life.augmented

Future Needs related to Inline Metrology applied in Semiconductor Manufacturing

STMicroelectronics

D. Le Cunff, Ph.D

8th July 2022

We are creators and makers of technology

One of the world's largest semiconductor companies

48,000 employees of which **8,400** in R&D

$12.8 B revenues in 2021

Over **80** sales & marketing offices serving over **200,000** customers across the globe

13 manufacturing sites

Signatory of the United Nations Global Compact (UNGC)
Member of the Responsible Business Alliance (RBA)

life.augmented

As of December 31, 2021

We offer quality, flexibility and supply security

Sweden
Norrköping

France
Crolles
Rousset
Tours
Rennes

Italy
Agrate
Catania

Morocco
Bouskoura

Malta
Kirkop

China
Shenzhen

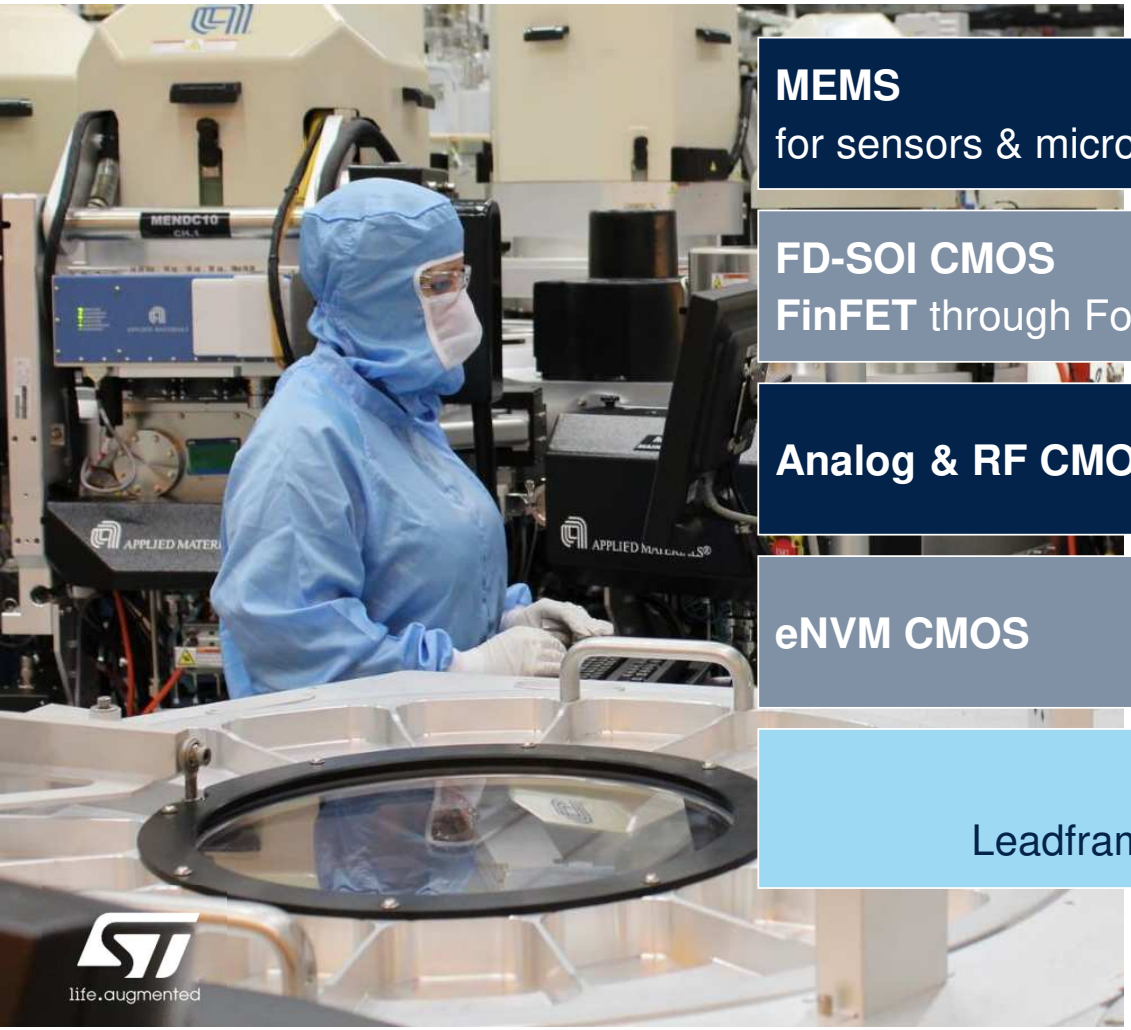
Philippines
Calamba

Malaysia
Muar

Singapore

Front-End
Back-End

Differentiated technologies are our foundation



MEMS
for sensors & micro-actuators

Smart Power: BCD
(Bipolar - CMOS - Power DMOS)

FD-SOI CMOS
FinFET through Foundry

Discrete, Power MOSFET, IGBT
Silicon Carbide, Gallium Nitride

Analog & RF CMOS

Vertical Intelligent Power

eNVM CMOS

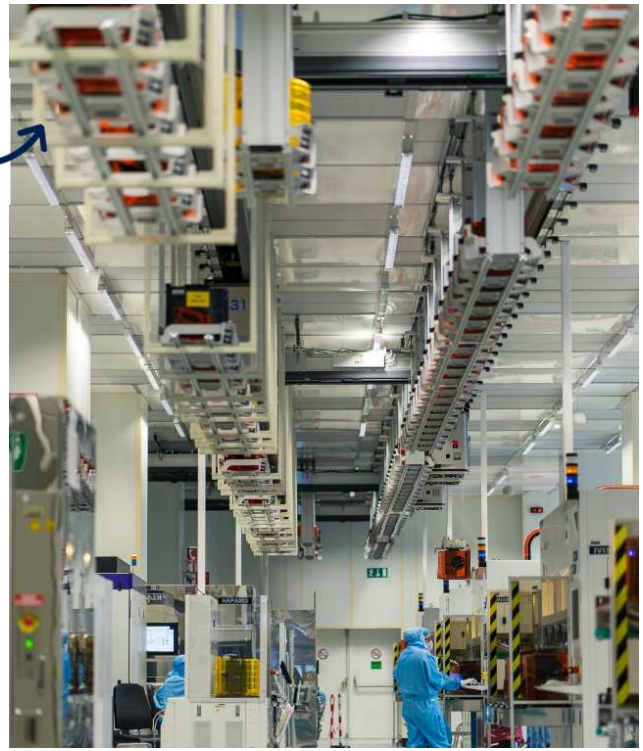
Optical sensing solutions

Packaging technologies
Leadframe – Laminate – Sensor module – Wafer level

STMicroelectronics Europe

Two of the most **modern and efficient** clean rooms worldwide

Equipped with automated transport system form the ceiling



Crolles & Agrate 300mm Factory
4.0 Industry

Human — Device — Method

Bundle of manufacture are going to move from one production to many others
to go through all the operations needed,
without ever passing between human's hands.
Human takes action on the maintenance of device and the implementation

Manufacture of channels : from 6 to 12 weeks – About 600 operations

life.augmented

R&D

Manufacturing

Design

Technologies & Libraries

Develop

Adapt Manufacturing processes & tools for the new Technology

Metrology For Development

Produce

200mm / 300mm wafers high volume production

Metrology For Manufacturing

Adapt Manufacturing processes & tools for the new Technology

200mm / 300mm wafers high volume production

Develop

Produce

Metrology For Development

Provide measurement solution to secure learning cycles and support critical decision for quick path finder

- Advanced Materials & Architectures
- Reference standards
- Smart approaches
- Workforce

Metrology For Manufacturing

Control and Detect process deviation through optimized sampling plan based on risk analysis

- Optimization & Better Control

Adapt Manufacturing processes & tools for the new Technology

200mm / 300mm wafers high volume production

Develop

Produce

Metrology For Development

Provide measurement solution to secure learning cycles and support critical decision for quick path finder

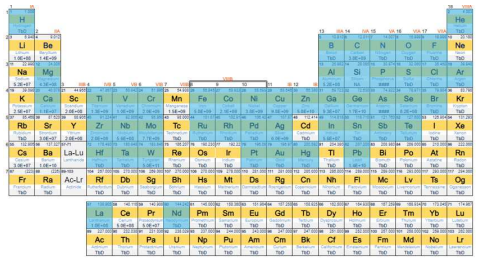
- Advanced Materials & Architectures
- Reference standards
- Workforce

Metrology For Manufacturing

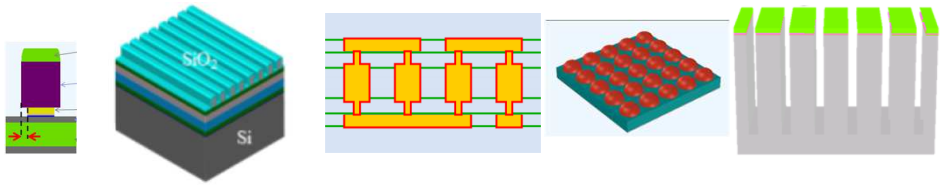
Control and Detect process deviation through optimized sampling plan based on risk analysis

- Optimization & Better Control
- Smart approaches

Advanced Materials & Structures



New material and chemical element introduction



Advanced CMOS *Large pitch and 3D structures* *Deep trenches*

New characteristics «More than Moore»:
- Optical transmission or emission
- Mechanical and thermal properties
- Stress, Adhesion
- Piezoelectrical

Complementary techniques needed
- Multi physics and multi scale modeling

Transfer lab to fabs
- Quick time to solution via collaboration
- Introduction in fab at early TRL

Ellipsometry, X-Ray, Acoustics, Raman, electrical…

Complex scaled structures
- 3D profile
- Massive measurement uniformity/EPE

High AR or Large pitch
- Small feature on large structures

Metrology target representativity
- Indie measurement / ML algorithm
- Edge of wafer

E-Beam, Scatterometry, CD-SAXS, SPM…

Adapt Manufacturing processes & tools for the new Technology

200mm / 300mm wafers high volume production

Develop

Produce

Metrology For Development

Provide measurement solution to secure learning cycles and support critical decision for quick path finder

- Advanced Materials & Architectures
- Reference standards
- Smart approaches
- Workforce

Metrology For Manufacturing

Control and Detect process deviation through optimized sampling plan based on risk analysis

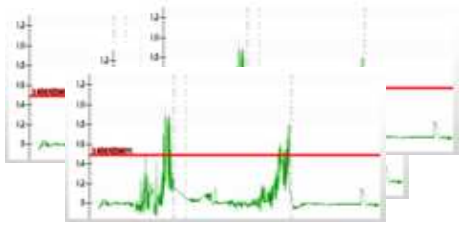
- Optimization & Better Control

Data / Sensors

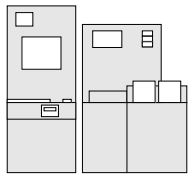
Production Equipment

Internal sensors

- Temperature
- Electronic
- Flux
- Voltage
- …

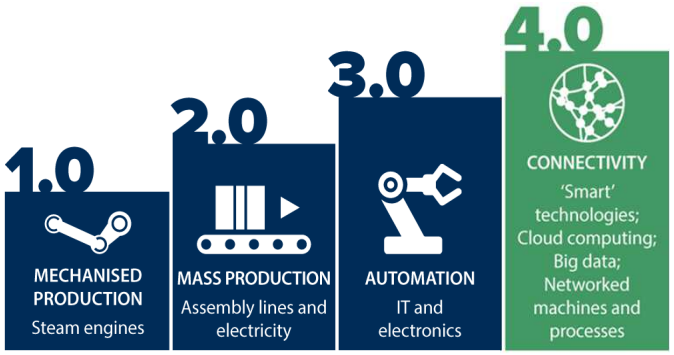


Digital Twin



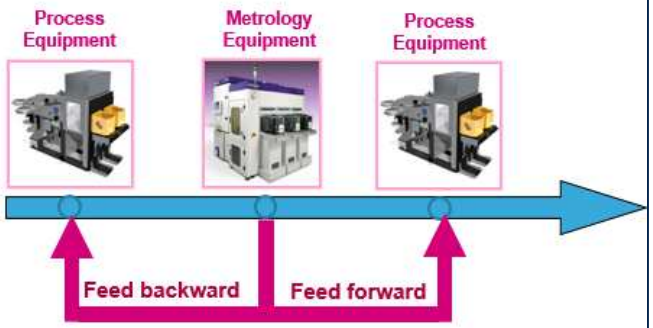
Fault Detection Control

- Control chart
- Statistical analysis
- …

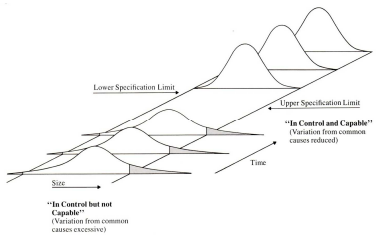


The stages of industrial development

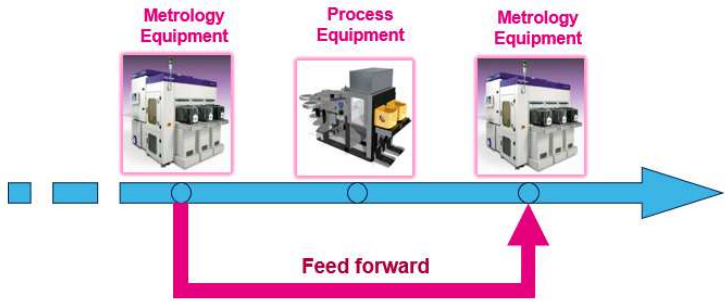
Advanced Process Control



$$\sigma^2_{Observed} = \sigma^2_{process} + \sigma^2_{Measurement}$$



Holistic Metrology



Adapt Manufacturing processes & tools for the new Technology

200mm / 300mm wafers high volume production

Develop

Produce

Metrology For Development

Provide measurement solution to secure learning cycles and support critical decision for quick path finder

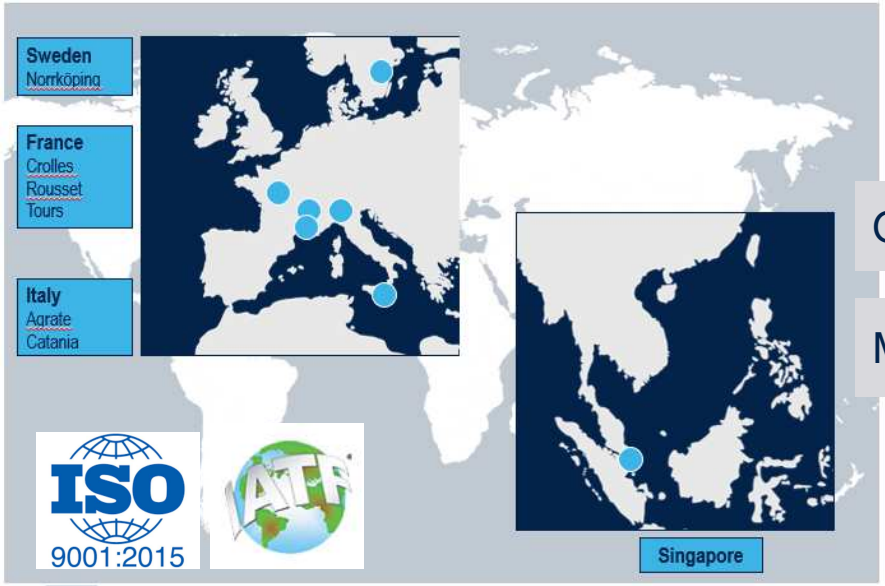
- Advanced Materials & Architectures
- Reference standards

Metrology For Manufacturing

Control and Detect process deviation through optimized sampling plan based on risk analysis

- Optimization & Better Control
- Smart approaches
- Workforce

Virtual Fab Strategy

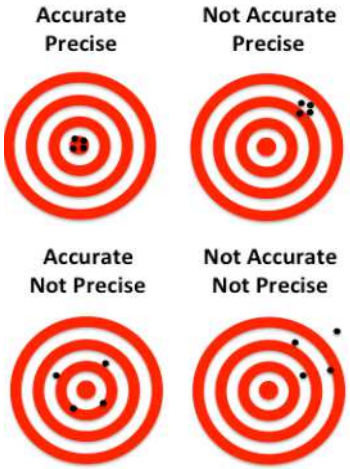


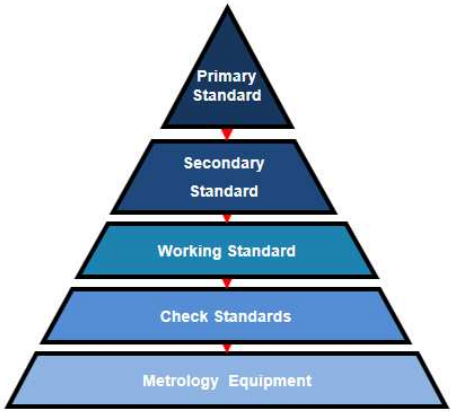
Quick and Safe Technology Transfer

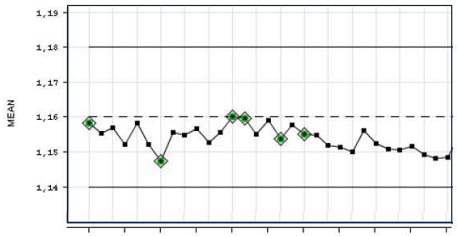
Mutualisation of Fab manufacturing Capacity

Alignment between fab metrologies is a pre-request

Need for reference standards :
- Industrial, stable over time and usage
- Cover all metrology techniques and ranges







AI layer in HKMG : 1.2 A +/- 0.4 A

- Multiples system → Virtuous cycle
- Precision requirements are more agressive than accuracy uncertainty

Adapt Manufacturing processes & tools for the new Technology

200mm / 300mm wafers high volume production

Develop

Produce

Metrology For Development

Provide measurement solution to secure learning cycles and support critical decision for quick path finder

Metrology For Manufacturing

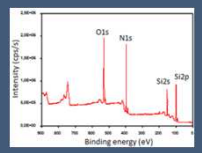
Control and Detect process deviation through optimized sampling plan based on risk analysis

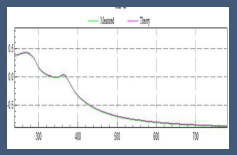
- Advanced Materials & Architectures
- Optimization & Better Control
- Reference standards
- Smart approaches
- Workforce

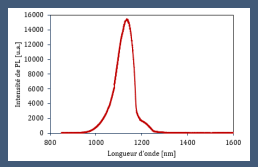
AI Approach - Large Adoption

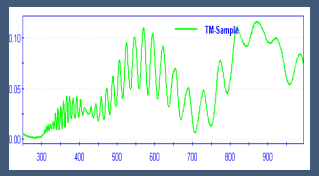
METROLOGY

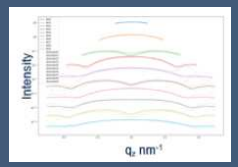
Raw output data (Spectrum, Counts…)











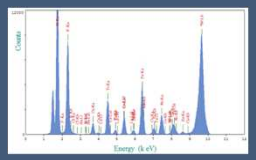
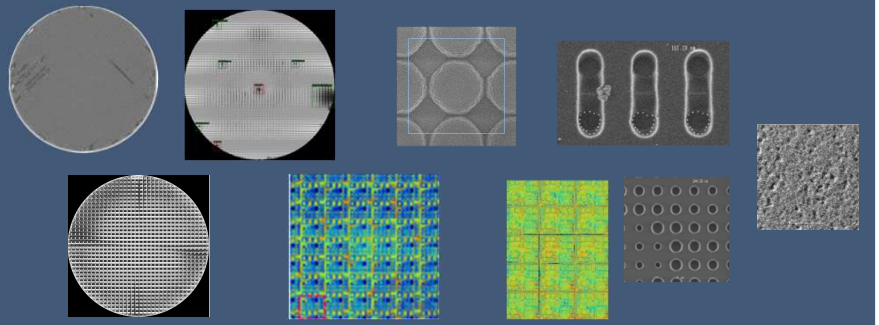
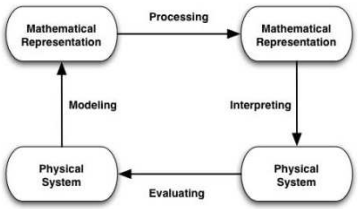


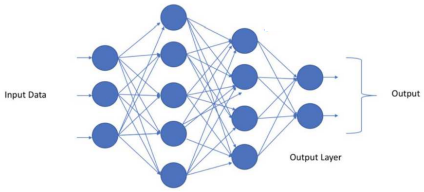
Image (Intensity, Gray Levels …)



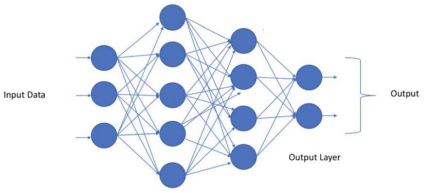


Physical Modeling

Measured Values of Parameter



NN algorithm



NN algorithm

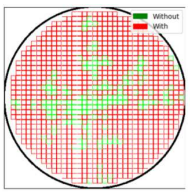
$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

Mathematic treatment

Measured Values of Parameter

Good/Bad



METROSPECTION

Adapt Manufacturing processes & tools for the new Technology

200mm / 300mm wafers high volume production

Develop

Produce

Metrology For Development

Provide measurement solution to secure learning cycles and support critical decision for quick path finder

Metrology For Manufacturing

Control and Detect process deviation through optimized sampling plan based on risk analysis

- Advanced Materials & Architectures
- Optimization & Better Control
- Reference standards
- Smart approaches
- Workforce

Need young talent

Create attractivity for Measurement Science

- Promote Innovation Projects
- Educational Events & Programmes
- Forums / Thematic weeks

life.augmented

Our technology starts with You

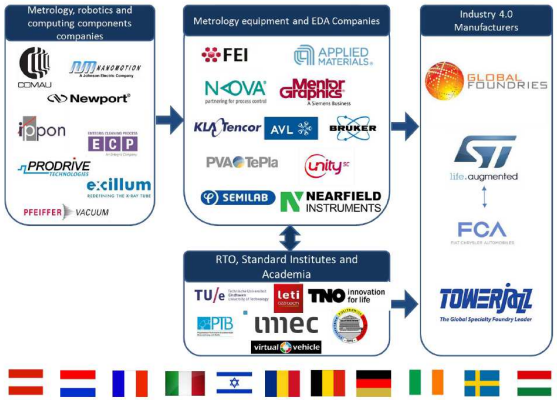
life.augmented

EMPIR: Support Letter for **ATMOC** and **ELENA** Joined Research Projects

Some on going projects

MADEin4

ECSEL Joint Undertaking



MADEin4 aims to bring production lines to a next level in productivity and predictability by focusing on two **boosters**; while fulfilling and/or exceeding also sensitivity, precision and accuracy requirements:

- Productivity booster 1: High throughput, next generation metrology and inspection tools development. This booster, yielding connected Cyber Physical Systems (CPS) enabling very high sampling and data-rates, will be developed by the metrology equipment manufacturers, module suppliers and knowledge institutes and will be demonstrated in an industry 4.0 pilot line at IMEC. It will address major challenges for ECS equipment, materials and manufacturing industries. .
- Productivity booster 2: Develop combinations of Design (EDA),Product/process Life Cycle Management (PLM), modelling, simulations and advanced metrology data analysis with Machine Learning (ML), Digital Twinning and predictive diagnostics of the process (predictive yield) and tools performance. This booster will be developed and demonstrated in an industry 4.0 pilot line at IMEC, by the EDA, and by computing and metrology partners. The digital twinning and predictive maintenance concepts will be demonstrated in two major 'digital industries': semiconductor industry and automotive production.

CHALLENGES
Real time nano CHAracterization reLatEd techNoloGiEeS

THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION
HORIZON 2020

CHALLENGES consortium is composed by **14 partners** from 7 Countries:

5 EU Countries (Belgium, France, Germany, Italy, Spain)

and 2 H2020-associated Countries (Israel and Belarus)

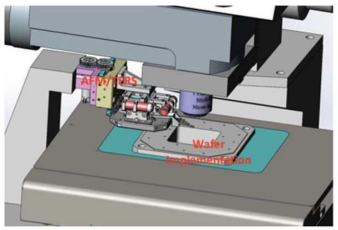


Figure 2 CAD design of the AFM proposed by NANONICS

The project Real-time nano-**CHA**racterization re**L**at**E**d tech**N**olo**G**i**E**e**S** – **CHALLENGES** – aims to develop **innovative Non-Destructive Techniques (NDTs) for reliable inline multiscale measurements down to the nanoscale, and fully compatible with different factory environments**. The developed metrology technologies will enable the **increase of speed, resolution, sensitivity, spectral range and compatibility within different nano-related production environments, finally improving products performance, quality and reliability, with the consequent bosting of competitiveness.** The CHALLENGES's innovation will be developed exploiting the plasmonic enhancement of optical signals. It will provide a non-destructive approach based on the use of multipurpose nano-optical techniques to enable a reliable real-time nano-scale characterization in the factory floor, using **plasmonic enhanced Raman, InfraRed (IR) and Photoluminescence signals.**