Predictive Maintenance:
Lessons learned from Semiconductor Manufacturing

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Industry 4.0
History

First Industrial Revolution
through the introduction of mechanical production facilities with the help of water and steam power

Second Industrial Revolution
through the introduction of a division of labor and mass production with the help of electrical energy

Third Industrial Revolution
through the use of electronic and IT systems that further automate production

Fourth Industrial Revolution
through the use of cyber-physical systems

Source: DFKI (2011), siemens.com
Industry 4.0
Fraunhofer Layer Model of Industry 4.0 Value Creation

- Three Layers
  - Production
  - ICT
  - Enterprise Transformation
- More than 150 topics
- Driven by experts from 20 institutes
- Knowhow based on more than 300 projects

http://www.academy.fraunhofer.de/
Agenda

1. Industry 4.0 in Semiconductor Manufacturing
2. Dr. Production, Predictive Maintenance and Beyond
3. Outlook
Semiconductor Manufacturing

... what comes to mind
Semiconductor Manufacturing
A semiconductor view on “Industry 4.0”

The most complex production system is a semiconductor Frontend.

Dr. T. Kaufmann,
Infineon
11th Innovationsforum for automation, 2014, Dresden
Semiconductor Manufacturing
Some history on standards

Most famous standard: „SECS/GEM“

- 1978: Hewlett-Packard proposed that standards be established for communications among semiconductor manufacturing equipment.
- 1980/1982: SEMI published the SECS-1/SECS-II standards
- 1992: GEM standard published
- Continued: HSMS, GEM300, EDA/Interface A, ...

„Semiconductor Equipment and Materials International“
- Founded in 1970
- Tradeshows (SEMICON), conferences, networking
- Industry standards (> 800 standards and safety guidelines)
- USA - Japan - Europa - Taiwan - Korea - China
- www.semi.org

GEM • Defines equipment behavior
SECS II • Data items, messages
SECS 1 • Electrics/mechanics, transactions
Overview of 300 mm SEMI Standards

Carriers:
- E1.9 (Cassette)
- E23 (Cassette Transfer Parallel I/O)
- E47.1 (FOUP)
- E103 (SWIT) → withdrawn
- E119 (FOBIT)
- M31 (FOSB)

Frames (BEOL):
- G74 (Tape Frame)
- G87 (Plastic Tape Frame)
- G77 (Wafer Frame Cassette)
- G82 (Load Port for Frame Cassettes)

Wafers:
- M1, M37, M62

E144 (RF Air Interface)
E57 (Kinematic Coupling)
E62 (FIMS)
E15.1 (Load Port)
S28 (Safety of Robots & Load Ports)
E84 (Carrier Handoff Parallel I/O)
E101 (EFEM)
E64 (Card Docking Interface)
E83 (PGV Docking Flange)
E85 (Stocker Interface)

Interfaces:
- Equipment – Facilities:
  - E97 Facility Package Integration, Monitoring & Control
  - F107 Process Equipment Adapter Plates
- Human:
  - E95 Human Interface for Semiconductor Manufacturing Equipment

E110 (Operator Interface)
E22.1 (Cluster-Tool End Effector)
E21.1 (Cluster-Tool Module Interface)

E70 (Tool Accommodation Process)
E72 (Equipment Footprint, Height, Weight)
E76 (Process Equipment Points of Connection to Facility Services)

Equipment-/Process-specific standards:
- E117 (Reticle Load Port)
- E152 (EUV Pod)

Integrated Metrology (IM):
- E127 (integrated measurement module communication)
- E141 (Ellipsometer equipment)

Automated Material Handling System (AMHS):
- E82 (Interbay/Intrabay AMHS SEM (IBSEM))
- E88 (Stocker SEM)
- E153 AMHS SEM Specification

E8 (Stocker Interface)
E63 (BOLTS-M) and/or E92 (BOLTS-Light) or E131 (IMM)
E25 (Cluster-Tool Access) and/or E26.1 (Cluster-Tool Footprint)

Equipment Packages Integration, Monitoring & Control

Automation concept

Remote access
- Remote diagnostics
- Remote debugging/fix
- Remote sensing
- Spare parts management

EE Data Collection And Storage

EE Applications
- APC Application
- OEE Application
- Other Application

Global EE Data

MES
- Equipment Control
- WIP Tracking
- Factory Scheduling

Interface B
- Data sharing between software applications (e.g. APC applications) and MES

Interface A
- High-speed port for communication between in-factory data gathering software applications and the factory equipment for purposes of data acquisition

Interface C
- Programmatic/remote access to equipment data allowing secure data exchange between support companies and customers

Equipment Engineering Network

SECS/ GEM Interface
- Controlling/Monitoring of manufacturing equipment by factory software

Internet

Firewall

EE Access Control

Remote access
- Remote diagnostics
- Remote debugging/fix
- Remote sensing
- Spare parts management
Semiconductor Manufacturing
Bridge the “productivity gap” by Advanced Process Control (APC)

- Feature size: ~12%-14%
- Wafer size: ~12%
- Yield improvement: ~8%
- Other productivity: ~8%
- Equipment productivity: >9%-15%
- Historical curve (Moore’s law): <2%
- 25% - 30% / year improvement

Present

Historical curve (Moore’s law)

25% - 30% / year improvement
Semiconductor Manufacturing
“Big data” and Advanced Process Control

- Objective: Ensure high productivity and product quality
- Fundamental goals of APC (“Advanced Process Control”):
  - to apply measures for process control close to the process
  - to automate control actions
- Typical APC methods (SEMI E133):
  - SPC, FDC, FP, RtR, VM, PdM
- Basis for APC:
  - Metrology data
  - Data from equipment & processes
  - Logistics data

Statistical Process Control
Fault Detection and Classification
Fault Prediction
Run-to-Run Control
Virtual Metrology
Predictive Maintenance

Basis for APC:
- Metrology data
- Data from equipment & processes
- Logistics data

money

response time after fault detection

application of measuring and control methods

loss
hours
days
time
Semiconductor Manufacturing

Interaction of APC elements

- Process data
- Run-to-run control
- Feedback
- Feed forward
- Download of parameters
- Fault detection and classification (FDC)
- Go/no go
- Predictive Maintenance (PdM)

Process n-1 → (Virtual) Metrology → Sensors → (Virtual) Metrology → Process n → Process n+1
Agenda

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Dr. Production
Part of the Fraunhofer Layer Model of Industry 4.0 Value Creation

- Predictive Maintenance
- Virtual Equipment
- In-situ Metrology
- Sensorless Monitoring
- Condition Monitoring
- Smart Sensors
Dr. Production
The Building Blocks – Industry 4.0 Components in a Nutshell

Expected profit

Cum. costs and benefits

Time To Failure (TTF)

Individual Consulting and Conception

Analysis of Production Process and relevant Data

Development of intelligent Algorithms
Data-driven manufacturing optimization provides a variety of optimization methods – we will help to find the right one.

- **Fault detection and classification** uncovers anomalies of systems/processes
- **Run-to-run control** automatically modifies process parameters to improve process results
- **Predictive maintenance** predicts the need for service and maintenance measures
- **Virtual metrology** enables the data-driven prediction of quality parameters
We develop concepts for step-by-step implementation of data-driven production optimization and we clarify necessary conditions.

Example: The benefits of implementing predictive maintenance through introduction of data-driven production optimization is greatly depending on the target equipment (right: analysis in semiconductor manufacturing).
Example 1: Predictive maintenance in ion-implantation

Relevant data are continuously collected and analyzed using a Bayesian network. The network predicts the real time remaining until the break of the filament with an accuracy of 10-20 hours.

Based on these forecasts, the maintenance tasks can be scheduled exactly. Thus, no “mere” preventive maintenance after a predetermined operating time or number of processes needs to be carried out, and no system failures are risked by missed maintenance steps.
Example 2:
Virtual metrology for deep-trench etching

Relevant data are continuously collected and evaluated using a “gradient boosting tree” algorithm. The algorithm predicts the actual depth of the trench after the etching process with a deviation of less than 4 nm compared to values obtained from physical metrology.

The application of virtual metrology allows “virtual” control of every single wafer, while regular, costly and time-consuming physical measurements can be limited.
We develop intelligent algorithms that analyze production data in real time and suggest or take necessary measures.

Example 3: Predictive maintenance in wire-bonding

Relevant data are continuously collected and evaluated to correlate quality parameters and equipment parameters with the wear status of the wedge.

First results show potential for an optimized wedge tool usage.
We develop intelligent algorithms that analyze production data in real time and suggest or take necessary measures.

**Example 4:**

*Detection of critical equipment states related to manual interaction*

Relevant data are continuously collected and correlated to equipment states that cannot be measured directly (e.g. state of clamping, torque).

First results show that the algorithm is able to detect critical equipment states and to give measures for optimization.
Example 5: Predictive Probing to reduce time for device test

Relevant data from upstream processes are continuously collected and analyzed to predict device properties without actually measuring them.

Accurate interpolation of LED properties with < 5% measured chips achieved, with significant time and cost savings.

We develop intelligent algorithms that analyze production data in real time and suggest or take necessary measures.

Same result, but: partly measured, partly reconstructed
We have validated the monetary benefits through the use of data-driven production optimization in several reference projects.

**Example:** Amortization of the cost of predictive maintenance (hardware, software, implementation costs, ...) in various systems in semiconductor manufacturing in less than 24 months.
Dr. Production
The Benefits

- Flexible, Self-learning Solutions
- Reduced Downtime
- Increased Productivity
- Enhanced Product Quality
- Less Cost
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Electronic Systems
From Materials to Power Electronic Applications – Everything from One Source

Semiconductors • Power Electronics
Cognitive Power Electronics 4.0

Intelligence & Power Electronics

Semiconductors • Power Electronics
Outlook
Cognitive Power Electronics 4.0

Vacuum System
- Condition Monitoring
- Predictive Maintenance

Equipment
- Fault Detection and Prediction
- Process Optimization
- Predictive Maintenance

Intelligent Grid
- Control, Stability
- Optimization of Interaction: Source – Storage – Load
Outlook
The Chance of Working Together

Lessons learned from I4.0 in semiconductor manufacturing

1. Collaborate (competitors, universities, …)
2. Know your process
3. Make use of standards
4. Good to have data from >1 year of production
5. Take care of data quality
6. Combine knowledge of data experts and process experts
7. Go for low-hanging fruits …
8. … but avoid “island-solutions”
9. Collaborate (beyond industry segments)
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Thank you for your interest!

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