SAFETY FOR EHS PROFESSIONALS:
MANAGING HAZARDOUS MATERIALS FOR PEACE OF MIND IN THE SUBFAB

Steve Cottle, Senior Applications Manager , Edwards Semiconductor Vacuum

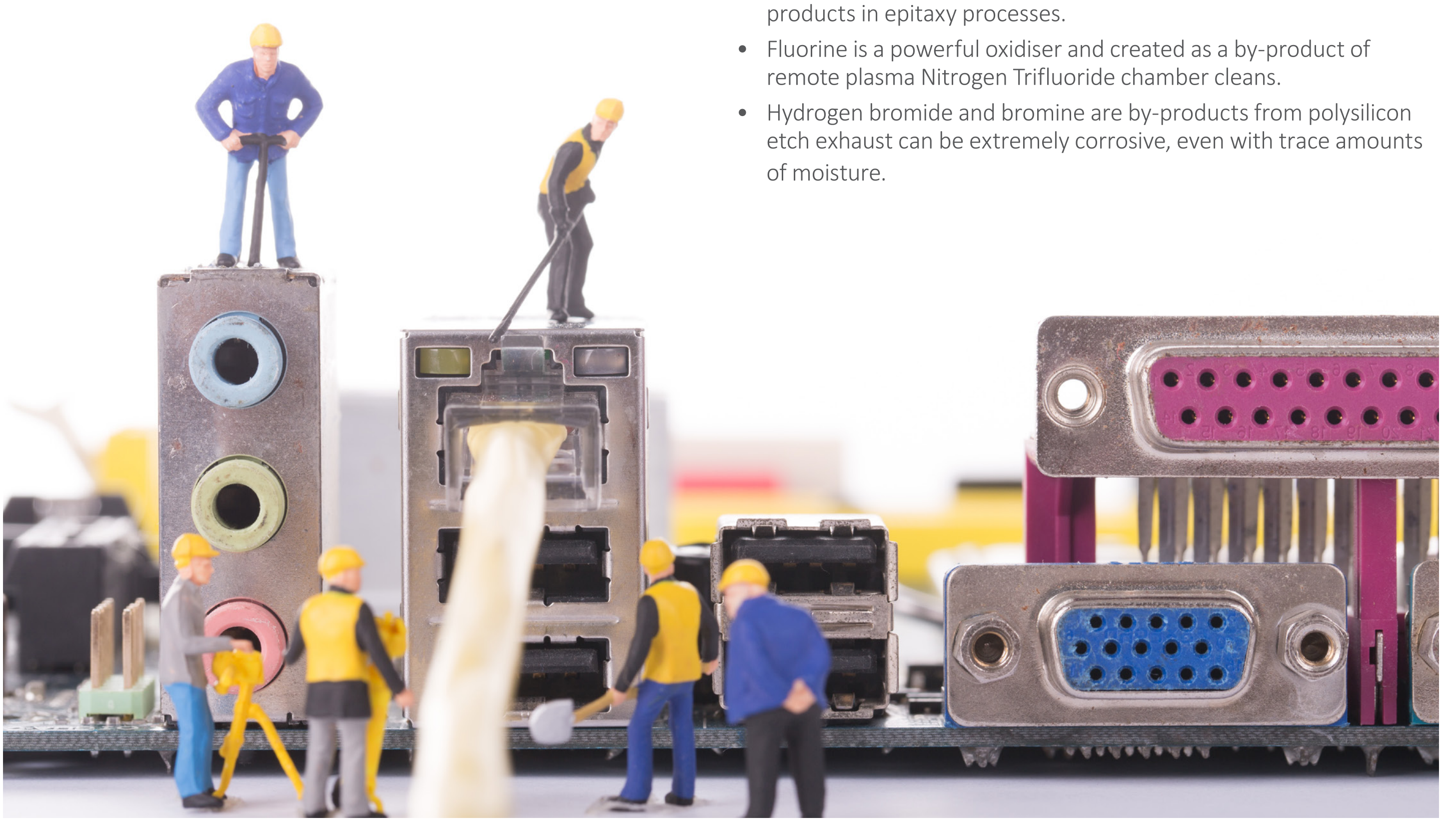
edwardsvacuum.com

Introduction

Knowledge and experience are critically important in safely managing hazardous materials used in or created by the semiconductor manufacturing process. Understanding and anticipating the chemical and physical behaviour of these materials is the first step in mitigating the risks they pose to personnel, the surrounding communities, and the environment. Many of them, certainly almost all the gases, pass through vacuum and abatement systems to exit the process.

As a supplier of those systems, Edwards has a unique opportunity to see the full range of hazards and an obligation to minimize risks in the design and operation of our equipment. We fulfil that obligation through a carefully structured program of safety review and risk management in our design and manufacturing activities and through our service and support organizations at our customers' facilities.

The following discussion provides an overview of our process. Much of it will be familiar ground to EHS professionals. We offer it here to demonstrate the priority we give to safety, the thoroughness of our risk management process, the depth of our process knowledge, and the breadth of our experience. It is our goal to give you peace of mind in the subfab.



Process gases and process by-products

We often consider the materials passing through our equipment in two categories: process chemicals, which are introduced into the chamber intentionally, and process by-products, which are created by interactions among the various input materials as during the process. Process chemicals are, generally ultrapure and have precisely known compositions and physical and chemical characteristics.

By-products, on the other hand, are less well characterized and their behaviour and relative abundance may change with changing process conditions. The hazards associated with process and by-product materials include flammability, pyrophoricity (spontaneously igniting in air), strong oxidation, toxicity, and more. Some examples:

Process materials

- Silane is used to deposit a variety of layers such as amorphous silicon. It is extremely flammable and pyrophoric.
- Arsine is used to dope silicon layers. It is flammable and extremely toxic.
- Chlorine trifluoride is used to clean process chambers. It is a strong oxidizing agent.

By-product materials

- Polychlorosilanes and siloxanes are energetic materials found as by-products in epitaxy processes.
- Fluorine is a powerful oxidiser and created as a by-product of remote plasma Nitrogen Trifluoride chamber cleans.
- Hydrogen bromide and bromine are by-products from polysilicon etch exhaust can be extremely corrosive, even with trace amounts of moisture.

A Hierarchy of Hazards

All hazards are not equal. Arranging them in a hierarchy by degree of risk helps to direct attention and resources to the most dangerous first. Fortunately, much of the work of classifying hazards has already been done.

Globally Harmonized System of Classification and Labelling of Chemicals – One widely used scheme is the Globally Harmonized System of Classification and Labelling of Chemicals (GHS), promulgated by the United Nations. It provides precise definitions for each class and ranks them by decreasing hazard as follows (classes not typically found in semiconductor manufacturing have been omitted.):

1. Explosives
2. Flammable gases - with subcategories for pyrophoric (spontaneously igniting), chemically unstable, and levels of flammability)
4. Oxidizing gases - a gas that promotes the oxidation/combustion of other materials more than air does.
5. Gases under pressure (including compressed gas, liquefied gas, refrigerated liquefied gas, dissolved gas)
6. Flammable liquids (with subcategories level of flammability based on flash point and boiling point)
7. Flammable solids
9. Pyrophoric liquids
10. Pyrophoric solids
12. Water reactive - substances or mixtures which, in contact with water, emit flammable gases
16. Corrosives to metals - substance or mixture which will materially damage or destroy metals by chemical action.

Toxicity – Another classification applies to toxic chemicals that are harmful to health or lethal if consumed or otherwise introduced into the body in sufficient quantities.

1. Acute toxicity
2. Skin corrosion/ irritation
3. Serious eye damage/ eye irritation
6. Carcinogenicity
7. Reproductive toxicity
10. Aspiration hazard

Environmentally damaging – This classification relates to materials that are hazardous to the aquatic environment or the ozone layer. We could also apply this classification to materials that may have a lasting impact upon the environment, for example, greenhouse gases.

Industry Guidelines

Industry guidelines play an important role in guiding our risk management activities relating to hazardous materials.

SEMI S30 Safety Guideline for Use of Energetic Materials in Semiconductor R&D and Manufacturing Processes – SEMI, the global industry association of electronics manufacturers and their suppliers, publishes guidelines (SEMI S30) for the use of energetic materials – materials that are dangerously exothermic, pyrophoric, or water reactive – specific to the industry. The guidelines provide a minimum set of safety criteria for the procurement, storage, handling, and use of energetic materials through all phases of use, from process chemical supply through abatement and final disposition.

SEMI S14 Safety Guideline for Fire Risk Assessment and Mitigation for Semiconductor Manufacturing Equipment – This Safety Guideline provides considerations to semiconductor equipment manufacturers to assist them in assessing and mitigating the risk to equipment and product associated with fire and combustion by-products. It is intended for use throughout the design and development of semiconductor manufacturing equipment. It may also be useful to users of such equipment and to other interested parties to assess and compare the described risks of various equipment designs or in the design and evaluation of ancillary equipment or modifications.

NFPA 318 Standard for the Protection of Semiconductor Fabrication Facilities – This standard from the National Fire Protection Association, an international organization based in the U.S., presents requirements to safeguard facilities containing cleanrooms from fire and related hazards to protect against injury, loss of life, and property damage. It applies to semiconductor fabrication facilities and comparable fabrication processes, including research and development areas in which hazardous chemicals are used, stored, and handled and containing a cleanroom, or clean zone, or both.

OSHA 1910.19 Process safety management of highly hazardous chemicals – As part of its extensive rules for workplace safety, OSHA (the Occupational Safety and Health Administration in the United States) provides extensive guidance on Process Safety Management. Especially relevant to this discussion is section 1910.119, which addresses Process Safety Management of Highly Hazardous Chemicals. This section contains requirements for preventing or minimizing the consequences of catastrophic releases of toxic, reactive, flammable, or explosive chemicals.

Risk Management Methods and Techniques

We use a wide range of methodologies in our efforts to understand and mitigate risks.

Hazard and Operability – Hazard and Operability (HAZOP) is a systematic approach to determining potential problems that may be uncovered by reviewing the safety of designs and revisiting existing processes and operations in chemical, pharmaceutical, oil and gas, and nuclear industries recognized in OSHA's Process Safety Management (PSM) standard. It is a form of risk management used to identify, evaluate, and control hazards and risks in complex processes that use highly hazardous chemicals.

Failure Mode and Effect Analysis – Failure mode and effects analysis (FMEA) originated with the U.S. military in the 1940s. It is a step-by-step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service. "Failure modes" are the ways in which something might fail and include any errors or defects, especially those that affect the customer. They can be potential or actual. "Effects analysis" refers to studying the consequences of those failures.

The technique prioritizes failures by how serious their consequences are, how frequently they occur, and how difficult they are to detect. The purpose of FMEA is to take actions to eliminate or reduce failures, starting with the highest-priority modes. It documents current knowledge and actions about the risks of failures for use in continuous improvement. FMEA is used during design to prevent failures. Later it is used for control, before and during ongoing operation of the process. Ideally, FMEA begins during the earliest conceptual stages of design and continues throughout the life of the product or service.

5Y – 5 Whys is an iterative interrogative technique used to explore the cause-and-effect relationships underlying a problem. The technique simply repeats the question, "Why?" Each answer forms the basis of the next question, "Why?" The "5" in the name derives from an anecdotal observation on the number of iterations usually needed to resolve a problem. The technique was originally developed by Sakichi Toyoda and later used at Toyota during the evolution of its manufacturing methodologies.

8D –The 8D methodology seeks to identify, correct, and eliminate recurring problems, making it most useful in product and process improvement. It establishes a permanent corrective action based on statistical analysis of the problem and focuses on the origin of the problem by determining its root causes. It originally comprised eight stages, or disciplines, but was augmented to nine with the addition of an initial planning stage.

Kepner Trago – The Kepner-Tregoe approach is based on the premise that the end goal of any decision is to make the "best possible" choice. This is a critical distinction: the goal is not to make the perfect choice, or the choice that has no defects. The decision maker must accept some risk. An important feature of the Kepner-Tregoe Matrix is to help evaluate and mitigate the risks of the decision.

Regulatory compliance

Regulatory compliance is an important consideration in the minimization of legal risks. At a minimum we ensure that our equipment meets legislatively mandated requirements of major jurisdictions such as the European Union and the United States. In addition, we comply with local regulations where applicable.

The main EU directives that are applicable are the Machinery and EMC directives and these are met by demonstrating conformity to the following standards.

- EN1012-2 – Mechanical safety; vacuum pumps
- EN ISO 12100 – Parts 1 & 2, Safety of machinery
- EN 61010-1 – Electrical safety laboratory measurement
- EN 61326-1 – Electromagnetic Compatibility
- EN 746-2 – Industrial thermo-processing equipment. Safety requirements for combustion and fuel handling systems

And US:

- UL61010A-1 Electrical Equipment for Laboratory Use.
- NFPA79 2005 National Electrical Code Electrical Safety Machines

Nationally Recognized Testing Laboratories – Nationally Recognized Testing Laboratories (NRTL) test and certify electrical equipment and other products to ensure that they meet safety standards and are safe with proper use. NRTL certification means that electronics, when used as intended, are:

- Up to code: Electronics with NRTL certification undergo independent evaluation to ensure they meet the specified safety standards.
- Safe: Electronics with NRTL certification are evaluated to help confirm they are free of recognized hazards that could cause injury or death.
- Genuine: Electronics with NRTL certification can be confirmed with the NRTL as genuine. Uncertified products may not be designed to meet applicable industry standards.

In addition to regulatory standards, Edwards products are NRTL certified to comply with SEMI S2 – EHS Guideline for Semiconductor Manufacturing Equipment. S2 incorporates:

- S1 – Safety Guidelines for Safety Labels
- S6 – EHS Guideline for Exhaust Ventilation of Semiconductor Manufacturing Equipment
- S8 – Safety Guidelines for The Ergonomic Engineering of Semiconductor Manufacturing Equipment
- S14 – Guidelines for The Fire Risk Assessment and Mitigation of Semiconductor Manufacturing Equipment

International Organization for Standardization – The International Organization for Standardization (ISO) is a Geneva based non-governmental agency with 169 national standards bodies. ISO 9001 sets out the criteria for a quality management system (QMS). Our QMS is ISO9001 compliant.

Safety in Practice

Our core team of six application technologists has over 100 years of aggregate experience in semiconductor manufacturing process application experience. They support more than one hundred application specialists around the world with hands-on training and application documentation. Regular global conferences provide a venue to discuss new processes, new safety issues, and new EHS opportunities.

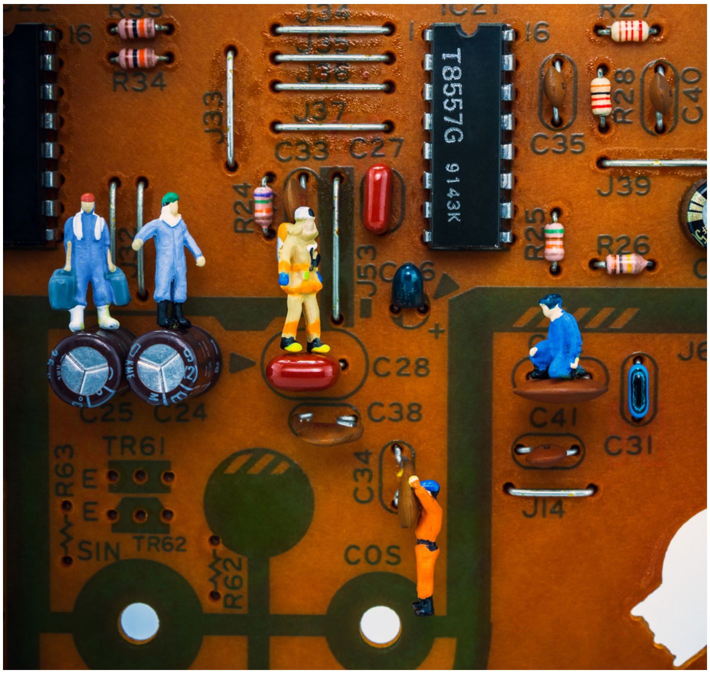
Knowledge Management – Organizing and disseminating our collective application knowledge throughout the applications group and on to our customers, is a fundamental aspect of our safety program. In addition to conferences and presentations, we place great emphasis on clear written communication of critical safety procedures. Edwards personnel and customers have access to a library that includes three especially important sets of documents.

Safety Applications Procedures (SAP) – these are Edwards specific documents specifically created for hazardous and/or potentially energetic processes. They provide a deep dive into understanding the application and the best-known methods to achieve the highest level of risk management.

An example would be – SAP for Pumping and Abatement for Reduced Pressure Silicon Epitaxy (RP Epi) Applications

Best Known Methods (BKM) – These are Edwards specific documents detailing our best-known methods for vacuum and abatement for individual processes.

Applications Information Bulletin (AIB) – These are Edwards specific documents detailing new tool set-up or continuous improvements and refinements that will contribute to BKMs.



Safety Culture

A safety culture is one in which safety is never out-of-mind. In a complex operation like semiconductor manufacturing, where hazards are inherent, layered safety procedures will have evolved; otherwise, the operation would not persist. As the operation continues without incident, it is easy to lose sight of the hazards. A history of safety does not mean that a process is safe, that the risks have disappeared. A safety culture is one that systematically encourages constant vigilance – it never forgets to be afraid.

One expert (Reason, J. (1998) Achieving a safe culture: theory and practice Work and Stress, 12, 293-306.) has suggested that safety culture consists of five elements:

- An informed culture – the organization collects and disseminates safety information to all personnel.
- A reporting culture – reporting unsafe conditions is encouraged and rewarded.
- A learning culture – personnel are open to new acquiring new information.
- A just culture – safety infractions are addressed promptly and fairly, and no one is ever penalized for raising safety concerns.
- A flexible culture – changes in processes and personnel must always be considered for their impact on safety and if needed, accommodated by changes in procedures.

Edwards believes strongly in the value of a safety culture and works continuously to inspire a commitment to safety at every level of our organization. We promote the principles of safety culture in every interaction with our customers.

Intellectual Property

Few industries place greater value on intellectual property than semiconductor manufacturers. Trust is essential. It is difficult to ensure safety without accurate knowledge of the materials that are passing through our systems, but that information is often proprietary and confidential. Edwards recognizes the importance of protecting the confidentiality of information exchanged between its own and its customers' personnel.

Conclusion

Edwards believes the health and safety of its employees, its customers, and the environment are as important as its commercial and financial goals. We have implemented an extensive program for risk assessment and mitigation for our products, our manufacturing operations, and the use of our products in our customers' facilities. Our deep knowledge and broad experience with the hazards found in semiconductor manufacturing position us uniquely to provide the safest solutions. Our business is your peace of mind.

EDWARDS