PRELIMINARY CONTROL TECHNOLOGY SURVEY

on

DATEL-INTERSIL CORPORATION
Mansfield, Massachusetts

to

U.S. Environmental Protection Agency
Industrial Environmental Research Laboratory
26 West St. Clair Avenue
Cincinnati, Ohio 45268

and

National Institute for Occupational Safety and Health
Division of Physical Sciences and Engineering
Engineering Control Technology Branch
4676 Columbia Parkway
Cincinnati, Ohio 45226

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by

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Survey Date: December 1, and December 3, 1983

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1.0 ABSTRACT

A preliminary control technology assessment survey was conducted at Datel-Intersil, Mansfield, Massachusetts on December 1 and 3, 1983, by Battelle Columbus Laboratories, Columbus, Ohio. The survey was conducted as part of a project under a U.S. Environmental Protection Agency contract funded through an Interagency Agreement with the National Institute for Occupational Safety and Health. Datel-Intersil manufactures printed circuit boards and hybrid microcircuits.

The process operations for printed circuit board fabrication include: (1) tooling, drilling and sanding fiberglass laminated boards, (2) copper fluoborate electroplating, (3) tin/lead fluoborate electroplating, (4) photoresist lamination, (5) photoresist stripping, (6) wet chemical etching of copper wtih chromic acid and sulfuric acid, (7) tin stripping, (8) nickel sulfamate electroplating, and (9) gold cyanide electroplating.

Engineering controls used during printed circuit board fabrication include: (1) process isolation used in copper etching and photoresist developing and (2) local exhaust ventilation used in electroplating operations, tooling, drilling and sanding, photoresist stripping, and tin stripping. Wet operations are used to control emissions of free crystalline silicon dioxide during scrubbing operations.

Additional control strategies employed during printed circuit board fabrication include personal protective equipment such as gloves and goggles used during chemical operations (electroplating, etching, stripping).

The process operations for hybrid microcircuit fabrication include: (1) thermal oxidation of single crystal silicon wafers, (2) metal deposition on ceramic and single crystal silicon substrates by electron-beam evaporation and radio frequency radiation, (3) electroplating of gold on substrates, (4) photolithography processes to define electrical circuit patterns including substrate preparation, contact mask alignment exposure, photoresist

developing and photoresist stripping, (5) laser trimming of metal layers, and (6) assembly of hybrid microcircuit components and testing.

Engineering controls used during hybrid microcircuit fabrication vary by process operation and process equipment. Several process operations are performed in sealed reaction chambers that isolate the processes from the workers. Process isolation is used in electron-beam evaporation and radio frequency spattering operations. Shielding is used in diffusion furnace assembly to prevent contact with hot surfaces and in contact mask alignment exposures to prevent emissions of ultraviolet light. Local exhaust ventilation is used to remove process gases and byproducts from thermal oxidation, photolithography operations (substrate development and photoresist stripping), and during hybrid microcircuit assembly.

Continuous area monitoring of toxic flammable gases or vapors is not performed. Installation of a combustible gas monitoring system is recommended.

2.0 INTRODUCTION

A preliminary survey was conducted at Datel-Intersil, Inc., 11 Cabot Boulevard, Mansfield, Massachusetts on December 1 and 3, 1981 as a part of a control technology assessment of the semiconductor manufacturing industry. The study was performed under U.S. Environmental Protection Agency Contract No. 68-03-3026 through an Interagency Agreement with the National Institute for Occupational Safety and Health. The survey was conducted by Battelle Columbus Laboratories, Columbus, Ohio.

The following plant representatives supplied information at Datel-Intersil:

1. Arthur A. Cronin, Personnel Director
2. Nicholas Kolkalus, Supervisor, Printed Circuit Boards
3. Bob Fortier, Supervisor, Hybrid Microcircuits
4. Bill Opie, Facilities Engineer.

The study protocol was provided to Mr. Arthur Cronin before the survey. During an opening conference, the study objectives and methods were described. Plant staff provided a detailed description of plant operations and facilities and reviewed the facility health and safety program.

Following the opening conference, the research team surveyed the printed circuit board production hybrid microcircuit assembly, packaging and testing, chemical storage facilities, air supply and exhaust systems, and waste treatment systems.

3.0 PLANT DESCRIPTION

3.1 GENERAL

Datel-Intersil manufactures printed circuit boards, thin film hybrid microcircuits, data printers, and computer peripheral equipment. Repair devices sold by Datel-Intersil is also performed at the facility. Integrated circuits used in the hybrid microelectronic circuits are purchased. The firm was founded in 1970 as Datel and was acquired in February 1979 by Intersil, becoming Datel-Intersil. General Electric then acquired the Datel-Intersil in March 1981.

The plant facility is a single story Class I, Type A, steel and concrete building consisting of 145,000 sq. ft. The present building occupied by Datel-Intersil was constructed in 1978 and was occupied in December 1978. The facility consists of the following areas: (1) 7,080 sq. ft. printed circuit board manufacturing, (2) 6,800 sq. ft. systems manufacturing, (3) 1,150 sq. ft. modular assembly, (4) 2,010 sq. ft. encapsulation, (5) 2,380 sq. ft. transformer room and (6) 1,440 sq. ft. panel meter room (manufacturing).

Datel-Intersil employs 340 workers in production and 204 in administration and technical support at the facility. Workers operate on 2 shifts, with the majority of production taking place during the first shift.

An emergency generator at the facility supplies power to emergency lighting, electrical outlets, and the diffusion furnace. The ventilation exhaust system is not on emergency power.

3.2 CHEMICAL STORAGE

The chemical storage room is adjacent to the integrated circuit area in an area intended for future expansion. The room is used for storage of equipment, supplies and chemicals. Caustic materials in 1 gallon containers are stored on metal racks. Acids and organic chemicals in 1 gallon containers are stored on the floor. The storage room was not diked and did not have a floor drain. There is some limited storage of process chemicals in unvented cabinets in the production areas for use during production.

3.3 GAS HANDLING SYSTEMS

The facility uses hydrogen, oxygen, nitrogen, and liquid nitrogen in the production operations. Hydrogen and oxygen are supplied from cylinders located outside the building in a covered locked area. Gases are distributed through stainless steel lines with compression (Swagelock) fittings. Nitrogen is supplied from a tank located outside and at the rear of the building.

3.4 MONITORING SYSTEMS

Monitoring systems for toxic or flammable chemical agents are not used at the facility. Smoke and fire alarms are located throughout the building.

3.5 VENTILATION SYSTEM

The ventilation system consists of air treatment and recirculation, and local exhaust ventilation. Heated, cooled, and filtered air is supplied to all plant areas through ceiling mounted diffusers. Air supply to the production areas includes (1) 11,200 cfm to the integrated circuit area, (2) 4,400 cfm to the photoresist area, (3) 13,120 cfm to the microelectronics area, (4) 8,840 cfm to the printed circuit board laboratory, and (5) 6,700 cfm to the area containing the routing, drilling and photoresist rooms, dark room, and camera (transformer) room. Ten percent of the air supply is fresh make-up air with the remainder recirculated air.

Local exhaust ventilation from process operations is exhausted through stacks to the atmosphere. Exhaust from the routing and drilling operations is passed through a fabric filter for removal of particulates. Air from all other local exhaust ventilation systems is exhausted without treatment. The quantity of air that is removed by local exhaust ventilation is not known by the plant facility engineering. Exhaust fans are located in the penthouse below roof level. The exhaust fans are not connected to the emergency power source. The exhaust stacks are constructed of polyvinyl chloride and exit the penthouse to the roof. The exhaust stacks have 180° elbows that direct air down onto the roof. Fresh air intakes for the air handling systems are also located on the roof. The configuration of the exhaust stacks in proximity to the fresh air intakes may potentially contaminate the supply air.

Local ventilation from plating, cleaning and etching tanks, vacuum pumps, and diffusion (oxidation) furnaces, automated photoresist developer, drilling/routing, fume hoods and testing ovens is exhausted through several stacks on the roof, designed with the 180° elbow as described above.

3.6 WASTE MANAGEMENT

Solvent wastes (trichlorethylene and acetone) are collected and stored in plastic 35 gallon drums located in the chemical storage area. Waste sulfuric acid is neutralized to pH 7.0 at the facility by a Calgon R system using sodium hydroxide.

Gold plating solution, containing cyanide salts, is cleaned by filtration at the facility and reused. The impregnated filter is then returned to the manufacturer for the recovery of gold. A chromic acid/sulfuric acid mixture used in etching copper from printed circuit boards is also collected and returned to the manufacturer. Some etching, cleaning, and plating operations require only replacement of the chemical solutions. All pump oils from oil-sealed mechanical pumps used in metallization operations are changed every six months. The used oils are recycled and reprocessed.

4.0 PROCESS DESCRIPTION

The fabrication sequence used in the manufacture of thin film hybrid microelectronic circuits varies depending upon the specific type of device manufactured. Process operations observed at the facility are discussed below. The specific sequence in which the process operations are performed is not presented. A general processing sequence for thin film hybrid microelectronic circuits is provided by Colclaser (1980) and should be consulted for a more detailed review of the fabrication process. Several process operations are employed more than once in the fabrication sequence and some equipment is used for more than one process operation.

Printed circuit boards are also manufactured at Datel-Intersil for use as a substrate in the assembly of components such as resistors, capacitors, and hybrid microelectronic circuits. Process steps include (1) tooling, drilling and sanding, (2) copper fluoroborate electroplating, (3) photolithography including lamination, mask transfer and developing, (4) pattern plating, (5) tin/lead fluoroborate electroplating, (6) photoresist stripping, (7) etching, (8) tin stripping (9) nickel electroplating, and (10) gold electroplating. Datel-Intersil purchases laminated fiberboards that are used on the substrate. The board is automatically drilled and sanded by computer assisted manufacturing process. Copper, acting as an electrical conductor, is deposited onto the board in a copper fluoroborate electroplating operation. A laminate photoresist film is applied to the copper-plated board. A mask pattern is transferred to the photoresist laminated board by overlaying the board with the mash and exposing it to ultraviolet light. The exposed board is developed by automated spraying with 2-butoxyethanol. Following the developing, a series of pattern plating operations are used to deposit copper, lead/tin, nickel, and gold. The fabrication sequence is shown in Figure 1. Materials used during fabrication of the printed circuit board are listed in Table 1 for each process.

FIGURE 1. PRINTED CIRCUIT BOARD (PCB) FABRICATION SEQUENCE, DATEL-INTERSIL

Purchase laminated Fiber Board	Tooling Drilling Sanding	Copper Fluoborate Electroplating	Laminate Photo-resist Film	Mask (UV)	Spray Develop 2-Butoxyethanol		
Electroless Copper Plating	Accelerator (Unspecified)	Palladium/ Acid (unspecified) Catalyst	Hydrochloric Acid	Sulfuric Acid	Sodium Persulfate (100°F)	Ethanolamine Immersion (175°F)	
Copper Fluoborate Electroplating	Acid strip (unspecified)	Sulfuric acid clean	Sodium persulfate	Sulfuric acid	Hydrochloric acid	Sodium persulfate	Sodium persulfate
Acid Cleaning (Unspecified)	Acid stripping of Tin (Unspecified)	Sulfuric Acid/ Chromic Acid Etching	Heat Dry	Wet pumice scrub (55% free crystalline SiO_2)	Acid stripping (unspecified)	Tin/Lead Fluoborate Electroplating	
Sulfuric Acid Cleaning	Sodium Persulfate	Sulfuric Acid	Hydrochloric Acid	Nickel Electroplating (Nickel Sulfamate)	Gold Electroplating (Cyanide)	Drying	Cutting

[1]Rinse with water between process steps.

TABLE 1. MATERIALS USED DURING THE FABRICATION OF PRINTED CIRCUIT BOARDS. DATEL-INTERSIL

Operations	Materials
Drilling, Sanding and Tooling	Fiberboard laminate (fiberglass)
Copper Fluoborate Electroplating	Cupric Fluoborate - $Cu(BF_4)_2$
Photolithography - Lamination	Proprietary organic polymer
- Developing	2-Butoxyethanol
	2-(2-Butoxyethoxy) Ethanol
Pattern Plating	Ethanolamine
	Sodium persulfate
	Sulfuric acid
	Hydrochloric acid
	Palladium/acid catalyst (unspec.)
Electroless Copper Plating	Formaldehyhde
	Organic mercury (unspecified)
	Sodium hydroxide
	Copper
Tin/Lead Fluoborate Electroplating	LAC 41
	Sulfuric acid
	Sodium persulfate
	Tin fluoborate
	Lead fluoborate
	Boric acid
	Peptone
	2-Butoxyethanol
	2-(2-butoxyethoxy) Ethanol
Photoresist Stripping	Pumice (55% free crystalline SiO_2)
Etching	Sulfuric acid
	Chromic acid
Tin Stripping	Unspecified acid
Nickel Electroplating	Nickel sulfamate
	Sulfuric acid
	Sodium persulfate
	LAC 41
Gold Electroplating Cyanide	Cyanide salts, gold

Hybrid microcircuit assembly consists of the following operations: (1) RF spattering of purchased ceramic, silicon and/or quartz substrates, with tantalum, aluminum oxide, quartz, nichrome, gold and aluminum, (2) thermal oxidation of silicon substrates, (3) electron-beam evaporation of nichrome, nickel and gold on ceramic, silicon and quartz substrates, (4) gold electroplating, (5) photolithography with contact masks alignment exposure, (6) assembly, (7) electrical testing, (8) laser trim, (9) packaging, (10) package seal testing (gas leakage and thermal shock), and (11) packaging stamping.

Datel-Intersil purchases ceramic, silicon and/or quartz substrates for use in the production of hybrid microcircuits. Silicon substrates are oxidized by thermal oxidation in a diffusion furnace assembly by exposing the substrates to an atmosphere of water vapor formed in the diffusion furnace tube by the combustion of hydrogen in oxygen. Metals are deposited in the substrates by radio frequency spattering and electron-beam evaporation. Heat treatment of the deposited nickel-chromium metal layers may be performed to stabilize the electrical resistivity of the metal layer. The nickel layer is annealed to stabilize the electrical resistivity property of the metal.

Photolithography processes are used to define the patterns of the electrically-conducting or resistor metals on the substrates. Positive photoresist is applied to the substrates manually as the substrate is spun to provide uniform distribution. A mask pattern is transferred to the substrate by contract mask alignment. The mask is positioned between the substrate and an ultraviolet light source manually aligned and exposed. Following exposure, the substrate is developed with a sodium hydroxide solution. The underlying metal layer is etched using (1) ammonium persulfate to remove nickel, and (2) 50% hydrochloric acid and 50% glycerin to remove nichrome. The photolithography process described above may be repeated to establish the metal patterns required for the specific device.

The completed substrate is trimmed using a xenon laser (0.5 usec pulse duration, 500 watts, wavelength unknown). The individual resistor die are separated by high-speed sawing. The final step in the resistor manufacturing process is visual inspection of each die.

Completed and inspected resistor die are transferred to the hybrid assembly area. Alumina ceramic substrates are used as carriers for the hybrid assemblies. The assemblies may include the resistor die produced at Datel-Intersil and other semiconductor devices such as integrated circuits and capacitators. The electrically conducting metal layer is first deposited in the substrate by electron-beam evaporation, radio frequency sputtering. The metal deposited may include tantalum, gold, nichrome, and nickel, depending on the device manufactured. Following metal deposition, photolithography processes are used to transfer the mask pattern to the substrate. A positive photoresist containing photosensitive organic polymers, cellosolve acetate, n-butyl acetate and xylene is deposited onto the substrate surface. The mask pattern is transferred to the substrate by exposure with ultraviolet light using contact mask alignment (Elliott, 1982). Photomasks are produced to plant specifications by contract to outside vendors. The exposed substrate is developed with an alkaline-based developer. The exposed underlying metal layer is removed by immersion in a tank containing (1) ammonium persulfate for etching nickel, (2) 50 percent hydrochloric acid and 50 percent glycerin for etching nichrome, or (3) an unspecified solution for etching gold. The remaining photoresist layer is stripped using trichloroethylene and acetone.

The substrate is visually inspected, measured for metallization thickness, and tested for metallization adhesion. The first step in hybrid assembly is to mount the thin film, gold interconnection substrate in a preformed ceramic package using an epoxy bond. The bond is cured in a resistance-heated oven at 150°C for 30 minutes. The individual die are attached to the thin-film substrate with an epoxy bond. Electrical connections of the die to the substrate and the substrate to the package are established using thermosonic bonding with gold wire. Thermosonic bonding uses ultrasonic energy to attach the wire to the die, substrate, or package (Colclaser). The gold wire bonding is performed by an automatic high speed thermosonic bonding system.

Following the wire bonding operation, a wire bond pull test is used to monitor the wire bonding process. The devices are electronically tested to ensure performance to product specifications. The device is repaired by laser trimming to remove electrically conductive metal from the thin-film substrate. The metal is vaporized by a pulsed xenon laser (0.5 usec) operating at 500 watts power. The completed package is sealed by either

(1) an epoxy preform and ceramic lid or (2) a hermetic formed gold seal by an automatic, overlapping, seam-brazing process performed in a nitrogen atmosphere at excess pressures (2 to 3 atmospheres).

Devices that are intended for military uses undergo high reliability testing consisting of a thermal shock test, gross leak test, and package seal test. The thermal shock consists of exposing the packages to a liquid nitrogen environment, followed by an oven bake. The gross leak test involves immersion of the package in a viscous solvent and visual detection of bubbles released from the packages. The package seal fire-leak testing consists of exposing package to helium under high pressures, followed by detection of helium rleasted from package. The packages then undergo a final electrical test. The packages are labelled with an epoxy-based ink before final shipment. Heated acetone contained in a covered beaker is used to strip ink from the packages.

5.0 DESCRIPTION OF PROGRAM

5.1 INDUSTRIAL HYGIENE

Datel-Intersil does not employ an industrial hygienist or safety engineer. A safety committee comprised of workers and management is responsible for site safety. The facility personnel director is responsible for health and safety. Production area supervisors are responsible for maintaining material safety data sheets on chemical agents used in production. No routine measurements of workplace emissions or worker exposures to chemical or physical agents in the work environment are performed.

5.2 EDUCATION AND TRAINING

Production area supervisors are responsible for training workers in safe work practices, handling of materials, and use of personal protective equipment. The facility has established an emergency evacuation plan. First aid training is provided off-site.

5.3 RESPIRATORS AND OTHER PERSONAL PROTECTIVE EQUIPMENT

Respirators are not used during routine operations. A self-contained breathing apparatus is available for emergency use. The facility does not have a respirator maintenance program.

Chemical goggles, gloves, and aprons are required only in areas with wet chemical operations. Workers are trained in the use of goggles by the area supervisor. Open toe shoes are prohibited in the facility.

Emergency equipment available at Datel-Intersil includes emergency showers, eye wash stations, and breathing oxygen.

5.4 MEDICAL

Datel-Intersil does not employ a full- or part-time physician or nurse. Medical services are provided by a physician located at a nearby medical center. Datel-Intersil does not require a pre-placement or periodic medical examination.

Emergency first aid is provided by employees trained off-site.

6.0 DESCRIPTION OF CONTROL STRATEGIES FOR PROCESS OPERATIONS OF INTEREST

6.1 PRINTED CIRCUIT BOARD PRODUCTION

Process operations encountered in the fabrication of printed circuit boards include (1) tooling, drilling, and sanding, (2) copper fluoborate electroplating, (3) photoresist film lamination and pattern transfer, (4) pattern plating by tin/lead fluoborate electroplating and electroless copper electroplating, (5) photoresist stripping, (6) etching, (7) tin stripping, (8) nickel sulfamate electroplating, and (9) gold electroplating.

6.1.1 Tooling, Drilling and Sanding

Fiber laminate panels are purchased for use as a printed circuit board substrate. The panels are cut to the required size by shearing. A manually operated router is used to sand the edges. Operators performing shearing and sanding operations wear goggles or safety glasses. Dust generated during sanding is removed by local exhaust ventilation. Ear muffs are available in the work area but were not worn during sanding operations. Slots are cut into the boards and the edges of the board are beveled. Local exhaust ventilation is used to control particulate emissions during slot cutting, beveling, and sanding. Personal protective equipment used during these operations included safety glasses, goggles, or face shields. A full-face respirator with an organic vapor and acid gas cartridge (Welsh, RM21B106) was available in the area but was not worn during operations.

6.1.2 Copper Fluoborate Electroplating

The electroplating of copper on printed circuit boards is accomplished by a copper fluoborate solution. The panels are manually loaded onto racks that provide automatic agitation of the boards in the copper bath. The sequence of plating operations is listed in Table 1. Local exhaust ventilation is used to control the emission of gases, vapors, and mists generated during the process. Ventilation slots are located on either side of the length of each tank. The tank width is approximately 12 inches with each tank containing approximately 20 gallons. Exhaust air from the tanks is not scrubbed but is released directly to the external plant atmosphere through stacks located on the roof. Copper fluoborate electroplating and electroless copper baths are 4' x 2' tanks with local exhaust ventilation slots located across the rear of each tank. Capture velocity and air flow rate through the slot were not monitored by the plant.

Personal protective equipment used during electroplating operations included goggles and aprons.

6.1.3 Tin/Lead Fluoborate Electroplating

The electroplating of tin/lead on printed circuit boards is performed using a tin/lead fluoborate electroplating operation. The process sequence is given in Table 1. Local exhaust ventilation is used to control emissions of gases, vapors, and mists from sulfuric acid, sodium persulfite, and hydrochloric acid tanks. Tin/lead fluoborate electroplating tanks did not have local exhaust ventilation. Electroless copper plating operations are ventilated by a slot located along one side of each tank (24" x 24" tank). Local exhaust air from the tanks is not scrubbed but is released directly to the external plant atmosphere through stacks located on the roof. Workers in the area wear goggles, gloves, and aprons during handling and transfer of boards. Monitoring of capture velocity and face velocity of local exhaust ventilation systems is not performed by the plant.

6.1.4 Photoresist Lamination

Photoresist, consisting of photosensitive organic polymers, is applied to the laminated fiber panel. A mask pattern is transferred to the panel by exposure of the panel to ultraviolet light with a mask positioned between the UV lamp and the panel. Following exposure, the exposed panel is developed in an automated in-line developer. The developer operation consists of a spray cell with local exhaust ventilation plenum located at the entrance and exit to the cell. The panels are placed on a chain drive belt and automatically transported through the ventilation plenum into the developer cell where 2-butoxyethanol is sprayed from above and below the panel. The temperature of the developer solution is maintained at 30°C. The sprayed panel passes through an exhaust plenum into a water spray rinse and passes through an air knife to remove water from the panel before exiting the developer unit.

The developer unit is enclosed to prevent emissions of developer mist from the spray cell. Local exhaust ventilation at the entrance and exit to the spray cell is used to control developer mist. Monitoring of emissions of developer solution or ventilation system performance has not been performed by the plant.

6.1.5 Photoresist Stripping

Following electroplating operations, photoresist is removed by hand scrubbing of the printed circuit board with an abrasive pumice material containing 55 percent free crystalline silicon dioxide.

Following electroplating operations, the photoresist is stripped from the board by immersion in a bath containing 2-butoxyethanol and 2-(2-butoxyethoxy) Ethanol maintained at 50°C. The board is rinsed and scrubbed by hand using an abrasive pumice containing 55 percent free crystalline silicon dioxide. The boards are dried in a resistance-heated oven, followed by additional stripping operations to remove the exposed, underlying tin/lead metal layer.

The abrasive cleaning of printed circuit boards is performed with a pumice/water slurry to control dust generation. THe stripping of photoresist by immersion is performed in a tank with local exhaust ventilation used to control vapor emissions.

The hood is a flanged slot extending beyond the length of the immersion tank. The air flow and capture velocity of the hood were not known by the plant staff.

6.1.6 Etching

Following photoresist stripping, the underlying, exposed copper layer is removed by spray application of chromic acid and sulfuric acid. The operation is automated and enclosed. The operator loads boards onto a conveyor belt and the boards are transported into the enclosed spray chamber. Local exhaust ventilation takeoffs at the entry and exit are used to control emissions. The acid, heated to 55°C, is sprayed onto the boards. The boards are transported through a rinse station and are unloaded by the operator. The acid stripping unit is contained within a diked area in the production facility. The acid solution is replaced weekly and the unit is cleaned by the operator weekly.

6.1.7 Tin Stripping

Tin is stripped from the printed circuit board by immersion in an unspecified acid solution. The operation is performed in an immersion tank wtih local exhaust ventilation used for controlling acid mists and vapors. The hood is a flanged slot that extends beyond the length of the tank. The air flow and capture velocity of the hood were not known by the plant staff.

Operators wear gloves and goggles during immersion stripping operations.

6.1.8 Nickel and Gold Electroplating

Printed circuit boards are cleaned by immersion in LAC 41 at 50°C. Local exhaust ventilation is provided by a canopy hood over the tank with a back panel extending from the rear of the hood to the tank. the tank is covered except during loading and unloading of boards. Operators wear gloves and goggles when handling boards.

Following the acid cleaning operation the boards are rinsed in water. The boards are then moved to a series of tanks where they are immersed according to the following sequence: (1) sulfuric acid, (2) water rinse, (3) sodium persulfate, (4) sulfuric acid, (5) water rinse, (6) hydrochloric acid, (7) nickel sulfamate electroplating, (8) water rinse, and (9) gold electroplating. The boards are removed and placed in a resistance heated drying oven.

Vapors and mists are controlled by local exhaust ventilation slots located along the length of each acid or electroplating tank. The tanks are approximately 30 cm (1 ft) by 60 cm (2 ft), with a ventilation slot located along the length of the tank. The air flow, capture velocity, and face velocity for the slot ventilation were not known by the plant staff.

Operators wear gloves and goggles when handling printed circuit boards.

6.2 HYBRID MICROCIRCUIT FABRICATION

6.2.1 Thermal Oxidation

Single crystalline silicon wafers are purchased for use as a hybrid thin film substrate. The wafers are oxidized in a diffusion furnace assembly. The furnace consists of a load station, a furnace cabinet containing furnace tubes and electrical resistance heating elements, a source cabinet enclosing the furnace tube end, and an electrical cabinet containing the furnace control systems. Process gases enter the furnace tube through gas supply lines that connect to the furnace through the source cabinet. The furnace cabinet acts as a protective barrier against the hot contact surfaces of the furnace tube.

Process gases used include hydrogen, oxygen and nitrogen for the thermal oxidation of silicon to silicon dioxide. The gases are supplied to the furnace from cylinders located in a locked, enclosed area adjacent to the building. Gases are distributed through welded stainless steel tubing.

The thermal oxidation process is performed by placing wafers in carriers that are loaded into the furnace tube. The furnace tube temperature is increased (the specific temperature depends on the operation step), and the furnace tube is purged with nitrogen. Water vapor is then formed in the furnace tube by the combustion of hydrogen in an oxygen atmosphere, forming a pyrophoric water atmosphere that oxidizes the silicon wafer. After the oxidation process is completed the tube temperature is decreased, the tube is purged, and the carriers are removed. The process operating parameters, including tube temperature, gas flow, process sequence, and other operating parameters, are controlled by the operator who monitors and adjusts the systems.

The furnace assembly is vented at the furnace cabinet and the furnace load end. The furnace cabinet is vented by an exhaust duct located at the top of the cabinet to control heat. The furnace tube opening is vented by a scavenger box that encloses the opening.

The facility does not employ monitoring systems to evaluate chemical agent emissions associated with the furnace.

Personal protective equipment used by operators include heat protective gloves for loading and unloading wafer carriers and for removal of furnace tubes for cleaning.

6.2.2 Metallization

Metals are deposited on the substrate surface using either radio frequency sputtering or electron-beam evaporation.

Sputtering is performed in a side mount system using a radio frequency power source at 33.63 KHz frequency. Wafers are mounted on a metal platen that is placed in a load lock chamber by the operator. The system is evacuated to very low pressure (approximately 10^{-6} torr), and the platen is automatically transported into the deposition chamber where the metal is deposited into the substrate surface. Materials deposited with the system include nichrome (nickel and chromium alloy), gold, tantalum, aluminum oxide, quartz, and aluminum. The chamber is vented through the vacuum pumping system which consists of an oil-sealed mechanical pump followed by a cryogenic pump.

Electron beam evaporation is performed in a bell jar-type assembly using an electron beam to evaporate a metal target. The operation is performed at very low pressure (approximately 10^{-6} torr). The substrates are loaded onto a planetary structure that is mounted in the bell jar chamber. The operation is initiated by push-button control. The bell jar chamber is sealed and the chamber is evacuated by the pump systems (an oil-sealed mechanical pump and a diffusion pump). The chamber is vented through the pump exhaust which is vented to the external plant atmosphere through a stack on the roof. Nickel, nichrome and gold are deposited by electron-beam evaporation. Equipment similar to that used for metal deposition by electron-beam evaporation is also used for metal deposition by radio frequency sputtering. The radio frequency power source is rated at 20 kilowatts (frequency unspecified).

No continuous monitoring systems are used for evaluating emissions or operator exposures to chemical or physical agents. Personal protective equipment requirements include protective glasses used when observing radio frequency sputtering through the window in the bell jar chamber.

6.2.3 Photolithography

The photolithography processes consist of four basic steps: (1) substrate preparation; (2) substrate exposure; (3) substrate developing; and (4) photoresist stripping.

Substrate preparation involves spin-on application of a positive photoresist consisting of a photosensitive organic polymer in a solvent containing cellosolve acetate, n-butyl acetate and xylene. The substrate is mounted on a platform and spun at high speed. The operator applies the photoresist using an eye dropper. The operation is performed in a ventilated laboratory-type fume hood.

A mask pattern that defines the electrical connections is transferred to the substrate by contact mask alignment. The substrate is aligned with the mask using a split field binocular microscope. Once aligned, the mask is brought into contact with the substrate. An ultraviolet light source mounted adjacent to the mask is used to expose the substrate. Local exhaust ventilation is used around the lamp enclosure to control heat production. The UV lamp is shielded to prevent operator exposure.

Exposed wafers are developed by immersion in a sodium hydroxide developing solution. After developing, the exposed underlying metal layer is etched using wet chemical methods. The substrate is immersed in a bath containing either ammonium persulfate (for nickel etching), and 50 percent hydrochloric acid and 50 percent glycerin (for nichrome etching). The etching operation is performed in a ventilated hood. The substrates mounted in carriers are immersed in the baths. Operators are required to wear protective gloves when handling substrates during wet chemical etching operations. The etching operation is performed in a ventilated hood with a perforated work deck. The hood is exhausted at 100 cfm.

No monitoring systems are present for evaluating emissions or operator exposures to chemical or physical agents.

6.2.4 Laser Trimming

Substrates containing deposited metal layers are electrically tested to determine compliance with quality control. Part of the metal pattern is removed from the substrate using a pulsed xenon laser (0.5 usec pulse duration, 500 watts power, wavelength unspecified). The operator aligns the laser with the metal layer on the substrate that is to be trimmed by viewing through a video monitor at the work station. Once aligned the laser is activated to trim the metal layer. The process is repeated until the device complies with production quality control requirements.

6.2.5 Assembly Testing

Operations performed to assemble the hybrid microcircuit include: (1) separation of resistor die, (2) mounting of substrate in a ceramic package, (3) die (resistors and integrated circuits) attachment to the substrate, (4) gold wire thermosonic bonding of the die to the substrate, (5) package sealing, and (6) package testing.

Separation of resistor die by sawing and mounting of the hybrid microcircuit substrate in the ceramic package were not observed during the walk-through survey.

Die, including resistors and integrated circuits, are attached to the substrate by epoxy bonding. Epoxy is applied to die-attach sites on the substrate using a syringe. The operator uses a binocular microscope to locate the bonding sites. Individual die are mounted onto the substrate by hand. Gold wire is used to make the electrical connections from the die to the substrate by thermosonic bonding (Colclaser, 1980).

After thermosonic bonding, the package is sealed by welding with gold. The sealing operation is performed in an enclosed chamber in a nitrogen environment. The sealed package is baked at 150°C in an oven with a dry nitrogen environment and is tested by: (1) immersion of the package in a viscous solution to detect gas bubbles escaping from the package (Fluorinert solvent 70 or 77), (2) helium leak test, and (3) thermal/cold shock test.

Packages passing the test are then labeled by silk screen printing with an epoxy based paint. Packages that have excessive paint or that do not meet the labeling specifications are cleaned by immersion in a heated mixture containing acetone and trichloroethylene. The solution is contained in a beaker with watch glass cover and is placed on a hot plate located beneath a canopy hood mounted against a wall.

No monitoring systems are used in any of the assembly operations for evaluating emissions or worker exposures to chemical or physical agents. Personal protective equipment is not used for the assembly operations.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Operations involved in hybrid microcircuit fabrication differ from those encountered during integrated circuit fabrication. However, some equipment used in integrated circuit fabrication is also used for the fabrication of hybrid microcircuits. This includes radio frequency and electron-beam sputtering, diffusion furnace assemblies for thermal oxidation and contact mask alignment. The engineering controls associated with this equipment is part of the equipment design. These controls include local exhaust ventilation, shielding and process isolation.

Operations performed in the manufacture of printed circuit boards differ from those encountered during hybrid microcircuit fabrication. The control strategies employed by Datel-Intersil in the printed circuit board fabrication area included local exhaust ventilation, process isolation, shielding (ultraviolet light), housekeeping, and personal protective equipment.

Specific recommendations for both production areas are outlined below.

1. Datel-Intersil should consider replacing trichloroethylene used in stripping epoxy paint from packages with a less toxic compound such as 1,1,1-trichloroethane.
2. Blood lead levels determinations should be conducted for workers employed in the printed circuit board area and workroom monitoring of lead concentrations should be performed.
3. Consideration should be given to supplying emergency power to exhaust ventilation systems for process operations using toxic or flammable materials.
4. Exhaust stacks should be altered to ensure that exhaust air is directed away from air intakes. The existing stack design has a duct exiting the roof with two 90° elbows that result in air being directed down onto the roof surface potentially resulting in recirculation of exhaust air through nearby air intakes. Several stack designs are available which will provide rain protection,

provide a lower fan static pressure drop and prevent recirculation of exhaust (American Conference of Governmental Industrial Hygienists, 1982).

5. The laser trimming equipment is designed such that reflection of the laser beam could occur during trimming. Datel-Intersil should consider enclosing the operation to prevent emissions.
6. Consideration should be given to installation of a flammable gas monitoring system in areas such as the diffusion furnace area (thermal oxidation operation) where hydrogen is used.
7. Monitoring of radio frequency radiation emissions from metallization operations should be conducted to evaluate radiation emissions and potential worker exposures.

8.0 REFERENCES

American Conference of Governmental Industrial Hygienists, 1982. Industrial Ventilation - A Manual of Recommended Practice. Committee on Industrial Ventilation, Lansing, Michigan.

Colclaser, R. A., 1980. Microelectronics: Processing and Device Design. John Wiley and Sons. New York.