CHALLENGES

Real time nano CHAracterization reLatEd techNoloGiEeS

Workshop: **«Nanospectroscopy and Nanotechnology: Challenges and Innovations»**

Session: **«Nanospectroscopy and Nanotechnology: Challenges and Innovations Basic principles of Nanospectroscopy»**

Wednesday September 16th 2020

Vittorio Morandi
CNR-IMM Bologna

Nano Innovation 2020 Rome, 15-18 September

Conference & Exhibition

Project General Information

MY PROJECT

HORIZON 2020

Call: H2020-NMBP-TO-IND-2019
Type of Action: RIA
Acronym: CHALLENGES
Current Phase: Grant Management
Number: 861857
Duration: 36 months
GA based on the: H2020 General MGA — Multi - 5.null
Start Date: 01 Apr 2020
Estimated Project Cost: €4,691,566.25
Requested EU Contribution: €4,691,566.25
Contact: Yanaris ORTEGA GARCIA

Title: Real time nano CHAracterization reLatEd techNoloGiES

Acronym: CHALLENGES

Research and Innovation Action: f. rate - 100%

Start date: 1st April 2020

End date: 31st March 2023

Duration: 36 months

GA n°: 861857

Estimated costs: 4.691.566,25 €

EU Grant: 4.691.566,25 €

PO: Yanaris Ortega Garcia

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861857".

Project Consortium

CHALLENGES
Real time nano CHAracterization reLatEd techNoloGiEeS

Real time nano CHAracterization reLatEd techNoloGiES

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)

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861857".

Project Consortium

Real time nano CHAracterization reLatEd techNoloGiES

CHALLENGES consortium is composed by **14 partners:**

1 Public University
(Sapienza)

4 Scientific Public Institutions
(CNR, PTB, CEA, IMEC)

8 Private Industries
(Lfoundry, Graphenea, Tiberlab, Nova, Nanonics, Scansens, Amat, Sol)

1 Consultancy services company
(Bewarrant)

No	Name	Short name	Country	Project entry month[8]	Project exit month
1	UNIVERSITA DEGLI STUDI DI ROMA LA SAPIENZA	UNISAP	Italy	1	36
2	INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM	IMEC	Belgium	1	36
3	GRAPHENEA SEMICONDUCTOR SL	GRAPHENEA	Spain	1	36
4	LFOUNDRY SRL	LFOUNDRY	Italy	1	36
5	CONSIGLIO NAZIONALE DELLE RICERCHE	CNR	Italy	1	36
6	TIBERLAB S.R.L.	TIBERLAB	Italy	1	36
7	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES	CEA	France	1	36
8	NOVA MEASURING INSTRUMENTS LTD	NOVA	Israel	1	36
9	NANONICS IMAGING LTD	NANONICS	Israel	1	36
10	SCANSENS GMBH	SCANSENS	Germany	1	36
11	APPLIED MATERIALS ITALIA SRL	AMAT	Italy	1	36
12	PHYSIKALISCH-TECHNISCHE BUNDESANSTALT	PTB	Germany	1	36
13	BEWARRANT	BEWG	Belgium	1	36
14	SOL INSTRUMENTS LTD	SOL	Belarus	1	36

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861857".

The Project in a Nutshell

The project Real-time nano-**CHA**racterization re**L**atEd 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.**

Unconventional plasmonic materials + unconventional spectrum ranges + tip enhanced spectroscopy

=

Revolutionary spectroscopic system for real time nanotechnology characterization compatible with semiconductor production

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861857".

CHALLENGES

Real time nano CHAracterization reLatEd techNoloGiEeS

Scientific Excellence

	Raman	Photoluminescence	InfraRed
Probing wavelength range	Visible (500 – 700 nm)	Visible (500 – 700 nm)	Mid-InfraRed (3000 – 10000 nm)
Detected wavelength range	Visible (500 – 700 nm)	Near-InfraREd (700 – 300 nm)	Mid-InfraRed (3000 – 10000 nm)
Far field resolution	0.25 μm	0.25 μm	5 – 10 μm
Plasmonic materials	TiN, TaN	TiN, TiMgN, TiScN, ITO, AZO	ITO, AZO, doped Si
CHALLENGES improved resolution	TERS: **20 nm** 2-Photon Raman: **5 nm**	s-SNOM: **50 nm** TEPL: **20 nm**	s-SNOM: **20 – 50 nm**
Measurable physical value	Strain, crystallinity, doping level	Dislocations, lifetime, doping level	Oxide composition, dangling bonds
Affected product characteristics	Junction leakage (dark current on CIS), transistor performance, yield of thin PV cells	Transistor performance, metal contamination during production, junction leakage	Transistors threshold voltage shift, oxides reliability to breakdown, less 1/f noise

“This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 861857”.

CHALLENGES
Real time nano CHAracterization reLatEd techNoloGiEeS

Main Objectives

1: To provide a fully automated AFM-based tool, optimized for plasmonic enhancement of optical signals in industrial production environments and not requiring human intervention in routine operations.
2: To develop large sample (6”, 8” and 12” wafer or 156x156 mm2 solar cell) XY piezo scanning stages.
3: To develop the optimum coupling solutions of light wavelengths, AFM tip shapes and unconventional materials to maximize plasmonic resonance, resolution and measurement capability in Silicon devices factory environment.
4: To design and demonstrate a nanoscale metrological NDT system that is compatible with production lines that need cleanroom environment.
5: To train a neural network capable to locate, with low-resolution hardware, relevant sites on the sample to probe with the high-resolution system, in a machine-learning framework.
6: To demonstrate the process-adapted nanoscale metrology for the manufacturing industry, through its use in three relevant industrial application contexts related to CMOS electronics, Silicon Photovoltaics and 2D Materials.

“This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 861857”.

Project Structure - WPs

	Title	WP Leader	Duration
WP1	Development and manufacturing of materials for tests and round robins	IMEC Ivan Gordon	M1 – M30
WP2	Development of clean room compliant tips	Sapienza University Daniele Passeri	M1 – M33
WP3	Instrumentation development	NANONICS Aaron Lewis	M1 – M33
WP4	Application techniques and validation of novel in-line characterization	CNR Vittorio Morandi	M1 – M33
WP5	Development of commonly agreed measurement protocols	PTB Rainer Stosch	M1 – M36
WP6	Exploitation and environmental impact	BeWarrant Lisa Bregoli	M1 – M36
WP7	Dissemination, communication and training	BeWarrant Isella Vicini	M1 – M36
WP8	Project management and coordination	Sapienza University Marco Rossi	M1 – M36

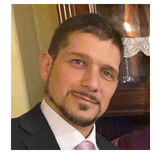
"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861857".

Project Structure - Governance

PROJECT COORDINATOR
Marco Rossi (Sapienza)

PROJECT Manager
Isella Vicini (BeWarrant)

EXPLOITATION Manager
Onofrio Antonio Cacioppo (LFoundry)

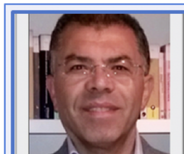


RISKS Manager
Daniele Passeri (Sapienza)

EXECUTIVE MANAGEMENT BOARD

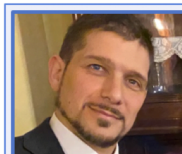
Project Coordinator
Marco Rossi

Project Manager
Isella Vicini



Exploitation Manager
Onofrio Antonino Cacioppo

WP1
Ivan Gordon - IMEC



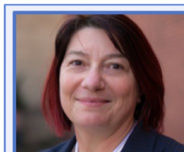
WP2
Daniele Passeri - UNISAP

WP3
Aaron Lewis - NANONICS

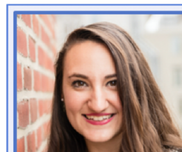
WP4
Vittorio Morandi - CNR

WP5
Rainer Stosch - PTB

WP6
Lisa Bregoli - BEWG



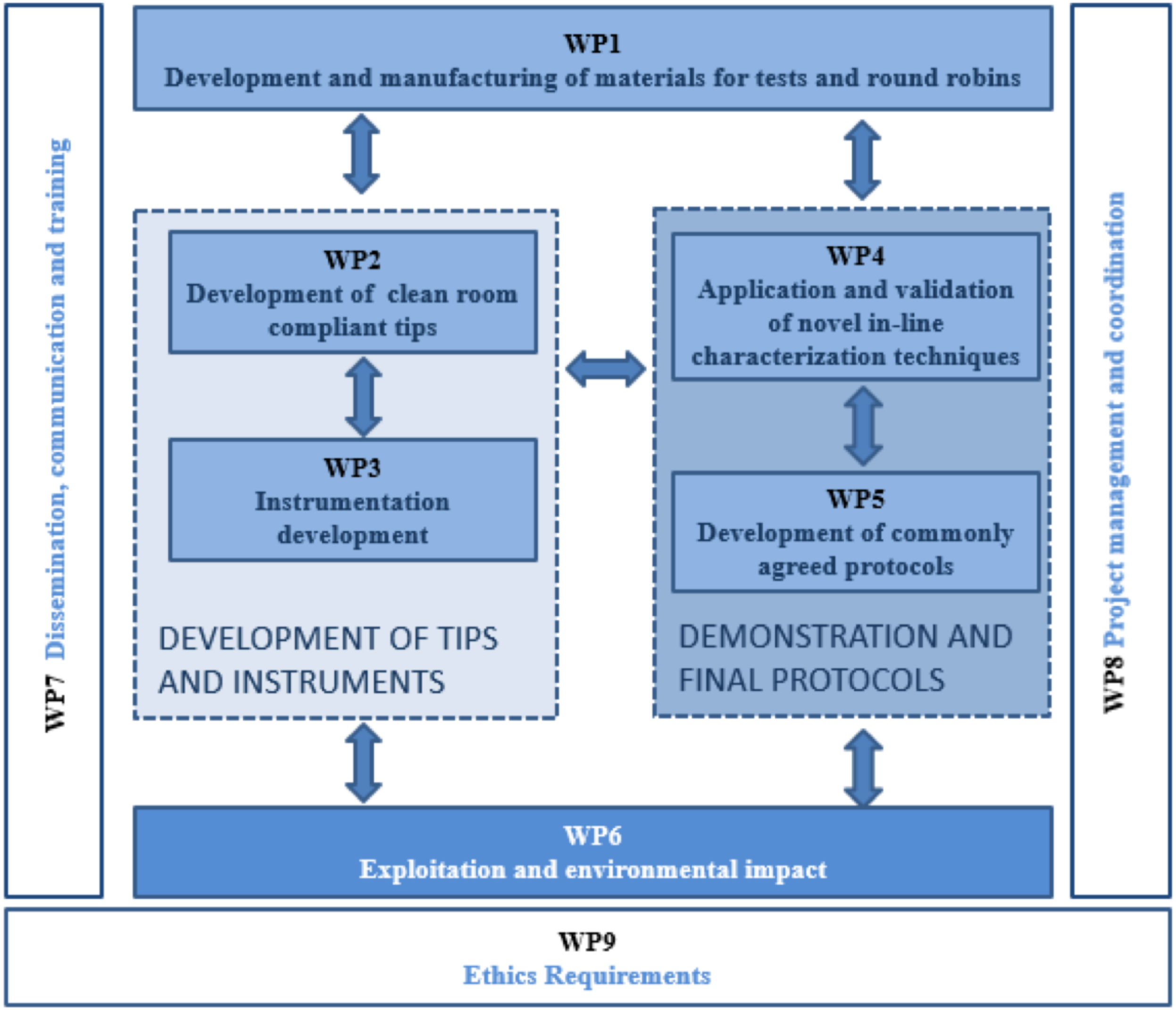
WP7
Isella Vicini – BEWG



WP 8
Marco Rossi - UNISAP
Stefania Melandri - BEWG

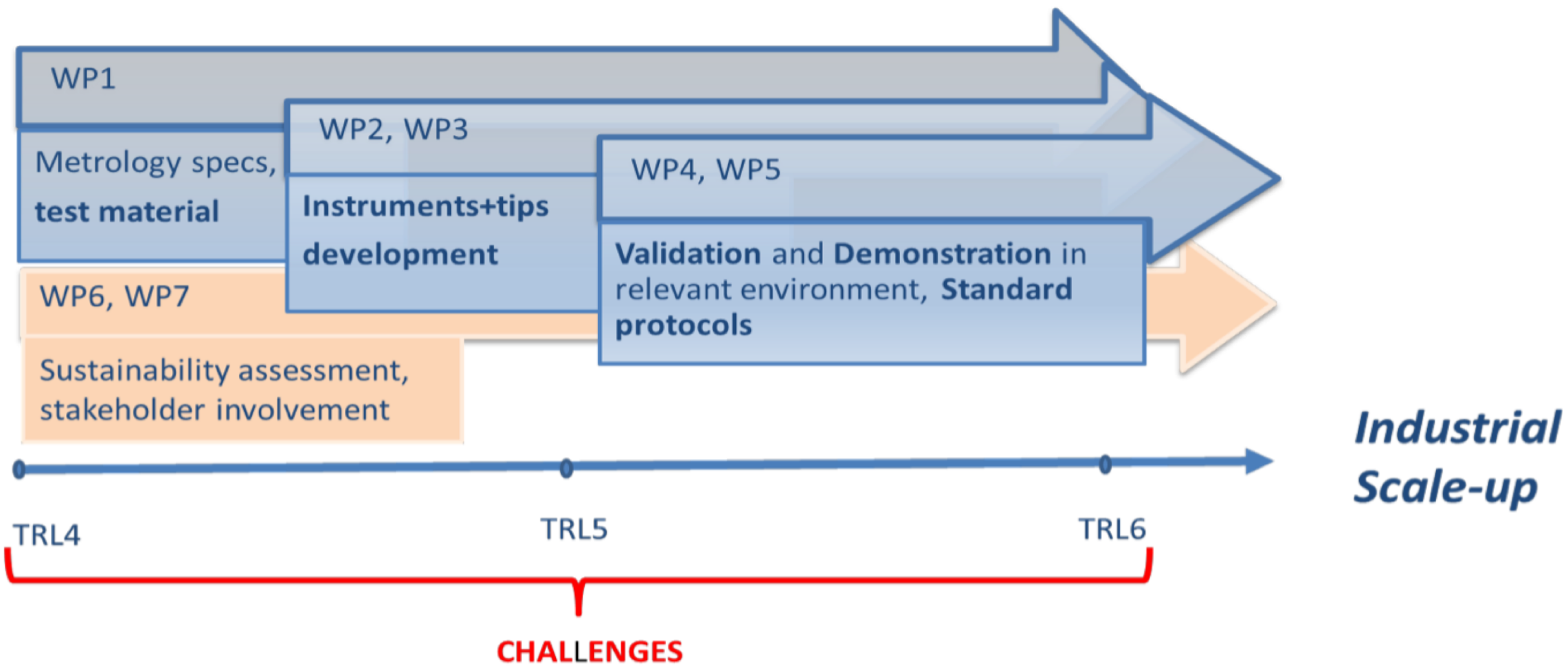
"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861857".

Project Structure - PERT



"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861857".

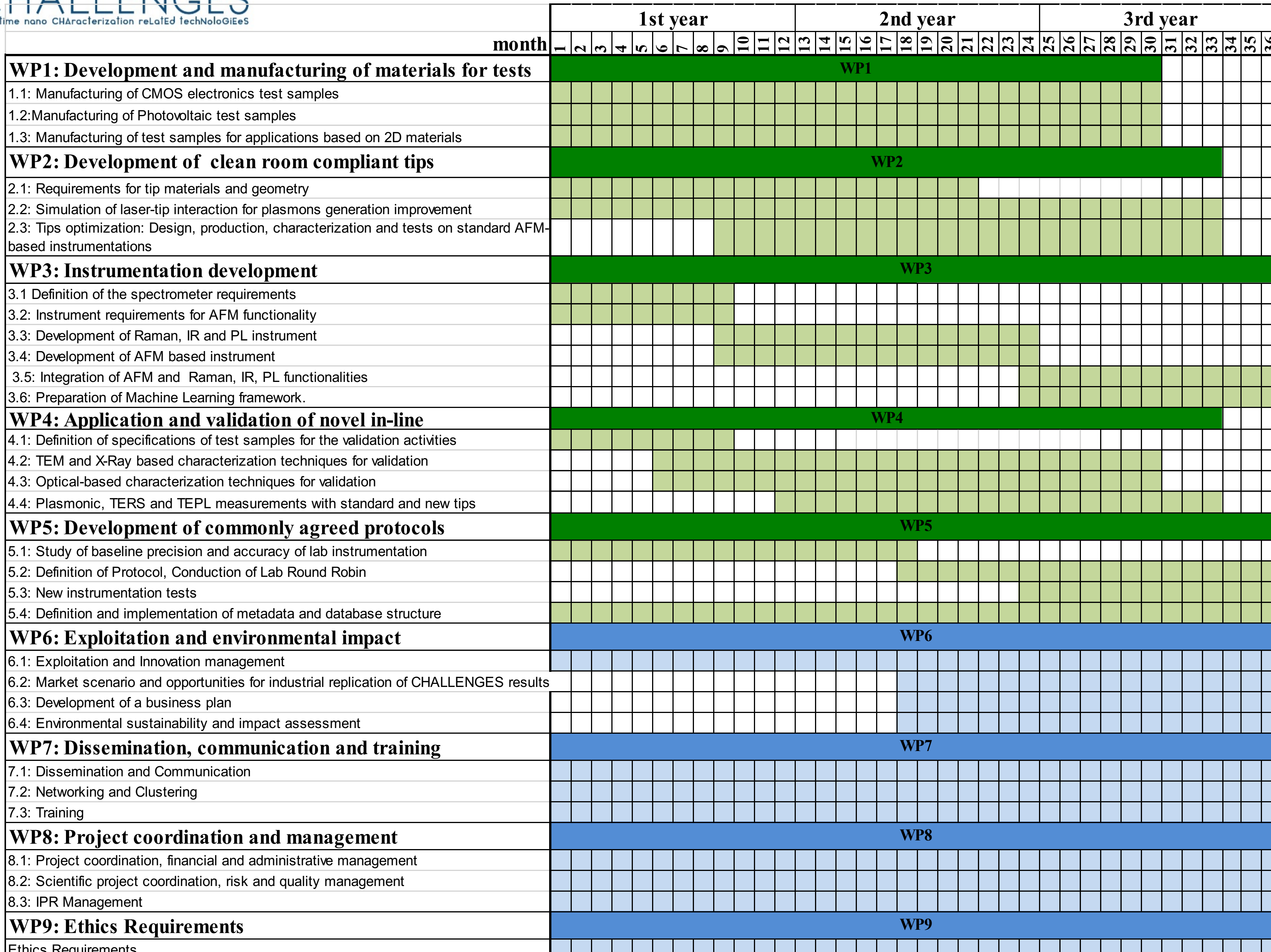
Project Structure - TRL



CHALLENGES will develop a family of optical-based multi-scale characterization technologies fully compatible with the manufacturing production lines and **will demonstrate and validate of the new related techniques in the identified relevant industrial environments, with the aim to increase their TRL at least up to TRL6**

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861857".

Project Structure - GANTT



Used Characterization Methods

List of main characterisation methods used in the project	Main reference in the project	Main contact in the project
AFM-based	UNISAP	Prof. Marco Rossi
TEM-based	CNR	Dr. Vittorio Morandi
XRD/XRF/XAFS	CEA	Dr. Narciso Gambacorti
s-SNOM in IR and PL	UNISAP	Prof. Marco Rossi
μ-EXAFS	PTB	Dr. Burkhard Bekhoff
Photoluminescence	CNR	Dr. Salvatore Lombardo
TERS and TEPL	NANONICS	Dr. Aaron Gordon
μ-Raman	CEA CNR	Dr. Narciso Gambacorti Dr. Alessandro Molle

“This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 861857”.

Developed Characterization Methods

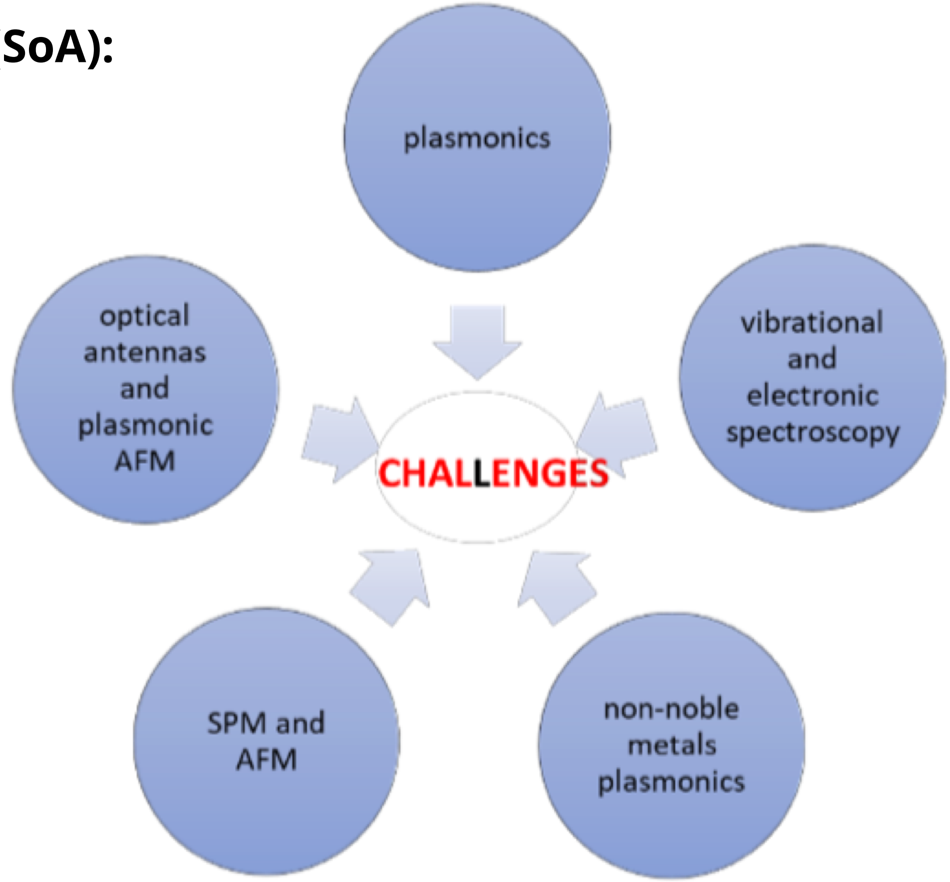
List of main characterisation methods developed in the project	Level of development in the project	Main reference in the project
TERS	Instrumentation Developer Method Developer	NANONICS SOL LFoundry
TEPL	Instrumentation Developer Method Developer	NANONICS SOL LFoundry
s-SNOM	Instrumentation Developer Method Developer	NANONICS SOL UNISAP
2-Photon TERS	Instrumentation Developer Method Developer	NANONICS SOL LFoundry
Random Defect Analysis (RDA) tool	Method Developer	NANONICS
Machine-learning framework	Method Developer	NOVA

“This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 861857”.

Main Impacts

Advances beyond state-of-the-art (SoA):

the main advancements beyond the SoA proposed by CHALLENGES are related to the **implementation of non-destructive nanoscale optical measurements by Plasmonic AFM-based technologies** with an improved throughput suitable for industrial environments.



"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861857".

CHALLENGES
Real time nano CHAracterization reLatEd techNoloGiEeS

Main Impacts

CHALLENGES proponents want to bring up innovative technological approaches to the standards of mainstream technologies like µRaman and µPhotoluminescence. In order to attain this dramatic change, some critical **advancements are needed with respect to SoA:**

- new materials for the tips, i.e. conductive ceramics, both compatible with production environments and more reliable in the use (harder and thus with lower wear rate);

- better, automatic tip-objective alignment, which would not require skilled operator time and enable semi-automatic use;

- contact AFM techniques (tapping or shear force); sample scanning AFM capable to move large samples, 200 mm and 300 mm wafers, with also faster speeds both of imaging and moving to test locations.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861857".

Industrial Needs

The project is totally oriented on the industrial needs.

It is based on three ***Real** Application Contexts,* for each of which the material characterization needs are addressed to the process control during the production in a non-destructive way, in real-time and with a resolution at the nanoscale:

- SEMICONDUCTOR INDUSTRY (110 nm CMOS Image Sensors and nanoscale transistors for logic and RF: CMOS 110nm Image Sensors (CIS) quality and reliability (***LFOUNDRY***) ; Strain engineering in Si-Ge advanced CMOS technology nodes (***CEA***)
- production of thin c-Silicon solar cells and modules (***IMEC, AMAT***)
- wafer-scale synthesis and production of devices based on Graphene and 2D Materials (***GRAPHENEA, CNR***)

Advanced characterizations able **to be performed in a reliable and non-destructive way, in real-time and with a resolution at the nanoscale** are pre-requisites for the production of new advanced devices exploiting the innovative properties of nanomaterials.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861857".

Industrial Involvement

Industrial partners	Application main field(s)	Type of Organization (SME/Mid/Large)	Main contact in the project
LFoundry	Semiconductors	Large	Dr. Onofrio Antonino Cacioppo
Applied Materials	Photovoltaics	Large	Dr. Giorgio Cellere
ScanSens GmbH	TERS AFM	SME	Dr. Andrew Shubin
NANONICS	AFM	SME	Dr. Aaron Lewis
Nova Measuring Instrument Ltd	Spectrometry / Metrology	Mid	Dr. Amiad Conley
TIBERLAB	Software	SME	Dr. Fabio Sacconi
GRAPHENEA	2D Materials	SME	Dr. Amaia Zurutuza

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861857".

CHALLENGES
Real time nano CHAracterization reLatEd techNoloGiEeS

Case Studies & Characterization Data

Application Context #1: Process control in semiconductor industry (110 nm CMOS Image Sensors and nanoscale transistors for logic and RF)

- CMOS 110nm Image Sensors (CIS) quality and reliability (LFOUNDRY)
- Strain engineering in Si-Ge advanced CMOS technology nodes (CEA)

CHALLENGES project will employ the plasmonics-enhanced technologies to enable nanoscale real-time strain measurement (by means of TERS to compare with Raman spectroscopy), gate-oxide composition for quality/reliability control (by means of TEIRAS to compare with IR absorption spectroscopy) and metal contamination control (by means of s-SNOM PL to compare with PL spectroscopy) after implantation and thermal annealing of Test structures of nanowire transistors.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861857".

Case Studies & Characterization Data

Application Context #2: Process control during production of thin c-Silicon solar cells and modules (IMEC, AMAT)

CHALLENGES will develop the appropriated methodology, based on plasmonics enhanced Raman spectroscopy, to enable the real-time detection down to the nanoscale of the strain in the ultra-thin Si wafers, during the various industrial processing steps from wafer formation all the way down to module assembly

Application Context #3: Process control during production of devices based on Graphene and 2D Materials (GRAPHENEA, CNR)

CHALLENGES will address the present lack of industrial relevant quality control methods for graphene, providing methodologies and instrumentation applied to graphene and of graphene-based systems for their effective use "in the fab"

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861857".

CHALLENGES
Real time nano CHAracterization reLatEd techNoloGiEeS

Modelling

MODELLING ACTIVITES (Partners: TIBERLAB, UNISAP):

Simulation of laser-tip interaction for plasmons generation improvement at a comparable level with the state-of-the-art of Ag-Si tips based systems

- Plasmonic properties of CMOS compatible materials analysed by Mie theory to find plasmonic resonances, dipole and higher modes, which have to be adjusted to the laser wavelength, and estimate the radiative damping
- The most promising plasmonic materials for a tip end will be chosen for further numerical studies
- First-principle simulations to provide dielectric models
- Finite Difference Time Domain (FDTD) and Finite Elements Methods (FEM) using commercial software like CST, Lumerical and COMSOL. Multiscale simulation with in-house TiberCAD software suite.

Tips design optimization

- Modelling of laser-tip interaction and optical properties of plasmonic materials
- Simulation of advanced tip structures and prediction of their performances

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861857".

CHALLENGES
Real time nano CHAracterization reLatEd techNoloGiEeS

Expected Results

Exploitable Results *(Owner)*	Target stakeholders and/or users
Plasmonic **tips** made of not noble metals materials *(SCANSENS, UNISAP, TIBERLAB, LFOUNDRY*)	Semiconducting manufacturing fabs. Academic and private laboratories. All AFM users and producers
Large size **sample holder stage** *(NANONICS)*	All AFM users and producers. Users and producers of similar characterization tools and platforms
High speed **AFM** ready for integration with spectroscopy equipment *(NANONICS)*	All AFM users
Raman/PL/IR **spectroscope** ready for 2-photon Raman, TEPL, TEIRAS, s-SNOM *(SOL)*	All existing and future users of these techniques in materials science and life science communities
Machine learning **algorithms** between tip enhanced tools and far field metrology tools *(NOVA, LFOUNDRY, GRAPHENEA, IMEC)*	All the companies with interest in advanced materials production and applications
Fully automated cleanroom- ready **system** with automatic loading and unloading of wafer cassettes *(NANONICS)*	Semiconducting manufacturing fabs

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861857".

CHALLENGES
Real time nano CHAracterization reLatEd techNoloGiEeS

Expected Results

Exploitable Results *(Owner)*	Target stakeholders and/or users
Industrial in-line Quality Control method for graphene wafer production line (GRAPHENEA)	Graphenea
Industrial in-line metal contamination control method for CIS wafer production line (LFOUNDRY)	LFoundry
Industrial control method for Nanowire CMOS wafer production line including a Raman stress control (CEA)	Semiconducting manufacturing fabs (Silicon foundries)
Improved production process for epitaxial silicon wafers (IMEC)	Semiconducting manufacturing fabs (Silicon foundries) and Silicon wafer sources
Improved production process for thin silicon solar cells and modules (IMEC, CNR)	Photovoltaic and semiconductor industries
Industrial in-line quality control method TMDs-CMOS wafer production line including (CEA, CNR)	Semiconducting and 2D-materials manufacturing fabs

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861857".

Networking and Future Collaborations

ACTIVITIES TO BE DEVELOPED TROUGH COLLABORATIONS

- **Networking** with the EU-funded Open Innovation Test Beds and Pilot Lines with the aim to customize the proposed technologies for **new applications beyond the project end**.
- **Dissemination** and **Communication**, also through the organization of joint events with others projects
- **Definition of a Metadata Structure** compatible with existing data workflows, taking advantage of feedback and collaboration from stakeholders in the EMMC and EMCC, as well as of clustering with other projects with similar objectives

also in collaborations with the European Materials Characterization Council http://characterisation.eu/

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861857".

CHALLENGES
Real time nano CHAracterization reLatEd techNoloGiEeS

Networking and Future Collaborations

ACTIVITIES TO BE DEVELOPED TROUGH COLLABORATIONS

- Characterization priorities **driven by Industrial Needs** in other fields
- Characterization needs, targets, priorities and challenges) **for specific Industrial Markets**
- Vision/Roadmaps of perspective needs for **Advanced State-of-the-Art Characterization Techniques** (i.e. Tomography, Cryo-EM, SPM techniques, Optical techniques with superesolution capabilities, etc)
- Definition of the requirement of **Academic Programs** (from the Bachelor level to Ph.D.) for the improvement of transversal skills, as fundamental requisite to fully exploit characterizations and modelling achievements **at the Industrial Level.**

also in collaborations with the European Materials Characterization Council http://characterisation.eu/

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861857".

Thank you for your attention

Vittorio Morandi
morandi@bo.imm-cnr.it

Institute for Microelectronics and Microsystems
National Research Council of Italy

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861857".