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PRELIMINARY CONTROL TECHNOLOGY SURVEY REPORT
UNITED TECHNOLOGIES MOSTEK
1215 WEST CROSBY
CARROLLTON, TEXAS 75006

to

U. S. Environmental Protection Agency
Industrial Environmental Research Laboratory
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Cincinnati, Ohio 45231

and

National Institute for Occupational Safety and Health
Division of Physical Sciences and Engineering
4676 Columbia Parkway
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by

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1.0 ABSTRACT

A preliminary control technology survey was conducted at MOSTEK Corporation, Carrollton, Texas, on December 9, 1981. The survey was conducted by Battelle Columbus Laboratories and PEDCo Environmental, Inc., as part of a control technology assessment of the electronic component industry. MOSTEK Corporation became involved in integrated circuits in 1969 and in the 1970's developed many significant products from metal oxide semiconductors.

MOSTEK manufactures metal oxide semiconductor integrated circuits, board level microprocessors, and memory systems. This preliminary survey focused on the following process operations: photolithography, ion implantation, diffusion, chemical vapor deposition, wet chemical etching, and plasma etching. The photolithographic process follows the common industry sequence of photoresist application, mask alignment exposure, and developing. Ion implantation is used to introduce impurities or dopants into the wafer surface. Diffusion is another method used to introduce dopants into a substrate to produce changes in its electrical properties. Chemical vapor deposition forms a stable compound on a substrate by the thermal reaction or decomposition of gaseous compounds. Both wet chemical and plasma (dry chemical) etching are used to remove specific materials or layers from the surface of the wafers.

General ventilation is provided within the fabrication area by laminar flow benches as well as the main exhaust system. There are local exhaust vents around the acid baths and in other process areas. Most compound gases are stored in a gas cabinet within the fabrication area. Phosphine, silane, and diborane are kept in gas cabinets in a separate room. Gases are piped from storage in welded or Swagelok^R jointed, stainless steel tubing; joints and connections are leak tested. A Matheson gas monitor is used to detect phosphine and/or arsine, and hydrogen monitors are employed in the fabrication area as well. Worker exposures to noise, microwave and radio frequency radiation, and chemicals are closely monitored.

A full-time industrial hygienist is employed at MOSTEK; corporate industrial hygienists are called in as needed. In addition, there are three full-time safety engineers. A part-time physician with a master's degree in public health and six nurses make up the medical staff. A registered nurse is

available on the premises during the week. There is a program of both preplacement and periodic physical examinations (including biological monitoring) for employees in specific job categories.

MOSTEK provides a number of training programs designed to promote worker safety including chemical, electrical, radiation, and materials handling safety; use of protective equipment; emergency procedures; and cardiopulmonary resuscitation and the Heimlich maneuver. MOSTEK has organized employee safety committees that meet monthly to review the safety record and the program's progress.

MOSTEK is recommended for detailed study in both the acid etching/ solvent cleaning and the plasma etching areas. Because plasma etching has not been frequently encountered, studying this process at MOSTEK would provide an example of a site with a good support program. In addition, MOSTEK's methods for success in achieving extremely low vapor concentrations in the wet chemical process area should be made available to the industry in general.

2.0 INTRODUCTION

A preliminary survey was conducted as part of the control technology assessment of the electronics industry (SIC 3674). The study was conducted through U.S. Environmental Protection Agency (EPA) contract 68-03-3026 through an Interagency Agreement AR 75-F0-142-0 with the National Institute for Occupational Safety and Health (NIOSH). The preliminary survey was conducted to identify and evaluate the control technology used to limit worker exposures. The information obtained from several preliminary surveys will be used to select sites for detailed assessments.

A preliminary survey was conducted on December 9, 1981, at MOSTEK Corporation, 1215 West Crosby, Carrollton, Texas. The survey was conducted by Battelle Columbus Laboratories and PEDCo Environmental, Inc., with the assistance of Mr. James H. Jones, NIOSH. The following individuals were contacted at MOSTEK:

Mr. Bob Wittkower - Corporate Safety and Health Manager
Mr. R. D. (Andy) Anderson - Security Manager
Mr. Pat Coil - Personnel Director

Mr. David Helmer - Safety Engineer
Mr. Joseph L. Hudgins - Manufacturing Mgr., Wafer Fabrication
Mr. Reynold Kelm - Manager, Wafer Fabrication
Mr. Richard A. Larsen - Corporate Counsel
Ms. Gayla McCluskey - Industrial Hygienist
Mr. Charles K. (Ken) Moody - Corporate Services Manager
Mr. Steven D. Mudgett - Safety Engineer
Mr. James E. Tindle - Vice President, Administration
Ms. Sylvia A. Waters, R.D., COHN - Supervisor, Health Services
Mr. Rick Werth - Security Supervisor.

A study protocol was provided to MOSTEK Corporate Services Manager, Mr. Charles K. (Ken) Moody, in advance of the preliminary survey. An opening conference was held with plant representatives to discuss the study objectives and methods. During this conference the plant staff provided an overview of MOSTEK's health and safety program. The plant layout, process description, specific unit operations, monitoring systems, gas handling systems, and the chemical storage program were also reviewed. Following the conference, the specific integrated circuit fabrication operations were toured.

3.0 PLANT DESCRIPTION

3.1 General

MOSTEK Corporation began its involvement in integrated circuits in 1969, and in the 1970's developed many significant products from metal oxide (MOS) semiconductors technology. In 1979, MOSTEK was acquired by United Technologies Corporation as a wholly owned division of the organization. The operations visited at MOSTEK included various process operations associated with the fabrication of n-channel metal oxide semiconductors (nMOS). The entire Carrollton, Texas facility covers an area of 1.6 million sq. ft. As of March, 1981, MOSTEK employed about 7100 individuals in a 3 shift per day manufacturing operation. Approximately 3700 of these persons are involved in direct production operations. The breakdown of workers by shift was not described.

3.2 Chemical Storage

MOSTEK uses acids, bases, solvents, and gases. Each chemical class is stored separately in diked storage areas to contain spills. Solvent storage rooms are ventilated to prevent an explosive vapor buildup.

Chemicals are stored in cases containing four 1-gallon bottles, and are transported by a cart or gondola as needed. Bottles are placed into the clean room through pass-through areas by chemical handlers. Empty acid bottles are washed in a bottle washer and placed in dumpsters segregating them from bases and solvents. Chemical handlers are specifically trained in safety and emergency procedures to follow when handling these liquids or gases.

3.3 Gas Handling System

Gas storage at MOSTEK is categorized into oxidizers and flammable gases; minimum storage distances between categories is 20 feet. Other gases (e.g., nitrogen) may be stored in either category. Cylinders are tested for leaks before being moved. Gases are transported by a gas cart from storage to the use point.

Most compressed gases within the fabrication area are stored in a gas cabinet. Nitrogen, argon, and helium do not require storage in a gas cabinet. All bottles are chained to an upright support except during transportation when they are chained to a gas cylinder cart. Toxic gases (e.g., arsine and phosphine) as well as silane and dichlorosilane are contained in ventilated gas cabinets. Silane and dichlorosilane must be stored in metal cabinets with metal exhausts.

Gases are piped from storage into the fabrication area in welded or Swagelok^R fitted, stainless steel tubing. Helium testing determines leakage at joints while bottle connections are tested with Snoop (a gas bubble testing liquid) after installation. Strategic bottles are protected by over-pressure valves to limit release in the event of line ruptures. Silane and phosphine have double regulators to provide backup in the event of a regulator failure. Solenoid valves (normally open for purge gases, normally closed for process gases) are in place on all process systems.

3.4 Monitoring System

Monitors are used in the fabrication areas to detect phosphine and/or arsine. The Matheson gas monitor is used; detection is reported as 1 percent of the TLV.

Hydrogen (flammable gas) monitors are employed in the fabrication area where hydrogen gas is used. The philosophy behind hydrogen detection is to have an early warning system. Hydrogen alarm levels are 250 ppm. The explosive limit is approximately 41,000 ppm. Early warning using the MSA7044 gives the chance to correct leaks before they become major problems.

3.5 Ventilation

General ventilation is provided within the fabrication area. This air is turned by laminar flow benches, as well as the main exhaust system. A portion of the air in the fabrication area is exhausted through vents around acid baths and other process vents. A portion of the air is also exhausted from the general ventilation system. Makeup air is conditioned and added to the recirculating air.

Process area ventilation is provided by both general ventilation and by local ventilation in the wafer fabrication area. The air intake system conditions ambient air by cooling or heating. This air is then filtered and ducted into the process area.

Air is removed from the process area through grills located near the floor. Air is also removed through local ventilation points. These points are positioned at processor stops such as the Wafer Trac^{R} photoresist application point, furnace exhaust scavenger boxes, and slots located around the baths in wet chemical benches.

Both the general ventilation system and laminar flow benches provide air recirculation. Mixing action by operation of laminar flow benches occurs because the bench takes in air at head level and forces it downward across the workbench. The air picked up by local ventilation is exhausted below waist level at the back of the bench. The general ventilation system provides air recirculation by blending a percentage of the air collected in the room with fresh air. The air is filtered and added to the plant ventilation system. The ratio of recirculated air to fresh air in the general ventilation system is estimated to be between 8 to 1 and 9 to 1 as estimated by MOSTEK facilities.

4.0 PROCESS DESCRIPTION

The primary purpose of MOSTEK's fabrication facility is to manufacture finished n-channel metal oxide-semiconductor (nMOS) integrated circuits, board level microprocessors, and memory systems. The production process includes some encapsulation of specific products. The process operations viewed during the preliminary survey were housed in Class 100 clean rooms, serviced with laminar flow ventilation, and high efficiency particulate air (HEPA) filters. The size and complexity of the MOSTEK facility prevented conducting a walkthrough survey that followed the exact flow of product fabrication during the 8 hour period allotted for the walkthrough. To make the most effective use of time, the walkthrough team focused on six process operations; photolithography, ion implantation, diffusion, chemical vapor deposition (CVD), wet chemical etching, and plasma etching. A detailed process description of each of these operations is provided in this report. Additional operations conducted at MOSTEK, but not considered here, included metalization, scribing and cutting, and thermo-compression bonding and encapsulation.

The metalization activities conducted at MOSTEK include aluminum and gold metal sputtering. The operation did not appear to present any hazardous or unusual working conditions and the exhaust system servicing the vacuum pumps was vented to the fabrication area scrubbed exhaust system.

The scribing, cutting, and thermo-compression bonding and encapsulation were viewed from outside the process rooms through glass panels along the length of an access hallway. MOSTEK uses mechanical saws to separate the individual die from the integrated circuit wafers. Local exhaust is provided to each cutting unit. Thermo-compression bonding and encapsulation operations are exhausted where epoxy glues are used.

The photolithographic process observed at MOSTEK follows the common sequence of events found throughout the industry; photoresist application, mask alignment exposure, and developing.

The application of photoresist to silicon wafers is performed using a completely automated, microprocessor-controlled, wafer processing system. The silicon wafers are loaded into the processing equipment in cassettes. Individual wafers are removed from the cassette and transported along parallel tracks to in-line process substations. The wafer is automatically mounted on an air chuck platform. Deionized water is sprayed on the spinning wafer followed by a nitrogen blow dry and prebake in an infrared oven. The wafer is transported from the oven to a second chuck platform where hexamethyldisilizane (HMDS) is spun onto the wafer. The HMDS promotes uniform adhesion of the photoresist to the wafer surface. Following application of the HMDS, the wafer remains at the station for the spin application of photoresist. A negative photoresist is applied to the silicon wafers. Finally, the coated wafer is baked in an infrared oven and unloaded into a cassette.

Substrate exposure is accomplished using a projection mask alignment with ultraviolet (UV) light exposure. Cassettes with coated wafers are loaded into the mask aligner where individual wafers are automatically removed from the cassette by a vacuum chuck. The operator aligns the mask manually through a binocular microscope. The mask and coated wafer are held together by a vacuum clamp and exposed to UV light. After a timed exposure, wafers are separated from the photomask and automatically queued into a cassette.

The photoresist developer is applied to the exposed wafer in a spin-on process similar to that used to apply photoresist. A xylene-based developer was used at MOSTEK. The developer spin-on is followed by a deionized water rinse and nitrogen blow dry. The developed wafers are finally transferred to a post- or hard-bake oven where the remaining photoresist pattern is cured. The finished wafers are loaded into cassettes and placed in staging areas for further processing.

Ion implantation is used to introduce impurities or dopants into the wafer surface. The implant pattern is determined by previous photolithographic processes. Dopants or ion impurities are created by a confined electric discharge that is sustained by the vapor 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 equipment at MOSTEK uses both gas and solid dopant sources. Solid sources are composed of arsenic dopant material. Gas sources (arsine and phosphine) are mixtures of the dopant and a carrier gas such as hydrogen. The source gases are supplied to the ion generator from 1-pound lecture bottles stored in nitrogen-purged, ventilated storage cabinets within the implantation unit.

The ion source is kept in a vacuum with four separate vacuum systems used for the source, beamline, target, and end station. The first three systems are maintained using an oil-sealed mechanical roughing pump, with a diffusion pump and/or cryogenic pump. The load and unload chambers are serviced by an oil-sealed mechanical pump. All pump systems are controlled by a microprocessor.

Cassettes containing wafers are placed in the loading chamber. Individual wafers are withdrawn automatically from the cassette and transported into a vacuum lock. The chamber is then evacuated and the wafer is transferred to the platen where it is mounted and positioned for exposure. Implantation of the wafer is controlled by the system microprocessor. Following ion implant, the wafer is transferred to the exit vacuum lock (where the chamber is purged) and a waiting cassette.

Diffusion is another method used at MOSTEK to introduce dopants into a substrate to produce changes in its electrical properties. Dopants used at the plant included n-type electron donors ($POCl_3$) and p-type electron acceptors (BBr_3). Substrate doping is performed in a direct digital control furnace. Wafers in cassettes are loaded into silica glass tubes or elephants. The elephant is placed in the load station of the furnace and connected to the furnace with a ground glass seal. A small round opening in the opposite end of the elephant receives a silica glass tube that is used to insert the carrier into the furnace at a programmed rate. The elephant is removed, after insertion is completed,and replaced with an end-cap to direct gases into furnace exhaust. The doping agents are introduced into the furnace along with nitrogen as a carrier gas. The doping agents diffuse into those areas of the substrate without a mask layer, previously removed by photolithographic processes.

Dopant diffusion into the substrate is determined by the temperature, gas flow, time sequence, and type of dopant. The dopant ($POCl_3$ or BBr_3) is contained in a quartz bubbler placed in the source cabinet of the furnace. Nitrogen is bubbled through the liquid and results in a gas containing sufficient $POCl_3$ or BBr_3 for doping. The $POCl_3$ or BBr_3 then reacts with oxygen in the furnace to produce P_2O_5 or B_2O_3, respectively. After doping, the furnace is purged with nitrogen as the doping atmosphere is exhausted. The elephants containing the doped wafers are removed from the furnace and placed in a staging area.

Chemical vapor deposition (CVD) forms a stable compound on a substrate by the thermal reaction or decomposition of gaseous compounds. Examples of CVD observed at the MOSTEK plant primarily include silicon nitride deposition performed in a direct digital control hot wall furnace. A general description of the direct digital control furnace follows.

The direct digital control (DDC) furnace system used for CVD employs a microprocessor that organizes general furnace processing via feedback control loops. The control loops are used to insert and withdraw wafer carriers at a specified rate, to raise or lower the furnace temperatures at a specified rate, to adjust the various gas flows as a function of time, and to monitor the actual temperature profile inside the furnace as a function of time. The microprocessor can clean the furnace automatically using hydrochloric acid or trichloroethane, perform an automatic calibration cycle, and tailor the dynamic performance of the furnace to a given process step. The advantage of the DDC furnace is the high degree of process replication possible with the system. Also, the system's safety feature is that it switches to nitrogen purge if either power or the computer fails.

The process equipment for CVD and diffusion consists primarily of an electronics enclosure, a jungle cabinet, a load station, furnace modules, and a source cabinet. The source cabinet is used for the diffusion furnace bubbler system, for the source dopant system, and as the intersection of the gas systems and the furnace tube.

The purpose of silicon nitride deposition in MOS integrated circuits is to facilitate their use in multilayered insulators. Silicon nitride is formed on silicon wafers in a direct digital control furnace. The wafers are loaded into boats, placed in a carrier, and inserted into the elephant. The elephant is attached to the furnace and the boats are loaded automatically into the furnace. The processing sequence is controlled by the system microprocessor described above. The wafers are heated in an atmosphere of silane (SiH_4) and ammonia (NH_3); silicon nitride is deposited on the wafer surface and hydrogen gas is liberated during the reaction. The furnace atmosphere is exhausted, by a closed ventilation system ducted into a special exhaust, after deposition of the silicon nitride film and the wafers are removed to a staging area.

Various wet chemical etching operations are used to manufacture integrated circuits. Acid etch baths containing sulfuric acid and hydrogen peroxide at 60 to 70C are used in the furnace area for wafer cleaning. Cassettes containing wafers are placed in cassette carriers which are lowered by hand both into the acid baths and the rinse baths of deionized water. Local exhaust is provided to carry away acid vapors.

Another acid cleaning step consists of spray cleaning the wafers in a nitrogen-purged, sealed, centrifugal spray unit. Wafers may be cleaned with hydrofluoric acid, ammonium hydroxide and hydrogen peroxide, or hydrochloric acid. Cassettes containing wafers are mounted in the centrifugal spray chamber and the chamber is ventilated at the bottom with a local exhaust takeoff. The operation is automated with a microprocessor controlling the unit.

Plasma etching is a dry chemical etching method used to remove a specific material or layer from the wafer surface. Plasma etching is used in the fabrication of semiconductor devices where fine line widths are required. The layer to be etched from the wafer surface may be thermal SiO_2, aluminum or aluminum alloy thin films, silicon nitride, or silicon. A photoresist layer is spun on the wafer, baked, and exposed. The wafer is then developed and hardbaked. At this point, the wafer contains a baked photoresist layer with areas of the underlying substrate exposed from the developing process. The substrate is then ready for etching and the gas used is selected based on the specific substrate.

MOSTEK has two types of plasma etching systems, planar and barrel reactor. Both plasma etching processes are located in Class 100 clean rooms under laminar flow hoods. The planar plasma etching system consists of a reaction chamber with parallel electrode plates. The top electrode is driven by radiofrequency (RF) voltage while the lower electrode holds the wafers. Wafers are loaded on platens and inserted into the reaction chamber. The chamber is sealed, purged with nitrogen, and evacuated to approximately 0.1 to 10 torr. A plasma is created between the plates by passing a reactant gas through the RF field. Ultraviolet (UV) radiation generated from the plasma may be released from the reaction chamber through the glass viewing port. However, all employees must wear polycarbonate or glass safety lenses which cut transmission of UV by 90 percent.

The plasma consists of a variety of ions and free radicals. The free radicals attack the substrate chemically but have no appreciable effect on the protective photoresist. The reaction products are removed from the chamber by the exhaust system to the local ventilation system. Sulfur hexafluoride was used as the reactant gas for parallel plate plasma etching system. The fluoride ions produced are reactive with silicon dioxide.

The barrel reactor system consists of a cylindrical chamber with the wafers vertically mounted in a fused silica carrier. A plasma is created by an RF coil outside the reactor chamber. Generally, a perforated cylinder surrounds the substrates that shunts the RF field and confines the plasma between the reactor wall and the cylinder. The reacting species pass through the perforated cylinder and chemically etch the substrate. The chemically active free radicals in the plasma react with the wafer surface, creating the etching through a reduced-pressure adsorption-reaction-deposition process. The sequence of events before etching is similar to those described above. The gas used for the barrel reactor is a mixture of tetrafluoromethane (Freon 14) and oxygen. The CF_4/O_2 mixture generates a plasma that is reactive with silicon nitride, silicon, and polycrystalline silicon. The etch is believed to be the result of atomic fluorine that diffuses to the silicon surface, forming a volatile SiF_4 which diffuses away from the surface. Oxygen appears to play an important role in the production of atomic fluorine and in the surface reactions.

The planar system's advantage over the barrel reactor system is its ability to produce anisotropic etching where the etch is primarily in one direction (generally perpendicular to the substrate surface). Wet chemical etching methods and barrel reactor plasma etching systems produce isotropic etching profiles when the etch rate is equal in all directions. Isotropic etching results in undercutting of the resist layers.

5.0 DESCRIPTION OF PROGRAMS

5.1 Industrial Hygiene

A full-time industrial hygienist is employed at MOSTEK's Carrollton, Texas, plant; corporate industrial hygienists are employed as needed. The United Technologies industrial hygiene laboratory is used as necessary for industrial hygiene consultation and laboratory services. The Continental Insurance Company Environmental Health Laboratory located in Dallas, Texas, is also consulted on matters of industrial hygiene and for laboratory services when immediate service is needed. In addition to the industrial hygienist, three safety engineers are employed at MOSTEK on a full-time basis.

The work area at MOSTEK is monitored by personal, area, and surface-wipe sampling methods. MOSTEK's Safety and Health Department uses Dupont Model P-4000 sampling pumps with high and low range capabilities. Bendix and Drager multi-gas detectors and sampling tubes are used when immediate air quality determinations are necessary. All methods used to collect and analyze air samples at the MOSTEK facility are approved by NIOSH. A Mine Safety Appliance, Model 260, Combustible Gas and Oxygen Indicator is also available for evaluation of the work environment.

Noise is evaluated by a Scott, Model 452, sound level meter. Exposures to microwave and radio frequency (RF) radiation are determined by a Narda, Model 8609, Broadband Isotropic Radiation Monitor.

Evaluations of the exhaust ventilating systems are routinely performed using Alnor velometers.

The industrial hygiene program at MOSTEK monitors worker exposures to specific agents, at specific process operations, periodically in a pattern designed specifically for the individual operation.

Workers involved in hand and wave soldering operations and at open-surface lead pots are monitored by personal samplers for inorganic lead. The monitoring is performed each time a significant change in the process occurs. Workers who are potentially exposed to arsenic are personally monitored and, as in the case of lead, monitoring is performed when the process equipment or procedure has undergone a significant change. Employees at ion implanters are monitored for exposures to both arsine (AsH_3) gas and arsenic.

In addition, MOSTEK has installed a continuous gas monitoring system to detect the presence of phosphine or arsine gas, or their carrier gases, i.e., hydrogen, or nitrogen. Continuous hydrogen gas monitors are also located in areas where hydrogen gas is used. Chemical handlers and process workers exposed to industrial solvents and etching acids are monitored by personal samplers on a quarterly or semi-annual basis. Specific emphasis is focused on trichloroethylene exposures.

Leakage measurements are taken periodically on all process equipment that could emit microwave or RF radiation. Exposure surveys of any process equipment making use of ionizing radiation are conducted according to Texas Health Department regulations.

5.2 Education and Training

MOSTEK provides its employees with a number of training programs designed to promote worker safety. These programs address the following specific topics: chemical, electrical, radiation, and materials handling safety; use of protective equipment; emergency procedures; and cardiopulmonary resuscitation and the Heimlich maneuver.

Wafer fabrication employees take the chemical safety training program semi-annually. The program includes a series of safety classes, slide presentations, and a handbook that covers the essentials of chemical safety.

This chemical safety training is also given to the chemical services, spill cleanup facility, and security employees. Repair and maintenance technicians take both the chemical and electrical safety training programs. Classes are also conducted on the use of the self-contained breathing apparatus (SCBA) for individuals in the fabrication area who are most likely to have need of the equipment.

Fire extinguisher demonstrations are given to all production employees and evacuation drills are performed in each building annually.

These training programs are given to specific employees on a periodic basis. However, before actual employment, all newly hired employees are given a general safety orientation to acquaint them with the nature of MOSTEK's work and the safety precautions they must follow during their daily activities.

MOSTEK has organized employee safety committees that meet monthly to review the safety record and progress of each program. The meetings focus on lost time prevention and review safety suggestions made by the employees.

5.3 Respirators and Other Personal Protective Equipment

The type of equipment worn and the extent of personal protection afforded MOSTEK employees depends on the tasks performed by the individual workers. General clean room attire is a minimal requirement for all fabrication process employees; this includes safety glasses or goggles, clean room gowns (bunny suits), and latex gloves. Those individuals charged with the task of handling industrial solvents or acids are required to wear closed toe safety shoes, face shields, chemically resistant aprons, sleeves, and gloves. As part of MOSTEK's industrial hygiene program, operations which might require the use of respirators during normal processing have been redesigned to engineer the exposure problem out of the worker's breathing area. In spite of the emphasis on engineering solutions to hygiene problems, some workers are given qualification physicals for wearing respirators. This is a precaution taken to ensure that, if respirators are needed, specific workers will be qualified to wear them.

Self-contained breathing apparatuses with pressure demand regulators are available for emergency use or during special maintenance activities.

5.4 Medical Program

MOSTEK's medical staff consists of a part-time physician, with a master's degree in public health, and six registered nurses. Emergency medical care is available by a registered nurse on the premises full-time during the normal workweek. On weekends, injured workers are transported to the emergency room of a local hospital.

Preplacement and periodic medical examinations are given to selected employees in specific job categories. The examinations include a series of tests conducted as part of MOSTEK's biological monitoring program, e.g., chest x-ray, audiometry, pulmonary function testing, blood chemistry, urinalysis, sputum cytology, and heavy metal screening.

5.5 Housekeeping

The fabrication areas at MOSTEK are enclosed in Class 100 clean rooms ($\leq$100 particles per cubic foot). Dust levels in these rooms are controlled by passing room air through HEPA filters located above the work areas. Production workers are required to wear bunny suits with hoods, booties, gloves, and safety glasses or goggles; individuals with facial hair are required to wear masks. These controls are designed to limit particulate levels in the fabrication area.

Additional engineering controls that eliminate many housekeeping problems have been included in the design of the facility. These engineering controls are discussed in detail in Section 7.

6.0 INDUSTRIAL HYGIENE DATA FROM PRELIMINARY OR PREVIOUS PLANT SURVEYS

Sampling data from previous plant surveys and equipment evaluations conducted by MOSTEK staff were not reviewed at the preliminary survey.

Monitoring data that are available include the results of plant surveys, personal monitoring of worker exposures, and ventilation equipment evaluations. Personal monitoring of workers has been conducted for various chemical agents and X-ray radiation. Equipment evaluations have also been conducted by plant staff to evaluate the hazard of release of ultraviolet, radiofrequency, and X-ray radiation.

7.0 DESCRIPTION OF CONTROL STRATEGIES FOR PROCESS OPERATIONS OF INTEREST

7.1 Photolithography

Microelectronic technology uses photosensitive organic compounds to delineate circuit patterns on silicon wafers. Exposure to light, particularly light at ultraviolet wavelengths, alters the resistive characteristics of these photoresist compounds. Photoresists are classified into two groups depending upon their reaction to UV light. Resists that become soluble upon exposure are called "positive" photoresists; resists that become insoluble upon exposure are called "negative" photoresists. MOSTEK uses both types of photolithographic techniques in its process operations. The negative photoresist processes were observed during the walkthrough and will be discussed below.

A photolithographic operation can be broken down into three steps: photoresist application, substrate exposure, and photoresist development. Each of these steps requires the process worker to be exposed under differing conditions to different chemical substances.

Wafer cleaning, heating, application of HMDS and photoresist, soft-bake, projection mask alignment, and hard-bake are performed under vertical laminar air flow with HEPA filtration. The spin-on process for application of HMDS and photoresist is enclosed by a protective plastic cover. The HMDS or photoresist solution is applied automatically. Local exhaust of the operation directs air downward around the perimeter of the spinning platform to a local exhaust take-off at the base of the platform. Air enters the enclosure through openings at the rear.

The projection mask alignment system contains internal environmental controls. A separate HEPA filter is located in the unit to filter air inside the unit and around the mask. A positive pressure Class 100 environment is created in the projection mask aligner. The wafer exposure area is enclosed to prevent contamination of the mask and wafer. The enclosure also serves to limit ultraviolet light emission. Ventilation to the mask alignment equipment also helps to cool the equipment. The ventilation is supplied through a 6- or 8-inch duct. Interlocks of the projection mask aligner are designed to prevent ultraviolet light emissions.

The wet chemical bench used for photoresist developing is free standing. The bench is made of polypropylene, a strong and rigid material capable of supporting heavy loads and which is also inert to acids. It is located in the photolithography area. The bench contains recessed dip tanks that hold deionized water and a stripping solution (either sodium hydroxide for positive photoresist or an organic solvent for negative photoresist). Removable handles for the wafer cassette are used to place the cassettes in the developing and rinse tanks. Local exhaust ventilation is also provided to the bench.

Process operations are monitored by automated controls. The process cycle for application of HMDS and the photoresist is controlled automatically so the photoresist application is uniform. No specific environmental monitoring of this process occurs regularly.

Personal protective equipment used in the photolithography area consists of the normal clean room attire: hood, gown, booties, latex gloves, chemical safety goggles or glasses, and closed toe shoes.

Workers use isopropanol for general equipment cleaning. This task is performed by workers wearing clean room attire.

7.2 Ion Implantation

MOSTEK conducts ion implantation of both n- and p-type dopants. The sources of these dopants are arsine and phosphine gas. The ion implantation equipment at MOSTEK is located in a standard Class 100 clean room.

Ion implantation is performed in high vacuum conditions (10^{-5} torr). The vacuum is established by a mechanical roughing pump followed by a cryogenic trap and a diffusion pump. The vacuum prevents the release of the ions into the workroom air; however, its purpose is to allow ions to travel unimpeded by the presence of air. Individual wafers are loaded into the ion implanter through loading locks that are evacuated with a mechanical pump. Before loading or unloading wafers, the lock is purged with nitrogen. Ion implant gases (boron trifluoride, phosphine, and arsine) are stored in a ventilated gas cabinet located inside the ion implanter unit.

The ion source is contained within two lead-shielded cabinets. Access to the source is through panels that are electrically interlocked to the system. The cabinets are electrically grounded.

The gas cabinet and vacuum environment of each ion implanter are vented to the acid fume scrubber system or hotwall exhaust scrubber system. MOSTEK claims this exhaust ventilation exceeds the rates suggested by the manufacturer of the implantation equipment.

Interlocks on the ion implantation vacuum system will shut down the ion implanter if leaks occur in the vacuum system. A microprocessor controls wafer cycling, determines the implant dose, and monitors the process. Hydrogen, arsine, and phosphine gas are monitored by a continuous system in the area of the ion implanters. Worker exposures to ionizing radiation are monitored by personal radiation badges and periodic Geiger Mueller surveys of the process equipment.

Personal protection requirements for workers operating the ion implanter consist of standard clean room attire. This attire includes hood, clean suit, booties, chemical safety goggles or safety glasses, latex gloves, and closed toe shoes.

The normal process work activities associated with operating ion implanters consist of running the control console, and loading and unloading wafer cassettes from the target area of the implanter. No process-specific precautions are needed during normal operation of the equipment. Maintenance of the equipment is conducted by designated maintenance workers at this plant. Toxic gas lecture bottles are mounted by designated chemical handlers who have taken the MOSTEK chemical handling course.

7.3 Diffusion

Diffusion operations at MOSTEK are performed using direct digital controlled (DDC) thermal diffusion furnaces. Dopant sources include phosphorus oxychloride and boron tribromide.

Ventilation of the DDC furnace consists of an exhaust ventilation takeoff located at the furnace tube opening, exhaust ventilation of the dopant source bubblers, and laminar air flow ventilation of the furnace loading station. Exhaust from the furnace end cap is carried first through metal ducts for a length of ten feet before entering a fully sprinkled fiberglass exhaust duct. Air flow in the furnace is directed from the source cabinet through the furnace tube to the furnace opening. A nitrogen purge of the furnace tube opening provides dilution of the reactant gases released from the furnace. The exhaust collar scavenges any gases that may be released from the furnace opening. The dopant bubblers, which supply gaseous dopant to the diffusion furnace, are located in open face compartments serviced by exhaust ventilation. The face velocity at the ventilation take-off is reported by the furnace manufacturer to be 600 to 1300 lineal feet per minute (lfpm).

The DDC diffusion furnaces are microprocessor controlled. These microprocessors control the process cycle, direct loading and unloading of the furnace, gas flow, temperature, calibration, and cleaning. A specific "recipe" is programmed for each individual process step. Hydrogen, arsine, and phosphine gases are continuously monitored in the area of the diffusion furnaces. The hydrogen gas delivery system is monitored for a number of parameters that might indicate a potential problem, including temperature and low flow. When temperatures fall below the working range of the process equipment or a reduction in gas flow is noted, the H_2 gas is automatically shut off and delivery lines are purged with nitrogen.

Personal protective equipment requirements for diffusion furnace workers include the normal clean room attire consisting of hoods, booties, clean suit, latex gloves, chemical safety goggles or safety glasses, and closed toe shoes. In addition to the basic requirements, heat-protective gloves are used by workers when unloading wafers from the diffusion furnace.

Diffusion furnace workers primarily set the microprocessor instrumentation and load-in and load-out silicon wafers. The major worker interaction with the equipment occurs during the handling of the wafers.

Wafers are received in fused silica cassettes or boats. The boats are loaded in queue onto a carrier and the carrier is placed into a silica glass tube called an elephant. The entire task is performed by a single operator at a laminar flow work bench close to the furnace. A glass plug is removed from the furnace tube and the elephant is lifted manually into the furnace loading station and attached to the furnace.

The silica glass elephant is ground at one end to promote a tight seal with the furnace tube. A small round opening at the opposite end of the elephant receives a silica glass tube called a boat puller. The boat puller is used to advance the boats into the furnace at the programmed rate and also retrieves the boats upon completion of the cycle. The process worker lifts the elephant full of finished wafer boats from the load-in area and transfers it back to the work bench. After elephant removal the end plug is reinserted.

7.4 Chemical Vapor Deposition (CVD)

The chemical vapor deposition (CVD) observed at MOSTEK is the reaction of silane (SiH_4) and ammonia (NH_4) to produce a constituent layer of silicon nitride (Si_3N_4) on a metal oxide semiconductor (MOS) chip. The process equipment consists of a hot-wall, resistance-heated, low pressure CVD or LPCVD.

The roughing pumps used to produce a low pressure environment within the CVD furnaces are vented to water scrubbers. The furnace openings are vented by exhaust collars or scavenger boxes. Reactant gases are piped to individual CVD furnaces through welded stainless steel lines.

No provision for specific environmental monitoring of this process operation was observed during the walkthrough survey. Monitoring of the process operation itself is performed by internal automatic controls through a microprocessor.

Workers are required to wear normal clean room attire during operation of CVD equipment. The attire includes boots, gowns, hoods, safety glasses or goggles, and latex gloves. No additional protective equipment is required during the normal operation of MOSTEK's low pressure, hot-wall CVD furnaces.

Worker activities in the furnace area include loading of wafer boats into quartz elephants and loading of the elephants onto the furnace tube. The wafer boats are loaded into the elephants at the laminar flow staging area across from the CVD furnaces.

7.5 Wet Chemical Processes

The silicon wafer cleaning process results in a clean, uniform, and stable surface. The cleaning operation is performed in Class 100 enclosures using ultrapure electronic grade chemicals.

The initial step in cleaning is the immersion of a cassette of wafers in a solution of sulfuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2). The solution is commonly referred to as sulfuric hydroxide ($H_2SO_4 \cdot H_2O_2$). The exact proportions of sulfuric acid to hydrogen peroxide were not specified by MOSTEK, but solutions used in the industry typically contain approximately 9 parts concentrated H_2SO_4 to one part H_2O_2. Nitric or hydrochloric acid may be added in small amounts. The initial solution is designed to remove organic residue that may have accumulated on the wafers during handling.

The second step is designed to remove unwanted silicon dioxide formed during the cleaning process. The clean wafers (in cassette) are submerged in a solution of one part hydrofluoric acid (HF) to ten parts deionized water. When oxide etching is completed, the wafers are rinsed in pure deionized water.

Following the deionized water rinse, the wafers are removed from cassettes and dried by spinning under a nitrogen blow-off.

Wet chemical benches are constructed of polypropylene and 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 wet chemical benches. The hot acid baths are heated with electrical resistance. Local exhaust ventilation of the tank is through slots located inside the tank around the top perimeter. Local exhaust ventilation of the entire bench is provided by slot ventilation with take-offs at the rear of the bench. Unlike some wet chemical benches used in the industry, there are not common "catch basins" below the bench top; however, this bench design is not unique to MOSTEK.

Workers at MOSTEK are monitored periodically for exposures to acids and organic solvents; however, no routine industrial hygiene monitoring is performed at the wet chemical process since the vapors in air are so low as to consistently fall below levels of detection. The face velocity of exhaust ducts and take-off slots located around the wet chemical operations are checked on a daily or every-other-day basis using Alnor velometers. MOSTEK has an established policy of maintaining ambient air concentrations below one-half of the TLV for any chemical. In practice, conditions in the work area show that 8-hour, time-weighted averages in wet chemical areas are two to three orders of magnitude below a given chemical's threshold limit value (TLV). This is probably because the total exhaust from a fabrication area of 24,000 square feet is about 50-60,000 cubic feet per minute.

Personal protective equipment worn by MOSTEK employees in the area of the wet chemical processes consist of standard clean room attire: safety goggles or prescription glasses, hoods, gowns, boots, latex gloves, and closed toe shoes. Workers responsible for changing the wet chemical solutions are required to wear, in addition to the above, face shields, sleeves, and aprons. During the dispatching of chemical agents, workers are required to wear rubber gloves and sleeves, aprons and safety shoes. During the mixing, disposal, or filtration of chemical solutions, face shields and safety shoes with rubber overshoes or steel toe rubber boots are required apparel. Failure to wear any of the specified equipment during certain chemical handling operation is considered a major infraction of company policy and can lead to immediate termination. Failure to wear safety items during other operations is a minor violation and can lead to termination after a four-step process.

Wafers entering the wet chemical processes of MOSTEK's fabrication facility are contained in cassettes or carriers of plastic construction. The cassettes are dipped into chemical baths and rinsing solutions using a handle.

Workers involved with dispatching, mixing, or disposing of chemical agents are specifically trained by MOSTEK.

7.6 Plasma Etching

Etching of silicon nitride is performed at MOSTEK with a continuous in-line planar dry plasma etching system using carbon tetrafluoride (CF_4) and sulfur hexafluoride (SF_6).

The dry plasma etching systems are located in the fabrication clean rooms. Vacuum pumps for each process unit are exhausted to the scrubber system through stainless steel ducts. The silicon nitride plasma etching operation is automated and involves little worker interaction with the process.

No continuous environmental monitoring of the dry plasma units was observed during the walkthrough survey. Microprocessors designed into the equipment control vacuum pumping, gas flow, process sequencing, and wafer motion.

Workers operating the dry plasma etching units are required to wear normal clean room attire, i.e., boots, gown, hood, safety goggles or glasses, and latex gloves. No additional protective equipment is required during normal operation of the dry plasma etching units.

During normal process operations, the major interaction of individual workers with the dry plasma units consists of loading and unloading wafer carriers or cassettes. The actual plasma etching process is automated allowing workers to perform other fabrication line activities.

Maintenance workers are required to periodically bleed the oil from the mechanical vacuum pumps; this task is performed manually.

8.0 CONCLUSIONS AND RECOMMENDATIONS

MOSTEK appears to have a well-controlled work environment. The combined emphasis on engineering controls and work practices seems to be effective in reducing the potential for hazardous exposure.

MOSTEK is recommended for detailed study, in both the acid etching/solvent cleaning and the plasma etching areas, as these areas are currently used in electronic processes and are expected to be used in the future. Plasma etching is a process that has not been frequently encountered; studying this process at MOSTEK will provide an example of a site that has good support programs as well as the process already in operation.

A study of the wet chemical processes would be valuable as MOSTEK has extremely low concentration of vapors in the work area. Determining these successful methods would be of benefit to the industry in general.