Semiconductor Manufacturing – The Role of Equipment Development, Assessment and Control

Areas for Effective International Cooperation

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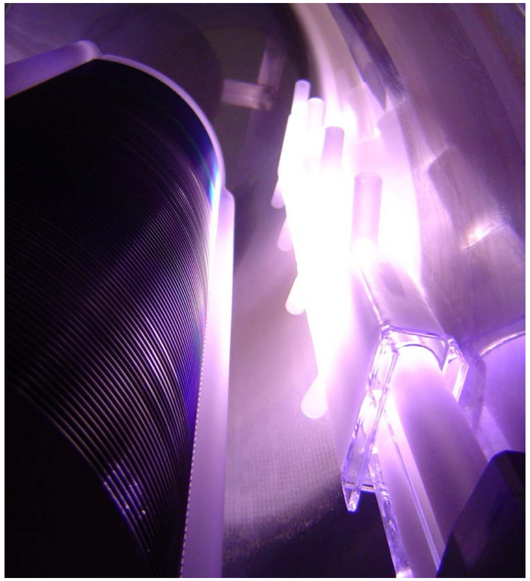
Fraunhofer Institut Integrierte Systeme und Bauelementetechnologie

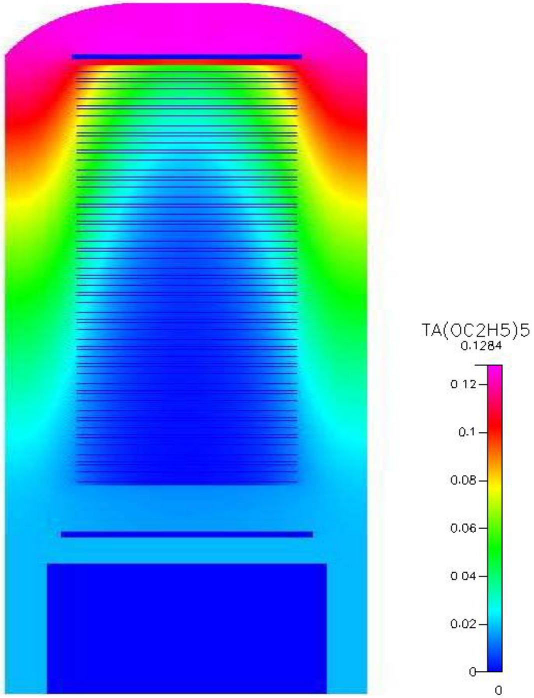
Equipment Development

Simulation development for new semiconductor manufacturing equipment – Need for collaboration Academia – Research Institution – Supplier - User

ALD batch reactor



Simulated precursor distribution



Mass fraction of $Ta(OEt)_5$ in the reactor after a pulse time of 30 s

Example:

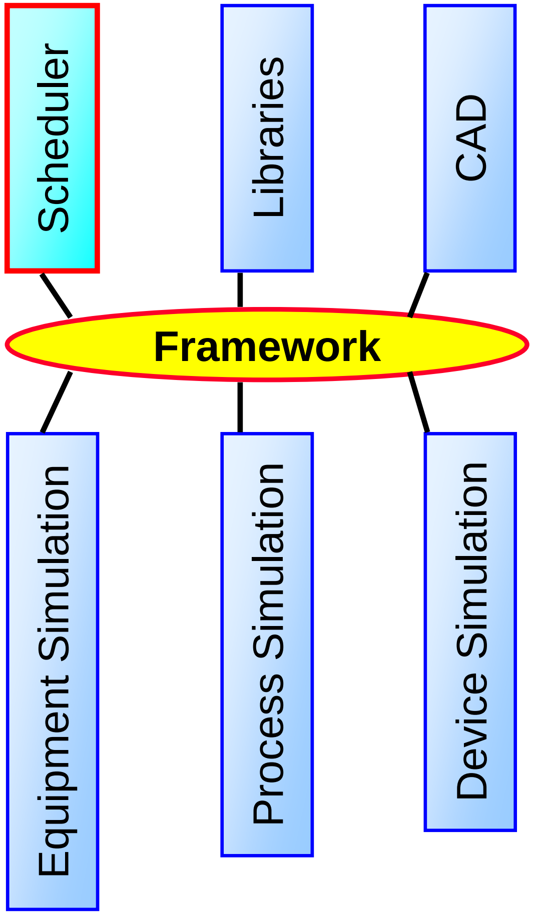
Equipment simulation to support process development in high throughput ALD

Simulation of Batch Equipment for deposition of Al_2O_3, Ta_2O_5, and HfO_2 layers

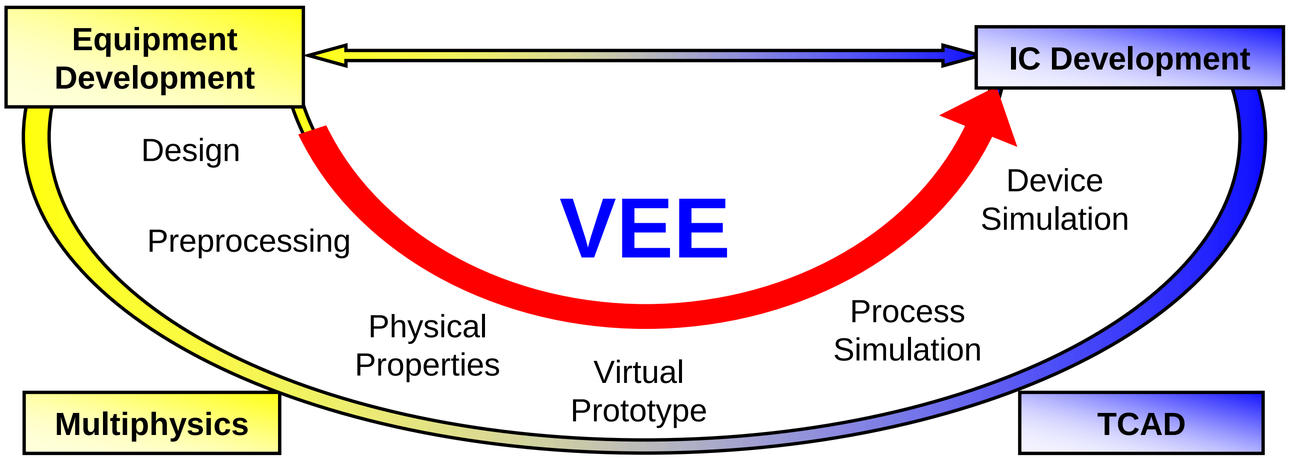
- Optimization of purge and pump cycles
- Model for precursor depletion process effects during deposition of Ta_2O_5, HfO_2 dielectrics

Equipment Development

Novel approach: Virtual Equipment Engineering (VEE):



- **Integrated** simulation, evaluation and optimization of the equipment towards the corresponding process
- **Concept:** Concatenation of existing and novel methods through a **framework** towards a flexibly configurable complete system
- Provision of broad information about the future equipment in the very **early development stages**
- **Application example:** faster version testing



Equipment Assessment: SEA-NET

- **Assessment of prototype equipment and novel enhancements to existing equipment, and their application to next generation semiconductor technologies and device architectures**
- **Bring together critical mass, research and development power to form synergies**
- **Make use of the excellent European 300mm research infrastructure at Fraunhofer IISB, LETI and IMEC**
- **Increase the chances for SME´s to get access to European and non-European IC makers**

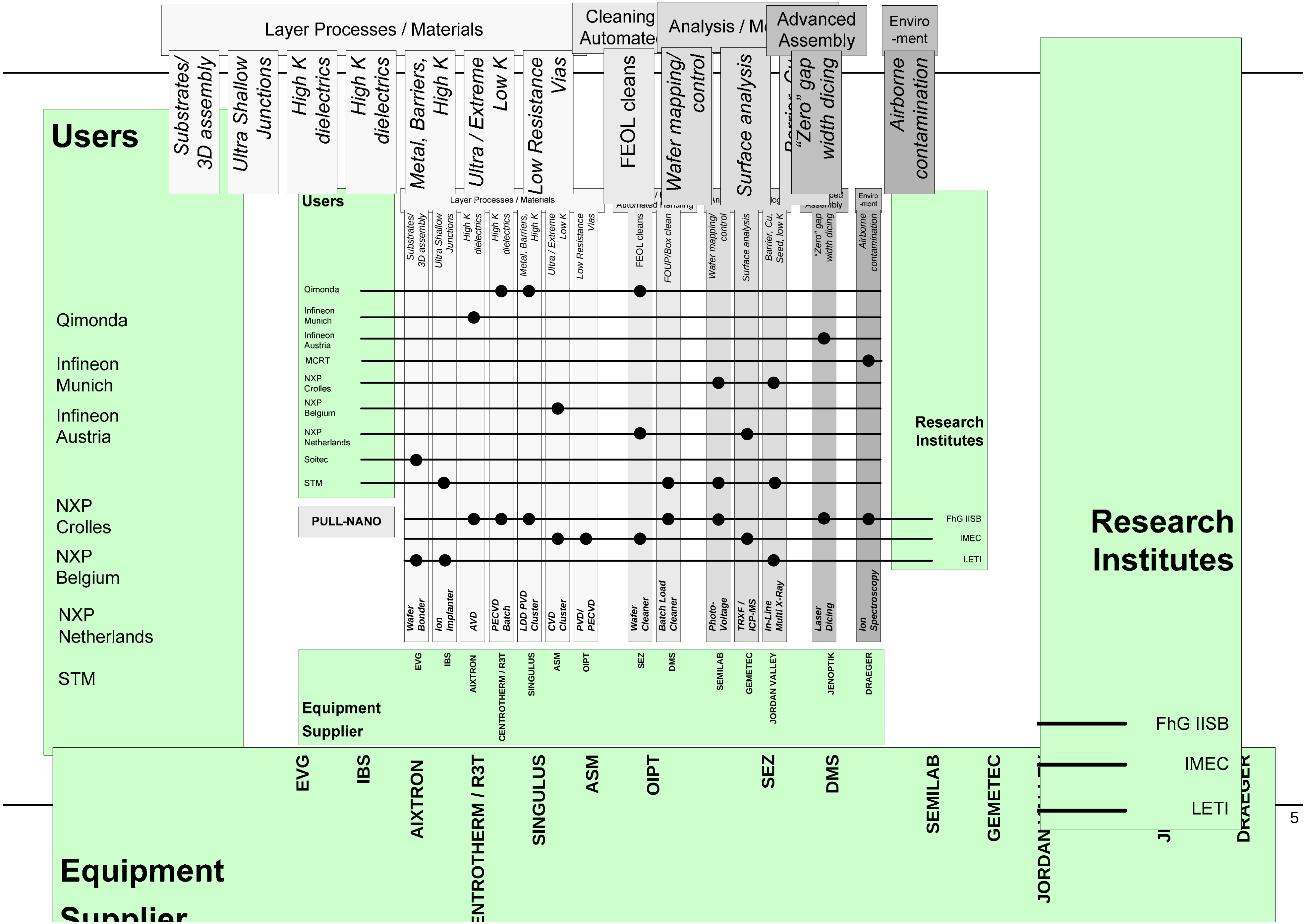
Partners: 27 Partners

equipment manufactures: EVGroup, ION BEAM SERVICES, AIXTRON. SINGULUS, Oxford Instruments, SEZ, DMS, SEMILAB, GEMETEC, JORDAN VALLEY JENOPTIK, Centrotherm, SOITEC, R3T, Dreager, MCRT

semiconductor manufactures: Infineon (Munich, Villach), Qimonda, NXP (Crolles, Netherlands, Belgium), STMicroelectronics Crolles II

R&D institutes: Fraunhofer IISB, IMEC, CEA-LETI, FH Wiener-Neustadt

Duration: January 2006 – December 2008


Users
Layer Processes / Materials
Substrates/ 3D assembly
Ultra Shallow Junctions
High K dielectrics
High K dielectrics
Metal, Barriers, High K
Ultra / Extreme Low K
Low Resistance Vias
Cleaning / Automated Handling
FEOL cleans
FOUP/Box clean
Analysis / Metrology
Wafer mapping/ control
Surface analysis
Barrier, Cu, Seed, low K
Advanced Assembly
"Zero" gap width dicing
Enviro -ment
Airborne contamination
Qimonda
Infineon Munich
Infineon Austria
MCRT
NXP Crolles
NXP Belgium
NXP Netherlands
Soitec
STM
PULL-NANO
Research Institutes
FhG IISB
IMEC
LETI
Wafer Bonder
Ion Implanter
AVD
PECVD Batch
LDD PVD Cluster
CVD Cluster
PVD/ PECVD
Wafer Cleaner
Batch Load Cleaner
Photo-Voltage
TRXF / ICP-MS
In-Line Multi X-Ray
Laser Dicing
Ion Spectroscopy
Equipment Supplier
EVG
IBS
AIXTRON
CENTROTHERM / R3T
SINGULUS
ASM
OIPT
SEZ
DMS
SEMILAB
GEMETEC
JORDAN VALLEY
JENOPTIK
DRAEGER

Equipment Assessment: Area Layer processes / Mater
SP3: RACING

Ruthenium - benefits

- Base resistivity
- Thermal stability
- Favorable work function for PMOS transistors
- Simple structuring with subtractive processes (masking and etching)

Ru(II)Oxid - benefits

- Good diffusion barrier

RACING – Ruthenium Atomic Vapor Deposition Competitiveness in Nanoelectronic Device Generations

Newly developed deposition equipment for the manufacturing of highly innovative metal electrode systems required for the fabrication of future nano-electronic devices in nearly all IC applications

AIXTRON Tricent® AVD® Reaction Chamber

Objectives

- AVD processing of Ru and RuO2 electrode layers for planar MIM applications.
- Processing of metal-nitride barrier layers (e.g. TiN, TaN).

Partners: AIXTRON AG, Fraunhofer IISB
Infineon Munich

IISB
Fraunhofer Institut Integrierte Systeme und Bauelementetechnologie

Equipment Assessment: Area Cleaning / Etching / Automated handling
SP8: SIWAC

SIWAC

Front-End-Of-Line Single-Wafer Cleaning

Development and implementation of APM based cleaning with Megasonic agitation

Benefits of SIWAC

- **High cleaning efficiency**
- **Short process times**
- **Flexible process integration: e.g. SC-1, SC-2, DHF last**

Objectives:

- Investigation of new FEOL cleaning concepts for the sub-45nm technology node
- Development and implementation of novel hardware features into beta-tool
- Beta-testing and tool assessment with IMEC

Partners: SEZ, IMEC, NXP Netherlands, Qimonda

Metrology Equipment Assessment: Area Analysis / Metrology
SP11: LEAD-IT

LEAD-IT
Low Energy and Dose Implant Test

Capacitive pick-up electrodes measure the lateral voltage drop in the implanted or epi layer

Benefits of LEAD-IT

Fully automated 300 mm metrology tool for the measurement of sheet resistivity

- Non-contact metrology
- Non-destructive
- High speed
- High resolution

Objectives:

- Use of junction photo-voltage to measure sheet resistance and thus annealed implant dose
- Provide non-destructive high speed, high repeatability full wafer mapping of dose.

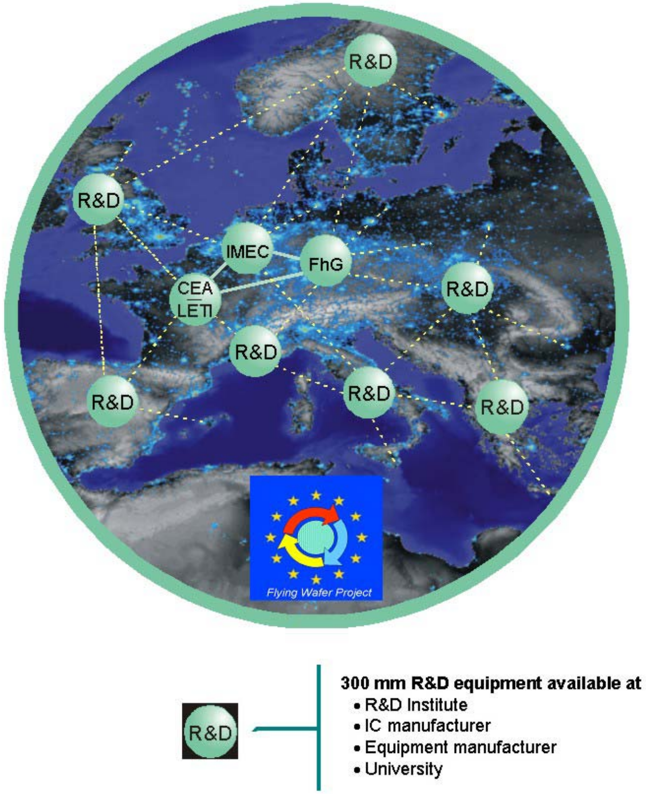
Partners: Semilab, Fraunhofer IISB
ST Microelectronics Crolles II, NXP Crolles R&D

Supporting Activities: Flying Wafer

Flying Wafer
Feasibility Study about distributed 300 mm R&D Line

Targets

- Network of European Micro- and Nano-electronics R&D centers
- Fast and reliable logistics and infrastructure for 300 mm wafer exchange
- Project consortium: Freescale, Philips, Infineon, Siltronic, Isiltec, INCAM Solutions, Entegris, IMEC, LETI and Fraunhofer IISB as project coordinator



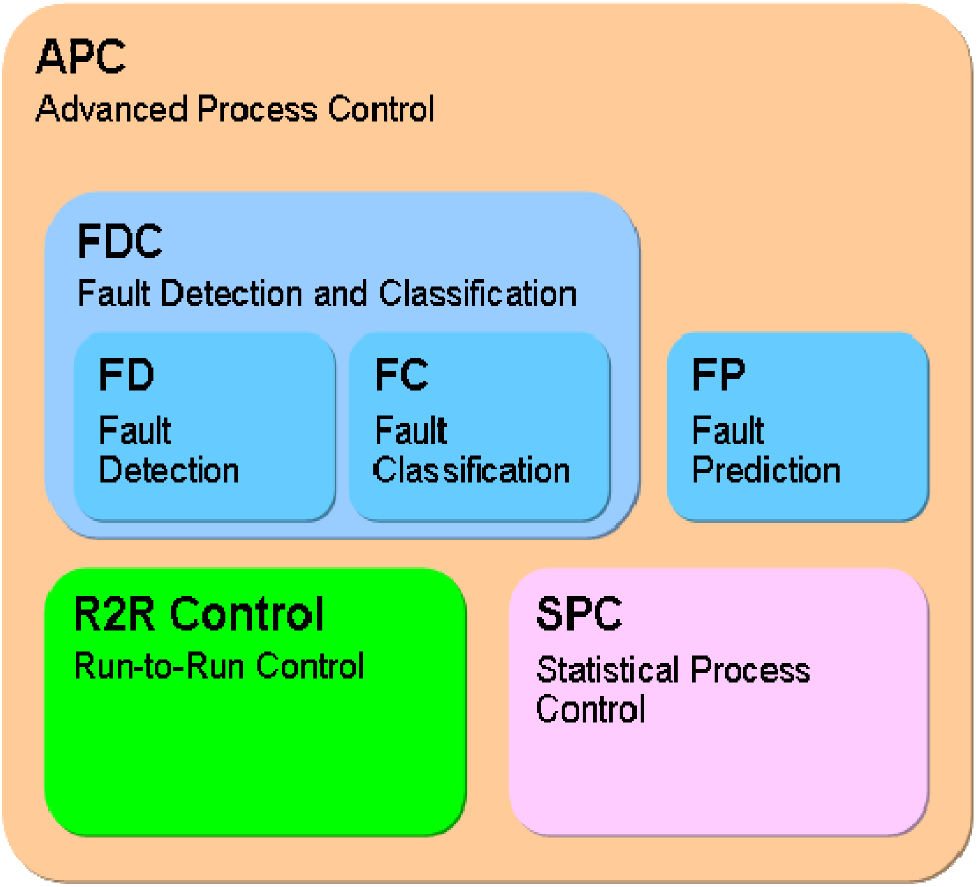
Results

- Specification of parameters for handling, transport, and logistics of silicon wafers and carriers
- Specification of parameters for silicon wafer input and output procedures
- Specification of parameters for wafer environment contamination control procedures and intervals
- Development of a functional model describing the complete sequence of wafer and data exchange between distributed locations
- Specification of parameters for a central planning and control system

Supporting Activities: Common Metrics + Standards

		initial status	after 6 months	after 12 months	after 18 months	Factory Acceptance Test (FAT)	Site Acceptance Test (SAT)	final target	change of final target
General Equipment specifications									
	Hardware Interface (loadport, FOUP, FOSB)								
	Software Interface (SECS/GEM)								
	cleanroomspace, footprint								
	Cleanroom class (minienviroment)								
	Weight								
	Energy consumption								
	Enviroment (Vacuum, N2 …)								
	Type of automation (robot, XY table, ...)								
	Envisaged Feature Size (Technology node)								
	Max. Batch Size								
	Number of process chambers								
	Wafer diameter								
	Wafer edge exclusion								
Handling/cleanliness									
	Wafer mis-handling								
	Particles added – handling								
	Particels added – process								
Equipment usability									
	Uptime (%)								
	MTBF (hours)								
	MTTR (hours)								
Cost-effectiveness									
	Equipment cost (€)								
	Throughput wafers/hr								
	Cost per wafer (€)								

Supporting Activities: AEC APC

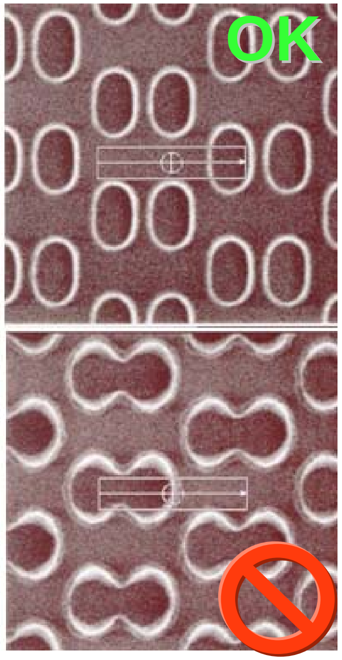


Benefits of Joint R&D

- Using of synergies in cross-cut activities
- Identification of emerging semiconductor equipment topics
- Allocation of additional R&D source for the sub-projects of SEA-NET
- Support of SMEs by streategic and innovative R&D topics

Supporting Activities: AEC/APC

CD Monitoring by Phi-Scatterometry



by courtesy of SEMICONDUCTOR300

Deep-trench DRAM structures

Measure intensity as a function of the azimuth angle

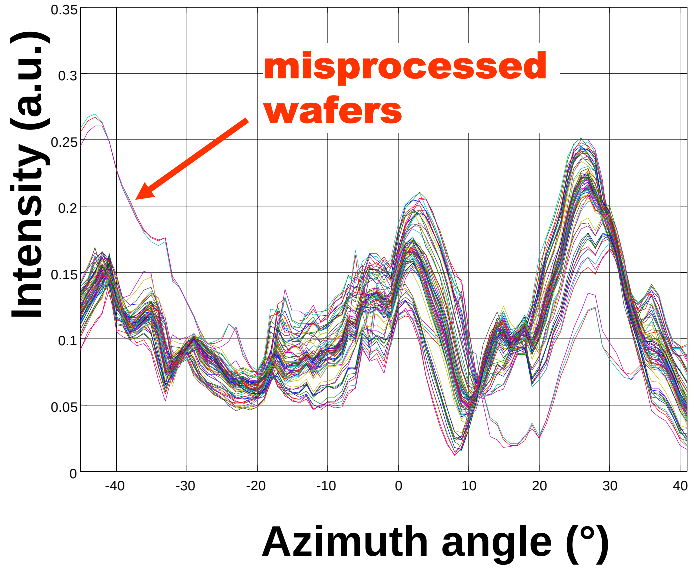
↓

Diffraction signature

↓

Fault detection: Good / Bad

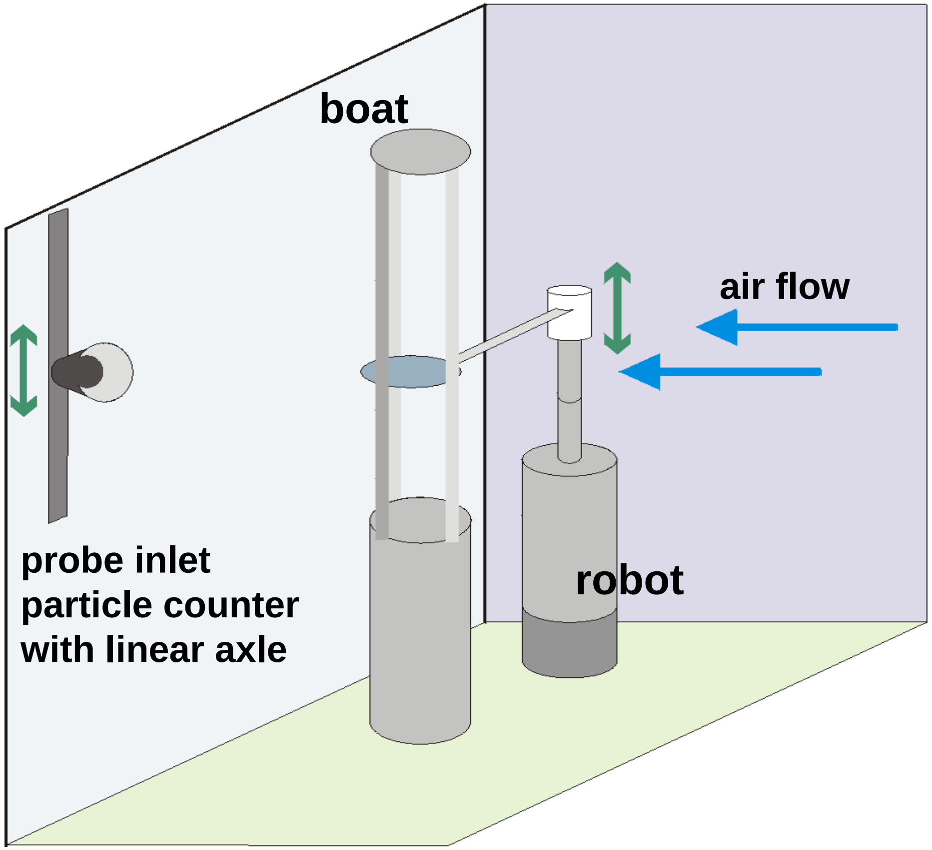
Picture by courtesy of Infineon, Dresden



Test on product wafers in 300 mm pilot line

Supporting Activities: AEC/APC

Detection of particle contamination inside furnaces

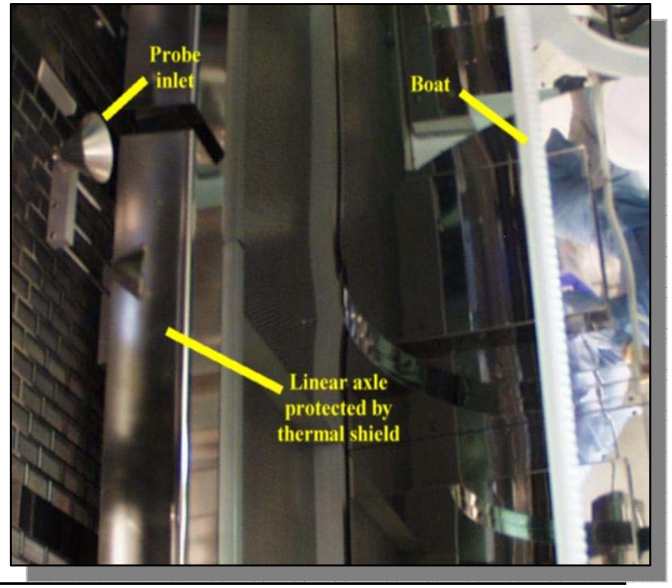


Handling Monitoring - In Situ Particle Monitoring:

Detection of generated particles carried by the airflow inside the loading station with a **particle counter mounted on a linear axle**

Results and benefits after demonstration in a production line:

- Detection of misalignment
- Optimization of quartz ware recycling
- Reduction of downtime
- 1% Uptime benefit (1,5 Mio €/y @ 15 furnaces)



Supporting Activities: ESH

Chemicals and Materials Management must provide timely ESH information to equipment design engineers and equipment users regarding the environmental, safety, and health characteristics of potential new process chemicals and materials.

Process and Equipment Management includes a continuing need for water, energy, and chemical conservation through process optimization, implementation of cost-effective use reduction solutions, and replacement of hazardous chemicals with more benign materials.

Facilities Energy and Water Optimization focuses on the need for resource conservation of the factory's support systems. The reduction of global warming emissions from both the generation of electricity and the use of etch and chamber clean process chemicals is a major consideration, because it could limit the use of energy and chemicals essential to the manufacturing process.

Sustainability and Product Stewardship are becoming important considerations driven by public opinion and the customers of the industry's products. To address these challenges in a cost-effective and timely way, *Design for Environment, Safety, and Health (DFESH)* must become an integral part of the design process and management's decision-making.

Conclusions and Summary

- **Cooperation in Roadmaps, Standards and Guidelines**
- **Cooperation in Equipment and Metrology Equipment Development and Assessment, a global gap in many areas of High-Tech, by mutual participation of**
  - **Users**
  - **Equipment suppliers**
  - **OEM and sub-systems suppliers**
  - **Research institutions and academia**
- **Common metrics**
- **Modelling and simulation**
- **E-Learning**
- **Advanced equipment and process control**
- **ESH issues**