Towards the resilient factory

Insights from semiconductor production for "Industrie 4.0"

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Insights from semiconductor production for "Industrie 4.0"

Fraunhofer IISB
Industry 4.0 and Cyber Physical Systems (CPS)
Semiconductor Manufacturing
  Standards
  Advanced Process Control (APC)
  From APC-enabled equipment to CPS
Summary and Outlook
Electronic Systems
From Materials to Power Electronic Applications – Everything from One Source

Semiconductors • Power Electronics
Fraunhofer Institute for Integrated Systems and Device Technology (IISB) and Chair of Electron Devices (LEB)

LEB:
- 700 m² office and lab area
- 1000 m² cleanroom (ISO Cl 3/4)
- Staff: approx. 50

Fraunhofer IISB:
- 8390 m² office and lab area
- 525 m² cleanroom (ISO Cl 3)
- Staff: approx. 290
- Subsidiaries:

Center for Automotive Power Electronics and Mechatronics ZKLM, Nuremberg
Technology Center for Semiconductor Materials THM, Freiberg (Saxony)
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**Industry 4.0 and Cyber Physical Systems (CPS)**

Semiconductor Manufacturing
- Standards
- Advanced Process Control (APC)
- From APC-enabled equipment to CPS

Summary and Outlook
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
Application Scenarios

- Networked Production
- Customer Integrated Engineering
- Resilient Fab
- Smart Factory Architecture
- Self-organizing, adaptive Logistics
- Intelligent Maintenance
- Sustainability by Up-Cycling
- Technology data Marketplace

“robustness and adaptability”
Industry 4.0
Cyber Physical Systems

Apparently: CPS is a foundation of resilient manufacturing
... what is a CPS?

Wikipedia:
A cyber-physical system (CPS) is a system of collaborating computational elements controlling physical entities. Today, a precursor generation of cyber-physical systems can be found in areas as diverse as aerospace, automotive, chemical processes, civil infrastructure, energy, healthcare, manufacturing, transportation, entertainment, and consumer appliances. This generation is often referred to as embedded systems. In embedded systems the emphasis tends to be more on the computational elements, and less on an intense link between the computational and physical elements.
Industry 4.0
Many Open Questions

“... 85% of the experts are convinced that most German companies have no clear understanding of Industry 4.0”
Jedem dritten Produktionsbetrieb ist Industrie 4.0 kein Begriff

- Umfrage unter Führungskräften in den industriellen Kernbranchen
- Aussteller zeigen die vernetzte Produktion in der „Bitkom Innovation Area Industrie 4.0“ auf der Hannover Messe
- 45 Vorträge und 10 Podiumsdiskussionen beim „Forum Industrie 4.0“

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**Semiconductor Manufacturing**

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Summary and Outlook
Semiconductor Manufacturing

… what comes to mind

Sources: finfacts.ie, computer-oiger.de, xbitlabs.com, de.wikipedia.org, dailytech.com
Semiconductor Manufacturing

A semiconductor view on “Industry 4.0”

In Semiconductor FrontEnd factories elements of a „Smart Factory“ are already realized.

- Manufacturing information in real time
- Paperless manufacturing
- Products uniquely identified & located
- Collaborative human-machine interaction

Dr. T. Kaufmann, Infineon
11th Innovationsforum for automation, 2014, Dresden
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Semiconductor Manufacturing

Standards
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Summary and Outlook
Standards
Some history

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)

Wafers:
- M1, M57, M62

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

Equipment - Facilities:
- 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)

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

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

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

Interfaces:
- E117 (Facility Package Integration, Monitoring & Control)
- F107 Process Equipment Adapter Plates

Equipment - Process-specific standards:
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Integrated Metrology (IM):
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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

Equipment Engineering Network

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

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

MES
- Equipment Control
- WIP Tracking
- Factory Scheduling

EE Applications
- APC Application
- OEE Application
- Other Application

Equipment Engineering System (EES)

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

Control
- Data

Integrated Metrology

Firewall
- EE Access Control

Internet

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

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

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

Factory Network

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Industry 4.0 and Cyber Physical Systems (CPS)

Semiconductor Manufacturing

  Standards

  **Advanced Process Control (APC)**

  From APC-enabled equipment to CPS

Summary and Outlook
APC in semiconductor manufacturing
The productivity gap

Present

Feature size
~12%-14%

~8%

~5%

~3%

~4%

~2%

7%-10%

<2%

<1%

25% - 30% / year improvement

Equipment productivity

Equipment, etc.

Other productivity

Yield improvement

Wafer size

Ln $ / function

Historical curve
(Moore’s law)

Time
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

APC in semiconductor manufacturing

"Big data" and Advanced Process Control

Statistical Process Control
Fault Detection and Classification
Fault Prediction
Run-to-Run Control
Virtual Metrology
Predictive Maintenance
APC in semiconductor manufacturing

Interaction of APC elements

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

Feed forward

Process data

Run-to-run control

Download of parameters

Feedback

Process data

go / no go

Predictive Maintenance (PdM)

Fault detection and classification (FDC)
APC in semiconductor manufacturing
Examples for productivity enhancement by APC

Real-time control of plasma processes by integrated OES
Higher productivity at equipment level
APC in semiconductor manufacturing
Examples for productivity enhancement by APC

Prediction of maintenance events by PdM
Optimized tool operation and maintenance planning

![Graph showing time to breakdown](Image)
- Prognosis
- Real time to breakdown

Ion source
new
used
broken
APC in semiconductor manufacturing
Examples for productivity enhancement by APC

Prediction of quality parameters by virtual metrology

Tight process control by "measuring" every wafer

Prediction of etch depth by VM - predicted data vs. metrology results
APC in semiconductor manufacturing
Examples for productivity enhancement by APC

Flexible sampling and predictive scheduling with W@R* indicator
Best quality control with minimized number of measurements

* Wafers at risk = amount of uncontrolled wafers
APC in semiconductor manufacturing

Estimation of benefits – RoI

- Investment assessment for APC in semiconductor manufacturing
- Identification of economic effects from APC – possible savings and cost
- Development of models to calculate economical figures of merit, e.g., RoI, payback period
- FMEA to identify and quantify new risks from the introduction of APC

![Cumulated results graph](image)
APC in semiconductor manufacturing
Structured approach for development and deployment

Phases in VM/PdM development as adapted from the Cross-Industry Standard Process for Data-Mining (CRISP-DM)

Equipment/process understanding
- Objective and success criteria for VM
- Analysis of equipment parameters and process steps
- Work plan

Data understanding
- Initial data collection
- Data description and exploration
- Analysis of data quality

Data preparation
- Data selection
- Data formatting
- Construction of derived variables

Modeling
- Selection of modeling technique
- Test design generation
- Model building and assessment

Evaluation
- Process and model review
- Determination of next steps (model refinement vs. move to deployment)

Deployment
- Planning of deployment
- Monitoring and maintenance
- Project documentation and review
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Summary and Outlook
From APC-enabled equipment to CPS
Cyber Physical Systems – basis for the resilient fab

Properties of a Cyber Physical System

- CPS are based on connectivity (IoT)
- CPS run complex analytics
- CPS extract knowledge from raw data

A cyber-physical system is characterized by a physical asset, such as a machine, and its digital twin; basically a software model that mimics the behavior of the physical asset. In contrast, the IoT in common parlance is generally limited to the physical assets, not their digital models.

http://www.designworldonline.com/big-future-for-cyber-physical-manufacturing-systems/#_
From APC-enabled equipment to CPS
Cyber Physical Systems – basis for the resilient fab

Data collection from various sources
(internal, external)

"Self"-Perception

Control of physical assets

Perception of environment

According action/re-action

INTERNAL

Communication

EXTERNAL
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Summary and Outlook
Summary & Outlook
The chance of working together

"Industry 4.0"

- Mostly linear production processes
- Combine physical objects with "intelligence" → "cyber-physical systems"

Semiconductor Manufacturing
- Most complex manufacturing chain
- Evolving to "augmenting reactive with predictive"

Custom Tailored Production
Resilient Fab
Self-organizing, adaptive Logistics

High mix – low volume
Process Control Systems
Predictive Scheduling

Smart Fab
Predictive Maintenance
Summary & Outlook
The chance of working together

Mission of Fraunhofer IISB

- Merge “Industry 4.0” trend with “augmenting reactive with predictive” trend
- From “APC-enhanced equipment” to “cyber-physical systems”
Summary & Outlook
The chance of working together

**ALLEINGÄNGE**
Die Unternehmen packen die Digitalisierung meist auf eigene Faust an, anstatt zu kooperieren.

**Kooperieren Sie mit Forschungseinrichtungen oder Thinktanks?**

- Nein und nicht geplant: 66%
- Nein, aber geplant: 6%
- Ja: 28%

N=94

**Kooperieren Sie mit Start-ups?**

- Nein und nicht geplant: 78%
- Nein, aber geplant: 6%
- Ja: 15%

N=93

**QUELLE: ACCENTURE**
Summary & Outlook
The chance of working together

Lessons learned from APC 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
Summary & Outlook
The chance of working together

Achievements in semiconductor manufacturing
- Standards and automation concepts evolved over more than 35 years
- Proven as basis for improving productivity

Potential for other industries
- "Hold on to what is good" – knowledge and definitions
- Well experienced R&D and suppliers available

The chance of working together
- From APC-enhanced equipment to cyber-physical systems
- Semiconductor manufacturing: strategic partnerships with other industries, spearheading with products and "manufacturing science"
Acknowledgment

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Thanks
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