Realizing Smart Manufacturing in Semiconductor Industry with SEMI Standards

Alan Weber
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Mr. Alan Weber, Vice President, New Product Innovations for Cimetrix Incorporated

Education: Bachelor’s and Master’s degrees in Electrical Engineering, Rice University

Experience:
- Semiconductor design automation
- Equipment and factory control system architectures
- Advanced Process Control (APC) and other key manufacturing applications
- SEMI Information and Control standards, especially GEM300 and EDA/Interface A
- Semiconductor manufacturing technology
Speaker Bio

Alan Weber is currently the Vice President, New Product Innovations for Cimetrix Incorporated. Previously he served on the Board of Directors for eight years before joining the company as a full-time employee in 2011.

Alan has been a part of the semiconductor and manufacturing automation industries for over 40 years. He holds bachelor’s and master’s degrees in Electrical Engineering from Rice University.
Abstract (1/2)

• Since the concept was first articulated in 2011 by a German government-supported program promoting deeper integration of manufacturing software and hardware across the production value chain, the term “Industry 4.0” (aka: “Smart Manufacturing”) has gained recognition and momentum as the rallying cry for the 4th industrial revolution.

• The foundation of a “Smart Factory” is the connectivity networks of the many devices in the tools that might need to communicate over the so-called “Internet of Things” by exchanging large volumes of manufacturing data. In the semiconductor industry, fabs have been collecting and using data from the equipment in their factories for many years following SEMI standards.
Abstract (2/2)

- As device sizes and process windows have shrunk continuously according to Moore’s Law, SEMI Standards have evolved by necessity to support increasing demand for data, exhibited by the process analysis and control applications that keep a modern fab running profitably.

- In this presentation, the author will introduce the newest set of SEMI standards, the Equipment Data Acquisition suite (EDA, also known as “Interface A”) which provides the power and flexibility to support a wide range of critical manufacturing applications and human users with ever-changing requirements; moreover, these standards can be deployed in a variety of system architectures without disturbing the “command and control” capabilities of existing factory systems.
Outline

• What is “Smart Manufacturing?”
• SEMI Standards evolution
• Equipment model examples
• Factory application use cases
• Conclusions
What is “Smart Manufacturing?”

*From Industry 4.0 Wikipedia…*

“… cyber-physical systems monitor physical processes, create a virtual copy of the physical world and make decentralized decisions.

Over the Internet of Things, cyber-physical systems communicate and cooperate with each other and with humans in real time…”
Components of a Smart Factory
Attributes of all these connected “things”

- Discoverable
- Autonomous
- Model-based
- Communicative
- Self-monitoring
- Secure
- Standards-based

Imagine the collaborative behavior that could emerge!
The insatiable demand for data and the evolution of SEMI Standards

<table>
<thead>
<tr>
<th>Node (nm)</th>
<th>800</th>
<th>600</th>
<th>350</th>
<th>250</th>
<th>180</th>
<th>130</th>
<th>90</th>
<th>45</th>
<th>32</th>
<th>22</th>
<th>14</th>
<th>10</th>
</tr>
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</table>

**Process window (Cpk)**

<table>
<thead>
<tr>
<th>Key applications</th>
<th>SPC</th>
<th>R2R</th>
<th>FDC</th>
<th>VM</th>
<th>PDM</th>
<th>Big Data</th>
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</thead>
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<tr>
<td>Data generated (MB/sec)</td>
<td>0.016</td>
<td>0.3</td>
<td>2.4</td>
<td>40</td>
<td>240</td>
<td>1500</td>
</tr>
</tbody>
</table>

**Supporting SEMI Standards**

SECS-II  GEM  GEM300  EDA I  EDA II  E164…
What’s different about EDA?
Key distinctions from other standards

• Ability to query equipment for its metadata model
• Multiple independent client applications
• Web-based communications technologies
• Powerful event/exception-based trace requests
• Support for “data on demand”
• Performance monitoring and notification features
• Secure access (local and remote)

Get the data you want...
when and where you need it
How the pieces work together
Operational sequence
Equipment metadata model

*Integrates all physical and logical components*
Standard metadata model benefits

Commonality across all equipment types

- Model structure exactly reflects tool hardware organization
- Complete description of all potentially useful information in the tool
- Always accurate, always available – no additional documentation required
- Common point of reference among tool, process, and factory stakeholders
- Source of unambiguous identifiers/tags for database [auto] configuration
- Enables “plug and play” applications
Equipment metadata model consumers

Something for everyone…

EDA Model

Pilot Factory Operations

Process Engineering

High-Volume Factory Ops

Equipment Development
Outline

- What is “Smart Manufacturing?”
- SEMI Standards evolution
- Equipment model examples
- Factory application use cases
- Conclusions
Example model-based applications

_In general order of increasing complexity…_

- Substrate tracking
- Process execution tracking
- Lot completion estimation
- Product time measurement
- External sensor integration
- Component fingerprinting
- Others…
Substrate tracking
E90 state machines and model content
Process execution tracking

**E157 state machine, model content, and results**
Lot completion estimation

Motivation and requirements

• Motivation
  – Inter-process wait times have direct negative impact on yield for critical process steps
  – Many advanced processes include a number of direct tool-to-tool material delivery steps
  – Productivity KPIs are also affected by inaccurate carrier completion estimates

• Requirements
  – Provide continuously updated estimates for current lot completion and equipment idle time for MCS/AMHS dispatching decision support
  – Provide notification events at configurable thresholds
  – Maintain substrate process times per recipe
Lot completion estimation

Algorithm summary

- **Sum # of wafers to be processed**
  - For each Carrier SEMI Object instance select ControlJobs with CarrierInputSpec that contains Carrier’s ObjID
  - For each ControlJob, count the # of substrates listed in each ProcessJob’s PRMtlNameList attribute

- **Calculate average time to return substrate to destination carrier**
  - Record time when first AtWork-AtDestination event is reached
  - When next AtWork-AtDestination event is reached, record difference as current average time to return substrate to carrier

- **Calculate initial carrier completion estimation**
  - = # remaining substrates * current average substrate return time

- **Update carrier completion estimation**
  - When each AtWork-AtDestination event is reached, subtract timestamp of first event from latest event, and divide by # of substrates
  - Use this value as new average substrate return time in calculating new carrier completion estimation
Equipment model content

*Used in lot completion estimation algorithm (1)*
Equipment model content

*Used in lot completion estimation algorithm (2)*

- **High-level Equipment structure**
- **JobManager Module**
- **ControlJob CarrierInputSpec attribute**
- **ProcessJob PRMtNameList attribute**
Product Time Measurement (PTM*)

How does it work?

EDA E164 Events → Material Movement Events (E90, E87) → Event Processor → $avings

*Now SEMI E168
How much data is required?

*The more data, the greater the benefit*

<table>
<thead>
<tr>
<th>Data Used</th>
<th>Analysis Enabled</th>
<th>Benefit / ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lot start/stop events (from MES)</td>
<td>Average throughput calculations by product and process</td>
<td>Establish performance baseline</td>
</tr>
<tr>
<td>Lot start/stop events (from equipment)</td>
<td>Actual throughput rates by product, recipe, and tool</td>
<td>Identify bottlenecks and laggards among toolset</td>
</tr>
<tr>
<td>Chamber-level wafer process start/stop events</td>
<td>Actual throughput rates by product, recipe, and chamber; tool-level wait time per wafer</td>
<td>Identify areas for improvement in equipment and process engineering</td>
</tr>
<tr>
<td>Wafer transport and location status events within equipment</td>
<td>Details of wait and active time per wafer</td>
<td>Identify recipe and equipment design issues</td>
</tr>
<tr>
<td>Other component-level signals related to wafer movement</td>
<td>Fine-grained analysis of wafer movement behavior</td>
<td>Identify even more recipe and equipment design/calibration issues</td>
</tr>
<tr>
<td>AMHS carrier movement and storage events</td>
<td>Wait and active (transport) time between tools; door-to-door value chain analysis</td>
<td>Identify areas for improvements needed in production scheduling, dispatching, and operations</td>
</tr>
</tbody>
</table>
Data Collection Level vs. Benefit

Revenue improvement potential

Data Collection Level

Delta Revenue %

Lot-level tool data

Wafer-level chamber data

Wafer-level component data

Carrier-level AMHS data

0 1 2 3 4 5

Data Collection Level
PTM Case Study

Throughput/Cycle Time Optimization

Previously invisible internal delay state

Source: NXP
Outline

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## SEMI Standards Coverage

### Smart Manufacturing Component Requirements

<table>
<thead>
<tr>
<th>Component Attribute</th>
<th>GEM</th>
<th>EDA / Interface A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discoverable</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Autonomous</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Model-based</td>
<td></td>
<td>✓✓</td>
</tr>
<tr>
<td>Communicative</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Self-monitoring</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Secure</td>
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<td>✓</td>
</tr>
<tr>
<td>Standards-based</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
A Vision for Smart Manufacturing

Evolutionary, demand-driven approach
唔該
Merci
감사합니다
Danke
多謝
ありがとうございます
Thank you