PRINTED CIRCUIT BOARD MANUFACTURING

A. PROCESS DESCRIPTION

Printed circuit boards are electronic circuits created by mounting electronic components on a nonconductive board, and creating conductive connections between them. The creation of circuit patterns is accomplished using both additive and subtractive methods. The conductive circuit is generally copper, although aluminum, nickel, chrome, and other metals are sometimes used. There are three basic varieties of printed circuit boards: single-sided, double-sided, and multi-layered. The spatial and density requirement, and the circuitry complexity determine the type of board produced. Printed circuit boards are employed in the manufacturing of business machines and computers, as well as communication, control, and home entertainment equipment.

Production of printed circuit boards involves the plating and selective etching of flat circuits of copper supported on a nonconductive sheet of plastic. Production begins with a sheet of plastic laminated with a thin layer of copper foil. Holes are drilled through the board using an automated drilling machine. The holes are used to mount electronic components on the board and to provide a conductive circuit from one layer of the board to another.

Following drilling, the board is scrubbed to remove fine copper particles left by the drill. The rinsewater from a scrubber unit can be a significant source of copper waste. In the scrubber, the copper is in a particulate form and can be removed by filtration or centrifuge. Equipment is available to remove this copper particulate, allowing recycle of the rinsewater to the scrubber. However, once mixed with other waste streams, the copper can dissolve and contribute to the dissolved copper load on the treatment plant.

After being scrubbed, the board is cleaned and etched to promote good adhesion and then is plated with an additional layer of copper. Since the holes are not conductive, electroless copper plating is employed to provide a thin continuous conductive layer over the surface of the board and through the holes. Electroless copper plating involves using chelating agents to keep the copper in solution at an alkaline pH. Plating depletes the metal and alkalinity of the electroless bath. Copper sulfate and caustic are added (usually automatically) as solutions, resulting in a “growth” in volume of the plating solution. This growth is a significant source of copper-bearing wastewater in the circuit board industry.

Treatment of this stream (and the rinsewater from electroless plating) is complicated by the presence of chelating agents, making simple hydroxide precipitation ineffective. Iron salts can be added to break the chelate, but only at the cost of producing a significant volume of sludge. Ion exchange is used to strip the copper from the chelating agent, typically by using a chelating ion exchange resin. Regeneration of the ion exchange resin with sulfuric acid produces a concentrated copper sulfate solution without the chelate. This regenerant can then be either treated by hydroxide precipitation, producing a hazardous waste sludge, or else concentrated to produce a useful product.

Growth from electroless copper plating is typically too concentrated in copper to treat directly by ion exchange. Different methods have been employed to reduce the concentration of copper sufficiently either to discharge the effluent directly to the sewer or to treat it with ion exchange. One method, reported by Hewlett-Packard, replenishes growth with formaldehyde and caustic soda to enhance its autocatalytic plating tendency, and then mixes it with carbon granules on which the copper plates out in a form suitable for reclaiming.

Following electroless plating a plating resist is applied to the panel and photo-imaged to create the circuit design. Copper is then electroplated on the board to its final thickness. A thin layer of tin lead solder or pure tin is plated over the copper as an etch resist. The plating resist is then removed to expose the copper not part of the final circuit pattern.

The exposed copper is then removed by etching to reveal the circuit pattern. Ammonia-based etching solutions are most widely used. Use of ammonia complicates waste treatment and makes recovery of copper difficult. An alternative to ammonia etching is sulfuric acid/hydrogen peroxide etching solutions. This latter etchant is continuously replenished by adding concentrated peroxide and acid as the copper concentration increases to about 80 g/L. At this concentration, the solution is cooled to precipitate out copper sulfate. After replenishing with peroxide and acid, the etchant is reused. Disadvantages of the sulfuric acid-peroxide etching solution are that it is relatively slow when compared with ammonia, and controlling temperature can be difficult.

Exhibit 1 shows the general processes in printed circuit board manufacturing.

B. SOURCES OF POLLUTION

Wastes are generated from the following five processes that are common to the manufacture of all types of circuit boards:

- cleaning and surface preparation
- catalyst application and electroless copper plating
- pattern printing and masking
- electroplating
- etching

The wastes generated include airborne particulates, spent plating baths, and waste rinsewater among others. Exhibit 1 indicates the sources of pollution.

EXHIBIT 1. Process Flow Chart of Typical Printed Circuit Board Manufacturing

C. POLLUTANTS AND THEIR CONTROL

Emissions of air pollutants from the manufacture of printed circuit boards stem primarily from the board cleaning and preparation process; other emissions are generally of much less significance. The majority of the emissions are acid fumes and organic vapors from the cleaning processes. Some particulates are also emitted in the drilling and finishing of the boards. Proper ventilation and exhaust of all process baths, rinse operations, and mechanical operations is essential to managing the air emissions of a printed circuit board manufacturing operation and can also contribute to reduction in liquid and metal waste generation. Exhibit 2 lists air pollutants and methods of control.

Each manufacturing process may generate multiple waste streams. Rinse water and other rinse solutions are usually the largest streams by volume, but are generally lower in concentration of hazardous chemicals than spent process baths. Contamination of rinse streams can be minimized by strategies that reduce drag-out of process solutions. Treatment and reuse of rinse streams is also effective in reducing overall waste generation.

Airborne particulates emitted from cutting, sanding, routing, drilling, beveling, and slotting operations during board preparations are usually controlled by baghouse and cyclone separators. The collected pollutants are then disposed of, along with other solid wastes at landfills.

Acid fumes from acid cleaning and organic vapors from vapor degreasing are usually not contaminated with other materials, and therefore are often kept separate for subsequent treatment. The acid fume air stream is collected via chemical fume hoods and sent to a scrubber where the acid is removed with water. The scrubbed air then passes on to the atmosphere, and the absorbing solution is neutralized along with other acidic waste streams. Similarly, organic fumes are often collected and passed through a bed of activated carbon. The carbon bed is then regenerated with steam. In many cases, the regenerative vapor is cooled and the condensate containing water and solvent drummed and set aside for off-site treatment. In a few cases, the regenerative vapor is combusted in a closed fumes burner.

The spent acid and alkaline solutions from the cleaning steps are either sent off site for disposal or neutralized and discharged to the sewer. Spent chlorinated organic solvents are often gravity separated and recovered in-house, or hauled away for reclaiming.

Most of the remaining wastes are liquid waste streams containing suspended solids, metals, fluoride, phosphorus, cyanide, and chelating agents. Low pH values often characterize the wastes due to acid cleaning operations. Liquid wastes may be controlled using end-of-pipe treatment systems, or a combination of in-line treatment and separate treatment of segregated waste streams. A traditional treatment system for the wastes generated is often based on pH adjustment and the addition of chemicals that will react with the soluble pollutants to precipitate out the dissolved contaminants in a form such as metal hydroxide or sulfate. The solid particles are removed as a wet sludge by filtration or flotation, and the water is discharged to the sewer. The diluted sludge is usually thickened before disposal in landfills. Recent improvements in in-line treatment technologies, such as reverse osmosis, ion exchange, membrane filtration, and advanced rinsing techniques, increase the possibility for the recovery and reuse of water and metallic resources. Exhibit 3 delineates the waste streams from printed circuit board manufacturing.

Exhibit 2: Air Emissions from Printed Circuit Board Manufacturing

Emission Point	Pollutants	Control Device
Surface Preparation	Particulates	

VOC Baghouses/Cyclone separators

Carbon adsorber
Surface Cleaning Acid fumes

VOC Wet scrubbers

Carbon adsorber

Exhibit 3: Waste Streams From the Manufacture of Printed Circuit Boards

WASTE SOURCE	WASTE STREAM DESCRIPTION	WASTE STREAM COMPOSITION
Cleaning/Surface Preparation	Spent acid/alkaline solution	metals, fluoride, acids, halogenated solvents, alkali, board materials, sanding materials
	Spent halogenated solvents	
	Waste rinse water	
Electroless Plating	Spent electroless copper bath	acids, stannic oxide, palladium, complexed metals, chelating agents, copper
	Spent catalyst solution	
	Spent acid solution	
	Waste rinse water	
Pattern Printing and Masking	Spent developing solution	vinyl polymers, chlorinated hydrocarbons, organic solvents, alkali
	Spent resist removal solution	
	Spent acid solution	
	Waste rinse water	
Electroplating	Spent plating bath	copper, nickel, tin, tin/lead, gold, fluoride, cyanide, sulfate
	Waste rinse water	
Etching	Spent etchant	ammonia, chromium, copper, iron, acids
	Waste rinse water	

D. REFERENCES

This report contains excerpts of information taken directly from the following sources:

1. Higgins, Thomas. Hazardous Waste Minimization Handbook. Chelsea, Michigan: Lewis Publishers, Inc., 1991.

2. Jacobs Engineering Group, Guides to Pollution Prevention: The Printed Circuit Board Manufacturing Industry. Pasadena, California, June 1990.

3. Kirsch, F. W., and Looby, G. P. Waste Minimization Assessment for a Manufacturer of Printed Circuit Boards, July 1991. EPA/600/M-91/022.