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Electronics Manufacturing

Industry Description and Practices

The electronics industry includes the manufacture of *passive components* (resistors, capacitors, inductors); *semiconductor components* (discretes, integrated circuits); *printed circuit boards* (single and multilayer boards); and *printed wiring assemblies.* This chapter addresses the environmental issues associated with the last three manufacturing processes. The manufacture of passive components is not included because it is similar to that of semiconductors. (A difference is that passive component manufacturing uses less of the toxic chemicals employed in doping semiconductor components and more organic solvents, epoxies, plating metals, coatings, and lead.)

Semiconductors. Semiconductors are produced by treating semiconductor substances with dopants such as boron or phosphorus atoms to give them electrical properties. Important semiconductor substances are silicon and gallium arsenide. Manufacturing stages include crystal growth; acid etch and epitaxy formation; doping and oxidation; diffusion and ion implantation; metallization; chemical vapor deposition; die separation; die attachment; postsolder cleaning; wire bonding; encapsulation packaging; and final testing, marking, and packaging. Several of these process steps are repeated several times, so the actual length of the production chain may well exceed 100 processing steps. Between the repetitions, a cleaning step that contributes to the amount of effluent produced by the process is often necessary. Production involves carcinogenic and mutagenic substances and should therefore be carried out in closed systems.

Printed circuit board (PCB) manufacturing. There are three types of boards: single sided (circuits on one side only), double sided (circuits on both sides), and multilayer (three or more circuit layers). Board manufacturing is accomplished by producing patterns of conductive material on a nonconductive substrate by subtractive or additive processes. (The conductor is usually copper; the base can be pressed epoxy, Teflon, or glass.) In the subtractive process, which is the preferred route, the steps include cleaning and surface preparation of the base, electroless copperplating, pattern printing and masking, electroplating, and etching.

Printed wiring assemblies. Printed wiring assemblies consist of components attached to one or both sides of the printed circuit board. The attachment may be by through-hole technology, in which the "legs" of the components are inserted through holes in the board and are soldered in place from underneath, or by surface mount technology (SMT), in which components are attached to the surface by solder or conductive adhesive. (The solder is generally a tin-lead alloy.) In printed circuit boards of all types, drilled holes may have to be copper-plated to ensure interconnections between the different copper layers. SMT, which eliminates the drilled holes, allows much denser packing of components, especially when components are mounted on both sides. It also offers higher-speed performance and is gaining over through-hole technology.

Waste Characteristics

Air Emissions

Potential air emissions from *semiconductor* manufacturing include toxic, reactive, and hazardous gases; organic solvents; and particulates from the process. The changing of gas cylinders may also result in fugitive emissions of gases. Chemicals

in use may include hydrogen, silane, arsine, phosphine, diborane, hydrogen chloride, hydrogen fluoride, dichlorosilane, phosphorous oxychloride, and boron tribromide.

Potential air emissions from the manufacture of *printed circuit boards* include sulfuric, hydrochloric, phosphoric, nitric, acetic, and other acids; chlorine; ammonia; and organic solvent vapors (isopropanol, acetone, trichloroethylene; n-butyl acetate; xylene; petroleum distillates; and ozone-depleting substances).

In the manufacture of *printed wiring assemblies*, air emissions may include organic solvent vapors and fumes from the soldering process, including aldehydes, flux vapors, organic acids, and so on.

Throughout the electronics manufacturing sector, chlorofluorocarbons (CFCs) have been a preferred organic solvent for a variety of applications. CFCs are ozone-depleting substances (ODSs). Their production in and import into developing countries will soon be banned. Hydrochlorofluorocarbons (HCFCs) have been developed as a substitute for CFCs, but they too are ODSs and will be phased out. Methyl chloroform, another organic solvent, has also been used by the electronics industry; it too is an ODS and is being eliminated globally on the same schedule as CFCs. Chlorobromomethane and n-propyl bromide are also unacceptable because of their high ozone-depleting potential.

Effluents

Effluents from the manufacture of *semiconductors* may have a low pH from hydrofluoric, hydrochloric, and sulfuric acids (the major contributors to low pH) and may contain organic solvents, phosphorous oxychloride (which decomposes in water to form phosphoric and hydrochloric acids), acetate, metals, and fluorides.

Effluents from the manufacture of *printed circuit boards* may contain organic solvents, vinyl polymers; stannic oxide; metals such as copper, nickel, iron, chromium, tin, lead, palladium, and gold; cyanides (because some metals may be complexed with chelating agents); sulfates; fluorides and fluoroborates; ammonia; and acids.

Effluents from *printed wiring assemblies* may contain acids, alkalis, fluxes, metals, organic solvents, and, where electroplating is involved, metals, fluorides, cyanides, and sulfates.

Solid and Hazardous Wastes

Solid and hazardous wastes from *semiconductor* manufacture may include heavy metals, solder dross (solder pot skimmings), arsenic, spent epoxy, and waste organic solvents (contributing the largest volume of waste). In *printed circuit board* operations, solid wastes may include scrap board materials, plating and hydroxide sludges, and inks. In the manufacture of *printed wiring assemblies,* solid wastes may include solder dross, scrap boards, components, organic solvents, and metals. Boards may also be treated with brominated flame retardants, which may pose some environmental risk when boards are disposed of in landfills. All conventional electronics present additional hazards in landfills because of the presence of lead in cathode-ray tube envelopes and in solder, as well as lead and other metal salts, particularly if they have not been cleaned in a postsoldering operation.

All three manufacturing processes may generate sludges containing heavy metals from wastewater treatment plants. Organic solvent residues also require management and disposal.

Pollution Prevention and Control

Semiconductor Industry

Measures such as plasma etching of silicon nitride (a dry process) in metal oxide semiconductor (MOS) technology replace the hot corrosive phosphoric acid (H_3PO_4) wet process and offer reductions in generated waste and better safety for workers while reducing the number of processing steps. Because of the reaction of the plasma with the substrate, several substances are formed that are regarded as carcinogenic or mutagenic and that may pose a danger to maintenance personnel. Risks are minimized by sweeping equipment with nitrogen before opening it. A gas mask with breathing equipment should be worn by personnel during repair and maintenance.

Printed Circuit Board Manufacturing

A number of process alternatives exist for the manufacture of printed circuit boards. These include:

- In board manufacture: SMT rather than plated through-hole technology; injection molded substrate; additive plating
- In cleaning and surface preparation: use of nonchelating cleaners; extension of bath life; improvement of rinse efficiency; countercurrent cleaning; recycling and reuse of cleaners and rinses
- In pattern printing and masking: aqueous processable resist; screen printing to replace photolithography; dry photoresist; recycling and reuse of photoresist strippers; segregation of streams; recovery of metals
- For electroplating and electroless plating: replacement of these processes by mechanical board production; use of noncyanide baths; extension of bath life; recycling and reuse of cleaners and rinses; improvement of rinse efficiency; countercurrent rinsing; segregation of streams; recovery of metals
- In etching: use of differential plating; use of nonchelated etchants and nonchrome etchant; use of pattern instead of panel plating; use of additive instead of subtractive processes; recycling and reuse of etchants.

Metal recovery by regenerative electrowinning results in a near-zero effluent discharge for segregated metal-bearing streams. Heavy metals are recovered to metal sheets, which eliminates 95% of sludge disposal. Metal-bearing sludges that are not treated for recovery of metals should be disposed of in secure landfills.

Printed Wiring Assemblies

In the printed wiring assembly process, nonozone-depleting alternatives are readily available for cleaning printed wiring assemblies. These alternatives include other organic solvents, hydrocarbon/surfactant blends, alcohols, and organic solvent blends, as well as aqueous and semiaqueous processes. More important, the industry has shown that even sophisticated printed wiring assemblies intended for military uses (where specifications are very exacting) can be made without cleaning by using low-residue fluxes that leave very little in the way of contamination on the boards. The no-clean concept does away with the use of organic solvents and the need to dispose of organic solvent waste, eliminates a process step and the corresponding equipment, and has been shown to give adequate product quality according to the application.

General

Organic solvent losses can be reduced by conservation and recycling, using closed-loop delivery systems, hoods, fans, and stills. Installation of activated carbon systems can achieve up to 90% capture and recycle of organic solvents used in the system. All solvents and hazardous chemicals (including wastes) require appropriate safe storage to prevent spills and accidental discharges. All tanks, pipework, and other containers should be situated over spill containment trays with dimensions large enough to contain the total volume of liquid over them. Containment facilities must resist all chemical attack from the products. In lieu of containment facilities, the floor and walls, to a reasonable height, may be treated (e.g., by an epoxy product, where chemically appropriate) to prevent the possibility of leakage of accidental spills into the ground, and there should be doorsills. (Untreated cement or concrete or grouted tile floors are permeable.) It is unacceptable to have a drain in the floor of any shop where chemicals of any description are used or stored, except where such a drain leads to an adequate water-treatment plant capable of rendering used or stored chemicals in its catchment area.

Waste organic solvents should be sent to a solvent recycling operation for reconstitution and reuse. Where recycling facilities are not available, waste solvents may need to be incinerated or destroyed as appropriate for their chemical composition.

Target Pollution Loads

Implementation of cleaner production processes and pollution prevention measures can yield both economic and environmental benefits. The following production-related targets can be achieved by measures such as those described in the previous section.

Ozone-depleting substances are not to be used in production operations unless no proven alternative exists. Discharges of organic solvents should be minimized, and alternative technolo-

gies should be considered where available. Solder dross should not be sent to landfills. (Waste can be sent to suppliers or approved waste recyclers for recovery of the lead and tin content of the dross.) Scrap boards and assemblies having soldered components should have their components and solder connections removed before they are sent to landfills or recycled for other uses.

Treatment Technologies

Wet scrubbers, point-of-use control systems, and volatile organic compound (VOC) control units are used to control toxic and hazardous emissions of the chemicals used in semiconductor manufacturing. It is often appropriate to scrub acid and alkaline waste gases in separate scrubbers because different scrubber liquids can then be used, resulting in higher removal efficiencies.

Air emission concentrations of chemicals such as arsine, diborane, phosphine, silane, and other chemicals used in the process should be reduced below worker health levels for plant operations.

Because of the many chemicals used in the electronics industry, wastewater segregation simplifies waste treatment and allows recovery and reuse of materials. Organic wastes are collected separately from wastewater systems. (Note that solvent used in the semiconductor industry cannot be readily recycled because much of it is generated from complex mixtures such as photoresist.) Acids and alkalis are sent to onsite wastewater treatment facilities for neutralization, after segregation of heavy-metal-bearing streams for separate treatment. Fluoride-bearing streams in a semiconductor plant are segregated and treated on site or sent off site for treatment or disposal. Treatment steps for effluents from the electronics industry may include precipitation, coagulation, sedimentation, sludge dewatering, ion exchange, filtering, membrane purification and separation, and neutralization, depending on the particular stream. Sanitary wastes are treated separately (primary and secondary treatment followed by disinfection) or discharged to a municipal treatment system.

Emissions Guidelines

Emissions levels for the design and operation of each project must be established through the environmental assessment (EA) process on the basis of country legislation and the *Pollution Prevention and Abatement Handbook,* as applied to local conditions. The emissions levels selected must be justified in the EA and acceptable to the World Bank Group.

The guidelines given below present emissions levels normally acceptable to the World Bank Group in making decisions regarding provision of World Bank Group assistance. Any deviations from these levels must be described in the World Bank Group project documentation. The emissions levels given here can be consistently achieved by well-designed, well-operated, and well-maintained pollution control systems.

The guidelines are expressed as concentrations to facilitate monitoring. Dilution of air emissions or effluents to achieve these guidelines is unacceptable.

All of the maximum levels should be achieved for at least 95% of the time that the plant or unit is operating, to be calculated as a proportion of annual operating hours.

Air Emissions

The air emissions levels presented in Table 1 should be achieved.

Liquid Effluents

The effluent levels presented in Table 2 should be achieved.

Ambient Noise

Noise abatement measures should achieve either the levels given below or a maximum increase in background levels of 3 decibels (measured on the

Table 1. Air Emissions from Electronics Manufacturing

(milligrams per normal cubic meter)

Parameter	Maximum value
VOC	20
Phosphine	1
Arsine	1
Hydrogen fluoride	5
Hydrogen chloride	10

Table 2. Effluents from Electronics Manufacturing
(milligrams per liter, except for pH)

Parameter	Maximum value
pH	6–9
BOD	50
TSS	
Maximum	50
Monthly average	20
Oil and grease	10
Phosphorus	5.0
Fluoride	20
Ammonia	10
Cyanide	
Total	1.0
Free	0.1
Total chlorocarbons and hydrochlorocarbons	0.5
Metals, total	10
Arsenic	0.1
Chromium, hexavalent	0.1
Cadmium	0.1
Copper	0.5
Lead	0.1
Mercury	0.01
Nickel	0.5
Tin	2.0

Note: Effluent requirements are for direct discharge to surface waters.

A scale) [dB(A)]. Measurements are to be taken at noise receptors located outside the project property boundary.

	Maximum allowable log equivalent (hourly measurements), in dB(A)	
Receptor	*Day (07:00–22:00)*	*Night (22:00–07:00)*
Residential, institutional, educational	55	45
Industrial, commercial	70	70

Monitoring and Reporting

Monitoring of sources of toxic emissions (such as the toxic gases used in the semiconductor industry, should be continuous and part of the process. Effluents should be monitored continuously for pH, and other parameters should be tested once a month.

Monitoring data should be analyzed and reviewed at regular intervals and compared with the operating standards so that any necessary corrective actions can be taken. Records of monitoring results should be kept in an acceptable format. The results should be reported to the responsible authorities and relevant parties, as required.

Key Issues

The key production and control practices that will lead to compliance with emissions requirements can be summarized as follows:

- Cylinders of toxic gases should be well secured and fitted with leak detection devices as appropriate. Well-designed emergency preparedness programs are required. Note that fugitive emissions occurring when gas cylinders are changed do not normally require capture for treatment, but appropriate safety precautions are expected to be in place.
- No ozone-depleting chemicals should be used in the process unless no proven alternatives are available.
- Equipment, such as refrigeration equipment, containing ozone-depleting chemicals should not be purchased unless no other option is available
- Toxic and hazardous sludges and waste materials must be treated and disposed of or sent to approved waste disposal or recycling operations
- Where liquid chemicals are employed, the plant, including loading and unloading areas, should be designed to minimize evaporation (other than water) and to eliminate all risk of chemicals entering the ground or any watercourse or sewerage system in the event of an accidental leak or spill.

Source

World Bank. 1997. "Industrial Pollution Prevention and Abatement: Electronics Manufacturing." Draft Technical Background Document. Environment Department, Washington, D.C.