Environment, Safety, and Health (ESH) Metrics for Semiconductor Manufacturing Equipment (SME)

International SEMATECH
Technology Transfer #02034261A-TR

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Abstract: This report from the International SEMATECH (ISMT) ESHF004 project identifies a set of key environment, safety, and health (ESH) performance parameters for semiconductor manufacturing equipment (SME) identified by the project working group during 2001 and refined by the ESH Program Advisory Group (PAG) during February 2002. These metrics were developed to provide a uniform method for evaluating the ESH performance of SME. Future work planned in this area is described, including populating a database of equipment ESH metrics to permit the evaluation and comparison of ESH performance for selected SME, assist in the development of equipment ESH goals for the International Technology Roadmap for Semiconductors (ITRS), and provide focus for follow-on projects with SME suppliers to further improve equipment ESH performance.

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1 EXECUTIVE SUMMARY

During 2001, the International SEMATECH (ISMT) ESHF004 Equipment ESH and Metrics project working group established a uniform set of equipment environment, safety, and health (ESH) metrics. The purpose of establishing these metrics was to permit ongoing 1) evaluation of the ESH performance of newer 300 mm semiconductor manufacturing equipment (SME) compared to 200 mm SME; 2) verification and documentation of the ESH performance of SME to goals in the *International Technology Roadmap for Semiconductors* (ITRS); 3) determination of potential areas of ESH improvement for further research with SME suppliers; and 4) identification of key data for inputs to Life Cycle Assessment (LCA) models. A longer-term goal is to quantify reasonable ranges for the ESH performance of each type of SME to help refine ITRS targets.

2 BACKGROUND

Since the late 1990s, interest regarding the quantification of the ESH performance of semiconductor manufacturing facilities and equipment has steadily increased among the semiconductor industry and various governmental and non-governmental bodies. Examples of this ongoing development work can be found in the following sources:

- The Semiconductor Industry Association (SIA) Environmental Metrics Program, which tracks five key facility-level ESH metrics for participating fabricators [1]
- Development of facility, process, and equipment ESH goals in the ITRS [2]
- The Semiconductor Equipment and Materials International (SEMI) Global Care program and development of a SEMI guideline for establishing equipment-level ESH metrics [3]
- World Semiconductor Council (WSC) initiatives to establish semiconductor industry consensus on ESH goals [4]
- International Organization for Standardization (ISO) [5]
- Industry publications and books [6]
- United States Environmental Protection Agency (USEPA) [7]
- Annual corporate environmental reports from SME suppliers and device manufacturers

In 2000, ISMT member companies identified the need and approved 2001 funding for establishing a standard set of equipment ESH metrics that would build upon and expand the scope of previous work completed at ISMT. Past work focused on equipment energy and utility consumption measurements and optimization studies. The task of establishing an overall, standard set of equipment ESH metrics was directed to the ESHF004 project. During 2002, this project was renamed Equipment ESH & Metrics to reflect a greater emphasis on the refinement and collection of equipment ESH metrics data. Close collaboration with the ISMT energy and water optimization projects was established to standardize measurement techniques and share data collection to make optimal use of available contract funding.

3 EQUIPMENT ESH METRICS AND DEFINITIONS

During 2001, a set of 15 metrics defining equipment ESH performance was generated and approved by the ISMT ESHF004 project working group through participation in teleconferences, emails, and face-to-face working group meetings. The ISMT ESH Program Advisory Group (PAG) elected to modify the list at the February 2002 PAG meeting by adding exhaust consumption, removing some metrics that did not receive the broadest member company support, and expanding the S2/S8 non-conformance metrics by delineating non-conformances by overall risk ranking category according to SEMI S10 definitions. The industry still has some difference of opinion on whether hazards identified in third-party S2/S8 evaluations as having an overall risk ranking of slight or low are in fact non-conformances and should be included as metrics [8]. These types of issues will be addressed in future working group meetings. Some additional industry guidance was also received from individual companies participating in the SEMI EHS Metrics task force.

The metrics generated are listed in a survey format in Table 1, while associated definitions and identified test methods are listed in Table 2. These were the key metrics identified by the working group and do not necessarily represent all equipment ESH metrics that can be developed. It is also recognized that further work in standardizing test methods for these metrics is required to optimize data collection procedures, lower associated measurement costs, and maximize data integrity. Sound data integrity is critical to permit meaningful comparisons and trending of the ESH performance of SME.

When collecting equipment ESH metrics for a particular piece of equipment, all pertinent equipment and process specifications should be accurately documented. The manufacturer, model number, date of manufacture, date of installation, any equipment modifications, baseline process or other specific process run during testing, associated throughput, number of wafers processed during test, size of wafers processed, start and stop readings for various meters, etc., are all pieces of information that are important to ensure data integrity and to permit meaningful comparison of collected metrics data.

ISMT intends to keep the most current version of these metrics available on the its public website (www.sematech.org). These metrics will also be included in the next revision of ISMT Technology Transfer #01064135B-ENG, *Uniform Procurement Specification for Equipment Environment, Safety, and Health (ESH) Requirements* (available on the ISMT public website in April 2002).

Table 1 Equipment ESH Metrics Questionnaire

Metric	Unit	Normalizing Factors
1. Energy consumption when idle	Kilowatt	N/A
2. Energy consumption when in process	Kilowatt-hour	Per wafer pass
2a. peak current	A, amperage	N/A
2b. inrush current	A, amperage	N/A
2c. connected load	KVA	N/A
2d. power factor	N/A	N/A
3. Exhaust consumption	$Meters^3/min$	N/A
4. DI water consumption when idle	Liters/min	N/A
5. DI water consumption when in process	$Liters/cm^2$	Per wafer pass
6. Hazardous waste generation	Kg/cm^2	Per wafer pass
7. Process chemical consumption (list by chemical)	Kg/cm^2	Per wafer pass
8. Specialty gas consumption (list by gas)	Kg/cm^2	Per wafer pass
9. Bulk gas consumption (list by gas)	Kg/cm^2	Per wafer pass
10. VOCs emission	Kg/cm^2	Per wafer pass
11. PFCs emission	CE Kg/cm^2	Per wafer pass
12. HAPs emission	Kg/cm^2	Per wafer pass
13. Packaging (weight of non-divertible waste)	Kg	Per piece of equipment delivered
14. SEMI S2 non-conformances	Number of non-conformances in S2 report	Per piece of equipment at delivery
14a. critical		
14b. high		
14c. medium		
14d. low		
14e. slight		
15. SEMI S8 non-conformances	Number of non-conformances in S8 report	Per piece of equipment at delivery
15a. critical		
15b. high		
15c. medium		
15d. low		
15e. slight		

Table 2 Equipment ESH Metrics Definitions and Test Methods

Term	Description
Baseline process	In the absence of a specific agreement between the supplier and end user, a baseline process shall be defined as a representative process adopted by a significant number of end users. [*SEMATECH Application Guide 2.0 for SEMI S2-93 and SEMI S8-95*].
Energy consumption	The electrical and power consumption of 1) the process tool and associated subcomponents such as pumps, radio frequency (RF) power supplies; 2) process cooling water; and 3) exhaust. See *Utility Consumption Characterization Protocol for Semiconductor Tools*, ISMT Technology Transfer #00043939A-ENG.
Deionized (DI) water consumption	Mobile ultrasonic flow meters permit non-intrusive measurements of ultrapure water (UPW) flow rates. The flow meter sensors, or transducers, are attached to the outside of the UPW feed or wastewater lines and require no interference with normal tool operations. Transducer placement can be close to the tool or in the sub-fab, but should be on a straight pipe length without bends, valves, or changes in pipe diameter. This is to avoid turbulence that may interfere with accurate flow measurements. The straight pipe length should be at least 10 pipe diameters (for a 1" O.D. pipe = 10" length). Piping material, outer diameter, and inner diameter must be entered into the software application; these parameters will also determine the transducer selection (Polymer or metal, O.D. > 1", or 0.25 < O.D. < 1", etc.)
Hazardous waste	Waste defined as hazardous by the USEPA in 40CFR Part 261 or governing regulations; generally categorized as corrosive, ignitable, toxic, or reactive, or specifically listed as hazardous waste in applicable regulations. (http://www.epa.gov/trs/index.htm).
Process chemical	Liquid chemicals except DI water. All chemicals used should be listed.
Specialty gas	Cylinder gases: AsH_3, PH_3, Cl_2, NF_3, etc. May also include non-traditional gases supplied in ton containers or tube trailers: NH_3, N_2O, CF_4, NF_3, etc.
Bulk gas	Traditional gases supplied in bulk: N_2, O_2, Ar, H_2, etc.
VOCs	Volatile organic compounds, any organic compound that participates in atmospheric photochemical reactions other than those organic compounds excluded by the USEPA in 40CFR Part 51 or excluded by other applicable regulations as having negligible photochemical reactivity. (http://www.epa.gov/trs/index.htm) Also refer to *Guidelines for Environmental Characterization of Semiconductor Equipment*, Technology Transfer # 01104197A-XFR. (http://www.sematech.org/public/resources/stds/supplierguide/esh.htm)
PFCs	Perfluorocompounds, including CF_4, CHF_3, C_2F_6, C_3F_8, NF_3, SF_6 based on agreement by WSC. Calculated in carbon equivalent weight, CE Kg. Also refer to *Guidelines for Environmental Characterization of Semiconductor Equipment*, Technology Transfer # 01104197A-XFR. (http://www.sematech.org/public/resources/stds/supplierguide/esh.htm)
HAPs	Hazardous air pollutants, air pollutants defined by the USEPA in 40CFR Part 63 or other governing regulations that may present a threat of adverse human health effects or adverse environmental effects. (http://www.epa.gov/trs/index.htm) Also refer to *Guidelines for Environmental Characterization of Semiconductor Equipment*, Technology Transfer # 01104197A-XFR. (http://www.sematech.org/public/resources/stds/supplierguide/esh.htm)
Idle	The state when the tool is fully powered on and ready to process wafers but is not actually running a process. If there are different stages of idle mode (e.g., minimum/baseline idle and maintenance/high flow idle for chemical-mechanical polishing [CMP] tools), then average idle consumption should be calculated.
Peak	The highest level of consumption of the utility by the equipment during normal use.
CE	Carbon equivalent

During late 2001, ISMT validated the collection of these metrics on three distinct pieces of SME in ISMT's Advanced Technology Development Facility (ATDF) in Austin, Texas. Results were shared with the National Science Foundation/Semiconductor Research Corporation (NSF/SRC) Engineering Research Center for Environmentally Benign Semiconductor Manufacturing (http://www.erc.arizona.edu/seminar/index.html) during a teleseminar in January 2002.

For 2002, ISMT's membership has approved increased data collection efforts and the expansion and refinement of the metrics database. The goal is to obtain data on a meaningful cross section of key SME (both 200 mm and newer 300 mm tools) to permit the trending of equipment ESH performance, comparisons with existing and development of improved ITRS goals, and to pinpoint areas for ISMT and SME suppliers to focus resources to further improve new equipment ESH performance.

To actively promote the collection of equipment ESH metrics data and encourage SME suppliers to provide this information to device manufacturers on an ongoing basis, ISMT is working with SEMI to incorporate this set of equipment ESH metrics into appropriate SEMI documents, such as a guideline, test method, and/or auxiliary information paper. The ISMT project manager is the current chair of the SEMI EHS Metrics task force developing draft document #3129A, *Guide for the Development of Environmental, Health, and Safety Performance Metrics for Semiconductor Manufacturing Equipment*. At the March 2002 SEMI Winter Standards meeting, the SEMI EHS Standards Committee encouraged the SEMI EHS Metrics task force to continue to work to gain international consensus on a uniform set of equipment ESH metrics and to generate a document with specific recommended test procedures. These test procedures were identified as a key item to provide value to SEMI members and to the overall semiconductor industry. Work in this area is anticipated to continue during 2002 through teleconferences and face-to-face meetings of the SEMI EHS Metrics task force.

4 REFERENCES

[1] Semiconductor Industry Association (SIA), 181 Metro Drive, Suite 450 San Jose, CA 95110, Phone: (408) 436-6600, Fax: (408) 436-6646, Environmental Metrics Survey, http://www.semichips.org/iss_environment.cfm

[2] *International Technology Roadmap for Semiconductors* (ITRS), 2001 edition, http://public.itrs.net/Files/2001ITRS/Home.htm

[3] Semiconductor Equipment and Materials International (SEMI), 3081 Zanker Road, San Jose, CA 95134-2127, Tel: 408.943.6900, Fax: 408.428.9600, http://www.semi.org/web/winitiatives.nsf/url/ehshome

[4] World Semiconductor Council (WSC) http://www.semiconductorcouncil.org/activities/envi.html

[5] International Organization for Standardization (IS0), 14000 series documents, http://www.iso.ch/iso/en/iso9000-14000/iso14000/iso14000index.html

[6] *Industrial Environmental Performance Metrics: Challenges and Opportun*ities, pp. 107-128, 1999, The National Academy of Sciences, National Academy Press, http://www.nap.edu/catalog/9458.html

[7] United States Environmental Protection Agency (USEPA), Performance Incentives Division (PID), Office of Policy, Economics, and Innovation, http://www.epa.gov/emergingstrategies/environ.html

[8] SEMI S2-0200, Environmental, Health, and Safety Guideline for Semiconductor Manufacturing Equipment, Section 8 - Evaluation Process (8.3.1.1).

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