The Design for the Environment Printed Wiring Board Project: A Partnership to Identify Cleaner Technologies

By Kathy Hart, Dipti Singh, Holly Evans, Lori Kincaid, Jack Geibig & Mary Swanson

Reflecting a trend in environmental protection toward increased cooperation and collaboration between government and "regulated entities," the U.S. Environmental Protection Agency (EPA) Design for the Environment (DfE) Program has been working closely with the Institute for Interconnecting and Packaging Electronic Circuits (IPC) and its member companies, the University of Tennessee's Center for Clean Products and Clean Technologies, and other partners (academic, research and public interest representatives) since 1994 on the Printed Wiring Board (PWB) Project. The primary goal of the DfE PWB Project is to encourage PWB manufacturers to implement cleaner technologies that will improve the environmental performance and competitiveness of the PWB industry. The overall goal of the DfE program is to encourage businesses to incorporate environmental, as well as cost and performance, considerations into the design and redesign of technologies, processes and products (Fig. 1).

Comparative Studies

Project partners have already completed a major comparative study of technologies used in the "making holes conductive" (MHC) step of PWB manufacturing (i.e., alternatives to the electroless copper process), and are now conducting a similar evaluation of technologies that may be used in the surface finishing step, in place of hot-air solder leveling. Results of the surface finishes study are expected to be published in a draft report in late 1999. A surface finishes project meeting will be held at the 1999 Conference for Environmental Excellence, sponsored by the AESF and EPA. The meeting is open to anyone who would like to learn more about or participate in the surface finishes project.

In addition to the MHC study, the DfE PWB Project has produced several technical reports, including two on pollution prevention and control technologies used in the PWB industry,[1,2] and produced and disseminated 10 pollution prevention case studies.

Study on Making Holes Conductive

The electroless copper plating process has long been the standard method of creating a conductive surface on the drilled through-hole walls of rigid, double-sided or multilayer PWBs required for electrolytic copper plating. Although the electroless copper process for making holes conductive is a mature technology that produces reliable interconnects, the typical process line is long (17 or more process tanks, depending on rinse configurations) and may have eight or more process baths. It is also a source of formaldehyde emissions and a major source of wastewater containing chelated, complexed copper.

In the MHC study, project partners developed and analyzed technical information regarding the potential human health and environmental risks, performance, costs and chemical and natural resource use of the electroless copper process and six "direct metallization" technologies (Table 1). These analyses were conducted by the University of Tennessee, and the results were compiled into a Cleaner Technologies Substitutes Assessment (CTSA)[3] and a CTSA summary document.[4] A detailed description of the CTSA methodology may be found in Section 1.3 of the CTSA document. We believe that the CTSA results described below demonstrate that the direct metallization technologies make good economic and environmental sense for PWB manufacturers.

Table 2 lists the suppliers who participated in the MHC CTSA and the technologies they submitted for evaluation. The suppliers provided publicly available chemistry data for their MHC chemical products, and were asked to provide the identities and concentrations of proprietary chemical ingredients.

Suppliers also completed a Supplier Data Sheet describing their products, and nominated test sites for a performance demonstration. PWB manufacturers completed a Workplace Practices Survey, which requested detailed information on their MHC processes, as well as worker activities related to chemical exposure.

The data collected from the suppliers and through the Workplace Practices Survey were aggregated to develop generic process steps and typical bath sequences for each technology category, while acknowledging that the types and sequence of baths in actual lines may vary, depending on facility-specific operating conditions.

There were a number of limitations to the study, because of the predefined scope of the project, the limit of the project's resources and uncertainties inherent to risk characterization techniques. Those limitations are discussed in detail in the MHC CTSA.

The cost, energy and resource use analyses determined the comparative costs and consumption rates of using an MHC technology in a model facility to produce 350,000 surface square feet (ssf) of PWBs. As with the risk characterization, this approach resulted in a comparative evaluation of

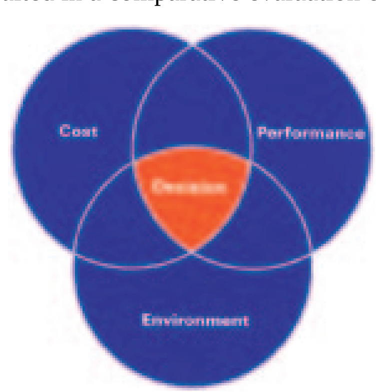

Fig. 1—EPA's Design for the Environment Program encourages businesses to consider environmental factors, as well as performance and cost, when making decisions.

cost or energy and natural resource consumption, not an absolute evaluation or determination.

Risk Characterization Of MHC Technologies

Risk results suggest that alternatives to the non-conveyorized electroless copper process pose lower overall occupational risks. This is a result of the reduced number of chemicals of concern in the alternative technologies for both inhalation and dermal exposure, and the level of cancer risk from inhalation exposure to formaldehyde in non-conveyorized electroless copper processes. Detailed information on potential occupational risk from inhalation and dermal contact for each technology may be found in the MHC CTSA. The indicators for public health risk (risk to residents near a facility), although limited to airborne releases, indicated low concern from all MHC technologies.

Performance Demonstration Results

In order to evaluate the relative performance of each technology category, a comparative performance demonstration was conducted. PWB panels designed to represent industry "middle-of-the-road" technology were manufactured at one facility, run through individual MHC lines at 25 facilities, and then electroplated at one facility. The panels were electrically pre-screened, followed by electrical stress (IST) testing and mechanical (microsection) testing, in order to distinguish variability in the performance of the MHC interconnect. The test methods used to evaluate performance were intended to indicate characteristics of a technology's performance, not to define parameters of performance or to substitute for thorough on-site testing; the study was intended to be a "snapshot" of the technologies.

The microsection and IST tests were run independently, and had extremely good correlation of results. In terms of IST results, product performance was divided into two functions: Plated through-hole (PTH) cycles to failure and the integrity of the bond between the internal lands (post) and PTH (referred to as "post separation"). The PTH cycles to failure observed in the study is a function of both electrolytic plating and the MHC process.

The mechanical testing and IST results indicated that each MHC technology has the capability to achieve comparable (or superior) levels of performance to electroless copper, if operated properly. Post separation results indicated percentages that were unexpected by many members of the industry. It was apparent that all MHC technologies, including electroless copper, are susceptible to this type of failure. A copy of the complete technical paper may be obtained by contacting Star Summerfield at the Institute for Interconnecting and Packaging Electronic Circuits, Northbrook, Illinois (847/790-5347).

Table 1—MHC Processes Evaluated in the CTSA*

MHC Technology	Equipment Configuration: Non-Conveyorized	Equipment Configuration: Conveyorized
Electroless	√	√
Carbon		√
Conductive		√
Graphite		√
Non-Formaldehyde Electroless Copper	√	√
Organic Palladium	√	√
Tin-Palladium	√	√

*Cleaner Technologies Substitutes Assessment

Table 2—MHC Technologies Submitted by Chemical Suppliers

Chemical Supplier	MHC Technology: Electroless Copper	Carbon	Conductive Ink	Conductive Polymer	Graphite	Non-Formaldehyde Electroless Copper	Organic Palladium	Tin-Palladium
Atotech USA, Inc.	√			√			√	
Electrochemicals, Inc	√				√			
Ehthone-OMI, Inc.	√							√
W.R. Grace and Co.			√					
LeaRonal, Inc.								√
MacDermid, Inc.	√	√				√		
Shipley Company	√				√			√
Solutions Technology								√

Cost Analysis Results

The results of the cost analysis indicated that all of the MHC alternatives are more economical than the non-conveyorized electroless copper process. The average cost for most MHC technologies ranged from 57 to 82 percent less than the baseline technology (the cost for non-formaldehyde electroless copper, non-conveyorized, was 22 percent less). Chemical cost was the single largest component cost for nine of the 10 technologies and equipment configurations evaluated. Equipment cost was the largest cost for the non-conveyorized electroless copper process. Three separate sensitivity analyses of the results indicated that chemical cost, production labor cost and equipment costs had the greatest effect on the overall cost results.

Energy & Resource Use Results

The energy and water consumption rates of MHC technologies were estimated, based on data collected by PWB manufacturers and their suppliers, and through direct observation during performance demonstration site visits. All of the technologies consumed significantly less water and energy than the baseline, non-conveyorized electroless copper technology. The water use savings for most technologies ranged from 85 to 96 percent per ssf, and energy savings ranged from 63 to 99 percent. Non-formaldehyde electroless, non-conveyorized, used 68 percent less water and 53 percent less energy per ssf.

Surface Finishes Study

DfE PWB Project partners are now evaluating lead-free alternatives to the hot-air solder leveling (HASL) process, in order to identify those surface finish technology alternatives that perform competitively, are cost-effective and pose fewer potential environmental and health risks. The most commonly used PWB finishing technologies are HASL and electroplated tin-lead. These technologies may pose potential health and environmental risks because of the use of lead. The HASL process also generates significant quantities of excess solder that must be recycled. In addition to the HASL process, which will be tested as the baseline technology, the alternatives being evaluated include: Thick organic solder protectorate, immersion tin, immersion silver, electroless nickel/immersion gold, and electroless nickel/electroless palladium/immersion silver. The alternative technologies are expected to generate substantially less hazardous waste and may be more cost effective than the baseline technology.

Performance data for some of the technologies have been developed by the Circuit Card Assembly and Materials Task Force (CCAMTF) and the National Center for Manufacturing Sciences (NCMS). However, performance data for other technologies, and information on the relative health and environmental risks and costs of all technologies, have not been generated. The DfE PWB Surface Finishes Project will supplement the work done by the CCAMTF, and is expected to provide valuable information to both the PWB manufacturing and assembly industries.

To evaluate the performance of each surface finish technology, a number of functional test boards were fabricated (a modified version of the IPC-B-24 board). The test boards contain a variety of circuitry (including high voltage/low current, high current/low voltage, high frequency and high speed digital), and can be subjected to multiple processing steps (wave, reflow and hand soldering). The boards were fabricated at one facility and then shipped to the volunteer demonstration sites, where the surface finishes were applied.

The boards were shipped to a common location for assembly, including both through-hole and surface mount components. Assembly was completed in November 1998. Half of the boards for each surface finish are being processed using a halide-free low-residue flux; a halide-containing water-soluble flux is being used on the other half. The circuit performance will be assessed under applicable environmental stresses, with the HASL process serving as a baseline. The functional boards will be evaluated through a series of reliability tests, including thermal and mechanical shock.

For More Information

For more information about the DfE Program or the DfE PWB Project, or to obtain copies of the CTSA or other documents produced by the Project, contact the Pollution Prevention Information Clearinghouse, U.S. Environmental Protection Agency, 401 M St., S.W. (7409), Washington, DC, 20460; phone: 202/260-1023; FAX: 202/260-4659; e-mail: PPIC@epa.gov. You may also view or order the project documents, including the CTSA, and obtain additional project information by visiting the DfE Program Website (www.epa.gov/dfe) or the IPC Website (www.ipc.org/html/ehstypes.htm#design). **P&SF**

References

1. Printed Wiring Board Pollution Prevention and Control Technology: Analysis of Updated Survey Results (EPA 744-R-98-003); August 1998.
2. Printed Wiring Board Pollution Prevention and Control Technology: Analysis of Survey Results (EPA 744-R-95-006); September 1995.
3. Printed Wiring Board Cleaner Technologies Substitutes Assessment: Making Holes Conductive, Volumes 1 and 2 (EPA 744-R-98-004a and 004b); August 1998.
4. Alternative Technologies for Making Holes Conductive: Cleaner Technologies for Printed Wiring Board Manufacturers (EPA 744-R-98-002); September 1998.

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