115-23

# PRELIMINARY CONTROL TECHNOLOGY SURVEY

on

COMDIAL SEMICONDUCTOR, INC.
1230 Bordeaux Drive
Sunnyvale, California 94086

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

4676 Columbia Parkway
Cincinnati Ohio 45226

August 12, 1983

by

Gary J. Mihlan and Robert D. Willson

BATTELLE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

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## 1.0 ABSTRACT

A preliminary control technology assessment survey was conducted at Comdial Semiconductor, Sunnyvale, California, on January 12, 1982. The survey was conducted by Battelle Columbus Laboratories 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. The facility manufactures metal oxide semiconductor (MOS) integrated circuits.

The process operations for integrated circuits manufacturing are performed in separate wafer fabrication areas in the building. The air supply to the area is treated by passage through pre-filters, bag filters, and high efficiency particulate air (HEPA) filters. Process operations performed at the facility include: 1) thermal oxidation of purchased silicon wafers, 2) photolithography including photoresist application, substrate exposure, and photoresist development, 3) wet chemical etching and cleaning, 4) plasma etching, 5) low pressure chemical vapor deposition of (LPCVD) silicon nitride, polycrystalline silicon, and silicon dioxide, 6) diffusion, 7) continuous chemical vapor deposition (CVD) of phosphorus-doped silicon dioxide, 8) hydrogen alloying, 9) metalization by electron beam evaporation, and 10) packaging and assembly.

Engineering controls used at the facility vary by process operation and process equipment. Several process operations are performed in sealed reaction chambers that isolate the process from the workers. Process isolation is used in LPCVD, metalization, and plasma etching. Shielding is used in plasma etching to control radio frequency radiation emissions and in substrate exposure to control ultraviolet emissions. Local exhaust ventilation is used to remove process gases and byproducts from continuous CVD, wet chemical etching and cleaning, photolithography, and operations performed in diffusion furnaces (e.g., diffusion, thermal oxidation, LPCVD, and alloying). Local exhaust ventilation is also used at gas storage cabinets.

Several process operations are automated with the process parameters and process sequence controlled by microprocessors. These operations include plasma etching, LPCVD, and metalization.

Continuous area monitoring in the fabrication area is limited to a single combustible gas detector located at the rear of the diffusion furnace

assembly used for thermal oxidation. Personal protective equipment is used to control operator exposures during normal process operations, maintenance, and repair. Specific requirements vary by task but generally include safety glasses. Gloves with gauntlets, aprons, and face shields are also required for operators handling liquid chemicals such as acids.

Fabrication area supervisors are responsible for training operators in safety, materials handling, and the use of personal protective equipment. The plant does not require preplacement or periodic medical examinations. Facility engineering personnel occasionally monitor the ventilation systems. Monitoring of operator exposures to chemical agents is limited to the gas detector tubes for leak-testing of gas cylinders. Work practices that may affect emissions or operator exposures to chemical or physical agents could not be addressed in detail in this report due to time constraints. These practices should documented during a detailed survey.

Recommendations for the plant include: 1) a detailed review of local exhaust ventilation systems, 2) use of local exhaust ventilation around source cabinets of the furnace assemblies, 3) use of nitrogen cylinder gas for purging gas lines rather than house nitrogen, 4) substitution of a lower concentration gas for 100 percent phosphine, 5) substitution of a less toxic degreasing agent for trichloroethylene, 6) installation of a combustible gas detection system and a continuous phosphine monitoring system, and 7) relocate shutoff valves for the diffusion furnace assembly to a more accessible location.

## 2.0 INTRODUCTION

A preliminary survey was conducted at Comdial Semiconductor, Inc., Sunnyvale, California, on January 12, 1982 as 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. Mr. Paul E. Caplan, NIOSH, Division of Physical Sciences and Engineering, accompanied the survey team.

The following individuals were contacted at Comdial:

1. Mr. Steve Kam, Process Development and Engineering Manager
2. Mr. John Hills, Facilities Engineer

The study protocol was provided to Mr. Kam before the preliminary survey. An opening conference was held at the plant, and the study objectives and methods were described. Plant staff provided a description of the health and safety programs at the facility as well as the process operations.

Following the opening conference, the facility was toured including production areas, gas and chemical storage areas, waste storage areas, and wafer testing and assembly. A closing conference was held following the survey.

## 3.0 PLANT DESCRIPTION

### 3.1 General

The facility manufactures metal oxide semiconductor (MOS) integrated circuits on a semicustom basis and also performs research and development for custom chip fabrication. The plant is part of Comdial Corporation, 50 Berry St., San Francisco, California.

The facility consists of a 20,000 square feet single story building of tilt wall construction with 6,000 square feet used for wafer fabrication, 8,000 square feet for warehouse space, and 6,000 square feet for offices. The building is 10 years old and has been used for wafer fabrication since 1980. The building has a water sprinkler system for fire control, but does not have an emergency power supply.

Alterations to the wafer fabrication area were being made during the survey and include the installation of new atmospheric pressure diffusion furnaces and wet chemical benches. Comdial employs 31 people, with 24 individuals in the wafer production, testing, and assembly area, and 7 individuals in administration. The plant operates one 8-hour shift per day. Wafer fabrication employees are not assigned to one specific operation but may work in all fabrication areas.

## 3.2 Chemical Storage

Chemicals are received in 1-gallon and 55-gallon drums and stored in a covered, secured area at the back of the building. Liquid chemicals are separated by class (flammable, corrosive, oxidizer) into bays approximately 12 ft. by 12 ft. that are separated by 6 ft. tall concrete block walls. None of the storage bays had drain systems and only the bay containing oxidizers was diked. Fifty-five gallon drums containing xylene, or n-butyl acetate, are also stored in an enclosure opposite the bays.

Chemicals in 1-gallon containers are transferred from the storage area to the fabrication area by a chemical technician. The chemicals are transported to the fabrication area in a metal cart and are stored in a cabinet below the bench or in a box near the point of use.

## 3.3 Gas Handling System

Process gases are supplied in cylinders and distributed to process equipment in stainless steel lines that are either welded or joined by compression fittings. Toxic or pyrophoric gases, such as phosphine, ammonia, silane, dichlorosilane, and hydrogen chloride, are stored in ventilated cabinets located in the diffusion furnace area. The gas cylinder regulator assemblies are located in the cabinets. Solenoid valves, included with the gas regulator assemblies, shut off toxic and pyrophoric gases during power failures. Gas supply lines will also automatically shut off if the house nitrogen supply is disrupted.

Hydrogen is supplied in cylinders using a silver-soldered copper line. Nitrogen is supplied by a bulk container and is distributed to the plant in stainless steel lines using compression fittings. Oxygen is supplied from a bulk container and is also distributed in stainless steel lines using compression fittings.

Non-flammable, non-corrosive, low toxicity gases, such as carbon tetrafluoride/oxygen, are supplied in cylinders that are stored next to the process equipment in the fabrication area. These cylinders are not stored in a ventilated cabinet.

Gas cylinders are replaced by the facility engineer. Gas supply systems are vacuum-purged using house nitrogen supplies. The nitrogen purge gas is delivered through lines containing check valves to prevent backflow of potentially contaminated gas into the house supply.

## 3.4 Monitoring Systems

Continuous monitoring systems used at Comdial include a Sierra Monitor Corporation® combustible gas monitor. The unit is a fixed point, solid-state monitor located in the gas jungle at the source end of the diffusion furnaces. The unit produces an audible and visual alarm in the diffusion furnace area. The monitor is reportedly set to activate at 2 percent hydrogen. The system has not been calibrated while in use at the facility.

## 3.5 Ventilation System

Nine air handlers supply air to the warehouse, production area and offices in the plant. Air is delivered to the wafer fabrication area through ceiling diffusers. The air is treated by passage through pre-filters and bag filters. Air supplied to individual work stations is treated by high efficiency particulate air (HEPA) filtration units located above the work station. A total quantity of 9,090 cfm of air is supplied to the diffusion furnace area. The air is recirculated with 25 percent makeup air added to the supply. The quantity of air supplied to office and warehouse areas was not documented during the preliminary survey since this information is not directly related to the control technology used during production of the integrated circuit.

Air is removed from the fabrication area by local exhaust ventilation of process equipment. The exhaust is treated by a packed tower scrubber using water as a collection medium. An estimated 14,000 cfm of air is treated by the scrubber. Local exhaust ventilation from wet chemical cleaning and etching operations, diffusion furnace operations and the photoresist developer spin operation are sent to the scrubber. Exhausts from the plasma etching operation and low pressure chemical vapor deposition (LPCVD) operation are vented directly to the atmosphere. Resistance-heated ovens used for drying wafers are vented directly to the room. The design of the air recirculation system, including the location of return air ducts, was not defined during the preliminary survey.

### 3.6 Waste Management System

Organic (solvent) wastes, including photoresist, developer, and pump oils are collected and poured into a 300-gallon tank located outside of the building in a fenced area. The wastes are transported by a waste management firm to an off-site chemical waste landfill for disposal.

Acid wastes from wet chemical cleaning and etching operations are aspirated and replaced daily. They are transferred through polypropylene lines to a collection tank. The acid wastes are neutralized with ammonia and released to a publicly operated treatment works (POTW). No specific waste management procedures are used for hydrofluoric acid wastes. Waste water from the packed tower scrubber is also treated by the acid neutralization system.

## 4.0 PROCESS DESCRIPTION

The fabrication sequence used for metal oxide semiconductor (MOS) integrated circuits will vary depending on the specific type of device manufactured. Process operations encountered at this facility will be presented instead of providing a description of the specific process fabrication sequence. The general processing sequence for MOS integrated circuits is provided by Colclaser (1980) and should be reviewed for further details about the fabrication process. Several process operations are employed more than once in the fabrication sequence and some equipment is used for more than one operation. The silicon wafers used for device fabrication are purchased.

In the thermal oxidation process, the wafers are oxidized at a high temperature (approximately 900 to 1200°C) in an atmospheric pressure diffusion furnace assembly using a hydrogen and oxygen atmosphere. Hydrogen chloride gas is used to clean the furnace tube. The wafers are loaded into carriers that are inserted into the diffusion furnace. The furnace tube is heated by electrical resistance and the tube is purged with nitrogen. Hydrogen and oxygen are introduced into the tube at the source end. The process gas flow is controlled by mass flow control units and the furnace tube temperature is monitored by thermocouples placed along the tube length.

Following thermal oxidation, wafers are ready for photolithography consisting of: 1) photoresist coating, 2) pre- or soft-bake, 3) mask alignment and exposure, 4) development, 5) post- or hard-bake, 6) etching, and 7) photoresist stripping. The wafer is coated with a negative photoresist by spin application using automated equipment containing four spin platforms. The operator places the wafers in a loading jig that is then placed over the spin platforms. The sequence is started by push-button control and the spin platforms lift the wafers from the jig. The photoresist, containing a proprietary photosensitive organic resin solution in a xylene carrier, is automatically spun onto the wafer. The coated wafers are removed by the operator and placed in a resistance-heated oven for soft-bake drying.

The mask pattern is transferred to the photoresist-coated wafers by contact printing using ultraviolet light with a peak wavelength of 365 nm. The operator places a wafer on the stage and aligns the mask with the wafer by viewing through a split field binocular microscope. The wafer is clamped to the mask and exposed to the ultraviolet light from a mercury lamp source located behind the mask. The mask is manufactured to plant specifications by a vendor. Masks are cleaned at a ventilated work station by dipping in a heated solution containing phenol, sulfonic acid, an unspecified aromatic solvent, and chlorobenzene.

The exposed wafers are developed by spinning a xylene and n-butyl acetate developer solution onto the wafer. The operation is performed with process equipment similar to that used for photoresist application. The developed wafers are hard-baked in a resistance-heated oven.

The exposed underlying layer may then be etched using either wet chemical etching or plasma etching techniques. Wet chemical etching is performed by immersing the wafers in an etching solution. The etching methods include: 1) hydrofluoric acid and ammonium fluoride for etching silicon dioxide; 2) phosphoric acid for etching aluminum, and 3) potassium hydroxide for etching polycrystalline silicon. The etching solutions are maintained at a temperature of 30 to 50°C. The etching operations are performed in tanks that are recessed in polypropylene benches. The benches are similar to laboratory hoods and they are ventilated either by slots across the rear of the bench and/or by an exhaust duct located at the top of the hood.

Plasma etching is performed by placing wafers in a plasma gas formed by a radio frequency field operating at 13.56 MHz with a maximum power of 600 watts. The plasma is formed in a sealed reaction chamber at a vacuum of approximately 0.1 to 20 torr created by an oil-sealed mechanical pump. The plasma contains ions, free electrons, and free radicals that are reactive with the exposed layer. A gas mixture of carbon tetrafluoride and oxygen is used to etch silicon nitride.

The photoresist is stripped from the wafer by immersion in a solution containing phenol, sulfonic acid, an unspecified aromatic solvent, and chlorobenzene. The operation is performed in a ventilated work bench similar to that used for wet chemical etching.

Doping is performed by diffusion in an atmospheric pressure diffusion furnace assembly. The process introduces impurities into the wafer surface that change the electrical properties of the substrate. The wafers are placed in carriers that are loaded into the furnace tube and exposed to a high temperature atmosphere containing the dopant. The dopants used at Comdial are phosphorus oxychloride and boron tribromide in sealed quartz bubblers. The bubblers are mounted in the diffusion furnace source cabinet, and nitrogen is bubbled through the liquid and into the furnace tube. Process gases used include nitrogen, hydrogen, and oxygen.

A layer of phosphorus-doped silicon dioxide is deposited on the wafer surface by continuous atmospheric pressure chemical vapor deposition. Wafers are mounted on platens that are placed on a heated conveyor and transported through the reaction chamber. Silane, oxygen, and phosphine are introduced over the wafer surface through a series of vertical parallel plates. A vapor phase chemical reaction produces solid products that are deposited on the wafer surface. Local exhaust ventilation is provided at the chamber entrance and exit.

Silicon nitride, polycrystalline silicon, and phosphorus-doped silicon dioxide are deposited on the wafer surface by low pressure chemical vapor deposition (LPCVD). The operation is performed in a sealed diffusion furnace assembly that is mechanically closed and evacuated to approximately 0.4 to 20 torr with an oil-sealed mechanical pump. The operation is automatically controlled by a microprocessor and requires only that the operator load and unload wafers into the furnace tubes. Gases used for LPCVD include: 1) silane, oxygen, and phosphine for deposition of phosphorus-doped silicon dioxide; 2) dichlorosilane and ammonia for deposition of silicon nitride; and 3) silane for deposition of polycrystalline silicon.

An aluminum layer is deposited on the wafer surface by electron beam evaporation. The operation is performed in a sealed reaction chamber at a vacuum of approximately $10^{-6}$ torr that is maintained by an oil-sealed mechanical pump and an oil diffusion pump. The operator loads wafers into a planetary that is mounted inside the reaction chamber, and initiates the processing sequence by pushbuttons.

Following metalization, wafers are heated in a hydrogen atmosphere in a diffusion furnace assembly to correct radiation damage from the metalization process. The operation is performed in an atmospheric pressure diffusion furnace assembly similar to that used for thermal oxidation. The wafers are exposed to a hydrogen atmosphere at high temperature.

Photolithographic processes are repeated at various steps in the fabrication sequence. After completion of the fabrication process, wafers are sent out for testing but are returned to be packaged at the facility.

The first step in the packaging process is diamond scribing of the wafer. Diamond scribing cuts a street in the wafer between the die. Scribing of the first street is aligned by the operator and the process is then automatically repeated. The wafer is rotated 90 degrees, the operator again aligns the first street, and the remaining streets are automatically scribed. The die are visually inspected under a microscope. A silver epoxy compound is placed on the package and the die is attached by hand. The package is mounted on a manual wire bonding system. The operator aligns the metal contact pad on the die with the corresponding electrical contact on the package. An aluminum wire is automatically attached to both contacts by ultrasonic bonding. The package is sealed with an epoxy compound in a ceramic package and heated in a resistance heated oven at 150°C.

## 5.0 DESCRIPTION OF PROGRAMS

### 5.1 Industrial Hygiene

Comdial does not employ a full- or part-time safety engineer or industrial hygienist. No consultants are used for any health or safety related areas.

Monitoring of emissions or worker exposures to chemical or physical agents is limited to the use of gas detector tubes used for leak testing of gas cylinders.

Ventilation system measurements are performed by facility engineering personnel using a swinging vane anemometer. No routine or periodic measurements for evaluating the local exhaust ventilation system performance are made.

### 5.2 Education and Training

Formal programs for training workers in safety, materials handling, personal protective equipment, emergency response, or hazard reporting procedures do not exist. Individual training in safety, materials handling, and personal protective equipment use is provided by the worker's supervisor.

## 5.3 Respirators and Other Personal Protective Equipment

All workers in the wafer fabrication and assembly areas are required to wear safety glasses or goggles. Operators working at wet chemical stations are required to wear aprons and solvent- or acid-resistant gloves with gauntlets (depending on the agent present). Open toe shoes are prohibited in the fabrication area. Operators are not required to routinely wear respirators. Half-face respirators with organic vapor cartridges and self-contained breathing apparatus (SCBA) are available for emergency use in the fabrication area. The SCBA is routinely inspected every 6 months. Additional emergency equipment available includes emergency showers and eye wash stations.

Workers in the wafer fabrication and assembly areas are required to wear product-protective equipment consisting of smocks to control particulate contamination.

## 5.4 Medical

The plant does not employ a physician or nurse on a full- or part-time basis. Preplacement or periodic medical examinations are not required. Emergency medical care is provided by workers trained in basic first aid. A nearby industrial medical clinic is available to supplement emergency medical care.

## 5.5 Housekeeping

Routine housekeeping in the wafer fabrication area includes a daily cleaning of the floors with deionized water. Work surfaces are cleaned by wiping with isopropanol. Trichloroethylene is used to clean oil contamination around pumps and is also used for general cleaning.

Planned maintenance operations are described in Section 7.0 for individual process operations.

## 6.0 SAMPLE DATA FROM PRELIMINARY OR PREVIOUS PLANT SURVEYS

Sampling for chemical and physical agents released by process operations was not performed during the preliminary survey nor were measurements of exhaust ventilation for process operations taken.

## 7.0 DESCRIPTION OF CONTROL STRATEGY FOR PROCESS OPERATIONS OF INTEREST

A variety of strategies are used at Comdial to control emissions and worker exposures. Strategies include local and general exhaust ventilation, process and environmental monitoring, and process isolation. Specific engineering control strategies for individual process operations are described below. Monitoring systems are described in Section 3.4 and briefly described below for each specific operation. Personal protective equipment requirements consist of general area requirements described in Section 5.3 with specific requirements for process operations provided below.

Automation has affected both work practices as well as operator exposures to chemical and physical agents. Automated controls require that the operator load and unload wafers, initiate the processing sequence by push-button controls, and perform routine cleaning operations. The operator is free to perform other tasks, such as wet chemical cleaning and etching or to operate other automated units and is not required to be at the unit for an entire work shift. Therefore, any exposures to chemical or physical agents at a specific site would be for brief time periods throughout the shift.

Specific descriptions of process operations and control strategies are given for thermal oxidation, photolithography, wet chemical etching and cleaning operations, plasma etching, diffusion, hydrogen alloying, chemical vapor deposition, metalization, and packaging and assembly. Several operations may be performed with similar types of process equipment.

### 7.1 Thermal Oxidation

An oxide layer is formed on the silicon wafer by exposing it to an oxygen/hydrogen and hydrogen chloride atmosphere at high temperature in an atmospheric pressure diffusion furnace. The diffusion furnace assembly consists of: 1) a load station at the furnace tube opening where carriers containing wafers are loaded into the furnace; 2) a furnace cabinet containing the quartz furnace tubes and electrical resistance heating elements; and 3) a source end containing a gas jungle attached to a metal support frame. The diffusion furnace operates by hybrid control using mass flow control of process gases with operator adjustment. Hybrid control is a manual analog control that is preset to deliver a constant gas flow but requires operator observation and adjustment as needed.

Wafers are mounted in carriers at a vertical laminar flow HEPA filter work station. The carriers are inserted into a quartz tube or elephant which is attached to the furnace tube. The carriers are inserted into the furnace using a quartz rod. Once the wafers have been inserted, the tube is purged and the process gases are introduced into the furnace. Gas manifolds are located at the source end of the furnace and are attached to a metal support frame. Main shutoff valves for the gas supply to the furnace are located at the source end. The metal support frame and gas supply lines at the furnace source end were very hot as a result of heat from the furnace cabinet. Operators could sustain burns by reaching into the gas jungle to shut off the valves.

Temperature in the furnace cabinet is controlled by a water heat exchanger. Local exhaust ventilation of the furnace tube is provided by a scavenger box located at the load end of the furnace tube. The ventilation flow rate at the scavenger box was not known. The furnace exhaust is treated by a packed tower scrubber. The source end of the diffusion furnace is not ventilated or enclosed. A vertical laminar flow HEPA filter unit is located at the load end of the diffusion furnaces. Four furnace tube banks containing a total of twelve tubes are enclosed in two load stations.

Monitoring systems present in the diffusion furnace area include a Sierra Monitor Corporation® combustible gas monitor described in Section 3.4. Personal protective equipment requirements for operators working at the diffusion furnace operations include heat protective gloves. Specific work practices for controlling emissions or operator exposures to chemical or physical agents were not observed during the preliminary survey. Maintenance of the diffusion furnace assembly includes removal of the quartz furnace tubes for cleaning with hydrofluoric acid. The furnace tubes are also cleaned in place by introducing hydrogen chloride gas into the tube. The hydrofluoric acid cleaning operation is described in Section 7.3.4.

## 7.2 Photolithography

Photolithography consists of four basic steps: (1) substrate preparation, (2) substrate exposure, (3) substrate developing, and (4) photoresist stripping. Following development, the exposed underlying layer may be etched using either a wet chemical etching or plasma etching operation, described in Sections 7.3 and 7.4 respectively. The photoresist stripping operation is also performed either by wet chemical etching or plasma etching and is described in those sections. The photolithography process may be repeated several times during the processing sequence.

7.2.1 Substrate Preparation. Wafers are placed in a loading jig and placed over a set of four spin platforms. The process is initiated by push-button controls. A negative photoresist containing a proprietary photosensitive organic resin solution in a xylene carrier is automatically spun onto the wafer. The photoresist is supplied in pressurized metal containers stored beneath the unit and is distributed to the spin platforms in plastic lines.

The spin platforms are ventilated from below through the waste drain into a collection tank that has an in-line blower to boost the exhaust into the main duct. Operators were observed spraying xylene from a squeeze bottle onto the spin platforms to clean them. No other work practices were observed.

Coated wafers are removed from the spin platform with the loading jig. The wafers are then soft-baked in a resistance-heated oven that is purged with nitrogen. The oven is vented to the room air.

No monitoring systems for evaluating emissions or operator exposures to chemical or physical agents were observed. Personal protective equipment used by the operator consists of safety glasses.

7.2.2 Substrate Exposure. The photoresist-coated wafers are exposed to the photomask pattern by contact printing using ultraviolet light at 365 nm. The wafers are placed on a stage that is rotated into position. The mask and wafer are aligned and the mask is then clamped to the wafer. A mercury lamp is used to produce ultraviolet light. The mercury lamp is enclosed in a housing that is vented into the main exhaust system to provide cooling and to catch mercury vapors should a lamp explode. The voltage differential of the lamp is continuously monitored and the lamp is changed after a preset limit (usually every 220 to 400 hours of operation).

Monitoring systems for evaluating emissions or worker exposures to chemical or physical agents associated with the process operation were not present. No personal protective equipment is used by the operators. No work practices that affect emissions or operator exposures were noted during the survey. Visible blue light was observed around the wafer loading stage, indicating that operators could potentially be exposed to the reflected light.

7.2.3 Photoresist Developing. The exposed wafers are developed by spin application of a proprietary developer solution containing xylene and n-butyl acetate. The process equipment is similar to that used for photoresist application and described in Section 7.2.1. The spin platforms are vented from below and are enclosed in a hinged plastic cover that is lifted for loading and unloading wafers.

Monitoring systems for evaluating emissions or operator exposures to chemical or physical agents associated with the process operation were not present. No personal protective equipment is used by the operators. Work practices require the operator to place wafers into a loading jig. The hinged cover enclosing the spin platforms is lifted and the jig is placed over the platforms. The process is then initiated by push-button controls, the loading jig is removed, and the cover is closed.

## 7.3 Wet Chemical Cleaning and Etching

Wet chemical operations are used to etch wafers, to strip photoresist from wafers, to clean photomasks, and to clean process equipment.

7.3.1 Substrate Etching and Cleaning. Polypropylene benches are used for stripping photoresist, for photomask cleaning and for acid etching. Tanks containing the acid etching solutions are recessed into the bench. The work surface is perforated with a spill plenum below the surface. The bench is enclosed on three sides and vented through the top of the unit. One bench was also vented by slots located across the rear of the bench. The benches have a splash shield across the top of the bench.

A vertical laminar flow hood that is mounted above one of the benches has been altered to operate as an exhaust hood. The original hood was designed to recirculate room air through the hood by a return air grill. However, altering the unit for use as an exhaust hood without sealing off the return air grill may affect the ability of the hood to control emissions.

Etching and cleaning agents include: 1) sulfuric acid and hydrogen peroxide, 2) hydrofluoric acid and ammonium fluoride, 3) hydrofluoric acid and acetic acid, 4) potassium hydroxide, and 5) phenol, sulfonic acid, aromatic solvent, and chlorobenzene. Potassium hydroxide, hydrofluoric/acetic acid and the phenol mixture are maintained at elevated temperatures of approximately 50°C. The tank containing the phenol solution is covered with aluminum foil to control evaporation.

Personal protective equipment requirements are described in Section 5.3. Monitoring systems for evaluating emissions or worker exposures to chemical or physical agents are not present. Bench exhaust velocity is checked periodically by the facility engineer.

Special work practices that may affect emissions or operator exposures include designating a specific chemical technician to be responsible for transporting and pouring all liquid chemicals in the fabrication area. The chemical technician is required to wear gloves, apron, and a face shield. Chemicals in 1-gallon bottles are transported into the room in metal carts and stored on the floor below or adjacent to the benches.

New wet benches were being installed during the survey. The newer style polypropylene bench had the tanks recessed in wells with lip exhaust around the well on all four sides. The wells are partially enclosed with a plastic shield that is cut out to allow the operator to lower cassettes into the tanks. The exhaust at the back of the benches includes a baffle demister.

7.3.2 Furnace Tube Cleaning. Furnace tubes are cleaned in a horizontal bench that is vented by slots across the rear of the bench. The tube is laid in recessed tanks in the bench and the acid (hydrofluoric, nitric, and acetic acid) is poured onto the tube by the operator. The bench work surface surrounding the tanks is perforated with a spill plenum below the surface that is exhausted through the ventilation takeoff at the rear of the bench. A splash shield is hung from the top edge along the front of the bench.

There is no monitoring performed in the area. The chemical technician performs the tube cleaning process and wears gloves, a face shield, and apron. No work practices affecting emissions or worker exposures were observed in the area.

## 7.4 Plasma Etching

Plasma etching is a chemical etching method using a plasma gas containing ions, free electrons, and free radicals to remove specific material or layers from the wafer surface. The plasma is created by ionizing a gas in a radio frequency field at 13.56 MHz. The gases and type of reactor used depend upon the layer to be etched. The operation is performed with the system reaction chamber pressure negative to the room pressure. The vacuum is approximately 0.1 to 20 torr and is maintained by an oil-sealed mechanical pump. The plasma gases, containing the volatile species formed by the plasma ions reacting with the substrate, are vented from the unit by the pump to the atmosphere. The process operation is automatically controlled. A detailed description of plasma etching technologies is provided by O'Neill (1981) and Bersin (1976) and should be consulted for additional information.

Comdial etches silicon nitride using a carbon tetrafluoride/oxygen plasma. The etching is performed using a barrel reactor system. The etching unit is located on a table in the fabrication area with the radio frequency power source and oil-sealed mechanical pump placed below the unit on the floor. The carbon tetrafluoride/oxygen gas is supplied in a cylinder that is stored next to the unit and chained to the table. The reaction chamber and radio frequency coil are enclosed in a metal cabinet to control radio frequency emissions.

Operators are required to conform with general fabrication area personal protective equipment requirements described in Section 5.3 and includes safety glasses. Open-toe shoes are prohibited in the production area.

Monitoring systems for evaluating emissions or worker exposures to chemical or physical agents from plasma etching were not present. Work practices that may affect emissions or operator exposures were not observed. Periodic maintenance activities include draining and replacement of the pump oil once per week. The oil is drained into a bucket and taken to the waste storage area described in Section 3.6.

## 7.5 Diffusion

Diffusion introduces impurities or dopants into the wafer surface that alter the electrical properties of the substrate. The operation is performed in an atmospheric pressure diffusion furnace assembly similar to that described in Section 7.1. The wafers are heated to a high temperature (approximately 600 to 1200°C depending on the dopant), and the dopant is introduced into the furnace tube. The dopants used at Comdial include phosphorus oxychloride ($POCl_3$) and boron tribromide ($BBr_3$). They are supplied in liquid source bubblers that are placed in the source cabinet of the diffusion furnace assembly and connected to the furnace tube. Nitrogen is bubbled through the liquid and enters the furnace tube where it comes in contact with the heated wafers.

Engineering controls present in the diffusion operation are described in Section 7.1 for diffusion furnace assemblies. The diffusion furnace assemblies used for doping differ from those used for thermal oxidation as the furnace source end is partially enclosed in a cabinet. However, the source cabinet is not ventilated.

Liquid bubblers are changed by a chemical technician. The technician fills the bubbler with the liquid in a ventilated work station located in the diffusion furnace area. No monitoring systems were present in the area for evaluating emissions or operator exposures to chemical or physical agents. Operators are required to wear general personal protective equipment described in Section 5.3 and includes safety glasses. Open-toe shoes are prohibited in the production area. Special operator requirements include the use of heat protective gloves for handling hot materials. Chemical technicians who change source bubblers wear aprons, gloves, and goggles. Diffusion furnace maintenance operations are described in Section 7.1.

## 7.6 Hydrogen Alloying

Wafers are heated in a hydrogen atmosphere to correct radiation defects formed during metalization. The operation, known as hydrogen alloying, is performed in an atmospheric pressure diffusion furnace assembly described in Section 7.1. The process gases used include hydrogen and nitrogen. The engineering controls and personal protective equipment requirements are identical to those described in Section 7.1.

Monitoring systems present in the diffusion furnace area include a combustible gas monitor described in Section 3.4. Specific work practices for controlling emissions or operator exposures to chemical or physical agents were not observed during the preliminary survey. Maintenance of the diffusion furnace assembly is described in Section 7.1.

## 7.7 Chemical Vapor Deposition

Chemical vapor deposition (CVD) is the process of depositing a film by a chemical reaction or pyrolytic decomposition in the gas phase. Atmospheric pressure CVD is used to deposit phosphorus-doped silicon dioxide. Low pressure chemical vapor deposition (LPCVD) is used to deposit silicon nitride, polycrystalline silicon, and phosphorus-doped silicon dioxide. Both systems are described below.

7.7.1 Low Pressure Chemical Vapor Deposition. Low pressure chemical vapor deposition is performed in a diffusion furnace assembly similar to that used for diffusion but operated at low pressure (approximately 0.1 to 3.0 torr). The LPCVD furnace consists of a furnace tube with mechanically sealed doors, gas control enclosure, gas flow control, electronic control, and vacuum pump. The process operation is controlled by a microprocessor using feedback control loops and programmed "recipes". The system controls the furnace temperature profile, gas flow, vacuum pumping and purging, and process sequence. The furnace tube vacuum is maintained by an oil-sealed mechanical pump located in the source cabinet. Nitrogen is introduced into the pump to control oil backstreaming and to dilute the exhaust (Baron and Zelez, 1978). The pump exhaust is vented to the atmosphere. The source cabinet containing the gas manifolds and flow controllers is ventilated by a local exhaust take-off located at the top of the cabinet. A portion of the source cabinet is used to house the vacuum pumps and is separately ventilated by a second exhaust take-off located at the top of the cabinet.

Process gases used include: 1) silane, oxygen, and phosphine for phosphorus-doped silicon dioxide deposition; 2) dichlorosilane and ammonia for silicon nitride deposition; and 3) silane for polycrystalline silicon deposition. Process gases are stored in a ventilated cabinet located near the LPCVD furnace.

The process operation requires the operator to load wafers onto carriers that are inserted into the furnace. The operator initiates the process operation by push-button controls. Following deposition of the desired film, the operator removes the wafers from the furnace.

Monitoring systems for evaluating emissions or worker exposures to chemical or physical agents associated with the process operation were not present. Personal protective equipment requirements are described in Section 5.3. No special personal protective equipment is used for changing gas cylinders.

Specific work practices for controlling emissions or operator exposures to chemical or physical agents were not observed during the preliminary survey.

7.7.2 Atmospheric Pressure Chemical Vapor Deposition. Phosphorus-doped silicon dioxide is deposited on the wafer surface by continuous atmospheric pressure chemical vapor deposition. The process equipment consists of a wafer transport conveyor, gas deposition head, gas flow control, and exhaust system.

The process equipment components are contained in a single cabinet located beneath a laminar flow HEPA filtration unit. Wafers are loaded onto platens that are placed on a conveyor. The conveyor heats the wafers and transports them to the deposition head. The deposition head consists of parallel metal plates that are mounted vertically and perpendicular to the conveyor. The plates provide uniform distribution of the process gases across the wafer surface. The chamber is ventilated at both ends where the wafers enter and exit. The exhaust system is monitored by a magnehelic gauge.

Process gases include silane, phosphine, oxygen, and nitrogen. Silane and phosphine are supplied in gas cylinders; however, the cylinder storage area was not observed.

Monitoring systems for evaluating emissions or operator exposures to chemical or physical agents were not used. Personal protective equipment requirements for the general area are described in Section 5.3 and includes safety glasses. Open-toe shoes are prohibited in the production area.

A vacuum system is available for cleaning silicon dioxide deposits from the process equipment and surrounding areas. The potential for operator exposure to silicon dioxide is not known as the unit was not in operation at the time of the preliminary survey.

## 7.8 Metalization

Metalization is done by electron beam evaporation in a sealed bell jar under vacuum. The wafers are loaded manually onto a planetary that is placed in the bell jar. The operation is automatic, and the oil-sealed vacuum pump exhausts to the atmosphere. There is no monitoring in the area. No extra personal protective equipment is required, and no work practices affecting emissions or worker exposures were observed.

## 7.9 Packaging and Assembly

Following completion of the fabrication process, wafers are forwarded to the customer for testing. Tested wafers are returned to Comdial for packaging. Individual die on the wafer are separated by a scribe-and-break technique. The area between parallel rows of the die, known as streets, is scribed with a diamond saw blade. The operator aligns the streets with the saw by viewing through a split field binocular microscope. The streets are scribed automatically by the saw. The wafer is rotated 90 degrees and the process is repeated. The scribed wafer is then removed and the die are separated by breaking where the wafer is attached to a plastic backing sheet and held between two flexible metal belts that are passed over a stationary roller. The wafer breaks along the scribed streets and is then rotated 90 degrees and the process is repeated.

The die are visually inspected with a microscope. A silver epoxy compound is placed on the ceramic package by the operator and the die is attached. Electrical contacts between the die and the package pins are made with an aluminum wire. The operator aligns the die contact with the package contact and the wire is attached by ultrasonic bonding. The process is repeated for the remaining contacts. The package is then sealed with a ceramic epoxy bond. The package is placed in a resistance heated oven and cured at 150°C.

Wafer scribing, inspection, bonding, and sealing operations are performed by workers in work stations with horizontal laminar flow HEPA filtration. Local exhaust ventilation was not used at any work station. Specific engineering controls used to control emissions or operator exposures were not observed. The potential for exposure to chemical or physical agents appeared to be slight due to the small quantities of chemicals used and the nature of the operations.

Monitoring systems for evaluating emissions or operator exposures to chemical or physical agents were not present in the area. General personal protective equipment requirements are outlined in Section 5.3 and includes safety glasses. Open-toe shoes are prohibited in the production area. Specific work practices to control emissions or operator exposures to chemical or physical agents were not observed during the preliminary survey.

## 8.0 CONCLUSIONS AND RECOMMENDATIONS

Process operations performed at Comdial Semiconductor represent current technology. The facility also performs process operations that are representative of future processing trends such as LPCVD and plasma etching. In addition to relying on controls that are integral to the process equipment, the plant has added engineering controls. These controls include scavenger boxes for local exhaust ventilation of some diffusion furnace assemblies and ventilation of wet chemical benches. The facility has installed a magnehelic gauge to monitor exhaust from the continuous CVD operation and added a vacuum cleaning system for use at the CVD unit.

Specific recommendations follow:

1. The gas jungle for the diffusion furnace assembly should be enclosed and vented to control potential gas leaks. The manual gas shutoff valves should be located outside of the jungle in a more accessible area.
2. The source cabinet in the LPCVD unit should be covered with a clear plastic shield to improve the capture of possible gas leaks at the bottom of the cabinet.
3. The source cabinet for the diffusion furnaces used for doping that contain liquid source bubblers should be ventilated. The cabinet should be enclosed as described above.
4. Nitrogen cylinders should be used for purging process gas lines rather than house nitrogen. Although the check valves should control backflow of a contaminant into the house supply, failure of the check valve could result in contamination of the gas distribution system.
5. The possibility of substituting 100 percent phosphine with phosphine at a lower concentration should be evaluated as the agent is highly toxic.
6. The possibility of substituting trichloroethylene with 1,1,1-trichloroethane or another less toxic degreasing agent should be investigated.
7. The combustible gas detector used at Comdial should be routinely calibrated. If the new furnace area will be using hydrogen gas,

the plant should consider installing a combustible gas monitoring system that will alarm other areas of the plant to ensure that someone responds to the alarm. The present system relies on an operator being present in the area and hearing the alarm.

8. The facility should consider installing a continuous phosphine monitoring system in the fabrication area where 100 percent phosphine is used and stored.

A detailed survey of the Comdial Semiconductor facility should evaluate the following:

- Benches originally designed for laminar flow HEPA filtration but altered for use as a ventilation hood should be evaluated to determine the effectiveness of the system to control emissions or operator exposures.
- The effectiveness of shielding ultraviolet radiation emissions from the contact printing operation should be evaluated, including the possibility of exposure to the operator and other workers in the area.
- The effectiveness of ventilation systems for the new wet chemical work stations to control emissions and operator exposures should be evaluated.
- The effectiveness of shielding and other engineering controls used in the plasma etching operation to control radio frequency radiation evaluation should be evaluated.

## 9.0 REFERENCES


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