The Fire-Safe Cleanroom Journey Continues

We're almost there...

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During the past 30 years, the semiconductor industry has experienced exponential growth, which has significantly affected our daily lives. This growth, however, has come at the expense of semiconductor process-related fires that have caused devastating property damage, production interruption and loss of market share.

Following the two large fires in Taiwan in 1996 and 1997, FM Global and other fire protection professionals stepped back and questioned, "How can we improve fire safety and change the industry's track record?"

Twelve years later—with the collective efforts of many organizations and individual contributions—the journey toward the fire-safe cleanroom is almost complete.

Factors that have led to this tremendous improvement include the following:

- Widespread use of non-fire propagating construction materials
- Safe process liquid heating systems
- Third-party assessment of process equipment prior to installation
- Improved handling and disposal of silane gas
- Adherence to improved codes and standards

Current State

Released in 1997 by FM Approvals, a Nationally Recognized Testing Laboratory (NRTL), the Cleanroom Materials Flammability Test Protocol (Class 4910) has become the industry standard for the evaluation of construction materials used in cleanrooms.

FM4910 measures two crucial fire-related elements of a product or material:

- The Fire Propagation Index (FPI), an indicator of the tendency of a material to ignite and propagate fire
- The Smoke Damage Index (SDI), an indicator of the amount of smoke generated

For material to be considered non-fire propagating under FM4910, its FPI must be equal to or less than 6.0 and its SDI equal to or less than 0.4. Materials that meet the "Cleanroom Materials Flammability Test Protocol" do not require, in and of themselves, fixed fire protection when used according to the appropriate FM Global Property Loss Prevention Data Sheets. Materials listed under FM4910 may burn locally in the ignition area, but will not propagate a fire beyond the ignition zone. Additionally, such materials produce little, if any, smoke or corrosive byproducts, thus minimizing non-thermal damage.

Today, there are 17 manufacturers producing nearly 150 different types of FM4910-listed materials. A complete listing of FM4910 materials can be found in the *Approval Guide*, located at: www.approvalguide.com.

This ever-expanding list has led semiconductor tool vendors to build the majority of products (e.g., wet benches) out of FM4910 materials. In fact, for some tool vendors, FM4910 material-constructed tools have become the standard of choice. Tools made with less expensive (but highly combustible) polypropylene or polyvinyl chloride are, in many cases, now available only by special order.

While FM4910 materials are prevalent in semiconductor cleanrooms, they can easily be applied in other industries that utilize cleanrooms (i.e., pharmaceutical, biotech, food processing, etc.). Although FM4910 fire-safe materials are helping prevent cleanroom fires, they cannot do it alone.

In the past, the typical fire scenario was a high-energy process liquid immersion heater or a hot plate igniting combustible plastic associated with wet benches. Once ignited, the fire was drawn into the process exhaust ductwork, which many times was constructed of combustible plastic. Once the ductwork was ignited, the fire would spread inside the ductwork all the way to the scrubber.

Companies have eliminated the exposure created by combustible process exhaust ductwork by installing ductwork that meets the FM Approvals Standard for Fume Exhaust Ducts or Fume and Smoke Exhaust Ducts (Class 4922). Even when subjected to a severe fire, FM4922-Approved ductwork will:

- Not collapse;
- Not propagate fire; and
- Release only minimal amounts of smoke

Increasingly, new and retrofitted cleanrooms are installing FM Approved ductwork. However, a considerable amount of combustible ductwork with no automatic sprinkler protection still remains in some facilities. Installing either FM4922 products or proper sprinkler protection in these cleanrooms is highly recommended.

Replacing combustible ductwork with FM Approved ductwork in existing operating cleanrooms is not as daunting a challenge as it may appear. In fact, a major semiconductor manufacturer has successfully completed such a replacement. To that company, the benefits substantially outweigh the potentially astronomical loss potential.

At top: A fire test of non-approved, polycarbonate containers;

At bottom, a test of FM Approved polyetherimide containers.

Codes/Standards

As mentioned previously, adherence to improved codes and standards as listed to the right has been a significant contributor in improving cleanroom fire safety.

Many of these codes/standards recommend the use of fire-safe construction materials for cleanroom applications. In cases where such materials are not used, fixed fire detection and suppression systems are the recommended alternative. If neither measure is taken, the results can be catastrophic.

In 2005, FM Approvals issued an assessment standard for Tools Used in the Semiconductor Industry (Class 7701). This assessment standard evaluates the following aspects of semiconductor manufacturing equipment (tools):

- Chemical
- Control and/or safety interlocks
- Electrical
- Fire
- Materials
- Ventilation

Currently, before new tools are installed, they often require on-site evaluation (either at the manufacturer's or client's facility) by a semiconductor specialist on a case-by-case basis. Due to the complexity and diversity of semiconductor manufacturing equipment, this can be a time-consuming and, potentially, costly endeavor.

Organization	Code/Standard	Comments
FM Global	Data Sheet 7-7 *Semiconductor Fabrication Facilities, 2003 Edition*	Addresses semiconductor device fabrication and associated hazards from a property loss prevention and business continuity perspective. *Currently under revision.*
FM Approvals	FM4910 *Test Standard for FM Approvals Cleanroom Materials Flammability Test Protocol, June 2009*	This test standard describes minimum performance requirements for materials that are intended for use in cleanroom facilities.
FM Approvals	FM4911 *Approval Standard for Wafer Carriers for Use in Cleanrooms, August 2006*	This test standard sets performance requirements for wafer carriers used in cleanrooms by evaluating the ability of these products to limit fire spread and smoke damage.
FM Approvals	FM4922 *Approval Standard for Fume Exhaust Ducts or Fume and Smoke Exhaust Ducts, April 2001*	This test standard sets performance requirements for ducts installed according to limitations and requirements specified for each individually manufactured duct system.
FM Approvals	FM7701 *Assessment Standard for Tools Used in the Semiconductor Industry, December 2005*	This standard is used for assessing manufacturing equipment (tools) used by the semiconductor industry as it relates to property conservation and business continuity.
National Fire Protection Association (NFPA)	NFPA 318 *Standard for the Protection of Semiconductor Fabrication Facilities, 2009 Edition*	Provides reasonable safeguards (protection against injury, loss of life and property damage) for the protection of facilities containing cleanrooms from fire and related hazards.
Semiconductor Equipment Materials International (SEMI)	S2-0706b *Environmental, Health, and Safety Guideline for Semiconductor Manufacturing Equipment, July 2009*	This safety guideline is intended as a set of performance-based environmental, health, and safety (EHS) considerations for semiconductor manufacturing equipment.
Semiconductor Equipment Materials International (SEMI)	S3-0360 *Safety Guideline for Process Liquid Heating Systems, March 2006*	*Complete rewrite in 2006.* Provides minimum general safety considerations for the design and documentation of heating systems used for changing or maintaining the temperatures of process liquids used in semiconductor and flat panel display manufacturing.
Semiconductor Equipment Materials International (SEMI)	S14-0704 *Safety Guidelines for Fire Risk Assessment and Mitigation for Semiconductor Manufacturing Equipment, March 2009*	Provides consideration to the manufacturers of semiconductor manufacturing equipment that will assist them in assessing and mitigating the risk to equipment and product associated with fire and combustion by-products.
International Code Council (ICC)	International Fire Code *2009 Edition*	This code establishes regulation affecting or relating to structures, processes, premises and safeguards. Chapter 18 addresses Semiconductor *Fabrication Facilities. Currently under revision.*
Compressed Gas Association (CGA)	G-13 *Storage and Handling of Silane and Silane Mixtures, Second edition 2006*	Addresses installation of systems and sources used to store, transfer or contain silane or silane mixtures. *Currently under revision.*

When a tool is evaluated under FM7701, it will require only a spot check after installation, saving tool vendors and semiconductor manufacturing companies significant amounts of time and money. And, fire-safe semiconductor equipment is critical in the event of a fire. Consider the fire damage consequences cited at the outset of this article.

Silane Gas Usage

Silane, more so than other gases used in semiconductor manufacturing, can lead to severe exposures. It is a stable gas but it is pyrophoric: under certain conditions, it can spontaneously ignite or have delayed ignition, which could lead to an explosion.

Silane has been involved in a considerable number of fires. Common scenarios included untreated silane released into combustible fume exhaust ductwork and improper cylinder change-out procedures resulting in leaks at the cylinder connection points.

During the past five years, there have been several unfortunate events, which have led to a renewed interest in the safe handling of silane. Several years ago, Air Products and Chemicals, Inc. organized a series of Silane Safety Seminars held in Taiwan, Korea, China, Singapore, and, most recently, in Portland, Ore., USA. The goal of these highly successful seminars was to educate the audience with respect to silane behavior and best-protection practices.

Open Issues

One significant cleanroom fire hazard—containers used to store in-process wafers—still needs to be addressed.

Wafer carriers or pods (200mm wafers) and Front-Opening Unified Pods, or FOUPs (300mm wafers), are currently made of highly combustible materials like polycarbonate and polypropylene. These pods or FOUPs are typically placed inside vertical storage systems known as stockers. And, fire grows rapidly for highly combustible materials placed in a vertical array.

FM Approvals issued the Approval Standard for Wafer Carriers for use in Cleanrooms (Class 4911). This standard provides testing criteria similar to FM4910 in order for a fire-safe wafer carrier to become FM Approved.

The final piece of the fire-safe fab puzzle was the development of a FOUP capable of passing the FM4911 non-fire propagating FOUP standard. At the beginning of 2009, the first FM Approved FOUP became a reality after many years of research and development. For a number of reasons, this was a significant event from both technical and business perspectives.

When FM4911 Approved FOUPs are used, there is no need for automatic sprinkler protection to be installed inside the stockers. Because FM Approved FOUPs, by definition, are non-fire propagating, the amount of fire and smoke generated is extremely limited. In fact, once the ignition source is interrupted, the fire associated with the burning FOUPs will either self-extinguish or can easily be extinguished with a hand-held fire extinguisher.

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Future Outlook

The outlook for further progress in cleanroom protection is very promising. The use of FM4910 materials and FM4922 ductwork is well established. Current codes/standards support the use of fire-safe materials. Attention needs to be focused toward using the FM Approved FOUP as well as bringing to market a second FM Approved FOUP. Recently released new products have provided a solution to areas previously lacking fire-safe alternatives. Products under development, which will add to cleanroom fire safety, include wall panels and wires/cables.

Development has started on the next generation of fabs, which will process 450mm wafers. Due to the extreme cost (> US$10 billion USD) to build and equip these fabs, a limited number of companies have expressed interest in these fabs. Standards are under development, prototype equipment is under evaluation, and plans are to have some type of pilot line by 2012. Production 450mm fabs could be online by 2015. There are many loss prevention challenges in which FM Global is working with fab companies, equipment vendors and standard-making groups to better understand these future facilities.

New Fire Safety Products

Recently, the products shown in the chart below received FM Approvals certification and can improve overall cleanroom fire safety.

Company	Product	Description
UFP Technologies Inc. (T-Tubes® registered trademark) www.t-tubes.com Zotefoams Plc. (Zotek® F) www.zotefoams.com Arkema Inc. (Kynar® PVDF) www.kynarfoam.com	Kynar PVDF Closed-Cell Foams for Cleanroom Insulation	FM4910-Listed material and FM4924-Approved pipe insulation. Uses include air conditioning ducts, steam pipes and other process components.
Solvay Solexis www.solvaysolexis.com	Galden® HT and HGalden® ZT Fomblin	FM Approved Industrial Fluid. Heat-transfer fluids for use in semiconductor equipment.
Mitsubishi Chemical Functional Products, Inc. www.alpolic-usa.com	Alpolic® /fr Panel	FM4910-Listed material. Exterior and interior wall panels.

About FM Global

For 175 years, many of the world's largest organizations have worked with FM Global (www.fmglobal.com) to develop cost-effective property insurance and engineering solutions to protect their business operations from fire, natural disasters and other types of property risk. The metrics used as the basis for the research and statistics referenced in this report were derived from Risk*Mark*®, a fact-based analytics tool developed by FM Global that produces data to help users precisely understand the risk of major property loss at each facility, the potential business impact and the best solutions to address related vulnerabilities. With clients in more than 100 countries, FM Global ranks among *Fortune* magazine's largest companies in America and is rated A+ (Superior) by A.M. Best and AA (Very Strong) by Fitch Ratings. The company has been named "Best Property Insurer in the World" by *Euromoney* magazine and "Best Global Property Insurer" by *Global Finance* magazine.

About the Author

Vinnie DeGiorgio is assistant vice president and FM Global's principal engineer for the semiconductor industry. DeGiorgio has more than 30 years of property loss control and business impact risk assessment experience associated with the semiconductor and related high technology industries. DeGiorgio holds a bachelor's degree in engineering and a master's degree in fire protection engineering. He maintains memberships with the National Fire Protection Association (NFPA) and Society of Fire Protection Engineers (SFPE), is a board member of Semiconductor Environmental Safety and Health Association (SESHA), and is the secretary of the NFPA 318 Technical Committee on cleanrooms. Of note, DeGiorgio has expansive knowledge of the semiconductor industry in Asia.

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