Title: SEMI S2, EQUIPMENT SAFETY GUIDELINE AND RELATED SAFETY STANDARDS FOR THE SEMICONDUCTOR INDUSTRY

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Abstract

What is safe semiconductor manufacturing equipment?
Does meeting the regulatory requirements make it safe?
How much risk management is necessary to make equipment safe?
The semiconductor industry has a challenge in providing equipment that meets the objective of providing an injury free work place for it personnel while meeting the technology challenges that drive the industry. Semiconductor manufacturing equipment is some of the most complex and advanced manufacturing equipment in the world. Add to that, that the equipment obsoletes itself ever other technology generation. Today's leading edge technology generations are 12-18 months in duration.
Facing this challenge, several visionaries in the mid 80 began an effort to create a standard that would reduce the risk of semiconductor equipment and still be able to keep pace with the ever changing technology. SEMI S2 is a risk management guideline and was not designed to be a regulation as written. Since it's creation in 91, SEMI S2 has been adopted by many regulatory agencies. The success of this unintended adoption has been mixed. Today the industry is working on finding a common path that will continue to meet the industry needs and satisfy regulatory agencies.

Introduction

Much has been written about the compliance issues that semiconductor manufacturing equipment manufacturers are facing. Each manufacturer must develop and manufacture the best product for its market. Often near the end of the design/manufacturing cycle, the buyer's local regulatory-compliance needs must be met.

This cycle tends to result in a constant stream of re-evaluation, re-engineering, and modification as the product is forced to meet each different set of compliance criteria during that last, crucial phase, equipment delivery. This situation is all too familiar to manufacturers of semiconductor processing equipment, which have been dealing with this challenge within their industry for years. Until recently, they also had to endure, as well, the financial and engineering burdens of catering to each end user's internal safety expectations and requirements.

Fortunately for these equipment manufacturers, some forward-thinking industry professionals decided that there was too much waste in the "business-as-usual" system and that it was time for a change. The cost of retrofit and of the delays in the shipment of equipment while they were brought into compliance was also taking its toll.

In 1985a group of industry representatives, drafted a plan for developing their own performance-based industry standard for the safety of semiconductor manufacturing process equipment before "Semiconductor Equipment and Materials International Standards" (SEMI Standards) organization. The group was concerned that if the industry did not take action to develop its own standard, outside agencies would impose other requirements and thus expand the wasteful cycle even more.

From 1985 to 1988, a SEMI task force worked on developing such a document. Its efforts were focused on delivering a standard that would cover all facets of process equipment. Many of the existing requirements had no inherent safety benefit, but merely led to a duplication of efforts and a high financial burden on both the manufacturer and the end user. With a consensus standard, manufacturers could instead concentrate their effort on a single design specification and undergo a single evaluation that every end user would accept.

In 1988, SEMI distributed a draft proposal to members of the industry for comment. The document, a collection of requirements aimed at increasing the safety, and reliability of process tools, continued to be modified based on industry comments until its eventual publication in 1991 as SEMI S2-91, “Safety Guidelines for Semiconductor Manufacturing Equipment.”

Whereas it had taken SEMI six years to develop and adopt SEMI S2-91, it took the task force less than a year to realize that its work was not done. Inadequacies were identified by those using and requiring SEMI S2-91, and modifications were proposed. Work was begun in 1992 on the rewriting and correction of those areas in which change was needed. SEMI S2-93 was published a year later.

For the next 3 years the document increased in use by the industry with no changes. In 1996 with the advent of the CE mark requirements for Europe, an appendix was added to assist the industry in meeting S2 and CE requirements. SEMI S2-93A was published. Also in 1996, a task force was begun to consider changes necessary to make SEMI S2 meet the challenges of the next century.

Standards Background

Lets take a look at what are standards

The term standard, as defined by ASTM is: 1) a reference used as a basis for comparison or calibration, 2) A concept that has been established by authority, custom, or agreement to serve as a model or rule in the measurement of quantity, or the establishment of a practice or a procedure.

Equipment manufacturers and end users (device manufacturers) often argue that standards increase cost and that the customer would not be competitive, if expected to comply with a voluntary standard whose scope went beyond that of standards used by its competitors. For some product standards this may be a valid line of reasoning, but for system (or process) standards, the assumption is unfounded; it can be shown that their adoption reduces both defects and costs, which may explain the rapid growth in popularity of system or process standards that favor suppliers and customers alike.

Prescriptive standards are straight forward; they specify performance parameters for a product or service, and conformity and non conformity are clearly delineated. Non-prescriptive standards are becoming more common with the growth of management systems. They invite the user to establish customize performance standards and determine uniquely how to meet the specified system requirements. The absence of either an overall system or a specified element within a system may be considered proof of gross noncompliance. Nonconformity, of an individual action within the system, may be dismissed as significant if the evidence suggests that the system is working as intended to correct the situation and prevents recurrence.

Why a standard is created

The standard process develops common language and test methods between suppliers, users and government regulators. A safety standard is intended to present minimum criteria necessary for the safety of workers at the point of operation. This is not to represent the best conditions obtainable by modern engineering practices.

How a standard is created.

Standards are generally created by technical consensus within a standards writing body. Today, most new standards are produced mainly by industry groups, but under the veiled threat of regulatory action if their standards do not turn out strong enough to protect the public or employees.

Advantages of using standards.

- Standards provide a common language for equipment suppliers and users to communicate with and define standard test methods for acceptance.

- Codes are an excellent starting place and offer a go/no-go checklist. They must be used creatively and judgmentally. They must be only the beginning, not the end, of the design process. If you merely make a selection from approved safety devices based on a code that does not set priorities, your machine may well turn out to be unsafe.

- Actual accident frequency will not reflect the greater number of near misses or close calls wide experience shows will have occurred, but went unreported. Standards provide a broad knowledge base and can reduce this type of condition.

- Early identification of the source of defects or hazards and the risk associated with them.

SEMI Safety Guidelines

SEMI International Standards, Facility and Safety Division, manages the Environmental Health & Safety Committee is chartered with the development of safety guidelines related to:

- Safety of design and operation of equipment and use of materials in the semiconductor industry

- Environmental issues created as a result of semiconductor manufacturing activities

- Storage, Use and Transportation of chemicals (solid, liquid, or gas) within the facility

Currently there is thirteen SEMI Safety guidelines. They are:

- S1-90, Safety Guideline for Visual Hazard Alerts (In Revision)

- S2-93A, Safety Guideline for Semiconductor Equipment (In Revision)

- S3-91, Safety Guideline for Heated Chemical Baths (In Revision)

- S4-92, Safety Guideline for the Segregation/Separation of Gas Cylinders

- S5-93, Safety Guideline for Flow Limiting Devices

- S6-93, Safety Guideline for Ventilation

- S7-95, Safety Guideline for Third Party Environmental Health and Safety Equipment Evaluation (In Revision)

- S8-96 Safety Guideline For Ergonomics/ Human Factors Engineering of Semiconductor Equipment, (In Revision)

- S9-95 Electrical Test Methods for Semiconductor Manufacturing Equipment

- S10-1296 Safety Guideline for Risk Assessments (In Revision)

- S11-1296 Safety Guideline for Semiconductor Equipment Mini-environments

- S12-0298 Safety Guideline for Equipment Decontamination

- S13-0298 Safety Guideline for Operation and Equipment Manuals

There are two more safety guidelines in the final review and approval process. One is for “Fire Protection” and the other is for “Gas Detectors”. Device makers in the United States, Japan, Europe, China, Taiwan, and Singapore are currently using these guidelines. The usage is non-uniform and application varies from device maker to device maker.

SEMI S2, Safety Guideline for Manufacturing Equipment

Few, if any, standards specifically address the manufacturing and design of process tools used in manufacturing semiconductors. In today's competitive environment, the expense and disruption caused by retrofitting equipment with safety features cannot be tolerated. The integration of safety during the equipment's initial design and construction phase is paramount. To accomplish this, equipment manufacturers must design according to a uniform equipment safety guideline. This will be mutually beneficial to both equipment manufacturers and users. This will help eliminate environmental, occupational health and safety hazards that are inherent in the operation of semiconductor manufacturing equipment. An international task force of SEMI Standards has developed a performance-based guideline for the semiconductor industry, SEMI S2. This guideline is predominately a non-prescriptive standard.

Why SEMI S2 was created.

- Before the creation of SEMI S2 there were no industry guidelines or common direction for equipment suppliers or end-users
- Visionaries in our industry realized the issue of a standard and its long term impact.
- Equipment related safety issues were applied as differing interpretations of regulatory codes, other industry standards and company policies.
- Customer's environmental, health and safety professionals were mandating post design safety modifications. Local government regulatory officials were also mandating post design changes.

SEMI S2 goal

To create a common set of expectations of environmental, health and safety issues and provide a path for supplier and user partnerships.

Elements of SEMI S2

This guideline is a performance based safety document. It’s intent is to be non-technology limiting, and to provide the path for integration of environmental health and safety features into the initial design of the equipment. Equipment features are intended to be clear, measurable and value added. Concurrent safety engineering with other engineering discipline is necessary to keep safety cost in line and to maximize benefits. The SEMI guideline was written not to just meet requirements for today, but provide long term goals and objectives for equipment suppliers.

S2 Philosophy

If there is one basic philosophy behind the SEMI S2-93 document, it is that safety measures should be incorporated into equipment from the start, not added as an option or a retrofit after it is designed or manufactured. Optimally, all potential hazards should be identified early in the design stage, when most problems can still be easily and cost-effectively corrected or eliminated. Modifications implemented later, after manufacture, often tend to hinder system and safety performance as well.

One of the major objectives of SEMI S2 is to establish a basic design philosophy ...

"No single point failure can cause injury to personnel, allow personnel to be exposed to hazardous materials, or cause damage to the equipment or facility."

This philosophy is restated several times throughout the guideline and is the basis for specific criteria.

Whenever possible, efforts should be made in the design stage to utilize technology and materials that are inherently less hazardous. If equipment hazards cannot be designed out, steps must be taken to design safeguards into the equipment to ensure that no single failure mode or operator error can effect a hazardous exposure of the operator, facilities personnel, or the environment.

S2 Performance

One of the driving goals in the development of SEMI S2 was to create a standard that was performance-based to allow for innovations in design. The authors did not want to produce a document that would dictate what parts, manufacturers must use or which circuit designs they must implement; rather, it would be the performance of the machine that would be scrutinized. SEMI S2-93 is thus a performance-based document, containing very few prescriptive clauses. Seventeen of the 20 sections of SEMI S2-93 are dedicated to the actual performance criteria that a process tool is required to meet.

SEMI S2-93 guideline required several years work and hundred of hours by industry volunteers. Listed below are some of the historical milestones of its development:

1985 Concept presented to the equipment safety committee.

1985-1990 SEMI Task Force, concepts supported by industry volunteers.

1988 SEMATECH held a workshop on equipment safety.

1988 1st draft circulated to industry for comment.

1989 SEMATECH's in-house equipment safety specifications were based on the draft document.

1989 Intel's in-house equipment safety specifications were based on the draft document.

1990 SEMATECH and SEMI jointly conducted a workshop on process equipment safety. Output of this workshop was incorporated into the final draft.

1990 Lesson learned by Intel's usage were adopted into the final draft.

1990 Document passes technical ballot.

1991 SEMI S2-91 published in the Facility & Safety Book of SEMI Standards.

1992 Task force formed to revise SEMI S2-91.

1993 SEMI S2-93 published in the Facility & Safety Book of SEMI Standards.

1995 SEMATECH member companies develop common interpretation of SEMI S2-93

1996 Task force formed to review SEMI S2-93 per the SEMI regulations

1999 Revised S2 is at Technical ballot

Related Safety Standards

In the semiconductor industry, few manufacturers limit their marketing strictly to domestic end users. Europe is increasing as an important market for U.S. & Japanese equipment manufacturers. Unfortunately, those trying to market their equipment in Europe are now discovering a new hurdle in their way in the form of CE Marking requirements. The need for CE Marking, a complication not anticipated during the original development of SEMI S2-93, has forced U.S. manufacturers back into the cycle of redesign and re-engineering, this time for equipment destined for Europe.

Compliance with the European Directive on Machine Safety, 89/392/EEC (known as the Machinery Directive) became mandatory on January 1, 1995, as did the marking of compliant equipment with the CE Mark. Compliance with the related Low Voltage Directive (73/23/EEC), the European safety Directive for equipment powered by voltages below 1000VAC, became mandatory on January 1, 1996. Compliance with a third Directive, the EMC Directive, also became mandatory on January 1, 1996. This Directive governs the emission of and the immunity to electromagnetic radiation and electric field phenomena. Even though the European Commission had provided for phase-in periods for all of these Directives, their coming into force took most manufacturers by surprise.

The general consensus of the industry is that semiconductor manufacturing equipment by and large falls within the scope of these three Directives. For this reason, SEMI, with the help of members representing the manufacturing community, has been trying hard to find ways to minimize the rework involved when a piece of equipment designed for the domestic market and compliant with SEMI S2-93 is sent to Europe. Numerous letters and questions have been directed to the European Commission in an attempt to clarify each side's position and interpretation and help to better define the issues involved.

Thanks to this effort, the European Commission has agreed that for those sections of SEMI S2-93 that overlap with the "essential health and safety requirements" of Annex I of the Machinery Directive, or with the Essential Health and Safety requirements of the Low Voltage Directive, equipment that complies with those similar sections of SEMI S2 will be deemed also to comply with the Machinery and/or Low Voltage Directives. This is tantamount to blasphemy for EU safety purists, as the Commission is essentially stating that the U.S. requirements have been accepted, and that in this case the use of European Harmonized or EN documents will not be mandatory! It is important to note that while this position still allows for at least an equivalent level of protection for the end-user, at the same time it will definitely save U.S. & Japanese equipment manufacturers the time and expense involved in performing reviews to two separate but nearly equivalent guidelines. With regard to those sections of Annex I of the Machinery Directive and SEMI S2-93 that do not overlap, SEMI has tabulated the differences and has listed them in an appendix to the '96 rewrite of the SEMI S2-93 standard, entitled SEMI S2-93A.

It should be noted that the traditional "standards route" using European standards is still a viable and unquestioned option for manufacturers wishing to market devices in Europe. Using established European EN documents remains the norm for many who feel uncomfortable with choosing the "essential health and safety" route. The "standards" route is more rigorous and more demanding of "European conformity" in both design and component selection, but once the manufacturer has met these requirements, there is little room for argument as to the equipment's conformity, provided that the manufacturer has chosen the correct EN standards against which to assess.

The "essential health and safety" route is less rigid and restrictive in the sense that it attests to the basic level of safety outlined in Annex I. In principle, it allows for review to U.S. or even a manufacturer's own internal safety standards, so long as the manufacturer is confident that the equipment meets the basic level of safety expected. This approach also permits the use of U.S. approved (NRTL) components in construction, thereby eliminating the need for multiple versions of the same equipment. It is not without risks: should an end user require compliance with certain EN or national standards, for example, a manufacturer could be sent back to the drawing board. Moreover, it is not a silver bullet. Manufacturers must be diligent in comprehensively assessing equipment to the requirements of Annex I. Issue may always be taken with a piece of equipment or a manufacturer's Declaration of Conformity, but if the data are there, the accuser must prove that a safety risk indeed exists.

Future of SEMI S2

SEMI S2 has changed the way that the Industry looks at and deals with equipment safety. We are now facing new challenges. For example, Authorities Having Jurisdiction (AHJs) are now using SEMI S2 to determine suitability of the equipment for use in their jurisdictions. To assist the Industry, educational workshops, professional development courses, and Third Parties providing consulting/evaluation services have evolved.

In February 96, a workshop was conducted by the SEMI International Standards EHS committee to determine the need for changes to SEMI S2-93A. The consensus was unanimous. It was time to update the guideline for the new millennium.

SEMI S2 is intended to be a path for integration of environmental, health and safety features into the early design of the equipment. SEMI S2-93A is being revised to support the requirements for today, as well as a framework for continuous improvement.

The three parts to the new S2 are:

- Core Text (Sections 1-27): This is the body of the Guideline.
- Appendices: This is supplemental information to support the Core Text.
- Related Information: These items are best practices and applications that are intended to assist the user of the guideline and are approved for publication by the SEMI Standards EHS Committee. This material is to update these items on a regular basis, published upon approval of the EHS Committee.

Four years and several thousand volunteer man-hours later, the new S2 is in its final industry acceptance process. 95% of the new S2 (street named S2-XX) has been approved. There are only a few sections, which must still complete the SEMI consensus process. The industry anticipates final approval in October. Listed below are the sections of the new S2. Those in **bold** have paragraphs or sentences that are still in the consensus approval process.

1. Purpose
2. Scope
3. Limitations
4. Referenced Documents
5. Terminology
6. Safety Philosophy
7. General Provisions
8. Evaluation Process
9. Documents Provided to User
10. Hazard Warning Labels
11. Safety Interlock Systems
12. Emergency Shutdown
13. Electrical Design
14. Fire Protection
15. Heated Chemical Baths
16. Ergonomics/Human Factors
17. Hazardous Energy Isolation
18. Mechanical Design
19. Seismic Protection
20. Automated Material Handlers
21. Environmental Considerations
22. Exhaust Ventilation
23. Chemicals
24. Ionizing Radiation
25. Non-Ionizing Radiation and Fields
26. Lasers

27. Sound Pressure Level
Appendix 1 — Enclosure Openings
Appendix 2 — Design Principles and Test Methods for Evaluating Equipment Exhaust Ventilation
Appendix 3 — Design Guidelines for Equipment Using Liquid Chemicals
Appendix 4 — Ionizing Radiation Test Validation
Appendix 5 — Non-Ionizing Radiation (Other than Laser) and Fields Test Validation
Appendix 6 — Fire Protection: Flowchart for Selecting Materials of Construction

Conclusion

Today most US semiconductor manufacturing companies are using the SEMI S2 guideline as a baseline for safety acceptance of the equipment they purchase. The other SEMI International Standards safety guidelines are use to support this baseline.

The semiconductor industry is one of change. Managing change and reducing the risk while on the leading edge of technology requires innovative thinking and solutions.

For 3 years, 200+ companies have been contributing thousands of volunteer man-hours to making SEMI S2 a viable choice for equipment safety in the next millennium.

The semiconductor industry meeting to discuss equipment safety and regulatory issues continue on a regular basis. These meeting range from formal technical conferences to ad-hoc regional topic specific sessions.

The long term success of industry standards it to have regulatory agencies accept them as technically valid standards. Regulator agencies must continually be education on the new technologies, challenges and solutions the semiconductor industry is facing and dealing with. Regulatory agencies are willing to work with the semiconductor industry, we just need to make them part of our continuously evolving process and environment.

Another Challenges to the industry is to orient those from other industries and new college graduates to the fast and ever changing environment of the semiconductor industry. Many of the industry needs and safety practices are unique to this industry and are not found in university text and courses. Conferences and workshops have been the most valuable to date and must continue.

SEMI S2 goes Beyond Regulatory Compliance. Safety programs and equipment design must continue to strive at making Safety 2nd Nature, and a standard way of doing business in the semiconductor industry.

World-class safety programs and equipment safety are the ultimate in customer satisfaction.

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