PRELIMINARY SURVEY REPORT:

CONTROL TECHNOLOGY FOR GALLIUM ARSENIDE PROCESSING

AT

TEXAS INSTRUMENTS
DALLAS, TEXAS

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I. INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) is the primary Federal agency engaged in occupational safety and health research. Located in the Department of Health and Human Services (formerly DHEW), 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 process, or specific control techniques. Examples of these completed studies include 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 document and evaluate effective control techniques for potential health hazards in the industry or process of interest, and to create a more general awareness of the need for or availability of an effective system of hazard control measures.

These studies involve a number of 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. Next, in-depth surveys are conducted to determine both the control parameters and the effectiveness of these controls. The reports from these in-depth surveys are then used as a basis for preparing technical reports and journal articles on effective hazard control measures. Ultimately, the information from these research activities builds the data base of publicly available information on hazard control techniques for use by health professionals who are responsible for preventing occupational illness and injury.

This particular research effort (the subject of this walk-through survey) was prompted by a growing interest in silicon alternatives for the semiconductor industry. For years, silicon had been the primary semiconductor material for integrated circuits. However, demands for higher speed devices for communication and military purposes led to an anticipated surge in the gallium arsenide technology. Gallium arsenide provides higher electron speeds, lower power consumption, and higher radiation resistivity than silicon.

This study will evaluate the technology available for the control of hazardous substances in gallium arsenide applications, particularly gallium arsenide dusts. The toxicity of gallium arsenide is not well established, but is thought to be similar to that of arsenic. As such, gallium arsenide should be treated as if it were arsenic, which would require stringent controls to maintain exposure to less than the current OSHA standard for arsenic of 10 ug/m3. Gallium arsenide will require more controls than needed for similar silicon processing. By determining controls needed before major expansion of today's gallium arsenide processing, controls are more likely to be included during construction rather than by costly retrofitting. Specific processes to be evaluated include (but are not limited to) ingot growing, sandblasting, wafer slicing, and the loading, cleaning, and maintenance of epitaxial reactors.

This report contains results of this preliminary study, conclusions, and recommendations relevant to the operations at Texas Instruments.

II. PLANT AND PROCESS DESCRIPTION

PLANT DESCRIPTION

The Texas Instruments (TI) facility is a large complex, including several buildings containing corporate headquarters, research and development operations and several different manufacturing operations. They produce gallium arsenide (GaAs) optoelectronic devices, monolithic microwave integrated circuits (MMIC's), and field-effect transistors(FET's) in low volume quantities. They also custom produce GaAs devices for outside customers.

Texas Instruments has been working with gallium arsenide since the early 1960's. Approximately 110 workers in two separate buildings are involved in GaAs production. Seven safety engineers, two nuclear engineers and two industrial hygienists are employed onsite. Operations include crystal growing, annealing, sawing, polishing, ion implantation, photolithography, metallization and wafer dicing. They use a low pressure liquid encapsulated Czochralski (LEC) process to grow crystals.

PROCESS DESCRIPTION

At Texas Instruments, in the LEC process, the gallium arsenide is compounded within the crystal pullers. Arsenic vapor is injected into a quartz cell located above a reservoir of liquid gallium. A solid source of arsenic is also supplied in the quartz cell. The arsenic vapor reacts with the liquid gallium at low pressure in the presence of boron oxide. The boron oxide floats on the melt and serves as a liquid encapsulant to prevent the arsenic vapor from escaping. A seed crystal is then lowered into the crystal puller and the desired GaAs crystal is obtained. The entire LEC process is completed in three to four days. The crystal is then removed from the puller. After crystal growth, all internal surfaces of the puller and crucible are vacuumed with a HEPA filtered vacuum cleaner and the top of the puller is wet-wiped.

After the GaAs crystal is removed, it is cleaned and annealed. For the annealing process, the crystal is heated in a dilute arsenic atmosphere furnace to relieve radiation-induced stress in the crystal lattice. The crystal orientation of the ingot is checked with x-ray diffraction and then designated by grinding one side of the crystal ingot flat using a surface grinding machine. Next, the gallium arsenide wafers are sliced from the ingot using automated saws. The edges of the wafer are beveled for smoothness with a grinder/edge-beveler machine. Finally, the wafers are etched with small amounts of chromic acid and polished.

For production of products other than wafers, additional steps in the production process include ion implantation, photolithography, metallization, wafer dicing, and packaging.

The ion implantation process deposits dopants into a gallium arsenide wafer at various depths by accelerating them through an electric field. Silicon tetrafluoride is the gaseous dopant source used at Texas Instruments. The dopant is ionized by electrical discharge. The beam of ions is focused on the target wafer and strikes the wafer, embedding the ions at various depths. A beryllium implanter is employed at Texas Instruments for their digital integrated circuit products. The implanter saws must be cleaned with a dry bead blaster after every thirty hours of operation.

Photolithographic processes are used to transfer circuit patterns on negative masks to the surface of the wafer substrate. The wafer substrate is coated with a light-sensitive material known as photoresist. Glycol ether-based photoresists are used at Texas Instruments. The wafer is then exposed using electron beam lithography instead of ultraviolet light. For the metallization process, conductive metals such as aluminum, titanium, or platinum are deposited, in a vacuum, on the wafer. The deposited metal links the circuits together on the wafer in order for it to be functional. The wafer is then diced and ready to be packaged.

POTENTIAL HAZARDS

Potential chemical hazards in the gallium arsenide industry are found primarily in the numerous solvents, acids and gases employed in wafer production. At Texas Instruments, some of the solvents and gases used include methanol, ammonia, and silane. Methanol can cause optic nerve damage and blindness. However, these symptoms occur principally after oral-ingestion of methanol and rarely after inhalation. Silane gas presents a fire and explosion hazard. Hydrochloric, hydrofluoric, nitric and sulfuric acids are also employed in wafer production. These acids may cause burning and scarring of the skin and mucous membranes. Chronic inhalation may cause bronchitis and pulmonary edema. In addition, small amounts of chromic acid are employed in the etching process. Chromic acid has a direct corrosive effect on the skin and the mucous membranes of the upper respiratory tract. Workers may also experience perforation of the nasal septum, chronic asthmatic bronchitis, dermatitis and dental erosion.[1]

Chronic exposure to arsenic may cause malaise, fatigue peripheral neuropathy, and perforation of the nasal septum. Arsenic is also suspected of causing skin and respiratory tract cancer.[2]

The glycol ether solvents at Texas Instruments include 2-methoxyethanol (2ME) and 2-ethoxyethanol (2EE). 2ME and 2EE have the potential to cause adverse reproductive effects in the male and female workers and embryotoxic effects, including teratogenesis, in the offspring of the exposed, pregnant female.[3]

Chemicals used in gallium arsenide production with little toxicological information include silicon tetrafluoride, tellurium, and cadmium telluride.

III. CONTROLS

PRINCIPLES OF CONTROL

Occupational exposures can be controlled by the application of a number of well-known principles, including engineering measures, work practices, personal protection, and monitoring. These principles 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 both in terms of occupational and environmental concerns. Controls which may be applied to hazards that have escaped into the workplace environment include dilution ventilation, dust suppression, and housekeeping. Control measures may also be applied near individual workers, including the use of remote control rooms, isolation booths, supplied-air cabs, work practices, and personal protective equipment.

In general, a system comprised of the above 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 effectiveness of the controls in use. Ongoing monitoring and maintenance of controls to insure 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 principles of control apply to all situations, but their optimum application varies from case to case. The application of these principles at Texas Instruments are discussed below.

ENGINEERING CONTROLS

A localized exhaust is currently being designed for the cleaning of the crystal pullers. Maximum worker exposures occur when the pullers are first opened. Therefore, this exhaust will minimize these initial hazardous exposures.

A dry bead blaster is employed for the cleaning of the beryllium implanter saws. The beryllium contaminated exhaust is vented to a series of filters. A filter, pre-filter, HEPA filter and a dedicated exhaust are employed to fully contain the effluents from the cleaning operation. The ion implantation room and abrasive blast area are classed as limited access areas and used only by designated personnel.

The minimum face velocity for chemical fume hoods in the production areas is 100 linear feet per minute (fpm) at minimum of two inches above the work surface. The maximum distance from the work surface to the protective sash on the hood is twelve inches. The minimum face velocity on the exhaust hoods for cleaning of the ion implant source areas is 125 linear fpm. These hoods are alarmed in case of loss of exhaust flow.

Exhausted gas cabinets are also employed at Texas Instruments for gases such as silane (5.0% concentration), nitrogen and ammonia (10.0%concentration). These gas cylinders are changed by designated workers.

The sawing or slicing of the GaAs wafers is a wet operation which reduces dust emission from this process. However, aerosolization of the contaminated coolant liquid may occur. Therefore, Texas Instruments enclosed the coolant catch basin with a rubber skirting.

WORK PRACTICES

After the LEC crystal pullers have cooled sufficiently following crystal growth, the pullers are opened and vacuumed with a HEPA filter vacuum cleaner. There is no scraping or scrubbing involved.

While the ion implanter is in operation, at least two people must be present in the room at all times. In addition, only personnel with approved radiation badges are allowed in the room. If contaminated parts are to be removed from the ion implanter and transported between areas, these parts are required to be bagged in double 6 mil plastic bags and properly labelled.

MONITORING

Texas Instruments monitored for arsenic annually including employee exposure monitoring and particulate sampling for arsenic during sawing operations and cleaning of the crystal pullers. The monitoring program was flexible enough to encompass any process changes or additions. If needed, follow-up monitoring was performed and a corrective action plan was obtained from the area supervisor.

No continuous monitoring for hydrogen was employed.

MEDICAL MONITORING

Preplacement medical examinations are conducted at Texas Instruments which include a 24-hour urine arsenic test. In addition, annual medical examinations are performed for the employees working in the crystal growing area.

PERSONAL PROTECTIVE EQUIPMENT

Safety glasses, gloves, disposable Tyvek coveralls, plastic sleeves, and high efficiency respirators are required during cleaning of the crystal pullers. Aprons are required in the sawing and grinding areas. Disposable Tyvek coveralls with bootlets, head covering and gloves are worn when cleaning ion implant source areas. In addition, a single-use high-efficiency disposable particulate respirator or a positive air purifying respirator is required during cleaning operations for the ion implant source areas.

OTHER OBSERVATIONS

Texas Instruments has developed a very extensive training program for their employees, covering such areas as personal protective equipment, respirator fitting, laser and radiation safety, chemical safety, and toxic gas handling and storage. They have also prepared videotapes for training highlighting material safety data sheets and toxic or reactive chemicals. Their current programs include safety committees, and a safety awareness program, a hazard communication program and a permit system which is issued by the safety department and used before the introduction of new materials into production. In addition, Texas Instruments has one safety engineer devoted full-time to evaluating production equipment for health and safety concerns prior to it being purchased. If he finds deficiencies, the equipment manufacturer is required to modify the equipment before Texas Instruments will purchase it. From this process, they have developed safety specifications for several different types of equipment.

IV. CONCLUSIONS AND RECOMMENDATIONS

Texas Instruments employs some useful control measures for limiting the potential exposures to arsenic and toxic gases. While this may be a good site for an in-depth survey, their low production rate means that activities we would want to evaluate are done infrequently. Therefore, other facilities may be more suitable for the purposes of this study.

V. REFERENCES

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