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# OVERVIEW OF THE SEMICONDUCTOR INDUSTRY AND ITS APPROACH TO CHEMICAL MANAGEMENT AND ENVIRONMENT, SAFETY, and HEALTH

The semiconductor industry has a long history of responsible chemical management programs and risk mitigation measures to ensure the safe use and effective management of chemicals. Additionally, it takes a proactive approach to environment, safety, and health (ESH) issues by anticipating and preventing problems rather than correcting them. This document provides an overview of the semiconductor industry and the methods the industry uses to ensure worker safety and environmental protection while promoting prosperity throughout the industry worldwide.

## Global Competitiveness and Collaboration

Semiconductor manufacturing is one of the world's most innovative industries with a fast-paced technical culture focused on meeting customer needs through responsible competition. Product *innovation, time to market,* and *global transferability of the manufacturing processes* are key elements in remaining competitive in this industry. The continued and timely availability of important specialty chemicals is central to industry success. If, for example, chemical availability in one part of the world is impacted, manufacturers there may find themselves at a disadvantage compared to their international counterparts.

Although highly competitive, semiconductor companies nevertheless recognize the value and advantages of pre-competitive collaboration. This is reflected in the *International Technology Roadmap for Semiconductors* (ITRS), the industry's 15-year strategic plan that identifies critical challenges and drives innovative solutions; semiconductor R&D consortia; industry standards-setting bodies; and the World Semiconductor Council (WSC).

## ESH Collaboration, Performance, and Policy within the Semiconductor Industry

The semiconductor industry takes a collaborative approach to ESH. Manufacturers, suppliers of process tools and chemicals, and universities and R&D consortia worldwide all work together on ESH issues. This international collaboration is evident in the ESH chapter of the ITRS, which is structured around the belief that good business stewardship includes an active awareness and commitment to responsible ESH practices.

Semiconductor manufacturers also collaborate on ESH issues in national associations, such as the Zentralverband Elektrotechnik- und Elektronikindustrie (ZVEI) in Germany and in regional associations, such as the European Semiconductor Industry Association (ESIA). The WSC, a global industry body whose aim is pre-competitive cooperation in areas including ESH, is composed of semiconductor trade associations from all the leading centers of semiconductor manufacture: Europe, Japan, Korea, the United States, Taiwan, and China.

The industry's collaboration at the WSC level has led to several voluntary global agreements on the responsible use of chemicals. One goal, to reduce absolute emissions of perfluorinated compounds (PFCs) 10% from baseline levels by 2010, was the first voluntary greenhouse gas emissions reduction goal to be established by any industry on an international basis. Another goal is to fully phase out perfluorooctyl sulfonates (PFOS) in non-critical processes, where alternatives exist, in 2007. The industry is well on its way to achieving these ambitious targets.

The industry has very low employee occupational injury and illness rates compared to the rest of the electronics industry and, certainly, compared to industry statistics in general, according to reports from the

U.S. and Europe. As a matter of course, the vast majority of European semiconductor fabs have ESH management systems in place (ISO14001, OHSAS18001 EMAS or equivalent).

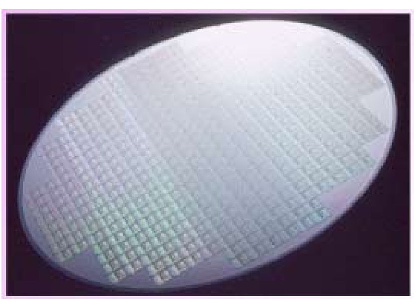
The industry makes continuous investments based on scientific findings and technological improvements to support its commitments. It maintains a safe and healthy work environment for employees and promotes safe and health-conscious work practices. It promotes international cooperation in chemical management using scientific evidence, health assessments, and risk assessments as the basis for effective workplace and community protection. The industry also supports international collaborative R&D efforts to create the science, technology, and educational methods to remain a leader in safe and environmentally conscious manufacturing.

# SEMICONDUCTOR MANUFACTURING AND RISK MANAGEMENT MEASURES

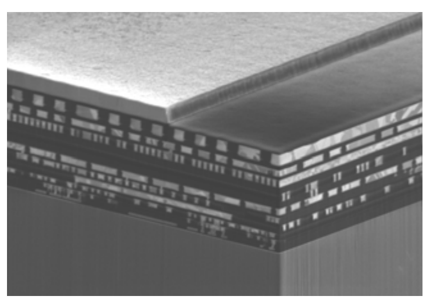
## Semiconductor Manufacturing

The semiconductor manufacturing cleanroom (commonly called the "fab" for fabrication facility) is a unique manufacturing environment characterized by perhaps the cleanest air found in any industry. In a typical fab manufacturing microchips, the temperature, humidity and particle contamination in the air are tightly controlled. Only 100 particles 1/10000 of a millimeter or larger in diameter per cubic meter are tolerated. Uncontrolled chemical vapors and gases are equally unacceptable because of their potential to contaminate wafers; chemical vapor control systems further enhance a safe and healthy working environment.

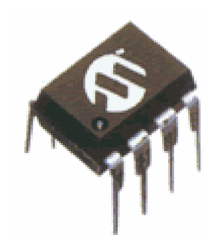
A microchip is manufactured in layers; as many as two dozen can contain millions and sometimes over a billion conductors, insulators, and transistors in a single microchip. The basic manufacturing process is simple in concept but complex in practice, with over 300 manufacturing process steps on as many as 80 different pieces of manufacturing equipment. The process starts with a blank wafer, typically silicon. Each wafer can contain several hundred microchips. In simple terms, semiconductor manufacturing uses chemicals to create functionality by adding and removing layers on the wafer. In this way, many interconnected layers that form the circuit within the microchip are built and replicated across the wafer.



**Semiconductor Wafer with Devices (75–300 mm diameter)**



**FIB Cross-Section of Microprocessor**



**Finished Microchip in Package**

Through a process known as photolithography, a microchip pattern is transferred onto a wafer. Diffusion and ion implant add metal molecules that give the silicon a particular electrical characteristic, creating transistors on the wafer. Metallization lays down the "wiring" of the microchip. Etching removes material from the wafer by energizing gases in a vacuum or by exposing the wafer to wet chemistries. Then, during assembly, the individual microchips are sawn from the wafer, mounted on a metal frame, and encapsulated in a "package."

## Chemicals Used In Semiconductor Manufacturing

The semiconductor industry uses many chemical materials in the production of microchips. These materials are typically used in the manufacturing process and do not remain in the final product. Semiconductor process chemicals can be generally categorized as follows:

Aqueous solutions such as acids and bases are used to chemically etch or clean the surface of the wafer. Examples: hydrochloric acid, sulfuric acid, ammonium hydroxide, tetramethylammonium hydroxide, ammonium fluoride, hydrofluoric acid.

Specialty gases are typically used in relatively small quantities as precursors to deliver a substance such as arsenic or tungsten onto the wafer or into the silicon lattice. Other specialty gases dry-etch a pattern onto the surface of the wafer. Examples: silane, phosphine, tungsten hexafluoride, arsine, carbon monoxide, fluorocarbons, nitrogen trifluoride.

Organic compounds are generally solvents, some of which are used as constituents in specialty chemicals. These chemicals clean the wafer. They are also part of the photolithography process. Examples: isopropanol, propylene glycol ethers, acetone, n-Methyl Pyrrolidone.

Metallic compounds are applied to the wafer in specific locations to create transistors or are used to plate wafers to provide electrical connections. Examples: copper sulfate, aluminum oxide, titanium oxide.

## Risk Management Measures Related to the Use of Chemicals

Risk management measures (RMMs), often exceeding regulatory requirements, are in place in the semiconductor industry as the result of numerous guidelines developed through Semiconductor Equipment and Materials International (SEMI) and collaboration between suppliers of process tools and chemicals and semiconductor manufacturers.

RMMs—such as chemical assessment, selection and control procedures, hazardous gas management systems, segregated exhaust systems, safety interlocks, and spill control/prevention—are common in semiconductor fabs. New fabs use totally enclosed processes, automation, and chemical delivery systems to create a barrier between workers and the process and to protect against chemical and physical hazards in the work environment. In many cases, secondary and even tertiary redundancy to these controls ensures that the necessary protection will be provided if one control fails. Because of the considerable control measures within a state-of-the-art semiconductor fab, under normal operating conditions, workers are not exposed to chemical or physical hazards. Numerous voluntary guidelines developed by the industry promote manufacturing equipment designs that minimize risk to workers whether during normal operation or during maintenance procedures. In addition to the safety systems such as interlocks and automated purge systems that protect workers during maintenance when normal risk management measures may have to be bypassed, workers use personal protective equipment to ensure their safety.

Following is a small sampling of the many RMMs in semiconductor manufacturing. See the Risk Management Measures table below for additional RMMs.

Exhaust systems are designed to remove chemical vapors or gases at the equipment level; systems are typically segregated to ensure proper handling and treatment and to prevent reactions between incompatible substances (e.g., acids, bases, solvents). Where necessary, exhaust abatement systems are incorporated into the exhaust scheme to treat the exhaust and minimize environmental emissions.

Waste management measures are applied according to the waste avoidance hierarchy. Solvent liquid waste is collected separately, preventing untreated liquids from entering the water environment. In those cases where treatment is not possible (e.g., some solvents), these spent chemicals are collected and shipped to vendors for re-use after purification or to approved treatment and disposal facilities. Solid non-hazardous and hazardous waste is minimized at the stage of generation, segregated, re-used, recycled, or disposed.

Wastewater treatment facilities are installed to treat wastewater streams not amenable to internal recycling or reuse.

Environmental spill prevention methods such as double-containment spill control in manufacturing and chemical distribution areas and double-walled piping minimize the risk of seepage into the soil.

Automation separates workers from the manufacturing process. The typical large modern manufacturing fab has highly automated production equipment, minimizing workers' exposure to chemical or physical hazards.

In newer fabs, chemicals are typically delivered to a process by an automated chemical delivery system, often from a remote location. For the most commonly used process chemicals, bulk chemical delivery systems (BCDS) minimize the need for chemical handling and eliminate the hazards of manually pouring chemicals at process stations.

Gas cabinets for enclosing and exhausting potentially hazardous leaks from gas cylinders are specifically designed by and for the semiconductor industry. These gas cabinets include safety features appropriate for the application, including steel construction, self-closing doors, negative ventilation, automatic fire sprinkler systems, excess flow sensors, gas leak monitoring, and automatic shutoff.

Sub-atmospheric gas systems developed for the semiconductor industry now deliver some hazardous gases in a way that eliminates the risks that otherwise accompany the use of high pressure gas cylinders. Rather than a constant pressure system, these are more like on-demand delivery systems based on the properties of the chemical material delivered.

## Risk Management Measures

| | Control Measures for Safe Use | Control Measures for Environment | Chemical Delivery/ Waste Management Controls | Aqueous Solutions | Specialty Gases | Organic Compounds | Metallic Compounds |
|---|---|---|---|---|---|---|---|
| **Chemical Management** | | | | | | | |
| Chemical Assessment and Selection | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Chemical Tracking and Control | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Process Level Controls** | | | | | | | |
| Robotic Wafer Transport and Handling | ✓ | ✓ | | | | | |
| Bulk Chemical Delivery Systems | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| Automated Gas Management and Delivery | ✓ | ✓ | ✓ | | ✓ | | ✓ |
| Automated Spill Control and Leak Sensors | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Safety Interlocks and Energy Isolation | ✓ | | | | | | |
| Totally Enclosed Process with Exhaust | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Exhaust Management | ✓ | ✓ | ✓ | | | | |
| Integrated Fire Protection Systems | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| **Gas Management** | | | | | | | |
| Sub-atmospheric Gas Sources | ✓ | ✓ | | | | | ✓ |
| Specially Designed Gas Cabinets/Manifolds<br>• Auto leak detection, flow control, shut-off<br>• Remote gas storage<br>• Auto-purge gas lines<br>• Integrated fire safety systems | ✓ | ✓ | | | ✓ | | ✓ |
| Delivery Containment Systems | ✓ | ✓ | ✓ | | ✓ | | ✓ |

| | Control Measures for Safe Use | Control Measures for Environment | Chemical Delivery/ Waste Management Controls | Aqueous Solutions | Specialty Gases | Organic Compounds | Metallic Compounds |
|---|---|---|---|---|---|---|---|
| **Liquid Chemical Delivery** | | | | | | | |
| Bulk Chemical Delivery Systems | ✓ | ✓ | | ✓ | | ✓ | |
| Automated Spill Control and Leak Sensors | ✓ | ✓ | | ✓ | | ✓ | ✓ |
| Delivery Containment Systems | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ |
| **Liquid / Solid Waste Management** | | | | | | | |
| Corrosive Neutralization Systems | | ✓ | ✓ | ✓ | | | ✓ |
| Solvent Collection Systems | | ✓ | ✓ | | | ✓ | |
| Metal Collection Systems | | ✓ | ✓ | ✓ | | | ✓ |
| Recycle/Reclaim Procedures | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| **Emissions Management** | | | | | | | |
| Point of Use Abatement Systems | ✓ | ✓ | | | ✓ | | ✓ |
| Central Abatement Systems | | ✓ | | ✓ | ✓ | ✓ | ✓ |
| **Special Protective Measures** | | | | | | | |
| Environmental & Safety Management Systems and Procedures | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Employee ESH Training | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Personal Protective Equipment | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Emergency Response Teams | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Building Chemical Storage Containment Systems | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Building Fire Suppression Systems | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Maintenance Hazardous Materials Purge Systems | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

## CONCLUSION

The semiconductor industry is a leader in environment, safety, and health management as demonstrated in this overview of industry efforts to use chemicals responsibly and to develop and institute safe chemical-handling practices. The industry has an excellent ESH performance record and will continue to be proactive in this area. It has numerous RMMs designed to protect people both inside and outside the fab, as well as the air, water, and soil. Through responsible chemical use, stringent engineering controls, and RMMs, the semiconductor industry strives to set an example in the effective and responsible management of chemicals.

The industry further supports efficient and effective regulation of chemicals to protect workers and the environment. Despite being a highly competitive industry, it is concerned that if a critical chemical were to become delayed or unavailable, the impact could be devastating to not only the European semiconductor industry, but to other industries that depend on microchips to produce their products. The time required to bring a new product to market determines whether opportunity is gained or missed and whether profit or loss is realized. Any delays in the time-to-market of a semiconductor device can dramatically affect a manufacturer, with potential losses of 2 million Euros per day in profits and loss of market share.