# Industria dei semiconduttori: progetti di Manufacturing R&D

**Giuseppe Fazio**
*Advanced Process Control & Advanced Equipment Control (APC&AEC )*

## XI GIORNATA DELLA RICERCA ANIE

### SMART FACTORY: L'INNOVAZIONE TECNOLOGICA PER IL RINASCIMENTO MANIFATTURIERO

Martedi' 19 Febbraio 2013

# Micron Italy Outline


| | |
|---|---|
| **Production:** | **Imagers - PCM** |
| **Process R&D:** | **Imagers – NOR - PCM** |
| **Design R&D:** | **NAND – NOR - PCM – e.MMC** |
| **Business Units:** | **WSG - ESG** |
| **Marketing & Sales:** | **DRAM – NOR - NAND - PCM** |

# Agrate R&D - R2/F14 Technology Development Center
# Facility gestita e condivisa da ST e Micron

- Facility 200mm wafers
- Clean rooms : ≈ 6000 m²
- Cpacita' massima:
  - 3500 wf/wk produzione
  - 500 wf/wk equiv R&D

- Professinisti
  - Ricercatori
  - Ingegneri/Tecnici
  - Operatori
- Laboratori di Ricerca & Attivita'
  - Laboratori "Electrical" & "Physical/chemical "
  - Laboratori di Ricerca Materiali & Dispositivi del CNR
  - Strette collabotazioni con Universita' e con Centro di Ricerca Europeo

# Il transistor (1947)

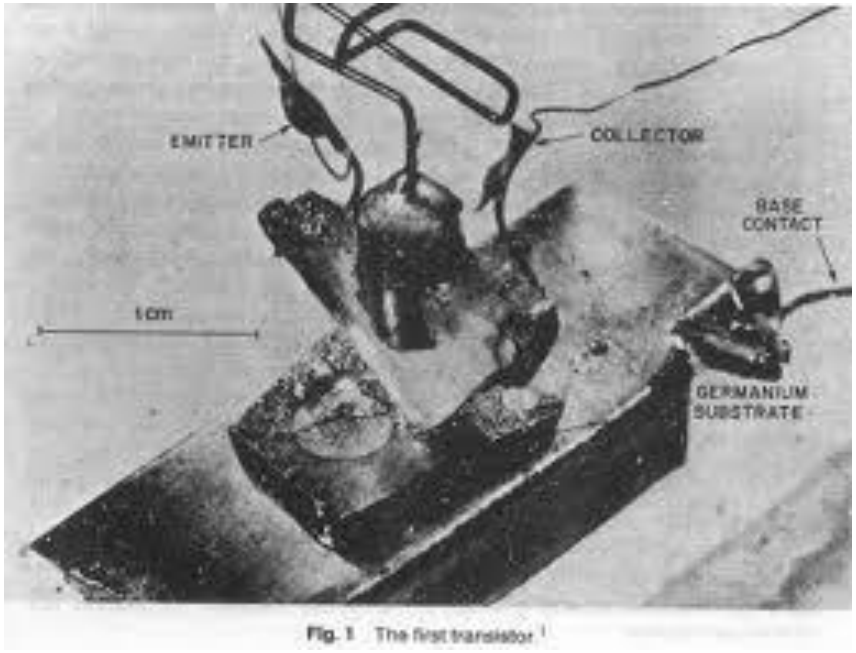
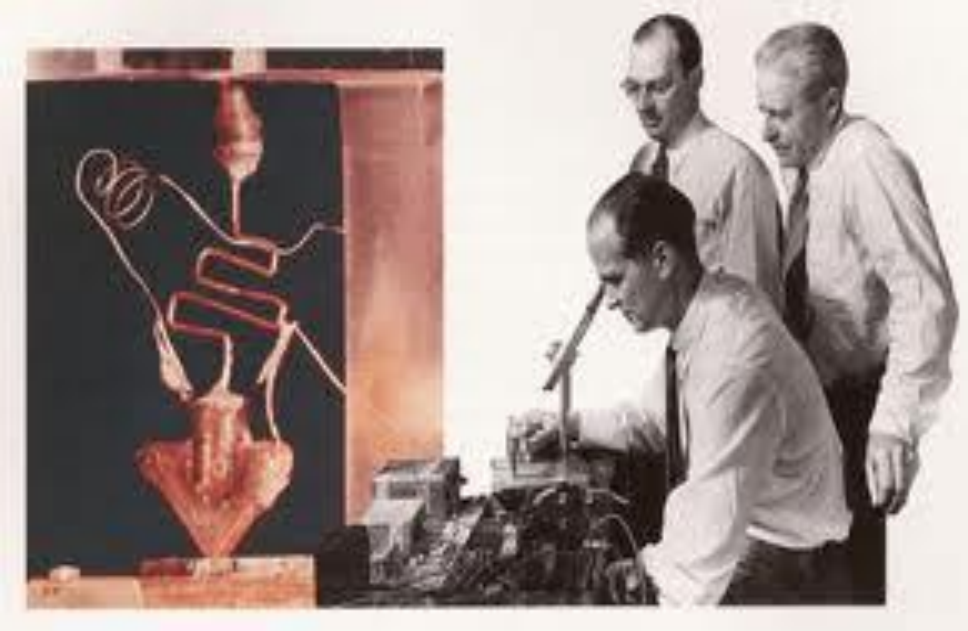


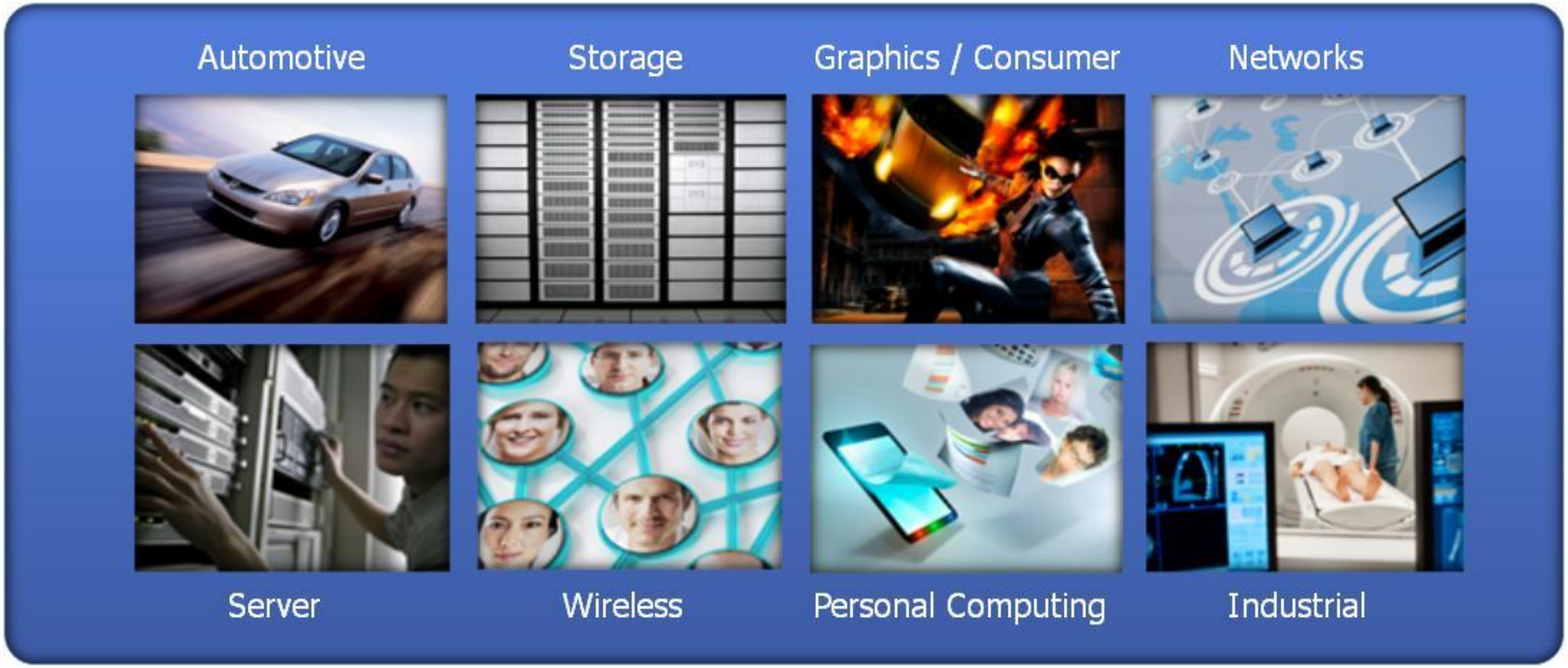
Fig. 1 The first transistor [1]

Il primo transistor



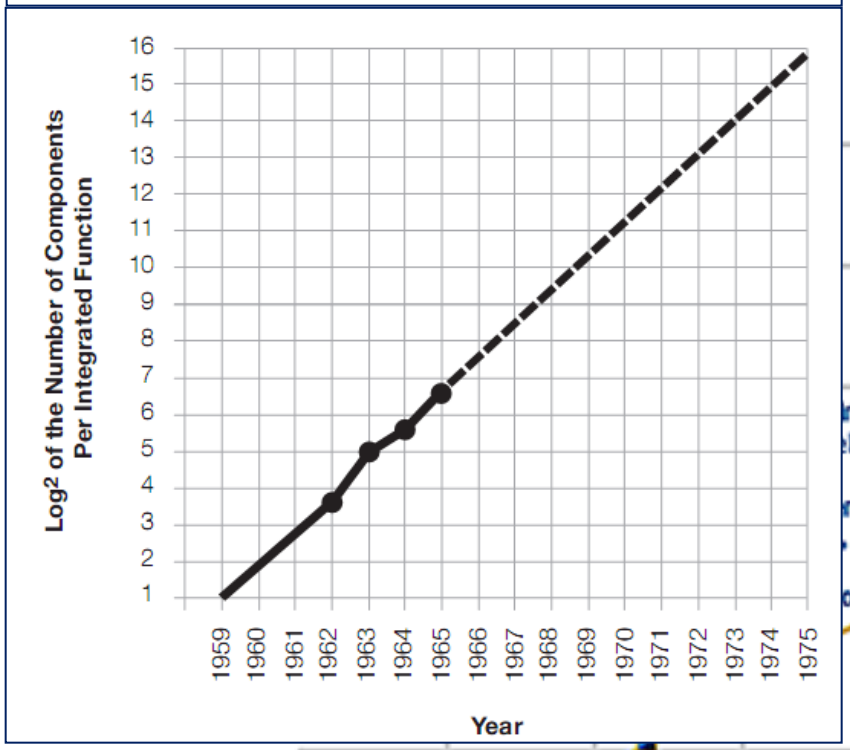
John Bardeen, William Shockley e Walter Brattain ai laboratori della Bell (1948)

# Applicazioni



Moore's Law was a curiosity in 1965,
an empirical law in 1975,
an economic necessity in the 90's.

## Cramming more components onto integrated circuits, G.Moore 1965



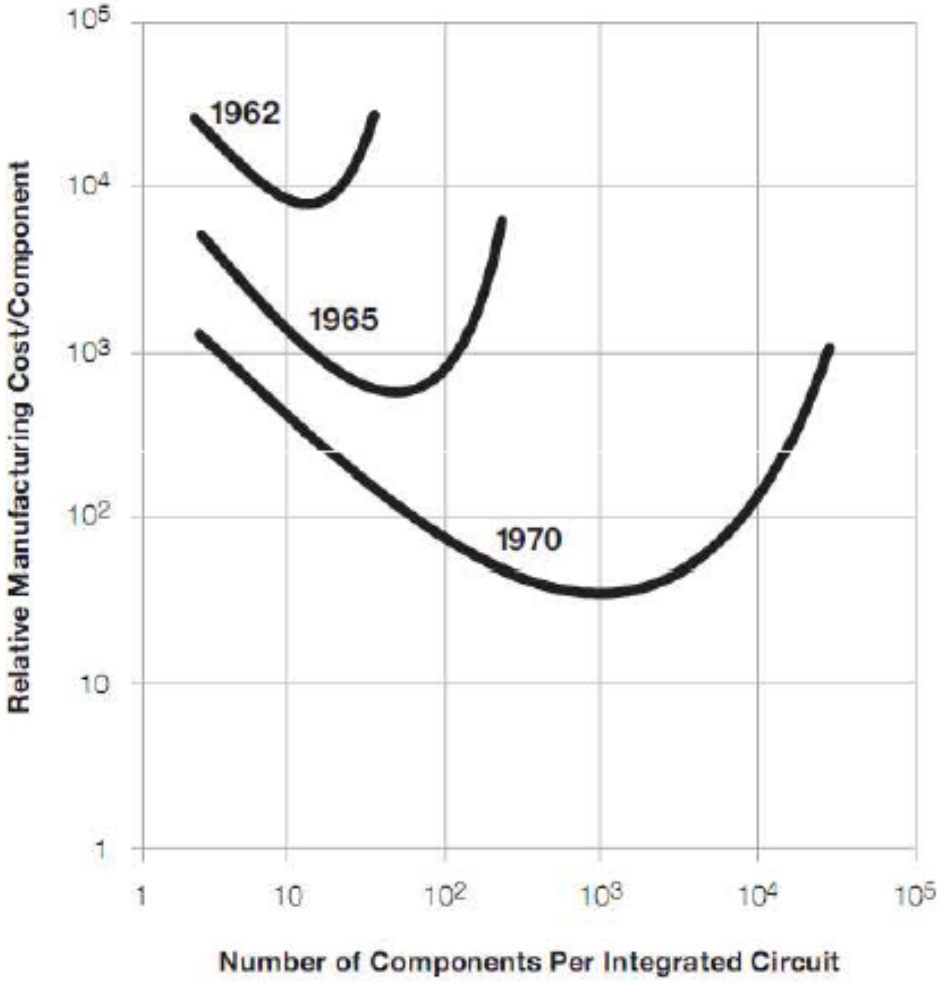




"The complexity for minimum component costs has increased at a rate of roughly a factor of two per year "

**L.Baldi, EuroNanoForum 2011 Budapest**

# The driving force




- Manufacturing cost per wafer is (almost) constant.
- Smaller size = more devices per wafer
- More devices per wafer = more revenue
- BUT it means also: producing more with less, therefore

**SUSTAINABILITY**

**L.Baldi, EuroNanoForum 2011 Budapest**

# Gordon Moore had a vision…

and reality exceeded his expectations:

- Low costs opened new markets
- Revenues pushed technology
- A huge business growing out of devices and services enabled by Microelectronics

**L.Baldi, EuroNanoForum 2011 Budapest**


# NVM Evolution:
# Phase Change Memories Start to Play Their Role

Paolo Cappelletti, Roberto Bez and Kunal Parekh

Micron Technology

## The Evolutionary Path Is Getting To Its End

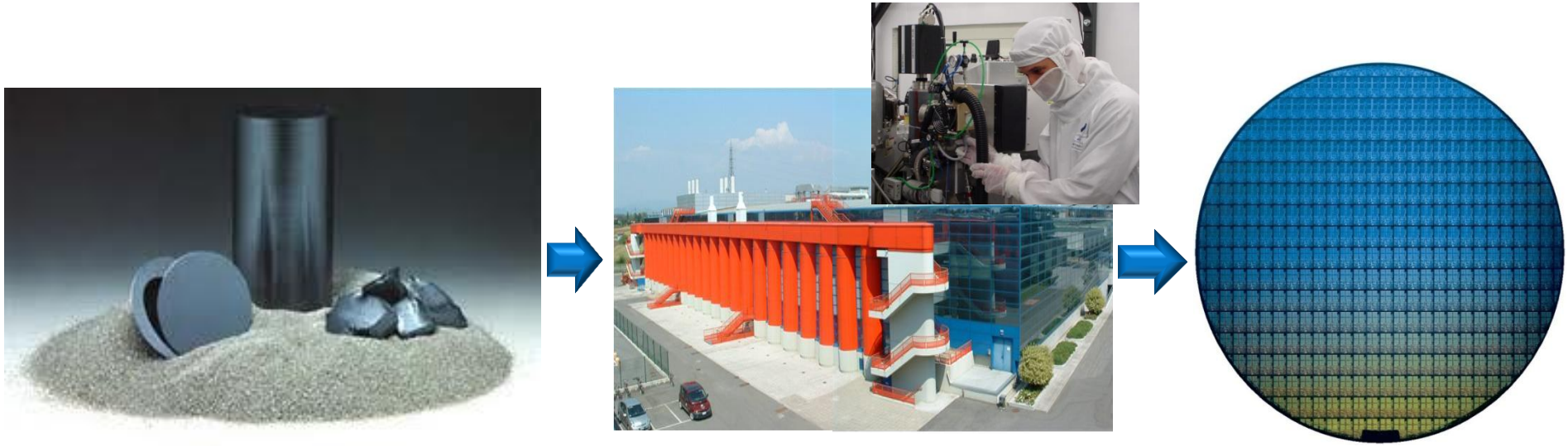
| year | 2004 | 2006 | 2008 | 2010 | 2012 | 2014 |
|---|---|---|---|---|---|---|
| Node | 90nm | 65nm | 45nm | 32nm | 22nm | 18nm |
| NAND | | | | | | |

Scaling is getting to the end because of:

- Structural limit
- Device physics limits

# Circuiti Integrati: produzione

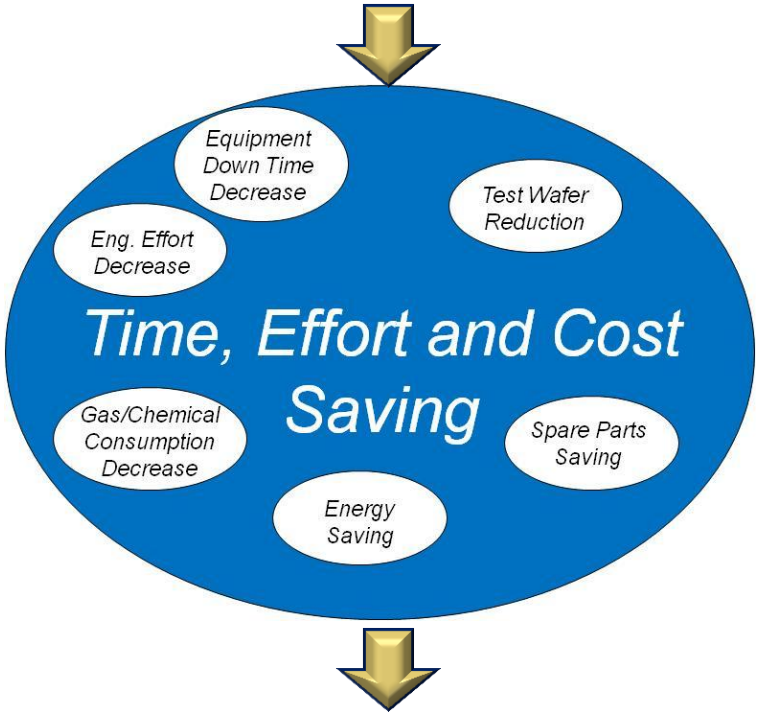
- A partire da barre di Siliciosi ricavano delle fette (“wafer ”)
- Attraverso processi chimico fisici si arriva alla realizzazione di circuiti integrati
- Da un wafer si possono ottenere da alcune centinaia ad alcune migliaia di IC.



# Monitoraggio e controllo della produzione

- Controlli “off-line”: Statistical Process Control (SPC)
- Controlli “on-line”: a livello equipment e processo
- Adavanced Process & Equipment Control (APC&AEC)
  - Tre conferenze dedicate (APCM Europe, AEC/APC USA, APC/AEC Asia)
  - Introduzione di Mass Flow Controller (MFC) per il controllo dei gas, Optical Emission Spectroscopic (OES) per il controllo di processo,..
  - Metodologie consolidate:
    - Fault Detection & Classification (FDC) e Run-to-Run (R2R)
  - Metodologie emergenti:
    - Virtual Metrology (VM) e Predictive Maintenance (PdM)

# Strong competitive pressure
# Maintain "ecosystem" in Europe




# Manufacturing science project

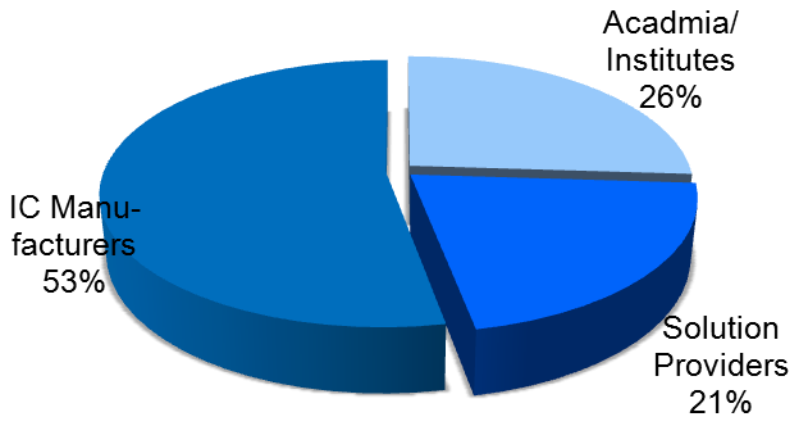
R&D Manufacturing project

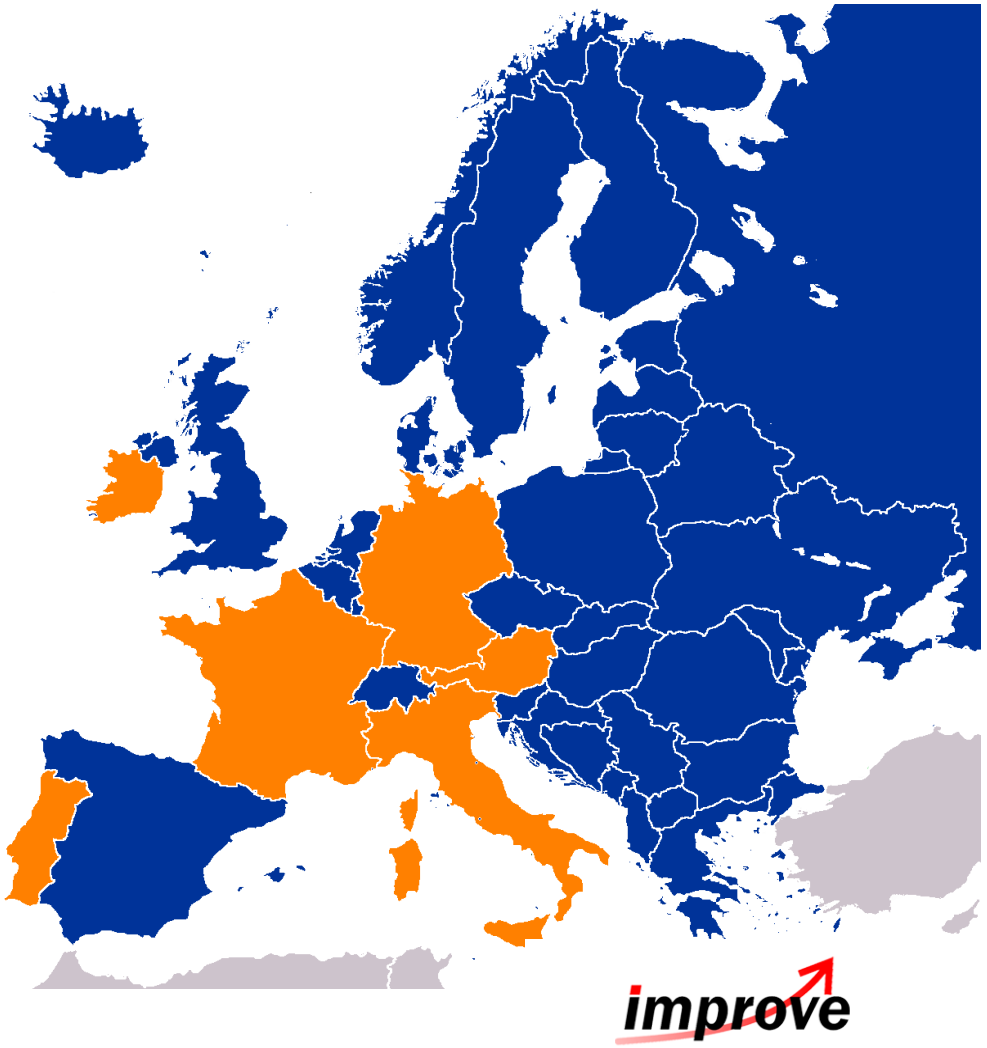
2009-2011 **improve** → 20013-2015 **integrate**

# Implementing Manufacturing science solutions to increase equiPment pROductiVity and fab pErformance

## Key figures

- 3600 men-months over 3.5 years (January 2009 to June 2012)
- Total headcount of 325
- 35 partners over 6 countries



# Consorzio Italiano

Partners Italiani (9 partners)

- 2 SC: Micron & ST-I
- 2 SMEs: LAM, TF
- 2 CNR: CNR-IEIIT (Padova-Torino) & CNR-IMM (Catania)
- 3 Universita': Milano, Pavia, Padova


Totale risorse in Italia:

- 1203 persons*month (34 ricercatori)
- 50/60 professionisti coinvolti

improve

# Acknowledgment

The IMPROVE project is funded by the ENIAC Joint Undertaking (project ID: 12005) and by the Public Authorities of Austria, France, Germany, Ireland, Italy and Portugal.


www.eniac-improve.eu

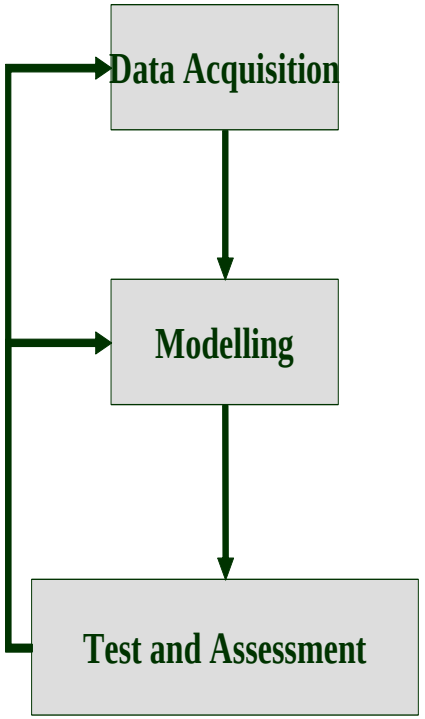
# IMPROVE Master Objectives

- To improve processes reproducibility and quality
- To improve the effectiveness of production equipment
- To shorten cycles time

=> ***To IMPROVE Fab Competiveness***

# IMPROVE focused on 3 major development axes

- **Virtual Metrology (VM):** techniques allowing the control of the process at wafer level whilst suppressing standard metrology steps.
- **Predictive Maintenance (PdM):** techniques to improve the process tools reliability whilst optimizing the maintenance frequency and increasing the equipment uptime.
- **Adaptive Control Plan (ACP):** concepts, suppressing unnecessary measurements steps whilst dynamically improving the control plan efficiency.




The impact of the integration of the developed techniques in the various line decision systems and IT infrastructure was also evaluated and assessed.

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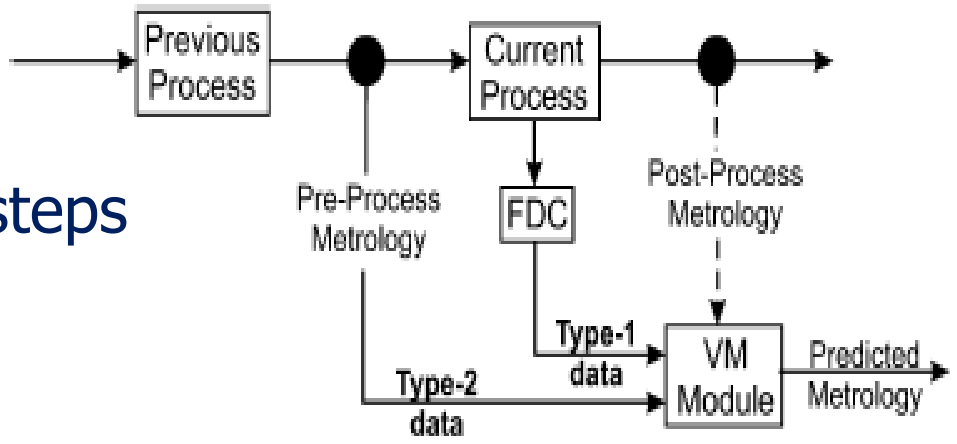
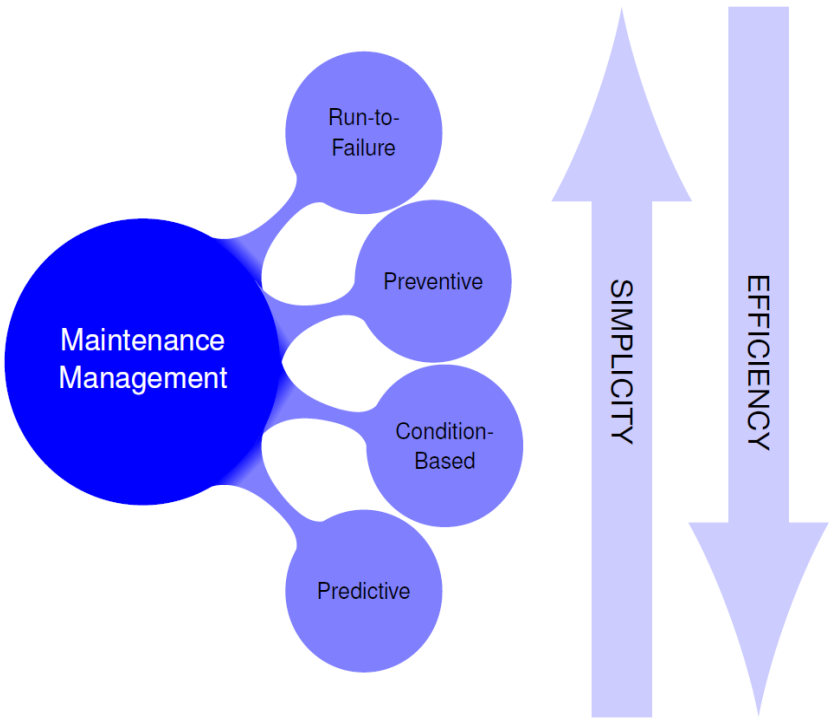
# Virtual Metrology

- Virtual metrology exploits sensors and logistic information to predict process outcome
- Allow measurement of every wafer in real time
- Improve process control from "run to run" to "wafer to wafer"
  - Increase device quality
  - Increase yield
- Reduce standard metrology steps
  - Cycle time improvement
  - Operating costs reduction



# Maintenance Classification

- **Run-to-Failure:** When repairs or restore actions are performed only after the occurrence of a failure.
- **Preventive:** The maintenance is carried out on a planned schedule with the aim of anticipate the process failures.
- **Condition-Based:** The action on the process are taken after the verification of conditions indicating a degradation of the process.
- **Predictive:** Maintenance actions are taken just when necessaries. Estimate future equipment health relying on historical process data and latent knowledge

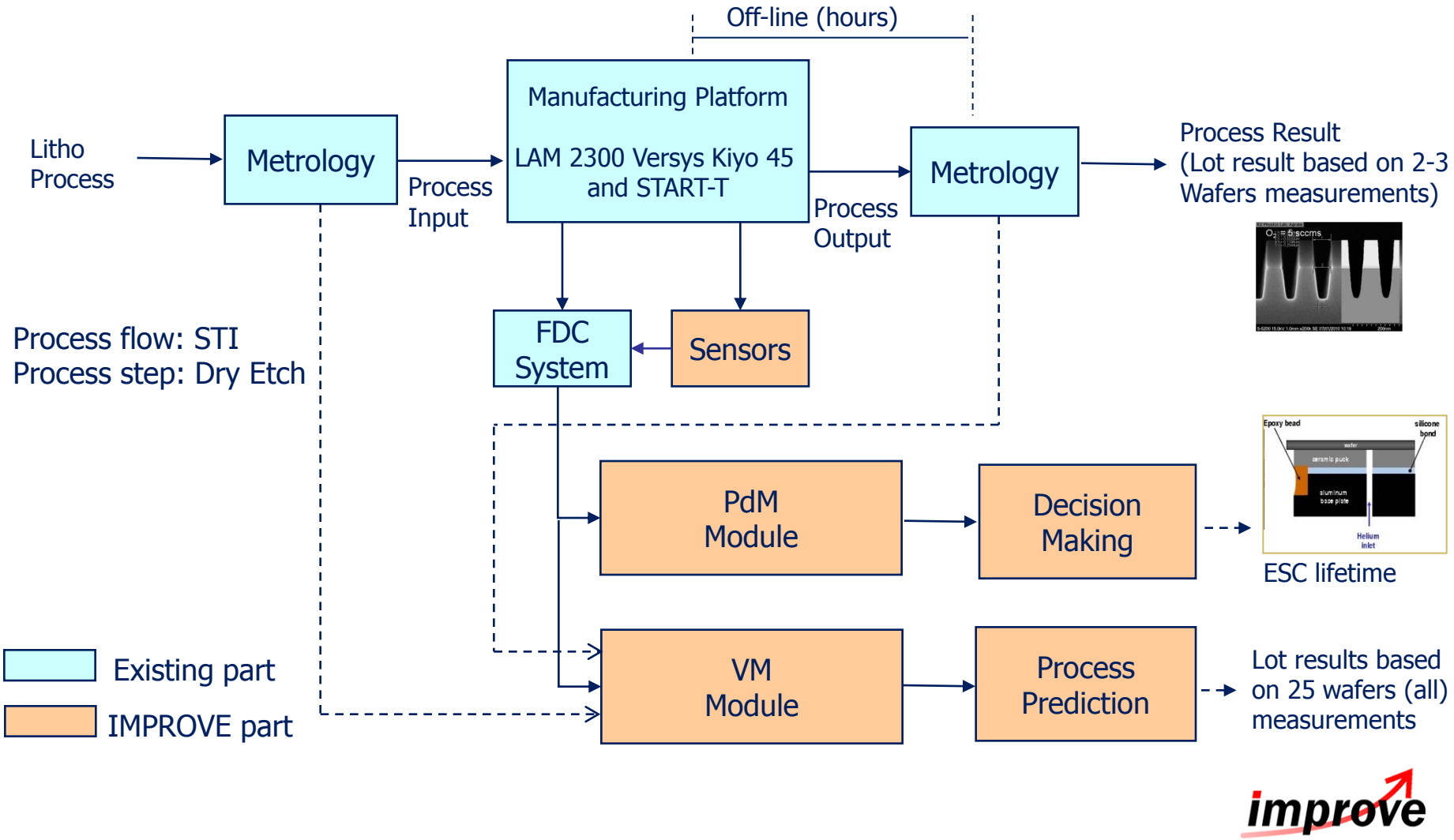



Reduce unscheduled equipment downtime

Increase equipment reliability

Reduce number of scrapped wafers

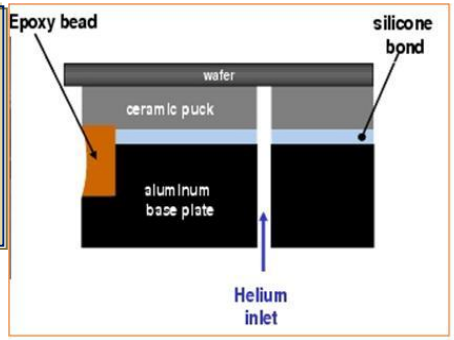
# Micron expectation

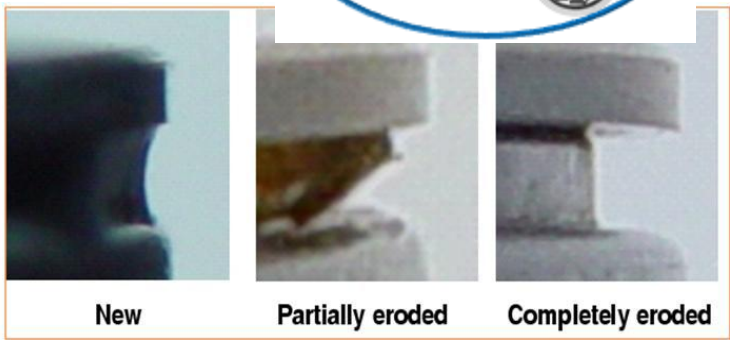


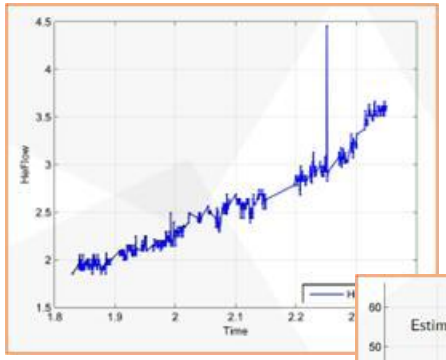
# Predictive Maintenance (PdM)

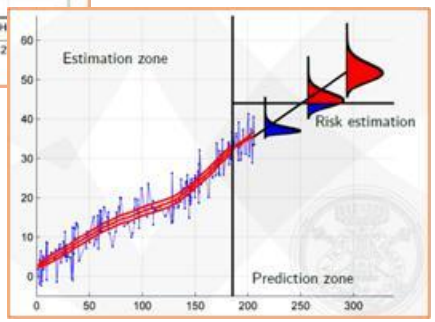
Hardware part evaluated:
Electrostatic Chucks

Health Factor : He Back Side flow

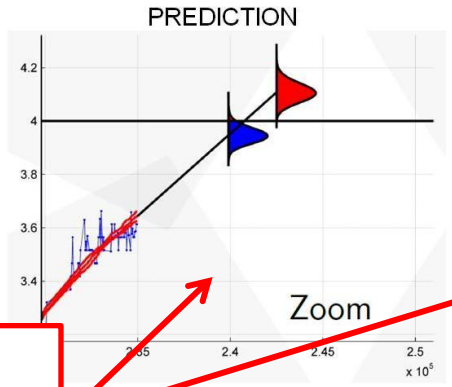


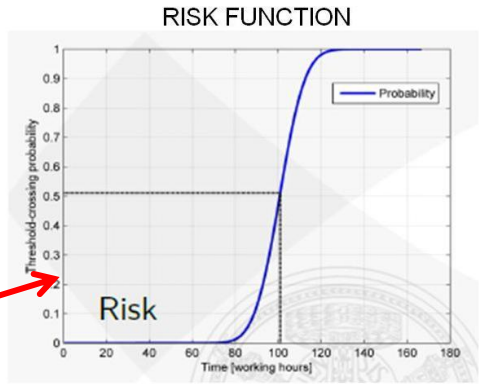




**State-space gamma filtering and prediction**




Probabilistic outcome, risk function (expert-specified configurable threshold)

**Risk function as input for decision system**
- 0-80 hours: no risk
- Expected failure: 90-110 hours
- Almost sure failure: 120+ hours

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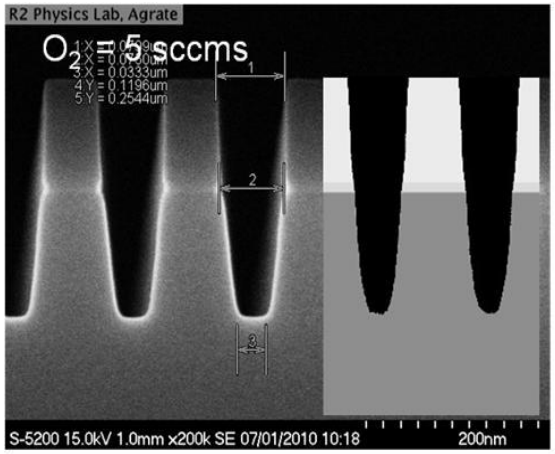
# Virtual Metrology
# Statistical approach

Platform:
LAM 2300 Versys Kiyo 45 and START-T

Process step:
STI definition in array

Process parameter:
Delta CD (CD After Etch – CD Pre Etch)




- State-of-art algorithms comparison: best results achieved with PLS and LASSO
- Prediction error < 2%
- Application: Process Diagnostics and Troubleshooting, Measurement validation, Recipe optimization

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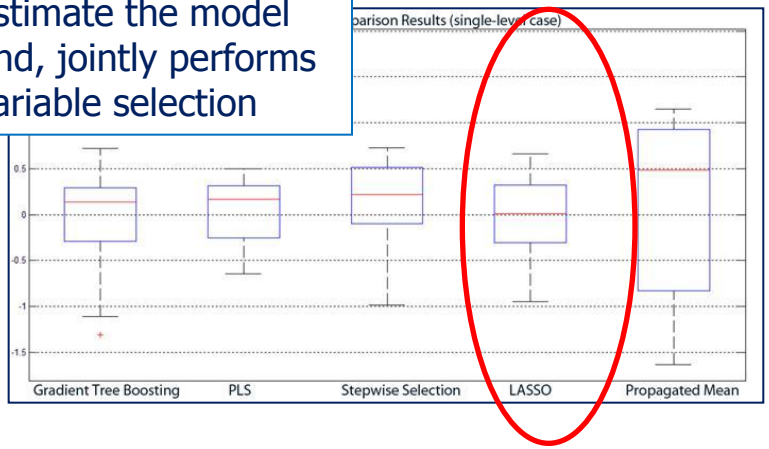
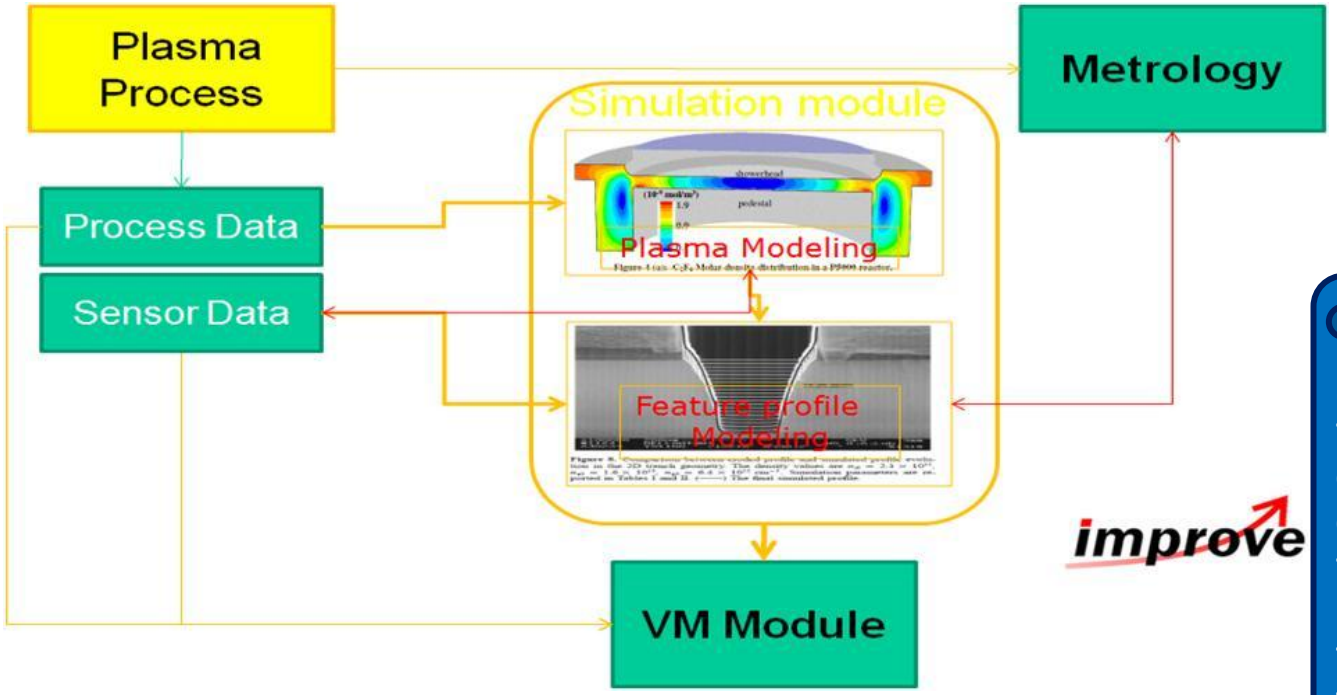
LASSO allows to estimate the model and, jointly performs variable selection



# Virtual Metrology Physical Model

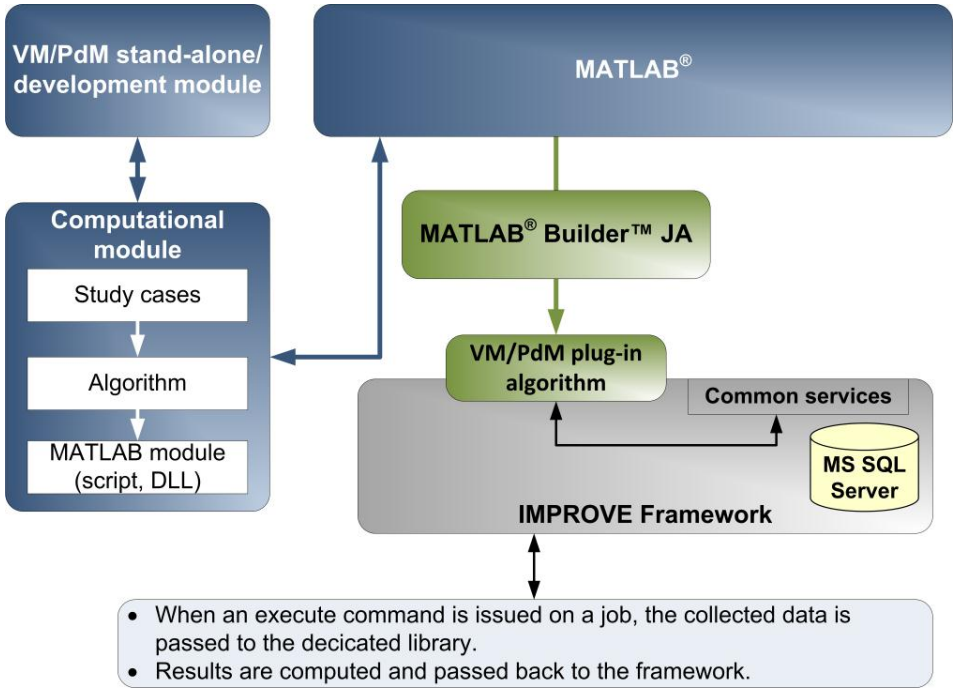
TCAD simulation code for the plasma processes

- completely new implementation with innovative features
  - Kinetic Monte Carlo (atomic resolution), 3D framework
  - Coupling with the plasma simulation – setting with the reactor parameters




Simulation aided VM for the solution of critical faults, process diagnostic and the fast R&D to manufacturing transfer of new technologies

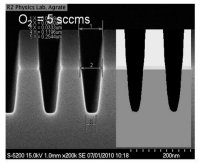
# Framework

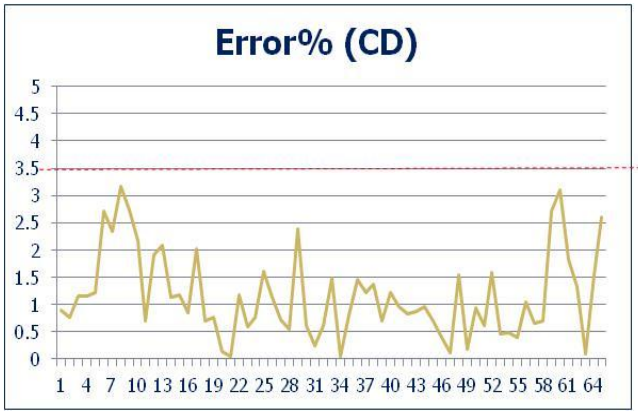



- When an execute command is issued on a job, the collected data is passed to the decicated library.
- Results are computed and passed back to the framework.

| Application | Algorithm | Response time | | | |
|---|---|---|---|---|---|
| | | Target | MATLAB | Java | Framework |
| PdM | Gamma Filter | minutes | < 7 sec | < 10 sec | < 39 sec |
| VM | Lasso | (periodically) | < 1 sec | < 2 sec | < 1 sec |
| VM | Predic-tion | minutes | < 1 sec | < 2 sec | < 1 sec |

CD prediction in real time and on all wafers




< 3.5 %

# Quantified achievements

- Predictive Maintenance (Estimate on case study)
  - The Maintenance events could now be scheduled with more precision.
    - ± 5 RF Hours tolerance
    - Down Time  reduction ~1%
  - We obtained an ESC lifetime increase since it could be used until it expired.
    - Cost reduction ~ 10%
- Virtual Metrology (Estimated on process diagnostic)
  - Time saving (~2H)
  - Wafers saving
  - Down time reduction (Estimated: 15%-20% & 25%-50%)
- Simulation Module (Estimated on one case study)
    - Wfs test reduction: 93%
    - Chemical reduction: 93%
    - Energy: 93%
    - Eq.Down Time: 93%
    - Eng effort: 67%

# Highlight

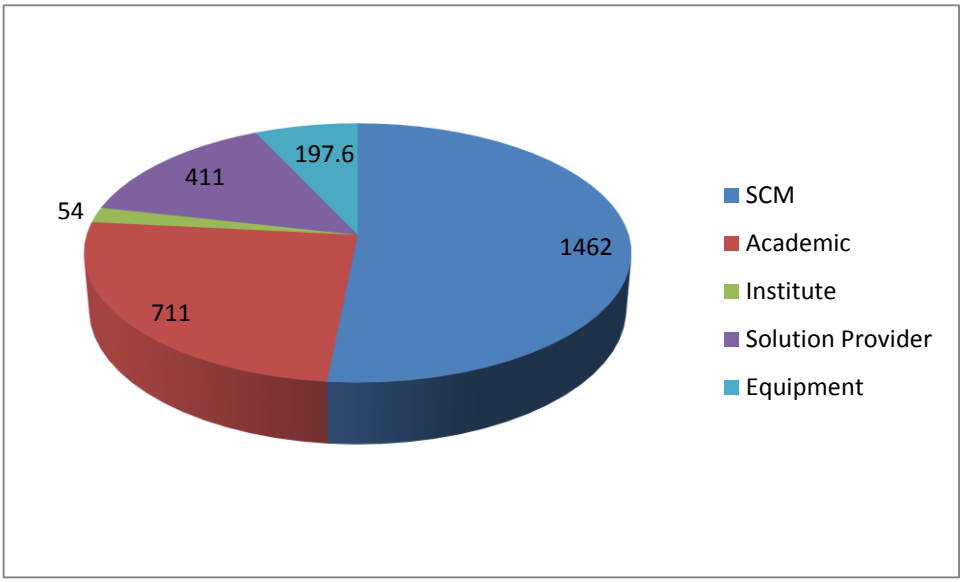
- All competencies are present within the project
  - End users – universities and research centers – solution providers
- We have gone through all the different aspects of the project:
  - Data acquisition – modeling (statistical and physical) – implementation
- We shared a lot of activities
  - Sensors – VM – PdM – Simulation – Adaptive Control Planning
- Additional competencies
- Increase Knowledge
- Network consolidation
- Basic for new collaborative project

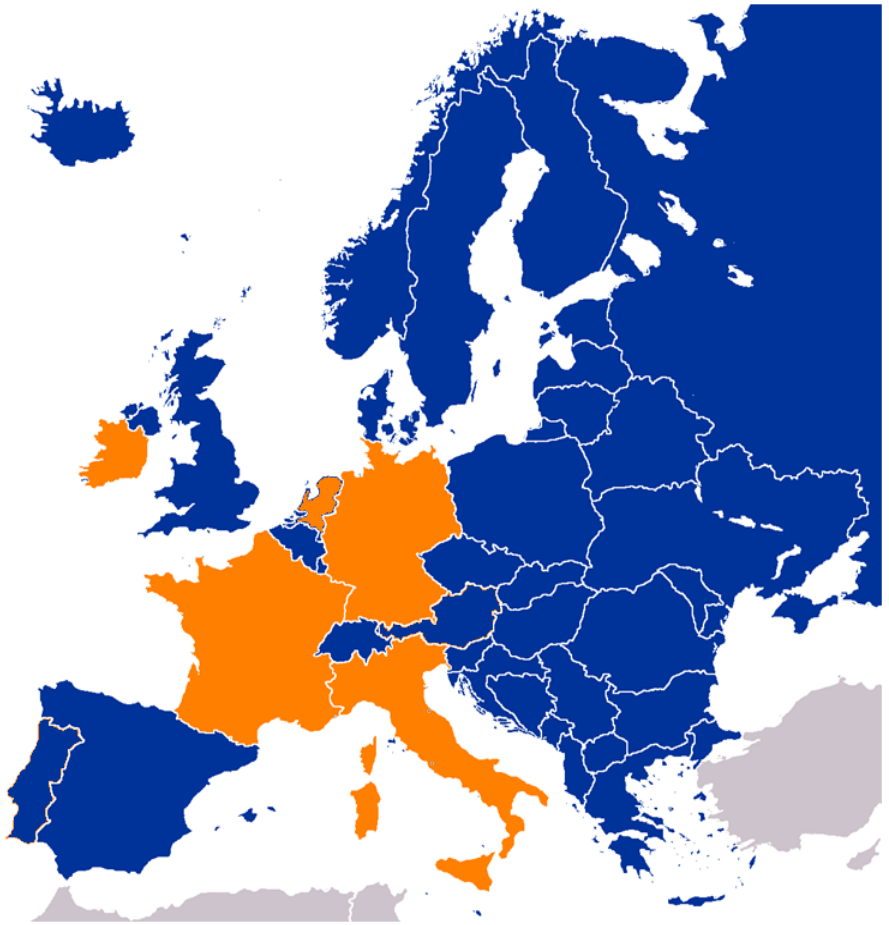
- **Scientific dissemination**
  - About **100 papers in international conferences** (ERIC 2010, ICINCO 2011, IEEE CASE 2011, ASMC 2011) **[more than 50 Italian co-authors]**
  - **Four best student papers [3 Italian students]**
  - Several papers published and submitted in international journals
  - Visibility in well-known conferences (IEEE CASE, MASM, ASMC, …)
  - Participation to the poster during the European Nanoelectronics Forum 2009, 2010, 2011
  - Presentations at Semicon 2010, 2012
- **Recognition**
  - Selected for Innovation Award Contest 2011
  - International Innovation article
  - 2nd prize Best Project Award Industrial Technologies 2012 (FP 5, 6, 7)

# Integrated Solutions for Agile Manufacturing in High-mix Semiconductor Fabs

**Key figures**

- 2835 Men Months over 3 years (Jan-2013 to Dec-2015)
- 78 full-time researchers
- 28 Partners over 5 countries

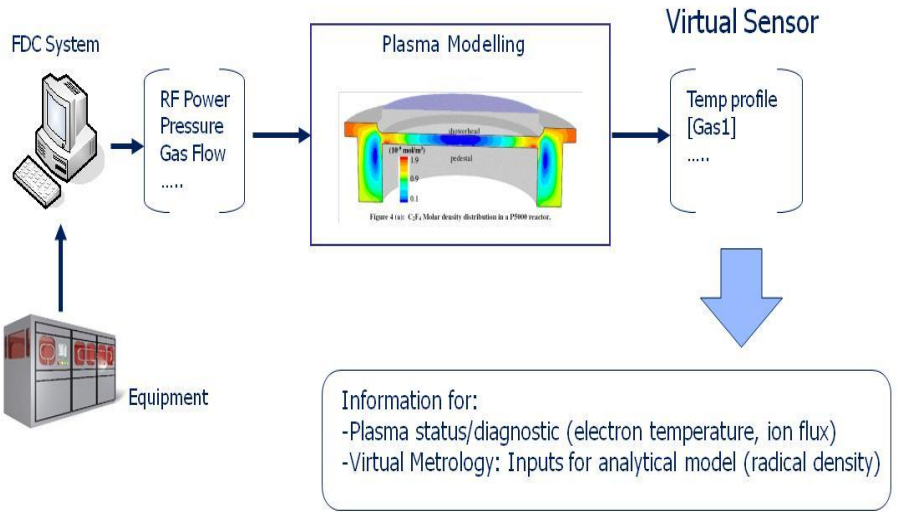


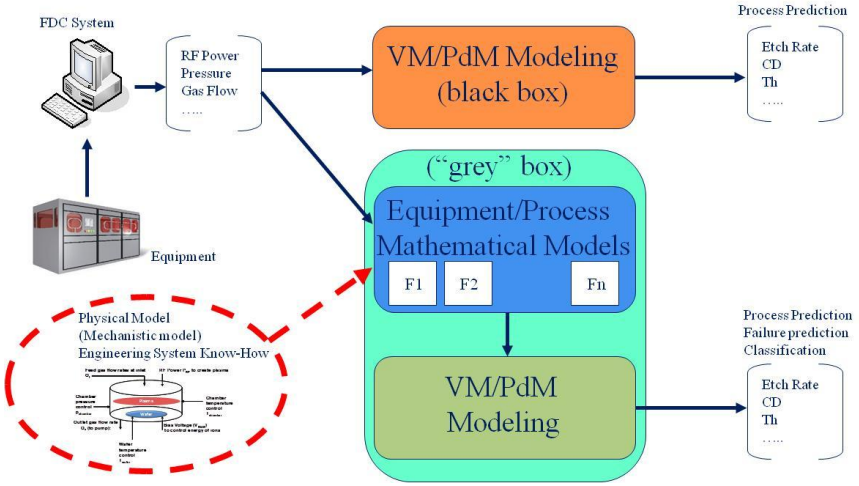
integrate

# Attivita' Micron (Esempio)

- Module for Virtual Sensor and Virtual Metrology
  - Integrate on-line the plasma simulation module
- Application:
  - Plasma status/diagnostic (electron temperature, ion flux)
  - Virtual Metrology: Inputs for analytical model (radical density)




- Grey box models
  - Develop mathematical models based on "knowledge mechanism"
- Application:
  - Virtual Metrology and Predictive Maintenance

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