Framework for Integration of Virtual Metrology and Predictive Maintenance

15. Workshop der GMM – Fachgruppe 1.2.3 Abscheide- und Ätzverfahren

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Outline

- The IMPROVE Project at a Glance
- Motivation
- Virtual metrology (VM) and predictive maintenance (PdM)
- Approach for a generic and reusable framework architecture
- Modeling and implementation of the framework
- Implementation and test of the framework in fab environments
- Conclusion
Implementing Manufacturing science solutions to increase equipment productivity and fab performance

Main objective: IMPROVE European Fab's Competitiveness, by
- improving processes reproducibility and quality
- improving the effectiveness of production equipment
- shortening cycles time and improve learning curve

Three Manufacturing Science R&D Topics
- Virtual Metrology
- Predictive Maintenance
- Dynamic Control Plan

Two Support Activities
- Survey, Specifications and Architectures
- Equipment Forum
Framework for Integration of Virtual Metrology and Predictive Maintenance - The IMPROVE Project at a Glance (2/3)

Key figures
- 3600 men-months over 3 years
- 100 full-time researchers
- January 2009 to July 2012
- 35 partners over 6 countries

Map showing distribution of partners across different regions in Europe.

- Academia/Institutes: 53%
- Solution Providers: 26%
- IC Manufacturers: 21%
Framework for Integration of Virtual Metrology and Predictive Maintenance - The IMPROVE Project at a Glance (3/3)

The IMPROVE Partners

- 6 major European IC manufacturers
- 2 Institutes
- 12 Academic labs
- 10 Solution providers
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Framework for Integration of Virtual Metrology and Predictive Maintenance - Motivation

- Complex systems for process control in semiconductor manufacturing
  - SPC, fault detection and classification, run-to-run control, and others
- Various approaches for the actual implementation possible
  - Some fabs implement new control entities equipment by equipment
  - Others follow dedicated bottom-up or top-down approaches
- Challenge: Implementation of new control paradigms in existing fab systems with different IT infrastructure?
- European project “IMPROVE”
  - Development of novel methods and algorithms for virtual metrology (VM) and predictive maintenance (PdM)
  - Challenge: How to ensure the reusability of developed solutions amongst the nine IC manufacturers’ fabs gathered in IMPROVE?

→ Need for a common architecture and optimized algorithms to integrate VM and PdM into the different existing fab systems
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Virtual metrology (VM) and predictive maintenance (PdM)  
Concept of VM for IC-manufacturing

- **State-of-the-art**
  - In current IC manufacturing, achievement of process stability and high production yield relies on reliable wafer monitoring by physical metrology
  - Critical parameters are assessed using monitor or product wafers
  - No broad implementation of concepts like virtual metrology

- **Deficiencies for monitoring and process control**
  - Limited possibility for process monitoring and control on wafer-to-wafer or on real-time basis
  - Critical parameters may not be measurable with in-line measurements
Virtual metrology (VM) and predictive maintenance (PdM)

VM objectives and benefits

- **VM definition**
  - Technology of prediction of post process metrology variables (either measurable or non-measurable) using process and wafer state information that could include upstream metrology and/or sensor data.

- **VM benefits**
  - Improved understanding of unit processes
  - Support or replacement of stand-alone and in-line metrology operations
  - Support of FDC, run-to-run control, and PdM
  - Improved equipment control for VM running on equipment level
Virtual metrology (VM) and predictive maintenance (PdM)
Concept of PdM for IC-manufacturing

- Current situation of scheduled maintenance in semiconductor manufacturing
  - Maintenance schedule based on elapsed time or fixed unit count usage
  - Maintenance frequency mainly depends on the process engineer’s experience and on known wear out cycles of certain parts of the tool
  - The considerations for preventive maintenance are generally based on worst case scenarios to avoid unscheduled maintenance due to unforeseen failures

- Ideal maintenance strategy - “Run to almost fail”
  - Predictive maintenance aims at replacing/repairing an equipment part when it has nearly reached its end of life
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Approach for a generic and reusable framework architecture

Initial situation

Typical available databases and fab applications

- SPC system and DB
- FDC system and DB
- RtR system and DB
- Equipment integration
- Product DB
- Dispatching system
- Maintenance system
- Context data
- other

How to implement VM/PdM?
Approach for a generic and reusable framework architecture

Architecture expectations and prerequisites

- Development of a VM/PdM architecture
  - Abstract from IT infrastructure of IC-manufacturers using an ideal architecture
  - Integration of VM and PdM modules into a common model
  - Mapping the ideal architecture to the existing infrastructures applying UML and developed software solutions

- Avoidance of island solutions by
  - Generic specifications and high reusability
  - Improved efficiency of design and implementation phases
  - Thorough analysis instead of ad hoc solutions and workarounds
Approach for a generic and reusable framework architecture
Concept for generic VM/PdM implementation

Definition of VM and PdM as EE applications on a conceptual level

- Abstraction from existing fab infrastructures
- Application of existing SEMI standards possible, including especially interface A and interface B standards
- Extension of the existing SEMI standard E133 to include VM
Approach for a generic and reusable framework architecture
Concept for generic VM/PdM implementation

UML description of the EE system and of a generic VM/PdM module

- Mapping to existing infrastructures
- Consideration of specific user requirements
- VM/PdM module: Inclusion of configuration, data analysis, and filter modules as plug-ins
Approach for a generic and reusable framework architecture
Consolidation of user requirements

Approach

- Catalogue with quantifiable criteria and well defined classification of user requirements for VM, PdM, and the framework architecture
- Collection of feedback from all users involved in IMPROVE
- Consolidation of user requirements
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### Modeling and implementation of the framework

**User requirements - examples**

<table>
<thead>
<tr>
<th>Type</th>
<th>Requirement</th>
</tr>
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</table>
| **Functional**     | **URF001: VM prediction result**  
  ● The SW shall predict the result of a metrology measurement.  
  ● The SW shall predict measurements based on algorithms (site, wafer or lot fine). | |
| **Interface**      | **URI001: VM data sources**  
  ● The predicted result is calculated by algorithms, e.g. by multivariate analysis from input data from the following possible data sources: SPC-Data, FDC-Data, RtR-Data, Sensor-Data others |
| **Maintainability**| **URM001: VM tool plug-ins and libraries**  
  ● The multivariate analysis algorithms are not hardcoded, but parameterized plug-ins with defined interfaces. The algorithms are in form of a library easily changeable.  
  ● If there is a new algorithm plug and play and in form of library MATLAB, R, C++,... is required. |
Modeling and implementation of the framework

Modeling of the IMPROVE framework

Main components and connections of the IMPROVE framework

IMPROVE framework: Transparency layer between the different fab architectures and the EE application modules
Modeling and implementation of the framework
Modeling of the IMPROVE framework

Main components and connections of the IMPROVE framework

**Fab-specific components**
- Data Access and Manipulation Adapter (fab specific)
- Data Gathering Adapter (fab specific)

**Connections**
- Pull fab data to the framework
- Push fab data to the framework
- Triggering of workflows

**IMPROVE framework**
Transparency layer between the different fab architectures and the EE application modules
Modeling and implementation of the framework
Modeling of the IMPROVE framework

Main components and connections of the IMPROVE framework

IMPROVE framework: Transparency layer between the different fab architectures and the EE application modules
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Main components and connections of the IMPROVE framework

IMPROVE framework: Transparency layer between the different fab architectures and the EE application modules
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Main components and connections of the IMPROVE framework

Detection of changes to data in the IMPROVE database (trigger)

Trigger of external fab applications, specific data output

IMPROVE framework: Transparency layer between the different fab architectures and the EE application modules
Approach for a generic and reusable framework architecture
Software implementation of the framework (1)

- Main features
  - Compliance with state-of-the-art technologies (Java Enterprise Edition platform, Enterprise Java Beans -EJB)
  - Use of WEB-services (SOAP, WSDL) at the communication layer
    - integration of modules from different platforms and operating systems and
    - simple integration of equipment connectors (station controllers) and legacy applications
  - Workflow tool
    - visual creation and change of process flows
    - changes of workflows possible at runtime and parallel execution for new-version testing
    - any module inside the IMPROVE framework can be used inside a workflow

- Main components of the framework
  - JBOSS 7 Application Server, JBPM 5 Workflow Engine,
    Oracle Database 11, Listeners, Clients, Software modules realized as EJBs
Approach for a generic and reusable framework architecture
Software implementation of the framework (2)

Software implementation of the framework and available services
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Implementation and test of the framework in fab environments
Implementation and test at Infineon Technologies

- Registration of a PdM algorithm at DAWN and database (data operation port, CQN registration port)
- Push of new data from the internal FDC database into the DAWN component and IMPROVE database (fab specific data gathering adapter, data push port, SQL query and data manipulation port)
- Trigger of PdM algorithm (continuous query notification port, data operation port)
- Conversion of value table into a MATLAB matrix and execution of MATLAB-based PdM algorithm
- Conversion of result from a MATLAB matrix into a value table; return and storage of result in IMPROVE database (data operation port, SQL query and data manipulation port)
- Result is available to trigger further actions (e-mail notifications, SAP maintenance requests, production equipment stops)
Implementation and test of the framework in fab environments
Implementation and test at Micron (Agrate)

- Test on PdM (required electrostatic chuck change) and VM (prediction of CD in a dry etch process)
- Selection of a Microsoft (MS) SQL Server as database platform
- Development of a specific data loader to merge data from two different FDC systems and two metrology measurements
- Extension to have a separate “development platform” for coding, maintenance, algorithm update and test, validation of code, and deployment
  - Compilation of the VM/PdM modules to Java
  - Testing of the Java package
  - Integration of the tested VM/PdM modules into the framework

<table>
<thead>
<tr>
<th>Application</th>
<th>Algorithm</th>
<th>Response time</th>
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<tbody>
<tr>
<td>PdM</td>
<td>Gamma Filter</td>
<td>minutes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 7 sec</td>
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<tr>
<td></td>
<td></td>
<td>&lt; 10 sec</td>
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<tr>
<td></td>
<td></td>
<td>&lt; 39 sec</td>
</tr>
<tr>
<td>VM</td>
<td>Lasso (periodically)</td>
<td>&lt; 1 sec</td>
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<tr>
<td></td>
<td></td>
<td>&lt; 2 sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 1 sec</td>
</tr>
<tr>
<td>VM</td>
<td>Prediction</td>
<td>minutes</td>
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Implementation and test of the framework in fab environments

Implementation and test at ams AG

- Test on a PdM use case to trigger a maintenance action and replace the source of a medium current implanter
- PdM algorithm for calculation of the projected remaining lifetime available as a plug-in programmed within the open source statistics package R
- Applying the specific data adapters, real time FDC data from the implanter is pushed into the framework and to the PdM module
- Passing of result to the framework and SPC system for visualization and to trigger an e-mail alarm 48 hours ahead of the projected breakdown
- Successful test of configuration in 24/7 production environment over two months
- Overall response time of 25 s satisfactory for PdM applications (delay time mainly by the provisional fab adaptors used, 3 s caused by framework)
Summary of scientific and technical experiences - Guidelines for implementation of VM, PdM, and fab-wide frameworks

- Experiences and results from framework development and VM/PdM module integration and performance
- Generic approaches, individual methods, new solutions and best practices for VM/PdM algorithm development
- Requirements and overall principles
- Implementation steps

Guidelines Outline

1. Definition of [...]  
2. State-of-the-art  
3. Status at IMPROVE fabs  
4. Architecture and interfaces for [...]  
5. Functional requirements  
6. Data requirements  
   6.1 Data quality  
   6.2 Data/information for investment assessment  
7. How-to: Steps to implement [...]  
   7.1 Pre-requisites  
   7.2 Three Phase Process: Data collection - Model development - Model validation  
   7.3 Overall principles  
   7.4 Risk assessment  
8. Examples and lessons learnt: IMPROVE solutions for [...]  
9. Literature
Conclusion

- Realization of a generic and reusable framework solution for implementation of VM and PdM into existing fab-environments
  - Compliance to a wide range of standards
  - Compatibility with different programming languages for VM/PdM algorithm realization

- Approach
  - Definition of VM/PdM as EE applications on a conceptual level and modeling of the EES as component system in UML
  - Framework acts as transparency layer between the fab architectures and the VM/PdM modules

- Realization, implementation, and test
  - Software realization by a service-oriented Java infrastructure
  - Framework implementation and test on VM and PdM applications at three IC manufacturers’ sites; proof of good performance and adaptability
Acknowledgment

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More information:
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