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16. Abstract (Limit: 200 words)

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1.0 ABSTRACT

A preliminary control technology survey was conducted at Texas Instruments, Dallas, Texas, on December 8, 1981. The survey was conducted by Battelle Columbus Laboratories and PEDCo Environmental, Inc., under U.S. Environmental Protection Agency contract through an interagency agreement with the National Institute for Occupational Safety and Health as part of a control technology assessment for the electronic component industry.

Texas Instruments (TI) manufactures integrated circuits using bipolar and metal oxide semiconductor technology. This preliminary survey focused on the following process operations: epitaxial growth, standard cleanup (a wet chemical operation), diffusion and chemical vapor deposition, photolithography, and metallization. Texas Instruments uses epitaxial deposition in bipolar circuits production to form a doped layer of crystalline silicon on silicon wafer substrates. Standard cleanup (a TI phrase) identifies wet chemical operations that clean or prepare the silicon wafers between individual process operations. Diffusion introduces 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. The photolithographic process follows the common industry sequence of photoresist application, mask alignment and exposure, developing and etching. Finally, metalization of the contact pattern for the integrated circuits is performed by either evaporative or sputter deposition of aluminum metal.

Vapors and gases emitted from processes and storage areas are controlled by local exhaust ventilation. General ventilation is also present in the work areas, but is primarily oriented toward maintaining Class 100 conditions for product quality. Approximately 90 percent of the air is recirculated, in a top-to-bottom room flow pattern.

Texas Instruments employs 34 safety engineers and 8 industrial hygienists. Two full-time physicians, four full-time nurses, and nine full-time emergency personnel comprise the medical staff. In addition, two other physicians are available part-time. There is a program of both preplacement and periodic medical examinations for selected employees.

Texas Instruments provides education and training programs in the areas of safety, materials handling, use of protective equipment, and emergency and hazard reporting procedures. Monthly safety training meetings are held to maintain the desired level of safety performance. Procedures and equipment are audited to ensure conformance to TI's safety program.

2.0 INTRODUCTION

The manufacture of electronic components, particularly semicon ductors, involves several unit processes or operations that are highly specific and are not encountered in any other type of manufacturing process. Thus, hazardous agents associated with these operations require special or novel control methods to prevent or limit emissions. This control technology assessment will identify the best means of controlling emissions and exposures in the semiconductor industry. Upon completion of control technology studies, research needs and priorities can be defined based on the information obtained. Preliminary surveys, such as this one at Texas Instruments, are conducted to identify and evaluate the control technology used to reduce emissions and work exposures. This information will then be used to select sites for more detailed assessments.

A preliminary survey was conducted on December 8, 1981, at Texas Instruments, 13500 North Central Expressway, Dallas, Texas. This survey was conducted under U.S. Environmental Protection Agency (EPA) Contract 68-03-3026 through interagency agreement AR 75-FO-142-0 with the National Institute for Occupational Safety and Health (NIOSH). The survey was conducted by Battelle Columbus Laboratories and PEDCo Environmental, Inc., and assisted by Mr. James H. Jones, NIOSH. The following individuals were contacted at Texas Instruments:

Mr. Junius C. McElveen, Jr., Attorney, Seyfarth, Shaw, Fairweather, and Geraldson
Mr. Walter Sutton, Jr., Corporate Counsel
Mr. Bill B. Turney, Corporate Safety Director
Mr. Robert D. Harris, Manager, Safety Engineering
Mr. Richard D. Ashmore, Senior Safety Engineer
Mr. Eugene V. Boren, Senior Safety Engineer
Ms. Frances S. May, Industrial Hygienist, Corporate Safety

The study protocol was provided to Mr. McElveen by mail before the preliminary survey. An opening conference was held with plant representatives to discuss the study objectives and methods. A detailed description of the health and safety programs at the Texas Instruments facility was provided by the staff. The plant structure, design, and layout, process operations, monitoring systems, gas handling systems, and chemical storage were reviewed.

Following the opening conference, the plant's production areas, gas and chemical storage areas, air handling systems, and waste management facilities were toured. A closing conference was held following the survey.

3.0 PLANT DESCRIPTION

3.1 General

The operations visited at Texas Instruments' Dallas, Texas, facility included various process operations associated with the fabrication of both bipolar and metal oxide semiconductors (MOS). The majority of the integrated circuit production at the Texas Instruments facility is performed over 1.0 million sq. ft. (92,900 m^2) of space in a steel and masonry building.

The exact number of employees is considered proprietary by TI. The linear front end, which is the operation that was visited, employs between 400 and 800 employees. Approximately 66 percent of the employees are involved directly in device manufacturing. The remaining 34 percent are indirect labor and exempt personnel such as engineering, supervisory, and clerical employees. Direct labor is apportioned uniformly across three production shifts. Indirect labor and exempt labor are mostly assigned to the first shift.

3.2 Chemical Storage

Texas Instruments uses a system of gallon glass bottles for chemicals handling. Deionized water is plumbed into the system. Arsenic spin-on is used in smaller bottles.

Bubblers of dopants such as BBr_3 and $POCl_3$ are used. These bubblers are standard Schumacher design.

Chemicals in bottles are stored in ventilated cabinets. Bulk chemicals are stored in ventilated rooms with a spill collection system. Oxidizers and organic compounds are stored in separate areas.

3.3 Gas-Handling System

A plant gas system supplies H_2, O_2, air, and N_2. HCl gas, arsine, phosphine, silane, and carbon tetrafluoride are stored in gas bottles in areas of use. Bottles are stored in ventilated cabinets, and are changed by designated workers. In silane cabinets, sprinklers are installed in case of a fire caused by the bottle venting inside the cabinet.

The gas tubing is made of stainless steel with welded connections. The facilities department installs and checks the tubing for integrity by pressure decay testing.

3.4 Ventilation System

Overall ventilation is provided by a general air-handling system. This system exhausts air from the ceiling through HEPA filters, and picks it up through grates installed in the floor. This air is then blended with filtered makeup air and conditioned for temperature and relative humidity. Approximately 80 to 90 percent of the air is recirculated, and blended with treated makeup air. Extensive local exhaust ventilation is provided on process equipment and at wet chemical baths. Local ventilation is exhausted through a wet scrubber in the epitaxy area. The other local ventilation in the plant is exhausted directly to the atmosphere.

A SCRAM system is provided for removal of air from the epitaxial area. This system purges the area with air directly to an exhaust system which is exhausted to the atmosphere. This system can be activated both manually and with an automatic H_2 monitor when the hydrogen level exceeds 300 ppm.

3.5 Monitoring Systems

Hydrogen monitors are used in the epitaxial reactor. The monitors provide an alarm if the H_2 concentration reaches 300 ppm, and activates the SCRAM system. No other on-line monitors are present.

4.0 PROCESS DESCRIPTION

The primary activity of the fabrication facility visited at Texas Instruments is the manufacture of linear integrated circuits using bipolar and MOS technology. The process operations viewed during the preliminary survey are housed in Class 100 clean rooms, serviced with laminar flow ventilation and high-efficiency particulate air (HEPA) filters. The size and complexity of the Texas Instruments facility prevented conducting a walkthrough survey that followed the exact flow of the product. To make the most effective use of time, the walkthrough team focused on six process operations in depth; epitaxial growth, standard wet chemical cleaning (called "standard cleanup" at TI), diffusion and chemical vapor deposition (CVD), photolithography, and metalization. Packaging and some mask repair are also done at this site but were not viewed. A detailed process description of each of these operations is provided in this writeup.

Texas Instruments uses the epitaxial growth operation to form a layer of doped crystalline silicon on silicon wafer substrates that will become bipolar integrated circuits. In this process, a film is grown on each silicon wafer to create a single-crystal layer with specific electrical properties. Texas Instruments uses vertical and horizontal gaseous phase growth techniques to produce the film.

"Standard cleanup" is a phrase used by Texas Instruments to identify wet chemical operations to clean or prepare the silicon wafers between individual process operations. The standard cleanup observed at Texas Instruments was achieved using an automated wet chemical cleaning unit made by FSI. The cleanup sequence begins with the loading of wafers into the spray chamber. The lid on the unit is lowered and a programmable microprocessor controls the dispersal of the etchant chemicals, deionized water rinse, and

Chemical vapor deposition (CVD) is the formation of a stable compound on a substrate by the thermal reaction or decomposition of gaseous compounds. An example of CVD observed at the Texas Instruments plant was spin drying in an N_2 atmosphere of the wafers. Upon completion of the cleaning cycle, the unit is opened and the wafers are removed.

Diffusion is used at Texas Instruments to introduce dopants into a substrate to produce changes in its electrical properties. During the walkthrough survey, arsenic was used as a dopant to create n-type electron donors. Doping of the substrate is performed in a direct digital control furnace. Wafers, coated with a proprietary mixture containing arsenic, are loaded in cassettes into silica glass tubes. The tube 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 tube receives a silica glass tube that is used to insert the carrier into the furnace at a programmed rate.

Diffusion of the dopant into the silicon substrate is determined by the temperature, gas flow, time sequence, and type of dopant. Following doping, the furnace is purged with nitrogen while the doping atmosphere is exhausted. The tube containing the doped wafers are removed from the furnace and placed in a staging area.

Doping is also performed using arsenic in a solvent. The dopant is "spun on" using an apparatus similar to a Wafer-Trak system. The solvent is then driven off in an electrically heated oven which is exhausted to the plant exhaust system.

silicon nitride deposition. The deposition of silicon nitride is performed in a direct digital control hot wall furnace.

The direct digital control (DDC) furnace system includes a microprocessor that organizes the overall furnace processing using 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 automatically clean the furnace 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. A disadvantage of the system is that all control is lost if the computer fails.

The primary components of the system include an electronics enclosure, jungle cabinet, load station, furnace modules, and source cabinet. The source cabinet is used for the diffusion furnace bubbler system, source dopant system, and as the point where the gas systems interface with the furnace tube.

The purpose of silicon nitride deposition in MOS integrated circuits is for use in multilayered insulators. Silicon nitride is formed on silicon wafers in a DDC 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 automatically loaded. The processing sequence is controlled by the system microprocessor as described above. The wafers are heated in an atmosphere of silane (SiH_4) and ammonia (NH_3). A chemical reaction occurs at the surface of the wafer, and silicon nitride (Si_3N_4) is deposited while hydrogen gas is liberated. When deposition of the silicon nitride film is completed the furnace atmosphere is exhausted and the wafers are removed to a staging area.

The photolithographic process at Texas Instruments follows the common sequence of events found throughout the industry which includes photoresist application, mask alignment and exposure, and developing. Photomask production is performed at this Texas Instruments facility, but was not viewed during the survey.

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. The wafer remains at the station for the spin application of photoresist. A negative or positive 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 performed 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 through a binocular microscope by hand. The mask and coated wafer are held together by a vacuum clamp and exposed to UV light. Following a timed exposure, wafers are separated from the photomask and queued automatically into a cassette.

The photoresist developer is applied to the exposed wafer in a spin-on process similar to that used to apply photoresist. The finished wafers are loaded into cassettes and placed in staging areas for further processing.

Metalization of the contact pattern for integrated circuits produced at Texas Instruments is performed using either evaporative or sputter deposition of aluminum metal. Wafers are mounted in planetary holders manually with tweezers. The operation is performed in a wafer staging area near the electron gun evaporator or sputtering equipment. The planetary holder containing the wafers is placed in a chamber that is sealed and pumped down to a low vacuum. The metal material is then deposited over the wafer surface while the planetary holder is rotated. Finished wafers are removed by repressurizing the chamber and manually removing the planetary holders.

5.0 DESCRIPTION OF PROGRAMS

5.1 Industrial Hygiene

Thirty-four full-time safety engineers and eight full-time industrial hygienists are employed at Texas Instruments. The company does not, as a rule, hire outside consultants when safety, hygiene, or engineering problems arise, but rather relies on the experience of their corporate staff.

Industrial hygiene monitoring of process operations is performed on a periodic basis and as required by specific OSHA standards (i.e., noise, lead, and arsenic). Continuous monitoring of specific process areas is performed for combustible carrier gas (H_2) in dopant sources (AsH_3, PH_3). Ventilating equipment is checked for proper face velocities on a monthly basis. Monitoring of process operations, workplace emissions, or equipment performance is conducted in response to both employee complaints and observations by safety/industrial hygiene personnel.

Work areas are designed with safety considerations as prime construction criteria. Drawings of proposed work stations, exhaust equipment, monitoring equipment, and chemical handling facilities are approved by the safety department before actual construction begins. Newly installed equipment is checked by the safety staff to see that performance requirements are met.

Safety standards exist at Texas Instruments for the proper use of hazardous chemicals. Hazardous chemicals requested by the user must have a permit issued by the facility's safety staff. The staff determines proper receiving, storage, use, and disposal of each agent before a permit is issued. Chemical agents are identified as approved, restricted, or forbidden. Approved chemicals are used under general safety rules. Restricted chemicals are dispensed only to process permit holders. Forbidden chemicals cannot be used in the plant.

5.2 Education and Training

Education and training programs are provided to Texas Instruments' employees in the areas of safety, materials handling, use of protective equipment, and emergency and hazard reporting procedures. The training includes both orientation for new employees and "refresher" courses in safety procedures.

The formal safety training program at Texas Instruments consists of 1) a 5-day orientation, 2) monthly safety training meetings, 3) a front-end certification program, and 4) special emphasis classes.

The 5-day orientation is given to new employees. The course covers chemical safety, general safety, training specific to the employee's position, and an orientation to Texas Instruments' "new employee safety orientation checklist".

Monthly safety training meetings are held to maintain the desired level of safety performance. Safety films are presented and fire extinguisher use is reviewed.

The front-end certification program is an accounting procedure designed to ensure that procedures and equipment used in the production area conform to the requirements of Texas Instruments' safety program. Safety procedures, process operations, and wearing of personal protective equipment are all audited. New equipment must receive certification before being placed into active use. The certification procedure incorporates many safety considerations.

Special training educates Texas Instruments' employees in cardiopulmonary resuscitation (CPR), the use of Scott AirPaks, and the dangers of high voltage equipment.

5.3 Respirators and Other Personal Protective Equipment

It is an established policy at Texas Instruments that all process equipment and workplace environments be designed to preclude having to require the use of respirators. Process ventilation is provided which, under normal operating conditions, prevents worker exposure to hazardous agents. Protective breathing devices, in the form of self-contained breathing apparatus (Scott AirPaks), are available for emergency use.

Personal protective clothing is required apparel for many of the Texas Instruments' employees and standard clean room attire is required in the device fabrication areas. This clothing includes safety goggles, clean room suits, head cover, and gloves. Safety glasses and safety shoes are required in specific areas, including areas of materials handling. Chemical-resistant clothing and gloves are worn during chemical handling operations.

5.4 Medical Program

The medical program at Texas Instruments is staffed by two full-time physicians, four full-time nurses, and nine full-time emergency personnel. In addition, two other physicians are available for part-time on-premises duty. Both preplacement and periodic medical examinations are performed at the Texas Instruments facility. The examinations are performed selectively in compliance with the provisions of the Occupational Safety and Health Act's standards on lead and arsenic. Emergency showers and eye washes are located throughout the production area. Emergency oxygen is available from the medical team and Scott AirPaks are strategically located throughout the facility.

5.5 Housekeeping

A formal program of general housekeeping was not discussed during the walkthrough. It was noted that Texas Instruments, in addition to its program in safety and industrial hygiene, does have an effective system of housekeeping. Work areas in fabrication processes were maintained in a clean, orderly fashion. Aisles between process equipment were free of obstructions and clutter. Small quantities of chemicals used during the process operations were promptly stored after use.

6.0 DESCRIPTION OF CONTROL STRATEGIES FOR PROCESS OPERATIONS OF INTEREST

6.1 Epitaxial Growth

The epitaxial growing operations observed at Texas Instruments used either a 60 Hz, 80 kW radiofrequency energy source or a 300 amp radiant heat source. Nitrogen (N_2) is used as a purge gas. Hydrogen (H_2) is used as a carrier gas and as part of the epitaxial growing atmosphere. Sources of silicon included tetrachlorosilane ($SiCl_4$) and dichlorosilane (SiH_2Cl_2). Arsine (AsH_3) and phosphine (PH_3) gases are used as dopant sources.

The epitaxial growth furnaces are located in a separate room away from the general fabrication area. Each furnace is exhaust-ventilated to remove reactant gases from the epitaxial growth chamber. These gases, including species of chlorinated silane, hydrogen, nitrogen, and various dopants, are exhaust-ventilated to a PMC water-type scrubber. The room is also equipped with a SCRAM fan system to rapidly exhaust the room air in the event of an emergency. The ventilating systems in the epitaxial growing area are checked on a monthly basis.

Hydrogen gas (H_2) concentrations are continuously monitored in the epitaxial furnace room. Hydrogen, which acts as a carrier gas during epitaxial growth, is used as an indicator of potential arsine gas release. If hydrogen gas concentration in the epitaxial furnace room is detected above 300 ppm, the SCRAM system activates and automatically sounds an alarm.

Routine industrial hygiene monitoring for arsenic is performed in accordance with OSHA regulations. Routine monitoring is performed even if no complaint or concern is voiced about the process operation, typically once every 18 months. Sampling is also performed following employee complaint.

The epitaxial equipment used at Texas Instruments is microprocessor-controlled and monitored by the process worker. Wafers are loaded into the epitaxial vacuum chamber and the chamber is closed, evacuated, and purged with N_2. The reactor is then heated to about 1200 C, and HCl introduced to etch the water surface. Dichlorosilane or tetrachlorosilane are then added as are PH_3 or AsH_3. The doped layer is formed in this manner. Following the deposition of the epitaxial layer, the chamber is cooled and again purged with H_2, and then with N_2 before opening. The process worker removes the finished wafers and repeats the entire process.

6.2 Standard Cleanup

Standard cleanup of the silicon wafers is performed in automated microprocessor-controlled units made by FSI. A solution of sulfuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2) is used to clean the wafers. Deionized water is used as a rinse and N_2 gas purges the spray etching chamber and dries the wafers.

Ventilation provided to the wet chemical operations at Texas Instruments is similar to ventilation found throughout the industry. Wet chemical baths in clean room areas are located under laminar air flow units with HEPA filters. Exhaust ventilation is provided through slots located around the lip of each bath and at the back wall of the laminar flow hood. Wafers are placed in a time clock controlled unit which submerges and removes them from the bath.

FSI units differ from manual wet chemical operations. Exhaust ventilation is provided to the spray chamber. The chamber is purged with N_2 and exhausted after each cycle to remove any chemical fumes or aerosols generated during the cleaning process. The unit is exhausted through a noncorrosive system which maintains the cabinet at -1.5 inches of water during operations. Use of this unit thereby limits the exposure of assembly workers to H_2SO_4, since this operation is totally enclosed.

Process workers load cassettes of wafers into the FSI unit, close the spray chamber lid, and start the processor-controlled cleaning sequence. Finished wafers are unloaded by workers and the process is repeated. Trained chemical handlers replenish the wet chemical solutions. The chemicals are poured into the chemical reservoirs of FSI units manually.

Standard clean room attire is required in the device fabrication areas consisting of latex gloves, lint-free hoods or head covers, lint-free suits, and booties. Safety glasses and closed toe shoes are also required in the fabrication area.

Process workers involved in the handling, dispensing, or collecting of wet chemicals are required to wear rubber gloves, chemical-resistant aprons, and face shields.

6.3 Diffusion and Chemical Vapor Deposition (CVD)

The diffusion doping and CVD operations observed at Texas Instruments included arsenic drive diffusion and silicon nitride deposition. CVD of silicon nitride is achieved using ammonia (NH_3) or nitrous oxide and silane (SiH_4). The drive diffusion operation and the CVD operation are both performed in tube furnaces. The sequence of operations and outward appearance of the equipment are similar.

Arsenic drive diffusion is performed using a Wafer-Trak and a diffusion furnace. An arsenic containing solution is spun onto the wafer in the Wafer-Trak, in an enclosed chamber with local ventilation. The wafer is then heated to drive off solvent vapors, and then cooled. The wafers are transferred to a diffusion furnace, where the arsenic dopant is "driven" into the wafer.

Because the doping is performed with a spun-on liquid, the arsine gas in the doping process is eliminated. The potential for worker exposure to arsenic-bearing vapor is thereby reduced, which represents a process improvement from the industrial hygiene standpoint.

Ventilation of the DDC furnace consists of an exhaust ventilation take-off located at the furnace tube opening, exhaust ventilation of the dopant source bubblers, and laminar air flow ventilation of the furnace loading station. 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 in the range of 600 to 1300 linear feet per minute (lfpm).

It is policy at Texas Instruments to perform routine monitoring on all process equipment using toxic agents regulated by OSHA. Arsenic diffusion doping is monitored initially during process startup. The monitoring is continued in cases of questionable reading or high levels and on an 18-month routine basis thereafter. Diffusion furnaces involved in hydrogen annealing of ion-implanted wafers are equipped with H_2 burn-off mechanisms that oxidize the excess H_2 to water.

The primary work activities of diffusion furnace workers consist of setting the microprocessor instrumentation and loading and unloading of silicon wafers. The major worker interaction with the equipment occurs during the handling of the wafers. The use of Direct Digital Control (DDC) reduces the potential of worker exposure to toxic gases and heat, because he is not at the load end when materials are added or withdrawn. DDC also minimizes the potential to turn on the wrong gas on a furnace.

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 into the furnace loading station and attached to the furnace by hand.

The silica glass elephant is ground at one end to promote a fairly 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. The boat puller 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.

6.4 Photolithography

Texas Instruments uses a KTI and Hunt photoresist polymer for their photolithographic process. The exposed photoresist is developed using a proprietary solution and a butyl acetate rinse. Both photoresist application and developing and rinsing operations are performed in GCA Wafer-Trak coaters and developers. The photoresist is applied using a spin application followed by a soft bake and ultraviolet light exposure. Exposed wafers are then developed in a proprietary solution and rinsed in butyl acetate. A final infrared bake is performed to cure the finished photoresist pattern.

Wafer cleaning, heating, application of HMDS and photoresist, soft bake, projection mask alignment, hard bake, and developing and rinsing are performed in Wafer-Trak systems under vertical downward laminar air flow with HEPA filtration. The spin-on process for application of HMDS and photoresist is enclosed with 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 located at the base of the platform. Air enters the enclosure through openings in 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 and also serves to limit ultraviolet light emission. Ventilation to the mask alignment equipment also helps in cooling the equipment. Interlocks of the projection mask aligner are designed to prevent ultraviolet light emissions.

The wet chemical bench used for photoresist is of plastic construction and is located in the photolithography area. The bench contains recessed dip tanks that hold deionized water and a stripping solution. Local exhaust ventilation is also provided to the bench.

Standard clean room attire is required in the photolithographic areas. This consists of latex gloves, lint-free hoods or head covers, lint-free suits, and booties. Safety glasses and closed toe shoes are also required in the fabrication area. Process workers involved in the handling, dispensing, or collection of wet chemicals are required to wear rubber gloves, chemical-resistant aprons, and face shields. Steel-toed safety shoes are required for material handlers only.

Process workers' interaction with the photolithographic process primarily involves the loading and unloading of cassettes of wafers into the automated equipment or chemical baths. The remaining activity consists of monitoring the operatign. Wet chemical operations and photoresist reservoirs are replenished by trained wet chemical handlers.

6.5 Metalization

Evaporative or sputter deposition of aluminum, titanium, and tungsten is performed at Texas Instruments. The deposition is accomplished using either electron gun heating or radiofrequency sputtering. The majority of the metalization observed at Texas Instruments consisted of aluminum deposition. Definition of the contact pattern is achieved by phosphoric acid (H_3PO_4) etching.

Evaporation and sputtering are performed in sealed stainless steel or glass chambers under vacuum conditions. Both systems use oil-sealed mechanical pumps, cryogenic traps, and diffusion pumps. Pump gases are vented along with the chamber exhaust to a water scrubber.

Periodic industrial hygiene sampling is conducted at the request of a safety engineer during a process change, or in response to an employee complaint. Exhaust ventilation provided to the vacuum chamber is periodically checked to ensure proper operation.

7.0 CONCLUSIONS AND RECOMMENDATION

Texas Instruments is a major manufacturer of MOS and bipolar components. The work environment appears to be well controlled. The technology used is representative of that used in most semiconductor processes today, except for the diffuson drive, arsenic doping process, which is advanced when compared to arsine gas doping.

TI would be a good candidate for a follow-up, detailed survey. A major area to concentrate on would be the epitaxial reactive area, especially the monitoring and SCRAM systems. The diffusion drive doping process would also be valuable to study relative to the arsine doping process.

The TI general ventilation scheme may be less desirable than those which remove exhaust slightly above the floor level. A spilled chemical could penetrate the grill. The exhaust carried across the spill could then carry fumes from a spilled chemical throughout the plant, especially since 90 percent of the plant air is recirculated. Measures to control this problem should be evaluated.