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

at

XEROX CORPORATION
Microelectronics Center
Electronics Division
El Segundo, California

Prepared by

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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
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Cincinnati, Ohio 45226

PLANT SURVEYED: Xerox Corporation
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SIC CODE: 3674

SURVEY DATE: September 1, 1981

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EMPLOYER REPRESENTATIVES CONTACTED:

Mr. Vir Dhaka, Vice President, Microelectronics Center
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TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

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2.0. ABSTRACT

A preliminary control technology assessment survey was conducted at Xerox Corporation, Microelectronics Center, Electronics Division, El Segundo, California on September 1, 1981. The survey was conducted by Battelle Columbus Laboratories 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 N-channel metal oxide semiconductor (NMOS) integrated circuits.

The process operations are performed in a clean room environment, with high efficiency particulate air (HEPA) filtration of room air supply and local laminar flow bench HEPA filtration of room air. Process operations performed at the facility include: (1) thermal oxidation of purchased, predoped silicon wafers; (2) low pressure chemical vapor deposition (LPCVD) of phosphorus-doped silicon nitride, silicon dioxide, and polycrystalline silicon; (3) photolithographic processes for defining circuit patterns, including wafer cleaning, photoresist application, substrate exposure, photoresist development and photomask production; (4) plasma etching; (5) wet chemical etching and cleaning; (6) metalization, including radio frequency (RF) and direct current (DC) sputtering and filament evaporation; (7) doping including diffusion and ion implantation; (8) hydrogen annealing; and (9) testing and packaging.

Engineering controls used at the facility vary by process operation. Several process operations are performed in sealed reaction chambers to isolate the processes from the workers. Such process isolation is used in plasma etching, spray etching, LPCVD, and metalization. Shielding is used in ion implantation units to limit X-ray emissions, in projection mask aligners to limit ultraviolet emissions, and in plasma etching units to limit radio frequency and ultraviolet emissions. Local exhaust ventilation is used to remove process gases and by-products from diffusion and LPCVD furnaces, and vapors from wet chemical cleaning and etching operations.

Several process operations are automated with microprocessor control of the process parameters and sequence of operations. These operations include CVD, LPCVD, plasma etching, metalization, thermal oxidation, diffusion, ion implantation, and parts of the photolithographic process.

Continuous area monitoring for arsine and phosphine is performed in the diffusion furnace area and gas storage room. Continuous monitoring for hydrogen is performed in the diffusion furnace area. Radiation film badges are used to monitor X-ray emissions from ion implantation units and to monitor worker exposures to X-ray radiation.

Personal protective equipment requirements vary by job function. Workers in the clean room area are required to wear hoods, lab coats, shoe covers, latex gloves, and safety goggles or glasses. Goggles and face shields are required when handling chemical solutions. Full-face air supplied respirators are used when changing gas cylinders. Self-contained breathing apparatus are required for workers changing gas lecture bottles located inside LPCVD units.

The facility has developed industrial hygiene review procedures for evaluating all new and existing process equipment. Employees are trained in safety, use of personal protective equipment, and emergency response. Workers potentially exposed to arsenic are monitored for urinary arsenic levels.

The facility should be considered a candidate for detailed study based on the diversity of process operations encountered, and the use of state-of-the-art technology and process equipment.

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3.0. INTRODUCTION

A preliminary survey was conducted at Xerox Corporation, Microelectronics Center, Electronics Division, El Segundo, California on September 1, 1981 as part of a control technology assessment of the semiconductor manufacturing industry. The study was performed under U.S. Environmental Protection Agency Contract No. 68-03-3026 through an Interagency Agreement with the National Institute for Occupational Safety and Health (NIOSH). The survey was conducted by Battelle Columbus Laboratories, Columbus, Ohio. Mr. James H. Jones, NIOSH, Division of Physical Sciences and Engineering, accompanied the survey team.

The following individuals were contacted at Xerox Corporation:

1. Vir Dhaka, Vice President, Microelectronics Center,
2. Dick Koo, Manager, Process and Device Development,
3. Chuck McHenry, Manager, Environmental Health and Safety,
4. Romeo A. Doty, Operations Manager.

The study protocol was provided to the corporate safety manager prior to the preliminary survey. During an opening conference with laboratory representatives, the study objectives and methods were described. Laboratory staff provided a detailed description of the health and safety programs at the facility. The laboratory construction type and layout, process operations, monitoring systems, gas handling systems, and chemical storage facilities were reviewed.

Following the opening conference, the team surveyed the facility, including production areas, gas and chemical storage areas, air handling systems, waste management facilities, and medical facilities. A closing conference was held following the survey.

4.0. FACILITY DESCRIPTION

4.1. General

The laboratory is part of the Reprographic Business Group, Electronics Division of Xerox Corporation. The facility provides technical development, prototype engineering and pilot pre-production of NMOS integrated circuits. The Microelectronics Center (MEC), where integrated circuits are manufactured, is contained within a building of tilt-up slab construction. Integrated circuits are manufactured in a 13,000 square feet Class 100 clean room. Utility services are provided within the clean room penthouse and equipment chases. The plant was constructed in 1975 and has since tripled in size. At the time of the preliminary survey renovations were being made in the clean room area. These renovations include consolidation of similar process operations into aisles, redesign of the ventilation system and installation of a continuous TELOS® phosphine/arsine monitoring system.

The facility employs approximately 220 people, 150 individuals in the production area and 70 in administration. The production staff includes 110 workers on the first shift, 25 on the second shift, and 15 on the third shift. The third shift performs maintenance and repair operations. Approximately 110 of the production staff work within the Clean room area.

Testing and packaging operations require approximately 50 workers. The test area is facilitated for HVAC (heating, ventilation, and air conditioning), Class 100 air capability. Packaging, located in a room adjacent to the clean room, is not currently facilitated for Class 100 air, but upgrade is a near term requirement.

4.2. Chemical Storage

Separate chemical storage rooms are used for gases and liquids. Gas storage is described in the following section. Liquid chemicals are stored in a locked, unvented room adjacent to the gas storage room. The room is accessible only through a rear diffusion furnace room. Chemicals are received in one-quarter pint, one-pint, and one-gallon bottles. The bottles are enclosed in plastic bags and stored on wooden shelves. The room has a floor drain, but it is not curbed nor designed to contain spills. Acids, bases, and organics are stored in the same room.

Isopropanol and acetone used for general cleaning are stored in the equipment chases. Chemicals used in electron beam lithography processes are stored in the photolithography chase.

4.3. Gas Handling System

Process gases are stored in a locked, ventilated room accessible only through the rear diffusion furnace room. The room air is continuously monitored with a Matheson Model 8040® arsine/phosphine monitor. Gases stored in the room include phosphine, boron trifluoride, forming gas (95 percent nitrogen and 5 percent hydrogen), silane, Freon 12, Freon 13, Freon 14, Freon 115, silicon tetrafluoride, dichlorosilane, and silicon hexafluoride. Nitrogen purge cylinders for dichlorosilane, silane, and ammonia are stored outside of the room in an adjacent storage area. Lecture bottles used in ion implantation are also stored in the room. Hydrogen chloride, ammonia, silicon tetrachloride, Freon, and carbon tetrachloride are stored in ventilated cabinets near the process equipment in which they are used. The cabinet exhausts are monitored by magnehelic gauges.

Gases stored in cylinders in the storage room are distributed to process equipment in welded stainless steel lines. Welds are radiographed and pressure tested at the source at the time of installation. Lecture bottles containing boron trifluoride or phosphine are stored in ventilated gas cabinets which are integral to the process equipment.

Gas lines from the gas storage room and bulk storage are connected to solenoid valves which stop gas flow in the event of a power outage. Phosphine used in low temperature oxide production and LPCVD is stored at the furnace. A flow limiting valve is used to stop excess gas flow (>20 cc/min.). A phosphine/arsine sampling port is located at the jungle cabinet of the LPCVD unit. Air is continuously monitored with the Matheson® arsine/phosphine monitoring unit. Process gas emergency shut-offs are located in the clean room change area and outside of the clean room at the entrance to the change room.

Nitrogen, hydrogen, and oxygen are stored in bulk containers in the pad area. Gases are plumbed to the point of use or moved from the pad to an equipment chase. Hydrogen lines are of coaxial construction with welded stainless steel lines inside a galvanized steel conduit tube.

Colorimetric indicator tubes are used to check for leaks in all gas cylinders received. If a leak is detected in a phosphine cylinder, and the leak cannot be repaired by reseating the valve, the cylinder gas is purged into a 55-gallon drum containing activated charcoal. The effluent of the purging system is connected to the plant gas scrubbing system. For any other cylinder leakages which cannot be contained, treatment procedures recommended by the manufacturer are followed.

4.4. Monitoring System

Three separate systems are used at Xerox to monitor the clean room area: (1) toxic gas monitoring, (2) combustible gas (hydrogen) monitoring, and (3) heat/smoke detectors. Toxic gas monitoring is performed for arsine and phosphine. Air is continuously sampled from the gas storage rooms and from a duct surrounding the jungle cabinet of the LPCVD unit, with the air sampling streams combined prior to analysis. The gas sampling is not sequenced between monitoring points. Analysis is provided by a Matheson® arsine/phosphine monitor. This analysis is based on arsine or phosphine reaction darkening a tape which changes the output of a photocell. Monitoring results are not permanently recorded but are linked to an alarm system. One problem with the unit is the feeding out of the tape without indication. The Permissible Exposure Limit (PEL) of arsine as determined by OSHA is 50 ppb continuous exposure for an 8-hour day. The Matheson® Model 8040 signals this level after approximately 30 minutes. For phosphine the monitor responds to a PEL of 300 ppb after approximately 10 minutes.

Combustible gas (hydrogen) detectors are located in ducts, ceilings, and equipment in the furnace area. Detectors are located above the jungle cabinets and ventilation scavenger systems of the diffusion and chemical vapor deposition furnaces. Hydrogen detectors are also located in the penthouse above the furnace area and in the ceiling above the diffusion furnaces. Smoke detectors are installed in the air supply systems.

Heat/smoke detectors are located in the MEC clean room. These detectors are interlocked to the gas handling system by solenoid valves which shutdown gas lines. Heat sensors are located in the equipment chase solvent cabinet and smoke detectors are located in the electron beam lithography room.

Ventilation flow for gas storage cabinets is monitored by magnehelic gauges. The pressure drop through HEPA filters in the laminar flow benches is also monitored with magnehelic gauges. The gauges are not connected to an alarm. Calibration of the gauges was not described. Face velocities on the laminar flow HEPA filter hoods are designed for 150 feet per minute (fpm) with records maintained for all systems.

At the time of the survey Xerox Corporation was preparing to replace the Matheson® system with a TELOS® arsine/phosphine monitoring system. The system will sequentially sample and monitor air from eight sampling points.

4.5. Ventilation System

Air is supplied to the clean room fabrication area by five air handlers which supply 173,000 cfm. The supply air is filtered in an initial particulate filter followed by filtration through an activated carbon bed. The air is delivered to the clean room through HEPA filter units located in the ceiling or in laminar flow hoods over the work stations. The clean room area is maintained at positive pressure (approximately 0.2 inches water gauge) to the rest of the building.

Air is recirculated from the clean room through chases which act as return air plenums. The air is drawn from the chases to a common ceiling plenum above the clean room. The air handlers located in a penthouse above the ceiling plenum draw air from the ceiling plenum which is then combined with fresh makeup air. Approximately 45,000 cfm or 26 percent fresh makeup air is used.

All process exhausts, including local exhaust ventilation of wet chemical stations, photolithographic operations, and diffusion furnaces, and pump exhausts from LPCVD, plasma etching, ion implantation, and metalization operations are vented to two wet scrubber units. The units handle a total of 45,000 cfm and consist of a packed bed with water spray followed by a demister.

4.6. Waste Management System

Waste organic solvents are collected by a solvent drain system and stored in a holding tank. Photoresist and developer wastes are also collected by the operators and added to the waste solvent which is disposed off-site by a waste management firm. Hazardous wastes, including liquids or solids, are stored in a designated hazardous chemical storage area for disposal off-site by a waste management firm. Waste pump oils are collected and stored in 55-gallon drums for recycling by a waste management firm. Waste acids and caustics, including scrubber blowdown, are drained to holding tanks where solids are settled, and pH is adjusted with aqueous ammonia. The neutralized waste is sent to a publicly operated treatment works.

5.0. PROCESS DESCRIPTION

Xerox manufactures NMOS-type integrated circuits. The processing sequence will vary for each specific product type manufactured. Therefore, a specific processing sequence is not described but rather a general overview of the process operation is provided.

Purchased pre-doped silicon wafers are oxidized in an open-tube diffusion furnace at atmospheric pressure. The wafers are placed in carriers and loaded into the furnace where they are maintained at high temperature (>600°C) and exposed to a pyrophoric water (hydrogen/oxygen) atmosphere. The silicon dioxide layer formed on the wafer surface acts as a protective layer isolating the silicon substrate for subsequent diffusion processes.

In the photolithographic process the wafers are removed from the carriers and placed in cassettes which are loaded into an automated microprocessor-controlled, wafer processing station. The station consists of dual in-line processes where individual wafers are removed from the cassetttes, transported to a spin platform, and rotated at high speed with a deionized water wash and nitrogen blow dry. The wafer is then dried in an infrared pre-bake oven and transported to a second spin platform where hexamethyldisilizane (HMDS) is spun onto the wafers. Following application of HMDS, the photoresist is spun onto the wafer and the wafer is transported to a second infrared oven where it is heated or "soft baked". The coated wafer is then loaded into another cassette.

The cassette is removed from the wafer processing system and transferred to the projection mask aligner where individual wafers are removed for exposure. Each wafer is mounted on a vacuum chuck, rotated into position, and manually aligned with the mask through a split field binocular microscope. When properly positioned, the wafer is exposed to ultraviolet radiation (300 -400 nm) from a mercury lamp source.

The photomask for the projection aligner consists of a precision glass plate with a chromium layer that has been etched to a specific pattern. The photomask is produced at the laboratory using techniques similar to the photolithographic process described above. The plate with a photoresist layer is exposed to an electron beam. The electron beam lithography process includes computer control of the beam, aperture, and mask position. Photomasks manufactured by an outside vendor to plant specifications are also used. The electron beam lithography process was not observed during the survey.

The cassette containing exposed wafers is transferred to an automated developer station. Individual wafers are removed from the cassette and transferred to a spin platform where a tetramethyl ammonium sodium hydroxide developer solution is dispensed onto the spinning wafer surface. The wafer is rinsed with deionized water and transferred from the spin platform to a resistance-heated oven. The dried wafers are loaded into a cassette and transferred to the etching operations.

Developing the photoresist exposes parts of the underlying wafer surface which may be either silicon nitride, silicon dioxide, polycrystalline silicon, or an aluminum alloy, depending on the step in the process sequence. The layer exposed by the photolithography process is etched using either a plasma etching or a wet chemical etching process.

Plasma etching systems used at Xerox include:

- o A continuous in-line planar plasma etching unit using Freon 14 to etch silicon nitride, and polycrystalline silicon
- o A continuous in-line planar plasma etching unit using carbon tetrachloride to etch aluminum followed by an oxygen plasma photoresist stripper
- o A barrel or tunnel plasma etching unit using oxygen to strip photoresist.

The planar plasma etching units are both automated with microprocessor control. The barrel reactor requires manual loading of the reaction chamber with microprocessor control of the etching cycle. Each plasma etching unit utilizes an oil-sealed mechanical pump to produce vacuum conditions in the reaction chamber. A cryogenic trap is included with the pump unit to eliminate water vapor from the chamber. The plasma for each unit is generated with a 13.56 MHz radio frequency source.

Wet chemical etching operations are performed by exposing the wafers to an acid, either by immersing the wafers in a tank containing the acid or by spraying the acid onto the wafers. Hydrofluoric acid buffered with ammonium fluoride is used to etch silicon dioxide. Cassettes containing wafers are dipped into an acid bath located in a ventilated, wet chemical processing station.

The photolithography process combined with plasma or wet chemical etching is used to build the layers and patterns which constitute the integrated circuit. The layers may be deposited to act as insulators or conductors, and to isolate parts of the substrate for doping. Selected areas of the wafer exposed by the photolithography process are doped using atmospheric pressure diffusion furnace systems or ion implantation systems.

Silicon nitride, polycrystalline silicon, or phosphorus-doped silicon dioxide are deposited on the wafer surface by low pressure chemical vapor deposition (LPCVD). The operation is performed in a sealed furnace tube assembly at a pressure less than 2 torr. The system consists of furnace tubes, gas control system, electronic control, and an oil-sealed mechanical pump. Wafers are loaded into the furnace tube which is then sealed and evacuated with the mechanical pump. Gases are introduced into the resistance-heated tube where a surface-catalyzed reaction results in the deposition of the desired layer. Gases used for LPCVD include 100 percent silane, 100 percent phosphine, and oxygen for phosphorus-doped silicon dioxide; 100 percent silane for polycrystalline silicon; and dichlorosilane and ammonia for silicon nitride.

Impurities (dopants) may also be introduced to the wafer through ion implantation. The ion implantation unit is totally automated with a microprocessor control of the process operation. Cassettes containing wafers are placed in the load station of the ion implanter. Individual wafers are removed from the cassette and transported to a vacuum load lock which is purged and pumped to a low vacuum using an oil-sealed mechanical pump. The wafer is mounted on a platen and rotated into position in the target chamber which is maintained under a separate vacuum with an oil-sealed mechanical pump and a diffusion pump. In this chamber, the wafer is exposed to phosphorus or boron ions which are generated by a confined electric discharge and sustained by the source gas (phosphine or boron trifluoride). Separate vacuum systems are used for the ion source, accelerator and analyzer tube, and exposure chamber. Following exposure, the wafer is removed from the chamber to a second, load lock which is purged to atmospheric pressure and then transferred to a waiting cassette for transport to the hydrogen annealing operation.

Hydrogen annealing repairs any damage caused by ion implantation. For annealing, the wafers are placed in fused silicon carriers, loaded into furnaces similar to the atmospheric pressure diffusion furnaces, and heated in a hydrogen/nitrogen forming gas atmosphere.

Doping is also performed in an atmospheric pressure diffusion furnace similar to that used for thermal oxidation. The wafers are loaded into the furnace tube and are exposed to an atmosphere containing 15 percent phosphine in an inert gas. The doping is followed by an oxidation of the wafer surface.

Following junction formation by diffusion or ion implantation, metal contacts are formed by deposition of an aluminum alloy layer using direct current (DC) or radio frequency (RF) sputtering. The operation is microprocessor controlled and is performed in a reaction chamber under vacuum conditions maintained by an oil-sealed mechanical pump and diffusion pump. The coated wafers are transferred to the photolithography process where the metal contact pattern is defined. The underlying exposed aluminum layer is etched with an in-line planar plasma etching unit, as previously described. The plasma etching operation includes an oxygen plasma photoresist strip.

A gold layer is deposited on the wafer backside using filament evaporation. The process is performed under vacuum conditions within a sealed bell jar. Wafers are mounted in a planetary fixture which rotates above the gold filament source. Thermal resistance heating of the gold filament is used to evaporate the gold which deposits on the wafer surface to produce a thin film. The coated wafers are then ready for testing and packaging.

Individual dies on the wafers are electrically tested and marked for quality and the wafers are scribed using a diamond saw, and cleaned with a deionized water scrub. Individual dies are separated and mounted on the chip carrier with a gold eutectic mount. Aluminum wires are connected to the die, and each chip is encapsulated in a preformed ceramic package and sealed in a nitrogen-purged oven at 500°C.

Various wet chemical operations are used during this integrated circuit manufacturing process. Acid etching baths containing sulfuric acid and hydrogen peroxide at 60° to 70°C are used in the furnace area for wafer cleaning. Cassettes containing wafers are manually dipped into these acid baths and then rinsed in deionized water.

Another acid cleaning step involves spray cleaning of the wafers in a nitrogen-purged, sealed centrifugal spray unit. Wafers may be cleaned with hydrofluoric acid (HF), ammonium hydroxide (NH_4OH) and hydrogen peroxide (H_2O_2), or hydrochloric acid (HCl). Cassettes containing wafers are mounted in the centrifugal spray chamber, rotated, and sprayed with the desired agent. The chamber is ventilated with a local exhaust takeoff located at the bottom. The unit is controlled by a microprocessor.

Wafer backside etching is performed using a hydrofluoric acid vapor. The etching is performed in a standard laboratory hood of plastic construction with local exhaust ventilation. Wafers are placed on a platform and covered with a plastic canopy. Nitrogen is bubbled through a container of hydrofluoric acid, and the acid-saturated nitrogen gas is vented to the plastic enclosure. The backside etching operation is manually controlled.

Solvent cleaning of the equipment is performed in a ventilated stainless steel laboratory hood. Isopropanol and acetone are used in this operation to clean production equipment glassware.

Fused silica furnace tubes are cleaned with hydrofluoric acid in an enclosed, ventilated unit. The unit is located in a room adjacent to the furnace area. The cleaning cycle is automatically controlled.

A detailed description of the process operations is provided in Section 8.0.

6.0. DESCRIPTION OF PROGRAMS

6.1. Industrial Hygiene

The laboratory employs a full time safety engineer with primary responsibility for safety and industrial hygiene. Xerox has also hired consultants as needed in the areas of health physics, fire safety, emergency medical care, and explosion control.

Limited monitoring of worker exposures to acid mists, arsenic, and organic solvents has been conducted. Worker exposures to ionizing radiation and radio frequency radiation have also been monitored. More extensive monitoring of worker exposure is planned for the future. Air flow of the laminar flow HEPA filtration units is measured to assure a face velocity of 150 fpm.

The laboratory has established a review program for all new and existing process equipment. The review includes the following: (1) electrical grounding, (2) electrical interlocks of equipment, (3) emergency shutdown, (4) fires, (5) gas installations, (6) engineering controls inherent in the equipment which offer protection during normal operations and emergency conditions, (7) potential for X-ray release, and (8) review of operating and maintenance procedures.

An extensive review of the ventilation system for the facility has recently been conducted. Problem areas that were identified in the review are now being renovated.

6.2. Education and Training

Training programs conducted by Xerox for plant personnel cover worker safety, materials handling, and use of personal protective equipment. A training session consists of three, one-hour lectures. Priority has been given to developing emergency response capabilities. A training program is being developed on toxic hazards which will be used to train staff emergency medical technicians and local hospital personnel.

6.3. Respirators and Other Personal Protective Equipment

Workers in the Clean room area are required to wear product-protective equipment consisting of hoods, lab coats, booties, and latex gloves. All production area workers are also required to wear safety glasses or goggles for personal protection. Goggles and face shields are required when handling chemical solutions. Full-face, air-supplied respirators are used when changing gas cylinders in the gas storage room. A self-contained breathing apparatus is required for workers changing phosphine and boron trifluoride lecture bottles in the ion implantation unit and LPCVD furnace. Emergency showers, eye wash stations, and self-contained breathing apparatus are available in the fabrication area. Long-sleeve rubber gloves with gauntlets are require for workers pouring or handling chemicals. Workers are trained in the use of personal protective equipment at a monthly or quarterly training session.

6.4. Medical Program

The facility employs two full time nurses during the first shift. Emergency care is available at the plant during the first shift and a nearby medical center is on call. All employees who work more than four hours per day must have a periodic medical examination. A periodic medical examination is required of workers in the fabrication area and includes a chest X-ray, lung function test, hematology, and urinalysis including creatinine and arsenic determinations.

6.5. Housekeeping and Maintenance

The production quality control requirements limit the particulate levels in the laboratory. The fabrication area is designed as a Class 100 clean room. Dust levels in the production area are controlled by laminar flow HEPA filter hoods placed above production equipment. Air is directed downward from the ceiling and across the equipment work station. Additional engineering controls which have been included in the design of the production area limit housekeeping problems. These controls include acid waste lines with aspirators for etching solution disposal and automated dispensing of photolithography chemicals directly from containers. When pump oils from oil-sealed mechanical roughing pumps are replaced, the used oil is drained into containers which are then transferred to a central waste oil container located adjacent to the gas storage room.

Maintenance is performed by an operator technician and by a third shift maintenance crew. Maintenance operations observed during the survey involved the addition of pump oil to a diffusion pump for he LPCVD system. Oil is manually changed every 3 to 5 days. The laboratory utilizes a central oil dispensing system where a 55-gallon drum of pump oil was connected to a distribution system. The oil is pumped from the drum to the pump, and the used oil is removed by a similar central collection system. The system is required to facilitate a daily requirement for oil replacement.

Maintenance procedures for additional process equipment are described below. Metal deposits inside the metalization chambers are removed by bead blasting the interior shields and the exposed parts with a glass-type abrasive. The bead blasting is performed in a glove box. The chamber is also wiped with isopropanol. Bead blasting is also used to clean the ion source from the ion implanter. Routine maintenance of plasma etching units includes wiping down the chamber with isopropanol. Pump oil for the plasma etching pumps is replenished every two weeks as described above. Gas handling system maintenance is performed by three technicians who have responsibility for changing gas bottles in the gas storage room and ion implanter. The maintenance is performed as required.

7.0. SAMPLE DATA FROM PRELIMINARY OR PREVIOUS SURVEYS

Monitoring for chemical or physical agents was not conducted during the preliminary survey. Sample data from previous surveys conducted by laboratory staff were not reviewed. Discussion with the staff indicated that personal monitoring has revealed that worker exposures to acids, organic solvents, arsenic, ionizing (X-ray) radiation, and radio frequency radiation did not exceed permissible exposure limits (PELs).

8.0. DETAILED PROCESS DESCRIPTIONS AND CONTROL STRATEGIES FOR PROCESS OPERATIONS OF INTEREST

Control strategies used at Xerox Corporation MEC consist of three general approaches: (1) local exhaust ventilation of wet chemical operations and thermal furnaces; (2) isolation of process operations in plasma etching, ion implantation, and metalization operations; and (3) shielding to control X-ray radiation leakage from ion implantation and to limit radio frequency and ultraviolet emissions from plasma etching. Plasma etching, LPCVD, ion implantation, and metalization operations are performed under vacuum conditions (i.e., pressure lower than that of the workroom). The isolation of the process through vacuum conditions is an integral part of the process operation.

Several process operations are controlled by microprocessors which reduces operator contact with the equipment. The production area is monitored for X-ray radiation, arsine, phosphine, and hydrogen. Production workers are required to wear normal clean room attire consisting of shoe covers, lab coats, hoods, gloves, and safety glasses or goggles. Additional personal protective equipment is required for handling hazardous materials. Some operators may perform several tasks requiring work at several process operations. The process operations and associated control strategies are summarized below. The process operations are not described in the actual processing sequence.

8.1. Photolithography

8.1.1. Process Description. Photolithography includes the following process operations: (1) photoresist application, (2) substrate exposure, (3) photoresist development, (4) photoresist removal, and (5) photomask preparation.

The application of photoresist to silicon wafers is performed using a wafer processing system which is completely automated and controlled by microprocessor. The silicon wafers are loaded into the processing system in cassettes. Individual wafers are removed from the cassette and transported along one of two parallel tracks to in-line process substations. The wafer is mounted on a spinning platform enclosed within a clear plastic shield. Deionized water is sprayed onto the spinning wafer followed by a nitrogen blow dry. The wafers are then dried in an infrared prebake oven. The wafer is transported from the oven to a second spin platform where HMDS is spun onto the wafers. Following application of HMDS the wafer remains at the station for the spin application of photoresist. A positive photoresist consisting of ethyl cellosolve acetate, xylene, n-butyl acetate, and diazo-ketone sensitizers is used. The coated wafer is baked in an infrared oven and unloaded into a cassette.

Substrate exposure is performed using a projection mask alignment system with ultraviolet (UV) light. Cassettes from the photoresist application process are placed in a staging area near the mask alignment equipment. A single cassette is loaded into the mask aligner where individual wafers are automatically removed from the cassettes by a vacuum chuck. The operator manually aligns the mask through a split field binocular microscope. The substrate is exposed to UV light for a specified time period before the shutter closes, and the wafer is automatically moved to another cassette.

The photoresist developer is applied to the exposed wafers using a spin-on process similar to that used during the application of photoresist. Cassettes containing exposed wafers are loaded into the developer system. Individual wafers are automatically removed from the cassette and mounted on vacuum chucks which then spin the wafer while a developer solution of tetramethyl ammonium hydroxide is applied. The developer dissolves the exposed positive photoresist leaving the unexposed pattern of the mask. Application of the developer is followed by a deionized water rinse and nitrogen blow dry. The developed wafer is then transferred to a post- or hard-bake oven where the remaining photoresist is cured. Finished wafers are loaded into cassettes and placed in a staging area for further processing.

Photomasks are either produced at the facility using electron beam lithography or by a photomask supplier. In either case, the mask pattern is designed and translated to a digitized set of X-Y coordinates which is stored on computer tape. This set of coordinates controls the electron beam exposure of the photomask. The mask consists of a precision glass plate with a hard surface coating of metallic chromium that is covered with a photoresist layer.

This plate is exposed to the electron beam as determined by the digitized information from the computer. After the exposed mask is developed and the remaining photoresist is checked for defects, the exposed underlying chromium layer is etched from the mask. Both these steps are performed in wet chemical work stations. Any mask defects are repaired using a helium-neon laser to burn off defects in the chromium layer. The photoresist layer is then stripped from the mask using an oxygen plasma stripper. The electron beam process for manufacturing photomasks was not observed during the preliminary survey.

8.1.2. Engineering Controls. The deionized water cleaning operation and application of HMDS and photoresist to the wafers are spin-on processes which are enclosed under plastic covers. The enclosures are ventilated at the base of each platform to produce a down-draft around the spinning platform. This ventilation system is designed to prevent redeposition of aerosols onto the wafer surface. The wafer processing system is located beneath laminar flow HEPA filter hoods.

The ventilation system appears to have been installed and modified with additional ducts added as process changes were introduced. The main ducts are located in the equipment chase with flexible process ducts penetrating the clean room to connect to the system. The ventilation system appeared to have been modified in a manner inconsistent with guidelines of the American Conference of Governmental Industrial Hygienists (ACGIH, 1978). For example, the ACGIH does not recommend the use of a four-way tee connection as observed in the photolithography aisle. The tee appeared to have three process exhausts entering at 90 degrees, and the exit duct was the same size as the duct entering the tee.

HMDS and photoresist are supplied in glass one-gallon bottles which are stored in the wafer processing unit. The liquids are automatically dispensed by suction probes placed in the bottles.

The mask pattern is transferred to the wafer by exposure to ultraviolet light transmitted through the photomask. The projection mask aligner is located under a laminar flow HEPA filter hood. The wafer and mask are aligned using a blue light source (wavelength unknown) filtered to prevent ultraviolet light release. Once the wafer is aligned, the microscope is rotated from the alignment stage, and the wafer is then exposed to ultraviolet light.

The photoresist is developed in a spin-on operation performed under a plastic cover. Wafers are automatically transferred from the cassette to the spin platform. The developer solution is supplied in one-gallon glass containers stored in the equipment, with the solution siphoned directly from the containers to the spin operation. The developer operation is located under a laminar flow HEPA filter hood with local exhaust ventilation provided at the base of the spin platform.

The electron beam lithography process operation is located in an aisle separate from other clean room operations. The computer and mask exposure are contained within two separate rooms adjacent to the clean room aisle. The electron beam power shutoff is located in the electron beam computer room. Equipment chases are located on both sides of the aisle. A cabinet for flammable liquids and a solvent storage cabinet are located in the chase.

8.1.3. Monitoring. Magnehelic gauges are located in laminar flow HEPA filter hoods in the photolithography aisle. Continuous workroom area monitoring for chemical and physical agents is not performed in the photolithography aisle.

The photoresist application and developing process, which includes the motion/location process sequence and operating parameters (type and quantity of solution dispensed), are controlled by a microprocessor. The photomask process operation is computer-controlled. Mask position and electron beam exposure are determined by the digitized data from the computer. Film badges are placed on equipment in the electron beam processes to monitor X-ray emissions. Workers are also required to wear film badges. Monitoring of ultraviolet emissions from projection mask alignment was not indicated.

8.1.4. Personal Protective Equipment. Workers are required to wear normal clean room attire consisting of shoe covers, lab coat, hood, latex gloves, and safety glasses or goggles. Except for safety glasses or goggles, the equipment is required for control of product quality.

8.1.5. Work Practices. Work activities in the photoresist application aisle consist of loading and unloading wafer cassettes in the wafer processing unit, replacement of photoresist and HMDS containers, and activation of push-button controls to initiate the processing sequence. Workers in the photolithography aisle may perform other related activities including wafer exposure, wafer and mask inspection, mask cleaning, and wafer developing. Consequently, operator exposures to chemical or physical agents would presumably be lower than that expected if the operator worked at one specific process operation for an entire shift. However, operators would possibly be exposed to a greater variety of agents. Approximately eight workers are employed in the photolithography area.

The projection mask aligner was observed in a standby mode during the preliminary survey. During normal operations, workers are seated at the projection mask aligner. At the time of the survey, shields around the lamp source were available but not in place, and blue light was visible around the unit.

Workers in the wafer development area transfer cassettes containing exposed wafers from the projection mask aligner to the developer station. They are also required to manually change developer solution containers which serve as reservoirs for the system. As indicated above, the variety of tasks performed by an operator could presumably result in lower exposures to chemical or physical agents but possibly to a greater variety of agents.

Specific work practices employed in the electron beam lithography process operation were not observed.

8.2. Plasma Etching

8.2.1. Process Description. Plasma etching systems are used to strip photoresist and to etch silicon nitride, polycrystalline silicon, and aluminum. As previously described, three plasma etching systems are used at the laboratory. These include two in-line planar plasma etching units and a barrel or tunnel plasma etching unit.

Stripping of photoresist is performed in the barrel or tunnel reactor plasma etching system. Wafers are loaded into carriers and manually placed in the reaction chamber. The chamber is sealed and pumped to vacuum (approximately 1 torr) using an oil-sealed mechanical pump. Oxygen is introduced into the chamber, a radio frequency field is applied to the electrodes in the chamber and an oxygen plasma is formed. The plasma reacts with the photoresist creating volatile species which are pumped from the reaction chamber. A viewing port on the front of the unit is constructed of quartz glass with a smoked lucite cover and metal mesh screen. The lucite cover is designed to control ultraviolet radiation emissions, and the metal mesh screen is designed to control radio frequency emissions.

Polycrystalline silicon and silicon nitride are etched in one of the continuous in-line planar plasma etching systems. Wafers are placed in a carrier and set in the load station. The wafers are automatically removed from the carrier and transported to the reaction chamber through a load lock station. From there, they are transported into the reaction chamber where a radio frequency field is established between the anode (transporting the wafers through the chamber) and the cathode. Freon 14 is used for etching polycrystalline silicon and silicon tetrafluoride is used for etching silicon nitride. The in-line plasma etching unit operates at a frequency of 13.56 MHz.

Aluminum is etched in another continuous in-line planar plasma etching system. The wafers are placed in cassettes and loaded to the reaction chamber as described above. They are transported through the chamber on a conveyor that acts as the anode of the radio frequency power source. Carbon tetrachloride is introduced to the chamber, and a radio frequency field is established between the anode containing the wafers and a cathode located opposite the wafers. A plasma is created in the radio frequency field which reacts with the aluminum. The metal volatilizes and is removed from the chamber by the vacuum pumping system. At a station integrated into the exit unload lock, photoresist is stripped using an oxygen plasma. The etched wafer is then transported to an unload cassette. The process is automatically controlled through a microprocesser system that continuously monitors process parameters and controls wafer motion/location and system logic. The operating radio frequency of the unit is 13.56 MHz.

8.2.2. Engineering Controls. The plasma etching systems are located under laminar flow hoods with HEPA filtration. Vacuum pumps for each process unit are located in the equipment chase immediately behind the units. The barrel reactor photoresist stripping system is mounted in the equipment chase with only the load door and controls in the clean room work area. Process gases are stored in a ventilated storage cabinet in the equipment chase. Vacuum pump exhausts are vented to the scrubber system through stainless steel ducts.

Both the polycrystalline silicon/silicon nitride and aluminum plasma etching systems are automated operations which limit worker contact with the process. Normal operation of the etching systems requires workers to load and unload wafer carriers and initiate processing sequence at the keyboard of the computer terminal.

8.2.3. Monitoring. Magnehelic gauges are mounted on laminar flow benches to measure pressure drop for the HEPA filtration unit. These gauges are not interconnected to alarms or other warning devices. However, limits for acceptable pressure drop are marked on the gauge face.

A microprocessor system with feedback control loops monitors the units during processing. The microprocessor controls vacuum pumping, gas flow, process sequencing, and wafer motion/location.

8.2.4. Personal Protective Equipment. Workers are required to wear normal clean room attire consisting of shoe covers, lab coat, hood, latex gloves, and safety goggles. Except for safety glasses or goggles, the equipment is required for control of product quality. Workers replacing gas cylinders are required to wear gloves and full-face supplied air respirators.

8.2.5. Work Practices. Wafers are loaded into carriers with tweezers or vacuum wands in a laminar flow staging area adjacent to the plasma etching operations. Workers are required to load and unload wafer carriers and initiate the process sequence controls. Processing is automatically controlled to allow workers to perform other job activities.

The barrel plasma reactor system for stripping photoresist is manually cleaned with isopropanol. Pump oils are manually drained and replaced. Process gases supplied in cylinders are changed by trained technicians. Procedures which are utilized for maintenance and cleaning activities were not observed during the preliminary survey. The automated control of the process equipment does not require that an operator be present during the operation. Therefore, if the plasma etching unit is emitting radio frequency radiation, the operator is not likely to be at the unit during an entire shift, but rather at some distance away from the source. The location of the operator away from the source and the variation in tasks performed by an operator during a work shift would both be considered controls which may decrease worker exposure.

8.3. Acid Etching/Cleaning Baths

8.3.1. Process Description. Wafers are etched or cleaned by immersion in a bath of acid. The bath is recessed in a polypropylene bench with a laminar flow HEPA filter unit overhead. Adjacent to the acid bath is a deionized water bath and a spin dryer. The acid bath contains either hydrofluoric acid buffered with ammonium fluoride for etching silicon dioxide or sulfuric acid and hydrogen peroxide heated to 70°C for cleaning wafers. Benches containing the acid etching/cleaning solution are located in the etching aisle and diffusion furnace areas.

Cassettes containing wafers are placed in the bath for a specific time period, after which they are removed and immersed in the deionized water bath. The cassettes are removed from the water bath and placed in a spin dryer located in the bench.

8.3.2. Engineering Controls. Both bench-type stations are equipped with overhead laminar flow HEPA filtration units. The laminar flow unit maintains a face velocity of 150 fpm downward and across the work surface for the purpose of controlling dust levels and improving product quality.

Local exhaust ventilation is provided by a slot located across the rear of the bench. The HF baths are covered by clear plastic lids. A spill plenum is also exhausted by a slot located below the work surface across the rear of the plenum. This plenum, located below the perforated bench surface of each unit, catches spilled acid and diverts the liquid to a waste acid drain. The plenum is flushed with water by the operator.

8.3.3. Monitoring. Monitoring of the process is limited to temperature control of the H_2SO_4/H_2O_2 hot pot. Laminar flow HEPA filtration units are monitored with magnehelic gauges located in the hood assembly. The laminar flow unit is periodically monitored to maintain 150 fpm face velocity of the units. Workroom monitoring of emissions from the process has not been performed.

8.3.4. Personal Protective Equipment. Workers loading chemicals into the acid baths are required to wear long sleeve gloves, acid aprons, and a face shield in addition to the normal clean room attire.

8.3.5. Work Practices. The spent etching solution is automatically aspirated from the acid baths and fresh solutions are added manually by pouring fresh acid from one gallon containers directly into the baths. Although the H_2SO_4 is already in a diluted form when purchased from the supplier, the H_2O_2 must be added to the acid. This mixing step is performed on site by the technicians in the area. Cassettes are handled using a removable Y-shaped handle which attaches to the end of the cassette. Workers generally perform tasks at other process operations in the etching aisle area, while wet chemical operations are in progress. Therefore, potential operator exposures to chemical agents are likely lower than if the operator remained at the bench for the entire work shift.

8.4. Solvent Cleaning

8.4.1. Process Description. Solvent cleaning removes organic contaminants from wafer handling equipment. The solvent tanks are contained in stainless steel tanks enclosed in a fireproof case which is serviced by local exhaust ventilation. Ultrasonic sound is used to assist cleaning. Solvent compounds, such as acetone or isopropanol, are pumped to the individual baths from pressurized solvent containers. Waste solvent is drained by aspiration to a solvent collection system and stored in a holding tank.

8.4.2. Engineering Controls. The solvent bath and fireproof enclosure are exhausted by ventilation slots located at the rear of the hood. Air is exhausted to the scrubber system. The location of the solvent bench in the diffusion area may be a potentially dangerous situation since furnaces operating at high temperatures (>400°C) are present. An accidental solvent spill or failure of the local exhaust ventilation at the tank could produce an explosion hazard. (The Lower Explosion Limit is 2.6 percent for acetone and 2.2 percent for isopropanol without ignition at 465°C and 440°C, respectively.)

8.4.3. Monitoring. No monitoring of the ventilation system or emissions from the process operation was identified during the preliminary survey.

8.4.4. Personal Protective Equipment. Workers are required to wear normal clean room attire consisting of shoe covers, lab coat, hood, latex gloves and safety glasses or goggles.

8.4.5. Work Practices. Specific work practices for use of the solvent cleaning tank are not indicated, since they were not in use during the preliminary survey. The solvent cleaning operation is used by repair and maintenance technicians in the diffusion furnace area. The tanks did not contain solvents during the survey.

8.5. Backside Etching

8.5.1. Process Description. The process operation consists of etching the reverse side of a silicon wafer with a hydrofluoric acid vapor. The process is performed to remove silicon dioxide build-up prior to metal deposition. Individual wafers are inverted and placed by hand on a small support platform that is covered with a plastic canopy. A length of plastic tubing attached to the canopy leads to a small reservoir of hydrofluoric acid. The etching vapor is produced by pumping the nitrogen through the HF solution, thereby saturating nitrogen with hydrofluoric acid. The vapor is forced through the plastic tubing and into the canopy. The fumes etch away any silicon dioxide present on the surface of the inverted wafer.

8.5.2. Engineering Controls. The entire backside etching apparatus, wafer support, canopy, tubing, and hydrofluoric acid reservoirs are in a laboratory hood of polypropylene construction. Spent HF vapor released from the plastic canopy are exhausted through ventilation slots located behind the apparatus at the rear of the hood. The process is placed on a flat plastic bench which did not appear to be designed to control spills of HF. The canopy was not purged with nitrogen while unloading the wafers.

8.5.3. Monitoring. The process sequence is monitored by a timer located in the bench. The flow of nitrogen into the acid reservoir is monitored by a variable-area type meter. Continuous monitoring of the local exhaust ventilation system or the emission of acid vapors is not conducted. Monitoring of the ventiliation system or emissions from the process operation was not described during the preliminary survey.

8.5.4. Personal Protective Equipment. Workers are required to wear industrial-type reuseable latex gloves in addition to the normal clean room attire when working at the backside etching operation.

8.5.5. Work Practices. Operation of the backside etching equipment requires manual loading and removal of the wafers. No interlocking mechanism or trip switch is present to prevent the worker from lifting the plastic canopy while the HF fume is being produced. Although local exhaust ventilation of the apparatus may prevent exposure, a potential for worker exposure to HF fumes may still exist when loading or unloading wafers. No specific work practices for controlling worker exposure were observed or identified by laboratory staff.

8.6. Furnace Tube Cleaning

8.6.1. Process Description. The quartz tubes of CVD furnaces are periodically removed and cleaned in a closed room adjacent to the CVD operations. Tubes are placed in a vertical tube cleaning unit, etched with hydrofluoric acid, rinsed in deionized water, and dried with nitrogen gas.

The cleaning unit is enclosed and ventilated. Interlocks prevent opening of the unit during the etching or rinsing cycles. The cleaning cycles are controlled by a programmable microprocessor. The etching acid is stored in holding tanks and mechanically aspirated.

8.6.2. Engineering Controls. Exhaust ventilation is provided to both the tube cleaning chamber and acid tanks. The system maintains approximately 50 to 100 cfm of exhaust air. The tube cleaning chamber is an enclosed cabinet of polypropylene construction.

8.6.3. Monitoring. Monitoring of the ventilation system, emissions, or process operation was not identified by laboratory staff during the preliminary survey. The laboratory staff were not questioned about specific systems which may be used in monitoring emissions or process parameters.

8.6.4. Personal Protective Equipment. Requirements for personal protective equipment in the furnace tube cleaning area were not identified by laboratory staff during the preliminary survey. The operation was not observed during the survey, and the staff were not specifically questioned about personal protective equipment requirements for the operation.

8.6.5. Work Practices. The tube cleaning operation was not observed during the preliminary survey. Specific work practices which may affect worker exposures were not identified by laboratory staff or specifically questioned by the survey team.

8.7. Spray Etching

8.7.1. Process Description. The spray etching operation uses computer-controlled semi-automated units. Cassettes containing wafers are manually loaded into a carousel in the exposure chamber of the spray etching unit. The lid to the chamber is closed and sealed, and the wafers are spun while being exposed to aerosols of etching solution. Hydrogen fluoride, ammonium hydroxide, and hydrogen peroxide solutions are used to etch and rinse the wafers at room temperature. Hot deionized water is used as a finishing rinse after each etching phase. The cassettes containing cleaned wafers are manually removed from the exposure chamber.

8.7.2. Engineering Controls. The spray etching operation is ventilated by a local exhaust takeoff located at the rear of the etching chamber. When the lid is closed, the chamber is sealed and the spray etching process is automatically controlled by a microprocessor. Before the lid opens the chamber is purged with air. The process is completely enclosed during normal operation. Chemicals are stored in reservoirs in the spray etching equipment which are filled by the operator.

8.7.3. Monitoring. The process operation sequence is monitored by the system microprocessor. The exhaust ventilation from the unit was not monitored.

8.7.4. Personal Protective Equipment. Workers are required to wear normal clean room attire in the spray etching operation. No additional personal protective equipment is required during normal operation.

8.7.5. Work Practices. Specific work practices were not identified during the preliminary survey. The spray etching operation was not in use at the time.

8.8. Metalization

8.8.1. Process Description. Metal deposition systems used at the facility include sputtering (DC and RF) and filament evaporation. Sputtering is used to apply an aluminum alloy film to the wafer surface. Wafers are manually mounted in a rotating structure, called a "planetary", using tweezers. This operation is performed at a staging area in a laminar flow HEPA filter work station adjacent to the unit, and the planetary is then placed in the chamber. The operator initiates the processing cycle through push-button control. The operation sequence is controlled by microprocessor and includes the following steps: (1) pumping down to low vacuum, (2) energizing the substrate, rotating the planetary, and starting the substrate heaters, (3) controlling temperature and pressure of the chamber for a specific time interval, (4) energizing the source, (5) resetting the deposit control and starting deposition, (6) turning off the source and substrate heat, (7) cooling down, (8) turning off substrate rotation, and (9) venting the chamber.

Filament evaporation is used to deposit gold. The wafers are mounted in a planetary device, as described above which is placed in a bell jar. The operator initiates the microprocessor-controlled process by a push-button, which lowers the bell jar over the planetary and filament source. The bell jar is sealed and the chamber is evacuated to a low vacuum (typically 10^{-6} torr). Worker interaction with the process is limited to loading and unloading wafers and push-button control of the process operation.

8.8.2. Engineering Controls. Sputtering and filament deposition are performed in sealed stainless steel or glass chambers under high vacuum conditions (chamber pressure negative to the room). Both systems employ oil-sealed mechanical roughing pumps, cryogenic traps, and diffusion pumps. The pump exhaust is vented to a process vent system and directed to a water-circulating scrubber. The air is then exhausted to the atmosphere.

The sputtering unit is mounted in the equipment chase wall with access to the unit from the clean room and the equipment chase. Pump systems for the unit are also located in the equipment chase. The planetary is mounted in the reaction chamber through the access door in the clean room which is under a laminar flow HEPA filter work station. Nitrogen is supplied to the unit in cylinders stored in the equipment chase. The cylinders are chained upright to the load-bearing wall.

The filament evaporation process is located in the clean room adjacent to the sputtering unit. Although the process is not located under a laminar flow work station, the staging area for loading wafers is within an adjacent laminar flow work station. Pumps for the unit are located in the equipment chase. Nitrogen is supplied to the unit from cylinders stored in the equipment chase. The DC power supply is located in the equipment chase inside a grounded cabinet which is interlocked to shutdown process power when opened. RF sources are similarly enclosed in a grounded cabinet which provides RF shielding.

8.8.3. Monitoring. The HEPA filtration unit for the laminar flow work station is monitored with magnehelic gauges mounted in the unit. The gauges measure pressure drop across the filter. The gauge is not connected to an alarm, however, high pressure levels are marked on the gauge face. The HEPA filter units are monitored to determine when filters must be replaced.

Process operation for both sputtering and filament deposition units are monitored by microprocessors with feedback control loops. A residual gas analyzer is used with the sputtering unit to determine the deposition end point. The microprocessor for the sputtering unit can store specific "recipes" for processing wafers using RF or DC sputtering in the same unit.

8.8.4. Personal Protective Equipment. Workers are required to wear normal clean room attire consisting of shoe covers, lab coat, hood, latex gloves, and safety goggles.

8.8.5. Work Practices. Workers are required to load and unload the planetary and to initiate process sequence microprocessor programs. The loading require simultaneous hand flexion and inversion of the wrist. Such hand motion could result in inflammation of the caspal tunnel of the wrist. However, the operation is not performed by the individual for extended periods. Routine maintenance operations for the units include manual filling and draining of roughing pump oil and diffusion pump oil, and wiping interior chamber surfaces with isopropanol. Internal parts such as bell jar shields, are periodically cleaned by bead blasting. Bead blasting is performed every one to two weeks in an unventilated abrasive blasting unit located in a storage room outside of the clean room environment.

8.9. Chemical Vapor Deposition

8.9.1. Process Description. Polycrystalline silicon, silicon nitride, and silicon dioxide are deposited using low pressure chemical vapor deposition (LPCVD) furnaces. The LPCVD furnaces are operated in a pressure range of 0.4 to 3.0 torr. An oil-sealed mechanical pump is used to establish vacuum conditions in the chamber. Gas flow is carefully controlled to produce the desired film and to remove decomposition products of the CVD reaction. These decomposition products may include hydrogen chloride, hydrogen, oxygen, ammonia, ammonium chloride, chlorine, and nitrogen dioxide (Baron and Zelez, 1978). Gases used in the LPCVD furnaces include the following: (1) dichlorosilane, ammonia, and nitrogen for silicon nitride deposition; (2) silane, oxygen, and phosphine for doped silicon dioxide deposition; and (3) silane, phosphine, and nitrogen for polycrystalline silicon deposition. Gases used in chemical vapor deposition (CVD) furnaces operted at atmospheric pressure include: (1) hydrogen and oxygen for oxidation and (2) silane and phosphine for deposition of phosphorus-doped silicon dioxide.

LPCVD furnaces are controlled by a microprocessor using feedback control loops and preprogrammed "recipes". The system controls the furnace temperature profile, gas flow, and vacuum pumping and purging. The microprocessor can automatically clean the furnace tube with hydrogen chloride, perform an automatic calibration cycle, and tailor the dynamic performance of the furnace to a given process step.

The wafers are loaded into fused quartz carriers which are inserted into the reaction chamber. The chamber temperature is stabilized, and the furnace tube sealed and evacuated using an oil-sealed mechanical roughing pump. Process gases are then introduced and their reaction at the wafer surface deposits the desired layer. Process gases are exhausted from the chamber through the pump exhaust to the facility scrubber system. After completion of this deposition the gas flow is stopped, the reactor is exhausted to approximately 10^{-3} torr and the chamber is filled with nitrogen to atmospheric pressure.

8.9.2. Engineering Controls. Vacuum pumping, gas flow, temperature, and deposition time are monitored by direct digital control. The operator can initiate and terminate the cycle. The vacuum pump exhaust is vented to a water scrubber. Local exhaust ventilation of the furnaces is provided by the scavenger box located at the opening of the furnace tube. The deposition of phosphorus-doped silicon dioxide is performed in a newer LPCVD furnace that is within a ventilated plexiglass panel shell. This shell is ventilated by drawing air from the space between the furnace system and the enclosure. Supply air is provided through openings at the instrument controls.

Process gases are supplied to the furnaces through welded stainless steel lines. The manifold lines are piped through a duct with air drawn through the duct from the point of use to the gas storage room. Phosphine is supplied to the newer LPCVD furnace as a 100 percent pure gas in one-pound lecture bottles which are stored in the LPCVD unit. Replacement bottles are delivered by the supplier upon specific request.

8.9.3. Monitoring. In the LPCVD system, each processing step is automatically controlled by a microprocessor. Feedback control loops assure proper system performance with minimal operator interaction. Workers are required to load and unload wafers from the furnace and to initiate the wafer processing sequence by pushbutton.

A phosphine monitor sampling port is located in the jungle cabinet above the LPCVD unit containing the phosphine lecture bottle. Air is continuously drawn from the jungle cabinet to the Matheson® arsine/phosphine monitor located adjacent to the toxic gas storage room. However, this system has presented reliability and detection limit problems and will be augmented by a TELOS® monitoring system. Laminar flow benches are monitored with magnehelic gauges.

Monitoring of the ventilation system for the furnace scavenger box exhaust, vacuum pump exhaust, and cooling system exhausts was not identified by laboratory staff during the preliminary survey.

8.9.4. Personal Protective Equipment. Workers are required to wear normal clean room attire consisting of shoe covers, lab coat, hood, latex gloves, and safety glasses or goggles. Workers changing the phosphine lecture bottles in the LPCVD unit are required to wear a self-contained breathing apparatus.

8.9.5. Work Practices. Worker activities in the furnace area include manual loading of wafers into carriers at a laminar flow staging area and loading of wafer carriers into the furnace tube. The process operation is initiated by pushbutton. Workers may perform several tasks during the work shift which are associated with CVD. These tasks include wafer handling, quality control, and wafer spray etching.

8.10. Ion Implantation

8.10.1. Process Description. Ion implantation is used to introduce impurities or dopants into the wafer surface. The implant pattern is determined by the photolithographic processes. Two ion implantation units are used at the laboratory. A third unit with dual implant chambers and microprocessor control is being installed.

Dopants are created by a confined electric discharge which is sustained by a gas of the ionized material. 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 targeting. The selected ions are targeted through an acceleration chamber and focused to produce a uniform dose to the substrate. The beam is scanned across the wafer and ions are implanted in the surface.

Ion implantation source gases include boron trifluoride (100 percent), arsine (15 percent in hydrogen), and phosphine (15 percent in hydrogen). The source gases are supplied in 26 cubic inch lecture bottles, which are stored in a nitrogen-purged, ventilated storage cabinet within the ion implantation unit.

The ion source is contained under vacuum conditions with three separate vacuum systems used for the source, beam line, and end station (exposure chamber). Each vacuum is maintained using an oil-sealed mechanical pump, diffusion pump, and/or cryogenic pump. The load and unload chambers are serviced by an oil-sealed mechanical pump. The pump systems are microprocessor controlled.

Cassettes containing wafers are placed in the input carriage. Individual wafers are automatically withdrawn from the cassette and transported into a vacuum lock. The chamber is evacuated, and the wafer is transferred to the platen where it is mounted and positioned for exposure. Implantation of the wafer is regulated by the system microprocessor. Following implantation of ions, the wafer is transferred to the exit vacuum lock, where the chamber is purged to atmospheric pressure, and the wafer is then transferred to a cassette.

8.10.2. Engineering Controls. Each ion implantation unit is ventilated by two independent systems. The vacuum pumps associated with the instrument are exhausted with the nitrogen-purged gas storage cabinet within the unit. The wafer handling area and control console are serviced by a vertical laminar flow unit with HEPA filtration. The ion implantation unit requires 600 cfm of exhaust.

The ion beam source is located within two lead-shielded cabinets to prevent X-ray leakage. Access to the source is through panels which are electrically interlocked to the system. The cabinets are electrically grounded.

8.10.3. Monitoring. Radiation film badges are used to monitor potential X-ray radiation emissions from the ion source. Employees working in the ion implantation area are required to wear film badges.

8.10.4. Personal Protective Equipment. Workers are required to wear normal clean room attire in the ion implantation area. Workers replacing phosphine or boron trifluoride lecture bottles are required to wear a self-contained breathing apparatus.

8.10.5. Work Practices. One worker is seated at a control panel at the ion implantation unit and is required to monitor the control panel. A second worker is responsible for loading and unloading cassettes. Regular maintenance is performed on the ion implantation unit. The arc electrode chamber of the ion generating source is disassembled every 8 hours, transported to a separate area outside of the clean room, and bead-blasted to remove dopant deposits. The ion extractor which is also associated with the ion source is removed and bead-blasted every 20 days. The roughing pump oil is frequently replenished with small amounts of oil and is changed approximately once a year.

8.11. Diffusion and Thermal Oxidation

8.11.1. Process Description. Diffusion introduces impurities or dopants into the wafer surface by maintaining the wafers at a high temperature in an atmosphere containing the dopant gas. The diffusion operation is similar to the thermal oxidation process in that wafers are first exposed to the phosphine dopant gas which is followed by an oxidation step. Thermal oxidation produces a silicon dioxide layer on the wafer surface. This layer may be formed by oxidation of the silicon in a pyrophoric water (hydrogen/oxygen) atmosphere, by exposure to oxygen, or by exposure to water vapor. The operation is performed in an atmospheric pressure diffusion furnace.

Wafers are placed in carriers and loaded into the furnace tube. The tube is first purged with an inert gas, while the wafers are heated. For the diffusion operation phosphine is introduced into the tube for a specified time period to obtain the desired diffusion depth. The diffusion is followed by an oxidation step using a pyrophoric water (hydrogen/oxygen) atmosphere or dry oxygen atmosphere. The tube is purged, and the wafers are unloaded.

The diffusion furnaces present at Xerox include both the direct digital control and hybrid furnaces. Direct digital control furnaces contain a microprocessor unit which monitors gas flow, temperature, processing sequence, and time using feedback control loops which automatically adjusts the diffusion furnace operating parameters. The older hybrid furnaces monitor similar furnace parameters but adjustments or corrections must be made by the operator. Both furnace types used hydrogen chloride gas to clean the furnace tubes. The furnace tube is heated by electrical resistance with the temperature monitored by thermocouples placed along the furnace tube.

8.11.2. Engineering Controls. The staging area and work station are under vertical laminar flow hoods with HEPA filtration. A scavenger box at the opening of the furnace tube provides local exhaust ventilation for the gas from the furnace tube. A flow rate of 400 cubic feet per minute is provided by the scavenger box. The system exhausts through a manifold to the solvent scrubber unit. A separate ventilation system is also provided for thermal control of the furnace tubes. The gas regulator panel where the gas supply lines connect to the furnace is ventilated with local exhaust. The exhaust is vented to the scrubber system.

8.11.3. Monitoring. The furnace area is continuously monitored for hydrogen by 15 hydrogen detectors located in the ducts, ceiling, furnaces, and gas storage room. The hydrogen levels for all detectors are reported at a central control panel in the Clean room change area. An audible and visual alarm is set at 10 percent of the lower explosive limit.

The process operation is monitored by feedback control loops of the direct digital control (DDC) microprocessor system. Those process parameters which are automatically controlled include furnace temperature, temperature gradient across the tube, and gas flow.

8.11.4. Personal Protective Equipment. Workers are required to wear normal Clean room attire as discussed in Section 6.3. Personal protective equipment requirements specific to the furnace area were not observed or identified by plant staff.

8.11.5. Work Practices. Workers may perform several tasks at various process operations in the furnace area. These tasks may include work at the spray etch operation, LPCVD operations, or the laminar flow work bench wafer staging areas.

8.12. Hydrogen Annealing

8.12.1. Process Description. Hydrogen annealing is used to heat-treat the wafers in order to "fix" the dopant atoms in the silicon crystal lattice and to repair damage to the lattice structure caused by ion implantation.

The process operation is performed in equipment similar to the atmospheric pressure diffusion furnace described in Section 8.12. The wafers are loaded into carriers in a laminar flow work station. The carriers are placed on paddles and loaded into the furnace where the wafers are exposed to a mixture of 5 percent hydrogen and 95 percent nitrogen (forming gas). The operation is microprocessor-controlled with feedback control loops monitoring the operation. After treatment in the forming-gas atmosphere the carriers are manually pulled from the furnace.

8.12.2. Engineering Controls. Engineering controls for the diffusion furnace are identical to those described in Section 8.11.2. and should be consulted for detailed information.

8.12.3. Monitoring. Monitoring systems are identical to those described in Section 8.11.3. and should be reviewed for detailed information.

8.12.4. Personal Protective Equipment. Workers are required to wear normal Clean room attire in the furnace area as described in Section 6.3. Additional equipment required during normal process operations were not identified by the plant staff or observed during the survey.

8.12.5. Work Practices. Workers may perform several tasks at various process operations in the furnace area. These tasks may include work at the spray etching operation, LPCVD operations, diffusion operations, or the laminar flow work bench staging areas.

8.13. Testing and Packaging

8.13.1. Process Description. Wafers are cleaned with a deionized water scrub. Every individual die on each wafer is electrically tested by probing circuits with a series of DC tests. Dies which do not meet set standards are marked with ink. The testing is performed in a clean room environment. After testing, wafers are transferred to cassettes and removed to the packaging area.

In packaging, the wafers are removed from the cassette and mounted in a scribing machine, where a scribing path or "street" is manually aligned. A diamond impregnated saw is then used to scribe a channel through the wafer. The scribing is automatically repeated in paths parallel to the channel. The wafer is rotated 90 degrees, and the scribing process is repeated. The wafer is removed from the equipment, and the dies are separated.

Die bonding is performed using gold eutectic bonding. The bond package containing the gold alloy is mounted on a heated bonding stage heated to approximately 400°C. The stage is heated using an electrical resistance heat source, and the individual die is placed on the gold alloy. The stage is cooled to room temperature which solidifies the eutectic weld.

Aluminum wire bonds are automatically attached to the die using ultrasonic bonding. The operator is required to align one wire bond, and the remaining bonds are automatically aligned and attached. Following wire bonding, a pre-seal functional test is performed. The die is then encapsulated in pre-formed ceramic packages. The ceramic package is sealed in a resistance-heated, nitrogen-purged convection furnace at 500°C.

The test area is located in a Clean room environment, while the packaging area is located in a room separated from the clean room fabrication area. A total of approximately 20 workers are employed in the test area, and 15 additional workers are stationed in the packaging area for all shifts.

8.13.2. Engineering Controls. Die testing, wafer scribing, and die bonding are performed on vertical laminar flow work benches. The sealing furnace has local exhaust ventilation which appears to have been altered. Two ventilation take offs are located at each end of the furnace. The ducts extend from the furnace to the ceiling but do not connect with the existing ceiling ducts.

8.13.3. Monitoring. Workroom area monitoring for chemical or physical agents has not been performed in the packaging or testing area.

8.13.4. Personal Protective Equipment. Current plans are for workers in the test area to wear normal clean room attire. Personal protective equipment is not required in the packaging area.

8.13.5. Work Practices. The majority of work in the die test area requires workers to be seated at test stations. Testing of dies is performed with the use of a microscope. Workers seated at the unit must manually align the dies and probes. No specific work practices for controlling worker exposure to chemical or physical agents were observed or identified by laboratory staff.

9.0. CONCLUSIONS AND RECOMMENDATIONS

Integrated circuits are produced at the Xerox MEC facility using state-of-the-art processing operations and production equipment. The process operations are representative of current MOS technology. In addition to MOS processing operations, the facility performs non-fabrication and support services which include photomask preparation (using electron beam lithography), die testing, and packaging.

Observations, recommendations, and conclusions regarding the effectiveness of control technology are as follows.

- Numerous changes to the process line have occurred since the plant was constructed in 1975. These changes may have altered the performance of the ventilation system.
- Engineering controls for many process operations are integrated into the equipment design by the equipment manufacturers. The facility has initiated a process safety review program to evaluate these controls in new and existing process equipment. The review process and results may be a valuable tool for hazard evaluation and should be investigated.
- The backside HF etching operation designed by the plant staff should be evaluated to determine the effectiveness of the controls and the potential for exposure during wafer handling.
- The effectiveness of engineering controls such as shielding of radio frequency radiation in RF sputtering and plasma etching operations should be evaluated.
- The effectiveness of engineering controls such as system interlocks and shielding of the ultraviolet light used in projection mask alignment or generated in plasma etching operations should be assessed.
- The effectiveness of X-ray shielding in the ion implantation area should be evaluated.

- o General clean room air supply and exhaust systems, laminar flow systems, and air scrubber systems should be evaluated. Special consideration should be given to assessing system performance during emergency or upset conditions, and documenting the use of clean room air recirculation.
- o Process operations that may not be encountered in other plants include HF backside etching, electron beam lithography for photomask production, and LPCVD. These operations should be considered for detailed evaluation.
- o Automation and/or microprocessor control with feedback control loops are used in several operations. The controls allow operators to perform several tasks which serve to limit worker contact with the process operations. The effectiveness of microprocessor controls limiting worker exposure to various agents should be investigated.
- o The location of the solvent cleaning bench in the furnace area may present a flammability or explosion hazard in the event of a spill or exhaust system failure. The bench should be located in an area separate from the diffusion and LPCVD furnace.

10.0. REFERENCES

American Conference of Governmental Industrial Hygienists. 1978. Industrial Ventilation. A Manual of Recommended Practice. American Conference of Governmental Industrial Hygienists. Cincinnati, Ohio.

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