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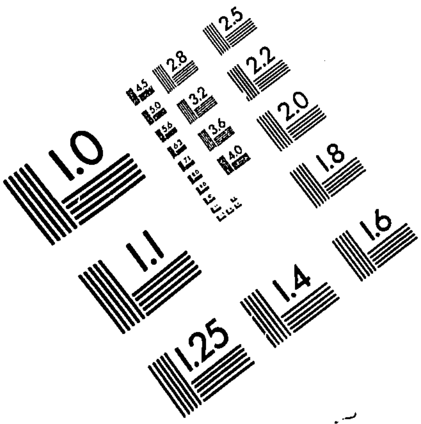

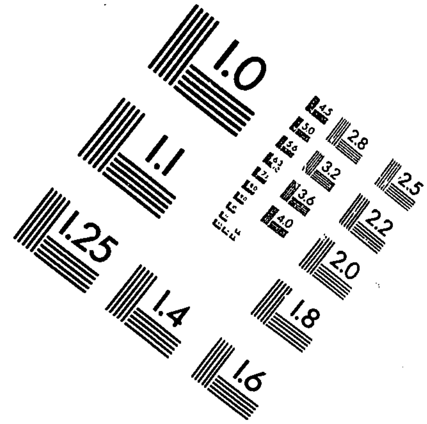

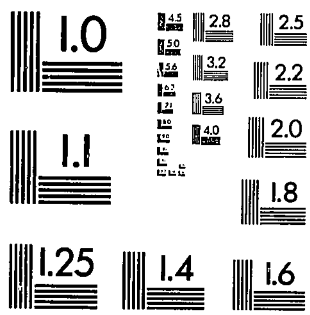

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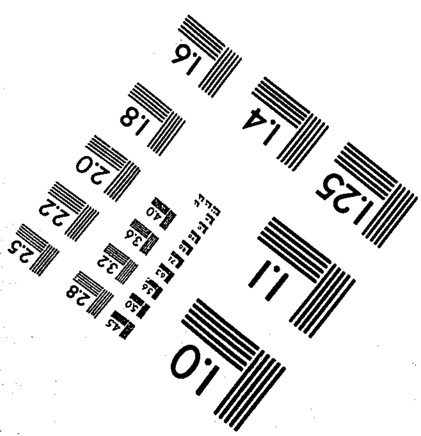

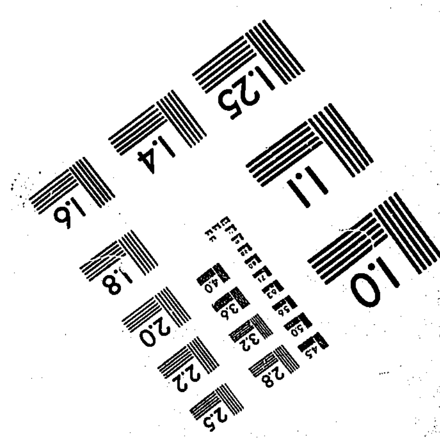

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CHAPTER 18

Diffusion and Deposition Furnaces: Hazard Control Systems

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INTRODUCTION

Open-atmosphere furnace systems are commonly used in semiconductor manufacturing operations during wafer fabrication to deposit dopant gases for junction formation, to create an oxide layer, and for other surface effects. Potential hazards associated with operation and maintenance of these furnaces include: hydrogen fires and explosion; electrical shock; airborne exposure to dopant gas, hydrogen chloride, and phosgene furnace emissions; and exposure to inorganic acid mixtures during quartzware cleaning operations.

Industrial hygiene air monitoring data show that air contaminant exposures are routinely at less than 10 percent of the threshold limit value (TLV).[1] The occupational health and safety issues associated with these processes and equipment have been described by several authors.[2-5]

DESCRIPTION OF PROCESS

Furnace systems that are open to atmosphere are a common type of equipment used to perform oxidation, deposition, and diffusion of dopant impurities onto the surface of silicon wafers in semiconductor device fabrication processes. Typically, a wafer will be processed in such a furnace ten or more times during the numerous steps involved in integrated circuit fabrication. Each processing step in such a furnace is performed according to a precise and repeatable combination of time, temperature, and gaseous environment.

Oxidation

Oxidation of the silicon wafer surface to obtain a masking or electrically insulated silicon dioxide layer or pattern is accomplished by processing the wafer with steam that is produced with combustion of oxygen and hydrogen or with oxygen by itself. This oxidation takes place at furnace temperatures ranging from 1000° to 1200°C.

Deposition

Deposition of electron acceptor and donor elements onto the silicon substrate to create p-n junctions is also accomplished with the same type of furnace equipment. Boron is a commonly used electron acceptor while phosphorus, arsenic, and antimony are the common electron donor elements utilized. Initial deposition of these dopant impurities can be accomplished in these furnaces where the dopant is deposited from the gaseous phase. Dopant material can also be applied to the surface by the ion implantation process or by the glass-source method, where the dopant impurity is contained in a silicon dioxide liquid emulsion. Drive-in or diffusion processing of the wafer is then performed in the heated tube furnace to obtain the desired diffusion profile of the dopant material.

Where the dopant is introduced to the wafer surface in these furnaces, liquid dopants, including POCl, PBr_3, and BBr_3, are utilized. Solid source wafers of the dopant materials can also be used. Ion implantation processes utilize either the gaseous hydride or metallic solid state of these dopant elements.

Equipment

Furnaces are generally located in the clean room environment to prevent surface contamination of the wafers. Depending upon the particular facility and clean room layout, furnace areas are usually part of the larger clean room and are positioned adjacent to acid or solvent wet benches, ion implanters, thin film, and chemical vapor deposition equipment. The location and layout for such equipment in the wafer fabrication is generally governed by such factors as wafer handling requirements, availability of process gases and utilities, and positioning of the back-end of the furnace into return air chases or other locations where particle generation does not adversely affect the clean room.

Wafer processing in these furnaces occurs in a quartz or polysilicon tube that can reach a length of over 8 feet and has a diameter several inches larger than the wafer being processed. The tube is heated to temperatures ranging from 800° to 1200°C by resistor heating elements that operate at 220 or 440 volts AC. Tube temperature can be precisely controlled along the entire length with multiple thermocouple controllers. Consoles containing four such tubes are generally supplied by manufacturers of this equipment.

Process gases (nitrogen, oxygen, hydrogen, and dopant vapor) are introduced into the quartz tube at the tapered end that is located in the source cabinet (Figure 1). Gas flow is precisely metered and controlled by mass flow controllers and other valves that connect into the furnace system's computer controls. Pressure regulators, process gas valves, liquid dopant source vials, and other components are enclosed in the source cabinet. Process gases are emitted at the "load-end" of the furnace tube and are captured by the "scavenger system," which is an exhaust ventilated enclosure adjacent to the tube opening (Figure 2).

Wafers are loaded in the open end of the quartz tube, stacked on edge in a quartz tray or "boat." Most furnace systems utilize automated systems for introducing and withdrawing the wafer boat at specific rates and times. The load station where wafers are present is generally provided with HEPA filtered down-draft laminar air flow to reduce contamination of the wafer with airborne particles.

Work Activities

The operator controls the furnace at the keyboard console located at the load end of the furnace. Instructions for furnace operation are entered at this work station. The operator also must load and unload wafers from the quartz boats. The furnace controls are microprocessor-based and monitor and control all furnace functions. Specific recipes can be stored and then utilized for processing wafers.

A variety of personnel directly operate diffusion and deposition furnaces or work adjacent to this process equipment, depending upon the manner in which the wafer fabrication is laid out and the scope of responsibilities assigned to employees in the wafer fabrication area. The furnace operator is generally responsible for entering instructions into the furnace controller and loading wafers in and out of wafer boats and tube loaders. Duties generally also include cleaning wafers in acid and water solutions

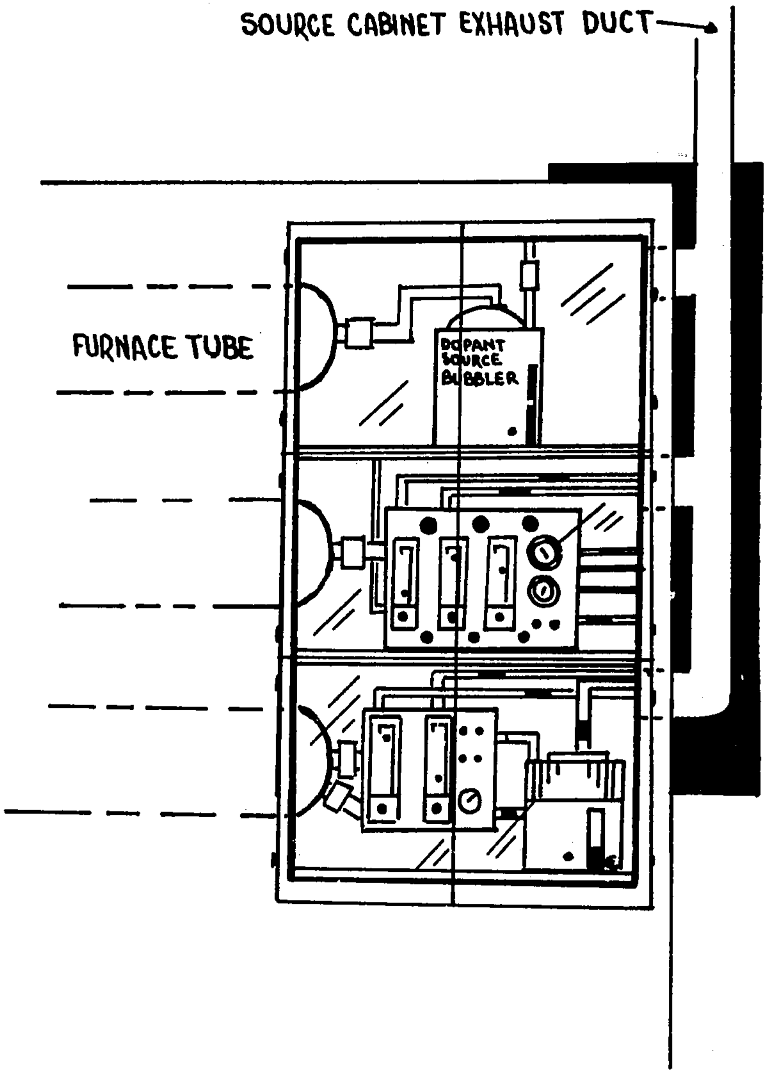

Figure 1. Dopant source cabinet for furnace system.

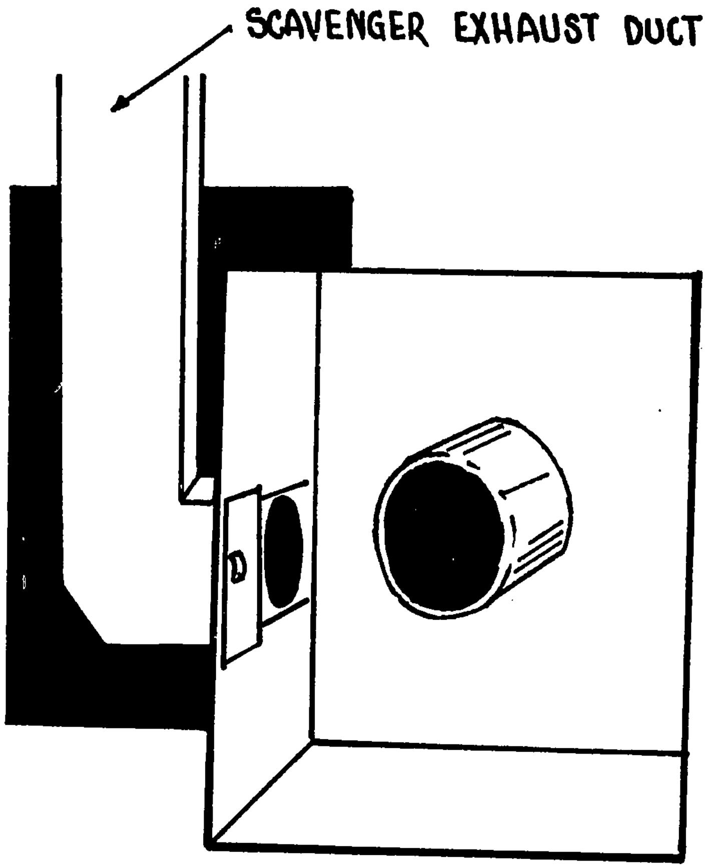

Figure 2. Scavenger system, vestibule enclosure, and exhaust ventilation of furnace tube emissions.

and drying them in spin-rinse driers prior to loading into furnaces. Maintaining process records are major job tasks.

Equipment technicians are involved in such activities as changing dopant bubblers, performing preventive maintenance and repairs on furnace system components, and system troubleshooting. Tube and quartzware cleaning may be done by these technicians or by specially designated personnel.

Process engineers, supervisors, and other wafer fabrication personnel spend some time in the area of the diffusion furnaces.

Process Materials

Table I provides a listing of the materials utilized for the oxidation, deposition, and diffusion processes. Furnace systems which perform oxidation processing of wafers utilize gaseous oxygen and hydrogen. Nitrogen is the most commonly used diluent and inerting gas.

Dopant materials utilized in the tube furnaces are usually liquids contained in quartz bubbler devices and deposit either phosphorus, boron, or arsenic. Liquid phosphorus dopants are either phosphorus oxychloride or phosphorus tribromide, while the most common liquid boron dopant is boron tribromide. Emissions from these tubes include P_2O_5 and chlorine gas, where POCl is the dopant, and B_2O_5 and bromine gas, where BBr_3 is the dopant. Solid dopant sources can also be utilized and most commonly are boron nitride, aluminum arsenate, and phosphorus pentoxide.

In situ tube cleaning and conditioning is performed utilizing hydrogen chloride gas. Methylchloroform (1,1,1-trichloroethane) dispensed from a nitrogen bubbler is a commonly utilized safer alternative for generating hydrogen chloride inside the hot tube.

The quartz or polysilicon tubes are periodically cleaned outside the furnace system in tube cleaning systems utilizing hydrofluoric and nitric acids.

HAZARD CONTROL SYSTEMS

A variety of hazard control systems are utilized to protect employees and prevent fire and other damages associated with the operation of atmospheric furnaces utilized in the semiconductor industry. Processing wafers in an open quartz tube heated to temperatures exceeding 1000°C, through which hydrogen and dopant materials flow, is inherently a dangerous process that requires proper equipment design and installation, failsafe process controls, and well-trained employees. The precise and repeatable recipes required to manufacture semiconductor devices have led to process equipment control systems that also provide the benefits of employee protection.

TABLE I. Materials Used in Oxidation, Deposition and Diffusion Processes

Material	Process Purpose
Argon	Diluent and inerting gas
Aluminum arsenate	Solid dopant arsenic source
Boron nitride	Solid dopant boron source
Boron tribromide	Liquid dopant boron source
Hydrofluoric acid	Cleans tubes and boats
Hydrogen	Combustion forms steam, creates reducing atmosphere
Hydrogen chloride	*In situ* conditioning of tube
Nitric acid	Cleans tubes and boats
Nitrogen	Diluent and inerting gas
Oxygen	Oxidizes silicon surface; oxidizes dopant
Phosphorus oxychloride	Liquid dopant phosphorus source
Phosphorus pentoxide	Solid dopant phosphorus source
Phosphorus tribromide	Liquid dopant phosphorus source
Trichloroethane	Thermal decomposition produces hydrogen chloride for *in situ* tube cleaning

Fire Safety

Gaseous hydrogen, oxygen, and nitrogen are commonly used in these furnace systems. Hydrogen release and possible fire or explosion are major safety concerns associated with these processes. A liquid hydrogen tank located outside the fabrication area commonly supplies gaseous hydrogen to these furnaces. Hydrogen distribution lines to the furnaces are continuous welded stainless steel. While copper piping may be used for nitrogen or oxygen distribution lines, it should not be used for hydrogen since it embrittles. Hydrogen sensors are installed in areas where hydrogen distribution lines are present. Automatic or manual hydrogen shut-off valves should be present that can be activated immediately if a significant hydrogen leak is detected. If hydrogen is supplied from a cylinder located inside a building, it should be in a safety cabinet that is equipped with an automatic fire sprinkler and an automatic shutdown device that is activated by an excessive gas flow. Any hydrogen lines that utilize other than welded fittings should be enclosed and exhaust ventilated. The source cabinet of the furnace is enclosed and exhaust ventilated because it contains numerous mass flow controllers, valves, and other components that must be replaced frequently (Figure 1). These components generally have VCR-type fittings that provide a metal-to-metal low-leak connection.

A fire or explosion hazard can exist within the furnace tube or at the opening to atmosphere if the flow and proportion of hydrogen, oxygen, and nitrogen are not controlled properly. The temperature of the tube must be above 635°C to create the controlled oxidation or combustion of the hydrogen inside the tube. Commercially available furnaces utilize the following safety systems to prevent these types of situations:

- Low temperature thermocouple sensor interlocked to hydrogen flow controllers.
- Oxygen flow is monitored and directly controls hydrogen flow to insure that the ratio of oxygen to hydrogen is always greater than 2.0.
- Hydrogen valve interlocked to nitrogen pressure that prevents hydrogen flow unless nitrogen pressure exists.
- Gas flow valves that fail open for nitrogen, and fail closed for hydrogen and oxygen in case of a power failure or other system failure.
- "Abort recipes" that are programmed into the furnace control systems that perform a safe shutdown of the system.

Dopant Systems

The source of dopant materials is usually either solid wafers stacked between device wafers on the quartz boat or a liquid source which is introduced into the furnace tube in vapor form by an inert carrier gas. Solid sources of dopant materials are safer to handle because they do not have a significant vapor pressure until they are heated. Solid sources also do not produce chlorine and bromine gas by-products associated with POCl, BBr_3, and PBr_3. Liquid sources, such as POCl, BBr_3, and PBr_3, must be handled carefully in closed containers and are incompatible with water. Spills or leaks from damaged bubblers containing these sources can create dangerous clouds of hydrochloric acid and hydrobromic acid mist. Most suppliers of these liquid dopants coat the outside of the quartz bubbler with a plastic that will contain the dopant even though the quartz is broken.

The source cabinet should be enclosed and exhaust ventilated (Figure 1) since it contains the bubbler, mass flow controllers, valves, and regulators with nonwelded connections, and other components that are prone to developing leaks. Access doors to the cabinet should hinge separately at each shelf. Exhaust ventilation is provided by a manifold to each shelf and creates an exhaust velocity of at least 100 feet per minute at all openings to the cabinet. This exhaust ventilation serves to capture and exhaust hazardous releases of hydrogen and dopant sources inside the source cabinet.

Dopant emissions at the load end of the tube are captured and exhaust ventilated by a scavenger system (Figure 2). The extent of enclosure around the tube discharge end depends on whether an automatic boat loader is being utilized and the extent that various tube caps and covers are utilized. An exhaust velocity of 300 feet per minute at the face of the scavenger enclosure is recommended. Experience has shown that exhaust ducting from scavengers must be leak tight at all duct connections. Experience also has shown that it is necessary to place a secondary exhaust ventilation enclosure around the scavenger exhaust duct sections that pass through areas that are part of the return air plenum (Figure 3). The positive pressure that exists between the clean room (where the furnace tube discharge and scavenger system exhaust opening is located) and the return air chase can produce a net positive pressure in the exhaust duct relative to the chase, resulting in a significant leakage of the captured furnace emissions from any cracks or openings in the ducting.

A procedure that utilizes a direct reading chlorine meter to measure chlorine emissions from the furnace scavenger was utilized to develop the specification for exhaust ventilation at the furnace scavenger. Figure 4 is a diagram that shows the positioning of the chlorine sensor and velocity meter relative to the scavenger system. Adjustment of the blast gate on the scavenger allows validation of the completeness of scavenger capture and exhaust as a function of the face velocity of the scavenger. Exhaust velocity at the scavenger should be measured with either a swinging or rotating vane anemometer, and not a thermoanemometer. Routine checks of the effectiveness of the scavenger capture can be performed utilizing subjective visual observation with either liquid nitrogen or dry ice (Figure 5). These methods are alternative procedures to "smoke tube observations" and are acceptable for the clean room environment where particulate generating sources are not permitted. Visual observation of capture effectiveness is important since cross drafts from laminar flow or other conditions can adversely affect the scavenger control system.

Tube Cleaning and Conditioning

The quartz furnace tubes must be periodically conditioned *in situ* with hydrogen chloride gas. An alternative method of obtaining the hydrogen chloride is from 1,1,1-trichloroethane supplied from a bubbler and pyrolytically decomposed inside the hot tube. This latter source of hydrogen chloride is safer because high pressure cylinders and associated regulators and piping are eliminated.

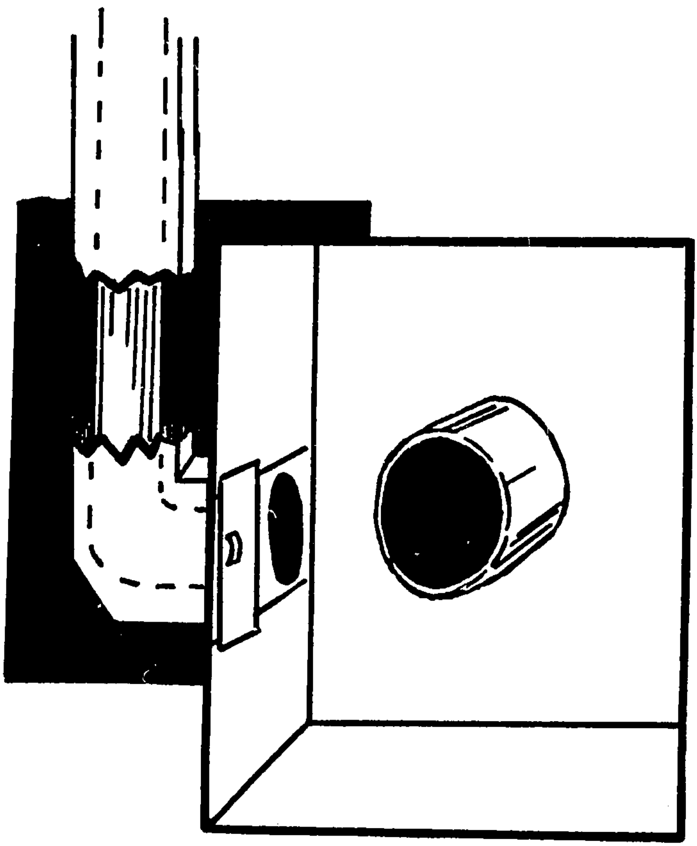

Figure 3. Secondary enclosure and exhaust ventilation of scavenger duct.

All of the previously described safety systems for hazardous gas distribution systems, source cabinets, and scavenger systems are utilized to prevent release of hydrogen chloride. A potential problem can be created with the 1,1,1-trichloroethane bubbler system if the nitrogen supply line is connected to the bubbler output line. This mistake results in liquid 1,1,1-trichloroethane being delivered into the tubes instead of the vapor-laden nitrogen carrier gas. The excess 1,1,1-trichloroethane is converted into phosgene.

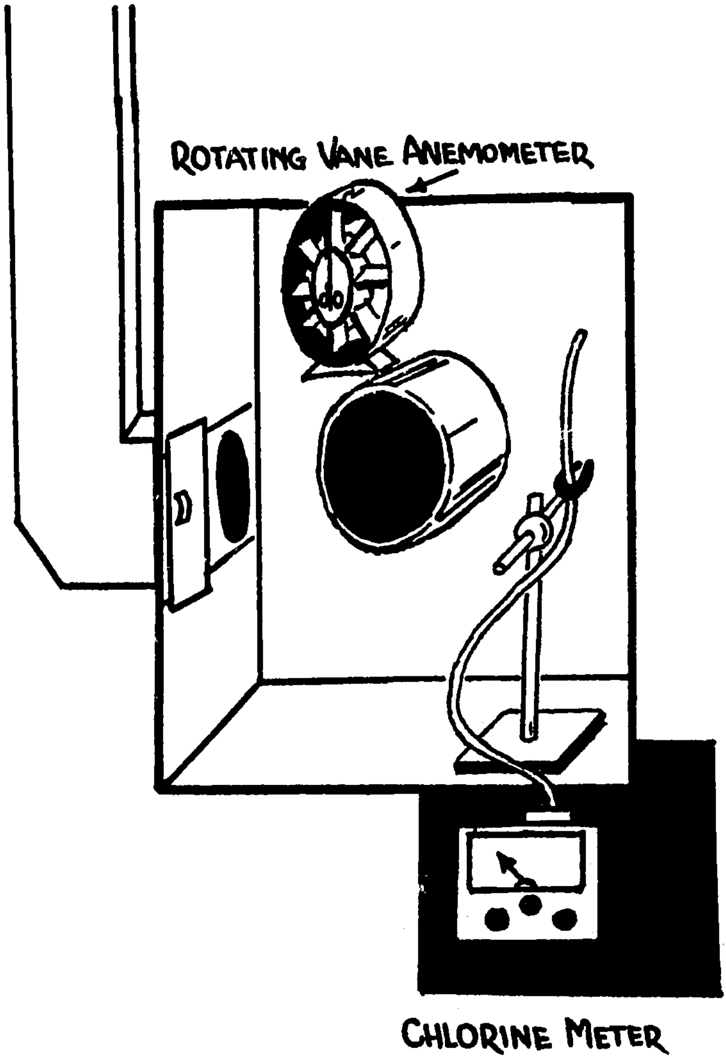

Figure 4. Validation of emission capture.

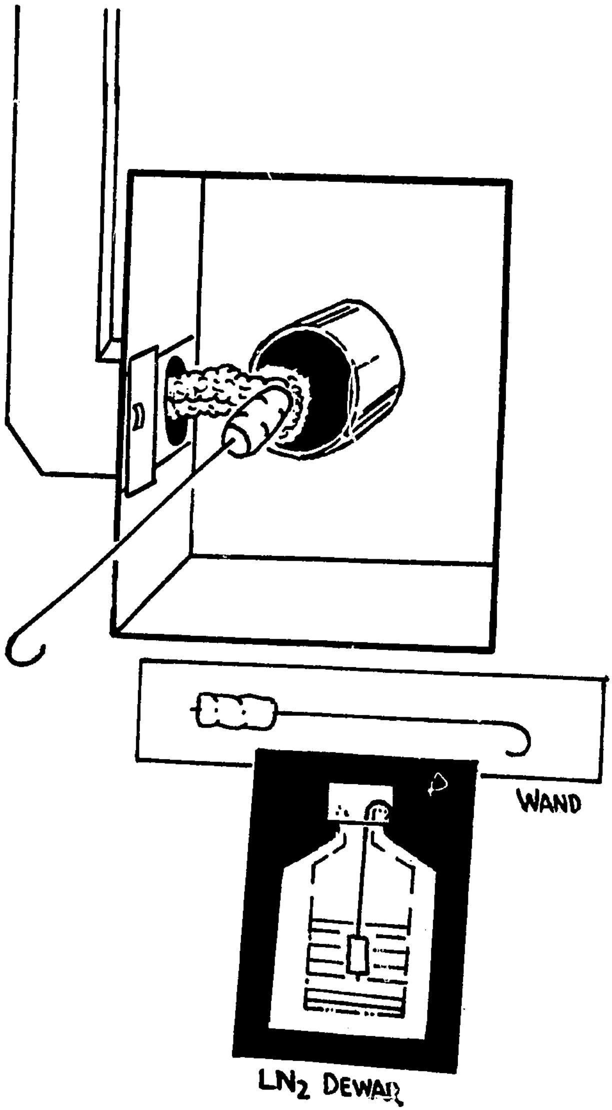

Figure 5. Liquid nitrogen method for evaluating ventilation capture effectiveness.

The quartz boats and tubes must be periodically cleaned in solutions of nitric acid, hydrofluoric acid, and other acids. Most commercially available tube cleaners are totally enclosed and exhaust ventilated. Older tube cleaning and quartzware cleaning stations have open tanks which are generally exhaust ventilated according to design criteria for surface tanks. The hazard of skin contact with these acids is ever present and requires stringent adherence to work practices that prevent contact as well as utilization of chemical protective gloves, aprons with sleeves, and a face shield.

Shock and Thermal Burns

An electrical shock hazard is not normally present to the operator. Access doors that expose live conductors, (e.g., tube heating elements) are generally interlocked to prevent electrical shock. Lock-out and tag-out work practice procedures should be utilized whenever repair or maintenance work must be performed on furnace systems components that could be electrically energized. Troubleshooting procedures often require that the maintenance technician work around exposed energized components. Such work should be done only by highly qualified and alert technicians, working in pairs.

Thermal burns are possible from contact with hot boats and quartzware. Thermal protective gloves or handling tools are utilized to handle these hot objects.

CONCLUSION

Substitution with safer materials, closed piping systems, enclosure and exhaust ventilation of emission sources, softwear programs and equipment that control process gas flow in a manner that is failsafe, and hydrogen leak detection systems that interlock to shutdown process equipment are all examples of the types of control systems employed to assure the safety of these manufacturing processes. None of the controls stand by themselves or are a unique hazard control technique; rather, they are examples of the systems engineering applications common in the semiconductor industry.

ACKNOWLEDGMENT

The assistance of Cynthia Hayes, Ron Cox, Laurie McManus, and Nancy Holland in preparing this presentation is sincerely appreciated.

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Library of Congress Cataloging-in-Publication Data

Hazard assessment and control technology in semi-
conductor manufacturing.

(Industrial hygiene science series)
Papers presented at a symposium sponsored by the
American Conference of Governmental Industrial
Hygienists and others and held in Cincinnati, Ohio,
Oct. 20-22, 1987.
Includes bibliographies and index.
1. Semiconductor industry—Safety measures—
Congresses. I. American Conference of Governmental
Industrial Hygienists. II. Series.
TK7871.85.H389 1989 621.3815'2 88-37742
ISBN 0-87371-132-7

LEWIS PUBLISHERS, INC.
121 South Main Street, P.O. Drawer 519, Chelsea, Michigan 48118

PRINTED IN THE UNITED STATES OF AMERICA

Preface

Hazard Assessment and Control Technology in Semiconductor Manufacturing was a symposium co-sponsored by the Semiconductor Industry Association, the National Institute for Occupational Safety and Health, the Occupational Safety and Health Administration, and the American Conference of Governmental Industrial Hygienists. It was held in Cincinnati, Ohio, from October 20–22, 1987. The purpose of the meeting was to provide a forum through which information could be exchanged among researchers, health and safety personnel from industry, equipment and material suppliers, and representatives from governmental agencies. Stated objectives were to:

1. Transfer health and safety technology.
2. Share existing health and safety information.
3. Provide insight into future research needs.

Areas covered during the course of the symposium were 1) health studies, 2) hazard control technology of manufacturing processes, 3) catastrophic releases, and 4) emerging technologies.

The manufacture of semiconductor components is best characterized by the rapid utilization of state-of-the-art manufacturing technologies and by paying careful attention to details. This symposium was testimony to the fact that health and safety technology is also on the leading edge and goes hand-in-hand with the advances made in the industry.

For individuals who attended the symposium, this book will serve as a lasting record of the excellent papers presented. For those who were not able to attend and others wishing to gain insight into health and safety issues facing the semiconductor industry, this text will serve as an excellent reference.

Finally, the Program Steering Committee would like to thank its invited luncheon speakers, Philip Bierbaum of the National Institute for Occupational Safety and Health, David LeGrande of the Communications Workers of America, Dr. Pat Buffler of the University of Texas, and Dr. Larry Sumney of the Semiconductor Research Corporation, for their important

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