PB84-183227

PRELIMINARY CONTROL TECHNOLOGY SURVEY
of
INMOS CORPORATION
1110 Bayfield Drive
Colorado Springs, Colorado 80906

to

U.S. Environmental Protection Agency
Industrial Environmental Research Laboratory
26 W. St. Clair Avenue
Cincinnati, Ohio 45268

and

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

October 1983

by

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BATTELLE
Columbus Laboratories
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Columbus, Ohio 43201

50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO.

2.

3. Recipient's Accession No.
PB84 183227

4. Title and Subtitle
Preliminary Control Technology Survey, INMOS Corporation, Colorado Springs, Colorado

5. Report Date

6.

7. Author(s)
Mihlan, G.J., and R.D. Willson

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Division of Physical Sciences and Engineering, NIOSH,
Cincinnati, Ohio

10. Project/Task/Work Unit No.
CT 115-13a

11. Contract(C) or Grant(G) No.
(C)
(G)

12. Sponsoring Organization Name and Address
Same as box 9.

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

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A walk through survey was conducted at INMOS Corporation (SIC-3674), Colorado Springs, Colorado on October 13, 1981 to evaluate control technology for integrated circuit fabrication. Operations performed at the facility included thermal oxidation; photolithographic processes; wet chemical cleaning and etching; plasma etching; chemical vapor deposition of silicon-dioxide (14808607), silicon-nitride (12033895), and polycrystalline-silicon (7440213); diffusion; ion implantation; metalization by radiofrequency sputtering; and hydrogen annealing. Engineering controls varied by process operation and included isolation, local exhaust ventilation, shielding, and enclosure, and process substitution. Microprocessors were used to control process equipment for several operations. Continuous area monitoring for arsine (7784421) and phosphine (7803512) was performed by infrared spectrophotometry. X-ray radiation emissions were monitored with radiation film badges. Personal protective equipment varied by job functions and included safety goggles or glasses, acid resistant shielding, and respirators. The authors conclude that the facility represents the current state of the art in clean room design using a tunnel bay layout. Specific observations and recommendations regarding the effectiveness of control technology at the facility pertain to air circulation, waste management, and valves on gas lines from cylinders containing flammable, toxic, or corrosive gases.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms
NIOSH-Publication, NIOSH-Author, Control-technology, Electronics-industry, Safety-engineering, Air-quality-monitoring, Safety-equipment, Industrial-hygiene-programs, Work-environment, Laboratory-workers

c. COSATI Field/Group

18. Availability Statement:

19. Security Class (This Report)

20. Security Class (This Page)

21. No. of Pages
37

22. Price

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

at

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Report No. 115.13a

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Engineering Control Technology Branch
4676 Columbia Parkway
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PLANT SURVEYED: INMOS CORPORATION
1110 Bayfield Drive
Colorado Springs, Colorado 80906

SIC CODE: 3674

SURVEY DATE: October 13, 1981

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

EMPLOYER REPRESENTATIVES CONTACTED:

Mr. Jeff Stumpf, Industrial Hygienist
Mr. Greg Karr, Plant Engineer
Ms. Shelley Hawn, Engineer, Diffusion Area

EMPLOYEE REPRESENTATIVES CONTACTED:

No Employee Represenatives

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1.0 ABSTRACT

A preliminary control technology assessment survey was conducted at INMOS Corporation, Colorado Springs, Colorado on October 13, 1981. The survey was conducted as part of a project under a U.S. Environmental Protection Agency contract funded through an Interagency Agreement with the National Institute for Occupational Safety and Health. The facility manufactures N-channel metal oxide semiconductors.

Silicon wafers are used as semiconductor substrates and are purchased from vendors. Process operations performed at the facility include: 1) thermal oxidation; 2) photolithographic processes for defining circuit patterns, including wafer cleaning, photoresist application, substrate exposure, photoresist development and photoresist stripping; 3) wet chemical cleaning and etching; 4) plasma etching; 5) chemical vapor deposition (CVD) of silicon dioxide, silicon nitride and polycrystalline silicon; 6) diffusion; 7) ion implantation; 8) metalization by radio frequency sputtering; and 9) hydrogen annealing. The operations are performed within a Class 100 clean room using high efficiency particulate air (HEPA) filtration of room air.

Engineering controls used at the facility vary by process operation. These controls include: 1) isolation of the process, 2) local exhaust ventilation, 3) shielding and enclosure of the process and 4) process substitution. Several process operations are performed in sealed reaction chambers at pressures negative to that of the workroom area. Process isolation is used in plasma etching, metalization, and ion implantation. Shielding is used in ion implantation units to control X-ray emissions and in plasma etching and radio frequency (RF) sputtering to control RF radiation. Some process equipment such as continuous vapor phase oxidation systems and diffusion furnace assemblies are enclosed to prevent operator contact with hot surfaces. Plasma etching may be considered a process substitution for acid etching operations. However, the decision to use plasma etching is primarily based on process engineering requirements for wafer fabrication.

Process equipment for several operations is automatically controlled by microprocessors. These operations include thermal oxidation, diffusion,

ion implantation, metalization, plasma etching and parts of the photolithographic process.

Continuous area monitoring for arsine and phosphine is performed using a MIRAN® infrared spectrophotometer with multipoint sampling. Radiation film badges are used to monitor X-ray radiation emissions from the ion implantation unit and to monitor operator exposures.

Personal protective equipment requirements vary by job function. All workers in the clean room are required to wear goggles or safety glasses. Acid-resistant aprons, gloves, and face shields are used by operators handling chemicals. Air line-supplied full-face respirators are used by operators changing gas cylinders. Self-contained breathing apparatus are available for emergencies. Workers are also required to wear product-protective equipment consisting of a hood, shoe covers, coveralls, and gloves. This equipment is worn to protect wafers from contamination by the worker.

Work practices that may affect emissions or operator exposures to chemical or physical agents could not be addressed in detail during the preliminary survey due to time constraints. These practices should be documented during a detailed survey.

2.0 INTRODUCTION

A preliminary survey was conducted at INMOS Corporation, 1110 Bayfield Drive, Colorado Springs, Colorado, on October 13, 1981. The study was performed under U.S. Environmental Protection Agency (U.S. EPA) Contract Number 68-03-3026 through an Interagency Agreement (Number AR 75-F0-142-0) with the National Institute for Occupational Safety and Health (NIOSH). The survey was conducted by Battelle Columbus Laboratories and PEDCo Environmental, Inc. Mr. James H. Jones, NIOSH Division of Physical Sciences and Engineering, accompanied the survey team.

The following individuals were contacted at INMOS Corporation:

(1) Mr. Jeff Stumpf, Industrial Hygienist
(2) Mr. Greg Karr, Plant Engineer
(3) Ms. Shelley Hawn, Engineer, Diffusion Area

The study protocol was provided to the industrial hygienist at the opening conference and the study objectives and methods were described. A detailed description of the health and safety programs at the plant was provided by the plant industrial hygienist.

Following the opening conference, the facility was toured, including production areas, gas and chemical storage areas, air handling systems, and waste management systems. A closing conference with plant personnel was held following the survey.

3.0 PLANT DESCRIPTION

3.1 General

The plant is part of INMOS, International, with corporate headquarters in Bristol, United Kingdom. The plant manufacturers N-channel metal oxide semiconductors (NMOS) integrated circuits, consisting of 16K static random access memory (RAM) and 64K dynamic RAM chips. The plant consists of a 130,000 square-feet facility, including clean room fabrication area, design, offices, storage, and support services. The plant was built in 1980 and began limited production in 1981.

The plant employs 700 workers of which approximately 300 are employed in production, testing, and assembly, and 400 in administrative support. The facility operates three shifts per day. Of the 300 production workers 50 are employed during the first shift, 35 to 40 during the second shift, and 35 during the third shift in the clean room fabrication area. Assembly and testing operations employ 25 workers during the first shift and 15 workers during the second shift. Repair and maintenance activities require 4 to 5 workers per shift for each of the three shifts.

Testing and assembly process operations are performed at a separate site in the Colorado Springs area. Wafer testing and assembly operations were not observed during the survey. INMOS has an emergency response team and spill team.

3.2 Chemical Storage

Incoming chemicals are received at a common shipping and receiving dock and are then segregated as acids and solvents (organics). Both storage areas are diked, and self-contained breathing apparatus (SCBA) units are located outside each room for use in cleaning up spills.

The acid storage room contains a drain in the center of the sloped floor which is connected to the plant acid waste treatment system. Drums of sodium bicarbonate are kept in the room for use in neutralizing acid spills before washing down the drain. Air is supplied to the storage room through overhead ducts and grilles. The supplied air exhausts through a wall with louvers to the outside. The ventilation rate for this room was not reported. All acids are received in 1-gallon bottles and are transported from the storage room to their point of use in plastic carts. The carts are compartmentalized to segregate the bottles and contain the contents in the event of a bottle rupture.

The solvent storage room, of similar construction to the acid room, also has a blowout wall and a sprinkler system. Ventilation air is supplied from overhead ducts and grilles. No exhaust ducts were noted. Barrels of absorbent are provided for use in spill control. Solvents are received as 1-gallon boxed shipments and in 5- and 55-gallon drums.

3.3 Gas Handling System

Process gases are supplied in cylinders and stored in a secured, covered dock at the plant. Gases are segregated into seven bays separated by 6-feet tall concrete block walls. Regulator and gas purge assemblies are mounted on the bay walls. A single nitrogen purge cylinder is used for each storage bay. The gas regulator assemblies for the first bay are located in a local exhaust hood designed to exhaust 50 to 75 cubic feet per minute (cfm). A hood assembly, which has not been installed, is planned for the second bay. A sampling probe for the MIRAN® 801 monitoring system is located in the exhaust hood of the first bay.

Welded stainless steel lines distribute gases from the cylinders to the process equipment. The stainless steel lines are enclosed in a common PVC tube from the gas bay to the building. The PVC line did not appear to be monitored for gas leaks or exhausted.

Gases stored in the bays include: (1) 4, 10, and 100 percent phosphine and nitrogen in the first bay; (2) phosphine, halocarbon, oxygen, and nitrogen in the second bay; (3) Freons (unspecified), sulfur hexafluoride, dichlorosilane, hydrogen, and acetylene in the third bay; (4) halocarbon 14, Freon 116, Freon 13, ammonia, hydrogen chloride, boron trifluoride, helium, and argon in the fourth bay; (5) silane, nitrogen, argon, and helium in the fifth bay. Gas cylinders are checked for leaks using a Snooper® bubble emission leak detector. Workers changing gas cylinders are required to wear full-face, air line-supplied respirators. A self-contained breathing apparatus is available in the area for emergencies.

Oxygen, nitrogen, and hydrogen are supplied in bulk tanks located behind the plant. Oxygen and hydrogen tanks are separated by a concrete block wall. The liquid oxygen tank is surrounded by a diked enclosure, and an exhaust flare is present on the hydrogen tank.

Gas supply lines are of welded stainless steel construction and they are helium leak-tested. These lines have check valves before the machines and have solonoid valves inside each machine.

3.4 Monitoring System

INMOS has two MIRAN® 801 monitors which are used to monitor phosphine and arsine depont gases. The sampling ports for one unit are located in the CVD furnace enclosures (near the source end), in the hood in the first gas bay storage area over the phosphine bottle manifold, and in the ion implantation units to monitor for arsine.

The ports for the second unit are located inside the clean room where phosphine or arsine is used.

The MIRAN® unit has a lower detection limit for phosphine of 3 ppm (TLV is 0.3 ppm). The low level alarm point is 5 ppm and the high level point is 10 ppm. According to plant reports, some of the Freon compounds will trip the phosphine alarms due to similar infrared responses at the phosphine wavelengths. The alarms from the MIRAN® units are connected to the central security station so that the guards can respond to a suspected leak. At the time of our visit the units had been returned to the vendor for repair; however, at this time they are in operation.

There are no other permanently installed, combustible-gas monitoring systems. The industrial hygienist uses a portable, combustible-gas meter to check suspected leaks.

There are a few static pressure gauges on some of the laminar flow HEPA filter hoods in the wet chemical etching stations. No pressure or velocity measuring gauges were noted in the exhaust system with the exception of magnehelic gauges on the scrubber units.

3.5 Ventilation System

The building air is supplied by eight air handlers, each rated at 38,000 cfm. Five of the air handlers supply the office and non-clean room manufacturing areas, and the other three units supply the clean room area. The makeup air is filtered through roughing bag filters, Pur-O-Fil® (potassium permanganate and activated alumina) odor filters, and high efficiency particulate air (HEPA) filters before delivery to the clean room area. All laminar flow work stations have HEPA filtration units installed overhead. The air supply to these units is approximately 40,000 cfm, with 26,000 cfm removed from the room by local exhaust ventilation of acid etching and cleaning operations, and the remaining 14,000 cfm removed by local exhaust ventilation of solvent cleaning stations, by exfiltration of room air and by the return air ducts. All solvent exhausts are vented directly to the outside whereas all acid exhausts pass through one of two packed plate acid scrubbers. The air supply system operates on an economizer cycle with a minimum of 40,000 cfm of outside makeup air used in both the summer and winter.

The clean room area is divided into five zones, each with air pressure maintained slightly above the preceeding zone, so that the cleanest area (photolithography) is positively pressurized with respect to all other wafer fabrication areas. The clean rooms are built with service chases behind wet stations and processing equipment. The air supply is delivered to the clean room with approximately 50 percent distributed through perforated ceiling panels from a common plenum. There are return air ducts both in the chases and in the clean room ceiling, although the balance of the system was not described by the plant staff during the preliminary survey.

All roughing pumps and diffusion pumps are exhausted through the acid scrubber system. All exhaust ducts in the facility are fiberglass-reinforced plastic with drain and cleanout points at strategic locations.

In case of chemical spills in the clean room area, there are manually activated controls which are placed strategically to enable shutdown of the normal air handling systems used for general recirculation of clean room air. These switches activate an alarm and puts the clean room on total outside air. In the event of a power failure two supply fans and the scrubber would continue to operate during power failures with power provided by a diesel generator.

INMOS's industrial hygienist has completed a ventilation survey of all laminar flow hoods and wet stations. With a few exceptions, laminar flow hoods blow air downward at a velocity of approximately 125 fpm, and wet chemical stations were maintained with a velocity of 75 to 150 fpm around the perimeter of acid tanks.

One interesting feature of the air handling systems is that the return air ducts for all eight air handlers release their air into a common room that acts as a large plenum to supply all units. Thus, a large chemical spill could potentially generate sufficient amounts of vapors which could contaminate the non-clean room fabrication and office areas of the plant unless manual shutdown of the air handlers were to begin immediately after the spill or release.

3.6 Waste Management

Waste organic solvents from photolithographic operations are collected in 55-gallon drums and stored on site in a secured, covered area. Hexamethyldisilizane (HMDS) waste is collected separately and stored in 55-gallon drums. The wastes including pump oils are collected for recycling by an outside contractor.

Hydrofluoric acid wastes from wet chemical operations are collected by an acid drain system and stored in two holding tanks located in the basement of the building. The acid wastes are neutralized with a caustic solution and treated with lime in a batch process to precipitate the fluoride. The calcium fluoride sludge is dried and taken offsite to a chemical waste landfill.

Exhausts from the acid work stations in the clean room are processed through a wet caustic scrubber and released to the atmosphere. Vacuum pump exhausts are also vented to the scrubber. Scrubber blowdown is monitored for pH and released to a publicly operated treatment works (POTW). Local exhaust of dry cleaning operations (perchloroethylene) is vented to the atmosphere. The arsenic sandblast waste is collected and held for disposal.

4.0 PROCESS DESCRIPTION

The plant purchases pre-doped silicon wafers. Photomasks used for defining the circuit patterns are produced to plant specifications by outside suppliers. The process operations performed at the plant include the following: (1) plasma etching; (2) wet chemical cleaning and etching; (3) photolithographic processes including photoresist application, wafer exposure, photoresist developing, and photoresist stripping; (4) chemical vapor deposition of silicon dioxide, silicon nitride, polycrystalline silicon;

(5) continuous vapor phase oxidation for silicon dioxide deposition; (6) thermal oxidation; (7) wafer doping, including diffusion and ion implantation; and (8) hydrogen annealing. The plant also performs dry cleaning of clean room garments.

Several process operations utilize similar types of equipment. The various wet chemical operations are performed in tanks within the benches that are of polypropylene construction with vertical laminar flow HEPA filtered air. Chemical vapor deposition of silicon dioxide, polycrystalline silicon, and silicon nitride is performed in similar direct digital control (DDC) atmospheric pressure diffusion furnaces.

The production of NMOS-type integrated circuits begins with an initial wash of the wafers in deionized water followed by a nitrogen blowdry. The wafers are oxidized in a diffusion furnace with a pyrophoric water atmosphere formed by introducing hydrogen and oxygen into the furnace tube. The wafers are loaded into carriers and placed in a quartz tube (or elephant) which is attached to the furnace. The wafer carriers are inserted into the furnace manually and the process sequence is initiated by push button. The microprocessor controls the process sequence, gas flow, temperature ramping, and automatic cleaning of the furnace with hydrogen chloride. It also performs calibration cycles and tailors the performance of the furnace to the specific "recipe" desired. Workers unload the furnace by pulling the carriers from the tube into the elephant. The elephant is then removed from the furnace by workers using heat protective gloves.

Cassettes containing wafers are loaded into an automatic in-line wafer processing unit. Process operations performed by the unit include: (1) deionized water spin wash, (2) wafer drying, (3) spin-on application of photoresist, and (4) soft bake of the wafer. The wafers are automatically loaded into a cassette and transferred to wafer exposure.

The wafer processing unit is ventilated with local exhaust located at the base of the spin platforms and below the surface of the drying units.

The spin operations are partially enclosed and shielded and the unit is located beneath a vertical laminar flow HEPA filter hood.

Plastic shields enclosing the spin platforms are cleaned in a solution of cellosolve acetate, butyl acetate, and xylene. The cleaning is performed in a stainless steel, ventilated hood by process operators once per shift for approximately one hour.

Cassettes containing photoresist-coated wafers are transferred to the photolithography area where circuit patterns are transferred to the wafer by direct step-on-wafer exposure. The stepping projection aligner uses step-and-repeat direct exposure of the wafer with refractive optics and reduction from a reticle of 10:1 down to 1:1. The wafer is held by vacuum on an X-Y stage, and a photomask containing the circuit pattern for an individual die is mounted between the wafer and a 436 nm blue light source. The die image is exposed on the wafer surface by the blue light, and the wafer is automatically moved to the next X-Y coordinate where the process is repeated. The stage location is monitored by a laser interferometer at predetermined fixed-step intervals.

The direct step-on-wafer equipment is enclosed in an environmental chamber with separate temperature control and HEPA filtration. The individual chambers are located in a room which is at positive pressure to other areas of the clean room. The operator monitors the process by remote control from a video display terminal located adjacent to each environmental chamber. The operator has access to the terminal through sliding plastic panels adjacent to the terminal.

Exposed wafers are developed by placing them in a sodium hydroxide developer solution or by spin-on of the solution to the surface of the wafer. The developer tank is made of polypropylene. Cassettes containing wafers are manually placed in the tank, the lid is closed, and the solution is agitated with nitrogen. The cassettes are removed from the tank to a deionized water wash and spin dried. The developer tank did not appear to be ventilated. Developer solution is added to the tank manually by pouring from a 1-gallon container into a beaker which is then poured into the tank. The operator is required to wear goggles and gloves which are resistant to caustics.

Wafers may also be developed by applying the solution to the wafer which is mounted on a spinning platform. A cassette containing exposed wafers is mounted in the unit, and individual wafers are automatically removed from the cassette and placed on the spin platform. At this point, the wafer is spun, and the developer solution is automatically applied. The wafer is rinsed with deionized water followed by a spin dry. The process is repeated until the cassette is completed, and the operator removes the cassette from the unit. The exposed underlying layer is then ready for further processing. The perimeter of the spin platform is shielded, and the entire unit is located within a cabinet enclosed on four sides. Local exhaust ventilation of the unit may have been present but was not observed.

The exposed layer may be etched using either wet chemical techniques or plasma etching, depending on the layer to be removed. Wet chemical etching consists of manually dipping cassettes in tanks containing the desired etching solution. This may be a mixture of any of the following; 1) nitric acid, phosphoric acid, acetic acid, and Triton (a wetting agent) for alunimum etching, 2) hydrofluoric acid, nitric acid, and acetic acid for etching polycrystalline silicon; or 3) hydrofluoric acid for etching silicon dioxide or silicon nitride. The tanks are polypropylene, and they are recessed into the bench with local exhaust ventilation by slots around the tank perimeter and/or slots across the rear of the bench. Workers are required to wear face shields, gloves, and aprons when working in wet chemical operations.

Plasma etching is a physical/chemical method of etching. Several different methods are used for handling wafers. The wafers are either placed onto platens which are manually loaded into the etching chamber; or they may be placed in carriers which are manually loaded into the reaction chamber. Another method involves the loading of cassettes into an automated planar plasma unit in which individual wafers are automatically removed from the cassette into the etching chamber. The etching operations are performed in a sealed reaction chamber pumped to 0.1 to 20 torr by an oil-sealed mechanical pump. A radio frequency field of 13.56 MHz is created between two electrodes, and a gas is introduced into the chamber. The gases used at INMOS include Freon 115, Freon 13, sulfur hexafluoride, carbon tetrachloride/argon, carbon tetrafluoride/oxygen, and helium/oxygen. Selection of the gases depends upon the layer to be etched.

Two plasma etching units employ a laser end point detector to determine the completion of the etching. Plasma etching operations may be considered a substitute for wet chemical etching. At this point, etched wafers are ready for additional processing that may include diffusion, ion implantation, metalization, or chemical vapor deposition.

Following the etching process, the photoresist is stripped from the wafer in a ventilated wet station. Cassettes containing wafers are dipped by hand in the solution followed by a deionized water wash and spin dry.

Selective doping of the wafer is performed by either diffusion or ion implantation. Diffusion is performed in a direct digital control (DDC) atmospheric pressure diffusion furnace where wafers are heated to high temperature (approximately 1,000°C) in an atmosphere containing phosphine gas as the dopant source. The wafers are loaded manually into the wafer carriers which are placed in a quartz elephant and connected to the furnace. The carriers are then inserted into the furnace with a quartz rod. The furnace temperature, process time, sequence, and gas flow are controlled by microprocessor. The furnace is identical to those used for thermal oxidation and chemical vapor deposition.

Wafers are also doped by ion implantation. Control of the process operation is totally automated by microprocessor. Cassettes are placed at the load station where individual wafers are automatically removed from the cassette to a load-lock chamber that is purged and pumped to vacuum using an oil-sealed mechanical pump. The wafer is transferred to a second vacuum chamber where it is mounted on a platen and rotated into position in the target chamber. The wafer is exposed to the dopant ions for a predetermined time period. The wafer is bombarded by boron, phosphorus, or arsenic ions created by a confined, electric discharge sustained by the source gas which is either 100 percent boron trifluoride, 15 percent arsine, or 15 percent phosphine. The wafer is automatically removed from the exposure chamber into a second load lock chamber that is purged to atmospheric pressure and transferred to a cassette for transport to the hydrogen annealing operation.

Hydrogen annealing is performed in a DDC atmospheric pressure diffusion furnace using a forming gas atmosphere of 5 percent hydrogen and 95 percent nitrogen. The operation is similar to the chemical vapor deposition and diffusion operations discussed previously.

Electrical contacts are formed in the integrated circuit by radio frequency sputtering of a metal conductor onto the wafer surface. The wafers are mounted on platens and placed in a load-lock chamber. The platen chamber is sealed and pumped to vacuum by an oil-sealed mechanical pump. The platen is then transported through the deposition zone where aluminum is deposited onto the wafer's surface by radio frequency sputtering. The coated wafers are removed from the platen and transferred to the photolithographic area where the contact platen is defined.

The photolithographic operations used to define the contact patterns are identical to those previously discussed. The alunimum layer exposed by the photolithographic process is then plasma etched.

A final metalization step by thermal evaporation involves the deposition of gold. Wafers are loaded into a planetary structure, which is mounted inside a stainless steel bell jar. The operation is controlled by microprocessor; the bell jar is lowered and the chamber is exhausted to vacuum ($<10^{-4}$ torr) using an oil-sealed mechanical pump followed by an oil diffusion pump.

5.0 DESCRIPTION OF PROGRAMS

5.1 Industrial Hygiene

INMOS employs a full-time industrial hygienist who is responsible for occupational safety and industrial hygiene. The industrial hygienist has developed programs in safety, materials handling, and personal protective equipment requirements. These programs are described in Section 5.2. An emergency response program has been established by the industrial hygienist which details procedures for plant evacuation, chemical spills, and power loss.

The industrial hygienist has performed personal monitoring of worker exposures to acids and organic solvents. Film badges placed on equipment and worn by operators monitor emissions and exposures to X-ray radiation at the ion implantation unit. Additional measurements include monitoring air velocity of laminar flow benches and face velocity of local exhaust ventilation in the wet chemical benches. At the request of the industrial hygienist, Dr. Bobby J. Gunter, NIOSH Region VIII industrial hygienist conducted a health hazard evaluation at the facility.

One problem noted by the industrial hygienist was an explosion in the silane gas line due to improper purging procedures.

5.2 Education and Training

The plant industrial hygienist has developed training programs in safety, materials handling, use of personal protective equipment, emergency response procedures, and hazard reporting.

New employees are given a one week orientation. A training bay has been established to demonstrate safe procedures for material handling and the proper use of personal protective equipment. Work practices of new employees are observed for one week and workers are then required to pass a competency test at the end of the training program. Disciplinary action, which was unspecified, is taken if proper procedures are not used by the workers.

Local area hospitals have been instructed on the potential hazards and a list of chemicals used at the plant has been made available to them to facilitate emergency care.

5.3 Respirators and Other Personal Protective Equipment

Specific process operations require personal protective equipment. All clean room employees are required to wear clean suits consisting of booties, coveralls, hood, gloves, and goggles or safety glasses. Except for safety glasses or goggles, the clothing is required to control particulate levels in the room and improve product quality. Workers are permitted to wear contact lenses in areas of the clean room. Additional personal protective equipment requirements include: 1) full apron (or apron and gloves with sleeves) and face shield for all wet chemical operations; 2) gloves and goggles for wafer developing; 3) face shield, apron, and gloves for photoresist stripping; and 4) thermal gloves for handling glassware for the diffusion furnaces. Safety shoes are required for repair, maintenance, and shipping/receiving workers.

Air line-supplied, full-face respirators are used for changing gas cylinders. Respirators, which were not observed or described during the survey, are required during repair and maintenance of dry cleaning equipment. Qualitative fit testing, which involves positive and negative pressure testing or exposure to smoke or isoamyl acetate, is required for respirator use. A written policy and procedures statement for the use of respirators has been developed.

Self-contained breathing apparatus are available for emergency use in the chemical and gas storage areas. Emergency showers, eye wash stations, and emergency breathing oxygen supplies are also available in the clean room area. Acid suits, air line-supplied respirators, and safety harnesses are required during maintenance of the acid gas scrubber. Maintenance practices require two workers for confined entry areas.

5.4 Medical Programs

A nurse was employed full-time at the plant during the day shift at the time of our visit; howver, now there is a nurse for the second shift and EMT for the third shift. A physician is available part-time at the plant. Individuals trained in emergency first aid and cardiopulmonary resuscitation are available during the first shift. Preplacement medical examinations and medical history questionnaires are required for all new employees. Periodic physical examinations are required according to results of the preplacement examination and the job function. Workers are required to undergo audiometric and vision examinations. Facility maintenance workers, who must occasionally wear respirators, are required to undergo pulmonary function tests. R&M workers involved in servicing the ion implantation area are required to be tested annually for blood and urinary arsenic levels.

5.5 Housekeeping

Central vacuum cleaning lines are available throughout the clean room fabrication area. The clean room floor is cleaned with deionized water. The frequency of cleaning activities was not reported by plant personnel.

6.0 SAMPLE DATA FROM PRELIMINARY OR PREVIOUS PLANT SURVEYS

A health hazard evaluation was conducted at INMOS by Dr. Bobby J. Gunter, NIOSH Region VIII, Denver, Colorado. The evaluation included personal and area monitoring of chemical agents, area monitoring of radio frequency radiation emissions, and measurements of face velocities and capture velocities of local exhaust ventilation. Results of the evaluation will be published by NIOSH as a health hazard evaluation (HHE) report.

7.0 DESCRIPTION OF CONTROL STRATEGY FOR PROCESS OPERATIONS OF INTEREST

A variety of strategies are used at INMOS to control emissions and worker exposures. Control strategies include local and general exhaust ventilation, process isolation, process and environmental monitoring, personal protective equipment, and safe work practices. Devices or work stations that contain toxic materials considered immediately hazardous to life or health are all controlled by monitoring and local exhaust ventilation systems, whereas less hazardous areas are controlled by general exhaust ventilation. Specific descriptions are given below for control strategies employed for support services, plasma etching, wet chemical processes, photolithographic processes, chemical vapor deposition, thermal oxidation, and doping.

7.1 Support Services--Dry Cleaning

A support area adjacent to the clean room and change area is devoted to dry cleaning of clean room garments. There are three commercial dry cleaning units present. The cleaning agent is perchloroethylene, and emissions are controlled by local exhaust ventilation of each machine. The three machines are vented into one 14 inch duct which is exhausted at the rate of 1000 cfm. Personal and area samples have been measured in this operation, and INMOS reports that measured levels of perchloroethylene have been below the TLV. The operator uses a respirator, gloves, and safety glasses when changing the fluid filters.

7.2 Plasma Etching

There are two types of plasma etching units used at INMOS. These include the planar and barrel reactor type etching systems. The units are within the Class 100 clean room, and the etching units are loaded under laminar flow hoods that deliver HEPA filtered air to the work area. Both plasma etching methods are operated under vacuum conditions with the system pressure being negative with respect to room pressure. The plasma gases are removed through exhaust ducts from the mechanical roughing pump to the acid scrubber. Mechanical pump oils are changed manually and recycled as hazardous waste. Both types of reactors use a 13.56 MHz radio frequency source of unknown power to produce the plasma. Some minor RF leakage was reported around the glass viewing port in the planar type reactor. Ultraviolet (UV) emissions may occur with both types of reactors.

The planar etchers use carbon tetrachloride, oxygen, argon and helium. Oxygen and tetrafluoromethane (Freon 14) are used in the barrel reactor. Gases for both types of reactors are stored in vented gas cabinets in the maintenance areas adjacent to the clean room. The exhaust rate for the gas cabinets was not specified.

A third type of plasma etching unit consists of a barrel type reactor that can contain parallel plates to hold the wafers. As with the other two types, this etcher operates under vacuum and is exhausted through the acid scrubber system. The unit is fitted with a laser end point detector. The laser wavelength and class were not reported, and the opportunity for personal exposure is very low. The laser system is interlocked to prevent inadvertent exposure during operation.

7.3 Wet Chemical Operations

Silicon wafers go through numerous wet processing steps, which principally include wet cleaning operations and wet etching operations. In some cases, solvent washers are used to dissolve organic residues from photolithographic steps.

Components of the in-line photoresist application system and quartz or glass diffusion furnace tubes are also cleaned in wet stations. The control strategy for all wet processes at INMOS includes the use of plastic wet chemical benches. The benches are located under laminar flow hoods. Air is passed through HEPA filters located in the ceiling above the work area and directed downward onto the bench surface. Acid tanks and deionized water tanks are recessed in the benches. Acid tanks are heated by electrical resistance heaters. Local exhaust ventilation of the tank is through slots located inside the tank around the top perimeter. Local exhaust of the entire bench is provided by slot ventilation located at the rear of the bench. Air flowing downward from the HEPA filters blows across the wet bench to the rear ventilation take off. Air is also presumed to move across the front of the benches and downward to the floor level, where it enters the recirculation system for the clean room via the clean service chase behind each wet station.

7.3.1 Equipment Cleaning.

The spin-on assembly consisting of circular plastic "O" rings, is removed periodically from the in-line photoresist application system and carried to a cleaning station. The cleaning station is located in the clean room change area, adjacent to the dry cleaning operation. The system consists of a wet chemical bench of plastic construction with two recessed tubs. The equipment components are cleaned in a mixture of cellosolve acetate, butyl acetate, and xylene.

The control strategy is local exhaust ventilation by means of take offs at the rear of the bench. A plastic shield is also attached to the top of the bench to protect the operator from splashes. Workers had reportedly put their heads inside the bench under the hinged shield, although they had been cautioned against doing so.

The worker performing the cleaning is required to wear personal protective equipment consisting of gloves, glasses, and apron. The workers are instructed, as a standard work practice, to keep their heads out of the hood.

7.3.2 Wet Metal Etching.

Wet metal etching is carried out at wet chemical benches made of polypropylene. The bench controls are located above the bench and approximately five feet above the floor. Normal bench construction includes a deionized water tank at the front of the bench, and one or two tanks are located at the rear for acid solutions. Adjacent to the wet bench is a spin dry operation of stainless steel construction, and next to it is a wet sink. The control strategy for wet etching stations includes air supply from a HEPA filtration unit and is directed downward onto the bench. Excess air spills to the floor level and is picked up by the return air system in the service chases. Local exhaust ventilation was reported by plant personnel, but connections could not be observed. Work practices were not observed for this operation. The personal protective equipment used by workers includes chemically resistant gloves with sleeves, aprons, and safety glasses.

7.3.3 Hydrofluoric Acid Etching.

Polycrystalline silicon layers are etched in wet stations with a mixture of hydrofluoric, nitric, and acetic acids, followed by two deionized water rinses and a spin dry station. The standard wet chemical station is used, with slot ventilation around the periphery of the acid tanks and slots along the back wall of the bench. Slot face velocities had been measured by INMOS in previous surveys but the values were not available. Bench exhausts are directed to the acid scrubber. Personal protective equipment included the usual safety glasses, aprons, and acid-resistant gloves with sleeves. Observed work practices included careful draining of wafer carriers to lessen the amount of acid droplets and fumes carried over into the deionized water tank.

7.3.4 Wet Chemical Cleaning. The wet etching station in the ion-implantation area used a mixture of sulfuric acid and hydrogen peroxide, known as "piranha etch," in two tanks located at the rear of a wet bench. The exhaust system consisted of holes, rather than slots, both around the two acid tanks and at the back wall of the bench. Slot velocities close to these holes were reported to be 70 to 105 feet per minute. The tops of the acid tanks sat slightly above (1 to 2 inches) the bench surface, and acid fumes were observed going over the tank edge down into the holes. Additionally, a plastic cover known as a "shift gate" was situated approximately 12 inches above the surfaces of the acid and deionized water tanks, with a cutout defining the zone. The reported purpose of the ship gate is to minimize the open bench area and capture more acid fumes for a given quantity of exhaust air. It also provides a zone of relatively calm air above the tanks so that fumes rising from the tank surface are not blown out into the room air by extraneous air currents or by diffusion. In addition, the two acid tanks were located at the rear of the wet station, with the deionized water tank at the front. The purpose of this arrangement is to keep the acid closest to the exhaust ports and to minimize the opportunity for the acid to spill onto the front of the bench. Personal protective equipment consisted of safety glasses, face shields, aprons, and acid-resistant gloves with sleeves.

7.3.5 Furnace Tube Cleaning. The tub wash station was a long wet chemical bench with local exhaust ventilation from a plenum located at the rear of the bench. There were two plastic wells to handle the simultaneous cleaning of two diffusion furnace tubes. The exhaust system consisted of holes along the edge of each tube well that drew fumes down into a plenum, which was exhausted at the rear. Personal protective equipment included face shields, safety glasses, aprons, and acid resistant gloves with sleeves. Work practices consisted of placing the tubes in the empty wells, filling the wells with deionized water, and then pouring hydrofluoric acid slowly into the wells.

7.3.6 Nitric Acid Etching. The nitric acid etching stations use a mixture of nitric and phosphoric acid or nitric and hydrofluoric acid. These stations are designed similarly to the other acid stations with acid tanks at the rear of the bench and deionized water at the front. The etching stations are exhausted at the rear of the bench and have movable plastic covers to minimize leakage. Personal protective equipment included face shields, aprons, and acid resistant gloves with sleeves.

7.4 Photolithographic Processes

The photolithographic process consists of an initial wafer cleaning followed by the application of photoresist. The photoresist layer is dried or "soft-baked" and the mask pattern is photographically transferred to the wafer by exposure to blue light. The exposed wafer is dried or "hard-baked" and the exposed underlying layer is then ready for further processing. These operations are described below.

7.4.1 Photoresist Application. Operators are required to wear normal clean room attire during loading and unloading of wafers. Operators work at several processes in the photolithography aisle during the work shift.

Photoresist is applied to the wafer using an automated in-line wafer processing system consisting of a deionized water spin wash, thermal drying, photoresist spin application, and thermal soft bake. Local exhaust ventilation is used at the spin operations to control mists or generated vapors and at the infrared ovens to control heat and/or vapors. Local exhaust ventilation take offs are located below the wafer surface on the spin operations and ovens. The spin operation is partially enclosed with plastic collars.

The wafer processing system is located below a laminar flow HEPA filter hood. The system is automated with a microprocessor to determine wafer motion/location and operation sequencing. Operators are required to load and unload cassettes to the system. The system is cleaned on each shift by the operator with a solution of 80 percent cellosolve acetate, 10 percent butyl acetate, and 10 percent xylene. Operators wear latex gloves during the cleaning operation. Operators also work at other operations in the photolithography aisle.

The collars used in the photoresist spin operation are removed after each shift and carried to a cleaning station described in Section 8.3.1. The operation is performed once per shift by one operator for a period of approximately 1 hour.

7.4.2 Substrate Exposure. Wafers coated with the photoresist are removed from the wafer processing station to the photolithography area. Wafers are exposed to the photomask pattern using a direct step-on-wafer system. The wafer is exposed to a blue light source with a 436 nm wavelength. The wafer exposure unit is contained within an environmental chamber with access to the chamber through sliding panels consisting of double glazed, yellow plastic. The environmental chamber contains internal controls to adjust temperature and provide a Class 100 environment by HEPA filtration of chamber air. The chamber is at positive pressure in relation to the room. Ninety five percent of the chamber air is recirculated with makeup air obtained from the surrounding room. The chamber cooling system is designed to be exhausted at 200 cfm.

The operator is seated at a video display terminal located adjacent to the chamber access panels. The panels were open during the survey but engineering interlocks to prevent worker exposure to the blue light source were not observed. The potential for operator exposure to the blue light is unknown.

Periodic maintenance required for the units includes cleaning of the wafer stepper unit with an organic solvent (unspecified), periodic oiling of the wafer stage, and replacement of the mercury light source every one to two weeks.

7.4.3 Photoresist Developing. The two photoresist developing units used at INMOS are a developer tank where wafers are immersed by hand in a developed solution followed by a deionized water rinse, and an automated spin-on application of the developer solution. Both operations use a sodium hydroxide based negative photoresist developer solution. The development of the wafer is followed by an etching operation described in Sections 4.0 and 7.2.

The developer tank is made of polypropylene plastic with a removable plastic cover. Developer solutions are manually poured into the tank from 1-gallon containers. Cassettes containing wafers are placed in the solution by operators wearing gloves and safety goggles. The solution is agitated with nitrogen, however the tank did not appear to be ventilated. The tank was not in use during the survey.

The spin-on developer operation is automated, requiring only that the operator load and unload the cassettes. The developer solution is automatically dispensed onto the wafer surface followed by a deionized water rinse. The unit did not appear to be ventilated.

Personal protective equipment requirements include gloves and safety goggles.

7.4.4 Photoresist Stripping. Following exposure and development, the photoresist layer is etched using a wet chemical or plasma etching process. The remaining photoresist is stripped in a wet chemical bath. The operation is performed at a wet chemical bench consisting of polypropylene plastic. The solution contained in an electrically heated tank recessed in the bench, is located at the rear of the bench with a deionized water rinse tank placed in front of the stripper tank. Local exhaust ventilation of the bench is provided by slots located across the rear of the bench. The slots consist of a line of holes approximately 10 to 20 mm in diameter spaced approximately 10 to 20 mm apart across the rear bench panel. The bench is located in a laminar flow HEPA filter hood.

Cassettes containing wafers are dipped manually into the tank followed by a deionized water rinse. Workers are required to wear a face shield, apron, and gloves when working at the station. Waste acids are aspirated from the tanks and the etching solution is replenished by the operator from 1-gallon containers. A control panel with temperature and process time is mounted at the top of the bench. Operators may perform other jobs in the photolithography area during photoresist stripping.

7.5 Chemical Vapor Deposition

Silicon dioxide, polycrystalline silicon, and silicon nitride are deposited on the wafer surface using an atmospheric pressure diffusion furnace system. Silicon dioxide is also deposited using continuous vapor phase deposition system. Both chemical vapor deposition (CVD) systems are described below.

7.5.1 Silicon Dioxide.

Silicon dioxide (SiO_2) is deposited on the wafer surface by the reaction of silane with oxygen. The processes used to deposit the SiO_2 layer includes a continuous vapor phase oxidation system operating at approximately atmospheric pressure and chemical vapor deposition using an atmospheric pressure diffusion furnace.

The continuous vapor phase oxidation system consists of a reaction chamber, gas control system, process display/control system, temperature control system, and exhaust/environmental control system. The process operation is automatically controlled. The unit is contained within a cabinet covered by a transparent plastic cover. Nitrogen purge zones are located at the load and unload stations at the sides of the cabinet. Wafers are placed on platens using tweezers and they are automatically transported through a preheat zone, deposition zone, and postheat zone. The platen is heated by electrical resistance which is automatically controlled. The gas control system provides automatic flow control of the silane and the dopant gases. The chamber exhaust is automatically controlled to provide a uniform deposition of the silicon dioxide in the wafer surface. Gas cylinders are stored in the gas pad located outside of the clean room fabrication area.

Atmospheric pressure diffusion furnaces are used to deposit a phosphorus-doped silicon dioxide layer on the wafer. The diffusion furnace consists of a ventilated source cabinet with process gas manifolds; the furnace cabinet containing the heating elements, support structures, quartz furnace tubes and gas scavenger box; the load station containing automated boat pullers for loading/unloading wafer carriers; and the control instrumentation.

Wafers are mounted in carriers at a laminar flow HEPA filter work station. The carriers are inserted into a quartz tube or elephant which is attached to the furnace tube and the carriers are inserted using a quartz rod. Once the wafers have been inserted into the furnace the process operation is controlled by microprocessor. Silane, phosphine and oxygen are introduced into the furnace at a controlled flow rate. A chemical reaction occurs above the wafer surface which results in the formation and deposition of phosphorus-doped silicon dioxide. The furnace tube air containing byproduct gases and unreacted process gases is exhausted through a scavenger box located at the furnace tube opening.

Process gases are delivered to the furnace in welded stainless steel lines which enter the tube at the source cabinet. Gas manifolds are located in the ventilated source cabinet.

The furnace cabinet containing the furnace tubes is enclosed and the cabinet is insulated and ventilated for temperature control.

The furnace is operated by a microprocessor which controls gas flow, tube temperature profile, sequencing, and tube cleaning with hydrogen chloride. Furnace operations are monitored and adjusted by feedback control loops. Diffusion furnace maintenance operations include removal of the furnace tubes for cleaning with hydrofluoric acid at a tube cleaning station described in Section 7.3.5.

Operators wear thermal gloves to load and unload wafers in the furnace. Operators may also perform other jobs in the furnace area including wet chemical cleaning.

7.5.2 Polycrystalline Silicon.

Polycrystalline silicon is deposited on the wafer surface by the reaction of silane at high temperatures (approximately 850 to 1000°C). The operation is performed in an atmospheric pressure diffusion furnace with automatic microprocessor control. The furnace is identical to that described above and consists of: (1) a ventilated source cabinet with process gas manifolds; (2) the furnace cabinet containing the heating elements, support structures and furnace tubes; (3) the load station consisting of a vertical laminar flow HEPA filter hood; and (4) the control instrumentation cabinet containing the system microprocessor and push-button panel. The furnace's engineering controls are identical to those described in Section 7.5.1.

7.5.3 Silicon Nitride.

Silicon nitride (Si_3N_4) is deposited on the wafer surface by the reaction of dichlorosilane and ammonia in an atmospheric pressure furnace. The furnace is similar to the unit described above and the engineering controls, work practices, monitoring systems, and personal protective equipment are similar to those described in Section 7.5.1. The process operations differ from the silicon dioxide process only in the use of dichlorosilane and ammonia as process gases.

7.6 Thermal Oxidation

An oxide layer is formed on the silicon wafer by exposing the wafer to an oxygen/hydrogen or oxygen atmosphere at high temperatures in an atmospheric pressure diffusion furnace. The operation is performed in furnaces similar to those used for chemical vapor deposition and diffusion. The furnace system consists of: 1) a ventilated source cabinet containing process gas manifolds; 2) a furnace cabinet containing the furnace tube, heating elements and support structure which is ventilated by a scavenger box at the furnace tube opening; 3) a load station; and 4) the electrical cabinet containing the control system. A detailed description of the furnace and associated control strategies is given in Section 7.5.1.

7.7 Doping

7.7.1 Diffusion. Diffusion of dopants onto the wafers is performed using direct digital control (DDC) diffusion furnaces operating at atmospheric pressure. The diffusion furnace assembly and control strategies used in the operation are described in Section 7.5.1. and should be referred to for detailed information. The diffusion process exposes wafers in a high temperature environment to the dopant. The wafers are maintained in the high temperature environment to allow the dopant or impurity to diffuse into the wafer. Ten percent phosphine in argon is used as the dopant source gas which is diluted in the furnace tube with an inert gas. The diffusion process differs from the CVD processes in the types of process gases, the operating temperature and the time that the wafers remain in the furnace.

7.7.2 Ion Implantation. Ion implantation is another method of introducing impurities or dopants into the wafer. The impurities are p- or rn-type ions created by applying a confined electric discharge to a source gas. Ions are created and accelerated through analyzing magnets that separate the desired ions. The beam is deflected to produce a uniform dose to the wafers. The implantation is performed in a sealed chamber at vacuum conditions of approximately 10^{-6} torr. Source gases include 15 percent arsine, 15 percent phosphine, and 100 percent boron trifluoride. The gases are stored in a ventilated cabinet located within the implantation unit. The gas cabinet is contained within a lead-shielded enclosure that is electrically grounded and interlocked to the power source. Three independent vacuum systems are used to maintain vacuum conditions. One system consists of an oil-sealed mechanical roughing pump which operates the load lock chambers for loading wafers. Another involves an oil-sealed mechanical roughing pump and diffusion pump which operates the target chamber, and the third system is an oil-sealed mechanical pump and diffusion or cyrogenic pump which operates the ion source. Pump oils are drained and replaced by hand. Pump exhausts are vented to the acid scrubber system.

The ion implanters are periodically cleaned with isopropanol. Cleaning of the ion source is performed in a glove box in the service chase outside of the clean room area. Radiation film badges are placed on the unit and worn by the operators to monitor X-ray radiation emissions and worker exposures.

7.7.3 Hydrogen Annealing. Wafers are heated in a forming gas atmosphere to repair damage to the wafer caused by ion implantation. The forming gas atmosphere consists of a mixture of five percent hydrogen and 95 percent nitrogen. The process operation is performed in furnaces similar to those used for chemical vapor deposition and diffusion. Wafers are loaded into carriers and placed in a quartz tube which is attached to the furnace tube opening. The carriers containing wafers are inserted manually into the furnace and the operator initiates the process cycle by push-button controls. The process operation is controlled by a microprocessor.

The furnace is ventilated by a scavenger box containing gas monitors located at the furnace tube opening where hydrogen is catalytically burned. The furnace tube is insulated and ventilated for temperature control. The source cabinet containing the gas manifold systems, where the forming gas mixture is introduced into the furnace tube, is ventilated. The furnace tube opening is in a laminar flow HEPA filter station.

Operators may perform several tasks in the area in addition to the hydrogen annealing. Operators are required to wear thermal mittens for loading and unloading wafers. Monitoring of the furnace area for hydrogen was not reported.

7.8 Metalization

Aluminum is deposited on the wafer surface to form the electrical contacts for the integrated circuit. Wafers are loaded onto a platen which is placed into a load lock chamber. The chamber is evacuated using an oil-sealed mechanical pump, and the platen is transported to the deposition chamber where aluminum is deposited onto the wafer surface by radio frequency (RF) sputtering. The process is automated with microprocessor control of the chamber vacuum, sputtering sequence, and platen location/motion. Exhausts from the pumps are released to the atmosphere. The unit is on the facility emergency power supply. Maintenance of the unit consists of an occasional cleaning of the bell jar with isopropanol.

Gold is deposited on the wafer in a separate metalization system using thermal evaporators. These units are located outside of the clean room environment. The system consists of a bell jar with the wafers mounted inside in a planetary. The system is controlled by a microprocessor. Wafers are placed in the planetary and push-button controls are used to initiate the process sequence. The chamber is evacuated by an oil-sealed mechanical pump and an oil diffusion pump which are exhausted through a stack to the atmosphere. The gold deposition system appeared to be used infrequently.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The INMOS facility represents the current state-of-the-art in clean room design using a tunnel bay layout. The process equipment present at the plant appeared to be representative of future trends (Eklund and Landrum, 1982). These trends include the use of plasma etching, wafer stepping exposure, ion implantation, DDC furnaces, and automated wafer preparation for photolithography operations.

The following is a list of specific observations, recommendations, and conclusions regarding the effectiveness of control technology at INMOS.

- The air supply system for the facility could cause clean room air to circulate into other plant areas. In an emergency, e.g., the spill of a volatile chemical or a toxic gas leak, the hazardous agent could be distributed throughout the plant. Altering the air supply system to prevent recirculation into non-production areas should be considered.

- As a waste management method, the solidification of hydrofluoric acid to a calcium fluoride sludge is an attractive alternative to the handling of liquid hydrofluoric acid waste.
- The safety, materials handling, and personal protective equipment training programs established at INMOS are well conceived. Specific training practices may be applicable to the industry in general and should be considered for detailed review.
- Flow limiting valves should be installed on gas lines from cylinders containing flammable, toxic, or corrosive gases. Solenoid valves which shut off gas supply during a power failure should also be installed on gas supply lines from cylinders containing toxic, flammable, or corrosive gases if the valves are not already present in the process equipment.
- The effectiveness of local exhaust ventilation of the wet chemical stations should be evaluated. The partial enclosures or ship gates surrounding some wet tanks may increase the effectiveness of the local exhaust in controlling process emissions.

9.0 REFERENCES

Eklund, M.H. and G. Landrum. 1982 Forecast on Processing. Semiconductor International. 5(1):43-55. 1982.