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

at

NEC Electronics U.S.A., Inc.
Electronic Arrays Division
Mountain View, California

Prepared by
Gary J. Mihlan and Robert D. Wilson

Battelle
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

Report No. 115-24a
May 31, 1983

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
Cincinnati, Ohio 45226

PLANT SURVEYED: NEC Electronics U.S.A. Inc.
Electronic Arrays Division
550 E. Middlefield Road
Mountain View, California 94043

SIC CODE: 3674

SURVEY DATE: January 13, 1982

SURVEY CONDUCTED BY: Mr. Gary J. Mihlan, Battelle-Columbus Laboratories
Mr. Robert D. Willson, Beta Associates
Mr. Paul E. Caplan, National Institute for Occupational Safety and Health

EMPLOYER REPRESENTATIVES CONTACTED:

Mr. Eugene J. Vaatveit, Director, Wafer Fabrication
Mr. Russell Childs, Process Engineering Manager
Mr. Richard Bolmen, Safety Manager
Mr. Wayne Ritter, Director, Human Resources

EMPLOYEE REPRESENTATIVES CONTACTED:

No Employee Representatives

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

1.0 ABSTRACT

A preliminary control technology assessment survey was conducted by Battelle Columbus Laboratories at NEC Electronics U.S.A., Inc., Electronic Arrays Division, Mountain View, California, on January 13, 1982. 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 metal oxide semiconductor (MOS) integrated circuits.

The process operations for integrated circuit fabrication are performed in a clean room environment. The supply air is passed through roughing filters followed by bag filters and high efficiency particulate air (HEPA) filters. Process operations performed at Electronic Arrays 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) doping, including diffusion and ion implantation; 6) low pressure chemical vapor deposition (LPCVD); 7) plasma-enhanced chemical vapor deposition (PECVD); 8) metalization by direct current (DC) sputtering; and 9) hydrogen annealing.

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 workers from the processes. The isolation technique is used in LPCVD, PECVD, plasma etching, ion implantation, and metalization. Shielding is used in ion implantation units to control X-ray radiation emissions, in plasma etching and PECVD to control radio frequency radiation emissions, and in substrate exposure to control ultraviolet emissions. Local exhaust ventilation is used to remove vapors, process gases and byproducts in diffusion furnaces used for thermal oxidation, diffusion and hydrogen annealing, wet chemical cleaning and etching, and photolithography. Local exhaust ventilation is also used for gas storage cabinets.

Several process operations are automated and controlled by microprocessors. These operations include DC sputt ring, some photolithography processes, plasma etching, ion implantation, LPCVD, PECVD, and DC sputtering.

Continuous area monitoring of the wafer fabrication area is performed by a Rexnord® combustible gas detection system. Electronic Arrays is considering installing a continuous phosphine monitoring system. Radiation film badges are used to monitor emissions and operator exposures to X-ray radiation from ion implantation units. Magnehelic gauges are used to monitor local exhaust ventilation of wet chemical benches.

Personal protective equipment is used by operators, maintenance and repair technicians, and chemical technicians to control worker exposures to chemical and physical agents. Operators are also required to wear product-protective equipment to control product quality. Electronic Arrays has established a health and safety program that includes safety, worker training, and industrial hygiene and is developing programs in the use of personal protective equipment, emergency response, and hazard reporting. No routine industrial hygiene measurements had previously been taken but the facility plans to monitor employee exposures to organic solvents, acids, noise, and radiation.

A variety of process operations are used at the facility that should be considered for detailed investigation. These include plasma etching, ion implantation, LPCVD, and PECVD. The effectiveness of the local exhaust ventilation of the newer wet chemical benches should be evaluated and compared to the other benches.

Work practices that may affect emissions or operator exposures to chemical and physical agents could not be addressed during the preliminary survey due to time constraints; however, they should be documented during a detailed survey.

2.0 INTRODUCTION

A preliminary survey was conducted at NEC Electronics U.S.A., Inc., Electronic Arrays Division, 550 East Middlefield Road, Mountain View, California on January 13, 1982. 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. Mr. Paul E. Caplan, NIOSH Division of Physical Sciences and Engineering, accompanied the survey team.

The following individuals were contacted at Electronic Arrays:

1. Eugene J. Vaatveit, Director, Wafer Fabrication,
2. Russell Childs, Process Engineering Manager,
3. Richard Bolmen, Safety Manager, and
4. Wayne Ritter, Director, Human Resources.

The study protocol was provided to the safety manager before the survey. During an opening conference with plant representatives, the study objectives and methods were described. Plant staff provided a detailed description of the process operations performed at the facility as well as a general description of the wafer fabrication area, waste management system, ventilation system, and health and safety program.

Following the opening conference, the facility was toured. A closing conference was held after completing the tour.

3.0 PLANT DESCRIPTION

3.1 General

Electronic Arrays was formed in 1968 and merged with NEC Electronics U.S.A., Inc. in 1978. Product lines have included metal oxide semiconductors (MOS), memory products and random logic products including read-only memories (ROMS), random-access memories (RAMS), erasable programmable read-only memories (EPROMS), and custom logic products. The facility currently manufactures ROMS and RAMS.

The facility consists of three buildings: 1) a 27,000 square feet building of tilt-up concrete slab construction built in 1966; 2) a 16,000 square feet building of tilt-up concrete slab construction built in 1980; and 3) a brick building constructed in 1961 with 40,000 square feet. Wafer fabrication is performed only in the first building. The remaining areas are used for testing and packaging, office space, engineering design, and sales.

The facility employs 425 people with 276 individuals in the production area and 149 in administrative and technical services. The production staff includes 76 men and 200 women and the administrative/technical services staff is composed of 99 males and 50 females. The facility operates two shifts per day with 226 production workers employed on the first shift and 50 employed on the second shift.

The plant has an emergency generator that supplies 45 kilowatts of power used for lighting. Electronic Arrays is planning to provide emergency power to operate the exhaust scrubbers during power failures.

3.2 Chemical Storage

Liquid chemicals are segregated as acids or organic solvents. Acids are segregated by type and stored in boxes on wood pallets in a separate chemical storage area. The floor is diked to contain spills and has a drain that flows to the acid waste neutralization system. The room has an emergency shower and eye wash station and is vented by general exhaust ventilation.

Organic solvents are stored in a separate room. The room is not diked and does not have a drain. The room is vented by general exhaust ventilation. A fire extinguisher is available in the room, but there is no emergency shower or eye wash station.

Chemicals are distributed to the wafer fabrication area by designated chemical technicians using plastic carts.

3.3 Gas Handling System

Gases used in wafer fabrication are supplied from cylinders and from bulk house supplies. Hydrogen, oxygen, and liquid nitrogen house supplies are distributed in stainless steel lines. The lines are welded in new areas of the plant or they are connected by compression fittings in older fabrication areas. Nitrogen is supplied in copper lines.

Gases supplied in cylinders are stored in ventilated cabinets in the wafer fabrication area or the cylinders are stored in a secured, outdoor area. Electronic Arrays will be changing all cylinder storage to ventilated gas cabinets. Cylinder gases are distributed in stainless steel lines that are either welded or joined by compression fittings.

The regulator assembly at the gas cabinet has a purge valve with bonnet and rupture disk that floods the cabinet with nitrogen. Some cylinder gas lines have solenoid valves that automatically shut off during a power failure. The lines also have flow-limiting valves that automatically close the line if the gas flow exceeds a preset limit.

Gas storage cabinets are ventilated at approximately 800 cfm through an 8-inch stainless steel exhaust duct. The takeoff is located at the top of the cabinet, and regulator assemblies are located in the gas cabinets. Nitrogen supplied in cylinders is used for purging gas lines. Gas cabinets that contain silane cylinders have a burn box as part of the cabinet exhaust duct. The burn box allows pyrophoric gases to burn before being vented.

Gas cylinders are changed by maintenance workers. The cylinders are tested for leaks using a Snoop® leak detection system. Personal protective equipment requirements for maintenance workers are presented in Section 5.3.

Gases in use, in addition to those noted above, are hydrogen chloride, ammonia, argon, dichlorosilane, arsine, phosphine, boron trifluoride, and freons (unspecified).

3.4 Monitoring System

The facility uses a Rexnord® combustible gas detection system for monitoring hydrogen in the wafer fabrication area. The system consists of two electronic control modules with 8 channels per module capable of monitoring a total of 16 locations where hydrogen leaks may occur. The system is set to activate at 20 percent and 40 percent of the lower explosive limit (LEL) for hydrogen. Gas detector sensors are placed in the diffusion furnace area on the ceiling, in the gas jungle at the furnaces, and in the diffusion furnace scavenger exhaust duct. Toxic gas monitoring systems were not used at the facility. Electronic Arrays is considering installing a continuous phosphine monitoring system in the future.

3.5 Ventilation System

The wafer fabrication area supply air is filtered through a bag filter followed by an activated charcoal filter and a high efficiency particulate air (HEPA) filter. The air is delivered to the room either through ceiling diffusers or through vertical laminar flow HEPA filtration units at the work station. A total of 150,000 cfm of filtered air is supplied to the fabrication area with 75 percent of the air recirculated. Fabrication room air is recirculated through wall panels that act as a return air plenum. The air enters through the wall at approximately floor level. The wafer fabrication area is maintained at positive pressure relative to the surrounding building.

Local exhaust ventilation is provided by two exhaust systems handling 15,000 cfm and 9,000 cfm, respectively. Each exhaust system has a water scrubber with a demister. The system uses 8 to 10 gallons of water per minute. The scrubbers treat 1) vacuum pump exhausts containing toxic or pyrophoric gases as byproducts from ion implantation and low pressure chemical vapor deposition; 2) diffusion furnace exhausts including furnace cabinet, source cabinet, and scavenger box exhaust; and 3) wet chemical etching and cleaning operation exhausts.

Exhaust ducts are either polypropylene or stainless steel and pass through the roof to connect with polypropylene trunk lines that enter the scrubber systems. Scrubbed air is vented through 36-inch diameter, 4- to 6-feet tall stacks.

The facility has ordered an emergency generator to run the scrubber systems and emergency lighting during power failures.

3.6 Waste Management

Liquid wastes are each handled separately and may be categorized as chromic acid waste, acids containing fluorides, photoresist waste, phenol wastes, and general organic solvent waste.

Chromic acid wastes are collected from the point of use and aspirated into an enclosed tank in a portable cart. From there, the waste acid is transferred into the original containers and stored in a trailer for periodic off-site disposal.

Photoresist waste is collected in containers located in the photolithography area. The chemical technician removes the container and transfers the waste to drums that are disposed off-site at a hazardous waste landfill. The phenol-containing waste is also collected separately, and transferred into a 1,500-gallon storage tank located in a diked, fenced area at the rear of the plant property. The waste is disposed off-site by a waste management firm at a hazardous waste landfill. The diked area has an emergency shower.

Acid wastes containing hydrofluoric acid are collected from the point of use in a portable cart used specifically for acid wastes. The waste is pumped into the cart and transferred to drums, and then transferred again into a 1,500-gallon storage tank. The tank is adjacent to the waste phenol tank in an enclosed, diked area at the rear of the plant property. The waste is disposed off-site by a waste management firm at a hazardous waste landfill.

Waste organic solvents, other than those containing chlorobenzene, are removed from the point of use by drains to an underground waste solvent tank. The waste solvents are removed by a waste management firm for off-site disposal.

Acids not containing fluorides are removed from the point of use by drains to an acid neutralization system where the pH is continuously adjusted with ammonia. Blowdown from the air exhaust scrubbers is also treated in this system.

Waste pump oils are collected and stored in 55-gallon containers located in a trailer for periodic off-site dispos l by a waste management firm. The oil is disposed off-site by a waste management firm. The pump oils are changed approximately once per month.

The waste collection cart is polypropylene and is equipped with an electrical pump used to transfer wastes into and out of the tanks. The flow of the pump is reversed by a switch located in the cart. The operator must connect the pumps to an electrical outlet for operation. The cart has a fire extinguisher, acid neutralization materials, and spill pillows.

4.0 PROCESS DESCRIPTION

The fabrication sequence used for metal oxide semiconductor integrated circuit manufacture varies depending upon the specific type of device manufactured. Process operations seen at the facility are described below. The specific sequence in which the process operations are performed is not presented. A general processing sequence for MOS 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 substrates for device fabrication are purchased.

MOS fabrication generally begins with the thermal oxidation of the silicon wafer. The wafers are oxidized at a high temperature (500 to 1000°C) in a diffusion furnace assembly using a pyrophoric water (i.e., hydrogen and oxygen) atmosphere. Hydrogen chloride gas is added to the gas stream for cleaning (i.e., gettering) sodium ion contamination from both the growing oxide and the furnace tube (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 then introduced into the tube at a controlled rate. The furnace has hybrid control where processing parameters, such as gas flow, are automatically controlled to preset limits but are monitored and adjusted by the operator. Mass flow controllers (MFC) are used to assure a uniform flow rate of process gases into the furnace tube. The MFC system has a digital readout and the flow is adjusted by the operator. Rotometers are also used to monitor gas flow and are monitored and adjusted by the operator.

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 a primer by spin application using hexamethyldisilizane (HMDS) in a xylene carrier. The negative photoresist, containing a proprietary mixture of organic polymers in a xylene carrier, is then 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 only load and unload cassettes. HMDS and photoresist spin application and wafer drying operations are performed in an in-line, cassette-to-cassette unit.

The mask pattern is transferred to the coated wafer by ultraviolet light (435 nm) using contact printing. The operator places a wafer on a stage and aligns the wafer with the mask. The wafer is clamped to the mask and exposed to ultraviolet light from a mercury lamp source located behind the mask. Masks are manufactured by an outside vendor to plant specification.

The exposed wafers are developed by spin application of a xylene and n-butyl acetate solution onto the wafer surface. The developed wafers are hard-baked in a resistance-heated oven. The operation is performed in an automated, cassette-to-cassette system similar to that used for photoresist application.

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 methods include 1) hydrofluoric acid and ammonium fluoride for etching silicon dioxide, 2) phosphoric acid for etching silicon nitride, 3) hydrofluoric and nitric acid for etching polycrystalline silicon, and 4) nitric and phosphoric acid for etching aluminum. The wet chemical etching operations are performed in tanks recessed in wells in polypropylene benches. Additional wet chemical operations include 1) wafer cleaning with sulfuric acid and hydrogen peroxide, 2) mask cleaning with a Freon solvent, 3) photoresist stripping with a phenol, sulfonic acid, chlorobenzene, and unspecified aromatic solvent mixture, and 4) mask cleaning with chromic acid.

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 to be etched. Gases includes carbon tetrafluoride and oxygen for etching silicon nitride and oxygen for stripping photoresist. The plasma is formed in a sealed reaction chamber at a pressure 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 phosphine or phosphorus oxychloride. Phosphine is supplied as a cylinder gas stored in a ventilated cabinet. Phosphorus oxychloride is supplied in a liquid source bubbler. The operation is performed in a diffusion furnace similar to that used for thermal oxidation.

Wafers are also doped using ion implantation. A source gas, either phosphine or boron trifluoride, 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, analyzing and accelerating chamber, and the wafer exposure station are operated at vacuum conditions of approximately 10^{-6} torr. This vacuum is maintained by one of two sets of pumps, either an oil sealed pump and a diffusion pump, or an oil-sealed pump and a cryogenic pump. 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 that is pumped to a 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 into a cassette.

At various steps in the processing sequence, a thin film is deposited in the wafer surface by chemical vapor deposition (CVD) in which the solid products of a vapor phase chemical reaction are deposited on the substrate. The film is deposited either by low-pressure chemical vapor deposition (LPCVD) or by plasma-enhanced chemical vapor deposition (PECVD).

LPCVD is used to deposit 1) silicon nitride by the reaction of dichlorosilane and ammonia, 2) polycrystalline silicon by the reaction of silane, and 3) phosphorus-doped silicon dioxide by the reaction of silane, phosphine, and oxygen. Hydrogen chloride gas is used as a pretreatment during polycrystalline silicon deposition. 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 carriers containing wafers into the furnace. The furnace door is closed and the sequence and operating parameters are controlled by microprocessor.

Plasma-enhanced chemical vapor deposition (PECVD) is also used to deposit silicon nitride by the reaction of 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 at approximately 0.2 to 1.0 torr. The operators place the wafers onto a metal platen that is loaded into the deposition chamber. The chamber is sealed and the process is initiated by pushbutton. The process operating parameters are automatically controlled.

An aluminum layer is deposited on the wafer surface by direct current (DC) sputtering. The metal is deposited on the wafer surface in a sealed reaction chamber that is maintained at a vacuum of approximately 10^{-7} torr by an oil-sealed mechanical pump and a diffusion pump. The operator places the wafers on a metal platen that is loaded into the load lock chamber. The operator initiates the process sequence by push-button control. The chamber is evacuated, the platen is transferred to the deposition chamber, and aluminum is sputtered onto the wafer surface.

Hydrogen alloying is performed after metalization to repair radiation defects caused by the metalization process. The wafers are heated in a 50 percent or 100 percent hydrogen atmosphere. The operation is performed in a diffusion furnace assembly similar to that used for thermal oxidation.

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 sulfuric acid and hydrogen peroxide. The cleaning operations are performed in wet chemical benches similar to those previously described.

5.0 DESCRIPTION OF PROGRAMS

5.1 Industrial Hygiene

A full-time safety manager is employed with responsibility for industrial hygiene and safety. Additional assistance is available from the plant's insurance carrier. The facility has also employed Stanford Research Institute (SRI) as consultants on fire safety and to perform air sampling. Larry Fluer, Inc., has also consulted in the area of gas safety.

Industrial hygiene monitoring in the past has been conducted by these consultants as needed. No routine industrial hygiene measurements are taken. The safety and industrial hygiene manager is planning a program in 1982 to monitor employee exposures to organic solvents, acids, noise, and radiation.

Measurements of the fabrication area local exhaust ventilation systems have been conducted by facility maintenance. This responsibility is being transferred to the safety/industrial hygiene program, and will include bi-annual measurements and certification of systems. The measurements have been performed using velometers or with inclined manometers permanently installed at specific work stations.

Film badges are used to monitor emissions and operator exposures to X-ray radiation from the ion implantation unit.

5.2 Education and Training

Training programs have been developed in the areas of worker safety and materials handling. Programs that are being developed include personal protective equipment use, emergency response procedures, and hazard reporting procedures. The company policy and procedure manual addresses these areas.

A safety committee at Electronic Arrays meets monthly to discuss specific topics such as identification of hazards. The committee consists of production workers and supervisory personnel.

New employees are trained by the supervisor in chemical handling procedures and use of personal protective equipment.

5.3 Respirators and Other Personal Protective Equipment

All workers in the wafer fabrication area are required to wear safety glasses. Workers performing specific tasks are required to use appropriate additional personal protective equipment. Chemical mix operators, who are responsible for mixing and distributing chemicals into the fabrication area and for transferring wastes, are required to wear acid-resistant aprons with gloves, sleevelets, face shields, and safety glasses. Face shields are also required for any operator where chemicals present a splash hazard.

Technicians performing maintenance operations are required to use additional protective equipment. Technicians changing gas bottles from the ion implantation unit and servicing equipment on toxic gas lines use self-contained breathing apparatus (SCBA). A particulate respirator (unspecified size and type) is worn by technicians who bead-blast arsenic deposits from parts in the ion implantation unit. Heat-protective gloves, aprons, and face shields are worn by maintenance technicians handling and cleaning quartz furnace tubes.

Product-protective equipment used by the operators to prevent contamination in the fabrication area includes coveralls, shoes or shoe covers, and gloves.

Emergency showers, eye wash stations, breathing oxygen, and SCBA are available throughout the plant.

5.4 Medical

The facility does not employ a full- or part-time nurse or physician. Medical services at the plant are limited to first aid and cardiopulmonary resuscitation (CPR) provided by trained employees. Approximately 10 percent of the general workforce and 50 percent of the supervisors are trained. Emergency medical care is provided by Peninsula Industrial Medical Clinic, Sunnyvale, California and by El Camino Hospital, Mountain View, California.

The facility does not require preplacement or periodic medical examinations of any employees. No routine biological monitoring is performed.

5.5 Housekeeping and Maintenance

Housekeeping and maintenance activities are necessary parts of maintaining product quality. Specific housekeeping procedures which were identified by the plant to prevent worker exposures to chemical agents include a central vacuum system in the photolithography area used for cleaning. The system is part of the local exhaust ventilation system.

Maintenance activities were not identified for each process operation at the facility. General maintenance activities include monthly draining and replacement of pump oils from oil-sealed mechanical pumps. Pumps associated with the LPCVD unit incorporate a continuous oil filtration system to increase the useful life of the oil. The oils drain by gravity into a waste container and are handled as hazardous waste as described in Section 3.6. Pump oil spills are cleaned up with a Freon solvent.

Diffusion furnace quartz tubes are removed from the furnace assembly and cleaned with an acid solution on weekly to monthly schedules. The operation is described in Section 7.3.

Scheduled maintenance of the ion implantation unit is performed by facility maintenance technicians. Maintenance operations include bead-blasting of the ion source. Pump oils are routinely changed as described above. The plant also has a service contract with a vendor to provide all other maintenance of the unit.

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 for process operations.

7.0 DESCRIPTION OF CONTROL STRATEGY FOR PROCESS OPERATIONS OF INTEREST

A variety of control strategies is used at Electronic Arrays to control emissions and worker exposures. These control strategies include local and general exhaust ventilation, process isolation, process and environmental monitoring, and personal protective equipment. 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. 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 that is monitored. General personal protective equipment requirements are described in Section 5.3 and specific requirements for some process operations are described below.

Work practices which affect emissions or operator exposures to chemical and physical agents are dependent upon the degree of process automation. Automated process controls limit the time that operators are working with the equipment. The operators manually 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 the operation of other automated units. The operator is not required to be at a particular unit for an entire work shift. Therefore, any exposures to chemical or physical agents would be for short time periods throughout the shift.

Specific descriptions are given below for control strategies employed for thermal oxidation, photolithography, wet chemical cleaning and etching, plasma etching, diffusion, ion implantation, low pressure chemical vapor deposition (LPCVD), plasma-enhanced chemical vapor deposition (PECVD), hydrogen annealing, and metalization. For some operations, similar equipment is used to perform a variety of operations. For example, similar diffusion furnace assemblies are used for thermal oxidation, diffusion, and hydrogen alloying.

7.1 Thermal Oxidation

A diffusion furnace assembly is used to oxidize purchased silicon wafers. The operation is performed by exposing the wafers to a pyrophoric (hydrogen and oxygen) environment in the furnace tube.

The diffusion furnace assembly consists of: 1) a load station where carriers containing wafers are loaded and unloaded in the furnace tube; 2) a furnace cabinet containing the furnace tubes and electrical resistance heat source; 3) a source cabinet that encloses the furnace tube end; and 4) an electrical cabinet containing the system controls. 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. Processing gases include hydrogen, nitrogen, oxygen, and hydrogen chloride. Hydrogen chloride is added to the gas stream to clean or getter sodium ion contamination from both the growing oxide and the furnace tube (Colclaser, 1980).

The diffusion furnace assembly is ventilated at three sites: 1) the source cabinet, 2) the furnace cabinet, and 3) the furnace tube loading end at the load station. The source cabinet encloses the gas assemblies and the ends of the furnace tubes and is vented by a local exhaust duct at the top of the cabinet to the plant scrubber system. The furnace cabinet is vented for temperature control by an exhaust duct at the top to the plant scrubber system. The furnace tube opening is vented by a scavenger box that encloses the opening to the plant scrubber system.

Nitrogen, hydrogen, and oxygen are supplied from house supplies described in Section 3.3. Hydrogen chloride gas is supplied in cylinders stored in a ventilated gas cabinet also described in Section 3.3. The cabinet is vented at 800 cfm through by an 8-inch stainless steel duct off the top.

The operation is 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 introduction of the process gases. After completion of the process sequence, the operator removes the carriers. The furnace operating parameters, including tube temperature and gas flow, are preset. The operator must readjust these parameters as needed.

Monitoring systems present in the area include a multipoint combustible gas (hydrogen) monitoring system described in Section 3.4. Detectors are mounted in the gas jungle, on the ceiling, and in the exhaust ducts. General personal protective equipment requirements are outlined in Section 5.3. Additional equipment includes hot work gloves for handling hot quartzware.

7.2 Photolithography

The photolithography process may be repeated several times during the processing sequence. The photolithography process consists of four basic steps: 1) substrate preparation, 2) substrate exposure, 3) substrate developing, and 4) photoresist stripping. Following wafer 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 photoresist stripping operation is also performed either by wet chemical etching or plasma etching. Photomasks used for substrate exposure are produced to plant specifications by an outside vendor.

7.2.1 Substrate Preparation. Silicon wafers are purchased from outside vendors. The operations performed in substrate preparation include 1) deionized water wash and nitrogen blow-dry, 2) spin-on application of hexamethyldisilizane (HMDS), 3) spin-on application of a negative photoresist, and 4) soft-bake of the coated wafer in a resistance-heated oven. These operations are performed consecutively in an in-line, cassette-to-cassette unit. The units are automated with microprocessor controls.

The operator loads a cassette containing wafers into the unit. Individual wafers are automatically removed and processed in the sequence described above. The wafers are transferred to a spin platform where the wafers are rotated and washed. The wafers are transported to a second cassette where they are removed and placed in a nitrogen-purged drying oven. The cassette is loaded into the in-line unit where individual wafers are transferred to another spin platform. HMDS in a xylene carrier solvent is spun onto the wafer. The HMDS mixture is supplied from enclosed reservoirs located in cabinets beneath the spin operation. The photoresist is then spun onto the wafer. The resist is a mixture of proprietary photosensitive organic polymers in a xylene carrier and n-butyl acetate or toluene carrier solution. Separate cassette systems are used to apply negative and positive photoresist. The wafers are transferred through a resistance-heated oven for soft-baking. The wafers may also be baked in a separate nitrogen-purged oven. The oven is vented to the room atmosphere.

The spin platforms are vented by either a common plenum that encloses adjacent platforms or by individual exhausts from each platform. The common plenum is a hinged hood that encloses adjacent platforms and is vented by a flexible duct at one end of the plenum. Individual spin platforms are also vented by local exhaust to a duct at the base of each platform. The platform is enclosed by a clear plastic shield. A container is located in the cabinet below the unit to collect liquid photoresist wastes. The container is vented to the exhaust ventilation system. All local exhaust from the photolithography area is treated by a water scrubber before release to the atmosphere.

No monitoring systems for evaluating emissions or operator exposures to chemical or physical agents are present in the area. The photolithography room is at positive pressure to the remainder of the wafer fabrication area. The room pressure is monitored by an inclined manometer mounted in the room. Personal protective equipment requirements are described in Section 5.3 and includes safety glasses and product-protective equipment. There is a house vacuum system at the end of each aisle in the photolithography area to facilitate cleaning of the area.

7.2.2 <u>Substrate Exposure</u>. A mask pattern is transferred to the photoresist-coated wafers by projecting the mask image with ultraviolet light using contact printing. The operator removes a wafer from a cassette and places it on the stage of the unit. The mask is aligned and clamped to the wafer. A mercury lamp source producing ultraviolet light at a peak wavelength of 435 nm is used to transfer the mask pattern. The lamp source is enclosed in a housing that is vented for temperature control. The enclosure is vented by a small fan located on the floor below the unit. The fan vents directly to the room.

The process is performed by an operator seated at the unit. The operator places the wafer on the stage and aligns the mask by viewing it through a split-field binocular microscope. The wafer and mask are clamped and rotated into position where the wafer is exposed to the light source. The wafer is removed and the process is repeated.

Engineering controls include shielding of the lamp source to prevent direct viewing. However, some blue light was visible on the stage of the unit while in a standby mode. The extent of possible exposure is not known. The intensity and uniformity of the mercury lamp is continuously monitored and the lamp is changed whenever the measurements exceed preset limits.

The personal protective equipment requirements are described in Section 5.3 and include safety glasses and product-protective equipment. No monitoring systems are present for evaluating emissions or operator exposures to chemical or physical agents.

7.2.3 Photoresist Developing. Photoresist-coated wafers that have been exposed to the mask pattern are developed by spin application of the developer solution. The operation is performed in process equipment similar to that described in Section 7.2.1. A proprietary mixture of xylene and n-butyl acetate or a mixture of unspecified aromatic and aliphatic hydrocarbons is used to develop the exposed wafer. The developer waste drains to the solvent drain system and into the solvent storage tank.

Engineering controls for the developer unit are identical to those described in Section 7.2.1. The spin platforms are enclosed and ventilated. The developer solution is supplied from a reservoir stored in the cabinet of the unit. The operation is automated requiring only that operators load and unload cassettes.

No monitoring systems were observed for evaluating emissions or operator exposures to chemical or physical agents. General personal protective equipment requirements for the fabrication area are described in Section 5.3.

7.3 Wet Chemical Operations

Wet chemical operations performed at the plant include: 1) etching of silicon dioxide with a hydrofluoric acid and ammonium fluoride solution;

2) photoresist stripping with a solution containing either chromic acid or phenol, sulfonic acid, chlorobenzene, and unspecified aromatic solvents; 3) photomask cleaning with chromic acid followed by a Freon solution; 4) wafer cleaning with sulfuric acid and hydrogen peroxide or ammonium hydroxide and hydrogen peroxide; 5) metal etching with phosphoric acid or nitric acid; 6) polycrystalline silicon etching with hydrofluoric and nitric acid; and 7) furnace tube cleaning with hydrofluoric acid.

The wet chemical operations are performed in two different types of plastic benches. The older wet chemical stations consist of tanks that are recessed into the bench top. Local exhaust ventilation is supplied by slots located across the rear panel of the station. The newer wet chemical stations consist of tanks that are recessed in wells inside the bench. Local exhaust ventilation of the tank is provided by perimeter slots on all four sides of each individual tank. A spill plenum is incorporated into the bench beneath the tanks and is vented to control acid condensation. A curved plastic shield covers the well containing the tank. The shield is open in the center to allow access to the tanks. The shield enclosing the well provides an area of approximately 8 to 10 inches above the tanks that is vented and at negative pressure with respect to the room. The exhaust plenum behind the station is baffled to act as a demister. The bench controls are located at eye level and are covered with a flexible, replaceable plastic shield that can be easily cleaned. A magnehelic gauge is mounted on the control panel for each unit to monitor exhaust from the station. Lids are placed over heated acid tanks to control evaporation of the acid.

Diffusion furnace tubes are cleaned with hydrofluoric acid in a vertical tube washing station. The tube is placed in the station, the access door is closed and the acid is sprayed into the tube. The tube is rinsed with water and dried with nitrogen. The access door is interlocked with a control unit to prevent opening during operation.

Acids are stored in tanks below the benches and some are pumped in a fill-and-dump fashion as required by the equipment. The acids are recirculated through a filter to increase the useful life of the acid. Deionized water rinses are also performed by filling a tank, rinsing the wafers, and draining the water. A spin drier, adjacent to the work station, is used to dry the wafers. Acid wastes are handled as described in Section 3.6.

No monitoring systems for evaluating emissions or operator exposures to chemical agents are present in the area. Personal protective equipment required by operators in the area is described in Section 5.3.

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. Two different plasma etching units are used for stripping photoresist and etching silicon nitride. Both units have barrel-type reaction chambers (Douglas, 1981). Photoresist is stripped using an oxygen plasma. Silicon nitride is etched using a carbon tetrafluoride/oxygen plasma. The gases are supplied from cylinders stored in a ventilated gas cabinet located in a service chase. 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 reaction chamber with the pressure negative to the room pressure. The vacuum is approximately 0.1 to 20 torr which is maintained by an oil-sealed mechanical pump. The plasma gases, containing the volatile species formed by the plasma ions reacting with the substrate, are exhausted from the unit by the pump. The pump exhaust is vented to the scrubber system, and the pumps are located in the service chase. Pump oils are drained and replaced approximately once a month. The waste is handled as described in Section 3.6.

No monitoring systems are present for evaluating emissions or operator exposures to chemical or physical agents. Personal protective equipment requirements are described in Section 5.3.

7.5 Diffusion

Diffusion introduces impurities, called dopants, into the wafer surface that alter the electrical properties of the substrate. The operation is performed in an atmospheric pressure diffusion furnace assembly similar to that described in Section 7.1. The wafers are heated to a high temperature (approximately 600 to 1200°C depending upon the dopant source used) and the dopant is introduced into the furnace tube. The dopants used at Electronic Arrays include phosphorus oxychloride ($POCl_3$) supplied in liquid source bubblers and phosphine (PH_3) supplied in gas cylinders.

The bubblers are placed in a cooling flask set in the source cabinet of the furnace and connected to the furnace tube. Nitrogen is bubbled through the liquid, and enters the furnace tube where it comes in contact with the heated wafers. Phosphine is supplied in cylinders and stored outside of the plant in an enclosed area described in Section 3.3. The facility plans to convert the phosphine storage to ventilated cabinets that will be located inside the building.

Engineering controls present in the diffusion operation are outlined in Section 7.1 for the diffusion furnace assemblies. The diffusion furnace room has an inclined manometer at the entrance to measure room pressure in relation to the outside areas. The room is maintained at positive pressure.

The diffusion furnace area has a combustible gas monitoring system for detecting hydrogen. The system is described in Section 3.4. No monitoring systems are used for evaluating emissions or operator exposures to phosphine. Personal protective equipment requirements for operators in the diffusion furnace area are described in Section 5.3 and include safety glases and product-protective equipment.

The liquid source bubblers are supplied by the manufacturer with a disposal kit. The used bubbler is placed in the original shipping container which contains vermiculite.

7.6 Ion Implantation

Ion implantation is used to introduce dopants into the wafer surface. The impurities are ions created by a confined electric discharge sustained by a dopant gas. 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 ion implantation unit operates at a power of 100 KeV.

Boron trifluoride and phosphine are used as the dopant source gases. The gases are contained in small cylinders or lecture bottles that are stored in a ventilated cabinet within the ion implantation unit.

The power source, ion source, and analyzing magnet are contained in a lead-shielded cabinet for the control of X-ray radiation emissions. The cabinet is located within a second lead-lined enclosure, which, in turn, is electrically grounded with its' access interlocked to the power supply. A glass window is present in the outer cabinet near the control console to allow the operator to view gauges within the cabinet. Any effect that the window may have on the effectiveness of X-ray shielding is unknown. The unit has emergency power shutoff controls that can be activated by the operator.

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 that evacuate the ion source chamber. The pump exhausts are vented to the scrubber system described in Section 3.5.

Scheduled maintenance of the unit requires removal of the ion source to clean off deposits by bead-blasting. Maintenance is also provided by an outside firm under a service contract.

Radiation film badges are used for monitoring emissions and operator exposures to X-ray radiation. The badges are worn by the operators and are also mounted on the unit. No other monitoring systems are used for evaluating emissions or operator exposures to chemical or physical agents. Personal protective equipment requirements include safety glasses. Additional requirements for workers changing lecture bottles are described in Section 5.3.

7.7 Chemical Vapor Deposition

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

7.7.1 Low Pressure Chemical Vapor Deposition. Low pressure chemical vapor deposition is performed in a diffusion furnace assembly similar to that described in Section 7.1 but operated at low pressure (approximately 0.1 to 3.0 torr). The LPCVD furnace consists of a furnace tube with mechanically sealed doors, gas control enclosure, gas flow control, electronic control, and vacuum pumps. The process operation is controlled by a microprocessor using feedback control loops and programmed "recipes". The system controls the furnace temperature profile, gas flow, vacuum pumping and purging, and process sequence. The furnace tube vacuum is maintained by an oil-sealed mechanical pump that is located in the source cabinet. The pump exhaust is vented to the wet scrubber system described in Section 3.5.

Process gases include 1) dichlorosilane and ammonia for silicon nitride deposition, 2) silane and hydrogen chloride for polycrystalline silicon deposition, and 3) phosphine, silane, and oxygen for phosphorus-doped silicon dioxide deposition. Process gases are stored in a ventilated storage cabinet described in Section 3.3.

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

Engineering controls include local exhaust ventilation of the source cabinet containing the gas manifolds and gas flow controllers. The cabinet is vented through a duct off the top of the unit. A part of the source cabinet houses the vacuum pump and is also vented through the local exhaust duct at the top of the cabinet.

The process tube is sealed with a stainless steel door that is interlocked by the microprocessor control unit to the vacuum pump to prevent operation of the pump while open. A pressure interlock prevents reactive gases from flowing if the system malfunctions. The process gas mass flow controllers are, in turn, centrally controlled by the system microprocessor unit.

A continuous pump oil filtration system is located outside of the cabinet. The filtration system is placed in a tray to contain oil spills. The waste pump oil is drained into a 5-gallon container. Handling of the waste is described in Section 3.6. Oil spills are cleaned up with a freon solvent.

Monitoring systems, present in the diffusion furnace area where the LPCVD units are located, consist of a combustible gas monitoring system described in Section 3.4. Personal protective equipment requirements include safety glasses and heat-protective gloves.

Pump oil spills, from draining and filling operations, are cleaned up with a Freon solvent.

7.7.2 Plasma-Enhanced Chemical Vapor Deposition. Plasma-enhanced chemical vapor deposition is used to deposit silicon nitride. The operation is performed at reduced pressure in a reaction chamber in which a plasma is formed using a radio frequency power source of unknown frequency and power.

The operator places wafers on a metal platen with a vacuum wand. A metal handle is attached to the platen and it is loaded into the reaction chamber. The operator initiates the process sequence by push-button control. The lid of the chamber is closed and the chamber is evacuated by an oil sealed mechanical pump. A radio frequency field is established between the metal platen and an electrode located above the wafers. The process gases are introduced into the chamber, forming a plasma and depositing silicon nitride. Process gases used include silane and ammonia. The gases are stored in a ventilated cabinet described in Section 3.3.

Engineering controls are integral to the process operation and equipment. These include: 1) the use of a sealed reaction chamber that isolates the worker from the process, 2) operation of the reaction chamber at a low pressure that is negative to the room, and 3) ventilation of the reactive byproducts from the chamber by the pump. The pump exhaust is vented to the scrubber system described in Section 3.5.

No monitoring systems are present for evaluating emissions or operator exposures to chemical or physical agents. Personal protective equipment for operators includes safety glasses. Additional requirements for changing gas cylinders are described in Section 5.3.

7.8 Hydrogen Annealing

Wafers are heated in a hydrogen atmosphere to correct radiation defects formed during metalization. The operation, known as hydrogen annealing is performed in an atmospheric pressure diffusion furnace assembly described in Section 7.1. The process gases used include 100 percent hydrogen or 50 percent hydrogen and 50 percent nitrogen. The engineering controls and personal protective equipment requirements are identical to those described in Section 7.1 for diffusion furnace assemblies used in thermal oxidation.

Monitoring systems present in the diffusion furnace room include a combustible gas monitor described in Section 3.4. Combustible gas detectors are located in the ventilation duct of the furnace and on the room ceiling. Scheduled maintenance activities include weekly or monthly removal of the furnace tube for cleaning with hydrofluoric acid. The furnace tube cleaning operation is described in Section 7.3.

7.9 Metalization

Aluminum is deposited on the wafer surface as an electrical contact. The metal is deposited by direct current (DC) sputtering in a sealed reaction chamber at very low pressure (approximately 10^{-7}torr). The wafers are placed on a metal platen by the operator. The platen is placed in a load lock chamber in the equipment. The operator then initiates the operation sequence by pushbutton. The load lock lid is automatically closed and the chamber is evacuated by an oil-sealed mechanical pump to a pre-set pressure. The pallet is automatically transferred to the sputtering chamber where metal deposition occurs. The sputtering chamber is operated at a pressure of approximately 10^{-7} torr by an oil diffusion pump. After metal deposition the platen is transferred back to the load lock chamber and removed. A Freon cooling system is used to cool valves and to trap water vapor in the reaction chamber.

Engineering controls, integral to the process operation and equipment, include isolation of the process from the worker in a sealed reaction chamber and operation of the chamber at a pressure lower than room pressure. The pump exhausts are vented directly to the external plant atmosphere. No monitoring systems were present for evaluating emissions or operator exposures to chemical or physical agents. Personal protective equipment includes safety glasses. Handling of waste pump oils is described in Section 3.6. Work practices that may affect emissions or operator exposures to chemical or physical agents were not observed. However, there appeared to be little potential for operator exposures.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The fabrication of integrated circuits at Electronic Arrays 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, ion implantation, and automation of some photolithography processes. Specific observations and recommendations are outlined below.

1. The effectiveness of the local exhaust ventilation on the newer wet chemical benches should be evaluated and compared to the older benches. The design of the newer benches differs substantially from the older benches.
2. The potential for exposure to reflected ultraviolet light from the contact printing operation should be evaluated. Work practices, such as the removal of safety glasses during wafer alignment, should also be observed and their effects on operator exposures determined.
3. The effectiveness of radio frequency shielding in PECVD and plasma etching equipment should be determined.

4. The effectiveness of X-ray radiation shielding provided by the cabinets in the ion implantation unit should be determined. The effect of the observation window on the integrity of the shield should be evaluated.
5. Preplacement medical examinations and periodic examinations should be established, especially fcr those individuals working with toxic agents such as chromic acid.

A variety of process operations are used at the facility that should be considered for detailed investigation. These include plasma etching, ion implantation, LPCVD, and PECVD. The effectiveness of the local exhaust ventilation of the newer wet chemical benches should be evaluated and compared to the other benches. Work practices that may affect emissions or operator exposures to chemical and physical agents could not be addressed during the preliminary survey due to time constraints; however, they should be documented during a detailed survey.

9.0 REFERENCES

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

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

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.

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