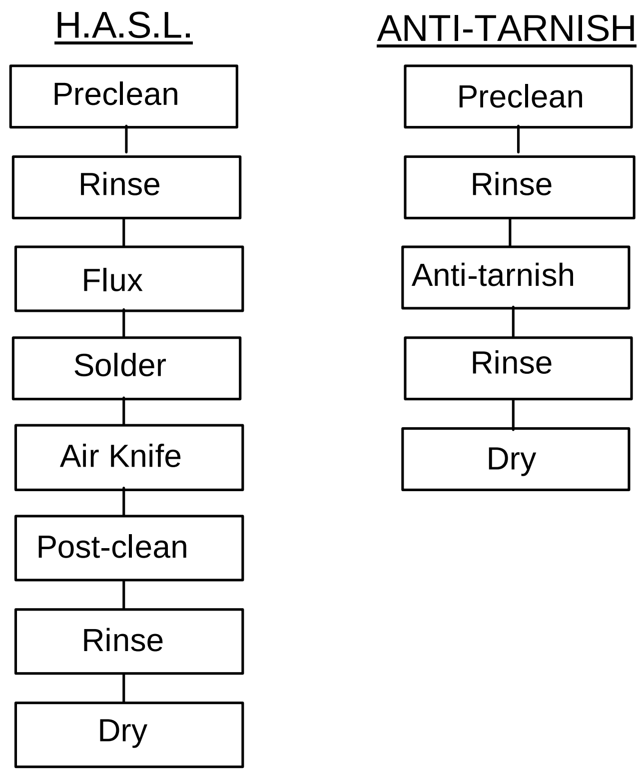

FIGURE 1 Process Flows

The PCB industry, as represented by the October Project[1], has been active in seeking alternative surface finish options to HASL. The October Project Topology Committee has been exploring the use of anti-tarnish as it is the only viable non-metallic surface finish option available. The bare copper process was evaluated by the committee, whose membership includes PCB suppliers, manufacturers, assemblers, and OEM's. Conclusions were that OSP technology is able to meet the technical and reliability requirements of the industry, costs less, and eliminates lead at the PCB manufacturer.

Pcb Fabrication Cost Comparison

An operational cost analysis was recently completed at Merix Corporation detailing the annual expenses associated with the HASL process versus a horizontal organic protective coating line[2]. Many factors were incorporated in this comprehensive study that may not have been included with a traditional operational cost analysis. During the course of the investigation, a number of "hidden" items and tasks were found to be necessary in order to support the HASL process; but not all were included in the normal operating cost. These hidden items accounted for an *additional 42% in costs* which normally would not have been captured in the traditional cost analysis. For example, the cost **of** materials and labor associated with masking and cleaning selectively gold-plated contacts was found to be a major expense. Exposed gold circuitry must be masked prior to processing through the HASL line in order to prevent the gold from dissolving into the molten solder bath. The method for subsequently removing this mask is equally, if not more, labor intensive. Masking gold contacts prior to applying the anti-tarnish coating is not required.

Another example not included is the additional cleaning that is often required by PCB's coated with a dry film soldermask. These masks typically absorb ionic contaminates introduced by the HASL process (flux & oils), thus requiring an added cleaning operation to satisfy surface insulation resistance (SIR) specifications. Again, this added operation is not required with anti-tarnish coated boards.

From the HASL equipment maintenance perspective, heavy duty hoists were installed for the removal of pumps and other parts from the solder pot section. Downtime from planned and unplanned maintenance, as well as fires causing a plant evacuation, were taken into consideration. Safety equipment designed to protect operators from the solder-bearing hazardous smoke and fumes must also be maintained. Workman's compensation claims for back-related injuries, burns, and asthma were found to be a substantial expense.

Additional items include the requirement that hazardous waste transportation and landfill are used to dispose of the lead-bearing frames routed from HASL panels. Disposing of these frames costs about \$0.12-\$0.15 per pound versus a reclaim value of \$0.02 per pound for bare copper frames. Finally, approximately twice the engineering support was required to maintain the HASL process when compared to an OSP line of similar production volume.

Assessment of the cost benefits for each board shop will vary depending upon labor rates, utility costs, supply network, and environmental compliance regulations. Figure 2 estimates are based on processing an equivalent volume of circuit boards with annualized cost assuming new equipment for each system. A break-even point was determined by converting approximately 30% of the HASL products to the OSP process. It must also be pointed out that the full cost savings will not be realized until the HASL process is replaced. If the approach is to add an alternative PCB finish, then the net result is an overall increase in the company's overhead expense for the new process.

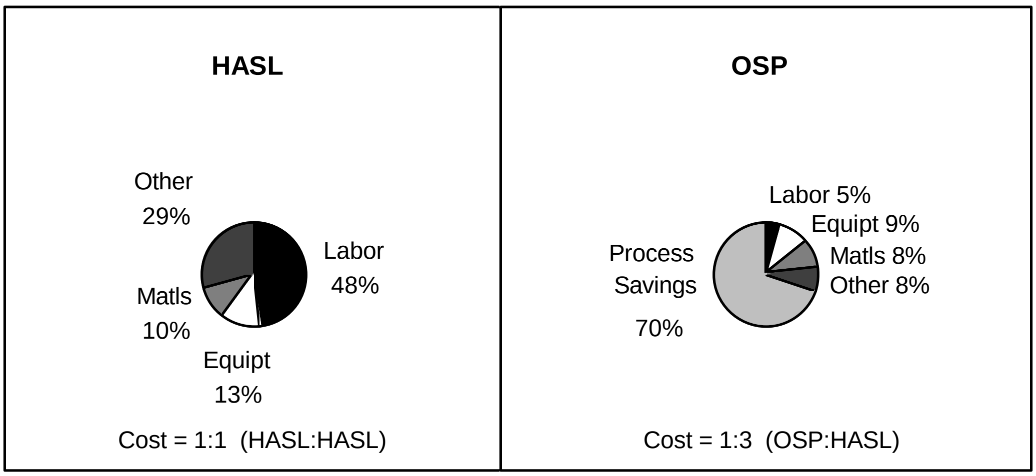

FIGURE 2
COMPREHENSIVE COST ANALYSIS AS A PERCENT OF THE HASL PROCESS

Board Shop Process Considerations

The board shop should be aware of several manufacturing related issues that must addressed during the implementation phase of the OSP process. The first consideration is deciding the type of process to install: vertical "batch and hoist" processing versus horizontal in-line equipment. Both systems have demonstrated success in the field. The horizontal conveyor system is recommended as it provides more uniform coverage, is able to condition and coat smaller diameter holes, and allows for better process control.

Unlike the HASL process, once characterized, the OSP process requires little engineering support. The coating thickness is controlled by solution concentration, pH, temperature, and dwell time. All variables can be held at levels that will provide minimal process variation.

Another area to consider during board fabrication is material handling. The OSP coating is very thin and fragile, thus handling precautions must be taken into account. Once the boards are coated, gloves should be worn to prevent perspiration and other body oils from contacting the PCB surface. Care should also be taken to avoid scratching the coated pads. Interleaving with sulfur-free paper is recommended, but often pads are recessed below the soldermask surface so typical board handling procedures are adequate.

A third consideration deals with electrically testing of the bare boards. The OSP coating is typically applied after rout and test and towards the end of the fabrication sequence to minimize handling. Electrical test pins must be able to pierce the heavy copper oxides formed during prior PCB fabrication steps, such as soldermask or nomenclature bakes. Chisel-point pins work well; others may want to evaluate different test pin alternatives. It is possible to pre-clean the boards prior to electrical test, but this adds unnecessary expense and scheduling problems since dwell time between clean and test must be minimized. It is recommended to focus on the type of test pin used rather than incorporate a non-value added operation. Testing the boards after the coating is applied is also not recommended. The pins will pierce the coating allowing the copper to oxidize, and may eventually cause solderability problems.

Packaging is another area to be taken into account. Boards must be dry before packaging otherwise degradation of the coating may occur. Packaging materials must be sulfur-free. Interleaf paper between the boards is not required if the copper coated surfaces are recessed below the soldermask surface.

Introducing The Process

The first step is to provide information to the assembly customer on the technology. Presentations describing the overall process, benefits, and limitations are recommended in order to properly address the needs of the customer. Eliciting help from potential OSP suppliers and making joint presentations can be very helpful. A comparison of the benefits and limitations of each process should be clearly outlined during this educational process (chart 1). Another useful tool for obtaining assembly feedback from the customer is a survey. An assembly survey addressing key process parameters such as product mix, flux type, solder equipment, etc. will help to identify potential compatibility issues with the organic coating.

	HASL	OSP
Surface Thickness Uniformity	Poor	Good
Pad Coplanarity	Poor	Good
Finished Hole Size Uniformity	Poor	Good
Plated Hole Size Compensation (design)	0.002 - 0.003 in. oversized	Not Required
Fine Pitch Quality (25 mils or less)	Poor	Good
Surface Contrast (Assembly)	Poor	Good
Solder Volume	Varies	Predictable (design for)
SIR, bare board	Acceptable	Excellent
Environmental Hazard	High	Low
Personnel Exposure (safety issue)	High	Low
Gold Contact Masking	Required	Not Required
Thermal Stress (PCB mfg. process)	Yes	No
Manufacturing Cost	High	Low
Equipment Maintenance Cost	High	Low
Rework ability	Difficult	Easy
Surface Finish Durability	Robust	Fragile

CHART 1 PROCESS BENEFITS COMPARISON

The next step is to introduce the actual product. At Merix, one key customer was chosen to help evaluate and pick the OSP supplier. There are a number of anti-tarnish suppliers on the market and it was decided to evaluate several of them in order to assess the performance of each. Several assembly divisions exist within the same customer base, thus providing a wide range of assembly processes, from a No Clean 100% through hole assembly environment to mixed technology with water soluble (OA) fluxes (chart 2). Asking the customer to help evaluate the performance of these alternative coatings and suppliers did several things:

- Provide "hands-on" experience and the means for introducing the new surface finish into the actual assembly line of the customer.
- Identify customer focus and the assembly criteria important to their product. Assemblies/instruments designated for an office environment require different reliability standards than those exposed to a more hostile environment, such as the polar ice caps.
- Provide quantitative assembly results to properly identify the best performing OSP coating.
- Provide a knowledge base of the customers' assembly operation. Having the board fabricator learn about PCB assembly processing can be very beneficial in understanding the needs of the customer.

The preliminary assembly evaluations helped identify the coating supplier by comparing respective coating performance. The following conclusions were drawn based on the results achieved with the established assembly processes:

- Anti-tarnish coated PCB's were cleaner (SIR) than HASL coated PCB's as received from the board shop.
- Anti-tarnish coatings were not detrimental to the cleanliness (SIR) of the assembled boards.
- Surface Mount assembly processing was compatible with anti-tarnish boards. This included No Clean, RMA, and OA solder pastes.
- The OSP coatings performed adequately with through hole wave solder assembly if a fairly active RMA or OA flux was used in mixed technology applications.
- OSP's did not perform well with all No Clean (2% solids) wave solder processes.
- Screen print rework was not a problem if a fairly active flux was used and dwell time was less than seven days.

The OSP supplier was chosen based on these preliminary assembly results and a willingness to support the assembler during the introduction phase. Developing a partnership with the supplier was considered key to introducing the new organic surface finish.

Once the OSP coating supplier is identified, the next step in the introduction phase is to offer prototype production boards (pilot runs) to customers. An assembly based survey will help identify those customers with OSP compatible processes. Customers with processes that may not be entirely compatible with the organic coating, such as No Clean wave soldering, will require a higher level of support.

Assembly Operation	SMT Paste Flux Type	Wave Solder Flux Type	OSP Results
Division 'A"	Organic Acid (OA)	Organic Acid (OA)	Compatible with all processes
Division 'B'	Active Rosin (RMA)	No Clean (2% Solids)	Compatible with SMT process; alternative No Clean wave flux acceptable
Division 'C'	Active Rosin (RMA)	Organic Acid (OA)	Compatible with all processes
Division 'D'	N/A	No Clean (2% Solids)	Alternative No Clean wave flux acceptable

CHART 2

It is important that sample boards are provided to the customer with an understanding that some process characterization may be required. Different fluxes, solder paste reflow profiles, or wave solder parameters may be required to obtain optimum yields. Having a knowledge base of the assembler's process will help to ensure success. For example, the number of thermal cycles prior to wave solder may affect the quality of hole fill. If excessive, nitrogen may be recommended in the reflow process, wave solder, or both. Typically, OSP suppliers advertise up to five thermal cycles can be achieved in open air without detrimental effects to solderability. It is also important to note that once characterized for OSP board assembly, the same process will typically work for HASL boards as well. The OSP process introduction requires an attitude of "making it work" instead of assessing the failures.

Manage The Conversion

Unique issues and problems may arise once pilot runs are underway. No two assembly lines are the same; what works well with one line may not work as smoothly in the next. The OSP supplier, along with a broad knowledge of assembly processing experience, will certainly help overcome these technical hurdles.

During the introduction phase, assembly processes using a fairly active water soluble (OA) or rosin (RMA) flux posed no significant problems. OSP coated boards required little to no process characterization in these lines.

On the other hand, PCB assembly with No Clean flux technology was an area that gave poor results during the introduction phase. Acceptable No Clean SMT assembly was seen; however, inadequate component and non-component hole fill during wave solder was observed. Previous studies performed by October Project Committee members indicated that nitrogen improved solderability characteristics of OSP coated boards[3]. This customer did not use nitrogen; it was imperative to develop a No Clean mixed technology assembly operation in air. Converting to an OSP compatible No Clean wave solder flux and optimizing the volume of flux delivered to the board produced the desired results. The OSP supplier played a key role in developing a workable process.

Good solder wetting of OSP coated boards occurs only where the flux comes into contact with the pads and holes. This must be kept in mind with all assembly operations, regardless of the flux used. Solder paste screen print registration should also be optimized.

Reworking boards from solder paste misprints was considered important by each assembly division. Rework capability depends upon the rework cleaning process, time delay between cleaning and re-print, and especially, the assembly process and fluxes used. More active fluxes had better results, up to one week dwell time between cleaning (water plus saponifier; 150°F rinse) and re-print was obtained where a fairly active, 17% solids, OA flux was used. It must also be pointed out that the contrast of the OSP coated copper-to-solder paste interface is much better than HASL. This helps to reduce misprints caused by poor visual alignment of the stencil to the PCB. Another fact is that OSP coated boards, unlike HASL, are easily reworkable by the PCB shop; therefore the assembler can have a fresh coating applied to PCB's whenever the coating is damaged.

A PCB design issue became apparent on product utilizing plated through holes for mounting and grounding purposes. The concern related to potential problems surrounding dissimilar metals between the now copper mounting holes and the plated hardware. These plated through holes are typically masked prior to the wave solder operation to prevent the holes from plugging with solder. This process leaves the mounting holes with bare copper. A new grounding hole design that provided a non-plated through hole for mounting and grounding was developed. This design (figure 3) provides minimal exposed copper without plugging the mounting hole during wave solder. A second benefit from this design is the elimination of the temporary mask operation prior to wave soldering. Another solution, depending upon the mounting hardware, would be to selectively gold plate the mounting holes. This only requires an artwork modification on product already using the selective plate process.

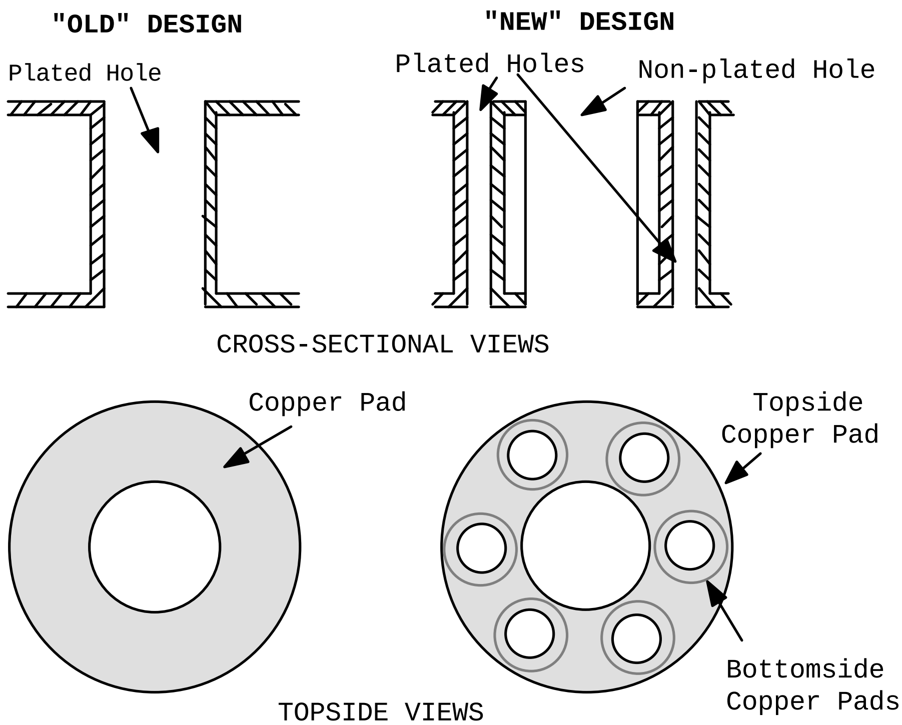

FIGURE 3 Mounting Hole Proposal

As these technical challenges are met, the information should continuously be transferred to the sales and marketing organization, and then to the customer. Communications may be in the form of technical articles and presentations detailing the specific test results, references of published articles, and supplier literature. It is also quite helpful to invite the OSP supplier to give technical seminars to the sales and marketing organization, as well as provide them with the necessary tools to address specific customer issues. Regularly scheduled meetings and conference calls are helpful in keeping the lines of communication open.

Sharing of information from experienced users through industry publications and groups, such as the October Project Committee, are good methods for transferring the knowledge and experience of industry experts. For example, Digital Equipment Corporation and Battelle performed a study to determine the reliability of bare copper versus solder coated boards[4]. This investigation examined the failure mechanism of metal migration under bias using fine-line technology product. *Conclusion was that bare copper boards are more reliable than solder down to a 0.004 inch line and space.*

At the beginning of the program, it is essential that resources and focal points at each level are identified for managing and implementing the introduction and replacement process of the alternative surface finish. An added benefit of this approach is the knowledge that is attained by working with the customers at the various levels. The PCB shop may not be aware of the functional requirements or assembly demands which are placed on their products. This implementation process is one methodology which places the PCB suppliers in the customers' position and allows them to gain a mutual understanding of the product requirements.

The ultimate goal is to build and ship products with the new finish. Once acceptable results are achieved with the prototypes, or pilot runs, selecting the top 5-10 parts in the shop may be used as vehicles for a volume ramp-up schedule. In some cases due to design or capacity constraints, it may not be economically feasible to perform a wholesale product conversion.

Summary

Converting from HASL to OSP technology requires an attitude of assessing benefits, rather than assessing failure. It is common to encounter expectations during each step of the project on "how to make the process fail", in lieu of "how to make it work". Industry wide introduction of the bare copper process is fairly new to this country, although it has been commonly used overseas for almost two decades. As early as 1979, published work in Japan[5] set the stage for the Far East circuit board industry to begin conversion from the established solder plating and HASL coating methods to bare copper. Some alterations have been made over the years beginning with the early pre-flux and benzotriazole compounds, to the current substituted benzimidazole coatings. Throughout this cycle the concept of bare copper was preserved.

The OSP surface finish is reliable and considered by many to be the high volume, low-cost replacement for HASL. An implementation plan designed jointly by the board shop and its customers provides multiple benefits in understanding their respective processes and concerns. Partnership with the OSP supplier is an important consideration during and after the introduction phase. Through this process the best assessment of limitations and economic gains may be achieved.

The planning process and dedication of resources to manage the testing, education, and conversion, takes a reasonable degree of commitment and time on the part of the PCB shop. It is common for this type of implementation program to take up to a year or more, depending upon the velocity of product conversion. Fortunately, with the increasing industry acceptance of the newer OSP technology, it is expected that the conversion rate will increase substantially over the coming years. This conversion will be further driven by the increase in fine-pitch technology, cost-reduction pressures, and environmental regulations.

Rarely in the industry has a process emerged which provides an opportunity to meet current and future technological demands, while simultaneously maintaining and even improving its competitive position in the market. The interest level and degree of published literature clearly indicate that OSP technology is a viable process and will meet the PCB requirements of the customer for the foreseeable future.

References

1. Payne B., "Copper Protective Coatings Research", IPC Printed Circuits Expo '94 Proceedings, Boston, Massachusetts 1994
2. Parquet D., Boggs D., "Getting Started With Bare Copper", SMI Conference and Expo '94 Proceedings, San Jose, California
3. S. Chen, S. Lewis, D. Denny, "Solder Wetting Characteristics of Bare Copper Printed Wiring Boards with Protective Anti-tarnish Coatings", NCR Corporation
4. W. Abbott, "Effects of Operating Environments on Migration of Copper on Printed Circuit Boards", Digital Equipment Corporation, 1989
5. Isobe M., Kobuna H., Suzuki K., Sato T., Noguchi S., "Application and Reliability of Copper Plated Through Hole Printed Wiring Boards", NEC Research & Development, October 1979