

IN-DEPTH SURVEY REPORT:

CONTROL TECHNOLOGY FOR THE
MICROELECTRONICS INDUSTRY AT
UNITED TECHNOLOGIES CORPORATION'S
MOSTEK FACILITY, CARROLLTON, TEXAS

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SIC CODE: 3674

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INTRODUCTION

BACKGROUND FOR CONTROL TECHNOLOGY STUDIES

The National Institute for Occupational Safety and Health (NIOSH) is the primary Federal agency engaged in occupational safety and health research. As part of the Department of Health and Human Services (formerly the Department of Health, Education, and Welfare), it was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct a number of research and education programs separate from the standard setting and enforcement functions carried out by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards. The Engineering Control Technology Branch (ECTB) of the Division of Physical Sciences and Engineering has been given the lead within NIOSH to study the engineering aspects of health hazard prevention and control.

Since 1976, ECTB has conducted a number of assessments of health hazard control technology on the basis of industry, common industrial processes, or specific control techniques. Examples include studies of the foundry industry, various chemical manufacturing or processing operations, spray painting, and

the recirculation of exhaust air. The objective of each of the studies has been to evaluate and document effective control techniques for the control of potential health hazards in the industry or process of interest and to create a more general awareness of the need for and availability of effective control measures.

Such studies are carried out in steps or phases. Initially, a series of walk-through surveys is conducted to select plants or processes with effective and potentially transferable control concepts or techniques. These are followed by in-depth surveys to determine the parameters of these controls and their effectiveness. The results of these in-depth surveys are used as a basis for preparing technical reports and journal articles on effective hazard control measures. Ultimately, the information gathered from these research activities forms a publicly available data base on hazard control techniques for the use of health professionals responsible for preventing occupational illness and injury.

BACKGROUND FOR THE MICROELECTRONICS INDUSTRY STUDY

The electronic components manufacturing industry, in particular the semiconductor (SIC 3674) manufacturing or microelectronics industry, has grown tremendously in the last decade. In 1977, this industry employed approximately 114,000 persons. A number of hazardous materials are used in the industry. These include arsine, phosphine, and boron. Little information is available on worker exposures to these materials, but according

to a Cal/OSHA study (1981), only a few plants have adequate controls for handling toxic gases such as arsine and phosphine. The Cal/OSHA study and a previous NIOSH study on the photovoltaic (NIOSH 1980) industry indicated that substances like arsine might pose an arsenic hazard to microelectronics workers.

BACKGROUND FOR THE MOSTEK SEMICONDUCTOR SURVEY

This in-depth survey was performed as part of a larger data-gathering effort to characterize basic exposures and describe the processes and controls so that an assessment can be made of the hazard control technology applied within the microelectronic industry. It is hoped that the firm visited during this survey and similar facilities throughout the industry will find the results presented herein useful in their attempts to control occupational hazards associated with production activities.

The MOSTEK facility at Carrollton, Texas, was selected for study on the basis of a preliminary walk-through survey conducted on November 30, 1982 (NIOSH 1983). This facility (which is operated by United Technologies) allowed NIOSH representatives to observe the fabrication of integrated circuits, an operation that involves a range of process and control technologies

Six of the many process operations common to the fabrication of integrated circuits were studied in detail: wet chemical stations, diffusion, ion implantation, radio-frequency, radiation sources, and gas handling and distribution systems.

PLANT PROCESS DESCRIPTION

This section describes the physical plant selected and various individual process operations at the MOSTEK facility. The fabrication of integrated circuits is not easily described because the process steps represent a mixture of both job shop and line operations, which may be repeated many times during the complete fabrication process. Indeed, many of the individual steps could be considered distinct processes in themselves. For the most part, the process descriptions in this report address discrete operations and interrelate these operations only when necessary to improve the reader's understanding. Throughout the discussion, the reader is referred to information sources that provide more detailed descriptions of the fabrication steps should such details be desired.

GENERAL DESCRIPTION

MOSTEK Corporation first became involved in integrated circuits in 1969, and in the 1970's developed many significant products with the metal oxide semiconductors (MOS) technology. In 1979, MOSTEK was acquired by United Technologies Corporation as a wholly-owned division of that organization. The operations

surveyed at MOSTEK included various process operations associated with the fabrication of n-channel metal oxide semiconductors (NMOS). The entire Carrollton, Texas, facility covers 1.6 million square feet. In 1981, MOSTEK operated three shifts per day and employed about 7100 individuals. Approximately 3700 of these persons were involved in direct production operations.

CHEMICAL STORAGE

MOSTEK uses a number of acids, bases, solvents, and gases during the fabrication of NMOS integrated circuits. Each of the liquid classes of chemicals 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 to the point of use by a cart or gondola as needed. Chemical handlers place the bottles in the clean room through pass-through areas. Empty acid bottles are washed in a bottle washer and then placed in dumpsters. Chemical handlers are specifically trained in the safety and emergency procedures that are to be followed when handling these liquids or gases.

GAS HANDLING SYSTEM

Gas storage at MOSTEK is categorized into oxidizers and flammable gases; minimum storage distances between the two categories is 20 feet. Other gases (e.g., nitrogen) may be stored near either category. Cylinders are tested for leaks

before being moved, and gas cylinders are transported by a gas cylinder handling cart from storage to the point of use.

The toxic or hazardous (pyrophoric) gases used in the fabrication area are stored in gas cabinets; however, nitrogen, argon, and helium do not require such storage and as a result are located outside gas cabinets. All bottles are chained to an upright support except during transportation, at which time they are chained to the gas cylinder cart. Arsine, phosphine, silane, and dichlorosilane are four examples of dangerous gases that are contained in ventilated gas cabinets. Because of the pyrophoric nature of silane and dichlorosilane, these gases are stored in all-metal cabinets with metal exhaust ducts.

Gases are piped from the gas cabinets into the fabrication equipment in welded or Swagelok[®]-fitted, stainless steel tubing. Joint leakage is determined by helium testing, whereas bottle connections are tested with Snoop[®] solution after installation. Toxic gas distribution is regulated by pressure-control valves, which limit release in the event of line ruptures. Silane and phosphine have double regulators that provide backup in the event of a regulator failure. Solenoid valves (open for purge gases and closed for process gases when not actuated) are in place on all process systems.

MONITORING SYSTEM

Matheson[®] toxic gas monitors are used in the fabrication areas to detect phosphine and arsine emissions. Detection is reported when gas levels reach or exceed the TLV.

Mine Safety Appliicance, combustible gas monitors (MSA7044) are used to detect hydrogen (H_2) in the fabrication area. The philosophy behind the use of a hydrogen detection system is two fold: first as detection for explosive H_2 and second as an indication of the presence of hazardous gas/ H_2 mixtures. This early warning system allows leaks to be corrected before they become major problems.

VENTILATION

General ventilation within the fabrication area is provided by laminar-flow high-efficiency absolute (HEPA) filters and a central exhaust ventilation system.

Ambient air that has been conditioned by cooling or heating is filtered and ducted into the process area to provide make-up air. Eighty to ninety percent of the clean room air is recirculated

Air is removed from the process area through grills located near the floor and through local exhaust ventilation points positioned at various points in the processing, such as the Wafer Trac[®] photoresist application point, furnace exhaust scavenger boxes, and slots located above the baths in wet chemical benches.

Both the general ventilation system and laminar-flow HEPA filters provide air recirculation. The laminar-flow units are located in the ceiling and provide a flow of clean air downward across the workbench. The exhaust ventilation system removes air from the individual process operations and directs it to a

20,000-cfm wet scrubber system. The furnace exhausts, all wet benches, plasma etchers, and ion implantation units are exhausted to a water-spray scrubber. Exceptions to this emission control design are the presence of separate injector venturi scrubbers on process exhaust containing silane or dichlorosilane and an afterburner on processes exhausting arsine gas

PROCESS DESCRIPTIONS

The fabrication sequence used for the manufacture of n-channel metal-oxide-semiconductor (NMOS) integrated circuits varies with the specific type of device being manufactured. The specific sequence in which these process operations are performed is not presented. Colclaser (1980) provides a general processing sequence for NMOS integrated circuits, and this study should be consulted for a more detailed review of the fabrication process. Several process operations occur more than once in the fabrication sequence, and some equipment is used for more than one process operation. The in-depth survey focused on six process operations: wet chemical stations (acid etching and cleaning), diffusion, ion implantation, radio-frequency radiation sources, and gas handling and distribution systems. Additional operations at MOSTEK that were not considered during this survey include: photolithography, chemical vapor deposition, metallization, scribing and cutting, thermo-compression bonding, and encapsulation

Wet Chemical Stations

Various wet chemical operations are performed at MOSTEK during the development of NMOS integrated circuits, but most of these operations are wafer etching operations. The following etching operations were observed: 1) hydrofluoric acid etching of silicon dioxide, 2) nitric acid etching of aluminum, and 3) sulfuric peroxide ($H_2SO_4 + H_2O_2$) cleaning. The wet chemical etching and cleaning are performed by immersing the wafers in an acid solution. The wafers are contained within a plastic cassette carrier equipped with a plastic handle. These etching and cleaning operations are performed in acid bath tanks recessed in polypropylene benches similar to laboratory-type hoods. Ventilation is provided by slots located across the rear of the bench. Similar wet chemical stations were used to contain caustic developer solutions and organic solvents.

Another acid-cleaning step consisted of spray-cleaning the wafers in a contained, nitrogen-purged, sealed, centrifugal spray unit. These units clean wafers with hydrofluoric acid, ammonium hydroxide, and hydrogen peroxide or hydrochloric acid. Cassettes containing wafers are mounted in the centrifugal spray chamber, the chamber is closed, and the operation is controlled by microprocessor.

Diffusion and Ion Implantation

Doping introduces impurities into the silicon wafer, which alter the electrical properties of the doped area. Wafers are doped at various stages of the processing sequence, either by

diffusion or ion implantation. Diffusion is accomplished by exposing the wafer to a high-temperature atmosphere containing the dopant. At MOSTEK, the operation is performed in diffusion furnace assemblies. The dopant sources in use at MOSTEK during the in-depth survey were phosphorus oxychloride and boron trichloride. A typical diffusion furnace consists primarily of a control console, a gas jungle* cabinet, a clear station, a furnace cabinet, and a source cabinet. The control console monitors and directs the operation of the diffusion furnace. It is located between the workplace and the gas jungle. This is the point at which process operators control the process equipment and observe the diffusion operation. The clean station is located on either side of the control console. The clean station is the point at which the operator manually loads or unloads cassette wafers onto "boats" for eventual placement in the furnace tubes. The furnace tubes are heated by electrical resistance and serviced by scavenger exhaust boxes. The scavenger boxes exhaust any dopant which escapes the furnace tubes during the diffusion process. The source cabinet is used to contain the bubbler system or gas lecture bottles which supply dopant to the furnace. It is also the intersection of the dopant gas systems and the furnace tube.

When doping is accomplished by ion implantation, a source material is ionized and passed through an analyzing magnet that

*Jungle is an industry term used to describe the complex network of gas lines servicing various pieces of process equipment.

collects, accelerates, and implants the desired ions into a target wafer. The ion source, the analyzing and accelerating chamber, and the wafer exposure station are operated at vacuum conditions of approximately 10^{-6} torr. This vacuum is maintained by two sets of pumps, either an oil-sealed pump and a diffusion pump or an oil-sealed pump and a cryogenic pump. The dopant sources used at MOSTEK during the in-depth survey included solid arsenic, arsine, phosphine, and diborane gases. In the process operation sequence, the operator either loads the wafers into the load station of the ion implantation unit individually (pallet-type implanters) or in cassettes (cassette-type implanters). In either case, wafers are transferred to the exposure chamber, which is pumped to vacuum with an oil-sealed mechanical pump. Wafers in the exposure chamber are implanted with dopant ions. The wafers are then transferred into a cassette automatically or manually removed and loaded into cassettes by the operator

Radio-Frequency Radiation Sources

The radio-frequency sources studied at MOSTEK during the in-depth survey are those process operations involved in plasma etching of the silicon wafers. MOSTEK has two types of plasma etching systems--planar and barrel reactors. Both types are located in clean rooms, under laminar-flow hoods. The planar system consists of a reaction chamber with parallel electrode plates. The top electrode is driven by radio-frequency (RF) voltage, and 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.

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. An exhaust system removes the reaction products from the chamber to the local ventilation system. Sulfur hexafluoride was used as the reactant gas for the parallel-plate plasma etching system. The fluoride ions produced are reactive with silicon dioxide.

The barrel reactor system consists of a cylindrical chamber in which wafers are vertically mounted in a fused silica carrier. A plasma is created by an RF coil outside the reactor chamber. Generally, a perforated cylinder that surrounds the substrates 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, and the etching is accomplished through a reduced-pressure adsorption-reaction-deposition process. The sequence of events before etching is similar to that described for the planar system. 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 and forms a volatile SiF_4 that diffuses away from the surface. Oxygen appears to play an important role in the production of atomic fluorine and in the surface reactions.

METHODOLOGY

The in-depth survey of the MOSTEK plant at Carrollton, Texas, included sampling for chemical agents, monitoring for physical agents, and the measurement of control parameters. The sampling apparatus, instrumentation, and analytical methods used during this in-depth survey are presented herein.

WORKPLACE MONITORING FOR CHEMICAL AGENTS

Several chemical agents were sampled. The sampling strategies used to characterize the workplace levels of these chemical agents depended on the agent in question, the nature of the process operation, and the nature of the job being performed by the exposed worker. The sampling apparatus and analytical methods used to quantify each chemical agent were taken from NIOSH's Manual of Analytical Methods (NIOSH 1982).

Arsenic (Collected as Arsine Gas)

Arsine concentrations in the workplace were determined by using the NIOSH Reference Method for Arsine (S229). The arsine was collected by drawing a measured volume of air through a charcoal tube with a low-flow (50-200 ml/min) stroke pump (SKC model number 222-3). The analyte was desorbed with nitric acid and analyzed by using flameless atomic absorption. A detection

limit of 0.01 μg was achieved during these analyses. The analytical results were corrected for reagent and charcoal blanks, and the sampling results were reported in micrograms per cubic meter of air.

Diborane (Measured as Boron)

Diborane concentrations in the workplace air were determined by using the NIOSH Reference Method for Diborane (P&CAM 341). Diborane was absorbed on an oxidizer-impregnated charcoal tube (SKC 226-67 or equivalent) by drawing a measured volume of air through a three-stage sampler consisting of a Teflon[®] filter cassette (Millipore PTFE or equivalent), the treated charcoal tube, and a personal high-flow pump (Dupont P2500, MSA Model G, or Bendix BDX 55-HD). The analyte was desorbed with 3 percent hydrogen peroxide and analyzed for total boron by plasma emission spectroscopy. A detection of 0.03 μg was achieved during these analyses. The analytical results were adjusted by using an empirically derived desorption efficient factor and corrected for charcoal tube and reagent blanks. The sample flow rates of the rotometer-controlled pumps were corrected for changes in temperature and pressure. The sampling results were reported in micrograms per cubic meter.

Hydrogen Fluoride

Breathing zone samples were taken during the first (primary) production workshift of the day. Hydrogen fluoride concentrations in the workplace air were determined by using the NIOSH

Reference Method for Hydrogen Fluoride (SI76). Hydrogen fluoride (as hydrofluoric acid aerosol) was collected in 0.1N sodium hydroxide by drawing a measured volume of air through a semipermeable membrane impinger (Industrial Hygiene Specialties Model 100500-2 or equivalent) with a personal high-flow pump (Dupont P2500, MSA Model G, or Bendix BDX 55-HD). The analyte solution was diluted with an ionic-strength activity buffer (TISAB) and analyzed by ion-specific electrode, which results in a 50- μ g detection limit. The analytical results were corrected for sample and reagent blanks. The sample flow rates of the rotometer-controlled pumps were corrected for changes in temperature and pressure. The sampling results were reported in micrograms per cubic meter.

Organic Compounds in Air

Concentrations of various organic compounds in the workplace air were determined by using an absorption on charcoal, desorption with CS₂, and analysis by mass spectroscopy. Organic compounds were collected by drawing a measured volume of air through a charcoal tube with a low-flow (50 to 200 ml/min) stroke pump (SKC Model No. 222-3). The analyte was desorbed with 1 ml of CS₂ and analyzed by mass spectroscopy with single ion monitoring. The following information describes the equipment, column, and operating conditions used during the analysis:

Gas chromatograph:	Hewlett-Packard 5992 GC-MS
Column:	10% TCEP (tris cyano ethoxy propane), 80 in. x 0.125 in. o.d. nickel
Detector:	Single ion monitoring MS, ions: 43, 45, 106, 146, 58, and 59

Initial column temperature: 50°C
Hold time: 5 min
Final column temperature: 150°C
Hold time: 7 min
Program rate: 10°C/min
Carrier gas: Helium at 0.45 torr
Injection temperature: 180°C

Although the detection limit for this method varies with the organic compound being analyzed, an OR column detection limit of 20 nanograms can usually be achieved. The analytical results were corrected for charcoal tube and reagent blanks. The sampling results were corrected for temperature and pressure and reported in parts per million.

Phosphine

Concentrations of phosphine (measured as airborne phosphate) in the workplace were determined by using the NIOSH Reference Method for Phosphine (S332). The phosphine was collected by drawing a measured volume of air through a treated silica gel tube (SKC 226-10-05 or equivalent) with a low-flow (50 to 200 ml/min) stroke pump (SKC model number 222-3). The analyte was extracted by using hot acidic permanganate solution, and then analyzed for phosphate following the formation of phosphomolybdate complex, the extraction into a mixture of isobutanol and toluene, and the reduction by the use of stannous chloride. The absorbance of the reduced phosphomolybdate complex was measured at 625 nm. The analytical results were corrected for silica gel tube and reagent blanks. The sampling results were corrected for temperature and pressure and reported in micrograms per cubic meter.

WORKPLACE MONITORING FOR PHYSICAL AGENTS

The single physical agent monitored during the in-depth survey was radio-frequency radiation. The monitoring strategies used to characterize the workplace exposures varied according to the nature of the process operation and the nature of the job being performed. The monitoring instruments and survey methods used during this survey are described.

Radio Frequency (RF) Radiation

Radio-frequency emissions were monitored with a Holaday[®] (Model HI 3002) meter by using an electric field probe having a frequency response of 500 kHz to 6 GHz and a magnetic field probe with a frequency response of 5 to 300 MHz. Readings were taken during normal process equipment operating cycles. Normal operating frequencies, power outputs, and cycle times were recorded. The results were reported for near-field measurements as maximum electric field strength (V^2/M^2) and maximum magnetic field strength (A^2/M^2).

MEASUREMENT OF CONTROL PARAMETERS

Face velocities, duct traverses, and general air flow observations were made during the in-depth survey. The velocity measurements were performed with a Kurz[®] Model 441 air velocity meter. The measurement results were reported in feet per minute. A multipoint traverse method of data collection was used to collect the air velocity measurements necessary to construct representative averages. The physical dimensions of exhaust ducts and takeoffs were also measured whenever possible.

CONTROL TECHNOLOGY

APPROACHES TO CONTROL

Occupational exposures can be controlled by the application of a number of well-known measures, including engineering measures, work practices, personal protection, and monitoring. These measures may be applied at or near the hazard source, to the general workplace environment, or at the point of occupational exposure to individuals. Controls applied at the source of the hazard, including engineering measures (material substitution, process/equipment modification, isolation or automation, local ventilation) and work practices, are generally the preferred and most effective means of control in terms of both occupational and environmental concerns. Controls that may be applied to hazards that have escaped into the workplace environment include dilution ventilation, dust suppression, and house-keeping. Control measures that apply to individual workers include the use of remote control rooms, isolation booths, supplied-air cabs, safe work practices, and the use of personal protective equipment.

In general, a system that includes these control measures is required to provide worker protection under normal operating conditions as well as under conditions of process upset, failure, and/or maintenance. Process and workplace monitoring devices,

personal exposure monitoring, and medical monitoring are important mechanisms for providing feedback concerning the effectiveness of the controls in use. Ongoing monitoring and maintenance of controls to ensure proper use and operating conditions and the education and commitment of both workers and management to occupational health are also important ingredients of a complete, effective, and durable control system.

These control measures apply to all situations, but their optimum application varies from case to case. The application of these measures at the MOSTEK plant in Carrollton, Texas, for the production of MOS integrated circuits is discussed.

DESCRIPTION OF PROGRAMS

Industrial Hygiene

MOSTEK's Carrollton plant has one full-time industrial hygienist, and corporate industrial hygienists are used as needed. The United Technologies industrial hygiene laboratory is also available for industrial hygiene consultation and laboratory services. The Continental Insurance Company's Environmental Health Laboratory located in Dallas, Texas, is also consulted on matters of industrial hygiene and for laboratory services when immediate service is needed. The Carrollton plant also has three full-time safety engineers.

The plant's work area is monitored by personal, area, and surface-wipe sampling methods. MOSTEK's Safety and Health Department uses Dupont Model P-4000 sampling pumps with both high- and low-range capabilities for the area and personal

monitoring. When immediate air quality determinations are necessary, Bendix and Drager multigas detectors and sampling tubes are used. All methods used to collect and analyze air samples at the MOSTEK facility are NIOSH-approved. A Mine Safety Appliance, Model 260, Combustible Gas and Oxygen Indicator is also available for evaluation of the safety of the work environment. Exposures to microwave and radio frequency (RF) radiation are determined by a Narda, Model 8609, Broadband Isotropic Radiation Monitor. Routine evaluations of the exhaust ventilating systems are made with Alnor[®] velometers.

As part of the industrial hygiene program at MOSTEK, worker exposures to specific agents at particular process operations are monitored periodically in a pattern designed specially for the individual operation. The monitoring is performed each time a significant change is made in the process. Workers who are faced with potential exposure to toxic substances as a result of process changes are monitored using personal sampling techniques.

In addition, MOSTEK has installed a continuous gas monitoring system to detect the presence of phosphine or arsine 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 semiannual basis.

Leakage measurements are taken periodically on all process equipment capable of emitting microwave or RF radiation. Exposure surveys of any process equipment making use of ionizing

radiation are conducted according to Texas Health Department regulations.

Education and Training

MOSTEK has several employee 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.

Wafer fabrication employees take part in the chemical safety training program on a semiannual basis. The program includes a series of safety classes, slide presentations, and a handbook covering the essentials of chemical safety. This training is also given to employees working in the chemical services group, in the spill cleanup facility, and in security. 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 working with toxic gases.

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

These training programs are given to specific employees on a periodic basis. Before all newly hired employees begin work, however, they receive 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 the prevention of lost time and a review of safety suggestions made by the employees.

Personal Protective Equipment

The type of equipment worn and the extent of personal protection afforded MOSTEK employees depends on the tasks each of them performs. 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. Individuals who handle industrial solvents or acids are required to wear closed-toe shoes, face shields and chemically resistant aprons, sleeves, and gloves. As part of MOSTEK's industrial hygiene program, operations that might require workers to use respirators during normal processing have been redesigned to engineer the exposure problem out of the workers' breathing area. Despite the emphasis on engineering solutions to hygiene problems, some workers are given qualification physicals for wearing respirators. This precaution is taken to ensure that specific workers will be qualified to wear respirators if they are ever needed.

WET CHEMICAL STATIONS

The wet chemical stations studied during the in-depth survey included three polypropylene, laboratory-type, acid benches, a polypropylene, laboratory-type, caustic developer bench; and a stainless steel solvent cleaning bench.

The three acid benches used nitric acid, sulfuric peroxide ($H_2SO_4 \cdot H_2O_2$), and hydrofluoric acid to clean and etch the wafers. The caustic developer bench used caustic solutions of varying composition to develop positive photoresist. Acetone or n-butyl acetate is used in the stainless steel solvent cleaning bench.

The silicon wafer cleaning process produces a clean, uniform, and stable surface. In the cleaning process, a cassette of wafers is immersed in a solution of sulfuric peroxide commonly referred to as piranha etch. MOSTEK did not specify the exact proportions of sulfuric acid to hydrogen peroxide used in the piranha etch, but typical solutions used in the industry contain approximately nine parts concentrated H_2SO_4 to one part H_2O_2 . Nitric or hydrochloric acid may also be added in small amounts. The piranha etch solution is designed to remove any organic residue that may have accumulated on the wafers during handling.

Another acid etching process observed at MOSTEK is designed to remove unwanted silicon dioxide from the wafer surface. 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 dried by use of a nitrogen blow-off before being transferred to other process operations.

Nitric acid solutions are used to remove unwanted aluminum from the surface of the wafer. The aluminum is deposited on the

wafer in order to interconnect the circuit devices formed during the fabrication process.

The caustic developer solutions are used to develop positive photoresist. The caustic solution removes the soluble unwanted photoresist and exposes the wafer substrate for eventual etching in an acid solution.

Solvent cleaning using n-butyl acetate or acetone is performed to remove organic material from the components of various process equipment.

The general bench design of wet chemical stations at MOSTEK incorporates a solid work surface with recessed tanks. The exhaust ventilation is provided through holes (perforations) or slots in the back wall of the bench. No exhaust takeoffs are located around the perimeter of the tanks, and most of the benches lack the splash guards or adjustable slashes common to other wet bench designs.

Monitoring Results

The design characteristics of MOSTEK's wet chemical stations appear to reflect the company's approach to organizing a clean room environment. Laminar-flow HEPA filters are located in the ceiling over the entire fabrication area rather than directly over individual process operations. The placement of HEPA filters directly over wet chemical work stations tends to disrupt exhaust airflow and reduce the effective distance of a system's capture velocity. Although MOSTEK's placement of the

HEPA filter in the ceiling has not solved this problem completely, ventilation measurements taken during the survey did not detect net airflows into the work environment from the process. Table 1 summarizes the ventilation measurements taken at six wet chemical stations.

As the monitoring results indicate, the measured face velocities, although uniformly positive in the direction of the exhaust take-offs, were found to fluctuate between highs of 350 fpm down to values near normal room air turbulence (50 fpm). These measurements were interpreted to indicate the presence of turbulence in the work areas. Figure 1 summarizes the general inconclusiveness of the ventilation measurements taken at the wet chemical stations. The six schematic diagrams represent stylized side views of the wet chemical stations studied. The estimated volumetric flow rates of both slot and perforated exhaust takeoffs are given for each bench.

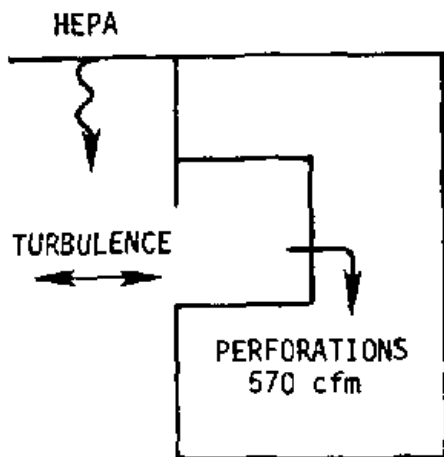
Workers at MOSTEK are monitored periodically for exposures to acids and organic solvents; however, because the vapor concentrations in air near the wet chemical stations are normally so low (they consistently fall below detection levels), routine industrial hygiene monitoring is believed to be unnecessary. The low airborne concentrations were verified during the in-depth survey. An active hydrofluoric acid-etching operation was monitored several times to see if normal worker interaction with the bench would cause a significant disruption of the airflow and result in exposures to hydrofluoric acid vapors or mist.

TABLE 1 SUMMARY OF VENTILATION MEASUREMENTS
TAKEN AT WET CHEMICAL STATIONS

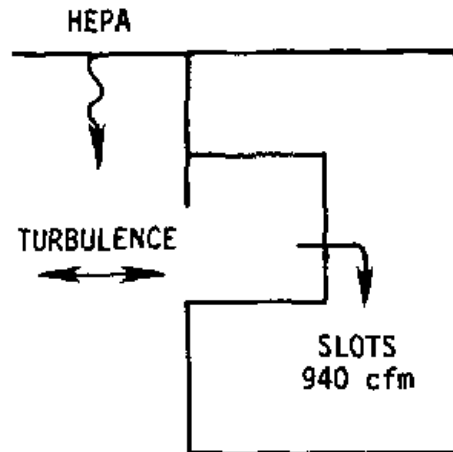
Description of equipment	Ventilation component	Measured airflow velocity, fpm	Exhaust take-off area, ft ²	Volumetric flow rate, cfm
Wafer etching wet station 1 (nitric acid)	Bench exhaust (Perforations on back wall)	4000	0 14	570
	Face of bench	50 - 275	2 8	*
Wafer etching wet station 2 (nitric acid)	Bench exhaust (Perforations and slots in back wall)	4000	0 17	680
	Face of bench	50 - 350	3 6	*
Wafer cleaning wet station 3 (sulfuric acid and hydrogen peroxide)	Bench exhaust (Perforations in back wall)	2200	0 34	750
	Face of bench	50 - 275	5 0	*
Wafer etching wet station 4 (hydrofluoric acid)	Bench exhaust (Slots in back wall)	4000	0 23	940
	Face of bench	50 - 175	7 4	*
Batch developer wet station (caustics)	Bench exhaust (Slots in back wall)	220	0 63	140
	Face of bench	50 - 360	7 0	*
Solvent cleaning (acetone or n-butyl acetate)	Bench exhaust (Perforations in back wall)	1290	0 27	350
	Face of bench	50 - 65	5 8	*

* Turbulence at bench face prevented accurate measurement of air velocity and calculation of volumetric flow rate

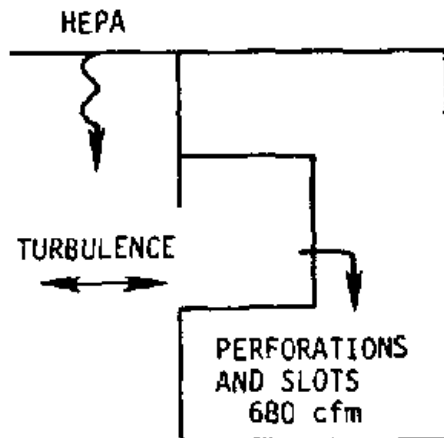
WAFER ETCHING (NITRIC ACID)



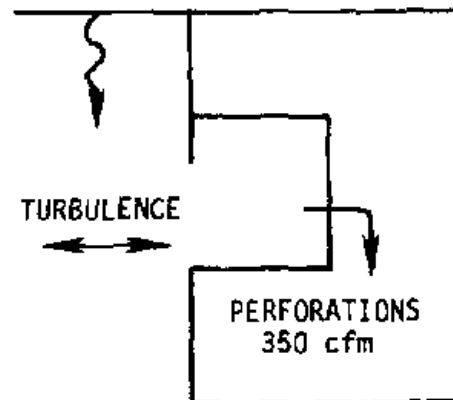
WAFER ETCHING (HYDROFLUORIC ACID)



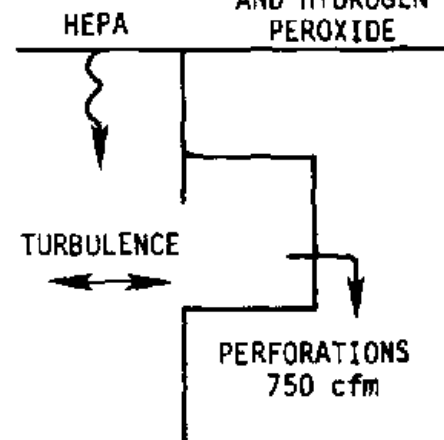
WAFER ETCHING (NITRIC ACID)



SOLVENT CLEANING (ACETONE
OR N-BUTYL ACETATE)



WAFER ETCHING (SULFURIC ACID
AND HYDROGEN
PEROXIDE)



BATCH DEVELOPER (CAUSTICS)

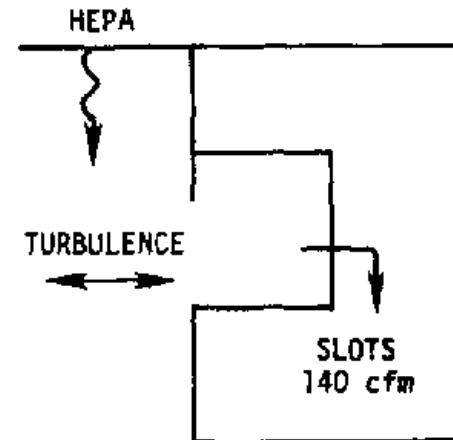


Figure 1. Summary of ventilation at wet chemical stations.

The results of this monitoring (Table 2) clearly indicate that no exposure hazard exists at the wet chemical station monitored. Indeed, the results suggest that although steady air velocity measurements could not be detected at the bench face, the exhaust ventilation inside the bench is sufficient to keep hydrofluoric acid from escaping the bench in detectable amounts.

Work Practices

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

Personal protective equipment worn by MOSTEK employees in the area of the wet chemical processes consists 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 also required to wear face shields, sleeves, and aprons. During the dispatching of chemical agents, workers must wear rubber gloves and sleeves, aprons, and safety shoes. During the mixing, disposal, or filtration of chemical solutions, they must wear face shields and safety shoes with rubber overshoes or steel-toed rubber boots. 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.

TABLE 2 SUMMARY OF AREA MONITORING FOR HYDROFLUORIC ACID
AT A WET CHEMICAL STATION

Job description or location of monitor	Sample duration, h min	Sample volume, liters	Measured concentration, mg/m ^{3*}	Time weighted average concentration, mg/m ³
Area monitoring of hydrofluoric acid etching station (inside hood)	0.16	17.6	<3 [†]	NA
Area monitoring of hydrofluoric acid etching station (outside hood)	0.16	16.4	<4 [†]	NA
Area monitoring of hydrofluoric acid etching station (inside hood)	0.15	16.5	<4 [†]	NA
Area monitoring of hydrofluoric acid etching station (outside hood)	0.15	15.3	<4 [†]	NA
Area monitoring of hydrofluoric acid etching station (inside hood)	0.15	16.5	<4 [†]	NA
Area monitoring of hydrofluoric acid etching station (outside hood)	0.15	15.3	<4 [†]	NA
Area monitoring of hydrofluoric acid etching station (inside hood)	0.15	16.5	<4 [†]	NA
Area monitoring of hydrofluoric acid etching station outside hood)	0.15	15.3	<4 [†]	NA

* Measured concentration determined as (sample-field blank)/sample volume

† Analytical results below detection limit of 60 µg

NA - Not applicable

DIFFUSION

Diffusion operations at MOSTEK are performed in thermal diffusion furnaces that use phosphorus oxychloride and boron tribromide dopants. Each of the diffusion furnace assemblies at MOSTEK consists of a furnace cabinet containing the furnace tubes and heating elements, a clean station (where wafers are manually or automatically loaded into the furnace), a source cabinet, and a control console. Several variations of this basic diffusion furnace design were observed throughout MOSTEK's facility. Figure 2 presents the basic components of a diffusion furnace and its associated work stations.

Ventilation of the DDC furnace consists of an exhaust ventilation takeoff at the furnace tube opening, ventilation of the gas "jungle," and exhaust ventilation of the dopant source bubblers. The ventilated scavenger box is positioned at the end of the furnace tube to control gas and particulate emissions from the tube opening. Exhaust from the furnace scavenger box is carried through 10 feet of stainless steel ducts before it enters a scrubber unit. Airflow 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 dilutes the reactant gases released from the furnace, and scavenger boxes capture gases that may be released from the furnace opening. The dopant bubblers, which supply gaseous dopant to the diffusion furnace, are located in source cabinets characterized by open-face compartments equipped with exhaust ventilation.

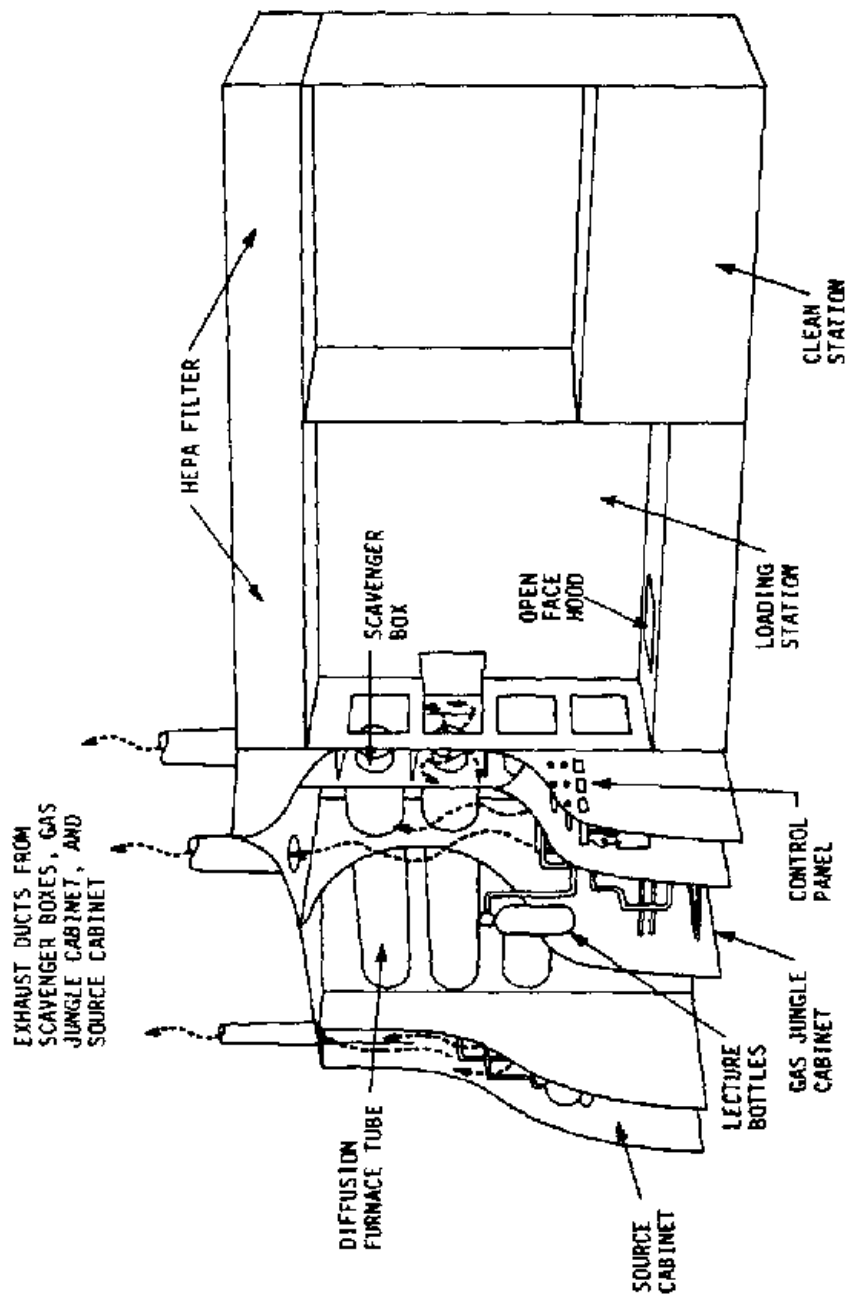


Figure 2. Diffusion furnace and associated work stations.

Monitoring Results

Area monitoring for emissions of phosphate was performed near a diffusion furnace using phosphorus oxychloride as a dopant source. Ventilation measurements were taken at the scavenger box and source cabinets. The area monitors were located 24 inches from an open scavenger box and at the wafer staging area (clean station) at a distance of 10 feet from the furnace. The sampling took place during normal wafer diffusion operations. The results of the sampling and analysis of workplace exposure to phosphorus oxychloride (as phosphate) are presented in Table 3.

The monitoring results are presented as total phosphate (molecular weight, 94.97); if converted to phosphorus oxychloride (molecular weight, 153.32), the single positive result represents a concentration of 257 $\mu\text{g}/\text{m}^3$. This value is approximately 40 percent of the TLV for phosphorus oxychloride.

Ventilation measurements were taken at the scavenger box opening and at the exhaust duct of the gas source cabinet. The scavenger box openings at MOSTEK were either round (with a diameter of 10 inches) or square (with a side measurement of 10 inches). Face velocities taken at the round scavenger box openings averaged 50 fpm, those at the square openings averaged 110 fpm. These velocities produced average volumetric flow rates of approximately 30 and 80 cfm. When the scavenger boxes were closed, the doors of the round scavenger box had small openings approximately 1.4 inches in diameter and the doors of

TABLE 3 SUMMARY OF AREA MONITORING FOR PHOSPHORUS OXYCHLORIDE
(AS PHOSPHATE)

Job description or location of monitor	Sample duration, h min	Sample volume, liters	Measured concentration, $\mu\text{g}/\text{m}^3$ *	Time weighted average concentration, $\mu\text{g}/\text{m}^3$
Area monitor located 24 inches from open scavenger box	3 15	20 7	159	NA
Area monitor located 24 inches from open scavenger box	1 41	10.7	<187 [†]	NA
Area monitor located at wafer staging area near furnace	3 18	20 3	<98 [†]	NA
Area monitor located at wafer staging area near furnace	1 26	9 0	<222 [†]	NA

* Measured concentration determined as (sample-field blank)/sample volume

† Analytical results were below the detection limit of 2.0 μg

NA - Not applicable

the square scavenger boxes had openings approximately 4.0 inches in diameter. With the doors closed, the round and square scavenger boxes delivered measured face velocity rates of approximately 1200 and 3000 fpm, respectively.

Air from the scavenger boxes is exhausted to stainless steel ducting, where excess gases are burned before the air exits to the penthouse scrubber system via a polyvinylchloride pipe. The phosphorus oxychloride (POCl_3) source cabinet is exhaust-ventilated through a duct 4.5 inches in diameter. At the time of the survey, this duct was operating in a two-thirds "open" position and was delivering an average velocity of 2600 fpm.

Work Practices

The work activities of furnace operators generally do not change with the type of material being diffused; the basic interaction of worker with equipment remains much the same.

During the in-depth survey it was noted that although one worker was responsible for a single bank of diffusion furnaces (i.e., four diffusion tubes), sometimes more than one process worker performed tasks in the vicinity of the diffusion furnace tubes. Thus, the sampling results may reflect workplace exposures for other workers in the fabrication area. The employee responsible for a bank of diffusion furnaces spends most of the workday at two primary work stations: 1) the loading station, where wafer boats are loaded in and out of the tube furnaces; and 2) the adjacent clean station, where incoming wafers are

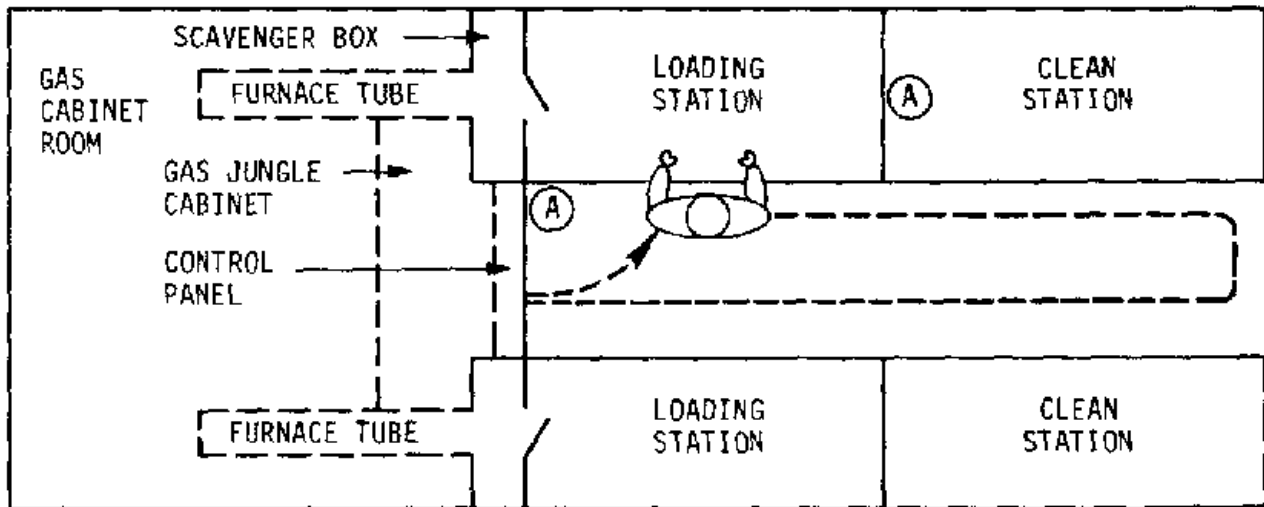
removed from cassettes and transferred to boats or finished wafers are removed from the boats and transferred back into cassettes. The operators frequently leave these primary work stations, but only for short periods of time. Diffusion furnace operators periodically leave the furnace area to obtain more wafers or to transfer finished wafers to a holding station. It was also common to see a worker approach the furnace control console and make adjustments. Figure 3 presents a pictorial diagram of a diffusion furnace work area, showing the location of the work stations and the placement of area monitors.

Required personal protective equipment for diffusion furnace workers includes the normal clean-room attire, which consists of hoods, booties, clean suit, latex gloves, chemical safety goggles or safety glasses, and closed-toe shoes. In addition to this basic equipment, workers use heat-protective gloves when unloading wafers from the diffusion furnace.

ION IMPLANTATION

Two major types of ion implanters are used within the electronics industry. These implanters can be described by the manner in which they receive silicon wafer implanters with cassette- or pallet-type wafer loading stations. Several examples of both were observed and monitored during the in-depth survey at MOSTEK.

Figure 4 presents a basic illustration of the two major types of implanters observed at MOSTEK.



PRIMARY WORK STATION, LOCATION OF WORKER DURING MOST OF THE DIFFUSION FURNACE OPERATION



SECONDARY WORK STATIONS, MOVEMENT OF WORKER DURING PROCESS OPERATION



LOCATION OF AREA SOURCE SAMPLING EQUIPMENT

Figure 3. Pictorial diagram of work activities and the location of area and personal monitors during diffusion furnace operations

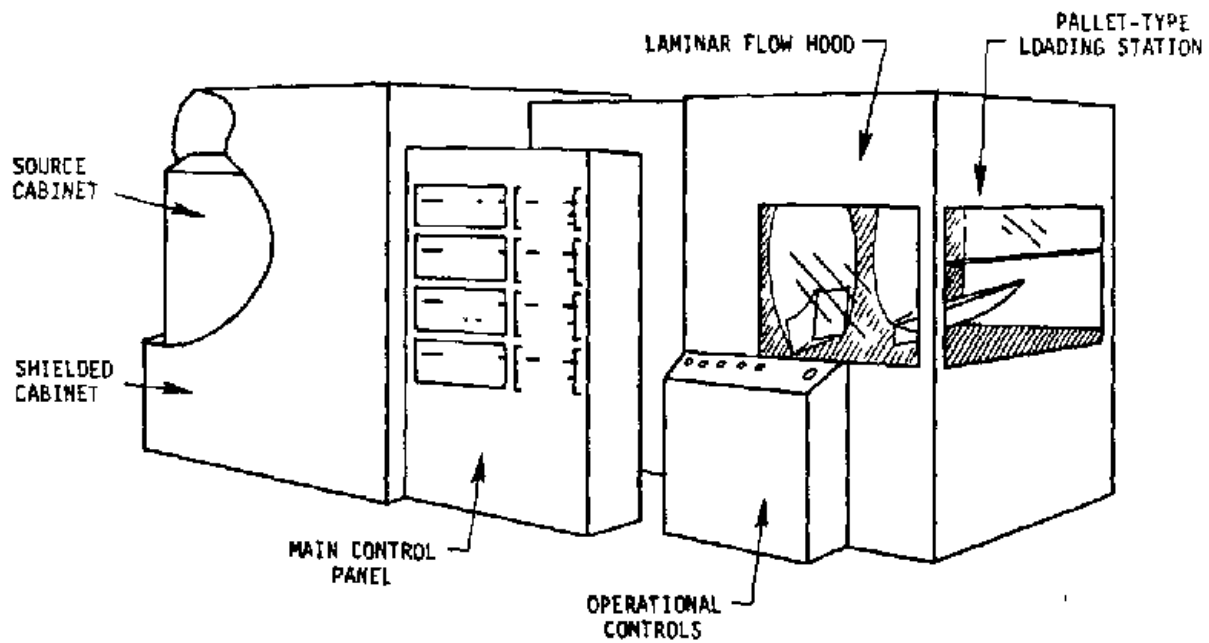
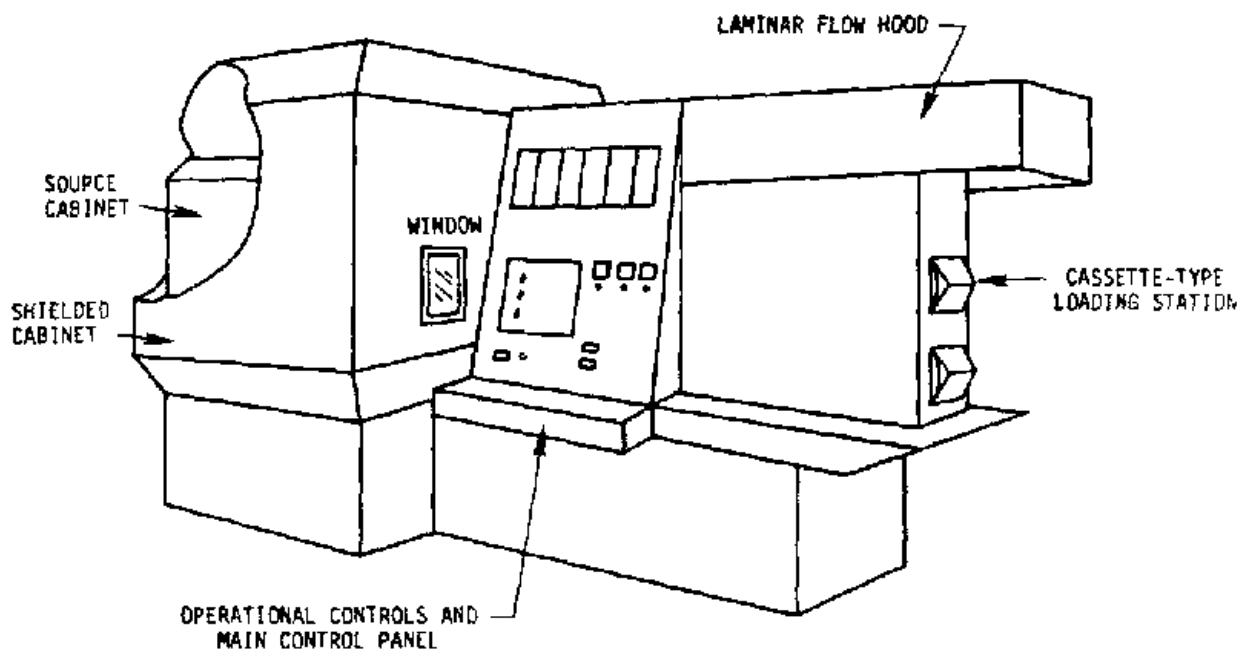


Figure 4. Cassette- and pallet-type ion implanters

MOSTEK uses both solid and gaseous source materials in their ion implanters. Solid arsenic is used as a source material in a NOVA-10 palette-type implanter. Arsine, phosphene, and boron trifluoride gases are used in other palette- and cassette-type implanters. The gaseous source materials are stored in ventilated gas cabinets built into the ion implantation unit.

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. During normal implantation, the vacuum prevents the release of the ions into the workroom air.

The ion source is contained within a double-shielded lead cabinet. Access to the source is through panels that are electrically interlocked to the system. 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.

The gas cabinet and the vacuum environment of each ion implanter are vented to an acid scrubber system or hot-wall exhaust scrubber system. MOSTEK claims the collection rates of this exhaust ventilation design exceeds those suggested by the manufacturer of the implantation equipment.

Scheduled preventive maintenance of the ion implantation unit includes periodic cleaning of the ion source, changing of

the beam manipulator, and periodic replacement of the vacuum pump oils. The ion source is located within a sealed source chamber maintained at pressures below atmospheric. When it is necessary to access the ion source, the chamber is purged and backfilled to atmospheric pressure before it is opened. During the opening the chamber is vented by a duct located above the ion source. During maintenance, the ion source is removed and taken to a stainless steel, laboratory-type, ventilated cleaning bench.

Monitoring Results

Ion implantation operations were monitored for arsenic (as arsine gas), boron trifluoride (as boron), and organics suspected of causing noxious odors. Ventilation measurements were also taken at exhaust ducting associated with the implantation units. Area monitoring for arsenic (as arsine) was performed at a Varian medium-current cassette-type implanter, and at two pallet-type implanters (a NOVA 10 and an Extrion 8010). The monitors were located at the control panel and wafer loading station of each implanter. Air samples were collected during normal ion implantation operations. Air samples also were collected during the maintenance and removal of ion sources from both the NOVA-10 and Extrion 8010 implanters. Table 4 summarizes the results of area monitoring for arsenic (as arsine gas) during both operational and maintenance activities associated with the ion implantation operations. The approximate location of the area monitors is presented in Figure 5.

TABLE 4 SUMMARY OF AREA MONITORING FOR ARSENIC
(AS ARSINE GAS)

Job description or location of monitor	Sample duration, h min	Sample volume, liters	Measured concentration, $\mu\text{g}/\text{m}^3$ *	Time weighted average concentration, $\mu\text{g}/\text{m}^3$
Area monitor at control panel of Varian medium-current ion implanter	0 56	7 1	1 47	NA
Area monitor at control panel of Varian medium-current ion implanter	3 58	30 2	0.69	NA
Area monitor at control panel of Varian medium-current ion implanter	2 18	17 5	1 78	NA
Area monitor at wafer loading station of Varian medium-current ion implanter	2 28	29 6	0 35	NA
Area monitor at wafer loading station of Varian medium-current ion implanter	2:26	29 1	0 35	NA
Area monitor at wafer loading station of Varian medium-current ion implanter	2 24	28 9	<0 35 [†]	NA
Area monitor at control panel of NOVA-10 ion implanter	5 28	18 7	1 11	NA
Area monitor at control panel of NOVA-10 ion implanter	5 26	18 2	<0 55 [†]	NA
Area monitor at control panel of NOVA-10 ion implanter	2 25	8 2	3 80	NA
Area monitor at control panel of NOVA-10 ion implanter	3 07	33 4	0 94	NA
Area monitor at control panel of NOVA-10 ion implanter	2 23	24 0	<0 42 [†]	NA

(continued)

Job description or location of monitor	Sample duration, h min	Sample volume, liters	Measured concentration, $\mu\text{g}/\text{m}^3$ *	Time weighted average concentration, $\mu\text{g}/\text{m}^3$
Area monitor at wafer loading station of NOVA-10 ion implanter	2 54	27 6	0 37	NA
Area monitor at wafer loading station of NOVA-10 ion implanter	2 36	24 8	0 83	NA
Area monitor at wafer loading station of NOVA-10 ion implanter	2 23	22 8	0.46	NA
Area monitor at wafer loading station of NOVA-10 ion implanter	3 08	33 4	0 94	NA
Area monitor at wafer loading station of NOVA-10 ion implanter	2 22	24 0	<0 42 [†]	NA
Area monitor at ion source during source change on NOVA-10	1 24	7 5	1 37	NA
Area monitor at ion source during source change on NOVA-10	1 29	3 0	3 40	NA
Area monitor at control panel of Extron 8010	6 53	80 4	0 26	NA
Area monitor at wafer loading station of Extron 8010	6 52	86 3	0 48	NA
Area monitor at ion source during change on Extron 8010	0 39	5 1	<1 96 [†]	NA
Area monitor at ion source during source on Extron 8010	0 21	5 8	5 38	NA

* Measured concentration determined as (sample-field blank)/sample volume

† Analytical results were below the detection limit of 0.01 μg

NA - Not applicable

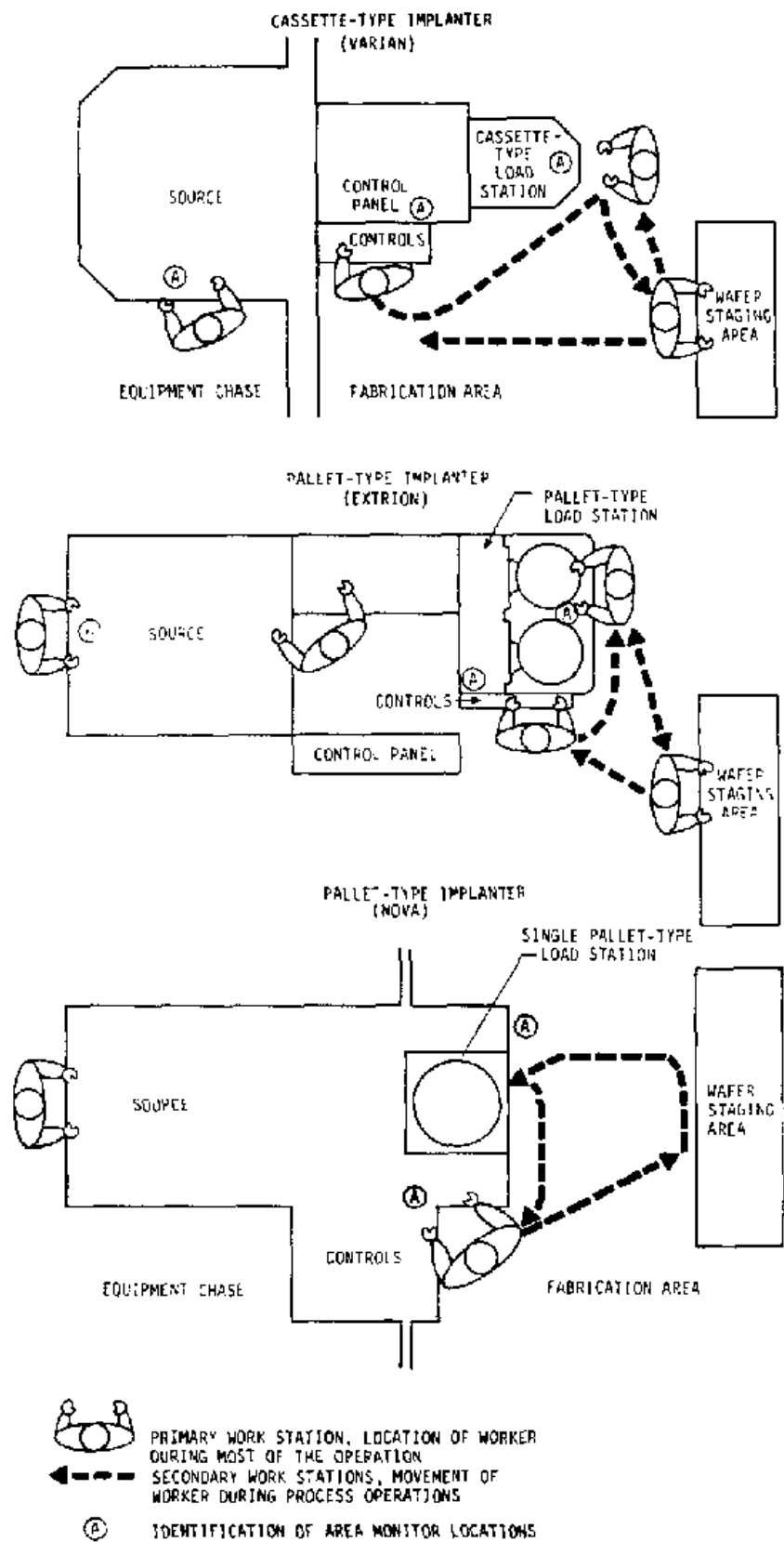


Figure 5. Pictorial diagram of work activities and location of personal and area monitors during ion implantation operations at implanters with cassette-type (top) and pallet-type (bottom) loading stations.

Area monitoring for boron trifluoride (as boron) was conducted at two Varian medium-current, cassette-type implanters. The monitors were located at the control panel and wafer loading station of the Varian DF-4, and at the wafer loading station of the Varian CF-5. Samples were collected during normal implantation operations. Table 5 summarizes the monitoring results.

The final monitoring effort conducted during implantation operations was the sampling of ion source chamber air for organic substances that might produce noxious odors. Two sampling efforts were conducted, one during the ion source removal on the Extrion 8010 and one during the ion source removal on the NOVA-10. Desorption of the analyte from the charcoal collection tubes and analysis by gas chromatograph/mass spectroscopy identified three nonarsenical organic compounds: acetone, n-butyl acetate, Cellosolve acetate, and xylene. All four substances are common constituents of workplace air in wafer fabrication areas that include photolithographic operations. Acetone and n-butyl acetate were collected in amounts of <10 µg, and Cellosolve acetate and xylene were detected in amounts of <1 µg. Because low amounts of these compounds were collected, it is assumed that their presence represents normal fabrication room background and not organic emissions specific to the ion implantation process.

Ventilation was measured on the exhaust systems incorporated in the construction of the Varian and NOVA-10 ion implantation units. The ion source cabinet of these implanters were

TABLE 5 SUMMARY OF AREA MONITORING FOR BORON TRIFLUORIDE
(AS BORDN)

Job description or location of monitor	Sample duration, h min	Sample volume, liters	Measured concentration, $\mu\text{g}/\text{m}^3$ *	Time weighted average concentration, $\mu\text{g}/\text{m}^3$
Area monitor at wafer loading station of Varian medium-current ion implanter	2 09	114	<0 25 [†]	NA
Area monitor at wafer loading station of Varian medium-current ion implanter	1 48	95	2 75	NA
Area monitor at wafer loading station of Varian medium-current ion implanter	2 10	116	0 25	NA
Area monitor at control panel of Varian medium-current ion implanter	2 08	142	<0 21 [†]	NA
Area monitor at control panel of Varian medium-current ion implanter	1 50	122	1 25	NA
Area monitor at control panel of Varian medium-current ion implanter	2 07	141	0 25	NA
Area monitor at wafer loading station of Varian medium-current ion implanter	5 30	331	<0 09 [†]	NA

* Measured concentration determined as (sample-field blank)/sample volume

† Analytical results were below the detection limit of 0 03 μg

NA - Not applicable

located in an equipment chase adjacent to the fabrication work area. A 0.36-ft² exhaust duct serviced each implanter. The air velocity provided through this ducting averaged approximately 1300 fpm and produced an estimated volumetric flow rate of 468 cfm.

Work Practices

Ion implantation operators spend most of their workday moving between three work stations: the control panel, the wafer-loading station, and a wafer staging area (see Figure 5). The normal process work activities associated with the operation of implanters consist of monitoring the control panel 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. The exact time spent at each station varies considerably, depending on the type of implanter being used and the type of product being implanted. The work stations can be ranked relative to the approximate amount of time spent at each: control panel (~60 percent), wafer-loading station (~20 percent), and wafer staging area (~10 percent).

The required personal protection for workers operating the ion implanter consists of standard clean room attire: hood, clean suit, booties, chemical safety goggles or safety glasses, latex gloves, and closed-toe shoes.

Maintenance of the equipment (i.e., changing of the ion source and lecture bottles) is conducted by designated maintenance workers. Toxic gas lecture bottles are changed by

designated chemical handlers who have taken the MOSTEK chemical-handling course. At the time of the in-depth study, no special protective equipment was provided for maintenance workers involved in ion source or lecture bottle changing. Since the in-depth study, however, MOSTEK has begun to provide these workers with full-face air-line respirators.

RADIO-FREQUENCY RADIATION SOURCES

The radio-frequency (RF) sources monitored were the plasma-etching systems for the removal of silicon nitride. These plasma etching operations involve batch etching of wafers with carbon tetrafluoride (CF_4) and sulfur hexafluoride (SF_6). Each of the four plasma etching operations observed were located in the fabrication clean room.

Monitoring Results

Table 6 presents the RF measurements taken during the in-depth survey. The two TEGAL Inline plasma etchers operated at a frequency of 13.56 MHz and 150 watts of power. The maximum period of RF generation during each TEGAL unit process cycle was reported to be 2 minutes. Based on this exposure time and the energy levels noted during the survey, neither TEGAL unit presents a radiation hazard to workers in the fabrication area.

The two Branson IPC units operate at a frequency of 13.56 MHz and 450 watts of power. For the Branson units, the maximum period of RF generation during each process cycle is reported to be 30 minutes. Monitoring performed during the in-depth survey indicates that both units present a potential electrical hazard

TABLE 6 SUMMARY OF RADIO-FREQUENCY RADIATION EMISSIONS FROM RF SOURCES

Equipment manufacturer and model	Frequency, MHz	Operating power, watts	Maximum duration of operation, min	Maximum electric field, V^2/m^2	Maximum magnetic field, A^2/m^2
TEGAL Inline 701 plasma etcher	13 56	150	2 min	200	0 08
TEGAL Inline 700 plasma etcher	13 56	150	2 min	None	0 01
Branson IPC-1 barrel etcher	13 56	450	20-30	40,000*	0 02
Branson IPC-2 barrel etcher	13 56	450	20-30	25,000*	0 04

* Electric field radiation exceeds the recommended threshold limit value of 18,453 V^2/m^2 for a 13 56 MHz source

to workers in the fabrication area. Branson IPC Unit 2 also presents a potential magnetic field hazard. The risk of exposure to these RF emissions is actually very low because the work regimen of MOSTEK employees prevents them from remaining in front of the plasma etching equipment for more than a few minutes at a time.

Protection from radio-frequency hazards are achieved through two engineering control approaches: equipping each plasma etcher with a metal screen over the viewing window, and grounding of the units to eliminate the shock potential. MOSTEK was in the process of eliminating the electrical and magnetic hazards by retrofitting each of the Branson IPC plasma units with grounded steel screens across the viewing windows. It is believed that this engineering control will significantly reduce the RF emissions.

Work Practices

Operators use tweezers or vacuum wands to load the wafers into carriers in a laminar-flow HEPA-filtered staging area adjacent to the plasma etching operations. Workers are required to load and unload wafer carriers and to initiate the process sequence. Processing is automatically controlled to allow workers to perform other job activities; for this reason, workers spend very little time in proximity to the equipment. Pump oils are manually drained and replaced. Process gases supplied in cylinders are changed by trained technicians. The procedures used for maintenance and cleaning activities were not observed

during the in-depth survey. The automated control of the process equipment does not require an operator to be present during the operation. Therefore, if the plasma etching unit is emitting radio-frequency radiation, the operator is unlikely to be at the unit during an entire shift, but normally will be some distance away from the source. The operator's distance away from the source and variation in tasks during a work shift would both be considered controls that decrease worker exposure.

Fabrication workers operating plasma 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 plasma units.

GAS HANDLING SYSTEM

Toxic, corrosive, pyrophoric, and flammable process gases are supplied to the fabrication area in cylinders, which are stored in ventilated gas cabinets. The gas cabinets are vented by 4.5-inch-diameter, galvanized-steel ducts that exit the top of the cabinets. Air velocities measured at the duct openings averaged approximately 2900 fpm, resulting in a volumetric flow rate of approximately 320 cfm. The exhaust ducts were one-third open on all the gas cabinets observed. The cabinets storing silane and dichlorosilane are specified to exhaust at 400 cfm to prevent explosion during large leaks.

GAS DISTRIBUTION SYSTEM

A diagram of the typical gas distribution setup at MOSTEK is presented in Figure 6. The process gas cylinder (containing a toxic or hazardous gas) is connected to the distribution system by a manual Whitey[®] shutoff valve. This shutoff valve is followed by a four-cornered intersection or gas manifold. The process gas is fed to the process equipment through a second Whitey[®] valve and into two gas regulators. The purpose of having two regulators is to assure proper gas flow in the event one regulator should fail. The process gas leaves the second regulator and passes through a third Whitey[®] shutoff valve to an automatic solenoid shutoff valve, which is normally closed (in the nonactuated position). The solenoid valve will shut down gas delivery during power failures. The gas then proceeds through a fourth Whitey[®] valve before entering the process equipment.

Bottled nitrogen (N_2) is used to purge the gas distribution system. The N_2 enters the system via the intersection manifold, through a check valve and a Whitey[®] manual shutoff valve. Gas purging is assisted by a vacuum generator that services the system through a solenoid valve. Gas purged by the N_2 /vacuum generator setup is exhausted through one of two emission-control units. The arsine gas distribution systems are exhausted to a gas-fired burner, which oxidizes the very toxic arsine to less-toxic arsenic trioxide. Other toxic or hazardous gases are vented to a hot-wall scrubber before being exhausted to the environment.

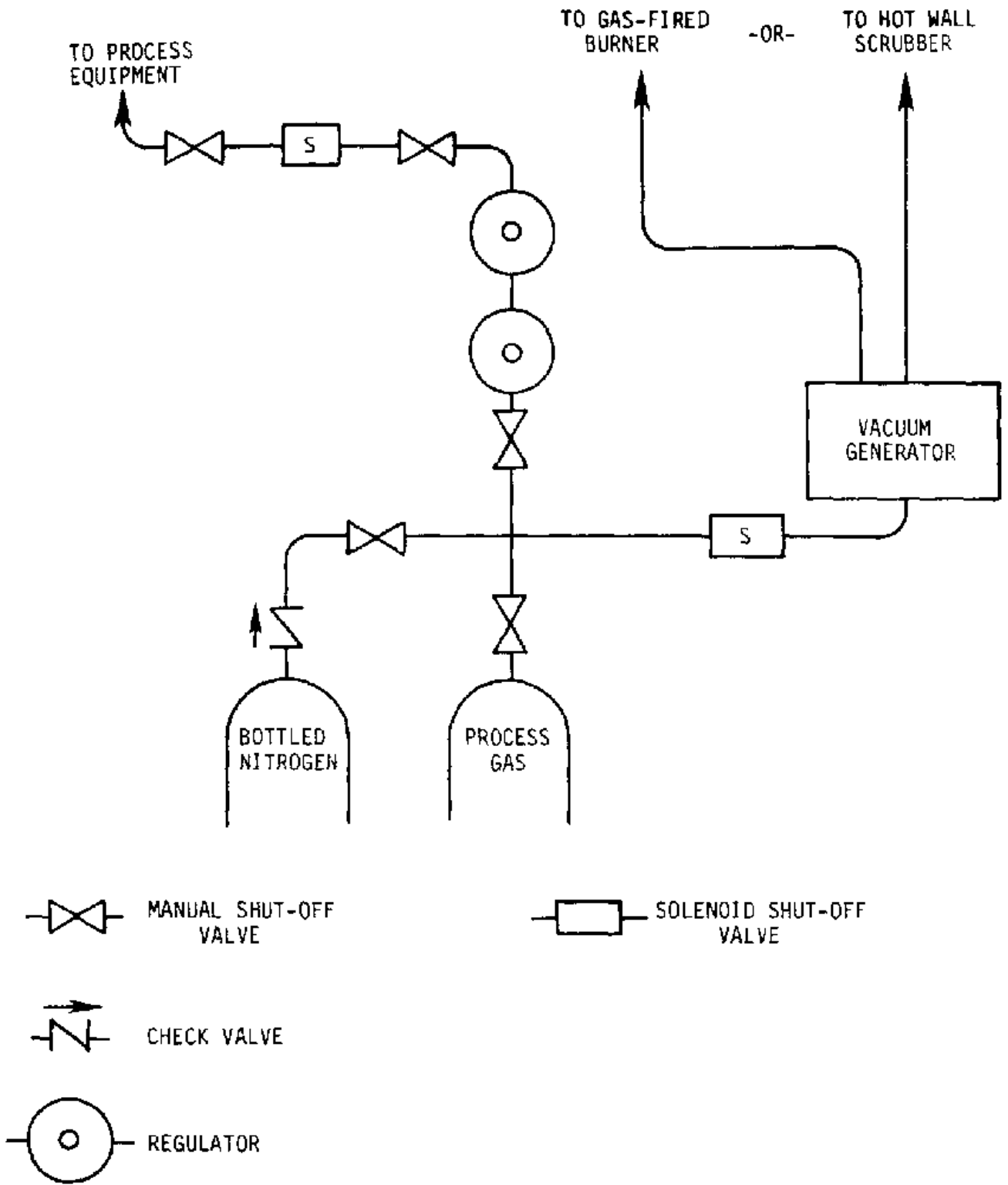


Figure 6. Gas distribution system

CONCLUSIONS

The results of the in-depth survey lead to the following conclusions, which correspond to each work activity or process operation discussed in the control technology section of this report

CHEMICAL HANDLING

Most of the chemical-handling tasks performed at the MOSTEK facility involve the movement of process chemicals from storage or holding areas into the circuit-fabrication process area. Toxic or hazardous gases used at MOSTEK are transferred from compressed gas cylinders to process machinery through a gas handling system. This system is an example of "good" contemporary engineering design. It incorporates 1) exhausted gas cabinets for safe storage of gas cylinders, 2) flow-limiting valves, 3) solenoid valves for emergency shutdown, and 4) welded stainless steel lines that contain a minimum of compression fittings. Unique to the MOSTEK system is the incorporation of double regulators and a vacuum generator to assist purging of the system (see Figure 6).

Worker exposures during the transfer of liquid chemicals are controlled through the use of personal protective equipment. The protective equipment for chemical handlers consists of

1) chemical-resistant aprons, 2) acid or chemical-resistant sleeves and gloves, 3) chemical-splash goggles and face shields, and 4) protective boots. The overall potential for accidental exposure to liquid chemicals is reduced further by limiting the supply vessels to 1-gallon containers, which are transported from diked and ventilated storage areas to ventilated wet chemical benches in special carts or gondolas.

PROCESS CONTROLS

In most instances, it was not possible to assess the effectiveness of more than one control option, either because of the lack of variation in control solutions at MOSTEK or because of the limits on the sampling effort by budgetary considerations. The controls that were observed were assessed in terms of their effectiveness at reducing or eliminating an exposure problem. Although the sampling approach taken during the in-depth survey was not designed specifically to calculate 8-hour time-weighted averages, a comparison of such values with recommended threshold limit values (TLV's) will provide a quantitative assessment of process control effectiveness.

Wet Chemical Stations

Worker exposures to hydrofluoric acid, sulfuric peroxide, nitric acid, caustic solutions, and organic solvents were observed at the wet chemical stations, which are of a "laboratory type" chemical bench design. This type of bench design at MOSTEK is limited to a work bench that includes local exhaust slots or perforations across the backwall of the bench. The

benches are constructed of polypropylene for caustics or acids and stainless steel for organic solvents.

Ventilation measurements taken at six wet chemical stations indicate that the bench design used at MOSTEK appears to prevent the flow of air from the process into the work environment (see Table 1). Face velocities measured at the wet benches were found to fluctuate between lows of approximately 50 fpm and highs of 360 fpm. The apparent success of these benches is attributed to the placement of laminar-flow HEPA filters in the ceilings outside the bench rather than directly over the process.

Hydrofluoric acid emissions were monitored at one wet chemical bench to see if normal worker interaction with the process would disrupt the exhaust airflow and produce the potential for an exposure. The results indicated that no exposure hazard exists at the wet chemical station and that the exhaust ventilation inside the bench is sufficient to keep hydrofluoric acid from escaping in detectable amounts (see Table 2).

Diffusion Furnaces

Phosphate emissions were detected at the diffusion furnace using phosphorus oxychloride as a dopant. Most of the diffusion furnace banks studied incorporated the use of three ventilation control measures: 1) ventilation of the enclosed source cabinets, 2) ventilation of the furnace tube bank and gas supply line "jungle," and 3) ventilated scavenger boxes equipped with closing doors.

Phosphate emissions were detected in a single area sample taken at the diffusion furnaces using phosphorus oxychloride. The area monitor, located 24 inches from an open scavenger box, detected phosphate emissions at a concentration of $159 \mu\text{g}/\text{m}^3$ (see Table 3). If converted to an equivalent amount of phosphorus oxychloride, the result represents a concentration of $257 \mu\text{g}/\text{m}^3$ of POCl_3 , approximately 40 percent of the TLV (see Table 3). This result identified the potential for the emission of phosphate or phosphorus oxychloride from diffusion furnace operations.

Scavenger box face velocities were measured at values as low as 50 fpm. It is reasonable to assume that under some circumstances the removal of wafer boats combined with the downdraft of air from overhead HEPA filters could effectively defeat the usefulness of the scavenger box exhaust. Although it was not possible to calculate a minimally acceptable value, the greatest practical air velocity that can be obtained should be used for scavenger boxes on diffusion furnaces handling toxic dopants. Air velocities measured at the source cabinets did not produce a similar concern. Typical readings were as high as 2600 fpm on diffusion furnace source cabinets containing toxic dopants.

Ion Implantation

Ion implantation processes and maintenance activities were monitored for airborne emissions of arsenic (as arsine gas), boron trifluoride (as boron), and organics suspected of causing noxious odors.

The operations at MOSTEK provided the NIOSH team an opportunity to study three makes of ion implanters: a number of cassette-type Varian medium-current units and three palette-type units; an Extrion-8010; and two NOVA-10 units. Area monitoring for arsenic (as arsine gas) emissions was conducted during normal operations of a Varian medium-current, a NOVA-10, and an Extrion-8010 implanter (see Table 4). Based on these results, operators performing normal work activities are potentially exposed to concentrations as high as $3.8 \mu\text{g}/\text{m}^3$ of arsenic. Levels monitored during maintenance activities (i.e., ion source charging) detected airborne levels as high as $5.38 \mu\text{g}/\text{m}^3$.

Area monitoring was conducted during normal operations of a Varian medium-current ion implanter using boron trifluoride as a dopant source. The monitoring results detected levels of airborne boron at $2.75 \mu\text{g}/\text{m}^3$. This is equal to approximately $6.28 \mu\text{g}/\text{m}^3$ of boron trifluoride or less than 1 percent of the TLV (see Table 5).

Area monitoring was also conducted for organics during the ion source changing activities. Organic emissions were not detected in significant amounts to be associated with the source changing activities.

Ventilation measurements taken at the exhaust ducts servicing each implanter showed an average air velocity of approximately 1300 fpm, which produces an estimated volumetric flow rate of 468 cfm.

The monitoring results indicate that the ventilation controls present on both cassette- and pallette-type ion implanters do not completely eliminate worker exposures to emissions of toxic dopants as previously thought; however, exposures are below current recommended standards. The results further indicate that the greatest exposure potentials exist during maintenance activities.

Radio-Frequency (RF) Sources

Radio-frequency or microwave radiation emissions were detected near most RF generating sources (Table 6). A single plasma-etching unit produced magnetic near-field energy levels that could result in exposures above the TLV for 13.56-MHz sources. Two plasma etchers produced electric field energy levels that could also result in exposures above the TLV for 13.56-MHz sources.

Based on the work habits of MOSTEK employees, it is unlikely that significant exposures to RF radiation will occur. The process operator's work regimen prevents them from spending any more than a few minutes near enough to the equipment to be exposed to the levels measured during the in-depth survey. Potential RF exposures were further reduced at MOSTEK through proper grounding of the equipment and following the installation of metal screens on viewing windows.

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