IN-DEPTH SURVEY REPORT:

CONTROL TECHNOLOGY FOR THE MICROELECTRONICS INDUSTRY AT NEC ELECTRONICS USA MOUNTAIN VIEW, CALIFORNIA

by

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SIC CODE:	3674
SURVEY DATE:	April 11 through April 13, 1983
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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 these 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, approximately 114,000 persons were employed in this industry. The industry uses several hazardous materials, e.g., arsine, phosphine, and boron, and little information is available on the resulting exposures to these materials. Indications from a Cal/OSHA study (CalOSHA 1981), however, are that only a few plants have adequate controls for handling toxic gases like arsine and phosphine. The Cal/OSHA study and a previous NIOSH study on the photovoltaic industry (NIOSH 1980) also indicate that substances such as arsine might pose an arsenic hazard to microelectronics workers.

BACKGROUND FOR THE NEC ELECTRONICS SEMICONDUCTOR SURVEY

This in-depth survey is a part of a larger data-gathering effort to characterize basic exposures and to 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 NEC Electronics USA, Inc., facility at Mountain View, California, was selected for study on the basis of a preliminary walk-through survey conducted on January 13, 1982 (NIOSH 1983). The NEC facility (which is operated by the Electronic Arrays Division) allowed NIOSH representatives to observe the fabrication of integrated circuits, an operation that involves a range of process and control technologies.

Four process operations common to the fabrication of integrated circuits were studied in detail: photolithography, operations using radio frequency radiation, and gas handling and distribution systems.

PLANT PROCESS DESCRIPTION

This section describes the physical plant, the entire circuit fabrication process, and various individual process operations at the NEC Electronics 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 those 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 if such details are desired.

GENERAL DESCRIPTION

Electronic Arrays was formed in 1968 and merged with NEC Electronics USA., Inc., in 1978. Product lines have included metal oxide semiconductors (MOS); memory products and random logic products including read-only memories (ROMS); random-access memories (RAMS); erasable programmable read-only memories (EPROMS); and custom logic products. The facility currently manufactures ROMS and RAMS.

The facility consists of three buildings: 1) a 27,000-square-foot building of tilt-up concrete slag construction built in 1966; 2) a 16,000-square-foot building of tilt-up concrete slag construction built in 1980; and 3) a 40,000-square-foot brick building constructed in 1961. Wafer fabrication is performed only in the first building. The remaining areas are used for testing and packaging, office space, engineering design, and sales.

The facility employs 425 people--276 in the production area and 149 in administrative and technical services. The production staff includes 76 men and 200 women, and the administrative/technical services staff is composed of 99 men and 50 women. The facility operates two shifts per day; 226 production employees work on the first shift and 50 work on the second shift.

An emergency generator supplies the plant with 45 kilowatts of power for lighting. Electronic Arrays also plans to provide emergency power to operate the exhaust scrubbers during power failures.

CHEMICAL STORAGE

Liquid chemicals are segregated as acids or organic solvents. Acids are segregated by type and stored in boxes, which are placed on wood pallets in an area separate from the organic solvents. The floor is diked to contain spills and has a drain that flows to the acid waste neutralization system. The room has an emergency shower and eye wash station and is vented by general exhaust ventilation.

Organic solvents are also stored in their own separate area. This room is not diked and does not have a drain; however, it is vented by general exhaust ventilation. A fire extinguisher is available in the room, but there is no emergency shower or eye wash station.

Designated chemical technicians use plastic carts to distribute the chemicals to the wafer fabrication area.

GAS HANDLING SYSTEM

Gases are supplied to the wafer fabrication operation from cylinders and from bulk house storage. Bulk hydrogen, oxygen, and liquid nitrogen are distributed in stainless steel lines. In the new areas of the plant the lines are welded; in the older fabrication areas, lines are equipped with compression fittings.

Toxic or hazardous gases are supplied from cylinders stored in ventilated cabinets in the wafer fabrication area or from cylinders stored in a secured, outdoor "pad" area. The NEC facility plans to change all cylinder storage to ventilated gas cabinets. The toxic gas cylinders are connected to the gas distribution system by stainless steel lines that are either welded (in the newer fabrication area) or joined by compression fittings (in the older fabrication area).

The regulator assembly at the gas cabinet has a purge valve with bonnet and rupture disk that floods the cabinet with nitrogen following a failure of the assembly. Some lines are equipped with solenoid valves that automatically shut off the gas flow during a power failure. The lines also have flow-limiting valves that automatically close the line if the gas flow exceeds a preset limit.

Gas storage cabinets are ventilated at approximately 800 cfm through an 8-inch stainless steel exhaust duct. The takeoff is located at the top of the cabinet, and regulatory assemblies are located within the gas cabinets. Nitrogen supplied in cylinders is used to purge the toxic or hazardous gas lines. Gas cabinets containing silane cylinders have a burn box as part of the cabinet exhaust duct. The burn box is designed to promote controlled oxidation of the pyrophoric gases before they are vented to the atmosphere.

Nitrogen and toxic and hazardous gas cylinders are changed by maintenance workers. The cylinders are tested for leaks with a Snoop® leak detection system. Personal protective equipment requirements for maintenance workers include the use of self-contained breathing apparatus (SCBA) during the changing of toxic gas cylinders.

Gases in use, in addition to those noted above, are hydrogen chloride, ammonia, argon, dichlorosilane, arsine, phosphine, boron trifluoride, and freons (unspecified).

MONITORING SYSTEM

The facility uses a Rexnord® combustible gas detection system to monitor hydrogen in the wafer fabrication area. The system consists of two electronic control modules with eight channels per module. This system is capable of monitoring a total of 16 locations where hydrogen leaks may occur. The system is set to activate at 20 percent and 40 percent of the lower explosive limit (LEL) for hydrogen. Gas detector sensors are placed in the diffusion furnace area on the ceiling, in the gas jungle at the furnaces, and in the diffusion furnace scavenger exhaust duct. Toxic gas monitoring systems were not in use at the NEC facility during the in-depth survey. Electronic Arrays is considering the installation of a continuous phosphine monitoring system in the near future.

VENTILATION SYSTEM

The wafer fabrication area makeup air is filtered through a bag filter, which is followed by an activated-charcoal and a high-efficiency particulate absolute (HEPA) air filter. The air is delivered to the room either through ceiling diffusers or through vertical laminar-flow HEPA filtration units at the work station. Fabrication room air is recirculated through wall panels that act as a return air plenum. The air enters through the wall at approximately floor level. The wafer fabrication area is maintained at positive pressure relative to the surrounding building. A total of 150,000 cfm of filtered air is supplied to the fabrication area; 75 percent of the air is recirculated and 25 percent is makeup air.

Local exhaust ventilation is provided by two exhaust systems handling 15,000 and 9,000 cfm, respectively. Each exhaust system has a water scrubber with a mist eliminator. The system uses 8 to 10 gallons of water per minute. The scrubbers treat 1) vacuum pump exhausts containing toxic or pyrophoric gases as byproducts from ion implantation and low-pressure chemical vapor deposition;

2) diffusion furnace exhausts including furnace cabinet, source cabinet, and scavenger box exhaust; and 3) wet chemical etching and cleaning operation exhausts.

Exhaust ducts are constructed of either polypropylene or stainless steel and pass through the roof to connect with polypropylene trunk lines that enter the scrubber systems. Scrubbed air is vented through 36-inch diameter stacks that are 4 to 6 feet tall. The facility has ordered an emergency generator to run the scrubber systems and emergency lighting during power failures.

WASTE MANAGEMENT

Liquid wastes are segregated and handled separately. The separate waste chemical categories are chromic acid waste, acids containing fluorides, photoresist waste, phenol waste, and general organic solvent waste.

Chromic acid wastes are collected from the point of use and aspirated into an enclosed tank in a protable cart. From there, the waste acid is transferred into the original containers and stored in a trailer for periodic offsite disposal.

Acid wastes containing hydrofluoric acid are collected from the point of use in a portable chart used specifically for acid wastes. The waste is pumped into the cart, transferred to drums, and then transferred again into a 1500-gallon storage tank. The tank is in a diked area at the rear of the plant property. The waste is disposed of at an offsite hazardous waste landfill by a waste management firm.

Acids not containing fluorides are removed from the point of use by drains leading to an acid neutralization system, where the pH is continuously adjusted with ammonia. Blowdown from the air exhaust scrubbers is also treated in this system.

Photoresist waste is collected in containers located in the photolithography area. A chemical technician removes the container and transfers the waste to drums, which are disposed of at an offsite hazardous waste landfill.

The phenol-containing waste is also collected separately and transferred into a 1500-gallon storage tank located in a diked, fenced area at the rear of the plant property. A waste management firm disposes of the waste at a hazardous waste landfill. The diked area is equipped with an emergency shower.

Waste organic solvents other than those containing chlorobenzene are removed from the point of use by drains leading to an underground waste solvent tank. The waste solvents are removed by a waste management firm for offsite disposal. Waste pump oils are collected and stored in 55-gallon containers located in a trailer for periodic offsite disposal by a waste management firm. The pump oils are changed approximately once per month.

The waste collection cart is made of polypropylene and is equipped with an electrical pump for transfer of the wastes into and out of the tanks. The flow of the pump is reversed by a switch located in the cart. The operator must connect the pumps to an electrical outlet for operation. The cart has a fire extinguisher, acid neutralization materials, and spill pillows.

PROCESS DESCRIPTIONS

The fabrication sequence used to produce random-access memories (RAMS), and read-only memories (ROMS) integrated circuits varies according to the requirements of the device being manufactured. The process operations observed at the facility are described in the subsections that follow. The specific sequence in which the process operations are performed is not presented. A general processing sequence for integrated circuits is provided by Colclaser (1980) and should be consulted for a more detailed review of the fabrication process. Several process operations are used more than once in the fabrication process sequence, and some equipment is used for more than one process operation.

Thermal Oxidation

Circuit fabrication generally begins with the thermal oxidation of the silicon wafer. The wafers are oxidized at a high temperature (500° to 1000°C) in a diffusion furnace assembly using pyrophoric water (i.e., hydrogen and oxygen) atmosphere. Hydrogen chloride gas is added to the gas stream from cleaning (i.e., gettering) sodium ion contamination from both the growing oxide and the furnace tube (Colclaser 1980). The wafers are loaded into carriers that are inserted into the diffusion furnace. The furnace tube is heated by electrical resistance to the operating temperature while the tube is purged with nitrogen. Hydrogen and oxygen are then introduced into the tube at a controlled rate. The furnace has hybrid control, where processing parameters such as gas flow are automatically controlled to preset limits but can be monitored and adjusted by the operator. Mass flow controllers (MFC) are used to ensure a uniform flow rate of process gases into the furnace tube. The MFC system has a digital readout, and the flow is adjusted by the operator. Rotometers are also used to monitor gas flow; these are monitored and adjusted by the operator.

Photolithography

After thermal oxidation, the wafers are ready for photolithography, which includes 1) primer and photoresist coating, 2) pre- or soft-bake, 3) mask alignment and exposure, 4) development, 5) post- or hard-bake, 6) etching, and 7) photoresist stripping. The wafer is first coated with a primer by spin application using hexamethyldisilizane (HMDS) in a xylene carrier. The negative photoresist, which contains a proprietary mixture of organic polymers in a xylene carrier, is then spun onto the wafer and the coated wafer is transferred to a resistance-heated oven. The entire photolithographic operation is automated, and the operator is only required to load and unload cassettes of wafers. HMDS and photoresist spin application and wafer drying operations are performed at NEC in automated in-line, cassette-to-cassette units and older individual developer units.

A mask pattern defining the circuit is transferred by ultraviolet light to the coated wafer by the use of contact printing. The operator places a wafer on a stage and aligns the wafer with the mask. The wafer is clamped to the mask and exposed to ultraviolet light from a mercury lamp source located behind the mask.

The masks used by NEC are manufactured by an outside vendor to the company's specification.

The exposed wafers are developed by spin application of a xylene and n-butyl acetate solution onto the wafer surface. The developed wafers are then hard-baked in a resistance-heated oven. The operation is performed in an automated, cassette-to-cassette system similar to that used for photoresist application.

The exposed underlying layer may be etched, either by wet chemical etching or plasma etching. Wet chemical etching is performed by immersing the wafers in an etching solution. The methods include 1) hydrofluoric acid and ammonium fluoride, for etching silicon dioxide; 2) phosphoric acid, for etching silicon nitride; 3) hydrofluoric and nitric acid, for etching polycrystalline silicon; and 4) nitric and phosphoric acid, for etching aluminum. The wet chemical etching operations are performed in tanks recessed in wells in polypropylene benches. Additional wet chemical operations include 1) wafer cleaning with sulfuric acid and hydrogen peroxide; 2) mask cleaning with a Freon solvent; 3) photoresist stripping with a phenol, sulfonic acid, chlorobenzene, and unspecified aromatic solvent mixture; and 4) mask cleaning with chromic acid.

Plasma Etching

Plasma etching is performed by placing wafers in a plasma field formed by a radio frequency power source operating at 13.56 MHz. The plasma gas contains ions, free radicals, and free electrons that are reactive with the layer to be etched. Selection of the gas used for creating the plasma is based on the individual layer to be etched. Gases used at NEC include carbon tetrafluoride and oxygen (for etching silicon nitride) and oxygen (for stripping photoresist). The plasma is formed in a sealed reaction chamber at a pressure of approximately 0.1 to 20 torr created by an oil-sealed mechanical pump.

Wafer Doping

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

Diffusion is accomplished by exposing the wafer to a high-temperature atmosphere containing the dopant. The operation is performed in a diffusion furnace assembly similar to that used for thermal oxidation, with the addition of phosphine or phosphorus oxychloride instead of hydrogen chloride. Phosphine is supplied from gas cylinders stored in a ventilated cabinet. Phosphorus oxychloride is supplied from a liquid bubbler located in a source cabinet attached to the diffusion furnace.

In the ion implantation technique, a source gas, is ionized and passed through an analyzing magnet, where the desired ions are collected, accelerated, and implanted into an individual wafer held in a vacuum chamber. During the in-depth survey the implanters were not in use but were equipped to use phosphine and boron trifluoride. The ion source, analyzing and accelerating chamber, and the wafer exposure station are operated at vacuum conditions of approximately 10^{-6} torr.

This vacuum is maintained by one of two sets of pumps, either an oil-sealed pump and a diffusion pump, or an oil-sealed pump and a cryogenic pump. The process operation sequence requires the operator to load a cassette into the load station of the ion implantation unit. Individual wafers are automatically removed from the cassette to a load-lock chamber, which is pumped to a vacuum with an oil-sealed mechanical pump. The wafer is transferred to the exposure chamber, where the dopant ions are implanted. The dosage received by the wafer is automatically controlled. The finished wafer is then transferred through a second load-lock chamber and into a cassette.

Chemical Vapor Deposition

At various steps in the processing sequence, a thin film is deposited on the wafer surface by chemical vapor deposition (CVD), in which the solid products of a vapor-phase chemical reaction are deposited on the substrate. The film is deposited either by low-pressure chemical vapor deposition (LPCVD) or by plasma-enhanced chemical vapor deposition (PECVD). The LPCVD technique is used to deposit 1) silicon nitride by the reaction of dichlorsilane and ammonia, 2) polycrystalline silicon by the deposition of silane, and 3) phosphorus-doped silicon dioxide by the reaction of silane, phosphine, and oxygen. Hydrogen chloride gas is used as a pretreatment during polycrystalline silicon deposition. The operation is performed in a sealed diffusion furnace tube evacuated to approximately 0.4 to 3.0 torr (Baron and Zelez 1978). The process operation requires the operator to load carriers containing wafers into the furnace. The furnace door is closed and the sequence and operating parameters are controlled by microprocessor.

The PECVD technique is also used to deposit silicon nitride by the reaction of silane and ammonia. The plasma is created by introducing the gases in a 13.56-MHz radio frequency field. The operation is performed under vacuum conditions in a sealed chamber at approximately 0.2 to 1.0 torr. The operators place the wafers onto a metal platen, which is loaded into the deposition chamber. The chamber is sealed and the process is initiated by pushbutton. The process operating parameters are automatically controlled.

Metallization

An aluminum layer is deposited on the wafer surface by direct current (DC) sputtering. The metal deposition is achieved in a sealed reaction chamber that is maintained at a vacuum of approximately 10^{-7} torr by an oil-sealed mechanical pump and a diffusion pump. The operator places the wafers on a metal platen, which is loaded into the reaction or load-lock chamber. The operator initiates the process sequence by pushbutton control. The load-lock chamber is closed and evacuated, the platen is transferred to the deposition chamber, and the aluminum is sputtered onto the wafer surface. The wafers are removed after the chamber has been repressurized.

Hydrogen Alloying

After metalization, hydrogen alloying is performed to repair defects caused by the metalization process. The wafers are heated in a 50 or 100 percent hydrogen atmosphere. The operation is performed in a diffusion furnace assembly similar to that used for thermal oxidation.

Process operations (e.g., photolithography, doping, metalization, and chemical vapor deposition) may be repeated several times during wafer fabrication. Between these processing steps, wafers may be cleaned with a solution of sulfuric acid and hydrogen peroxide. The cleaning operations are performed in wet chemical benches similar to those previously described.

METHODOLOGY

The in-depth survey at the NEC Electronics Mountain View plant included sampling for chemical agents, monitoring for physical agents, and measuring 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 during the in-depth survey. 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).

Organic Compounds In Air

The concentration of various organic compounds in the workplace air were determined by using absorption on charcoal, desorption with CS_2, 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 CS_2

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

The detection limit for this method varies with the organic compound being analyzed; however, 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.

WORKPLACE MONITORING FOR PHYSICAL AGENTS

Two physical agents were monitored during the in-depth survey: radio-frequency radiation and gamma or X-radiation. The monitoring strategies used to characterize these workplace exposures varied according to the agent being studied, the nature of the process operation to be characterized, 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).

Ultraviolet (UV) Light

Exposures to ultraviolet light were surveyed with an International Light IL 730A UV Actinic Radiometer. The photoelectric cell detector supplied with this instrument has a frequency response range of 235 to 315 nanometers (nm), with peak response at 270 nm. The minimum detectable actinic ultraviolet radiation level for this instrument is 1×10^{-3} microwatts per square centimeter ($\mu W/cm^2$).

MEASUREMENT OF CONTROL PARAMETERS

Face velocities, duct traverses, and general air flow were observed 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 (fpm). 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 housekeeping. 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 NEC Electronics facility for the production of integrated circuits is discussed.

DESCRIPTION OF PROGRAMS

Industrial Hygiene

The plant has a full-time safety manager who is responsible for industrial hygiene and safety. Additional assistance is available from the plant's insurance carrier and an outside industrial hygiene consultant. The facility has also employed Stanford Research Institute (SRI) as consultants on fire safety and to perform air sampling. Larry Fluer, Inc., was consulted in the area of gas safety.

Industrial hygiene monitoring in the past has been conducted by these consultants as needed. Although NEC does not conduct any routine industrial hygiene monitoring, the safety and industrial hygiene manager is presently implementing a program to monitor employee exposures to organic solvents, acids, noise, and radiation.

Measurements of local exhaust ventilation in the fabrication area have been conducted by facility maintenance personnel. This responsibility is now being transferred to the safety/industrial hygiene program, and will include biannual measurements and certification of each ventilation system. The measurements have been performed with velometers or with inclined manometers permanently installed at specific work stations.

Film badges are used to monitor emissions and operator exposures to X-radiation from the ion implantation unit.

Education and Training

Training programs have been developed and implemented in the areas of worker safety and materials handling. Programs currently under development include personal protective equipment use, emergency response procedures, and hazard reporting procedures.

A safety committee at NEC meets monthly to discuss specific topics related to employee health and safety at the Mountain View facility. The committee consists of production workers, supervisory personnel, and safety officials.

New employees are trained by process supervisors in chemical handling procedures and to correctly use personal protective equipment.

Personal Protective Equipment

Product-protection equipment used by the operators to prevent contamination in the fabrication area include coveralls, shoes or shoe covers, and gloves. In addition to normal clean room attire, all workers in the wafer fabrication area are required to wear safety glasses. Workers performing specific tasks are required to use appropriate additional personal protective equipment. Chemical mix operators, who are responsible for mixing and distributing chemicals into the fabrication area and for transferring wastes, are required to wear acid-resistant aprons with gloves, sleevelets, face shields, and safety glasses. Face shields are also required for any operator who works where chemicals present a splash hazard.

Technicians performing maintenance operations are required to use additional protective equipment. Technicians changing gas bottles from the ion implantation unit and servicing equipment on toxic gas lines use self-contained breathing apparatus (SCBA). A particulate respirator (unspecified size and type) is worn by technicians who bead-blast arsenic deposits from parts in the ion implantation unit. Heat-protective gloves, aprons, and face shields are worn by maintenance technicians handling and cleaning quartz furnace tubes.

Emergency showers, eye wash stations, breathing oxygen, and SCBA are available throughout the plant.

Medical

The facility does not employ a nurse or a physician, either a full- or part-time. Medical services at the plant are limited to first aid and cardiopulmonary resuscitation (CPR) provided by trained employees. Approximately 10 percent of the general workforce and 50 percent of the supervisors are trained. Emergency medical care is provided by Peninsula Industrial Medical Clinic, Sunnyvale, California, and by El Camino Hospital, Mountain View, California.

The facility does not require employees to have preplacement or periodic medical examinations. No routine biological monitoring is performed.

Housekeeping and Maintenance

Housekeeping and maintenance activities are necessary parts of maintaining product quality. Specific housekeeping procedures were identified by the plant as being practiced to prevent worker exposures to chemical agents. These include a central vacuum system in the photolithography area, which is used for cleaning. The vacuum system is part of the local exhaust ventilation system.

Maintenance activities were not identified for each process operation at the facility. General maintenance activities include monthly draining and replacement of pump oils from oil-sealed mechanical pumps. Pumps associated with the LPCVD unit incorporate a continuous oil filtration system to increase the useful life of the oil. Pump oil spills are cleaned up with a Freon solvent.

Diffusion furnace quartz tubes are routinely removed from the furnace assembly and cleaned with an acid solution on weekly to monthly schedules.

Scheduled maintenance of the ion implantation unit is performed by facility maintenance technicians. Maintenance operations include bead-blasting of the ion source. Pump oils are routinely changed. The plant also has a service contract with a vendor to provide all other maintenance of the unit.

PHOTOLITHOGRAPHY

Photolithography includes the following operations: 1) spin-on application of a primer, hexamethyldisilizane (HMDS); 2) drying; 3) spin-on of photoresist; 4) soft-baking; 5) wafer exposure by projection mask alignment or contact printing; 6) spin-on application of a developer solution of n-butyl acetate and xylene; 7) hard-baking; and 8) wafer inspection.

The photolithographic operations observed at NEC were located in a single large clean air room. The operation included both state-of-the-art automated Wafer Trak^R systems and older IMS^R batch unit processing equipment. Wafers were also aligned and exposed to UV light in this clean room.

The operations performed in substrate preparation include 1) deionized water wash and nitrogen blow-dry, 2) spin-on application of hexamethyldisilizane (HMDS), 3) spin-on application of a negative photoresist, and 4) soft-bake of the coated wafer in a resistance-heated oven. These operations are performed consecutively in an in-line, cassette-to-cassette Wafer Trak^R units, which are automated with microprocessor controls.

The operator loads a cassette containing wafers into the unit. Individual wafers are automatically removed and processed in the sequence described above. The wafers are transferred to a spin platform where they are rotated, washed and then transported to a second cassette where they are removed and placed in a nitrogen-purged drying oven. The cassette is loaded into the in-line unit, where individual wafers are transferred to another transferred to another spin platform. The HMDS, in a xylene carrier solvent, is spun onto the wafer. The HMDS mixture is supplied from enclosed reservoirs located in cabinets beneath the spin operation. The photoresist is then spun onto the wafer. The resist is a mixture of proprietary photosensitive organic polymers in a xylene carrier and n-butyl acetate or toluene carrier solution.

Separate cassette systems (older nonautomated units) are used to apply negative and positive photoresist. The wafers are transferred through a resistance-heated oven for soft-baking. The wafers may also be baked in a separate nitrogen-purged oven. The oven is vented to the room atmosphere.

The spin platforms of the older units are vented by either a common plenum that encloses adjacent platforms or by individual exhausts from each platform. The common plenum is a hinged hood that encloses adjacent platforms and is vented by a flexible duct at one end of the plenum. Individual spin platforms are also vented by local exhaust to a duct at the base of each platform. The platform is enclosed by a clear plastic shield. A container is located in the cabinet below the unit to collect liquid photoresist wastes. The container is vented to the exhaust ventilation system. All local exhaust from the photolithography area is treated by a water scrubber before release to the atmosphere.

A mask pattern is transferred to the photoresist-coated wafers by projecting the mask image with ultraviolet light by use of contact printing. The operator removes a wafer from a cassette and places it on the stage of the unit. The mask is aligned and clamped to the wafer. A mercury lamp source producing ultraviolet light at a peak wavelength of 345 nm is used to transfer the mask pattern. The lamp source is enclosed in a housing that is vented for temperature control. The enclosure is vented by a small fan located on the floor below the units. The fan vents directly to the room. The exposure process is performed by an operator seated at the unit. The operator places the wafer on the stage and aligns the mask by viewing it through a split-field binocular microscope. The wafer and mask are clamped and rotated into position where the wafer is exposed to the light source. The wafer is removed and the process is repeated. Engineering controls include shielding of the lamp source to prevent direct viewing. The intensity and uniformity of the mercury lamp are continuously monitored, and the lamp is changed whenever the measurements exceed preset limits.

Photoresist-coated wafers that have been exposed to the mask pattern are developed on the IMS units by spin-application of the developer solution. A proprietary mixture of xylene and n-butyl acetate or a mixture of unspecified aromatic and aliphatic hydrocarbons is used to develop the exposed wafer. The developer wastes are aspirated into the solvent drain system and into the waste solvent storage tank.

The spin platforms are enclosed and ventilated. The developer solution is supplied from a reservoir stored in the cabinet of the unit. The operation is automated, and operations are only required to load and unload cassettes.

Monitoring Results

The workplace air in the photolithography area was monitored for six organic substances: hexamethyldisilizane (HMDS), acetone, n-butyl acetate, xylene, Cellosolve acetate and methyl Cellosolve. Ultraviolet (UV) light emissions were also monitored at mask alignment-exposure units. Table 1 presents a summary of the results of area monitoring for airborne organics in the photolithography area. Monitoring was performed at work stations near both the Wafer Trak® and IMS® units. An area monitor was also located at a position that allowed a general room air sample to be obtained.

The mask alignment-exposure instruments were monitored for ultraviolet light emissions in the actinic spectral region by placing the photoelectric detector of the UV radiometer at various distances from visible blue light sources of emission. Table 2 presents the results.

Work Practices

Workers monitoring the Wafer Trak® or IMS® batch developer units do not remain positioned at a given work station. Wafer Trak® workers remain within a few feet of the unit throughout the workshift, but are involved in frequent wafer- and cassette-handling tasks that require them to move about the photolithography room.

TABLE 1. SUMMARY OF RESULTS OF AREA MONITORING FOR ORGANIC SUBSTANCES IN THE PHOTOLITHOGRAPHIC AREA

Job description and location of monitor	Sample duration (h·min)	Sample volume (liters)	Measured concentrations* (µg/m^3)			
			Hexamethyldisilizane	Acetone	n-butyl acetate	Xylene
Area monitor located over Wafer Trak^R photoresist spin-on station	3·37 2:12	59 3 35.9	426.6 473.3	224.3 169.9	204.0 261.8	12263.1 13211.7
Area monitor located over IMS^R batch developer	4·44	44.9	-	13.8	46.8	1507.8
Area monitor located at video monitor over Wafer Trak^R	3:15 1:18	30.8 23.4	- -	113.6 89.7	808.4 1183.8	3456.7 3106.8
Area monitor located over Wafer Trak^R near post-bake oven	1·58 2·34	24.2 31.6	- -	243.8 107.6	516.5 363.9	22045.4 7598.1
Area monitor located over IMS^R batch developer	3:23 2.28	58.6 44.5	- -	117.7 103.4	659.3 1011.2	3595.6 2856.2
Area monitor general room measurement	3:07 2:14	37.2 26.7	- -	107.5 131.1	379.0 465.9	5521.5 3681.6

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* The analytical method used to measure concentrations of organic substances achieved the following detection limits hexamethyldisilizane - 15 µg, acetone - 0 5 µg, n-butyl acetate - 0.5 µg, and xylene - 0.2 µg. Cellosolve acetate and methyl cellosolve were not detected in any of the air samples above a detection limit of 0 5 µg

TABLE 2. SURVEY OF ULTRAVIOLET RADIATION EMISSIONS FROM MASK ALIGNMENT-EXPOSURE UNITS

Location of photoelectric detector during survey	Irradience* (μW/cm²)
Ventilation port on upper rear portion of mask alignment-exposure instrument (distance of 12 inches)	0.14†
Ventilation port on upper rear portion of mask alignment-exposure instrument (distance of 36 inches)	0.004
Reflection of UV light from right side of mask alignment-exposure instrument (distance of 12 inches)	0.007
Transmission of UV light through sneeze guard in front of mask alignment-exposure instrument (distance of 12 inches)	0.003

[*] The irradience values given represent the average emission detected over a 2- to 3-minute period. The spectral response of the monitoring instrument used during this survey is limited to the actinic ultraviolet spectral region.

[†] Based on an effective irradience at 270 nm, the ultraviolet light emissions detected at this location exceed the recommended TLV for an 8-hour exposure (0.1 μW/cm²).

During the in-depth survey no employees were observed staying near the IMS® batch developers for more than a few minutes. In contrast to Wafer Trak® and batch developer workers, employees operating the mask alignment-exposure instruments remain seated at their work stations for long periods of time. During the survey, mask alignment-exposure workers were observed operating the instruments for several 1- to 3-hour periods during the main workshift.

Photolithogrpahy workers are required to wear normal clean room attire. Workers responsible for replenishing organic solvents or photoresist chemicals at Wafer Trak® units are provided with additional protective equipment, including chemical-resistant aprons, gloves, and face shields.

RADIO-FREQUENCY RADIATION SOURCES

Radio-frequency (RF) radiation was used at NEC Electronics to perform batch plasma etching of silicon wafers. Two plasma units were monitored for RF emission, one unit in particular, a Dionex Series 2000 plasma etcher, was monitored in great detail because it provided an excellent opportunity to study a variety of exposure problems associated with process operations using RF energy sources.

Monitoring Results

Table 3 presents a summary of the RF measurements taken during the in-depth survey. Radio-frequency emissions (magnetic and electric) were found along the seams of adjoining metal plates, through metal screens attached to equipment viewing

TABLE 3. SUMMARY OF RADIO FREQUENCY RADIATION EMISSIONS FROM PLASMA ETCHING WORK STATIONS

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)
Branson IPC plasma etcher (all readings taken 4 inches in front of unit)	13.56	400	3.0	19,000*	0.03
		200	1.0	500	0
		100	6.0	0	0
Dionex Series 2000 plasma etcher	13.56	400	9.0		
a_1 4 inches in front of unit				18,000	0.03
a_2 12 inches in front of unit				1,600	None
a_3 36 inches in front of unit				1,000	None
b left side of unit				9,500	None
c right side of unit				210,000*	0.3†
d rear of unit				25,000*	None
e stripchart recorder				15,000	None
f thermal controller				650,000*	None
g power cable				-	0.35†
h RF power supply				10,000	0.19†
i service table located to the left of etcher				50,000*	None
j service table located to the right of etcher				3,500	None

* Electric field radiation exceeds the recommended TLV for RF radiation at 13.56 MHz (1.8×10^4 V^2/m^2 for a 6-min exposure).

† Magnetic field radiation exceeds the recommended TLV for RF radiation at 13.56 MHz (0.13 A^2/m^2 for a 6-min exposure).

windows, along power supply cables, and along support structures near the plasma etching equipment. Initial measurements of these emissions or leakage were made 10 cm (4 inches) from the enclosed cabinet. If these measurements indicated elevated RF, additional measurements were made at greater distances from the emission source.

A Branson IPC plasma etching unit was monitored during operation at three power settings--400, 200, and 100 watts. As indicated in Table 3, an electric field hazard was encountered only at the highest setting. No magnetic field hazard was detected in the work environment at any power setting.

A Dionex Series 2000 plasma etching unit was monitored during normal operating power settings of 400 watts. This unit presented a variety of exposure problems at NEC. Figure 1 depicts the Dionex unit and the associated plasma etching work station. The unit was supported by a steel table connected by metal braces to two adjacent steel tables. The RF power source for the plasma etching unit was located beneath the center table. A stripchart recorder and thermal controller were situated atop the plasma etcher.

Capital letters identify the locations at which RF measurements were taken in both Figure 1 and Table 3.

Plasma Etcher--

The RF emissions detected at several locations (a_1, a_2, a_3, b, c, and d) were originating from the plasma etcher unit itself. At the "a" series of locations the attenuation of RF emissions

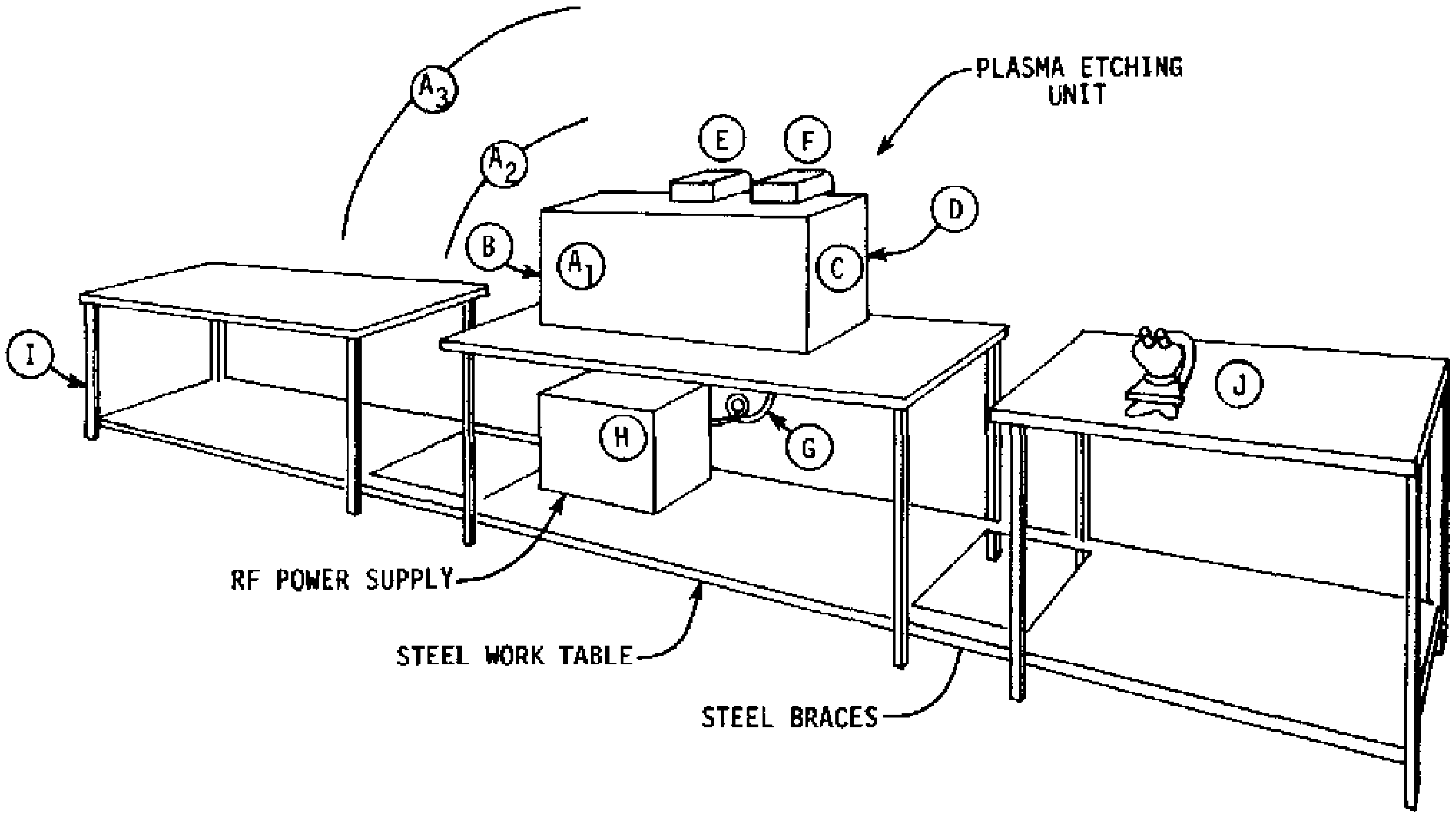

Figure 1 Location of RF measurements taken at a plasma etching work station.

was measured at distances of 10 cm (~4 inches), 30 cm (~12 inches), and 90 cm (~36 inches) from the front of the plasma etcher. As indicated in Table 3, electrical field energies were detected at all three distances; magnetic field emissions dropped off to zero after approximately 30 cm. Electrical field emissions were also detected at location "b." None of these emissions presented either electrical or magnetic hazards. The measurements at locations "c" and "d" presented an electrical field hazard in excess of the recommended TLV for a 13.65-MHz source. A magnetic field hazard was also detected at location "c".

Auxiliary Equipment--

The stripchart recorder (e), the thermal controller (f), the power cable (g), and the RF power supply all emitted varying levels of RF emissions. The thermal control appears to present a potential electric field hazard. Magnetic field hazards were also detected at the RF power supply and along the power cable.

Adjacent Structures--

In addition to the plasma etcher and auxiliary equipment associated with the operation, the three supporting metal tables also were found to be sources of RF emissions. The metal braces interconnecting the three steel structures conducted RF energy at a distance of 4 to 6 feet from the RF power supply before emitting it into the workplace. A potential electrical field hazard exists at location "i" even though it was 6 feet from the power source. Electric field emissions were also detected at location "j," but at levels below the TLV for a 13.56-MHz source.

The RF hazards found at the NEC facility help to identify the major potential sources of workplace RF exposures from plasma etching processes. Some RF exposures may occur under normal operating conditions if process workers are stationed directly in front of the viewing windows for long periods of time (>6 min). Auxiliary equipment or nearby metal structures may transfer and radiate RF energy to unusual or unexpected areas of the workplace. The RF power supplies and power cables may be direct sources of radiation. Most of the noteworthy RF hazards appear to be from electric field exposures. For frequencies below 30 MHz, ungrounded objects can couple to the RF field and present a serious potential for shock or burns.

Work Practices

Work practices varied with different types of equipment and during the processing of different products. One unusual work practice observed during the survey was that the workers operating plasma etching equipment tended to interrupt the process by opening the reactor chamber door in what appeared to be mid-cycle. During this interruption, the workers moved or manipulated the wafers manually with a pair of tweezers before closing the chamber door and allowing the etching cycle to proceed. This potentially dangerous work practice was of concern to the NEC health and safety personnel, and they had asked management to ascertain the necessity of this practice. No monitoring for hazardous chemical species or RF radiation was performed during this unusual practice.

Workers involved in the operation of RF sources are not required to wear any additional personal protective equipment other than the normal clean-room attire.

GAS HANDLING SYSTEM

Toxic, corrosive, pyrophoric, and flammable process gases are supplied in cylinders, which are stored in ventilated gas cabinets. The cabinets are ventilated by 6- or 8-inch galvanized exhaust ducts. The 6-inch exhaust ducts typically provide a velocity of 900 fpm, which results in a volumetric flow rate of 177 cfm. The 8-inch exhaust ducts provide air velocities of 950 to 1100 fpm, which results in a volumetric flow rate of 333 to 385 cfm. Exhausts from the gas cabinets, wet chemical stations; diffusion furnace pumps, and gas cabinet purge lines are handled by wet scrubbers. These scrubbers are designed to handle 10,000 to 15,000 cfm.

GAS DISTRIBUTION SYSTEM

A diagram of the typical gas distribution setup at NEC is presented in Figure 2. The process gas cylinder (containing a toxic or hazardous gas) is connected to the distribution system by a "Y" connector followed by an automatic solenoid valve. The "Y" connector also makes an attachment to the gas purge system through a manual purge gas "inlet" valve. The solenoid valve, when open (the actuated position) feeds process gas to a 0.3-μm borosilica filter. In the closed (non-actuated) position the solenoid valve vents the process gas to the wet scrubber.

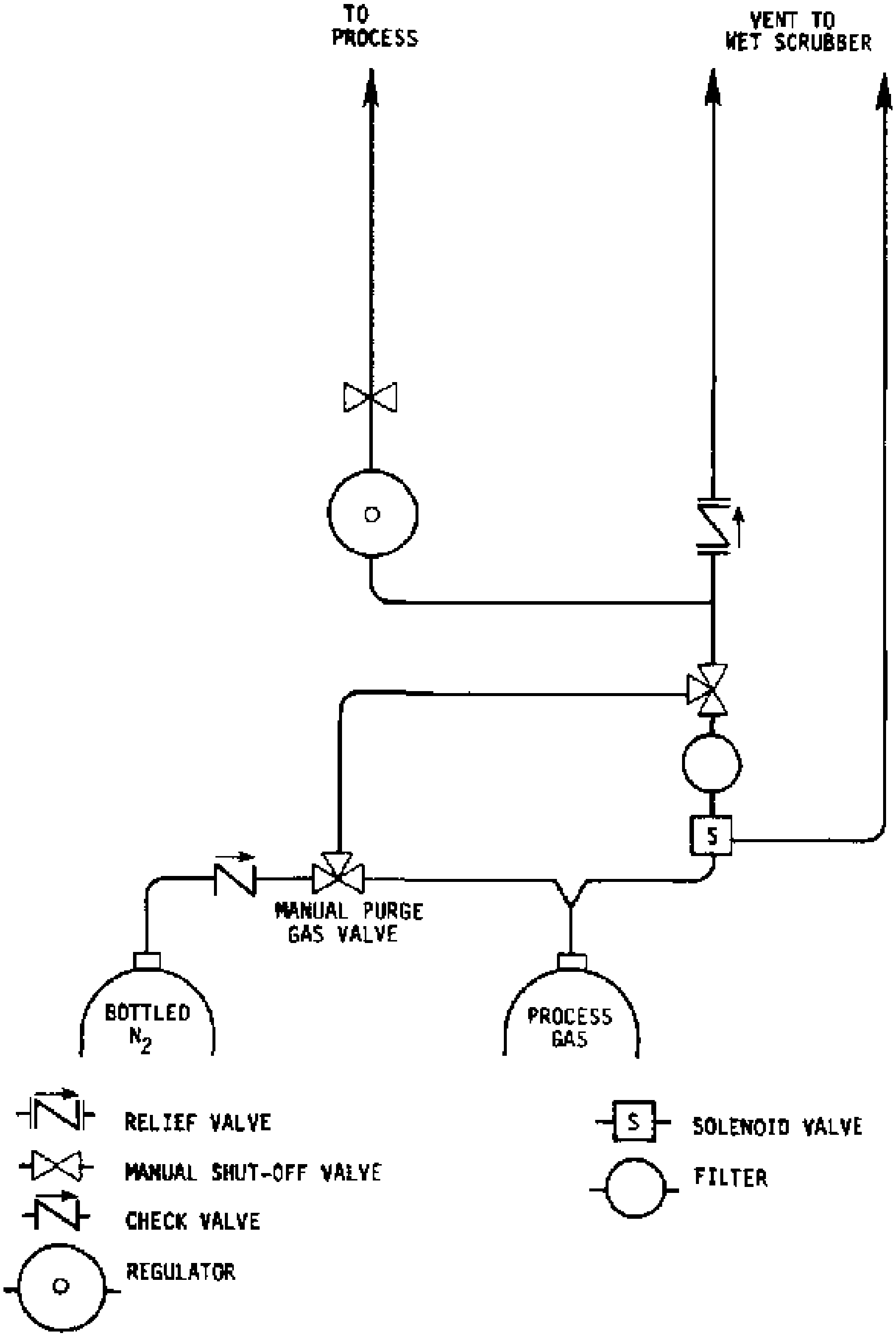

Figure 2. Gas distribution system

Following filtration the process gas enters a "T" connection and under normal operating conditions flows to the process gas regulator. When the process line experiences over-pressurization the gas vents through a relief valve to the wet scrubber.

The process gas continues through the regulator past a manual shut-off valve to the process equipment.

The nitrogen purge system enters the gas distribution system from gas cylinders through a check valve. The nitrogen is then directed to the "Y" connection or to a bypass purge line via the control of a manual "purge gas" valve. The bypass line is used when NEC wishes to manually purge the entire 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 at the NEC facility involves the movement of process chemicals from storage or holding areas into the circuit-fabrication area. Toxic or hazardous gases used at NEC are transferred from compressed gas cylinders to process machinery through a gas handling system. This system is an example of contemporary engineering design. As described previously and shown in Figure 2, 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.

Worker exposure during the transfer of liquid chemicals is controlled through the use of personal protective equipment. The protective equipment for chemical mix operators consists of 1) chemcial-resistant aprons, 2) acid- or chemical-resistant sleevelets and gloves, and 3) chemical-splash goggles and face shields. The overall potential for accidental exposure to liquid chemicals is reduced further by the use of a portable cart that pumps acid wastes from the process tanks or equipment into the cart for transfer to drums.

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 NEC or because of budget limitations on the sampling effort. The controls that were observed were assessed in terms of their effectiveness in the reduction or elimination of 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.

PHOTOLITHOGRAPHY

Photolithographic operations expose integrated circuit fabrication workers to a number of potential hazards, both chemical and physical in nature. Fabrication workers are exposed to low levels of organic substances from photolithographic operations around both automated wafer Trak^R systems and IMS^R batch developer units. The airborne levels proved to constitute only a fraction of the recommended TLV's for a number of substances (see Table 1). The area monitoring conducted at

NEC detected acetone, n-butyl acetate, xylene, and hexamethyldisilizane in the workplace air. Acetone and n-butyl acetate were detected at levels less than 1 percent of their respective TLV's. Xylene was detected at levels as high as 5 percent of its TLV. Hexamethyldisilizane (for which a TLV has not yet been established) was detected at levels of 426 and 473 $\mu g/m^3$.

Ultraviolet light emissions from mask alignment-exposure units were measured to estimate the potential worker exposure to UV radiation during normal process activities (Table 2). The spectral response of the instrument used during this survey was limited to the actinic ultraviolet spectral region. Based on an effective irradience at 270 nm, the UV light emissions near the rear of the unit exceeded the recommended TLV for an 8-hour exposure (0.1 $\mu W/cm^2$). Because of the location of workers during the exposure tasks, however, it is unlikely that these UV emissions present an actual hazard. A potential might exist for maintenance workers making repairs or adjustments should they be positioned to the rear of the instrument for long periods of time. Although not specifically designed as a control to UV emissions, the plastic "sneeze shield" placed in front of the worker appears to provide a 50 percent reduction in reflective UV emissions from the instrument.

Radio-Frequency Sources

The plasma etching operations at NEC provided NIOSH the opportunity to observe and monitor a number of exposure problems associated with RF-powered process equipment. Two plasma etching units were monitored for RF emissions. One unit in particular, a Dionex 2000 Series plasma etcher, was surveyed in great detail (see Table 3 and Figure 1).

The survey results indicate that RF sources can emit radiation into the workplace directly from the process equipment and indirectly from auxiliary equipment and adjacent support structures. Direct emissions of both magnetic and electric field energies can be controlled through the use of shielding and grounding of the process equipment. However, it appears to be difficult for microelectronics health and safety personnel to identify and control indirect emissions without conducting in-depth monitoring of the process equipment when it is in place and operating. RF power sources, power cables, stripchart recorders, and support tables can couple with RF fields from the plasma etcher and emit hazardous levels of RF emissions. The site of these indirect emissions cannot often be determined intuitively following inspection of the worksite. Both the direct and indirect emissions of RF radiation were detected at levels in excess of the TLVs for both the electric field and magnetic field components of a 13.56 MHz source.

The primary engineering solution employed by NEC for the reduction of electric and magnetic field emissions is the proper maintenance and fitting of equipment cabinets and through the installation of metal screens across the view ports or plasma etchers, and grounding of the instrumentation.

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