IMPROVE – A joint European effort to boost efficiency in semiconductor manufacturing

APC Conference XXIV 2012

University of Michigan, Ann Arbor, Michigan, September 10-12, 2012

*M. Schellenberger, **M. Koitzsch**, G. Roeder, M. Pfeffer, U. Schöpka, A. Mattes, L. Pfitzner*
matthias.koitzsch@iisb.fraunhofer.de

Fraunhofer Institute for Integrated Systems and Device Technology (IISB), Erlangen, Germany
www.iisb.fraunhofer.de

improve

Fraunhofer IISB

Agenda

- *Manufacturing Science as "Competitiveness Enabler"*
- The IMPROVE Project at a Glance
- The R&D Topics and Support Activities of IMPROVE
- Summary & Outlook

Manufacturing Science as “Competitiveness Enabler“

The „European“ Context

“**Semiconductors are critical to European industry** and welfare and must be prioritized to keep the European industry competitive.”

Yet…

“In spite of enormous efforts, the European **semiconductor base is shrinking** and more and more companies are choosing to outsource device manufacturing to other regions, mainly to Asia.”

SEMI white paper, 2008

Manufacturing Science as “Competitiveness Enabler“

The „European“ Context

- To maintain and improve its competitiveness the European SC manufacturing must rely on advanced solutions in **Manufacturing Science**
- The development of these solutions
  - can only be done through **cooperation** between industrialists, SMEs, academia and institutes
  - must take advantage of the existing **technology clusters** around the SC manufacturers
  - requires the **support** of Europe and National PA's

ENIAC first project call, Sub Programme 8
Target Activity 1: Advanced Line Operation (Manufacturing Science)

Objective: To allow European device makers to increase the productivity and sustainability of the most advanced CMOS and derivative technologies semiconductor fabs

Manufacturing Science as “Competitiveness Enabler“

… for “More Moore“ or “More than Moore”?

Two Technical Challenges for the Future…

Scaling down CMOS (More Moore)

- Down to the 22 nm node and below
- Manufacture devices in high volumes at reduced cost per die

Managing high-mix and heterogeneity (More than Moore)

- Increase of non productive time (gating metrology, recipe qualifications, wait and down time)
- Stagnating equipment reliability, availability and utilization
- Increasing variations by increased number of equipment per process step (and vice-versa)

… one Objective

To enable the production of high-quality nanoscale devices at reasonable cost

improve

Fraunhofer IISB

Manufacturing Science as “Competitiveness Enabler“

Pave the way from “reactive” to “predictive” manufacturing

- Solutions to **Process Control** issues, e.g.
  - Virtual metrology
  - Dynamic control plan
  - Data mining and data reduction
  - Data / time synchronization
- Improving **Equipment Efficiency**, e.g.
  - Predictive Maintenance
  - Remote diagnostics
  - Lots scheduling
  - Resources planning

Agenda

- Manufacturing Science as “Competitiveness Enabler“
- *The IMPROVE Project at a Glance*
- The R&D Topics and Support Activities of IMPROVE
- Summary & Outlook

The IMPROVE Project at a Glance (1/3)

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

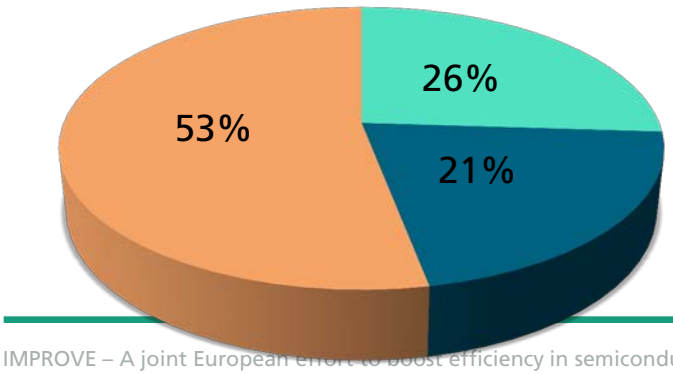
Two Support Activities

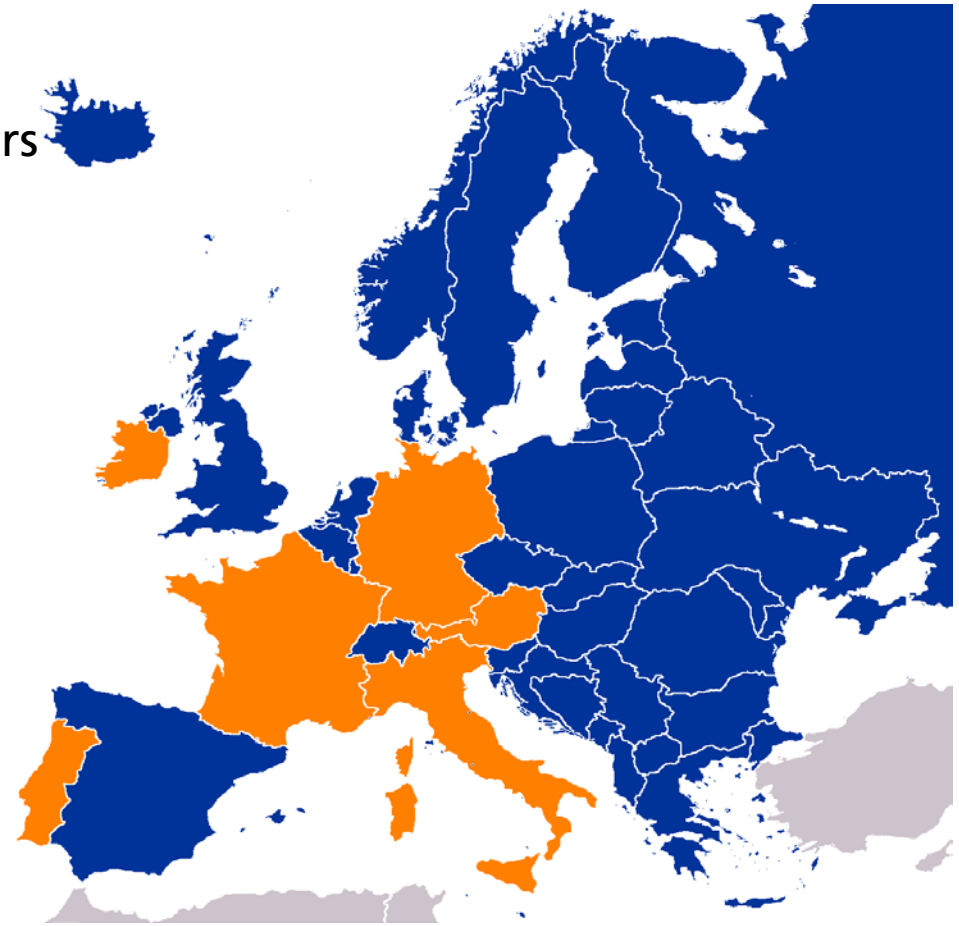
- Survey, Specifications and Architectures
- Equipment Forum

The IMPROVE Project at a Glance (2/3)

Key figures

- 3600 men-months over 3.5 years
- 100 full-time researchers
- January 2009 to June 2012
- 35 partners over 6 countries





The IMPROVE Project at a Glance (3/3)

The IMPROVE Partners

- 6 major European IC manufacturers
- 2 Institutes
- 12 Academic labs
- 10 Solution providers

Agenda

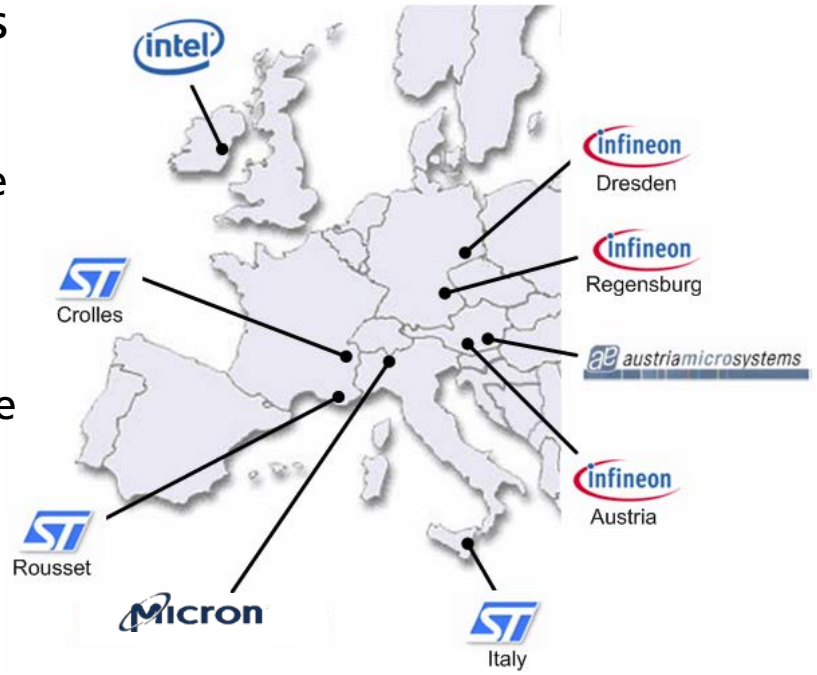
- Manufacturing Science as “Competitiveness Enabler“
- The IMPROVE Project at a Glance
- *The R&D Topics and Support Activities of IMPROVE*
  - Fabs’ status & requirements – What are the needs?
  - Architecture & specifications to keep solutions re-usable
  - Virtual Metrology
  - Predictive Maintenance
  - Virtual Equipment
  - RoI Calculator
  - Adaptive Control Plan
  - Guidelines for long-term applicability
  - The Equipment Forum
- Summary & Outlook

R&D Topics and Support Activities of IMPROVE

Fabs' status & requirements – What are the needs?

Technical 1-2 day **workshops at each manufacturing site**

- Discussion about more than 60 questions
- Status of…
  - Data Infrastructure, Control Infrastructure
  - Manufacturing and Logistics
- Requirements for…
  - Virtual Metrology, Predictive Maintenance
  - Adaptive Control Planning
  - Sensor Networks
  - Master Framework
  - Return on Investment



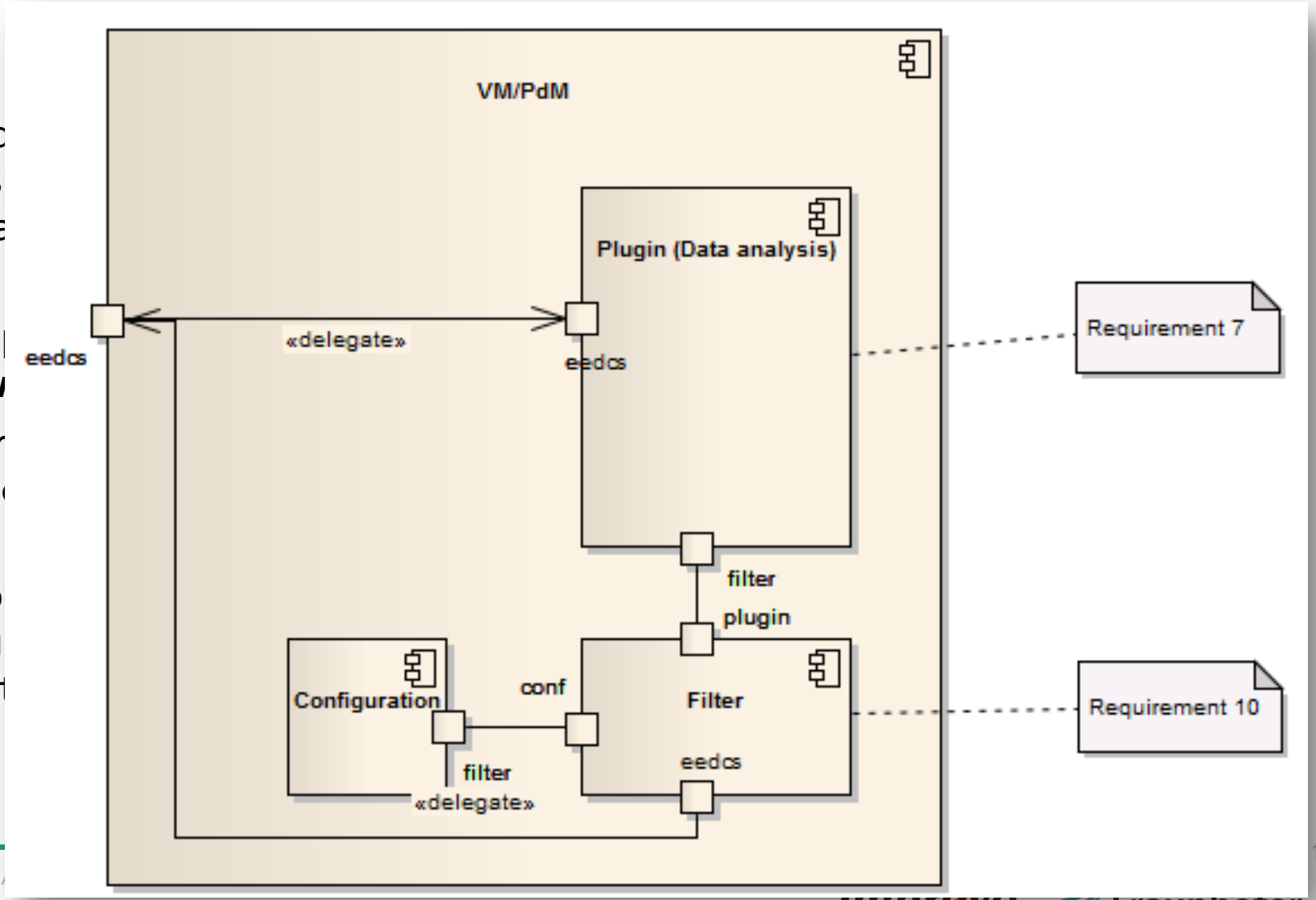
R&D Topics and Support Activities of IMPROVE

Architecture & specifications to keep solutions re-usable

Basec
and s
packa

Exam
Fab-v

- Ar
  "t
- …
  sp
  fu
  int



R&D Topics and Support Activities of IMPROVE

Virtual Metrology

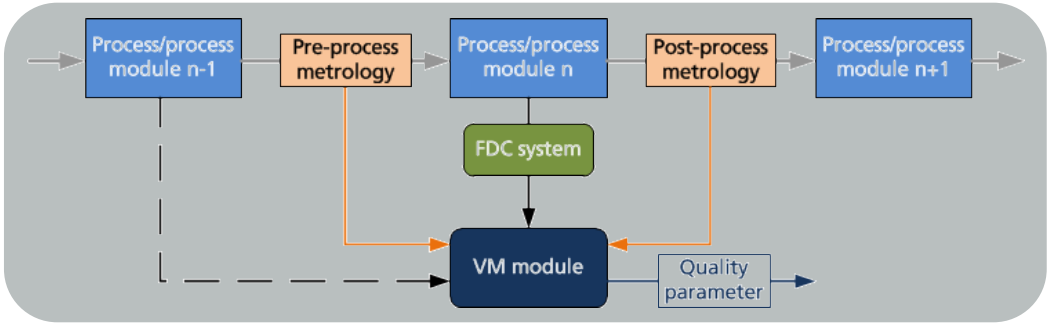
Objective

- Development of virtual metrology algorithms to **predict physical and electrical characteristics** of the wafers from the process tools parameters and advanced sensor data

Expected benefits

- Improved process understanding and process control
- Reduction of cycle time by avoidance of measurement steps
- Increased productivity of equipment and people

Place of execution of VM in a process flow

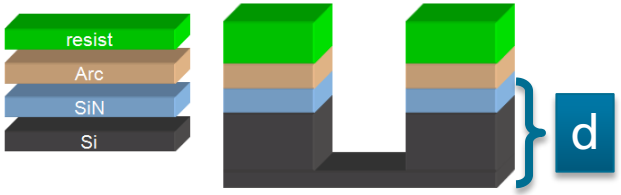


R&D Topics and Support Activities of IMPROVE

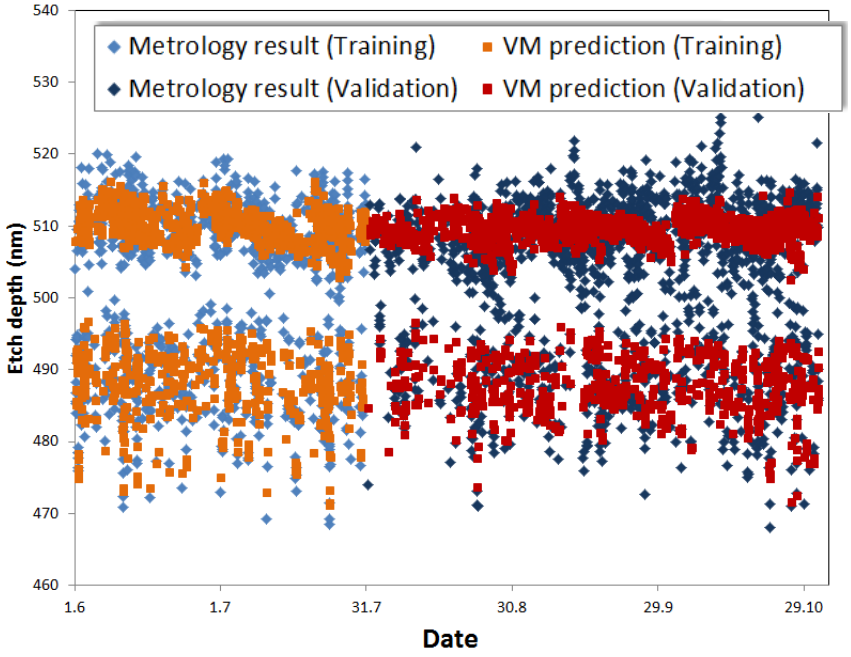
Virtual Metrology

Example: Trench-etch process

- Predict etched-depth in a trench-etch process, two depths
- Variety of statistical modeling techniques assessed
- Data quality monitoring for tracking of process and potential VM adjustments
- Consideration of critical integration aspects (automation, interpretation, speed)



Trench-etch process



Prediction of etch depth by stepwise linear regression

R&D Topics and Support Activities of IMPROVE

Predictive Maintenance

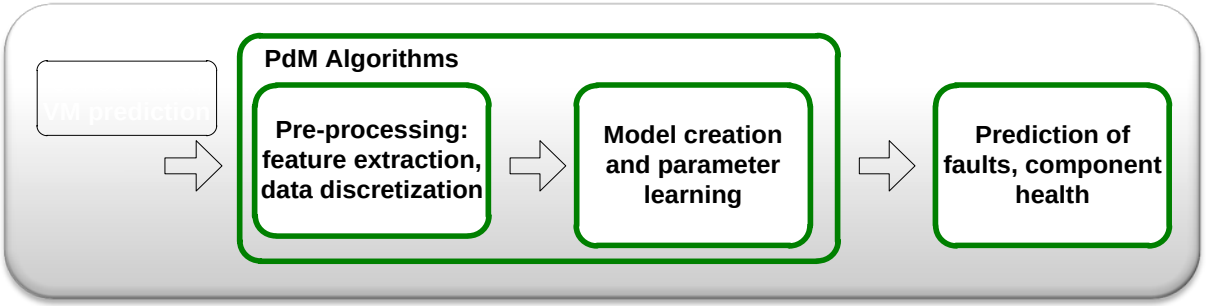
Objectives

- Development of predictive maintenance techniques to **improve equipment reliability** whilst optimizing the maintenance frequency and increasing uptime.

Expected benefits

- Improved equipment control
- Reduction of down time by reduction of unscheduled tool failures
- "Equipment Health Factor" for improved control planning (WP4)

PdM workflow utilizing Bayesian Networks

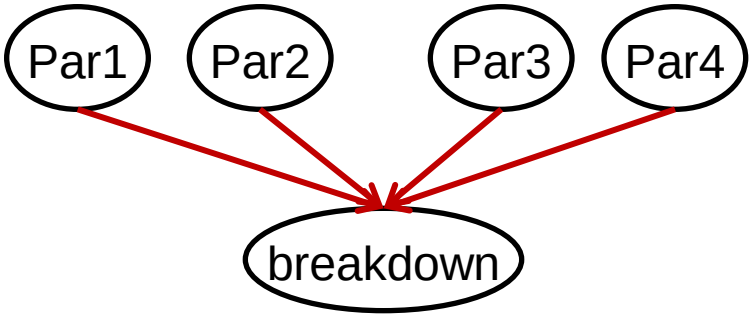


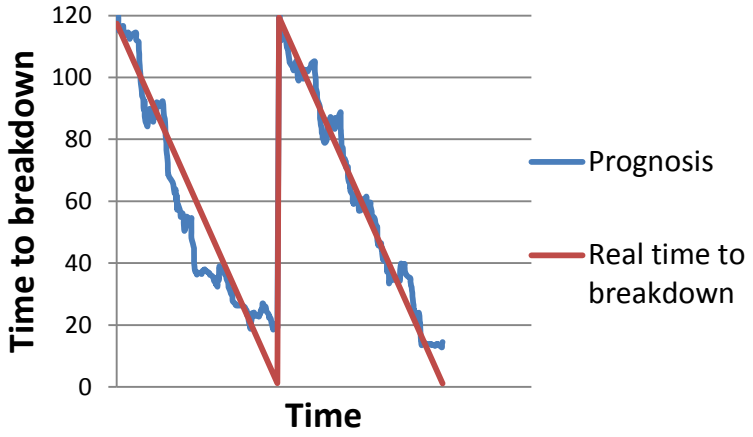
R&D Topics and Support Activities of IMPROVE

Predictive Maintenance

Example: Filament breakdown

- Modeling of filament breakdown in an ion implanter source
- Investigation of predicting parameters
- Creation of Bayesian Networks model
- Investigation of soft discretization method for improved model performance
- Comparison of modeling methods in collaboration with partners
- Model still works with noisy data from high mix production environment





R&D Topics and Support Activities of IMPROVE

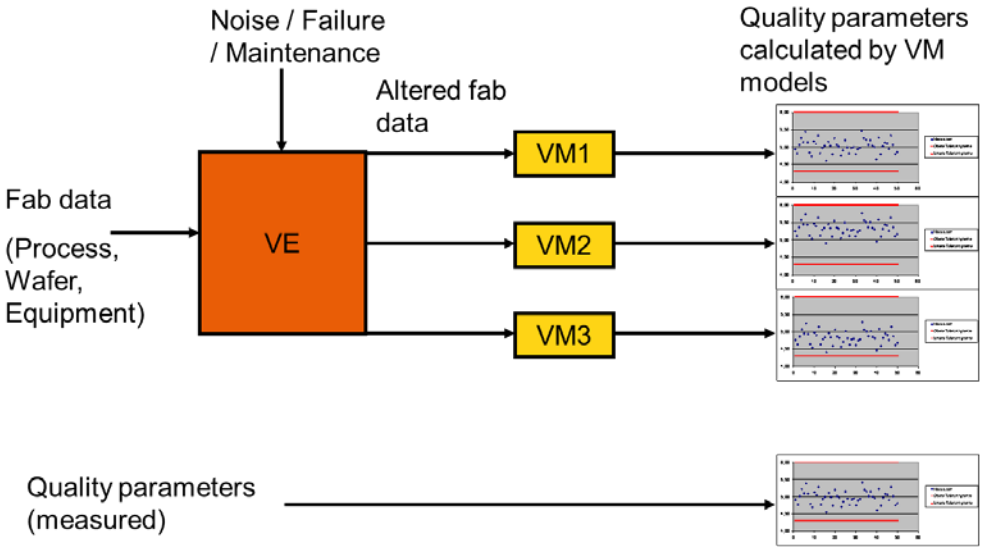
Virtual Equipment

Objectives

- Setup of a “virtual equipment” as benchmark tool for virtual metrology and predictive maintenance algorithms
- Utilization of history fab data and simulation of relevant equipment and process behaviour

Expected benefits

- Evaluate selected algorithms using production data sets including the application of typical faults, process drifts, mix and match scenarios, noise effects, etc.

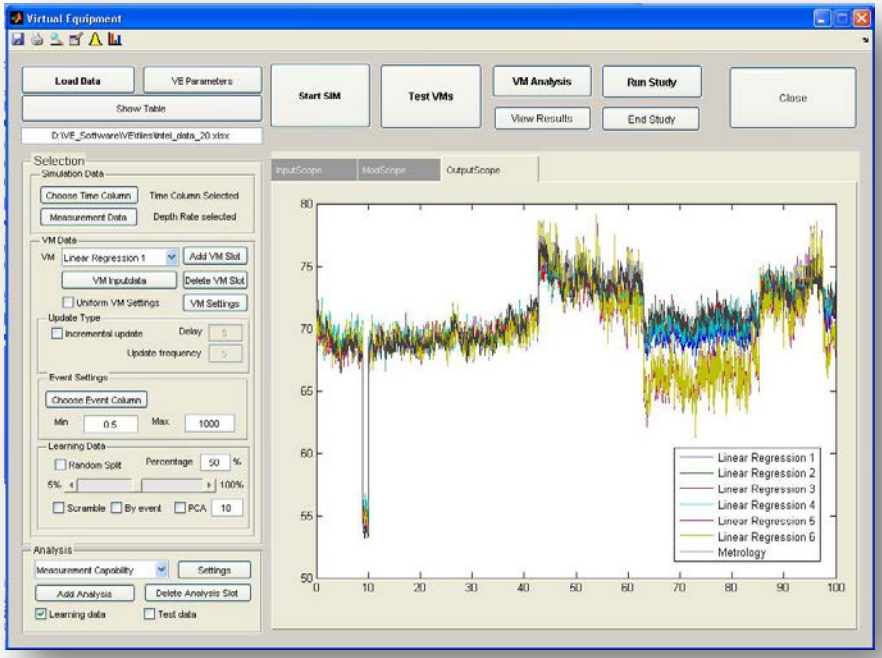


R&D Topics and Support Activities of IMPROVE

Virtual Equipment

Achievements

- Capability to compare multiple VM / PdM models
- Generation of test data sets for common and uncommon situations
- Integration of statistical and physical simulation
- Utilization of “real” fab data sets
- Evaluation of performance and sensitivity of VM / PdM algorithms
- Input data preparation for the VM / PdM algorithms



User interface of the virtual equipment

R&D Topics and Support Activities of IMPROVE

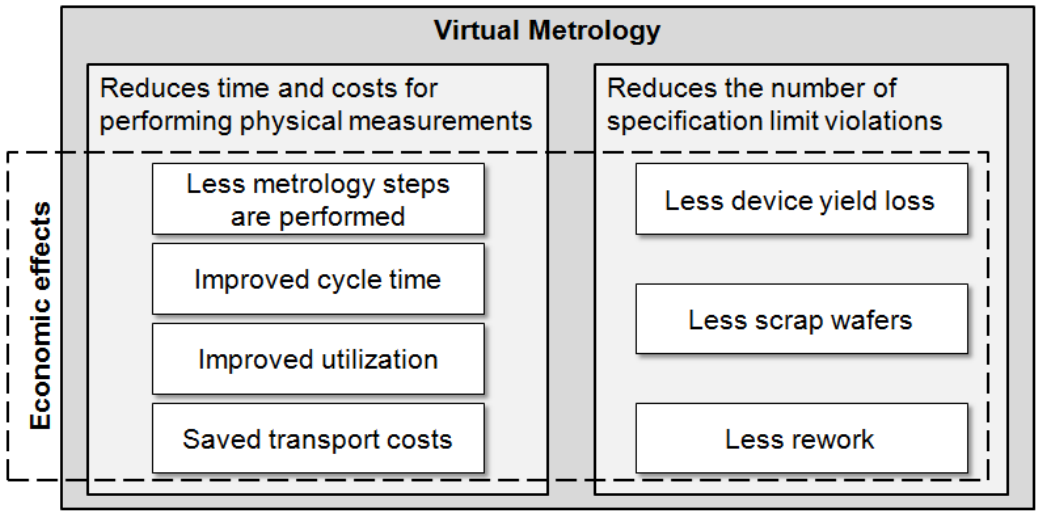
RoI Calculator

Objectives

- Modeling of benefits, costs and damages for calculating investment assessment figures (payback period, RoI, NPV)

Expected benefits

- Economic effects of VM/PdM identified
- Discussion with IMPROVE partners: FMEA and RoI workshops



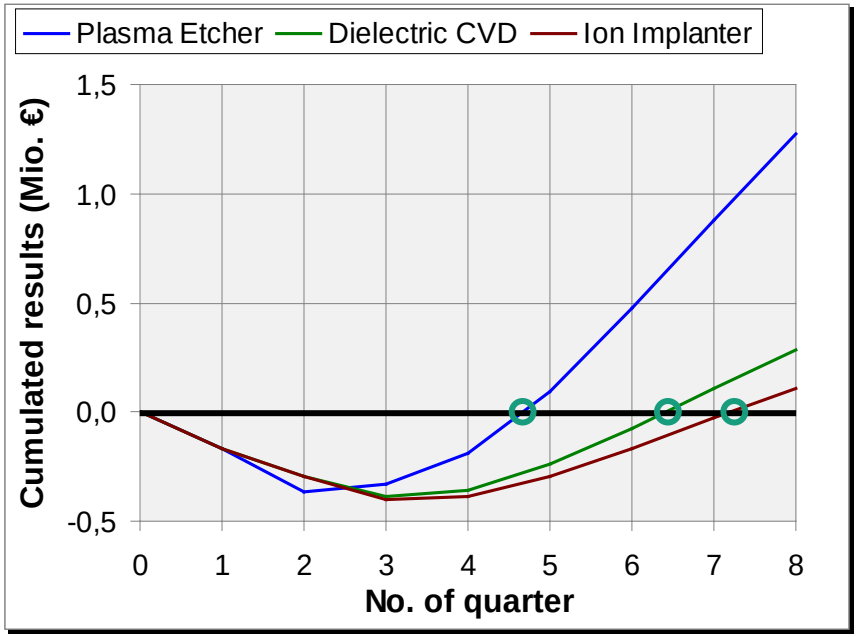
Economic effects of Virtual Metrology (VM)

R&D Topics and Support Activities of IMPROVE

RoI Calculator

Achievements

- RoI Calculator developed, based on:
  - Potential benefits from identified economic effects
  - Potential financial damages from FMEA results
  - Publicly available data from SEMATECH (default values)
  - Identification and estimation of costs with IDM
  - Discussion with IDMs



Economic figures: Payback Period PdM

R&D Topics and Support Activities of IMPROVE

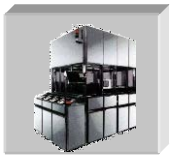
Adaptive Control Plan

Objectives

- Development of a comprehensive approach that reduces process excursions and guarantees an optimal use of various control techniques (metrology, sensors, etc).

Expected benefits

- Yield improvement through incremental set-up of a fab wide comprehensive control plan
- Cycle time and learning cycle improvement through optimal use of various "measurement" resources.

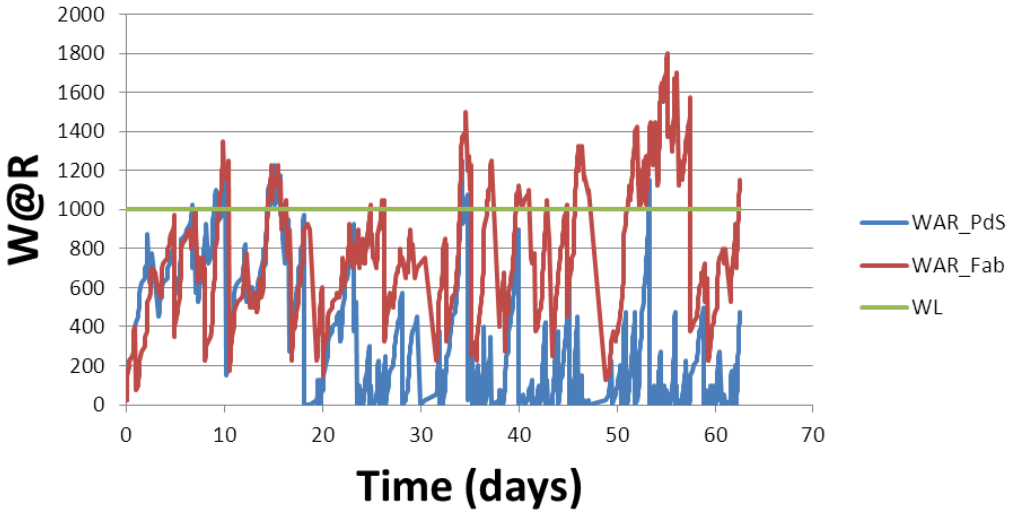


R&D Topics and Support Activities of IMPROVE

Adaptive Control Plan

Example: Predictive sampling strategy for defect inspections

- Implementation of a Wafer@Risk indicator for risk assessment of manufacturing equipment
- Reduction of risk (W@R) by upto 85 %
- Reduction of measurement steps by upto 53 %



R&D Topics and Support Activities of IMPROVE

Guidelines for long-term applicability

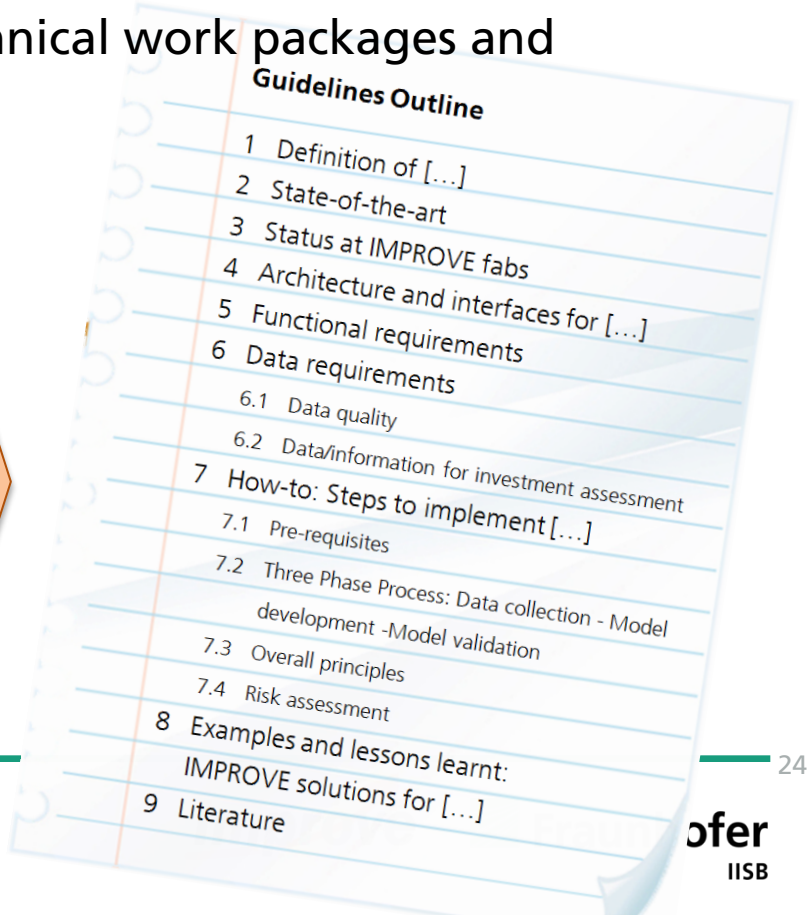
Virtual Metrology
Predictive Maintenance
Adaptive Control Plan
Sensor Networks
Master Framework

Guidelines cover …

- Findings from the survey, specification and architecture phase
- Results and lessons learnt from the technical work packages and implementation.

Inputs

- Experiences
- Best practices
- Technical solutions
- Status at partner's fabs
- State-of-the-art
- Requirements
- Specifications
- Literature
- Other relevant data gathered within IMPROVE

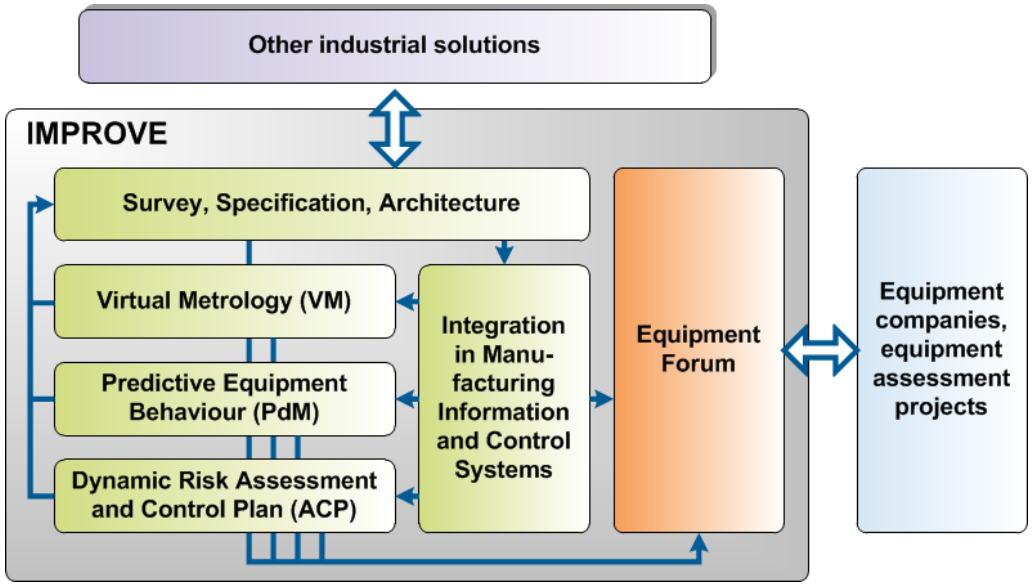


R&D Topics and Support Activities of IMPROVE

The Equipment Forum

Objective: **Relay the results and knowledge gained in the IMPROVE project to equipment companies**. As a mid-term effect, it is expected that this will lead to enhanced or novel equipment that better suits the needs and requirements of the IDMs and IC manufacturers gathered in IMPROVE.

- Foster contacts between IC manufacturers and equipment suppliers
- Collection of specifications and requirements for future equipment
- Database for equipment specifications and equipment quality requirements



Discussion

Equipment Forum
May 9, 2012, Grenoble

improve

Build a **„Who's Who"** in semiconductors – including SW companies!

Variability of equipment is the first critical point - especially if mix increases and volume increases --> cost increase!

Manufacturing science as **new science**?

Collaboration

Get **data back from the fab** is important for equipment supplier for further development

Data Exchange

How can we build up a **common understanding** and "common voice"

How can (backend) equipment manufacturers get **support from EC**

IMPROVE: **get data out of the tool** with context, definition, quality

Spill-over from 450 mm equipment to 300/200 mm

Next challenge = Get **3D into manufacturing** (convergence with FE)

Future

Role of **KET pilot li**nes? **ENI2**?

Traditional growth of Front-End eq. may end soon (down to 12 nm), then Backend will get the new focus. Equipment landscape will change – **IMPROVE will not change much**.

Roadmapping

Spill-over of manufacturing science solutions to other industries

Agenda

- Manufacturing Science as “Competitiveness Enabler“
- The IMPROVE Project at a Glance
- The R&D Topics and Support Activities of IMPROVE
- *Summary & Outlook*

Summary

- Thorough survey, architecture and specification phase inevitable to gain common technical ground
  - Collection of user requirements
  - Transfer of requirements into architectures
  - Avoidance of island-solutions and duplicate efforts
  - Improved communication
- Combination of
  - In-depth R&D (VM, PdM, ACP) and
  - Integration of developed solutions in the manufacturing environment
- Equipment Forum as bridge beyond IMPROVE

Outlook

- The IMPROVE project funded by ENIAC to **keep manufacturing in Europe** – additional activities will follow
  - Significant step into R&D of manufacturing science
  - Collaboration beyond fab boundaries
  - Building block to enhance efficiency in semiconductor manufacturing
- Further increase of **collaboration** and common manufacturing aspects amongst
  - Leading edge manufacturers and fast followers
  - More-than Moore manufacturing
  - Academia & research institutes
- Enhance the collaboration in the **full supply chain** of
  - Materials
  - Equipment
  - Technology
  - Device manufacturing
- Improve R&D towards “Intelligent Manufacturing” on a global scale for further advances in micro and nano electronics

Acknowledgment

Thanks to a great group of "collaborators" in IMPROVE!

- The IMPROVE project is funded by the ENIAC Joint Undertaking (project ID: 12005) and by the Public Authorities of the countries involved: Austria (Österreichische Forschungsförderungs-gesellschaft mbH), France (Direction Générale de Compétitivité, de l'Industrie et des Services), Germany (Bundesministerium für Bildung und Forschung), Ireland (The industrial Development Authority), Italy (Ministero dell'Istruzione, dell'Università e della Ricerca), Portugal (Fundação para a Ciência e a Tecnologia).

- More information: www.eniac-improve.eu