Environmental, Health, and Safety Guidelines for Semiconductors & Other Electronics Manufacturing

Introduction

The Environmental, Health, and Safety (EHS) Guidelines are technical reference documents with general and industry-specific examples of Good International Industry Practice (GIIP)[1]. When one or more members of the World Bank Group are involved in a project, these EHS Guidelines are applied as required by their respective policies and standards. These industry sector EHS guidelines are designed to be used together with the **General EHS Guidelines** document, which provides guidance to users on common EHS issues potentially applicable to all industry sectors. For complex projects, use of multiple industry-sector guidelines may be necessary. A complete list of industry-sector guidelines can be found at: www.ifc.org/ifcext/enviro.nsf/Content/EnvironmentalGuidelines

The EHS Guidelines contain the performance levels and measures that are generally considered to be achievable in new facilities by existing technology at reasonable costs. Application of the EHS Guidelines to existing facilities may involve the establishment of site-specific targets, with an appropriate timetable for achieving them.

The applicability of the EHS Guidelines should be tailored to the hazards and risks established for each project on the basis of the results of an environmental assessment in which site-specific variables, such as host country context, assimilative capacity of the environment, and other project factors, are taken into account. The applicability of specific technical recommendations should be based on the professional opinion of qualified and experienced persons.

When host country regulations differ from the levels and measures presented in the EHS Guidelines, projects are expected to achieve whichever is more stringent. If less stringent levels or measures than those provided in these EHS Guidelines are appropriate, in view of specific project circumstances, a full and detailed justification for any proposed alternatives is needed as part of the site-specific environmental assessment. This justification should demonstrate that the choice for any alternate performance levels is protective of human health and the environment.

Applicability

The EHS Guidelines for Semiconductors and Other Electronics Manufacturing include information relevant to semiconductors and other electronics manufacturing projects and facilities. It does not include information about the extraction of raw materials, assembly of general components, manufacturing of screens for the assembly of internal components within the plastic structure, or production of standard connectors. Annex A contains a full description of industry activities for this sector. This document is organized according to the following sections:

[1] Defined as the exercise of professional skill, diligence, prudence and foresight that would be reasonably expected from skilled and experienced professionals engaged in the same type of undertaking under the same or similar circumstances globally. The circumstances that skilled and experienced professionals may find when evaluating the range of pollution prevention and control techniques available to a project may include, but are not limited to, varying levels of environmental degradation and environmental assimilative capacity as well as varying levels of financial and technical feasibility.

1.0 Industry-Specific Impacts and Management

The following section provides a summary of EHS issues associated with semiconductors and other electronic manufacturing that occur during the operational phase, along with recommendations for their management.
Recommendations for the management of EHS issues common to most large industrial facilities during the construction and decommissioning phases are provided in the **General EHS Guidelines**.

1.1 Environment

Environmental issues in semiconductors and other electronics manufacturing projects primarily include the following:

- Hazardous material use and waste management
- Air emissions
- Wastewater
- Energy use
- General process modifications

Hazardous Materials and Wastes

Almost all processes in semiconductors and other electronics manufacturing generate hazardous or potentially hazardous wastes, such as spent deionized water (containing inorganic acid), spent solvents and developers (e.g., iso-paraffinic hydrocarbons), spent cleaning solutions, sludges from wastewater treatment, spent epoxy material (printed circuit board [PCB] and semiconductor manufacturing), spent cyanide solutions (electroplating), and soldering fluxes and metals residue (printed circuit board assembly [PCBA]).

In addition to the relevant measures on hazardous materials management indicated in the **General EHS Guidelines,** specific pollution prevention techniques include process modifications and substitutes as follows:[2]

- Implementing process or equipment modifications, including:[3]
  - Regenerate plating baths by activated carbon filtration to remove built-up organic contaminants, which reduces the volume of plating baths to be disposed of and reduces the need for new chemicals;
  - Adopt automated gas cabinet systems to control fugitive emissions of gases from cylinders, particularly during changes;
  - Use of lead solder replacements with substitutes, such as tin alloys and other lead-free solders;
- Raw material substitution or elimination—for example, substitution of cyanide plating solutions (for gold plating in PCB industry) with acid sulfate copper, gold sulfite, and electroless nickel; replacing Cr VI with Cr III plating baths (PCB manufacturing, although the use of chromic plating baths is obsolete);
- Hazardous substance and waste segregation, separation, and preparation—for example, segregation of wastewater sludge by metal contaminants enhances waste recovery; storage of plating chemicals to segregate incompatible substances, such as cyanides from acids, and oxidizing agents from combustibles;
- Metal recovering and recycling, primarily in the semiconductor and PCBA sectors —for example, recovering copper and precious metals by electrolytic process; removing and recovering copper and tin from

[2] The use of lead, mercury, cadmium, chromium (Cr VI), polybrominated biphenyls, and polybrominated diphenyl ethers should be restricted or phased out as described by European Union (2003a and 2003b). Use of chlorofluorocarbons and trichloroethylene are phased out. Restrictions to the use of perfluorooctane sulfonates are being considered through the amendment of EU Council Directive 76/769/EEC (COM/2005/0618 final - COD 2005/0244). Voluntary measures to limit the use and the releases of perfluorooctane sulfonates have been adopted by the World Semiconductor Council (WSC) and the Semiconductor Equipment and Materials International (SEMI).

[3] Additional information is presented in Annex A.

boards by electrolysis-chemical precipitation; recovery of arsenic and gallium from gallium arsenide (GaAs) processing wastes (through thermal separation of GaAs solid wastes and recovery from GaAs polishing wastes);

- Reduce releases of perfluorooctane sulfonates (PFOS) in semiconductor manufacturing by phasing out non-critical uses of PFOS-based substances, such as some etching mixtures for which substitutes exist. For critical PFOS uses where no alternatives exist, such as shorter wavelength technologies used in the manufacture of semiconductors, controlled disposal of wastes should be carried out, particularly if incineration is involved.[4]

Hazardous materials management is discussed in the **General EHS Guidelines**. Specific measures for this sector include:

- Process chemicals storage areas should be regularly checked to identify leaks;
- Underground piping should be in a double pipe, with a means of identifying leaks from the inner pipe;
- Pipework carrying hazardous materials should be constructed of compatible materials and should be sufficiently supported, clearly labeled, and installed with high-quality joints. Piping should also be designed with low point drains, high point vents, and isolation valves every 30 meters maximum;
- Waste spill containment trays should be used.

Solid and hazardous waste management is discussed in the **General EHS Guidelines**. In this sector include, all wastes with hazardous properties (such as spent deionized water, spent solvents, spent cleaning solutions, sludges from wastewater treatment, spent epoxy material, and spent cyanide solutions, among others) should be clearly labeled and stored separately from general waste in dedicated and contained storage areas that are chemically resistant. Safe storage and containment are essential due to the high reactivity and toxicity of industry waste and by-products, as also discussed in the following section on occupational health and safety;

Air Emissions

The main emissions of concern generated by the semiconductors and electronics manufacturing industry include greenhouse gases, toxic, reactive, and corrosive substances (for example, acid fumes, dopant, cleaning gases, and volatile organic compounds [VOCs]), resulting from diffusion, cleaning, and wet-etching processes.[5]

There are three types of abatement systems for toxic and hazardous gases:

- Point-of-use (POU) systems that are relatively small and typically dedicated to a single process tool. These systems can remove up to 99.99 percent of effluent gases. For example, a POU scrubber can remove arsine to less than 50 ppb. Six basic technology types are used for POU abatement of gaseous and particulate pollutants, including perfluorocarbon compounds (PFCs), as follows:
  - o Wet scrubbing in semiconductor manufacturing, although it has a limited treatment range. Wet scrubbers are also used to treat acid gases and by-products of combustion/oxidation treatment;
  - o Hot chemical beds in semiconductor manufacturing;

[4] PFOS is on the list of chemical substances that display toxic, persistent and bioaccumulative properties, and therefore is being considered for inclusion in the list of persistent organic pollutants (POPs) of the Stockholm Convention. As indicated above, the industry sector (WSC and SEMI) completed a voluntary global agreement that describes elimination of all but critical uses and requires incineration of all non-wastewater emissions that contain PFOS. This agreement can be found at http://www.sia-online.org/pre_stat.cfm?ID=294

[5] Approximately 30 hazardous air pollutants have been identified by the US Environmental Protection Agency in semiconductors manufacturing, although it is estimated that more than 90 percent of all emissions are hydrochloric acid, hydrofluoric acid, propylene glycol ethers and their acetates, methanol, and xylenes.

  - Combustion / oxidation through fuel burners or electrically heated chambers, often combined with wet scrubbers (semiconductor and PCBA manufacturing);
  - Plasma reactors in semiconductor manufacturing, although they have a limited treatment range and require additional downstream abatement units;
  - Cold adsorbers in PCBA industry;
  - Traps, filters, cyclones, and precipitators in PCBA industry for removing solids and condensing vapors from exhaust stream.
- House systems that are relatively much larger and placed outside a fab (semiconductors foundry) and can handle high flow rates of effluents from many different sources;
- Emergency release scrubbers suitable for handling a large and sudden release of toxic gases are usually dedicated to the exhaust ventilation of gas cylinder storage areas. Emergency release scrubbers are aimed at preventing uncontrolled releases. However, most toxic gases can be controlled in special cabinets that are scrubbed or scrammed to atmosphere after careful monitoring of gas concentration to ensure that the gases are safely released with no impact on health and environment.

Perfluorocarbon Compounds and Other Greenhouse Gases

PFCs—including CF_4, C_2F_6, and C_3F_8—nitrogen trifluoride (NF_3), HFC-23 (CHF_3), and sulfur hexafluoride (SF_6) are used in semiconductor manufacturing, as cleaning gases in chemical vapor deposition (CVD) systems, in plasma etching, and, primarily, in thin film transistor-liquid crystal display (TFT-LCD) screens manufacturing. The main environmental issue associated with PFCs is their high global warming potential (GWP), which is linked to their long atmospheric life.[6]

PFC emission reduction and control techniques include the following:[7]

- Process optimization, especially in CVD cleaning processes;
- Chemical substitution, for example, using c-C_4F_8 or NF_3 as a drop-in alternative chamber cleaning gas instead of C_2F_6 in a modified CVD chamber, minimizing atmospheric emission;
- Abatement, through dissociation of the molecules into non-PFC by-products, by combustion, catalytic decomposition, or plasma destruction systems (the latter is applicable to etch tools only, less than or equal to 200 mm). Thermal destruction technology can be applied to chamber cleaning and etching processes within a fab (POU applications) or fab-wide (end-of-pipe applications);
- Capture and reuse of PFCs from exhaust streams, which is, however, a technically and economically challenging process.
- Additional information on the management of greenhouse gases is discussed in the **General EHS Guidelines**.

Acid Fumes

Potential emissions of acid fumes (mainly, hydrochloric acid and hydrofluoric acid) are related to the following processes in semiconductor manufacturing and PCBA industry:

- Cleaning, etching, and resist-stripping operations in semiconductors manufacturing;
- Etching, during which hydrogen chloride vapors may be released;

[6] In May 2005, the members of the World Semiconductor Council agreed to reduce PFC emissions by at least 10 percent from the baseline value (of 1995 for European, American, and Japanese associations; 1997 for the Korean association; and 1998 for Taiwan) by 2010.

[7] Additional information on emission reductions of PCFs through a variety of emission control technologies is provided in Intergovernmental Panel on Climate Change (2000).

- Cleaning, surface preparations, cupric chloride etching, and plating in PCB manufacturing.

Sulfuric acid aerosol emissions are also associated with the treatment of wafers with acid-etching mixtures. The most commonly used mixture contains sulfuric acid and hydrogen peroxide.

Acid fume emissions are reduced through the installation of horizontal (cross-flow) wet scrubbers or vertical (counterflow) wet scrubbers. Pollution prevention measures also include the following:

- Use of a mist suppressant on bath solution surfaces and use of wetting agents (surfactants);
- Reprocessing sulfuric acid used during wafer fabrication through heating and distillation to purify the acid stream; which is recovered and pumped back into wet stations;
- Installation of plating bath covers and meshpad mist eliminators.

Volatile Organic Compounds

Volatile organic compounds (VOCs) are primarily used in semiconductor manufacturing and PCBA industry. VOCs may be released in most cleaning and photolithography processes, during resist-drying, developing, and resist-stripping operations. Usually, VOC emissions are adsorbed onto activated carbon systems to facilitate recovery and / or treated by thermal oxidizers. Applicable pollution control techniques or add-on control devices used to control emissions consist of the following:

- Regenerative thermal oxidizers, which are usually practical when process exhaust stream volumetric flow rates are above about 3,000 scfm;
- Zeolite rotor concentrators with recuperative thermal oxidizers, which are used to concentrate dilute VOC streams prior to sending them to a destruction or recovery device;
- Fixed bed carbon adsorption with steam stripping for VOC recovery (either reuse or recycling off site);
- Fluidized bed carbon adsorption with hot nitrogen desorption and VOC recovery (either reuse or recycling off site);
- Fluidized bed polymer adsorption with hot nitrogen regeneration and VOC recovery where practical or with recuperative thermal oxidizers.

Nitrogen Oxides

As in other industrial sectors, NO_x emissions in semiconductors manufacturing include by-products of combustion processes. These by-products are derived from heating system boilers, emergency standby power generators, and thermal oxidizers that reduce VOC emissions. Relevant emission prevention and control technologies are presented in the **General EHS Guidelines**.

Dust

Drilling and routing processes during PCB manufacture generate significant amounts of dust, while semiconductor and PCBA industries are not significant emitters of dust. Some limited dust is generated by laser cutting, trimming, chemical mechanical polishing and backgrinding process in semiconductors manufacturing, as well as from the manufacturing of magnetic devices and passive components. Recommended control measures include:

- Water sedimentation systems
- Abatement with bag filters or electrostatic precipitators

Energy Consumption

Because there are many thermal processes and wafers handling is highly mechanized, semiconductor manufacturing involves significant energy use, which demands optimal energy consumption. The use of specialized equipment, which combines improved performance efficiency and energy efficiency should be implemented, for example:

- Air-handling equipment that controls humidity and temperature, allowing up to 25 percent of energy saved;
- High-efficiency chillers; and
- Recovering heat from water condensers that use heat exchangers may allow a modern industrial facility to save up to 40 percent of its needs.

Advanced technologies in emissions abatement also provide new equipment with enhanced abatement efficiency and lower energy consumption.

Wastewater

Industrial Process Wastewater

Wastewater effluents may be impacted by organic and inorganic compounds, such as metals, acids and alkalis, cyanides and suspended solids. To minimize both water use and potential discharge impacts, rinse water should be recovered to return treated water to the process for reuse.

Process wastewater may include organic compounds, particularly non-chlorinated solvents (e.g. pyrrole-based, amine-based, fluoro / ether-based resists, isopropyl alcohol, and tetramethylammonium hydroxide) from a number of semiconductor and PCBA manufacturing steps, including cleaning, resist drying, developing, and resist stripping; metals from metallization and CMP processes; acids and alkalis from spent cleaning solutions, process operations such as etching, cleaning, and metallization, among others; cyanides from metallization processes, and suspended solids from film residues and metallic particles (derived from photolithography, metallization, backgrinding, and dicing processes).

Process Wastewater Treatment

Since the semiconductors and electronics manufacturing operations use a diverse range of raw materials, chemicals and processes, wastewater treatment may require the use of unit operations specific to the manufacturing process in use and the specific contaminant. Techniques for treating industrial process wastewater in this sector include (i) source segregation and pretreatment of wastewater streams containing high concentrations of non-biodegradable compounds using phase separation such as solvent recovery, air stripping, chemical oxidation, adsorption processes, etc. (ii) reduction in heavy metals using chemical precipitation, coagulation and flocculation, electrochemical recovery, ion exchange, etc. (iii) chemical oxidation of cyanides; and (iv) dewatering and disposal of residuals in designated hazardous waste landfills. Additional engineering controls may be required for (i) advanced metals removal using membrane filtration or other physical/chemical treatment technologies, (ii) removal of recalcitrant organics and halogenated organics using activated carbon or advanced chemical oxidation, (iii) reduction in effluent toxicity using appropriate technology (such as reverse osmosis, ion exchange, activated carbon, etc.), and (iv) containment and treatment of volatile organics stripped from various unit operations in the wastewater treatment system.

Management of industrial wastewater and examples of treatment approaches are discussed in the **General EHS Guidelines**. Through use of these technologies and good practice techniques for wastewater management, facilities should meet the Guideline Values for wastewater discharge as indicated in the relevant table of Section 2 of this industry sector document.

Other Wastewater Streams & Water Consumption

Guidance on the management of non-contaminated wastewater from utility operations, non-contaminated stormwater, and sanitary sewage is provided in the **General EHS Guidelines**. Contaminated streams should be routed to the treatment system for industrial process wastewater. Recommendations to reduce water consumption, especially where it may be a limited natural resource, are provided in the **General EHS Guidelines**.

Printed Circuit Board (PCB) Manufacturing

Several pollution prevention measures have been developed in the PCB manufacturing process described in Annex A. Examples of process modifications with environmental benefits include:

- *Board manufacture*: surface mount technology (SMT) rather than plated through-hole technology, injection molded substrate, additive plating;
- *Cleaning and surface preparation*: use of non-chelating cleaners, extend bath life, improve rinse efficiency, counter current cleaning, and recycle/reuse cleaners and rinses;
- *Pattern printing and masking*: aqueous processable resist, screen printing to replace photolithography, ink-jet printing, dry photoresist, recycle/reuse photoresist strippers, segregate streams, and recover metals;
- *Electroplating and electroless plating*: replace by mechanical board production, non-cyanide baths, extend bath life, recycle/reuse cleaners and rinses, improve rinse efficiency, countercurrent rinsing, segregate streams, and recover metals.
- *Etching*: use differential plating, non-chelated etchants and non-chrome etchant, pattern versus panel plating, additive versus subtractive process, and recycle/reuse etchants;
- Metal recovery by regenerative electrowinning and ion-exchange technologies results in a near zero effluent discharge for segregated metal bearing streams. Heavy metals are recovered to metal sheets, which eliminate 95% of sludge disposal. Metal-bearing sludges that are not treated for recovery of metals should be disposed in secure landfills.

1.2 Occupational Health and Safety

Occupational health and safety hazards in semiconductors and other electronic manufacturing projects primarily include the following:

- Exposure to material released by substrates during handling or mechanical manipulation;
- Exposure to hazardous process chemicals, including metallic powders;
- Physical hazards and exposure to energy hazards (kinetic, electrical, pneumatic and hydraulic);
- Exposure to Ionizing and nonionizing radiation and lasers.

Substrates

While silicon-based semiconductor substrates (silicon dioxide) are non toxic dust arising from their manufacture and use can be hazardous. However GaAs and indium phosphide (InP) substrates pose more serious health and physical impacts. The most common exposure pathway for GaAs and InP is inhalation of particulates. Because of the high toxicity of arsenic and indium, both of these compounds have low occupational exposure levels. InP is flammable and can react with water vapor and acids to form phosphine, a toxic and flammable gas. GaAs is a hazard when ground, cut, or polished.

Prevention and control of these hazards involve the adoption of engineering and administrative controls to safeguard workers. The following precautions in use are commonly adopted:

- Use of local extraction from grinding or wet lapping. These operations should be done wet, and residues should be carefully rinsed. Dry grinding or lapping of GaAs should be avoided;
- Extraction and ventilation should be used for all processes involving these substrates, including cutting, grinding, polishing or etching operations;
- Clothes should be periodically cleaned to prevent contamination, and good hygiene practices should be promoted;
- Excessive heating should be avoided, and contact with strong acid reducing agents to produce highly toxic arsine or phosphine gas should be carefully avoided;
- Arsine and phosphine feedstocks should be housed in reduced-pressure containers.

Hazardous Process Chemicals

The semiconductors and electronics manufacturing process may include the use of numerous potentially hazardous chemicals.[8] Metallic powders also may be present in the manufacture of passive components and magnetic devices. Material-specific chemical protection programs should be developed and implemented as described detailed in the **General EHS Guideline**. Worker should be protected from exposure to process chemicals including but not limited to: acids, bases, solvents, metals powders and metal sludge as well as toxic, cryogenic and pyrophoric gases. Additional, sector specific recommendations include:

- Substitutions of hazardous materials, such as ethylene-based glycol ethers, with less hazardous substitutes in semiconductor manufacturing;
- If silane (SiH_4) or other potentially hazardous gases (e.g., HF, H_2) are used in semiconductor manufacturing, installation of integrated alarm systems with gas detectors and alarms set at regulatory or industry established safety margins;
- Use of isolated, automated, manufacturing systems to prevent worker exposure when hazardous chemical substitution is not feasible in both semiconductor and PCB assembly industry;
- Use of engineering controls such as dust and vapor extraction and ventilation systems to remove airborne compounds from work area should be installed in both semiconductor and PCB assembly industry.

Physical Hazards and Energy Hazards

Physical hazards potentially present in semiconductor and electronic manufacturing include the movement of heavy objects—for example, large wafer carriers (especially for the 300 mm wafer size) and final packaged products, and work in proximity to automated equipment. General recommendations for the prevention and management of physical and energy (including kinetic, electrical, pneumatic and hydraulic) hazards in the workplace are presented in the **General EHS Guidelines.**

Ionizing and Non-ionizing Radiation and Lasers

The manufacturing process may include sources of ionizing radiation such as x-rays, gamma rays, and alpha and beta particles, all of which are characterized by a short wavelength and high energy. Potential types of nonionizing radiation in the manufacturing process may include radio frequency radiation (used in equipment producing plasma), UV radiation, infrared radiation, and visible light. Non-ionizing radiation may be

[8] A sample list includes: acetone, ammonia, ammonium hydroxide, arsine, boron trifluoride, carbon dioxide chlorine, chlorine trifluoride, diborane, dichlorosilane, disilane, fluorine, gallium arsenide, germane, hydrochloric acid, hydrofluoric acid, hydrogen, indium phosphide, methane, nitric acid, nitric oxide, nitrogen fluoride, nitrous oxide, ozone, phosphorus oxychloride, phosphine, phosphoric acid, silane, sulfuric acid, tetrafluoro methane, trichlorosilane, trimethyl arsenic, and trimethyl Indium.

produced by some types of high-powered heaters, test equipment, and high-powered antennas.

Lasers are classified by their ability to damage the eyes or skin. If directed or reflected on an object, laser light can be partially absorbed, raising the temperature and causing an alteration of the exposed material.

Exposures to radiation sources should be prevented through use of protective enclosures and interlock for source equipment, and worker training in the importance and maintenance of these enclosures and interlocks. Additional information of radiation exposure is presented in the **General EHS Guidelines.**

Engineering controls, such as protective housing with interlocks, protective filter installations, and system interlocks, should be installed to prevent hazards from laser use.

1.3 Community Health and Safety

Community health and safety impacts during the operation, construction and decommissioning of semiconductors and other electronics manufacturing plants are similar to those of most industrial facilities and are discussed in the **General EHS Guidelines**.

2.0 Performance Indicators and Industry Benchmarks

2.1 Environment

Emissions and Effluent Guidelines

Tables 1 and 2 present effluent and emission guidelines for this sector. Guideline values for process emissions and effluents in this sector are indicative of good international industry practice as reflected in relevant standards of countries with recognized regulatory frameworks. These guidelines are achievable under normal operating conditions in appropriately designed and operated facilities through the application of pollution prevention and control techniques discussed in the preceding sections of this document. These levels should be achieved, without dilution, at least 95 percent of the time that the plant or unit is operating, to be calculated as a proportion of annual operating hours. Deviation from these levels in consideration of specific, local project conditions should be justified in the environmental assessment.

Effluent guidelines are applicable for direct discharges of treated effluents to surface waters for general use. Site-specific discharge levels may be established based on the availability and conditions in use of publicly operated sewage collection and treatment systems or, if discharged directly to surface waters, on the receiving water use classification as described in the **General EHS Guidelines**.

Emissions guidelines are applicable to process emissions. Combustion source emissions guidelines associated with heat - and power-generation activities from sources with a heat input capacity equal to or lower than 50 MWth are addressed in the **General EHS Guidelines** with larger power source emissions addressed in the **EHS Guidelines for Thermal Power**. Guidance on ambient considerations based on the total load of emissions is provided in the **General EHS Guidelines**.

Table 1. Effluent levels		
Pollutants	**Units**	**Guideline Value**
pH	—	6–9
COD	mg/L	160
BOD_5	mg/L	50
Total suspended solids	mg/L	50
Oil and grease	mg/L	10
Total phosphorus	mg/L	2
Fluoride	mg/L	5
Ammonia	mg/L	10
Cyanide (total)	mg/L	1
Cyanide (free)	mg/L	0.1
AOX (adsorbable organic bound halogens)	mg/L	0.5
Arsenic	mg/L	0.1
Chromium (hexavalent)	mg/L	0.1
Chromium (total)	mg/L	0.5
Cadmium	mg/L	0.1
Copper	mg/L	0.5
Lead	mg/L	0.1
Mercury	mg/L	0.01
Nickel	mg/L	0.5
Tin	mg/L	2
Silver	mg/L	0.1
Selenium	mg/L	1
Zinc	mg/L	2
Temperature increase	°C	<3[a]

a At the edge of a scientifically established mixing zone which takes into account ambient water quality, receiving water use, potential receptors and assimilative capacity.

Table 2. Air emission levels[c]		
Pollutants	**Units**	**Guideline Value**
VOC[a]	mg/Nm^3	20
Organic HAP[b]	Ppmv	20
Inorganic HAP[b]	Ppmv	0.42
HCl	mg/Nm^3	10
HF	mg/Nm^3	5
Phosphine	mg/Nm^3	0.5
Arsine and As compounds	mg/Nm^3	0.5
Ammonia	mg/Nm^3	30
Acetone	mg/Nm^3	150

NOTES:
[a] Applicable to surface cleaning processes.
[b] Industry-specific hazardous air pollutants (HAPs) include: antimony compounds, arsenic compounds, arsine, carbon tetrachloride, catechol, chlorine, chromium compounds, ethyl acrilate, ethylbenzene, ethylene glycol, hydrochloric acid, hydrofluoric acid, lead compounds, methanol, methyl isobutyl ketone, methylene chloride, nickel compounds, perchloroethylene, phosphine, phosphorous, toluene, 1,1,1-trichloroethane, trichloroethylene (phased-out), xylenes. Current industry practice is not to use ethylbenzene, toluene, xylene, methylene chloride, carbon tetrachloride, chromium compounds, perchloroethylene, 1,1,1-trichloroethane, or trichloroethylene.
[c] At 3 percent O_2.

Resource Use and Waste Generation

Table 3 provides examples of resource consumption indicators for energy and water, in addition to waste generation in this sector. Industry benchmark values are provided for comparative purposes only and individual projects should target continual improvement in these areas.

Table 3. Water and energy consumption and waste generation

Inputs per unit of product	Unit	Industry benchmark
Water **Wet bench ultrapure water (UPW) use**	l/300-mm wafer pass	42
UPW consumption	l/200-mm wafer	4 000–8 000
Net feed water use	l/cm²	8–10
Fab UPW use	l/cm²	4–6
Energy **Total fab tools**	kWh/cm² per wafer out	0.3–0.4
Total fab support systems		0.5–0.6
Outputs per unit of product	**Unit**	**Industry benchmark**
Waste[a] **Hazardous liquid waste recycle and reuse**	*%*	*80*
Solid waste recycle and reuse	*%*	*85*

NOTES:
[a] The semiconductor manufacturers should aim at realizing a "zero waste" plant.
Source: International Technology Roadmap for Semiconductors (2005).

Environmental Monitoring

Environmental monitoring programs for this sector should be implemented to address all activities that have been identified to have potentially significant impacts on the environment, during normal operations and upset conditions. Environmental monitoring activities should be based on direct or indirect indicators of emissions, effluents, and resource use applicable to the particular project.

Monitoring frequency should be sufficient to provide representative data for the parameter being monitored. Monitoring should be conducted by trained individuals following monitoring and record-keeping procedures and using properly calibrated and maintained equipment. 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. Additional guidance on applicable sampling and analytical methods for emissions and effluents is provided in the **General EHS Guidelines.**

2.2 Occupational Health and Safety

Occupational Health and Safety Guidelines

Occupational health and safety performance should be evaluated against internationally published exposure guidelines, of which examples include the Threshold Limit Value (TLV®) occupational exposure guidelines and Biological Exposure Indices (BEIs®) published by American Conference of Governmental Industrial Hygienists (ACGIH),[9] the Pocket Guide to Chemical Hazards published by the United States National Institute for Occupational Health and Safety (NIOSH),[10] Permissible Exposure Limits (PELs) published by the Occupational Safety and Health Administration of the United States (OSHA),[11] Indicative Occupational Exposure Limit Values published by European Union member states,[12] or other similar sources.

[9] Available at: http://www.acgih.org/TLV/ and http://www.acgih.org/store/
[10] Available at: http://www.cdc.gov/niosh/npg/
[11] Available at: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992
[12] Available at: http://europe.osha.eu.int/good_practice/risks/ds/oel/

Accident and Fatality Rates

Projects should try to reduce the number of accidents among project workers (whether directly employed or subcontracted) to a rate of zero, especially accidents that could result in lost work time, different levels of disability, or even fatalities. Facility rates may be benchmarked against the performance of facilities in this sector in developed countries through consultation with published sources (e.g. US Bureau of Labor Statistics and UK Health and Safety Executive)13.

Occupational Health and Safety Monitoring

The working environment should be monitored for occupational hazards relevant to the specific project. Monitoring should be designed and implemented by accredited professions[14] as part of an occupational health and safety monitoring program. Facilities should also maintain a record of occupational accidents and diseases and dangerous occurrences and accidents. Additional guidance on occupational health and safety monitoring programs is provided in the **General EHS Guidelines**.

[13] Available at: http://www.bls.gov/iif/ and http://www.hse.gov.uk/statistics/index.htm

[14] Accredited professions may include certified industrial hygienists, registered occupational hygienists, or certified safety professionals, or their equivalent.

3.0 References and Additional Sources

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Annex A: General Description of Industry Activities

The electronics industry includes the manufacturing of semiconductors, printed circuit boards (PCBs), printed wiring assemblies (PWAs), screens, passive components, and magnetic devices.

Semiconductors Manufacturing

Semiconductors manufacturing uses silicon, silicon carbide (SiC), gallium arsenide (GaAs), metals, chemicals, water, and energy. The purity of all materials must be very high, so specialty gas systems, automated chemical handling systems, and clean dry air (CDA) systems in the clean rooms are essential, especially in photolithography. An ultrapure water (UPW) system is also necessary, because semiconductor manufacturing needs a large volume of UPW, primarily in wet-cleaning processes, but also in acid etching, solvent processes, and tool-cleaning processes. Many new fabs are reducing water consumption by recycling an important portion of the wastewater that is derived from rinsing steps. This process does not add significantly to water contaminants. Because integrated circuits are becoming smaller, vibration control and foundation design of the facility have become more significant.

The manufacturing process includes hundreds of operations that are performed layer by layer on a solid crystalline material, mainly silicon, and more recently on silicon carbide (SiC). Gallium arsenide (GaAs) is used for many military and commercial applications, including lasers, light-emitting diodes (LED), and communication devices (for example, cellular phones use GaAs chips as microwave oscillators).

Semiconductor manufacturing includes two basic series of operations: manufacturing of semiconductor wafers and Assembly, Packaging, and Test (APT), which is the assembly of wafers into usable integrated circuits.

Figure A.1 (last page) summarizes the main steps in semiconductors manufacturing, highlighting inputs of chemicals and other fluids, and emissions / effluents / waste generation points.

Semiconductor wafer manufacture needs a uniform crystalline multilayer structure of silicon (silicon wafer), which is obtained using controlled techniques, such as chemical vapor deposition (CVD) or molecular beam epitaxy (MBE). Subsequently, a thin layer of silicon dioxide, which insulates and protects the silicon, is formed over the silicon wafer by heat treatment in a high temperature furnace (900°C to 1,200°C). Then, the wafer is uniformly coated with a thin light-sensitive material, called photoresist (positive or negative), and is exposed to ultraviolet light or x-rays passing through a glass mask or stencil, previously created with the circuit pattern.

Positive photoresist becomes soluble in the exposed areas and can be removed by chemical developers, revealing the pattern of the photoresist made by the mask on the silicon dioxide (developing). Silicon dioxide is then removed through wet or dry etching: the former treatment uses acids, bases, or caustic solutions; the latter, also called plasma etching, uses a reactive ionized gas and provides a higher resolution and less wastes. The excess photoresist is finally removed by solvent or plasma stripping. By repeating the steps (up to 25 to 30 times) from silicon oxidation through photoresist removal and using different masks, different regions are formed on the layers and are insulated from each other. This entire process is called photolithography or microlithography.

The use of plasma etching of silicon nitride, a dry process, in Metal Oxide Semiconductor (MOS) technology, allows replacing the hot corrosive phosphoric acid (H_3PO_4) wet process, and provides reductions in generated waste, and better safety for workers, while reducing the number of processing steps.

To change the conductivity of silicon regions, dopants are introduced by diffusion or ion implantation. Diffusion can be gaseous or nongaseous, and it is performed in a high temperature environment. Ion implantation consists of a bombardment of the exposed areas of silicon with accelerated ions. Selective interconnection of different regions and layers on the wafer is obtained through metallization: a dielectric material is deposited and patterned in damascene processing; then the features are filled with aluminum alloys under vacuum or copper by electroplating or electrochemical deposition (ECD). The excess copper is removed with chemical mechanical polishing (CMP) or planarization. Other metallization techniques, especially with copper, include physical vapor deposition (PVD) and atomic layer deposition (ALD). Finally, a surface layer of oxide or polyamide is applied over the wafer surface through passivation to provide a circuit protective seal.

Very thin semiconductors are needed in new applications; therefore, the wafer thickness is reduced by backgrinding or stress relief. Each finished wafer may contain hundreds of chips that are all electrically tested (measurement) before being cut into individual chips with an ultrathin diamond blade (dicing) and marked. After electrical testing, each chip is mounted on a metal or ceramic frame, connected with thin gold wires, and encapsulated for mechanical support and protection against external environment. The final package can contain one or several connected chips.

Nanotechnology and Micro-electromechanical Systems

Nanotechnology involves the creation of functional structures on an atomic or molecular scale, with at least one characteristic dimension measured in nanometers. Evaporation of some metal oxide powders (ZnO, Ga_2O_3, SnO_2, and so on) at high temperature allows synthesizing nano-belts and nano-wires of the same metal oxides. The resulting semiconductors are generally used as sensors, transducers, or in other applications for electronic and optoelectronic devices.

Microelectromechanical systems (MEMS) are essentially made of microtransducers (for example, microsensors for temperature, pressure, chemical substances, and radiation). Their fabrication techniques are similar to those used for chips. Materials used in MEMS production are diverse, with specific electrical properties, but they also have selected mechanical and thermal or chemical properties. Silicon is used most often.

The most common production technology for MEMS devices involves deposition and pattern of a silicon oxide layer, followed by deposition and pattern of a polysilicon layer and removal of the oxide layer, allowing the polysilicon layer to move as a cantilever, which usually is performed in hydrofluoridric acid mixtures.

Cutting and separating processes are critical, because the movable parts on the MEMS device are fragile. Device testing is application specific, and assembly of MEMS devices is generally demanding because of their fragility. Packaging is again application specific, but all packages are aimed at protecting the die from environmental effects, without preventing access to the environmental parameters that are essential to proper operation (for example, application for a pressure sensor in airbags). MEMS devices are used in many industrial sectors, including inter alia the automotive, industrial control, office equipment, aerospace, medical, and communications sectors.

Printed Circuit Board (PCB) Manufacturing

PCB manufacturing is related to the etching and pattern plating of circuits on base materials, which are often layered. PCBs can be single-sided, double-sided, multilayer, and flexible. Additive, semi-additive, or subtractive technologies can be used, although the subtractive technology is most commonly applied. Board preparation consists of cleaning, laminating, and drilling holes; chemical and mechanical cleaning is required before electroless plating. The imaging step allows circuit patterns to be transferred onto the board through the photolithography process or screen printing; electroplating (usually copper) is then used to thicken the conductive layers and to protect them against corrosion or erosion. In solder coating (or hot air solder leveling), the PCB is dipped into a molten solder, typically a low melting alloy (for example, lead-free tin alloys). The excess solder is eliminated by hot air leveling. PCB manufacturing includes final production steps in which electrical tests, dimensional and visual inspections, packaging, and labeling are performed.

Printed Circuit Board Assembly (PCBA) Manufacturing

PCBs are essentially formed by a base, which is made of pressed epoxy resin, Teflon™, fiberglass, or ceramic, on which semiconductors (silicon, silicon carbide, or GaAs) and passive components are mounted. Specific electrical components are attached and soldered on PCBs. A chemical flux is typically used to clean the board and ease the following solder connection. Soldering can be performed by different techniques, including wave soldering, surface mount technology (SMT) and hand soldering. In the PCB assembly process, non-ozone depleting alternatives are available for cleaning printed circuit board assemblies including, for example, other organic solvents, hydrocarbon/surfactant blends, alcohols, and organic solvent blends), and aqueous and semi-aqueous processes. Currently, the flux residue is removed with deionized water; Freon 113 (CFC-113) and trichloroethane (TCA), now banned, were used previously. The industry has shown that even sophisticated PCB assemblies can be made without cleaning by using low residue fluxes that leave very little in the way of contamination on the boards.

Screen Manufacturing

Flat panel displays are classified in a projection and direct view group, which is further classified in emissive and nonemissive subgroups. The most popular flat panel display is the liquid crystal display (LCD), in which the liquid crystal (LC) arrangement is controlled through an electric field. What the viewer sees depends on the LC molecular arrangements. A color filter and a thin film transistor (TFT) are aligned and sealed together, with a spacer between them; LCs are injected and the end seal is formed. Finally, the polarizer, tape carrier package, electronics, backlight, and chassis are assembled.

Organic light-emitting displays (OLEDs) have a simple structure and are solid state displays, because they have no vacuum, liquid, or gas inside. OLEDs use small molecules of luminance material that are deposited by vacuum evaporation. Polymer LEDs (PLEDs) use polymers of luminance materials usually deposited by ink-jet printing or spin coating. To improve their performance, a TFT is added. The OLEDs have the advantages of simple production process, high optical efficiency, and low voltage drive, but they have a short lifespan.

Passive Components Manufacturing

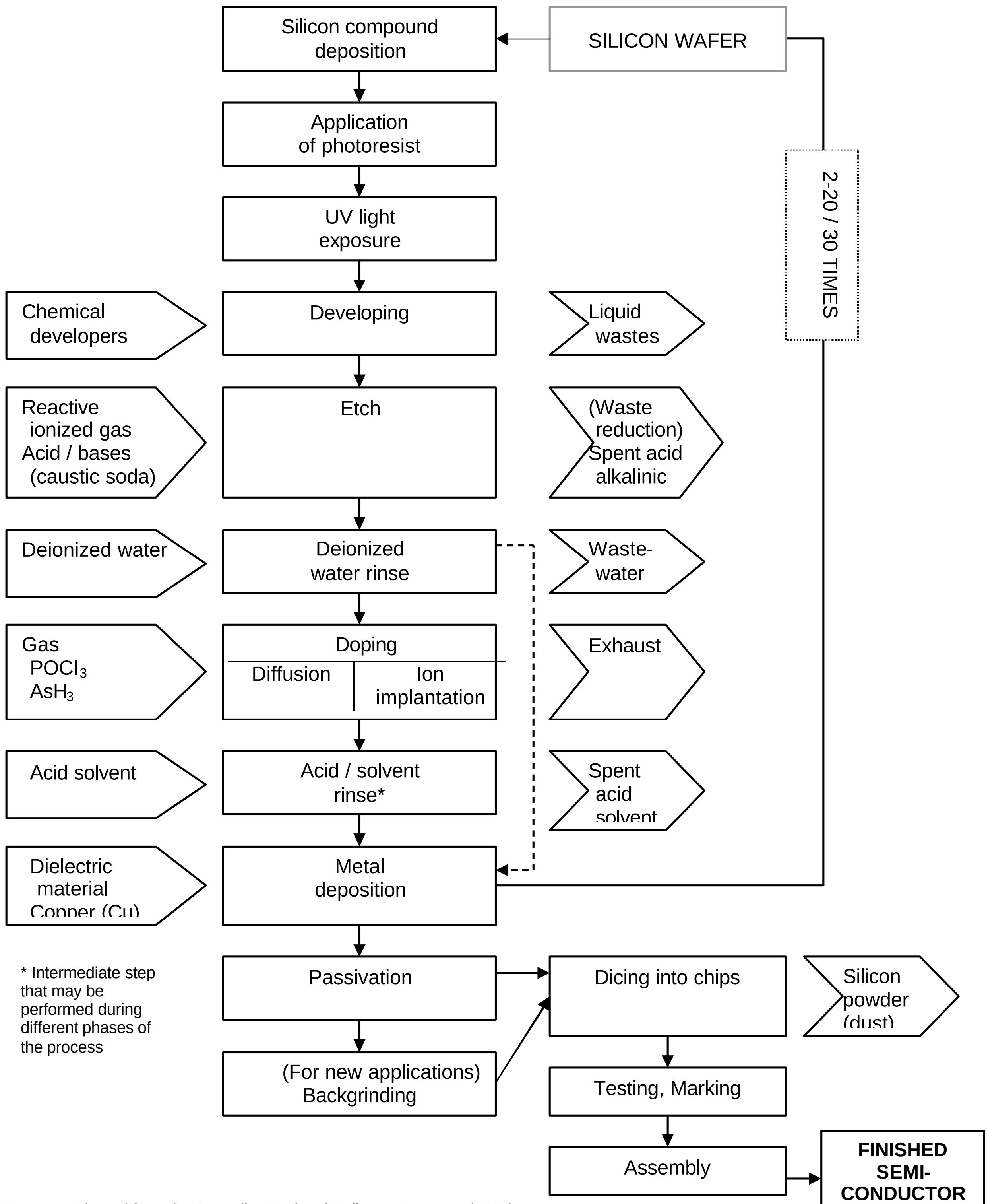
The main technology used for passive components manufacturing is the pressing and/or sintering of powders—alumina (Al_2O_3), aluminum nitride (AlN), and so on—to obtain ceramics with insulating, conducting, or piezoelectric characteristics. The most common manufacture is the production of ceramic insulating substrates (Al_2O_3, AlN) for integrated microcircuits.

For high power substrates, AlSiC or CuSiC are used to obtain an improved thermal conductivity, compared with the standard Al_2O_3. Mixing additives to a carbon or SiC base, resistors of any dimension and ohmic value are produced. Piezoelectric characteristics are mainly used in all fields of pressure sensors (automotive), stress sensors, and ultrasound cleaners in the industry, or to emit ultrasounds for echography. Special zinc oxide (ZnO) ceramics are used for spike voltage suppressors (varistors).

Magnetic Devices Manufacturing

The magnetic devices manufacturing processes are based on mixing magnetic powders (iron or rare earth elements) to obtain magnetic films or tapes for data storage in the informatics industry, and ceramic or sintered metal with enhanced magnetic characteristics, used for manufacturing the core of small pulse transformer or special extra powerful magnets for motor industry or for static magnetic resonance equipments.

Figure A.1: Schematic View of Semiconductors Manufacturing Process



Source: Adapted from the Australian National Pollutant Inventory (1999)