WALK-THROUGH SURVEY REPORT:
CONTROL TECHNOLOGY FOR INTEGRATED CIRCUIT FABRICATION

at

DIGITAL EQUIPMENT CORPORATION
LSI Semiconductor Operations
Hudson, Massachusetts

Prepared by

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and

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

PLANT SURVEYED: Digital Equipment Corporation
LSI Semiconductor Operations
75 Reed Road
Hudson, Massachusetts

SIC CODE: 3674

SURVEY DATE: December 2, 1981

SURVEY CONDUCTED BY: Mr. Gary J. Mihlan, Battelle-Columbus Laboratories
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EMPLOYER REPRESENTATIVES CONTACTED:

Mr. John Cox, Environmental Health and Safety Manager
Mr. Dennis Rossi, Senior Industrial Hygienist
Mr. Larry Hutker, Facilities Manager
Mr. Scott Sieber, Bipolar Process Engineer
Mr. Steve Baronowski, Bipolar Supervisory Engineer
Ms. Judy Powell, Nurse Administrator

EMPLOYEE REPRESENTATIVES CONTACTED:

Mr. Gary Kenefick, Employee Relations Representative

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1.0 ABSTRACT

A preliminary control technology assessment survey was conducted at Digital Equipment Corporation, Hudson, Massachusetts, on December 2, 1981 by Battelle Columbus Laboratories, Columbus, Ohio. The survey was conducted as part of a project under a U.S. Environmental Protection Agency contract funded through an Interagency Agreement with the National Institute for Occupational Safety and Health. Digital Equipment Corporation manufactures custom bipolar and metal oxide semiconductor (MOS) integrated circuits.

The process operations for integrated circuit fabrication are performed in a clean room environment with high efficiency particulate air (HEPA) filtration of room air supply. Process operations performed at the facility include: (1) thermal oxidation of purchased, pre-doped silicon wafers, (2) photolithography for defining circuit patterns, including photoresist application, substrate exposure, and photoresist development, (3) wet chemical etching and cleaning, (4) plasma etching, (5) epitaxial silicon growth, (6) doping, including diffusion and ion implantation, (7) wafer annealing and alloying, (8) low pressure chemical vapor deposition (LPCVD) of silicon nitride, polycrystalline silicon, and phosphorus-doped silicon dioxide, (9) plasma-enhanced chemical vapor deposition of silicon nitride, (10) atmospheric pressure chemical vapor deposition of phosphorus-doped silicon dioxide, and (11) metalization, including direct current (DC) and radio frequency (RF) sputtering and filament evaporation.

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 processes from the workers. Process isolation is used in plasma etching, epitaxial silicon growth, ion implantation, low pressure chemical vapor deposition, plasma-enhanced chemical vapor deposition and metalization. This isolation is integral to the process operation. Shielding is used in ion implantation units to limit X-ray emissions, in substrate exposure to control ultraviolet emissions, and in plasma etching units and plasma-enhanced chemical vapor deposition to control radio frequency radiation. Local exhaust ventilation is used to remove process gases and byproducts from alloying, annealing, atmospheric pressure

and plasma enhanced CVD, photolithography, and wet chemical cleaning and etching. Local exhaust ventilation is also used at storage cabinets containing toxic and flammable gases.

Several process operations are automated with microprocessors controlling the process parameters and process sequence. These operations include photoresist application, photoresist developing, plasma etching, epitaxial silicon growth, diffusion, annealing, alloying, LPCVD, PECVD, ion implantation, atmospheric pressure CVD, and metalization.

Continuous area monitoring of selected chemical agents is provided in the wafer fabrication area by a TELOS® Arsine/Phosphine Analysis System. A Bacharach® combustible gas monitor continuously monitors for hydrogen. X-ray and radio frequency radiation emissions are checked quarterly by plant staff. Radiation film badges are used to monitor emissions and operator exposure to X-ray radiation.

Personal protective equipment is also used to control operator exposures during normal process operations, maintenance, and repair. Operators are also required to wear product-protective equipment to prevent contamination of the wafers.

The facility has developed a comprehensive occupational health and safety program that includes industrial hygiene, environmental engineering, health physics, safety, and health services.

The DEC facility should be considered for detailed study as it uses state-of-the-art process operations and equipment and is representative of current fabrication area design trends.

2.0 INTRODUCTION

A preliminary survey was conducted at Digital Equipment Corporation (DEC), LSI Semiconductor Operations, 75 Reed Road, Hudson, Massachusetts, on December 2, 1981 by Battelle Columbus Laboratories, Columbus, Ohio. The following individuals were contacted at DEC:

1. John Cox, Environmental Health and Safety Manager
2. Dennis Rossi, Senior Industrial Hygienist
3. Larry Hutker, Facilities Manager
4. Scott Sieber, Bipolar Process Engineer
5. Steve Baronowski, Bipolar Supervisory Engineer
6. Judy Powell, Nurse Administrator
7. Gary Kenefick, Employee Relations Representative

The study protocol was provided to the Environmental Health and Safety Manager before the visit and the study objectives and methods were described. A description of the health and safety programs at the plant was provided by the plant Environmental Health and Safety staff, and a detailed review of the wafer fabrication operations was presented by process engineers.

Following the opening conference the facility was toured, including production areas, industrial hygiene laboratory, air handling systems, and service areas. A closing conference was held with plant personnel following the survey.

3.0 PLANT DESCRIPTION

3.1 General

Digital Equipment Corporation manufactures custom bipolar and metal oxide semiconductor (MOS) integrated circuits. The plant consists of two buildings. Wafer fabrication is limited to one building with a total area of 226,000 square feet. The building was constructed in two phases beginning in 1977 and completed in 1980. An addition of 22,000 square feet will be built in 1982 for electron beam lithography. The building is brick and consists of sandwich panel construction with a metal deck, rigid insulation, and built-up roof. Wafer fabrication was started in the facility in February 1980. Engineering design and marketing takes place in a second building of 307,000 square feet that was completed in 1981.

The workforce in the wafer fabrication building includes 1,100 people, 700 employed in digital large scale integration (LSI) manufacturing. Of these 700 employees, approximately 261 work in wafer production, including repair and maintenance technicians, 89 in wafer probing and testing, and 350 in administrative services. The LSI Semiconductor Division operates three production shifts per day with 148 workers employed during the first shift, 55 on the second shift, and 58 on the third shift. The plant also operates three wafer probing and testing shifts (49 first shift, 27 second shift, 13 third shift). Administrative staff in the LSI Division are employed on all three shifts (approximately 263 first shift, 53 second shift, and 34 third shift).

3.2 Chemical Storage

Chemicals are stored in areas segregated as acids and organics. Due to the size of the plant and time constraints, the chemical storage areas were not observed on the tour. Chemicals are transferred from the bulk storage areas to the chemical mix room where both acids and organic solvents are distributed. Acids are mixed in the chemical mix room and distributed in plastic 1-gallon containers by chemical technicians. The technicians use chemical carts for moving bottles to and from work stations. The carts are made of polypropylene or similar material and are designed to prevent bottle-to-bottle contact. Chemicals for daily use are stored in plastic carriers under the wet chemical work stations and in ventilated pass-throughs. Fully trained chemical technicians are authorized to carry and pour chemicals at wet stations. Specially trained teams are responsible for responding to chemical spills or gas leaks. Chemical spill control carts for containment and cleanup of spills are located in the service areas adjacent to the wafer fabrication area and are, at a minimum, inspected weekly.

3.3 Gas Handling System

The outside gas storage area was not observed during the preliminary survey. Hydrogen, oxygen, and nitrogen are piped to various locations within the wafer fabrication area from outside gas bunkers. Hydrogen is piped in heliarc-welded stainless steel, and oxygen and nitrogen are piped in silver-soldered copper pipe. Gases used in cylinder quantities are all housed in ventilated gas cabinets located in the service chases adjacent to the wafer fabrication area, while small cylinders are placed directly in vented cabinets that are located in the operating equipment, e.g., the ion implantation units. The gas cabinets are vented at a rate of at least 200 cfm. Compressed oxygen escape capsules are located in service chases in the event of a leak or line rupture around any of the toxic gases. The supply lines from the gas cabinets are vacuum-purged.

3.4 Monitoring System

There are three permanently installed gas monitoring systems in the plant. A TELOS® Arsine /Phosphine Analysis System is used to monitor for arsine and phosphine. The sensors are located in gas cabinets, gas bunkers, the ion implantation units, and in the epitaxial reactor cabinets. In addition, a Bacharach® flammable gas detector system is used to monitor for hydrogen and other flammables within the wafer fabrication area. Hydrogen sensors are placed above the gas jungle and source cabinets of CVD furnaces and the epitaxial reactors. Hydrogen sensors are also located in the plenum above the false ceiling in locations containing hydrogen supply lines. A Matheson® unit is used to monitor for phosphine leaks in the vented cabinet within a gas cabinet that serves the low temperature oxidation (LTO) unit.

3.5 Ventilation System

The wafer fabrication area is served by an air handling system separate from that for the remainder of the building. The area is maintained at a positive pressure with respect to the rest of the plant by supplying 120,000 cfm and exhausting approximately 90,000 cfm of air. The remaining 30,000 cfm maintains the positive pressure in the room. The supply air is delivered to HEPA filter banks above individual work stations and through ceiling mounted grilles. The process exhausts, including all acid etching and cleaning stations, vacuum pumps, gas cabinets, diffusion furnaces, and organic solvent exhausts go through one of three 30,000 cfm caustic scrubbers mounted on the roof.

With one exception (plasma etching area), all process exhausts go vertically to the roof when leaving a process area; they are then joined by other ducts, and then exit through the roof to the respective scrubber. This practice makes it easier to service and inspect the duct work, minimizes the number of penetrations of the ceiling plenum in the clean room area, and makes it easier to add additional process stations. All ductwork is fiber-reinforced polyethylene treated with antimony trioxide fire retardant.

3.6 Waste Management

Liquid acid wastes are aspirated from the wet chemical benches to a central acid drain system. Acids are collected in a tank located in the basement. The treatment operation is a batch process. The pH is adjusted to 10.5 (fluoride precipitating out as calcium fluoride), followed by coagulation, equalization, flash neutralization, flocculation, clarification, and release to a publicly operated treatment works (POTW).

Organic chemicals, such as photoresist and developer wastes, and used pump oils are collected and stored for off-site disposal by a waste management firm. The waste is either incinerated or disposed in a hazardous waste landfill. The storage areas, where wastes are held before collection, were not observed during the preliminary survey.

4.0 PROCESS DESCRIPTION

The fabrication sequence used for bipolar or MOS integrated circuits manufacturing will vary depending on the specific type of device manufactured. Process operations encountered in bipolar and MOS fabrication are similar except for the use of an epitaxial silicon layer in bipolar circuits. Therefore, the bipolar wafer fabrication process was observed during the preliminary survey, and it served as a surrogate for all other process operations performed at DEC. A review of the general processing sequence for MOS and bipolar integrated circuits is provided by Colclaser (1980) and should be reviewed for additional information regarding the fabrication process. Several process operations are employed more than once in the fabrication sequence, and some process equipment is used for more than one operation. Purchased silicon wafers are used as a substrate for device fabrication.

In the thermal oxidation process, wafers are oxidized at high temperature (approximately 800° to 1,000°C) in an atmospheric pressure diffusion furnace assembly using a pyrophoric water (hydrogen and oxygen) and dry oxygen atmosphere. Hydrogen chloride gas is added to the gas stream to decrease electrical defects in the layer (Colclaser, 1980). The operation consists of loading wafers into carriers that are inserted into the diffusion furnace tubes. The furnace tubes are heated by electrical resistance to the operating temperature while the tube is purged with nitrogen. Hydrogen, oxygen, and hydrogen chloride are introduced into the tubes at a controlled rate. The furnaces are automatically controlled by direct digital control (DDC). The furnace operating parameters, including temperature, process sequencing, and gas flow are monitored and adjusted by feedback control loops to programmed specifications (Douglas, 1981).

In photolithography, the process consists of: (1) primer and photoresist spin application, (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 by spin application with hexamethyldisilizane (HMDS) in a Freon carrier. The photoresist, containing a proprietary mixture of organic polymers in a xylene and ethyl benzene carrier, is spun onto the wafer, and the coated wafer is baked in a resistance-heated oven. The operation is automated, requiring only that the operator load and unload cassettes.

The mask pattern is transferred to the coated wafer by ultraviolet light (wavelength unknown) using projection mask alignment. The operator aligns the wafer with the mask by viewing it through a split field binocular microscope. A lens is interposed between the mask and the wafer with the ultraviolet light source located behind the mask. The masks are periodically removed and cleaned with an isopropanol and soap solution. The masks are manufactured to plant specifications by a vendor.

The exposed wafers are developed by spin application of the developer solution. The operation is similar to that used for photoresist application. The developer is either n-butyl acetate/isopropanol and synthetic aliphatic hydrocarbons for negative photoresist or an unspecified aqueous alkaline-based solution containing organic salts and chelating agents for positive photoresist. The developed wafers are dried or hard-baked in a resistance-heated oven. The operation is performed in an automated in-line cassette-to-cassette system.

The exposed underlying layer may be etched using either wet chemical or plasma etching techniques. In wet chemical etching, the wafers are immersed in an etching solution. The methods include: (1) sulfuric acid and hydrogen peroxide for cleaning wafers, (2) nitric and hydrofluoric acid for etching platinum, (3) hydrogen peroxide for etching tungsten, (4) hydrofluoric acid and ammonium fluoride for etching silicon dioxide, and (5) phosphoric, nitric, and acetic acid for etching aluminum. The etching operations are performed in tanks recessed in polypropylene benches.

Plasma etching consists of placing wafers in a plasma that contains ions, free radicals, and free electrons formed by a radio frequency power source. The plasma is formed in a sealed reaction chamber at a vacuum of approximately 0.1 to 20 torr maintained by an oil-sealed mechanical pump. The operation is performed either in batches or continuously. In the batch process, carriers containing wafers are loaded into the reaction chamber, the door is closed and the operator initiates the process sequence with push-button controls. The continuous process requires the operator to load and unload cassettes into the unit. Individual wafers are automatically removed and transported through a load lock into the reaction chamber where the exposed aluminum layer is etched. The wafer is transported through an exit load lock into a second cassette.

Both the batch and continuous process equipment use a 13.56 MHz radio frequency source of unknown power. The gases used for forming the plasma include (1) Freon and oxygen for etching silicon nitride and (2) oxygen for stripping photoresist. The gases used for etching aluminum were not identified. The aluminum plasma etching operation was not observed during the preliminary survey.

Doping may be performed at various stages in the processing sequence. Doping introduces impurities into the wafer that alters the electrical properties of the doped area. Doping of the wafer is accomplished by either diffusion or ion implantation. In diffusion, the wafers are exposed to a high temperature atmosphere containing a dopant gas. The operation is performed in an atmospheric pressure diffusion furnace assembly using phosphorus oxychloride or boron tribromide as dopants. The direct digital control (DDC) diffusion furnace assembly is similar to the one previously described.

Wafers are also doped using ion implantation. A source gas is ionized in a vacuum environment with the ions passing through an analyzing magnet so the necessary ions can be collected, accelerated, and implanted into an individual wafer held in a vacuum chamber. The ion source, analyzing and accelerating chamber, and wafer exposure station are operated at vacuum conditions of approximately 10^{-6} torr. This vacuum is maintained by two sets of pumps with each set consisting of an oil-sealed mechanical pump, and a diffusion or cryogenic pump. The dopant source gas is either arsine, phosphine, or boron trifluoride. The process operation sequence requires that the operator load a cassette into the load station of the unit. Individual wafers are automatically removed from the cassette to a load lock chamber that 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 then transferred to a second load lock chamber and into a cassette.

Annealing takes place in a nitrogen and oxygen atmosphere to drive in dopants and correct wafer damage from ion implantation. Alloying is performed in a hydrogen atmosphere to correct radiation damage from metalization. These operations are performed in the DDC diffusion furnaces previously described.

A single crystal silicon layer is deposited on the wafer by epitaxial growth in an enclosed, heated chamber. The silicon layer is deposited by the reaction of dichlorosilane and hydrogen with arsine introduced as a dopant for the epitaxial layer. The layer is deposited at high temperatures (approximately 950° to 1,250°C) produced by a radiant heat source. The operation is performed at atmospheric pressure or reduced pressure. The operation sequence is automatically controlled and requires that the operator load wafers onto a barrel susceptor that is then lowered into the reaction chamber. A description of epitaxial silicon deposition is provided by Atherton (1981) and Hammond (1978) and should be consulted for more detailed information.

Another process performed during the fabrication sequence is the chemical vapor deposition (CVD) of a thin film on the wafer surface consisting of the solid products of a vapor phase chemical reaction. Low pressure chemical vapor deposition (LPCVD) is used to deposit silicon nitride, phosphorus-doped silicon dioxide, or polycrystalline silicon. Process gases include: (1) silane, phosphine, oxygen, and nitrogen for phosphorus-doped silicon dioxide; (2) silane and nitrogen for polycrystalline silicon; and (3) dichlorosilane and nitrous oxide or silane and ammonia for silicon nitride deposition. The LPCVD operation is performed in a sealed diffusion furnace tube evacuated to approximately 0.4 to 3.0 torr (Baron and Zelez, 1978). The LPCVD process operation requires the operator to load cassettes containing wafers into the furnace. The furnace door is closed and the process operating parameters are then automatically controlled by a microprocessor.

Plasma-enhanced chemical vapor deposition (PECVD) is also used to deposit silicon nitride by the reaction of either silane, nitrogen, and oxygen or silane, ammonia, and phosphine. The plasma is created by introducing the process gases in a radio frequency field (either 13.56 MHz or 70 to 150 KHz). The operation is performed under vacuum conditions in a sealed reaction chamber or tube at approximately 0.2 to 1.0 torr. PECVD systems that were used at DEC include a cassette-to-cassette unit and a furnace tube assembly similar to the diffusion furnace, with a radio frequency power source, sealed chamber tube, vacuum system, and wafer boat. The process sequence requires the operator to either load cassettes containing wafers into the unit (cassette-to-cassette) or to mount wafers in a series of vertical parallel plates that are then loaded into the furnace tube. Both types of units are automatically controlled by system microprocessors.

A metal layer is deposited on the wafer surface by either radio frequency (RF) sputtering, direct current (DC) sputtering or filament evaporation. RF and DC sputtering are used to deposit platinum, titanium, tungsten, aluminum and platinum/nickel, copper/aluminum, silicon/aluminum, and silicon/copper/aluminum alloys. Wafers are mounted on a platen that is inserted into a load lock chamber. The platen is transported into the deposition chamber where the metals are deposited onto the wafer. The operation is performed at a vacuum of approximately 10^{-6} torr that is maintained by an oil-sealed mechanical pump and a cryogenic pump. Filament evaporation is used to deposit gold onto the wafer backside. Wafers are mounted on a planetary that is contained in a metal chamber. The chamber is sealed and pumped to a vacuum of approximately 10^{-6} torr. A gold filament is heated to evaporation and the gold is deposited on the wafer.

Before backside gold deposition, the wafer is visually inspected and the backside is lapped or removed. The wafer is cleaned with 1,1,1-trichloroethane and mounted (backside exposed) onto a platen coated with paraffin wax. A layer of silicon is removed by lapping. The wax is melted from the platen and the wafers are removed and spray cleaned with 1,1,1-trichloroethane followed by ultrasonic cleaning. The cleaned wafers are then ready for backside gold deposition as described above.

5.0 DESCRIPTION OF PROGRAMS

5.1 Industrial Hygiene

The industrial hygiene program at DEC is part of the environmental health and safety organization. The organization has a staff of nine, including two full time industrial hygienists, an environmental engineer, and analytical laboratory staff who are responsible for industrial hygiene, environmental engineering, health physics, safety, and analytical services.

Industrial hygiene responsibilities include conducting area and personal monitoring for chemical and physical agents, designing engineering controls, specifying and training workers in the use of personal protective equipment, recommending administrative controls, and responding to monitoring system alarms. In addition, industrial hygienists are also required to perform respirator fit tests for workers using respiratory protection.

Analytical services are provided by an in-house environmental health laboratory with analytical capabilities in gas chromatography, ion chromatography and atomic absorption spectrophotometry. The laboratory analyzes air, water, liquid waste, and biological (e.g. urine) samples.

The program has established standard operating procedures for spill cleanup and requires that plant security be notified in the event of any spills. The health and safety staff and a spill response team are then notified by plant security, and the spill team initiates cleanup activities. Following cleanup, a spill team investigation report must be completed.

The radiation safety program at DEC has responsibility for monitoring personal radiation (X-ray), registering ionizing radiation equipment, monitoring source and area radiation (ultraviolet, X-ray, radio frequency, microwave, and beta radiation), designing engineering controls, and recommending administrative controls.

DEC utilizes a computerized recordkeeping system for storing medical and exposure data. Records are retrievable only by qualified individuals. The computer allows DEC to retrieve records in various formats including chronological exposure profiles, as well as individual medical and industrial hygiene case files. Detailed statistical analyses are possible with this computer capability. The program is described in detail by Rossi et al. (1981).

A plant emergency organization has been established by DEC for emergency response and is directed by the general environmental health and safety program. The organization's responsibilities include medical crisis response, gas leak/equipment shutdown, fire/evacuation, chemical spill response, electrical failure, and salvage.

5.2 Education and Training

Training programs have been established in the areas of safety, materials handling, use of personal protective equipment, emergency response procedures, health monitoring, hazard recognition, electrical safety, and chemical spill response. New employees are given a detailed orientation to the facility operations and are instructed in the above mentioned programs. These programs are organized into 12 modules which are presented by plant staff with the aid of videotape training films and a training manual. The training program includes a pre- and post-test. Workers are also instructed in the use of material safety data sheets and the application of engineering controls that are used to protect workers and to improve product quality.

DEC has established a quarterly training program in emergency response for production, repair, and maintenance workers. Training programs have also been established for forklift operators and additional programs are provided by chemical supply vendors. The facility has also written detailed training manuals for radiation safety and chemical spill response. Both manuals provide a comprehensive review of the respective subjects and appear to be extremely useful training guides. The radiation safety guide reviews all ionizing and nonionizing radiation sources at DEC, describes the different types of radiation, its effects, and the appropriate control strategies. The chemical spill manual is a reference and training manual that describes specific procedures to be used for controlling spills, including personal protective equipment requirements and standard operating procedures for spill cleanup and disposal.

5.3 Respirators and Other Personal Protective Equipment

Personal protective equipment requirements at DEC are specified in the facility safety manual and are reviewed with the operator during training. Specific personal protective equipment requirements are outlined in Table 5.3-1. These requirements vary by the type of work or task performed by the operator and include: (1) latex gloves with sleeves, vinyl apron, and safety glasses for wet chemical operators; (2) latex gloves with sleeves, vinyl apron, safety glasses, and face shield for chemical pouring; (3) nitrile gloves for solvent cleaning operations; (4) supplied air respirators for workers changing certain gas bottles (e.g., 100 percent phosphine) and cleaning cold traps from ion etching; and (5) jackets, hoods, and thermal gloves for glass shop workers.

Training in the use of personal protective equipment is provided as described in Section 5.2. Emergency equipment available in the fabrication areas include eye wash stations, emergency showers, and emergency escape breathing apparatus.

Normal clean room attire includes a hood, goggles or safety glasses, surgical mask to cover facial hair, jump suit, surgical gloves, and shoe

TABLE 5.3-1. PERSONAL PROTECTIVE EQUIPMENT REQUIREMENTS AT DIGITAL EQUIPMENT CORPORATION, HUDSON, MASSACHUSETTS

Body Part Protected	Type of Equipment	Activities Requiring Use
Hands	Nylon gloves	Soldering; sanitary liner for chemical gloves
	Chemical gloves	Acid (latex) and solvent (nitrile) handling
	Surgical gloves	Wafer handling
	Heat/Cold insulated gloves	Handling hot/cold materials
Eyes	Safety glasses	Chemical areas; tinted glasses in photolithography areas only for aligning photo aligners
	Welders glasses	Glass shop area
	Safety goggles	Chemical pouring/mixing
	Face shields	Chemical areas
Whole Body	Plastic aprons	Handling acids
	Plastic sleeves	Handling acids
	Full body suit with hood	Spill response team
Respiratory System	Organic vapor/acid gas respirator	Waste staging
	Toxic particulate respirator	Glass shop; equipment maintenance
	Supplied air respirator	Gas bottle changing; cold trap cleaning
	Self-contained breathing apparatus	Emergency response
Ears	Ear muffs and ear plugs	Specified high noise areas

covers. The clothing is required for protecting product quality. Open toe/heel shoes, canvas (tennis) shoes, or cloth shoes are not allowed in the fabrication area.

5.4 Medical

DEC employs four full time nurses to cover all three production shifts. A physician is on the premises two hours per week and is also on-call. The facility has employed consulting services for hearing and pulmonary testing. The medical monitoring program at DEC is described in detail by Rossi et al. (1981).

All workers are required to undergo a pre-employment medical examination. The examination includes a health questionnaire, height, weight, vital signs, visual and hearing acuity, laboratory tests (hematocrit, urinary specific gravity, albumin, and glucose), tuberculin test, and psychological status.

In addition, a supplemental battery of clinical diagnostic tests are conducted on employees in the "high risk" category. High risk employees are those working in the manufacturing environment where there is greater risk for exposure to potentially toxic chemical and physical agents. Additional testing includes creatinine, serum glutamic pyruvic transaminase (SGPT), blood urea nitrogen (BUN), complete blood count (CBC), complete urinalysis, pulmonary function tests, chest X-ray, electrocardiogram (EKG), and urinary biomonitoring (arsenic, phenol, fluoride).

Currently, the continuous biochemical profiling in the high risk population is restricted to urinary biomonitoring. A vigorous sampling regime has been developed and implemented as toxic substances, such as arsine, hydrofluoric acid, and a proprietary mixture containing phenol, are extensively used in the process of manufacturing semiconductors. Accordingly, baseline studies are conducted on all new employees, and quarterly samples are collected and analyzed thereafter. Repeat (pre- and post-shift), as well as spot samples, may also be collected if normally monitored samples approach levels potentially hazardous as determined by NIOSH criteria documents.

Emergency care is provided by the nursing staff, staff emergency medical technicians, and individuals trained in first aid and cardiopulmonary resuscitation. Two area hospitals are available for emergency services if needed.

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 made of exhaust ventilation. Results of monitoring performed by DEC were not obtained due to time constraints.

7.0 DESCRIPTION OF CONTROL STRATEGIES FOR PROCESS OPERATIONS OF INTEREST

A variety of strategies are used at DEC 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 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 mentioned below. Personal protective equipment requirements consist of general area requirements described in Section 5.3 and specific requirements for some process operations are described below.

Automation has affected work practices as well as emissions or operator exposures to chemical or physical agents. Automated process controls limit the time that operators are working with the equipment. They 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. Thus, the operator is not required to be at the unit for an entire work shift and any exposures to chemical or physical agents would be for small time periods throughout the shift.

Specific descriptions are given below for control strategies used for photolithography, wet chemical cleaning and etching, plasma etching, epitaxial silicon deposition, diffusion, thermal oxidation, annealing, alloying, ion implantation, low pressure chemical vapor deposition, plasma-enhanced chemical vapor deposition, atmospheric pressure chemical vapor deposition, and metalization.

7.1 Photolithography

The photolithography process 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 7.2.1 and 7.3, respectively. The photoresist stripping operation is also performed either by wet chemical etching or by plasma etching and is described in those sections. The photolithography process may be repeated several times during the processing sequence.

7.1.1 Substrate Preparation. Silicon wafers are purchased from outside vendors. Wafers are inspected and placed onto a track system. Following a deionized water rinse and dehydration bake, HMDS, in a Freon carrier, is applied by spinning followed by application of either a negative resist solution containing xylene and ethyl benzene or a positive resist solution containing n-butyl acetate, xylene, and cellosolve acetate. The HMDS and photoresist solutions are supplied in 20-gallon metal containers that are pressurized with nitrogen. The solution is delivered to the spin platform through plastic tubing. Negative and positive resist are applied onto the wafer by separate cassette-to-cassette systems. HEPA filtration units are located above the systems.

Engineering controls include local exhaust ventilation of the plastic cup surrounding the platform. Photoresist and HMDS wastes are collected in closed containers located in cabinets beneath the system. The ventilation system exits the back of the unit where it joins a plenum box at floor level running the length of the room. An inclined manometer is used to measure the pressure drop in the exhaust system, and it is monitored regularly. Following photoresist application, the wafers are soft-baked in a resistance-heated oven. There are no air sampling monitors permanently installed in the photolithography area. Personal protective equipment used by operators consists of safety glasses. No specific work practices were noted in this area.

7.1.2 Substrate Exposure. The wafers are exposed in projection mask aligners that utilize a mercury lamp source of unspecified ultraviolet wavelength. The lamps are enclosed in exhausted lamp housings to provide cooling air and to contain mercury in case a bulb explodes. The extent of possible emissions of ultraviolet radiation to either the operator or repair technician is not known. The projection mask aligners are located under laminar flow HEPA stations which have a reported downward velocity of 80 feet per minute. The mask aligner room is positively pressurized with repect to the other areas of the clean room. No recirculated air is supplied to this area. Supply air, in addition to the HEPA stations, is also delivered through perforated ceiling panels. No personal protective equipment is required in this area. No work practices regarding safety and health items were observed. There is no fixed air monitoring in this area. As part of routine maintenance, photomasks are removed from the aligners and cleaned with isopropanol and water in a wet chemical work station similar to that described in Section 7.2.1. Local exhaust ventilation is provided by a slot across the rear of the bench, a perforated deck across the front of the bench, and by slots located around the tank perimeter.

7.1.3 Photoresist Developing. An n-butyl acetate/isopropanol and synthetic aliphatic hydrocarbon solution is used for developing negative photoresist, while a caustic based developer is used for developing positive photoresist. Developing is performed by spin application with equipment similar to that described in Section 7.1.1. Engineering controls are similar to those previously described. The developer solution is spun onto the wafers that are then hard-baked in a resistance heated in-line oven. After inspection, any masks that are not properly aligned are stripped and reused. No specific work practices were observed in this area during the preliminary survey. There are no air sampling monitors permanently installed in the photolithography area.

7.2 Wet Chemical Operations

Wet chemical operations are used to etch wafers, to strip photoresist from wafers, and to clean process equipment. Polypropylene benches are used throughout the facility. The operations and control strategies are described below.

7.2.1 Acid Etching and Cleaning. Acid etching is performed in plastic benches with exhaust slots at the rear wall, the front inclined lip, and around the perimeter of each tank at the bench surface. Exhausts exit the rear of the benches and are gathered into exhaust plenums and exit vertically to the scrubbing system on the roof. Acid benches are filled by chemical technicians who wear gloves, aprons, gauntlets, and face shields. Tanks are emptied into the acid drain system by aspiration. Personal protective equipment for bench operators consists of safety glasses, acid-resistant gloves, and aprons. There is no permanently installed air monitoring equipment in the vicinity of acid etching stations. Local exhaust ventilation of some benches is monitored with an inclined manometer. Eventually all bench exhausts will incorporate manometers to check ventilation flow.

7.2.2 Furnace Tube Cleaning. A vertical tube washer is used for periodic cleaning of CVD furnace tubes. The washer is a polypropylene cabinet, and has interlocks to prevent inadvertent operation when the door is open. A furnace tube is placed in the washer by a production technician. The wash cycle is automatic and includes hydrofluoric acid washing, deionized water rinsing, and nitrogen drying. The tube washer is vented at the bottom where the duct joins a main exhaust plenum at floor level. A bell jar washer is used for cleaning epitaxial reactor chambers. It uses a nitric acid wash and is interlocked and ventilated in the same manner as the furnace tube unit.

7.3 Plasma Etching

Plasma etching is a dry 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. Oxygen is used to strip photoresist, and carbon tetrafluoride and oxygen are used to etch silicon nitride. Both processes are performed in a barrel or tunnel plasma etching unit.

Plasma etching is performed with the system reaction chamber negative to room pressure. The vacuum is approximately 0.1 to 20 torr that is maintained by an oil-sealed mechanical pump. The plasma gases containing the volatile species formed by the plasma ions react with the substrate and are vented from the unit by the pump. The pump is vented through a coalescer to remove pump oil from the gas before venting to the plant scrubber system. The vacuum pumps for the units are located in a service tunnel or chase behind the etching unit. The pump oils are changed approximately every 6 months. Radio frequency radiation emissions from the etching system are controlled by the shielding provided by the metal cabinet. Process gases are stored in cylinders in ventilated cabinets located in the service tunnel. The cabinets are exhausted at 200 cfm to the plant scrubber system.

Operators are required to wear safety glasses and product-protective equipment described in Section 5.3. The use of automated controls may affect the emissions or worker exposures as the need for operator interaction with the equipment is limited. The operator is required to load and unload cassettes containing wafers and to initiate the processing sequence by push-button controls. The operator is then able to perform other tasks and is not required to be at the unit for the entire work shift. Therefore, any exposures to chemical or physical agents would be for short time periods throughout the shift.

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

7.4 Epitaxial Silicon Growth

A single crystal silicon layer is grown on the silicon wafer in an epitaxial reactor system. The unit consists of a reactor assembly cabinet and system control console. The operation is controlled by microprocessor and is performed at atmospheric pressure and at reduced pressure (approximately 100 torr). The components of the reactor assembly cabinet include a gas distribution system, power supply, vacuum pump, reactor chamber, chamber pump, and system exhaust.

The operator loads wafers on a barrel susceptor that is automatically lowered into the reaction chamber. The chamber consists of a quartz bell jar. The typical process sequence includes an inert gas purging cycle, a hydrogen purging cycle, programmed elevation in wafer temperature, wafer etching with hydrogen chloride, epitaxial silicon deposition, control and shutdown of process gas streams, and reduction in wafer temperature followed by a hydrogen and a nitrogen purge. The barrel susceptor is automatically raised, and the wafers are removed by the operator. The wafers are heated by a radiant heat source that surrounds the bell jar, and is insulated and enclosed within a cabinet. An emergency water cooling system is present for controlling the reactor chamber temperature during power failures. A system of detectors and interlocks monitors the process operation and is programmed to shutdown the process in the event of a hazardous situation, e.g., a gas leak. Solenoid valves are used to stop gas flow during a power failure.

The reactor chamber is exhausted by a pump located in the cabinet. A horizontal laminar flow HEPA filter work station is built into the cabinet load station to control particulate contamination of wafers.

Process gases include dichlorosilane, hydrogen chloride, hydrogen, and arsine (100 ppm in hydrogen). Hydrogen is supplied from tube trailers located outside the building and distributed to the equipment through welded stainless steel lines. Nitrogen gas for purging the reactor chamber is supplied from bulk storage tanks. The remaining gases are supplied in cylinders stored in a ventilated cabinet that is exhausted at 200 cfm to the plant scrubber system.

A TELOS® Arsine/Phosphine Anaysis System is used to monitor arsine and phosphine. Combustible gas is monitored by a Bacharach® gas detection system. Both monitoring systems are described in Section 3.4.

Personal protective equipment required in the area include safety glasses and product-protective equipment described in Section 5.3. Specific work practices that affect emissions or operator exposures to chemical or physical agents were not observed during the preliminary survey.

7.5 Diffusion, Thermal Oxidation, Annealing and Alloying

Diffusion of dopants into the wafer is performed in a diffusion furnace assembly at atmospheric pressure. The furnace assembly is also used to form a thermal silicon dioxide layer on the wafer by oxidation, to alloy wafers, and to drive in dopants after ion implantation.

The diffusion furnace assembly consists of a load station, a furnace cabinet containing furnace tubes and electrical resistance heating elements, a source cabinet enclosing the furnace tube end, and an electrical cabinet containing the direct digital control (DDC) system. Process gases enter the furnace tube through gas supply lines that connect to the furnace through the source cabinet. The furnace cabinet acts as a protective barrier against the hot contact surfaces of the furnace tube.

Process gases used include (1) hydrogen, hydrogen chloride, and oxygen for thermal oxidation; (2) nitrogen and oxygen for annealing; and (3) hydrogen for alloying. Nitrogen is also used as a purge gas for all furnace operations. Dopants are supplied in a liquid form and include phosphorus oxychloride ($POCl_3$) and boron tribromide (BBr_3) supplied in bubblers which are located in cooling flasks set in the source cabinet. The bubbler is connected to the furnace by tubing that is designed to prevent improper connection.

The above operations are performed by placing wafers in carriers that are loaded into the furnace tube. The temperature is increased (the specific temperature depends on the operation performed), and the furnace tube is purged with nitrogen followed by the introduction of the specific process gases. Dopant gases for diffusion are supplied by bubbling nitrogen through the liquid source which is then introduced into the furnace tube. Thermal oxidation is performed by introducing hydrogen and oxygen into the furnace tube to form a pyrophoric water atmosphere. The wet oxidation may be followed by a dry oxidation using oxygen and hydrogen chloride. Annealing and alloying are performed by introducing the respective process gases into the furnace tube.

The tube temperature is then decreased, the tube is purged, and the carriers are removed. The process operating parameters, including tube temperature, gas flow, process sequence, and other process operating parameters are controlled by either an operator who monitors and adjusts the system or by direct digital control (DDC). The DDC systems use feedback control loops that monitor and adjust the performance of the furnace (Douglas, 1981).

The furnace assembly is vented at three areas: (1) the source cabinet, (2) the furnace cabinet, and (3) the furnace load end. The source cabinet encloses the gas assemblies and furnace tube ends of all four tubes in the furnace cabinet. The source cabinet is ventilated by an exhaust duct located at the top of the cabinet which is monitored with an inclined manometer. The cabinet is accessible through a hinged clear plastic panel. The furnace cabinet is vented for temperature control by an exhaust duct at the top of the cabinet. The furnace tube opening is vented by a scavenger box that encloses the opening. The face velocity of the scavenge box is 100 to 150 fpm. The exhaust from the hydrogen alloying furnace passes through a burner located in the scavenger exhaust duct.

Maintenance operations for the diffusion furnace assemblies include biweekly removal of the furnace tubes for cleaning with a hydrofluoric acid solution in a ventilated wet chemical bench. The furnace tubes are also cleaned in place by introducing hydrogen chloride, steam, and oxygen into the tube. The cleaning cycle is programmed into the DDC system.

Monitoring systems present in the area include a Bacharach® multipoint combustible gas monitoring system and a MIRAN® infrared spectrophotometer with multipoint sampling. Both monitoring systems are described in Section 3.4. Personal protective equipment requirements include safety glasses. Product-protective equipment is described in Section 5.3. Operators are also required to use heat-protective gloves for handling hot quartzware.

Special work practices have been developed for handling quartz bubblers. Workers are instructed in the proper installation procedures and in proper response to spills. Specific work practices were not described during the preliminary survey.

7.6 Ion Implantation

Ion implantation is the process of introducing impurities or dopants into the wafer. The impurities are p- or n-type ions created by a confined electric discharge that is sustained by a dopant source gas. The ion beam is drawn from the arc chamber by an extraction electrode and directed to 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 dopant source gases used include either arsine, phosphine, or boron trifluoride at 15 percent mixtures in an inert gas or in hydrogen. The source gases are in lecture bottles stored in a ventilated cabinet located in the ion implantation unit. The power source, ion source, and analyzing magnet are contained in a lead-shielded cabinet to control X-ray radiation emissions. The cabinet is located within a second lead-lined enclosure that is electrically grounded and interlocked to the power supply.

Three independent vacuum systems are used to maintain vacuum conditions: (1) an oil-sealed mechanical pump operates the load-lock chambers, (2) an oil-sealed mechanical pump and an oil diffusion pump operate the target chamber, and (3) an oil-sealed mechanical pump and oil diffusion pump or cryogenic pump operate the ion source. The pumps are exhausted to the scrubber system.

Scheduled maintenance of the ion implantation unit includes weekly cleaning of the ion source and a semiannual cleaning of the entire system. Specific cleaning procedures were not described.

The system exhaust is monitored by an inclined manometer at the top of the enclosure. The equipment is monitored for X-ray radiation emissions quarterly using a Geiger counter. Personal dosimeters (radiation film badges) are used to monitor X-ray emissions and operator exposures. The film badges are changed monthly. The area is monitored for arsine and phosphine with a TELOS® Arsine/Phosphine Analysis System. The system is described in Section 3.4.

The operator is required to load and unload cassettes containing wafers into the load station. The process is automatically controlled by a system microprocessor. Operators are able to perform other tasks in the area during implantation including cleaning of the wafers in nitric acid, sulfuric acid and hydrofluoric acid, and loading cleaned wafers into cassettes.

Personal protective equipment required in the area includes safety glasses and general clean room attire described in Section 5.3. Operators are required to use a supplied air-line respirator to change dopant gas cylinders.

7.7 Low Pressure Chemical Vapor Deposition

Low pressure chemical vapor deposition (LPCVD) is used to deposit a silicon nitride, polycrystalline silicon or phosphorus-doped silicon dioxide layer on wafers. The operation is performed in a diffusion furnace assembly similar to that used for thermal oxidation and described in Section 7.5, but operated at low pressure (approximately 0.4 to 3.0 torr). The LPCVD furnace consists of a furnace tube, gas control enclosure, gas flow controllers, electronic controls, vacuum section, and quartzware for loading wafers. The furnaces are controlled by a microprocessor with feedback control loops and preprogrammed "recipes" that control the furnace temperature profile, gas flow, vacuum pumping and purging, and process sequencing. The operator is required to load wafers into carriers that are inserted into the furnace. The operator initiates the process operation by pushbutton control. After completion of the process, the operator unloads the wafers from the furnace.

The furnace tube vacuum is maintained by an oil-sealed mechanical pump located in the service tunnel. The pump is exhausted through a coalescer (to remove oil from the exhaust) to the scrubber system. The pump is enclosed in a ventilated cabinet and nitrogen is introduced into the pump exhaust.

Process gases used include: (1) silane, phosphine (100 percent), oxygen, and nitrogen for phosphorus-doped silicon dioxide; (2) silane and nitrogen for polycrystalline silicon; and (3) dichlorosilane and nitrous oxide or silane and ammonia for silicon nitride deposition. Process gases are stored in ventilated cabinets that exhaust at 200 cfm to the scrubber system.

The furnace assembly is vented at the furnace loading station, at the furnace cabinet, and at the source cabinet. The furnace loading end is vented by a scavenger box and the furnace cabinet and source cabinets are vented by separate ducts at the top of each cabinet. The furnace cabinet is vented for temperature control. The source cabinet is enclosed with a hinged clear plastic panel and the cabinet exhaust is monitored with an inclined manometer.

The furnace area is monitored with a Bacharach® combustible gas detector system and a TELOS® Arsine/Phosphine Analysis System. The systems are described in Section 3.4.

Personal protective equipment required in the area include heat protective gloves for handling hot materials, safety glasses, and general clean room attire described in Section 5.3. Additional requirements include the use of a supplied-air respirator for changing phosphine gas cylinders.

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

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 70 to 150 KHz or 13.56 MHz. PECVD systems used for silicon nitride deposition include an automated cassette-to-cassette unit and a furnace tube assembly.

The cassette-to-cassette unit processes individual wafers. The 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 gas. Silicon nitride is deposited on the wafer as it passes through the chamber. The wafer is then transported into a load-lock exit into a second cassette. The deposition process is performed under vacuum conditions of approximately 2 torr. The process is controlled automatically by a microprocessor. Workers are required to load and unload cassettes and to enter appropriate commands into the computer by push-button controls. Process gases include silane, nitrogen, and oxygen.

The second PECVD system is similar to a diffusion furnace assembly and consists of a furnace tube, gas control system, vacuum pumping system, radio frequency power source, and wafer boat. The wafer boat consists of parallel, vertical metal plates that act as the anode and cathode for the radio frequency field. Wafers are loaded onto the metal plates, the boat is inserted into a load platform and then connected to the furnace tube where the wafer boat is inserted. The furnace tube is sealed and pumped to a vacuum of approximately 2 torr. The radio frequency power is applied to the boat, creating a radio frequency field between the parallel metal plates. Process gases are introduced into the tube and form a plasma in the RF field, depositing silicon nitride or silicon dioxide on the wafer surface. The furnace is cleaned by an automatically controlled, in situ plasma etching using Freon and oxygen. Process gases used for silicon nitride deposition include silane, ammonia, 15 percent phosphine, and nitrogen.

The PECVD furnace assembly is exhausted by the vacuum pump system that evacuates the furnace tube. A blower is connected to the pump to exhaust the system. Process gases for both types of units are stored in ventilated cabinets located in the service tunnel that exhaust at a rate of 200 cfm to the scrubber system.

Engineering controls for both PECVD systems are integral to the process operation and equipment. Both units are operated at pressures negative to the room atmospheric pressure. Any leaks occurring in the unit would result in air moving into the reaction chamber. The in-line unit uses load-locks that are purged before unloading the wafer. The PECVD furnace assembly has a scavenger box located at each furnace tube opening. The furnace door will not open under pressure. It is mechanically held closed and is interlocked to prevent operation of the RF generator and vacuum system while the door is open. Radio frequency radiation shielding is provided by the metal support cabinets for both units and by metal mesh screens over glass viewing ports.

Monitoring systems for evaluating emissions from process operations or worker exposures to chemical or physical agents are described in Section 3.4 and include a TELOS® Arsine/Phosphine Analysis System and a Bacharach® combustible gas detection system. Radio frequency radiation emissions are monitored quarterly by plant industrial hygienists using a Narda® broadband isotropic monitor.

Specific work practices implemented to control emissions or worker exposures to chemical or physical agents were not observed during the preliminary survey. Personal protective equipment required in the area include safety glasses. General clean room attire is described in Section 5.3.

7.9 Atmospheric Pressure Chemical Vapor Deposition

Phosphorus-doped silicon dioxide is deposited by a continuous atmospheric pressure chemical vapor deposition system. The process equipment consists of a reaction chamber, gas control system, process display/control system, temperature control system, and exhaust/environmental control system. The process operation is controlled automatically.

The process equipment components are contained within a single cabinet. Wafers are loaded onto platens and automatically transported through the reactor chamber. The reactor chamber consists of a nitrogen purge zone, wafer preheat zone, deposition zone, cooldown curtain, and final nitrogen purge. The wafers are heated by electrical resistance as they are transported through the chamber. Phosphorus-doped silicon dioxide is deposited in the reactor chamber deposition zone by the reaction of silane, oxygen, and phosphine. The wafers are then transported through a cooldown zone to a final nitrogen purge and into an unloading station where the platens containing wafers are removed. The process is a continuous operation with temperature, gas flow, wafer movement, and system exhaust automatically controlled. The controls also include system interlocks that shut off gas flow when any potentially hazardous conditions occur.

Process gases are supplied in cylinders that are stored in ventilated cabinets exhausted at 200 cfm to the plant scrubber system. Engineering controls for the system are integral to the process equipment and are necessary to assure product quality. These controls include exhaust of the reaction chamber monitored and controlled automatically to provide a controlled deposition. The chamber is vented to the plant scrubber system. The reaction chamber is also enclosed within a cabinet to prevent operator contact with hot surfaces.

Monitoring systems for evaluating emissions from the process operation are described in Section 3.4 and include a TELOS® Arsine/Phosphine Analysis System with multipoint sampling and a Bacharach® combustible gas detection system.

Specific work practices that affect emissions or operator exposures to chemical or physical agents were not observed during the preliminary survey. Personal protective equipment required in the area includes safety glasses. General clean room attire is described in Section 5.3.

7.10 Metalization

Two different types of process equipment are used to deposit metal on the wafer surface, a side mount sputtering system and a bell jar system. The side mount system is used for both radio frequency (RF) and direct current (DC) sputtering of metals and metal alloys in both MOS and bipolar fabrication. The bell jar system is used to deposit gold on the wafer backside by filament evaporation. Both systems are described below. DC sputtering is also performed using a bell jar system. The bell jar system is performed in the MOS fabrication process but was not observed during the preliminary survey.

7.10.1 Sputtering. Sputtering is performed in a side mount system using either radio frequency or direct current power. Wafers are mounted on a metal platen that is placed in a load lock chamber by the operator. The system is evacuated to very low pressure (approximately 10^{-6} torr), and the platen is automatically transported into the deposition chamber where the metal is deposited onto the wafer surface. Metals deposited with the system include platinum, titanium, tungsten, aluminum, platinum/nickel, copper/aluminum, silicon/aluminum, and silicon/copper/aluminum. The chamber is vented through the vacuum pumping system consisting of an oil-sealed mechanical pump and a cryogenic pump. RF sputtering is performed at a frequency of 13.56 MHz and a power of 300 to 2500 watts.

Engineering controls that are used to limit emissions or operator exposures to chemical or physical agents are integral to the process operation and equipment. The unit is operated under vacuum conditions at pressures negative to the work area. Workers are shielded from RF radiation emissions by the metal cabinet.

No continuous monitoring systems are present for evaluating emissions from process operations or operator exposures to chemical or physical agents. However, radio frequency radiation emissions are monitored quarterly by plant industrial hygienists using a Narda® broadband isotropic monitor.

Specific work practices implemented to control emissions or operator exposures to chemical or physical agents were not observed during the preliminary survey. Personal protective equipment required in the area includes safety glasses. General clean room attire and product-protective equipment are described in Section 5.3.

7.10.2 Filament Evaporation. Gold is deposited on the wafer backside by filament evaporation. The operation is controlled automatically and is performed in a sealed metal chamber. The wafers are mounted in a planetary that is placed inside the chamber. The chamber is then sealed and pumped to a vacuum of approximately 10^{-6} torr by an oil-sealed mechanical pump and a diffusion or cryogenic pump. A gold wire is heated to evaporation and the vaporized gold is deposited on the wafer. The operator is required to load and unload wafers and to start the process sequence by push-button control. The oil-sealed mechanical pump exhaust is passed through a coalescing unit to trap pump oils.

Engineering controls that control or limit emissions or worker exposures to chemical or physical agents are integral to the process operation. These controls include operation at low vacuum which prevents release of the metal into the workroom air, enclosure of the operation to prevent contact with hot surfaces, and venting of pump exhaust to the plant ventilation system.

Operators are required to wear safety glasses and the product protective equipment described in Section 5.3. Work practices that may affect the emissions or worker exposures include the use of automated controls which limit the need for operator interaction with the equipment. Workers use tweezers to load wafers into the planetary which requires simultaneous hand flexion and inversion of the wrist.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The fabrication of integrated circuits at Digital Equipment Corporation (DEC) is representative of the present state-of-the-art in wafer processing. Process operations observed that may also be indicative of future processing trends include plasma-enhanced chemical vapor deposition, low pressure chemical vapor deposition, and plasma etching. These and the remaining process operations observed at DEC are performed using new processing equipment that is frequently controlled by microprocessors.

Control strategies used at DEC include engineering controls, monitoring systems, work practices, and personal protective equipment. Engineering controls and monitoring systems have either been developed by DEC or they are integral to the process operation and/or equipment. The use of automated controls, such as those found in DDC diffusion furnaces, and plasma etching, may play an important role in determining work practices that affect operator exposures to chemical or physical agents. Specific work practices used by operators, chemical technicians, and repair and maintenance technicians generally could not be observed during the preliminary survey due to time constraints.

DEC has also developed an occupational health and safety program with responsibilities in industrial hygiene, environmental engineering, health physics, safety, and health services. These programs provide comprehensive coverage of health and safety. Training programs, manuals, and materials that have been developed by DEC are well designed and appear to provide employees with a comprehensive introduction to health and safety.

The DEC facility is of recent construction and should be representative of current design trends in air supply, exhaust ventilation, waste handling, gas handling, and fabrication area layout.

The facility should be considered for detailed study given the use of current state-of-the-art process operations and equipment in a facility that is representative of current fabrication area design trends. Specific process operations that should be considered for detailed study include PECVD, LPCVD, ion implantation, and plasma etching.

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