PRELIMINARY CONTROL TECHNOLOGY SURVEY

on

FAIRCHILD SEMICONDUCTOR
333 WESTERN AVENUE
SOUTH PORTLAND, MAINE 04106

to

U.S. Environmental Protection Agency
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

and

National Institute for Occupational Safety and Health
Division of Physical Sciences and Engineering
Engineering Control Technology Branch
4676 Columbia Parkway
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TABLE OF CONTENTS

1.0 ABSTRACT

A preliminary control technology assessment survey was conducted at Fairchild Semiconductor, South Portland, Maine, on December 4, 1981. The survey was conducted 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 digital bipolar integrated circuits.

The process operations for integrated circuit fabrication are performed in a clean room environment. The supply air is passed through a pre-filter, a bag filter followed by a high efficiency particulate air (HEPA) filtration. In some areas such as the photolithography area charcoal adsorbers are placed within the air handling system. Process operations performed at Fairchild Semiconductor include: 1) thermal oxidation of purchased, pre-doped silicon wafers; 2) photolithography processes for defining circuit patterns, including photoresist application, substrate exposure, and photoresist development; 3) wet chemical etching and cleaning; 4) plasma etching; 5) epitaxial silicon deposition; 6) low pressure chemical vapor deposition (LPCVD) of silicon nitride; 7) atmospheric pressure chemical vapor deposition (CVD) of phosphorus-doped silicon dioxide; 8) doping, including diffusion and ion implantation; 9) plasma-enhanced chemical vapor deposition (PECVD) of silicon nitride; 10) metalization, including radio frequency (RF) sputtering, electron beam evaporation, and thermal evaporation; 11) wafer backside grinding; and 12) beam tape (Beta) fabrication.

Engineering controls used at the facility vary by process operation and process equipment. Several process operations are performed in sealed reaction chambers which isolate the process from the workers. The isolation technique is used in LPCVD, PECVD, plasma etching, epitaxial silicon deposition, ion implantation, and metalization. Shielding is used in ion implantation units to control X-ray emissions, in plasma etching and PECVD to control radio frequency radiation emissions, and in substrate exposure to control ultraviolet emissions. Local exhaust ventilation removes process gases and byproducts from atmospheric pressure CVD, PECVD, photolithography, wet chemical cleaning and etching, diffusion, backside grinding and Beta film

fabrication. Local exhaust ventilation is present at storage cabinets containing all gases (toxic, flammable, corrosive, pyrophoric, and inert).

Several process operations are automated and controlled by microprocessors. These operations include CVD, LPCVD, thermal oxidation, PECVD, plasma etching, epitaxial silicon deposition, diffusion, ion implantation, Beta film fabrication, metalization, and some photolithographic operations.

Continuous area monitoring of selected chemical agents in the wafer fabrication area is performed by a Matheson® arsine/phosphine monitor. Continuous monitoring for hydrogen is accomplished with a MSA® combustible gas detection system. Radiation film badges are used to monitor emissions and operator exposures to X-ray radiation from ion implantation units.

Personal protective equipment controls operator exposures during normal process operations, maintenance, and repair. Operators are also required to wear product-protective equipment to control contamination of the wafers. Fairchild has also developed a comprehensive occupational health and safety program that includes industrial hygiene, safety, worker training, and emergency response.

A variety of process operations are used at the facility that should be considered for detailed investigation. These include diffusion, using solid and gaseous dopant sources, PECVD, LPCVD, and plasma etching. Work practices that may affect emissions of or operator exposures to chemical and physical agents could not be addressed during the preliminary survey due to time constraints; they should be documented during a detailed survey.

2.0 INTRODUCTION

A preliminary survey was conducted at Fairchild Semiconductor, South Portland, Maine, on December 4, 1981 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.

The following plant representatives supplied information at Fairchild Semiconductor:

1. Rip Dyer, Safety and Industrial Hygiene Coordinator
2. Rolf Dries, Supervisor Engineer, Photolithography
3. Bill Black, Supervisor Engineer, Sputtering, Evaporation, PECVD, Silox, Backside Grinding
4. Ron Gagne, Supervisor Engineer, Diffusion, Ion Implantation, Epitaxial Growth
5. Terry Weymouth, Supervisor Engineer, Packaging.

The study protocol was provided to Mr. Rip Dyer before the survey. During an opening conference, the study objectives and methods were described. Plant staff provided a detailed description of the health and safety program of the facility, including a review of the plant construction, monitoring systems, gas handling systems, and chemical storage facilities.

Following the opening conference, the research team surveyed the wafer fabrication and Beta film fabrication areas and the medical facilities. A closing conference was held following the survey.

3.0 PLANT DESCRIPTION

3.1 General

The Fairchild Digital Products Division, South Portland, Maine, plant was constructed in 1961. The facility consists of two buildings of concrete block construction with a combined area of 220,000 square feet. The facility manufactures digital bipolar integrated circuits. Operations performed at the facility include wafer fabrication, lead fabrication, assembly, packaging, circuit design, and research and development activities.

The facility employs 1360 people with 890 individuals in the production area and 270 in administration. The production staff includes 531 workers on the first shift, 215 workers on the the second shift, and 146 on the third shift.

Approximately 230 of the 890 production workers are in the wafer fabrication area. The remaining production employees are in integrated circuit testing, wafer sorting, die scribing and separation, die bonding, packaging, reliability testing, and film production (Beta Film).

3.2 Chemical Storage

Chemical supplies for the fabrication area are stored in an individual container chase adjacent to the clean room fabrication area. Liquid chemicals are supplied in 1-gallon containers that are transported in carts to exhausted cabinets containing sprinklers in the walls of the fabrication area. The chemical storage area was not observed during the preliminary survey.

3.3 Gas Handling System

Process gases are supplied in cylinders that are stored in ventilated cabinets located in or near the process equipment. Process gases are distributed to the equipment in welded stainless steel lines and are connected to the equipment with compression fittings. Nitrogen is supplied from a bulk storage tank. This supply, known as house nitrogen, is used as a purge gas. Dual check valves with a relief valve in between are used in the nitrogen lines to prevent contamination of house supplies. Cylinder gas supply lines have flow-limiting valves. Dual cylinders of arsine and diborane are provided with regulator assemblies that automatically switch gas flow from an empty cylinder to a full one. There are emergency hydrogen shutoffs for each area using hydrogen.

Gas cylinders are replaced by workers wearing air line-supplied respirators. Those cylinders are leak-tested with a soap bubble test (SNOOP®) or an ammonium hydroxide vapor test in the case of cylinders containing chlorine compounds (hydrogen chloride, dichlorosilane, silicon tetrachloride, boron trichloride, etc). Solenoid valves, which stop gas flow in the event of a power failure, are incorporated in the gas handling system within the epitaxial reactor.

Gases supplied in cylinders include the following: 1) arsine in 50 ppm in hydrogen and 20,000 ppm (2 percent) in nitrogen, 2) phosphine in 20 ppm and 50,000 ppm (5 percent) in hydrogen, 3) diborane, 4) boron trichloride, 5) hydrogen chloride, 6) silicon tetrachloride, 7) dichlorosilane, 8) silane (1.5 percent and 100 percent), 9) ammonia, 10) hexafluoroethane (Freon 116), 11) carbon tetrafluoride (Freon 14), and 12) sulfur hexafluoride, 13) Argon, 14) Boron trifluoride, 15) nitrous oxide, 16) trichlorofloromethane (Freon 11), and 17) both 15 percent arsine and phosphine in lecture bottles.

3.4 Monitoring Systems

Arsine and phosphine are monitored with a Matheson® Model 8040 located in the service aisle at the rear of the diffusion furnace area. Air sampled from the diffusion furnace area is pulled through a filter tape impregnated with chemical reagents sensitive to arsine or phosphine manifested by a chemiluminescent reaction that is monitored by the unit. The unit sounds an alarm in the furnace area only when arsine or phosphine levels exceed the Threshold Limit Value (50 ppb and 300 ppb, respectively).

The facility is installing a TELOS® continuous multipoint arsine/phosphine monitoring system that will activate area of leak, fab maintenance, and plant security. The system is capable of monitoring 16 remote locations throughout the plant which will be installed in the gas storage and wafer fabrication areas.

Hydrogen is monitored with a MSA® combustible gas detection system using 18 remote sampling points throughout the wafer fabrication area. The unit is calibrated once every 3 months. Alarms for the unit are located in the guard station.

3.5 Ventilation System

The ventiliation system consists of air treatment and supply, air recirculation, and local exhaust ventilation. The wafer fabrication room supply air is cleaned by passing air through a fiberglass prefilter followed by a charcoal bed and high efficiency particulate air (HEPA) filter. The filtration system is housed in the penthouse located on top of the building. The clean room air is at positive pressure to the surrounding areas in the building.

Recirculation of clean room air is restricted to the photolithography area. The room air is supplied through ceiling grates and return air is exhausted through louvers located in the wall of the room, approximately 3 feet above the floor. Twenty-five percent of the recirculated air supply is fresh makeup air which is again passed through the filtration system before distribution. The quantity of air that is supplied or recirculated in the fabrication areas was not reported.

Air is exhausted from the wafer fabrication area by either exfiltration from the room or by local exhaust ventilation of process equipment. Local exhaust ventilation for process operations is described in Section 7.0. Exhaust air from the arsenic trioxide diffusion furnaces is passed through a fiberglass prefilter, a bag filter, and a HEPA filter. The unit handles 2310 cubic feet per minute (cfm) of air from the two diffusion furnace stacks. Exhaust from wet chemical benches using nitric and hydrochloric acid is treated by passing the exhaust through a wet scrubber. The system treats 4500 cfm of air exhausted by four benches. Additional air treatment includes the use of oil separators that trap oil from pump exhausts. The system is reported to be 99.5 percent efficient in removing oil from the exhaust air and is used on most oil-sealed pumps. The pump exhaust is vented directly to the atmosphere.

Supply air intakes are located on top of the penthouse. The nearest exhaust stack is located approximately 100 feet away.

3.6 Waste Management

Liquid wastes are handled separately and may be categorized as acids containing fluorides, all other acids, chlorinated hydrocarbon solvents, Freons, and all other non-chlorinated organic solvents. Wastes are either collected by an operator and transferred to a storage or treatment area or they are collected by a drain system that connects to a storage tank or treatment facility.

Acids containing fluoride are collected by a separate drain system and stored in two 4200-gallon tanks that are located in a polypropylene containment tank set in a diked area. The waste acid is removed by a waste management firm for disposal. Other acids are collected by a separate drain system and directed into an acid tank where the pH is adjusted with anhydrous ammonia. The treated acids are then released to a publicly operated treatment works (POTW). Chlorinated hydrocarbon solvents, such as 1,1,1-trichloroethane, are collected by a separate drain system into a 100- to 200-gallon tank. The waste is transferred to 55-gallon drums that are collected by a waste management firm for off-site disposal. Freon wastes are collected separately and stored in 55-gallon drums for recycling by a waste management firm. Photoresist wastes are collected separately and added to the non-chlorinated organics waste solvent.

Waste pump oils are collected and stored in 55-gallon drums. The waste oils are treated as a hazardous waste and disposed off-site by a waste management firm. The storage areas where liquid wastes are held before collection were not observed during the preliminary survey.

Solid hazardous wastes, such as arsenic trioxide and antimony trioxide, are collected and stored in 55-gallon drums for off-site disposal by a waste management firm. The wastes originate from the diffusion furnace area and from diffusion furnace exhaust air filters. Roughing filters, bag filters, HEPA filters, and personal protective clothing (coveralls) worn by workers changing the filters are placed in drums for collection and disposed off-site by a waste management firm.

Fairchild has instituted a pre-production, drain authorization program to determine the method and location of liquid waste disposal for those wastes originating in the fabrication area. Liquid wastes can only be disposed of in drains specifically identified for that type of waste.

4.0 PROCESS DESCRIPTION

The fabrication sequence used for bipolar integrated circuit manufacture varies depending upon the specific type of device manufactured. Process operations seen at the facility are discussed below. The specific sequence in which the process operations are performed is not presented. A general processing sequence for bipolar integrated 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. The silicon wafers used as a substrate for device fabrication are purchased.

In the thermal oxidation process, the wafers are oxidized at a high temperature (approximately 900 to 1200°C) in a diffusion furnace assembly using a pyrophoric water (hydrogen and oxygen) atmosphere. Periodically, hydrogen chloride gas is added to the gas stream for cleaning or gettering both the growing oxide and the oxidation tube of sodium ion contamination (Colclaser, 1980). The wafers are loaded into carriers that are inserted into the diffusion furnace. The furnace tube is heated by electrical resistance to the operating temperature while the tube is purged with nitrogen. Hydrogen and oxygen are introduced into the tube at a controlled rate. The furnace has direct digital control (DDC) of the operating conditions including temperature, processing sequence, and tube temperature. The furnace is automatically controlled by feedback control loops that monitor the furnace performance and adjust the conditions to programmed specification (Douglas, 1981).

Following thermal oxidation, the wafers are ready for photolithography including: 1) primer and 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 first coated with primer by spin application using either hexamethyldisilizane (HMDS) or bistrimethylsilyacetamide (BSA) in a xylene, methyl ethyl ketone, or Freon carrier. The photoresist, containing a proprietary mixture of organic polymers in a xylene carrier, is spun onto the wafer and the coated wafer is baked in a resistance-heated oven. The operation is automated and only requires that the operator load and unload the cassettes.

The mask pattern is transferred to the coated wafer by ultraviolet light (365 to 415 nm) using either projection mask alignment or contact printing. The operator aligns the wafer with the mask by viewing through a split-field binocular microscope. In projection mask alignment, a lens is interposed between the mask and the wafer with the ultraviolet light source located behind the mask. In contact printing, the wafer is clamped to an emulsion mask and exposed to ultraviolet light from a mercury lamp source located behind the mask. Masks used for projection mask alignment are manufactured by vendors. Masks used for contact printing are manufactured by Fairchild from a chrome submaster mask produced by a vendor. The contact mask is a precision glass plate with a silver halide emulsion. The mask pattern is transferred from the submaster with ultraviolet light. Exposed masks are developed with a hydroquinone-based solution.

The exposed wafers are developed either by immersion in a developer tank or by spin-on application of the developer. A mixture of n-butyl acetate and xylene develops the negative photoresist and a potassium hydroxide solution develops the positive photoresist. The developed wafers are rinsed with deionized water and "hard-baked" in a resistance-heated oven.

The exposed underlying layer may 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) hydrogen peroxide for etching titanium/tungsten alloy; 2) hydrofluoric acid and ammonium fluoride for etching silicon dioxide; 3) phosphoric acid for etching silicon nitride; 4) nitric acid and iodine for etching silicon; 5) nitric, phosphoric, and acetic acid for etching aluminum; and 6) nitric and hydrochloric acid for metal etching. The etching operations are performed in tanks recessed in polypropylene benches (equipped with splash shields) similar to laboratory type hoods. The acid tanks are located in the rear of the benches. Local ventilation of the tanks is provided by slots around the tank perimeter and/or by slots located across the rear of the bench.

Plasma etching is performed by placing wafers in a plasma gas formed by a radio frequency power source operating at 13.56 MHz. The plasma gas contains ions, free radicals, and free electrons that are reactive with the layer to be etched. The gas used for creating the plasma is selected based upon the individual layer and includes: 1) Freon and oxygen for etching silicon dioxide, 2) carbon tetrachloride for etching aluminum, and 3) oxygen for stripping photoresist. 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.

Doping introduces impurities into the wafer, altering the electrical properties of the doped area. Wafers are doped at various stages of the processing sequence either by diffusion or ion implantation. Diffusion is accomplished by exposing the wafer to a high temperature atmosphere containing the dopant. The operation is performed in a diffusion furnace assembly using either a solid (arsenic, antimony trioxide, boron nitride), liquid (phosphorus oxychloride, boron trichloride, phosphorus tribromide), or gaseous (arsine or diborane) dopant source. Both direct digital control (DDC) diffusion furnaces and hybrid control diffusion furnaces are used at Fairchild.

Wafers are also doped using ion implantation. A source material is ionized and passed through an analyzing magnet where the desired ions are collected, accelerated, and implanted into an individual wafer held in a vacuum chamber. The ion source, the analyzing and accelerating chamber, and the wafer exposure station are operated at vacuum conditions of approximately 10^{-6} torr. This vacuum is maintained by two sets of pumps; either an oil-sealed pump and a diffusion pump or an oil-sealed pump and a cryogenic pump. The dopant source is either a gas (boron trifluoride) or a solid (elemental arsenic or phosphorus). The process operation sequence requires the operator to load a cassette into the load station of the ion implantation unit. Individual wafers are automatically removed from the cassette to a load lock chamber which is pumped to vacuum with an oil-sealed mechanical pump. The wafer is transferred to the exposure chamber where the dopant ions are implanted. The dosage received by the wafer is automatically controlled. The implanted wafer is transferred through a second load lock chamber and then into a cassette.

The doped wafers are heated in a nitrogen or oxygen atmosphere in a diffusion furnace during the processing sequence. The furnace assembly is similar to that previously described for thermal oxidation.

A single crystal layer of silicon is deposited on the wafer surface by epitaxial growth in an enclosed chamber. The single crystal silicon layer is deposited by the reaction of dichlorosilane and hydrogen, or silicon tetrachloride and hydrogen. A doped silicon layer is deposited by introducing arsine or phosphine. Epitaxial silicon is deposited at high temperature (approximately 950 to 1250°C) in a reaction chamber at atmospheric pressure and heated by either radiant heat or radio frequency radiation. The operation sequence is automatically controlled and requires the operator to load wafers onto a metal platen or barrel which is then inserted into the reactor chamber. A description of epitaxial silicon deposition is provided by Atherton (1981) and Hammond (1978) and should be consulted for more detailed information of the process.

Another process operation performed during the fabrication sequence is the deposition of a thin film on the wafer surface by chemical vapor deposition where the solid products of a vapor phase chemical reaction are deposited on the substrate. Low pressure chemical vapor deposition (LPCVD) is used to deposit silicon nitride by the reaction of ammonia and dichlorosilane. The operation is performed in a sealed diffusion furnace tube evacuated to approximately 0.4 to 3.0 torr (Baron and Zelez, 1978). The process operation requires the operator to load cassettes containing wafers into the furnace. The furnace door is closed and the sequence and operating parameters are then controlled by microprocessor.

Plasma-enhanced chemical vapor deposition (PECVD) is also used to deposit silicon nitride by the reaction of either 2 percent silane and nitrogen or 100 percent silane and ammonia. The plasma is created by introducing the gases in a 13.56 MHZ radio frequency field. The operation is performed under vacuum conditions in a sealed chamber or tube at approximately 0.2 to 1.0 torr. Two PECVD systems are used at Fairchild for silicon nitride deposition. These include an in-line cassette-to-cassette unit and a furnace assembly similar to the diffusion furnace with a radio frequency power source, sealed chamber tube, vacuum system, and a wafer boat. The boat consists of a set of vertical, parallel metal plates onto which the wafers are mounted.

The operation sequence requires the operator to either load cassettes containing wafers into the unit (cassette-to-cassette system) or to mount wafers on a series of vertical parallel plates which are then loaded into the furnace tube. Both types of equipment are automatically controlled by a system microprocessor.

Atmospheric pressure chemical vapor deposition (CVD) is used to deposit a phosphorus-doped silicon dioxide layer by the reaction of 100 percent silane, oxygen, and phosphine. The operation sequence requires the operator to load wafers onto flat plates or platens and insert them into the unit. Once inside the unit the sequence is automatically controlled.

A metal layer is deposited on the wafer surface by either radio frequency sputtering, electron beam evaporation, or thermal evaporation. The metal is deposited on the wafer surface in a sealed reaction chamber or bell jar that is maintained at a vacuum of approximately 10^{-6} torr by an oil-sealed mechanical pump and an oil diffusion pump or cryogenic pump. Radio frequency sputtering (at 13.56 MHz) is used to deposit aluminum, aluminum/copper, platinum, titanium/tungsten, and gold; electron beam evaporation is used to deposit aluminum; and thermal evaporation is used to deposit gold. The process operation sequence requires the operator to load the wafers in a planetary structure or platen and to place it inside the process equipment. The process operation is then automatically controlled by a system microprocessor.

Process operations such as photolithography, doping, metalization, and chemical vapor deposition may be repeated several times during wafer fabrication. Between these processing steps wafers may be cleaned using a solution of nitric and sulfuric acid, nitric and hydrochloric acid, or hydrofluoric acid. Photoresist may be stripped by oxygen plasma etching or by wet chemical methods. The latter method may use: 1) phenol and perchloroethylene, 2) sulfuric acid and hydrogen peroxide, 3) 1,1,1-trichloroethane, or 4) isopropanol. These wet chemical operations are performed in partially enclosed bench stations (equipped with splash shields) similar to laboratory hoods. The stations are ventilated by local exhaust slots at the rear of the benches or around the perimeter of the immersion tank.

Following gold sputtering onto the wafer surface, a photoresist laminate film is applied to the wafer which is then exposed to a mask pattern using ultraviolet light. The pattern exposes areas of the wafer that will serve as electrical interconnections to the individual die. The exposed wafer is developed using 1,1,1-trichloroethane to uncover the underlying gold layer. A gold film is then plated onto the exposed areas in a potassium cyanide gold electroplating process. The laminate is stripped from the wafer with methylene chloride and the exposed gold layer is etched using a cyanide solution. A titanium/tungsten layer exposed by the gold etching process is then stripped using hydrogen peroxide. The process produces gold bumps that provide contacts with the film carrier in the final package. A detailed review of the process, known as wafer bumping, is provided by Liu et al. (1980).

The final step in the wafer fabrication sequence is backside grinding of the wafer. The wafers are first cleaned with isopropanol, then mounted (backside exposed) on a metal plate that has a laminate sheet adhesive. The exposed wafer backside undergoes a process known as Blanchard grinding. The wafers are removed and cleaned with isopropanol. Additional operations that may be performed include a backside diffusion and backside gold deposition.

Following wafer fabrication, each die on the wafer is electrically tested and most of these units are shipped overseas for packaging. A percentage of these utilize Beta film packaging techniques where the wafers are scribed and individual die are attached to a Beta film carrier.

The Beta film (i.e., beam tape) carrier is manufactured by Fairchild in a separate area adjacent to the clean room wafer fabrication area. The carrier consists of a copper film with an adhesive and polyimide layer. Initially, the adhesive-coated polyimide film is cut and perforated and a copper film is laminated to it. The laminated film is cured in a nitrogen purged oven at 120°C. The copper is cleaned with sulfuric acid followed by sodium persulfate and water. The photoresist laminate film is applied to the tape with a heated roller. The film carrier pattern is transferred to the film by exposure with ultaviolet light at 380 nm. The exposed film is developed with butyl cellosolve, rinsed, and dried. The backside of the film is coated with silk screen ink in an acetone carrier using a roller coating process. The film is cured in a nitrogen purged oven and cleaned with sodium persulfate. The exposed copper film is then etched with an ammonium hydroxide spray followed by a water rinse and air dry. The remaining photoresist and backside coat film is stripped, rinsed in acetone, dried, and then inspected before shipment. The process is a continuous automated operation. A detailed review of beam tape carrier fabrication is provided by Cain (1978) and Hayakawa et al. (1979).

5.0 DESCRIPTION OF PROGRAMS

5.1 Industrial Hygiene

A full-time industrial hygienist is employed at the facility with responsibility for industrial hygiene, safety, security, training, and medical. Additional assistance in industrial hygiene and safety is available from the corporate headquarters in Mountain View, California.

Monitoring of worker exposures has been conducted during normal operations, maintenance and emergency conditions such as chemical spills. Monitoring equipment used in previous analyses includes a portable infrared analyzer (MIRAN® 1A), direct reading detector tubes, midget impingers, and charcoal tubes. X-ray radiation emissions and operator exposures in the ion implantation area are monitored with radiation film badges and a Geiger Counter.

Measurements of the ventilation system are limited to monitoring face velocities of local exhaust ventilation systems using a swinging vane anemometer. Some operations also require careful monitoring of air exhausts to assure product quality. The measurements are performed by facility engineering personnel and the industrial hygienist.

Scheduled renovations to the wafer fabrication area will include the use of magnehelic gauges to monitor local exhaust ventilation from the diffusion furnaces. The ventilation system design drawings have recently been updated to trace all process ventilation systems from the point of exhaust to the air cleaner and/or exhaust fan. This documentation was required for emergency response planning and to identify all agents potentially exhausted through a given system. Also it was used to determine compatibility of the exhaust system and planning of facility renovations.

An emergency response team has been organized to handle chemical spill hazards and emergency evacuation. Emergency drills are performed twice a year. Fairchild has also established an internal emergency telephone number for reporting accidents or hazardous situations. Telephones are accessible throughout the wafer fabrication area. The communication system is also on emergency power and there are 2-way radios for safety personnel and chemical spill teams as well as other key supervisors.

5.2 Education and Training

Fairchild's training programs include safety, materials handling, personal protective equipment, emergency response, and hazard reporting. These programs cover chemical safety, handling and labeling of hazardous wastes, use of self-contained breathing apparatus and respirators, and emergency evacuation procedures. Programs are offered twice a year as a refresher.

A chemical training program (1 hour) is offered weekly for all new employees. Specialized training for new employees or employees new to a production area is the responsibility of the area supervisor. Supervisors instruct new employees on safety items that are also outlined on a safety review checklist. This checklist includes: 1) specific job safety requirements; 2) emergency evacuation procedures; 3) required action for specific alarms; 4) location of emergency showers, eye wash stations, fire extinguishers, and telephones; 5) safety function of exhaust fume hoods; 6) eating and smoking policies; 7) work alone policy; 8) proper chemical storage procedures; 9) aisle clearance; 10) medical department location; 11) accident or hazardous situation reporting; and 12) housekeeping practices. There is also supervisor training with other facility supervisors and a 2-hour tour with IH.

5.3 Respirators and Other Personal Protective Equipment

The safety and medical departments at Fairchild have specific personal protective equipment requirements for each area in the plant including production, maintenance, support facilities, and office areas. The requirements cover the use of safety glasses, contact lenses, ear and head protection, and the designation of radiation and non-smoking areas. The general requirements are supplemented by specific task or job functions within the areas and safety specifications are written for each piece of process equipment.

Workers are required to wear safety glasses in the wafer fabrication area. Open toe shoes and contact lenses are prohibited. Specific requirements by job category or task include: 1) apron, gloves with gauntlets, and face shields for operators, 2) aprons, acid gloves with gauntlets, face shields, and boots for chemical technicians transporting or mixing chemicals, 3) air line-supplied respirators for technicians changing gas bottles, 4) respirators (3/4 face with goggles) for maintenance workers changing arsenic and antimony air filters, and for cleaning silicon dioxide deposits from the vapor phase deposition system, and 5) air line-supplied respirator for technicians changing the plasma etching system cold trap.

5.4 Medical Program

The facility employs two full-time nurses and one part-time nurse to provide health services on all three production shifts. A physician is employed on the premises on a part-time basis. Emergency care services and health education are provided by the nurses.

All personnel are required to undergo a preplacement medical examination and a periodic examination every 1 to 2 years. Chest X-rays are required for fabrication area workers and chemical mix operators. Periodic hearing examinations are required for workers in areas with noise levels greater than 85 dBA. Vision testing is required for all employees. All fabrication area workers are required to have blood tests, including a full blood profile. Urine samples are required from all workers in areas using arsenical compounds to determine urinary arsenic levels.

5.5 Housekeeping

Housekeeping and maintenance activities are a necessary part of maintaining product quality. Specific housekeeping procedures that were identified by the plant as preventing worker exposures to chemical agents include the use of a portable vacuum system for cleaning areas where antimony trioxide powder is used. The system is used for routine cleaning and control of dry spills. Cleaning and maintenance operations associated with each process operation are described in Section 7.0.

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 the ventilation system performed. Results of monitoring performed by the Fairchild industrial hygienist were not obtained; however, an extensive amount of data was available.

7.0 DESCRIPTION OF CONTROL STRATEGIES FOR PROCESS OPERATING OF INTEREST

A variety of strategies are used at Fairchild to control emissions and worker exposures. These control strategies include local and general exhaust ventilation, process isolation, process and environmental monitoring, personal protective equipment, and safe work practices. Devices or work stations that contain toxic materials considered potentially of immediate danger to life and health are all controlled by local exhaust ventilation and monitoring systems, whereas less potentially hazardous areas are controlled by general exhaust ventilation. Specific engineering control strategies for individual process operations are described below. Monitoring systems are described in Section 3.4 and briefly described below for the specific process operation. General personal protective equipment requirements are described in Section 5.3; specific requirements for some process operations are described below.

Process automation has influenced many work practices and, therefore, operator exposures to chemical and physical agents. Automated process controls limit the time that operators are working with the equipment and only require that the operator load and unload wafers, initiate the processing sequence (with push-button controls), and perform routine cleaning operations. The operator is then free to perform other tasks such as wet chemical cleaning and etching or to operate other automated units as he or she is not required to be at the unit for an entire work shift. Hence, any potential exposures to chemical or physical agents would be limited to small time periods throughout the shift.

Specific descriptions are given below for control strategies employed for chemical vapor deposition (CVD), low pressure chemical vapor deposition (LPCVD), thermal oxidation, plasma-enhanced chemical vapor deposition (PECVD), epitaxial silicon growth, photolithography, doping, wet chemical etching and cleaning, plasma etching, metalization, and wafer backside grinding.

7.1 CVD, LPCVD, and Thermal Oxidation

Chemical vapor deposition (CVD) is used to deposit a silicon dioxide layer on the wafer surface and is performed in an atmospheric pressure diffusion furnace. In addition, the units are used to produce a thermal silicon dioxide layer by oxidation of the silicon substrate, and for base and isolation drive-in of dopants. The diffusion furnaces are also used for doping wafers as described in Section 7.6. Low pressure chemical vapor deposition (LPCVD) is used to deposit silicon nitride and is performed in a diffusion furnace assembly operated at low pressure.

The diffusion furnace assembly consists of 1) a load station with a scavenger box exhaust where carriers containing wafers are loaded into the furnace, 2) a furnace cabinet containing the furnace tubes and electrical resistance heat source, 3) an exhausted source cabinet enclosing the furnace tube end, and 4) an exhausted electrical cabinet containing the system controls. Process gases enter the furnace tube through gas supply lines connected 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 include 1) hydrogen, nitrogen, and oxygen for thermal oxidation and base and isolation drive-in and 2) silane, oxygen, and phosphine for deposition of phosphorus-doped silicon dioxide.

The deposition of silicon nitride by LPCVD is performed in a furnace assembly (similar to those described above) under vacuum conditions in a sealed furnace tube. The furnace assembly is similar to that used for thermal oxidation but differs in the use of an oil-sealed mechanical pump that evacuates the tube to approximately 1 to 2 torr. Process gases used for silicon nitride deposition are ammonia and dichlorosilane.

CVD and LPCVD furnace tube cleaning is routinely performed in the furnace assembly by introducing hydrogen chloride gas into the tube. Additionally, the tube is periodically removed and cleaned with hydrofluoric acid and nitric acid in a wet cleaning station described in Section 7.3.

The CVD and LPCVD operations are performed by placing wafers in carriers that are loaded into the furnace. The tube temperature is increased (the specific temperature depends on the operation performed), and purged with nitrogen followed by the introduction of the process gases. After completion of the process sequence, the tube temperature is decreased and the carriers are removed. The process operating parameters, including tube temperature, gas flow, sequence duration, and other process operating conditions, are either controlled by the operator or by feedback control loops that monitor and adjust the dynamic performance of the furnace (Douglas, 1981).

The diffusion furnace assembly used for CVD is ventilated at three places 1) the source cabinet, 2) the furnace cabinet, 3) the furnace tube (scavenger box) load end, and 4) the electrical cabinet. Four furnace tubes are stacked in a furnace cabinet. The source cabinet encloses the gas assemblies and the ends of the four furnace tubes. The furnace cabinet is vented for temperature control by an exhaust duct at the top of the furnace cabinet. The furnace tube opening is exhausted by a scavenger box that encloses the opening. During operation, a cover is placed over the scavenger box opening at the work station to improve the capture efficiency of the exhaust. The quantity of air exhausted is 100 cfm, however, the capture or face velocity was not specified.

Monitoring systems present in the area include a multipoint combustible gas (hydrogen) monitoring system described in Section 3.4 with detectors in the room, drop ceiling, and the roof of the building. General personal protective equipment requirements are outlined in Section 5.3. Additional requirements include the use of asbestos gloves for handling hot quartzware.

Process gases are supplied from house nitrogen, oxygen, and hydrogen stores. Dichlorosilane, ammonia, and hydrogen chloride are supplied in cylinders stored in ventilated gas cabinets. The quantity of air exhausted from the cabinets is unknown.

7.2 Photolithography

The photolithography process consists of three basic steps: 1) substrate preparation, 2) substrate exposure, and 3) substrate developing. Following developing, 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 photolithography process may be repeated several times during the processing sequence. Associated with photolithography is the production of emulsion masks used in contact printing. The photolithography and mask production processes are described below.

7.2.1 Substrate Preparation. The operations involved in substrate preparation include: 1) H_2SO_4/H_2O_2 clean in some areas, 2) deionized water wash and nitrogen blow dry, 3) spin-on application of hexamethyldisilizane (HMDS) or bistrimethylsilyacetamide (BAS), 4) spin-on application of a positive or negative photoresist, and 5) soft bake of the coated wafer in an infrared oven. These operations may be performed consecutively in a single in-line cassette-to-cassette unit, or each operation may be performed by individual processing units. These systems are described below.

With the in-line cassette-to-cassette unit, a cassette containing wafers is loaded into the unit, and wafers are automatically removed and transported to a spin platform. The wafer is rotated and washed with deionized water, dried with nitrogen, and transported to an infrared drying oven. The wafers are transported through the oven to a second spin platform where HMDS or BAS is applied followed by application of the photoresist. Both negative and positive photoresists are used at Fairchild. The wafer is transported through a second infrared drying oven and loaded into a cassette. HMDS, BAS, and photoresist are automatically dispensed onto the wafer from pressurized metal containers that are electrically grounded. The process is controlled by a microprocessor.

The processes described above are also performed by individual equipment components. A cassette containing wafers is loaded into an automated spin application station where individual wafers are removed, mounted on a spin platform, and HMDS or BAS is applied. Photoresist is then applied to the wafer which is transferred to another cassette. The coated wafers are oft-baked in a resistance-heated oven.

Local exhaust ventilation for the in-line unit is provided by enclosing the spin platforms in a common exhaust plenum. The captured air is removed by a duct at one end of the plenum. A container is located in the cabinet below the unit to collect waste photoresist. The ventilation system for the unit has an exhaust boost fan located in-line with and positioned after the waste container to exhaust the spin platform and container. The in-line infrared drying ovens are ventilated by a local exhaust at the base of the ovens. The exhaust air from both operations is released directly to the atmosphere.

Local exhaust ventilation of the individual spin application station is provided by a takeoff located at the base of the spin platform. The duct connects to a sealed container in the station's cabinet that is used to collect photoresist waste. The exhaust duct extends from the container to the exhaust fan which discharges directly to the atmosphere. The resistance-heated drying ovens are vented to the workroom atmosphere.

Routine maintenance operations of the process equipment include cleaning of equipment parts with xylene in a vented wet chemical bench described in Section 7.3. The process equipment is also cleaned by wiping with xylene or acetone. Workers are required to wear chemically resistant gloves while cleaning the equipment.

7.2.2 Substrate Exposure. A mask pattern is transferred to the photoresist-coated wafers by projecting the mask image with ultraviolet light (UV) using either projection printing or contact printing. In projection printing, the mask pattern is transferred to the wafer using reflective optics and ultraviolet light. In contact printing, the mask is clamped to the wafer and the pattern is transferred with ultraviolet light. The ultraviolet light source for both operations is a mercury lamp that emits UV light at 365 to 415 nm wavelength. The mercury lamp enclosure in the projection printing systems is exhausted by local ventilation that exhausts to the room atmosphere.

The process is performed by an operator seated at the unit. The photoresist coated wafers are automatically removed from a cassette and rotated into position. The operator aligns the mask and wafer with a split field binocular microscope, then exposes the wafer to UV light. The wafer is removed and the process is repeated.

Most of the masks used in projection printing are produced to plant specifications by vendors and consist of a precision glass plate with a metallic chromium coating that has been etched to the desired pattern. A few contact printing masks are produced at the plant using a silver halide emulsion photomask. The mask consists of a glass plate that is coated with a fine grain silver halide (silver chloride, silver bromide, or silver iodide) emulsion. A chromium submaster mask is used to transfer the pattern to the emulsion mask by contact printing with UV light at 546 nm wavelength. The exposed emulsion mask is developed using a hydroquinone-based developer followed by a fixer, a water rinse, and drying. The production of emulsion masks was not observed during the survey.

Both types of wafer exposure systems were enclosed to prevent direct viewing of the mercury lamp source. However, blue light emissions were observed around the wafer platform on the exposure systems. The light may be reflected by the wafer as it is rests on the platform before alignment.

Operators are required to wear safety glasses which may be effective in protecting workers from UV exposure. However, glasses are removed by the operators when aligning the wafer and mask through the binocular microscope.

7.2.3 Substrate Developing. Photoresist-coated wafers that have been exposed to the mask pattern are developed by either applying the developer directly to the wafer surface or immersing the wafer in the developer solution. A proprietary mixture of n-butyl acetate and xylene is used to develop the negative photoresist, and potassium hydroxide is used to develop the positive photoresist. The developers are applied to the wafer in a spin-on operation similar to that used for photoresist application described in Section 7.2.1. The spin operations are automated, only requiring the operator to load and unload cassettes. The positive resist developer may also be applied by dipping the wafers into a developer bath.

Following application of the developer solution, the wafers are rinsed with deionized water, spun dry, and "hard-baked" in a resistance-heated oven. The operation may be performed in a continuous in-line system described in Section 7.2.1, or it may be performed at an individual work station where the wafers are dipped into a deionized water bath and placed in a resistance-heated drying oven.

Engineering controls used in the spin-on operation are described in Section 7.2.1 and include local exhaust ventilation at the base of the spin platform and at the base of the continuous in-line drying oven. The individual infrared drying ovens are exhausted to the workroom.

The immersion developing of wafers is performed in a wet chemical bench. The bench work surface is perforated with a spill plenum located below the surface and the plenum is exhausted at the rear of the bench. The developer tank is located against the rear of the bench and is exhausted by a slot across the rear panel.

Personal protective equipment requirements for clean room operations are outlined in Section 5.3.

7.3 Wet Chemical Etching and Cleaning

Wet chemical operations are used to clean wafers, to etch deposited layers, and to clean process equipment. Polypropylene benches are used for acid cleaning and etching operations, whereas stainless steel benches are used for organic cleaning operations. Chemicals used in wet benches include: (1) hydrogen peroxide for metal etching; (2) sulfuric acid and hydrogen peroxide for wafer cleaning; (3) hydrofluoric acid and ammonium fluoride for etching silicon dioxide; (4) hydrofluoric and nitric acid for cleaning quartzware; (5) phosphoric and nitric acid for etching silicon nitride; (6) nitric, phosphoric, and acetic acid solution for etching aluminum; (7) phenol and perchloroethylene mixture for photoresist stripping (only one product); (8) hydrofluoric and nitric acid for cleaning the epitaxial reactor; (9) nitric and hydrochloric acid (aqua regia) for metal etching; and (10) isopropyl alcohol or trichloroethane for wafer cleaning.

Furnace tube cleaning benches differ from other wet chemical benches by their size and construction. Tube cleaning benches at Fairchild include (1) horizontal benches in which the furnace tubes are laid in a long well in the bench and acid is added to the well to soak the tube; and (2) a vertical cleaning station in which the furnace tubes are placed in a vertical position in the station and sprayed with the acid solution. The horizontal bench is ventilated by local exhaust at the rear of the bench. Clear plastic splash shields are present. The vertical station is of polypropylene construction with ventilation of the unit at the base of the spray chamber, however, the vertical tube cleaning station is no longer used.

Engineering controls used on wet chemical benches are similar for all operations, although some variations in the use of local exhaust ventilation do exist. The tank containing the etching or cleaning solution is recessed in the bench. The tank perimeter is exhausted on all tanks except the tube cleaning benches. The benches are also exhausted by a slot across the rear of the bench or by a perforated deck located across the front of the bench. A magnehelic gauge is mounted in one wet chemical bench to monitor local exhaust. Facility engineering personnel perform air velocity measurements on local exhaust ventilation using a swinging vane anemometer.

Acid tanks may be heated by an immersion heater placed in the tank or by a hot plate built into the bench and located beneath the tank. The fluid level on some of the tanks are automatically monitored and interconnected to the heater which will turn off at low fluid levels. Most of the tanks have thermostats which shut off the power at a set temperature. These thermostats are checked monthly.

Personal protective equipment requirements for operators at wet chemical stations are described in Section 5.3 and include aprons, safety glasses, face shields, and gloves with gauntlets. Wet chemical benches also have clear plastic splash shields across the front of the benches at a height of approximately 4 to 6 feet.

Chemicals are replaced in the wet benches by designated chemical operators. The chemicals, in 1-gallon plastic or glass bottles, are transported to the wet bench in a cart and added to the tanks by the chemical mix operator.

7.4 Plasma Etching

Plasma etching is a chemical etching method using a plasma gas containing ions, free electrons, and free radicals to remove a specific material or layer from the wafer surface. The plasma is created by ionizing a gas in a radio frequency field at 13.56 MHz. The gases and types of reactors used depend upon the layer to be etched. A barrel plasma etching unit is used to etch silicon dioxide with freon and oxygen and to strip photoresist with oxygen. A cassette-to-cassette planar plasma etching unit is used to etch aluminum with carbon tetrachloride. A separate plasma unit is included in the exit load lock of the cassette-to-cassette unit to strip photoresist with an oxygen plasma. A second planar plasma etching system is used to etch silicon and silicon dioxide with freon. The system is also used to etch silicon nitride using carbon tetrafluoride and to etch titanium with freon and oxygen. A detailed description of plasma etching technologies is provided by O'Neill (1981) and Bersin (1976) and should be consulted for additional information.

Plasma etching is performed in a sealed reaction chamber at a pressure negative to the room pressure. The vacuum is approximately 0.1 to 20 torr and maintained by an oil-sealed mechanical pump. The plasma gases, containing the volatile species formed by the plasma ions reacting with the substrate, are exhausted from the unit by the mechanical roughing pump. The pump exhaust is either vented to the atmosphere or is collected by freezing in a cold trap. When not in operation the cold trap is placed in a ventilated sink for evaporation and disposal of liquids. The exhaust from the sink is vented directly to the atmosphere. The cold trap was used for collecting exhaust from the aluminum etching system.

Oil-sealed mechanical pumps are stored in ventilated cabinets that are vented directly to the external plant atmosphere. Pump oils are changed approximately once every 2 weeks. Gases are supplied in cylinders which are stored in ventilated cabinets near the process equipment.

Operators are required to conform with general area personal protective equipment requirements described in Section 5.3. No special personal protective equipment is required for operators working at the process. When the cold trap is changed it is necessary to wear an airline respirator, apron, and solvent gloves with gauntlets.

Monitoring systems for evaluating emissions or worker exposures to chemical or physical agents from plasma etching operations were not present.

Work practices that may affect emissions or worker exposures include the use of automated controls which limit the need for operator interaction with the equipment. The operator is required to load and unload cassettes and to start the processing sequence with pushbuttons and is not required to be at the unit for the entire work shift. The operator is then free to perform other tasks such as wet chemical cleaning and etching, or to operate other automated units. Any potential exposures to chemical or physical agents would only be for small time periods throughout the shift.

7.5 Epitaxial Silicon Growth

A single crystal silicon layer is grown on the silicon wafer in an epitaxial reactor system consisting of a reactor assembly cabinet and system control console. The operation is controlled by a microprocessor and is performed at atmospheric pressure. The components of the reactor assembly cabinet include a gas distribution system, power supply, vacuum pump, reactor chamber, and system exhaust.

The operators load wafers on a barrel or flat plate susceptor that is automatically lowered into the reactor chamber. This chamber consists of a quartz bell jar. The typical process sequence includes an inert gas purging cycle, a hydrogen purging cycle, programmed elevation in temperature, wafer etching with hydrogen chloride, expitaxial silicon deposition, control and shutdown of process gas streams, reduction in temperature followed by a hydrogen purge, and, finally, a nitrogen purge. The susceptor is then automatically raised and the wafers are removed by the operator. The wafers are heated either by a radiant heat source or a radio frequency source surrounding the bell jar. The reactor chamber is insulated and enclosed within a cabinet.

The reactor chamber is ventilated and purged by a pump that is exhausted to the atmosphere. A system of detectors and interlocks monitors the process operation and is programmed to safely shut down the process in the event of a hazardous situation, e.g., a hydrogen leak. Solenoid valves connected to gas supply lines control gas flow in the event of a power failure.

The reactor assembly cabinet is vented at the gas jungle located at the rear of the cabinet. The reactor chamber is exhausted by a pump located in the cabinet. The loading station of the reactor cabinet is ventilated with horizontal laminar flow HEPA filtration to control particulate levels during wafer loading and unloading. The laminar flow ventilation system directs air across the loading station toward the worker to reduce particulate contamination within the reaction chamber.

Hydrogen monitors are located in the reactor cabinet and are also located in the ceiling of the room. These detectors are connected to an alarm system at the plant security office. The monitoring system is described in more detail in Section 3.4.

Process gases include 1) dichlorosilane, hydrogen chloride, and hydrogen for deposition of undoped epitaxial silicon; and 2) silicon tetrachloride, arsine, phosphine, hydrogen chloride, and hydrogen for arsenic-or phosphorus-doped epitaxial silicon. Hydrogen and nitrogen purge gases are provided from a house supply. The remaining gases are supplied in cylinders and stored in a ventilated cabinet. The quantity of air vented by the cabinet was not reported. Hydrogen chloride cylinders are leak-tested by applying an ammonium hydroxide vapor around the regulator assembly generated by a hand-held aspirator bottle. A soap bubble test is also applied to regulator assemblies to test for leaks of other process gases. The gas handling system is described in Section 3.3. A compressed air outlet is available at the gas storage cabinet for connection to an air line-supplied respirator used by operators to change cylinders.

7.6 Diffusion

Diffusion of dopants into the wafer is performed in a diffusion furnace assembly similar to that described in Section 7.1 for thermal oxidation. The wafers are heated to a high temperature (approximately 600 to 1200°C depending on the source used), and a dopant is introduced that diffuses into the wafer. The dopant is supplied as either a liquid, solid, or gas. Liquid dopants include phosphorus tribromide (PBr_3), phosphorus oxychloride ($POCl_3$), and boron trichloride (BCl_3). Solid dopants include elemental arsenic, antimony trioxide, and boron nitride (BN). Gaseous sources include arsine (AsH_4) and diborane (B_2H_6).

Liquid source dopants are supplied in bubblers that are placed in the source cabinet of the furnace assembly and connected to the furnace tube. Boron trichloride is supplied in lecture bottles. Solid source dopants are supplied as either a powder Sb_2O_3, a plug of elemental arsenic, or a pressed boron nitride wafer (BN). The solid boron nitride wafer is placed in the wafer carrier between silicon wafers, and the carriers are inserted into the furnace tube. The powdered antimony trioxide is loaded with a spoon or paddle into a small source furnace, located in the source cabinet and attached to the furnace tube. The solid source elemental arsenic plug is placed in an elephant, i.e., quartz tube, along with the carriers containing silicon wafers. The elephant is sealed and loaded into the furnace tube. After the wafers are heated in the furnace for a specific time period, the elephant is withdrawn and moved to a sink where water is poured onto the tube for cooling. The tube is then cracked open by the operator and the wafers are removed.

Gaseous dopants (arsine and diborane) are supplied in cylinders and stored in a ventilated cabinet located in the service chase at the rear of the diffusion furnaces. The gas storage system is described in Section 3.3.

Engineering controls present in the diffusion operation are outlined in Section 7.1 for the diffusion furnace assemblies. Additional engineering controls are used as required by the dopant source. Liquid source bubblers are placed in either the exhausted source cabinets or in an enclosed support connecting two furnace tube banks together. The enclosed support structure connecting the furnace banks is ventilated by a duct at the top of the enclosure but the enclosure did not appear to be sufficiently tight to ensure adequate capture of air from the lower shelves. Covers were placed over the scavenger box openings on the antimony diffusion furnaces to improve the collection efficiency of the scavenger box exhaust. A white powder deposit was observed around the scavenger box cover that may have been antimony condensed from the cooled gas stream and escaped from the furnace. The condensation of this material around the scavenger box could have been due to the low quantity of air vented by the scavenger.

Adjacent to the diffusion furnace source cabinets is a ventilated work station enclosed on three sides by an exhaust canopy. The station is used for transferring antimony trioxide powder from the container to the loading paddle. A portable vacuum cleaner was present to clean up antimony trioxide that may be spilled during handling.

The solid source elemental arsenic used in diffusion is a solid plug or chunk and is not in powdered form. The use of a solid plug or chunk rather than a powder limits the potential for dispersion and therefore decreases the possibility of worker exposure. The solid arsenic is loaded into the elephant in a service area behind the furnace assembly.

Monitoring systems in the area include a Matheson® Model 8040 arsine/phosphine monitor located in the service chase area behind the furnace assembly and near the arsine storage cabinet. A multipoint combustible gas monitoring system is also located in the furnace area. Both systems are described in detail in Section 3.4. A Telos unit has been ordered and is now in operation.

General personal protective equipment requirements for workers in the diffusion area are described in Section 5.3. Specific operator requirements include the use of Zetex gloves for handling hot quartzware. Operators are also required to wear a face shield with goggles while unloading the seal tube ampoule.

7.7 Ion Implantation

Ion implantation is used to introduce impurities or dopants into the wafer surface. The impurities are p- or n-type ions created by a confined electric discharge sustained by a dopant gas or vapor of the ionized material. The ion beam is drawn from the arc chamber by an extraction electrode and directed toward the analyzing magnet. The magnet resolves and focuses the ion beam and selects only the desired ion species for wafer implantation. The selected ions are targeted through an acceleration chamber and focused to produce a uniform dose to the substrate. The ion implantation is performed in a sealed chamber at vacuum conditions of approximately 10^{-6} torr.

The source of the dopant ion is either a gas or solid. Boron triflouride is the source gas used for ion implantation and is contained in a small cylinder or lecture bottle that is stored in a ventilated cabinet within the ion implantation unit. Solid dopant sources include arsenic and phosphorus. The solid material is loaded into a vaporizer ion source within the ion implantation unit. The material is loaded into the vaporizer source in a glove box.

The power source, ion source, and analyzing magnet are contained in a lead-shielded cabinet for control of X-ray radiation. The cabinet is additionally located within a second lead-lined enclosure, electrically grounded and interlocked to the power supply.

Three independent vacuum systems are used to maintain vacuum conditions and are: (1) an oil-sealed mechanical pump that evacuates the load lock chambers, (2) an oil-sealed mechanical pump and oil diffusion pump that evacuate the target chamber, and (3) an oil-sealed mechanical pump and oil diffusion pump or cryogenic pump that evacuate the ion source. The pump exhausts are passed through an oil separator, i.e., coalescer, and vented by a stack to the atmosphere.

Scheduled maintenance of the ion implantation unit requires removal of the ion source once every 2 weeks for cleaning. The ion source is placed in a glove box enclosure and bead-blasted to remove deposits. The source is cleaned with isopropanol in a wet chemical station and returned to the unit.

Radiation film badges are used for monitoring operator exposures to X-ray radiation from the ion implantation unit.

The ion implantation process operation was not observed during the preliminary survey. Therefore, operator work practices which may affect exposures are not described here.

7.8 Plasma-Enhanced Chemical Vapor Deposition

Plasma-enhanced chemical vapor deposition (PECVD) is used to deposit silicon nitride. The operation is performed at reduced pressure in a reaction chamber or furnace tube in which a plasma is formed using a radio frequency power source at 13.56 MHz. Either silane and nitrogen oxide or silane and ammonia are the gases used.

Two separate PECVD systems are used for silicon nitride deposition. These include an automated cassette-to-cassette in-line unit, and a furnace tube assembly. With the cassette-to-cassette unit individual wafers are automatically removed from the cassette and transported through a load-lock chamber into the reaction chamber where the wafers are exposed to the plasma. Silicon nitride is deposited on the wafer as it passes through the chamber. The wafer is then transported to a second load lock and into a cassette. The deposition process is performed under vacuum conditions of approximately 2 torr. The process is controlled by a microcomputer at the unit. Workers are required to load and unload cassettes and to enter appropriate commands into the computer by push-button controls.

The second PECVD system consists of a furnace tube, gas control system, vacuum pumping system, radio frequency power generator, and wafer boat. Wafers are loaded into the boat, inserted into a load platform, and connected to the furnace tube where the boat is inserted. The radio frequency field is formed between the vertical metal plates of the boat. The furnace tube is sealed, pumped to a vacuum of approximately 2 torr, and the radio frequency power is applied to the metal plates. Process gases introduced into the tube that form a plasma in the radio frequency field and deposit silicon nitride on the wafer surface. Process gases for both types of units are stored in ventilated cabinets located in the service chases adjacent to the equipment. More detailed information about the gas handling system is provided in Section 3.3.

Engineering controls for the PECVD units are integral to the process operation and equipment. As previously noted, both units are operated at pressures negative to the room atmospheric pressure. Therefore, any leaks occurring in the unit would result in air moving into the chamber. The in-line unit uses load locks that limit release of process gases into the workroom from the deposition chamber. The PECVD furnace assembly has scavenger boxes located at the furnace tube opening. The furnace door will not open under pressure. It is held closed mechanically and interlocked to prevent operation of the radio frequency generator and vacuum system. Viewing ports or panels are present on both units. The in-line units have metal mesh screens over the viewing ports that may be effective in controlling radio frequency emissions.

Both types of units employ an automatic cleaning cycle in which carbon tetrafluoride and oxygen replace the normal process gases in the plasma and result in plasma etching of silicon nitride deposits in the reaction chamber.

Operators are required to comply with area personal protective equipment requirements described in Section 5.3.

7.9 Metalization

A metal or metal alloy is deposited on the wafer surface as an electrical contact. Metals are deposited by: 1) thermal evaporation for gold deposition; 2) electron beam evaporation for aluminum deposition; and 3) radio frequency (RF) sputtering for aluminum/copper, titanium/tungsten, aluminum, platinum, and gold deposition. Fairchild uses a variety of process equipment types. However, the metalization process for each is performed in a sealed reaction chamber under low pressure (approximately 10^{-6} torr) maintained by a set of pumps including an oil-sealed mechanical pump and diffusion pump or an oil-sealed mechanical pump and cryogenic pump.

All metalization processes are automatically controlled. Operators are required to load wafers into the equipment by either: 1) mounting wafers onto a planetary structure and placing it inside the bell jar chamber; 2) placing wafers onto a platen and inserting it into the deposition chamber; or 3) placing a cassette containing wafers into a load/unload mechanism that automatically removes individual wafers for processing.

The radio frequency field for sputtering is formed by an RF generator operating at 13.56 MHz. The power level for the electron beam evaporation system could not be determined at the time of the survey.

Radio frequency radiation emissions for RF sputtering systems or X-ray radiation emission from the electron beam evaporation system have not been measured.

Personal protective equipment requirements for operators are described in Section 5.3.

7.10 Backside Grinding

Wafer grinding is performed in a horizontal grinding unit using wet abrasion. Wafers are cleaned with isopropyl alcohol, then mounted on a metal plate with a laminate adhesive. The exposed backside of the wafer is ground with a wet abrasive and the finished wafers are cleaned with isopropyl alcohol at a stainless steel work station. The stainless steel station contains a tank of solvent that is vented by slots around the perimeter and by a slot across the rear of the tank.

Local exhaust ventilation is also provided at the grinding unit. Personal protective equipment requirements are described in Section 5.3. There appeared to be very little opportunity for operator exposures.

7.11 Beam Tape (Beta) Film Fabrication

Beta film carrier is manufactured at the Fairchild plant in a non-clean room area. The film is used for automated bonding of the integrated circuit die and is manufactured by a continuous reel-to-reel process. An adhesive-coated polyimide tape is laminated to a copper film. The laminated film is dried in a heated, nitrogen-purged oven. The exposed copper is cleaned with sulfuric acid and sodium persulfate, and a photoresist laminate film is applied to the tape with a heated roller. The mask pattern is transferred to the tape by exposure to a 380 nm light source and the film is developed with butyl cellusolve. The film is backside-coated using an acetone-based ink. The film is cured, cleaned with sodium persulfate, and etched with an ammonium hydroxide spray. The remaining photoresist and backside coat is stripped and the copper film is cleaned in acetone, dried, and inspected.

Engineering controls observed in the Beta film fabrication area include the use of local exhaust ventilation at the photoresist lamination process. The quantity of air exhausted is not known. The ultraviolet light source for the film exposure is enclosed to control UV emissions.

General personal protective equipment requirements are described in Section 5.3. Specific requirements for workers in the Beta film area include the use of hearing protection in the tape perforating area.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The Fairchild facility in South Portland, Maine, has an extremely well-managed health and safety program that includes industrial hygiene, safety, and occupational health.

The facility uses a variety of control strategies to control emissions and limit worker exposures to chemical and physical agents. The control strategies include: 1) engineering controls, such as local exhaust ventilation, X-ray and radio frequency radiation shielding, and process isolation or enclosures; 2) personal protective equipment; and 3) monitoring systems. Work practices may also play a significant role in controlling emissions or operator exposures, but they could not be documented due to survey time restraints. The engineering controls are frequently included in the original design of the purchased equipment or are an integral part of the process operation.

Specific observations and recommendations are outlined below.

1. Specific personal protective equipment requirements and clothing policies have been established for every area in the facility and for workers performing specific tasks or working with specific process equipment.
2. Local exhaust ventilation of process equipment is used throughout the plant wherever potentially dangerous, toxic, corrosive, or flammable liquid chemicals are used.
3. A variety of process equipment types and materials may be used to perform a given process operation. The Fairchild facility offers the opportunity to evaluate these systems in a single plant.
4. The physical form in which the solid dopant is used may affect the possibility of operator exposure during materials handling. Sources in a solid pellet or pressed wafer form offer less potential for exposure than those in a powdered form. Work practices in handling solid source dopants should be investigated.
5. Solid and gaseous dopants present substantially different health hazard potentials. The selection of the dopant material may be determined more by process engineering and product quality requirements than by industrial hygiene. If not, operator exposures to similar dopants in different physical forms (e.g., elemental arsenic vs. arsine, or phosphorus vs. phosphine) should be compared. Work practices associated with the use of each dopant type should be identified and their effects on operator exposures should be determined. Although beyond the scope of this study, a risk analysis should also be performed to compare the potential impact on workers during normal operations vs. emergency conditions. With this information, the dopant form presenting the lowest risk to the operator could be determined.

6. The facility uses advanced process technologies such as plasma etching, PECVD, and LPCVD. Radio frequency radiation emissions and the methods of controlling radio frequency emissions by shielding and engineering interlocks should be evaluated.
7. Although the purge lines use two check valves in series (with a relief valve in between) the failure of the valves could result in contamination of the house supply. The use of nitrogen cylinder gas rather than house nitrogen for purging toxic, corrosive, or pyrophoric gas supply lines should be evaluated.
8. Several process operations are automatically controlled to ensure product quality. The automation limits the need for operator interaction with the equipment and may be considered an engineering control strategy positively affecting work practices.
9. The use of a cold trap to condense carbon tetrachloride plasma exhaust may also condense toxic byproducts. Operator exposures during replacement and disposal of the condensed material should be evaluated. The ability of the local exhaust ventilation at the disposal sink to capture the evaporated products should be determined.
10. The deposition of a white material, presumed to be antimony trioxide around the furnace tube opening indicates that this material is being emitted into the workroom area. The ventilation of the furnace tube by the scavenger box was apparently not removing a sufficient quantity of air.
11. The facility employs a variety of systems for controlling atmospheric emissions. These systems include coalescers to capture oils from vacuum pump exhaust prefilters, bag filters, and HEPA filters in the exhaust from arsenic diffusion furnaces as well as sprays at the acid benches to control acid mists.

9.0 REFERENCES

Atherton, R. W., Fundamentals of Silicon Epitaxy. Semiconductor International. 4(11):117-130. 1981.

Baron, M., and Zelez J., Vacuum Sytstem for Plasma Etching, Plasma Deposition, and Low Pressure CVD. Solid Sate Technology. 21(12):61-82. 1978.

Bersin, R. L., A Survey of Plasma-Etching Processes. Solid State Technology. 19(5):31-36. 1976.

Cain, R. L., Beam Tape Carriers - A Design Guide. Solid State Technology. 21(3):53-58. 1978.

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

Douglas, E. C., Advanced Process Technology for VLSI Circuits. Solid State Technology. 24(5):65-72. 1981.

Hammond, M. L., Silicon Epitaxy. Solid State Technology. 21(11):68-75. 1978.

Hayakawa, M., T. Maeda, M. Kumura, R. H. Holly, and T. A. Gielow., Film Carrier Assembly Process. Solid State Technology. 22(3):52-55. 1979.

Liu, T. S., W. R. Rodrigues de Miranda, and P. R. Zipperlin. A Review of Wafer Bumping for Tape Automated Bonding. Solid State Technology. 23(3):71-76. 1980.

O'Neill, T. G., Dry Etching Systems for Planar Processing. Semiconductor International 4(4):67-89. 1981.