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Productivity Infrastructure for Semiconductor Smart Manufacturing

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Agenda

- Presentation objectives
- Smart Manufacturing Productivity
 - Principles
 - Concepts and Standards
- Infrastructure Implementation (digital twin)
 - Sensing and Connecting
- Now what...



Presentation objectives

Provide participants a basic understanding of

- Range of standardized productivity metrics already defined/available
- Data sources required to calculate them
- Manufacturing applications that can improve them
- Manufacturing stakeholders involved
- Role of equipment suppliers in providing required data
- Need for further collaboration to drive global industry benefit

... and provide context for the next speaker's case study





Smart Manufacturing Productivity

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Key Principles

- Productivity metrics must be considered as a set...
 - Quality
 - Capacity
 - Throughput
 - Cycle time
 - WIP levels
 - On-time delivery
 - Equipment utilization
- There are no participation trophies in manufacturing we keep score (KPIs) and reward winners!
- New process technologies (EUV, ALD, ...) pose continuous productivity challenges
- Lost time can never be recovered... especially on expensive, bottleneck tools
- Project ROI (projected, actual) should be based on improving KPIs





Important SEMI Standards for Productivity Improvement Provide evolutionary, complementary insights and capability

- Overall Equipment Effectiveness/Efficiency (OEE)
 - E10, E58 Equipment Reliability, Availability, Maintainability (RAM, ARAMS)
 - E79, E116 Measurement of Equipment Productivity, Equipment Performance Tracking (EPT)
- Product Time Measurement (PTM) (née Wait Time Waste, or WTW)
 - E168, .1, .2, .3 PTM for 300mm production equipment, Material Control System (MCS), transport equipment (AMHS)

GEM/GEM300

- E30, E40, E94 Machine States, Process Job Management, Control Job Management
- E87, E90 Carrier Management, Substrate Tracking
- E157 Module Process Tracking, Recipe Execution Tracking
- Equipment Data Acquisition (EDA / Interface A)
 - E120, E125, E164 Equipment Metadata Model
 - E132 Authentication and Authorization
 - E134 Data Collection Management

Metrics (definitions)

Mechanics (data collection)



Definition and Measurement of Equipment Reliability, Availability, and Maintainability (RAM) and Utilization (aka OEE)

- Key concepts
 - Six equipment states intended to cover the entire manufacturing calendar (i.e., no white space)
 - Equipment state hierarchy that provides more detail about distinctions between states
 - Basic formulas for equipment reliability, availability, and maintainability based on accumulated time in these states





Automated Reliability, Availability, and Maintainability Standard (ARAMS): Concepts, Behavior, and Services

- Key concepts
 - Conversion of E10 stack chart into state diagram
 - Definition of explicit equipment events that trigger transition between states
 - Definition of sub-states to provide more detail about equipment behavior
 - Standby for what?
 - Unscheduled downtime for what reason?
 - Scheduled downtime for what purpose?
 - Engineering time for what stakeholder group?
 - Object/attribute and table structure definitions to support services (messaging) interface to factory systems
 - Configuration options involving user-initiated transitions
 - Detailed compliance requirements (fundamental, additional)







Standard for Definition and Measurement of Equipment Productivity

Key concepts

- Conversion of everything to time basis, change "effectiveness" to "efficiency"
- Refined/juxtaposed equipment state hierarchy to provide context for new definitions
- Definition of "loss" categories to allocate and quantify sources of sub-optimal performance
- Detailed formulas for calculating all the above (including multi-chamber equipment)
- Description of methods for determining theoretical minimum for processing material <u>on a recipe basis</u> ("THT")
- Involves range of stakeholder groups to fully implement







Specification for Equipment Performance Tracking (EPT)

- Key concepts
 - Simple production state model to be applied at the "module" level (executes single task)
 - Fully automated (no human input required)
 - Task type definitions (process, material movement, measurement, etc.)
 - Reason code definitions for blocked states
 - Single "EPT state transition" event defined with available context parameters
 - Enables drill down into individual module behavior that may degrade equipment performance even when aggregate OEE remains high
 - Enables automatic calculation of E79 metrics





SEMI E157 Specification for Module Process Tracking

- Key concepts
 - Recipe execution tracking at step transition level
 - Definition of state transition events (7) and associated context information (process job, recipe, step #, substrate, etc.) to accumulate time accurately
 - Enables precise "framing" for application-specific data collection (e.g., FDC during critical steps)
 - Eliminates need to sample all variables at highest needed frequency during entire recipe execution
 - Enables tracking of actual process time <u>by recipe</u> required vs. THT_r to provide important component of rate loss calculation
 - Required by SEMI E164 (EDA Common Metadata)



GeneralExecution-StepActive ModuleID ProcessJobID ProcessJobIDList RCID RecID RecipeParameters StepCount StepID SubstrateID



Specification for Product Time Measurement (PTM)

Key concepts

- Definition of non-overlapping product material states ("time elements") intended to cover the entire manufacturing calendar
- Time elements fall into two categories ("wait" and "active") at multiple levels; most detailed level (4) can be subdivided on lot or substrate basis
- Definition of specific GEM300 events that bracket beginning and end of each time element (E30, E40, E87, E90, E94, and E157)
- Parent standard (E168) defines overall concept and methodology; subordinate standards define specific time elements for
 - 300mm process equipment (E168.1)
 - Material Control System (MCS) interaction with factory system (E168.2)
 - Automated Material Handling System (AGV, OHT, ...) hardware (E168.3)









Infrastructure Implementation Technologies

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SEMI GEM/GEM300 Equipment automation

- Key concepts
 - Definition of unambiguous state machines (states, transition events, associated parameters, naming conventions) for all equipment mechanisms
 - Definition of additional mechanisms to support full 300mm automation (Process/Control Job, Carrier Management, Substrate Tracking, Recipe Execution)
 - Definition of interlocking operations sequences ("scenarios") to indicate how these are standards are used together in automated 300mm manufacturing
 - Compliance requirements specified in a way that enables validation by automated test software







SEMI Equipment Data Acquisition (EDA) / Interface A *High-performance on-demand data collection*

- Key concepts
 - Equipment-resident hierarchical metadata model represents complete interface capability
 - Powerful data collection plan (DCP) structure used to express consumers' data collection requirements to equipment; DCPs are defined and activated by user but validated by and stored on equipment
 - Multi-client architecture supports independent consumers (applications) of equipment data
 - Internet-based networking technologies (SOAP/XML, gRPC and Protocol Buffers)
 - All communications occurs in context of secure session with authenticated client









Substrate tracking use case E90 state machines and model content





Recipe execution tracking and analysis use case DCP design (*primarily E157 event reports*)

DCP Definition







Machine Learning and AI support use cases Increasingly prevalent in production systems

- Problem statement
 - Machine Learning and AI applications depend on massive amounts of good data... exactly the problem SEMI EDA standards were designed to address
- Solution components
 - Handcrafted, open source, or commercial Machine Learning libraries
 - Feature extraction/transformation modules
 - Experimentation frameworks to support algorithm selection, model training/cross validation, hyper-parameter comparison, etc.
- SEMI Standards leverage
 - Multi-client capability for independent algorithm development
 - Powerful structures for targeted data collection
- Key ROI factors
 - Any and all...





Smart Factory Integration Platform Scalable, cloud-native future-proof system architecture







Now what...?

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Future work Across the value chain

- Raise awareness of the body of standard productivity metrics definition and implementation technologies
- Identify gaps and inconsistencies in implementation approaches at factories and equipment suppliers
- Establish collaborative forum (potentially SEMI Standards) to address problem areas
- Develop and distribute application prototypes (i.e., reference implementations) to bring these interpretations to life
- Include more rigorous definitions in purchase specifications



EDA Equipment metadata model definition process *... and the importance of good purchase specs*







Backup Material

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Wafer-level vs. Lot-level Wait Time analysis





Wait Time Elements for equipment (from SEMI E168 PTM)

Level 1	Level 2	Level 3	Level 4 Production Unit (Lot) Level	Level 4 Production Unit (Substrate) Level
Total Time	Wait Time	Wait for Factory System	Wait for Command to Production Equipment	Wait for Command to Production Equipment
			Wait for Job Definition on Production Equipment	Wait for Job Definition on Production Equipment
		Wait for Production Equipment	Wait for Prior Lot to Clear at Production Equipment	Wait for Prior Lot to Clear at Production Equipment
				Wait for Prior Substrates To Clear at Production Equipment
				Wait for Last Substrate to Complete at Production Equipment
			Wait for Lot-Based Setup at Production Equipment	Wait for Lot-Based Setup at Production Equipment
				Wait for Substrate-Based Setup at Production Equipment
				Wait for Substrate Transport within Production Equipment
			Wait for Lot-Based Post-Processing at Production Equipment	Wait for Lot-Based Post-Processing at Production Equipment
				Substrate Post-Process Waiting in Process Module
		Wait for AMHS	Wait for AMHS Preparation	Wait for AMHS Preparation



Source: SEMI

<u>Active</u> Time Elements for equipment (from SEMI E168 PTM)

Level 1	Level 2	Level 3	Level 4 Production Unit (Lot) Level	Level 4 Production Unit (Substrate) Level
Total Time	Active Time	Active Time for Production Equipment	Active Chemical or Physical Processing of Lot by Production Equipment	
				Active Chemical or Physical Processing of Substrate by Production Equipment
			Active Time for Carrier Transport within Production Equipment	Active Time for Carrier Transport within Production Equipment
				Active Time for Substrate Transport within Production Equipment
			Active Time for Lot Pre-Processing at Production Equipment	Active Time for Lot Pre-Processing at Production Equipment
				Active Time for Substrate Pre-Processing at Production Equipment
			Active Time for Lot Post-Processing at Production Equipment	Active Time for Lot Post-Processing at Production Equipment
		Active Time for Carrier Handoff	Active Time for Carrier Arrival	Active Time for Carrier Arrival
			Active Time for Carrier Departure	Active Time for Carrier Departure



Source: SEMI



Questions and Answers

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Thank You

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