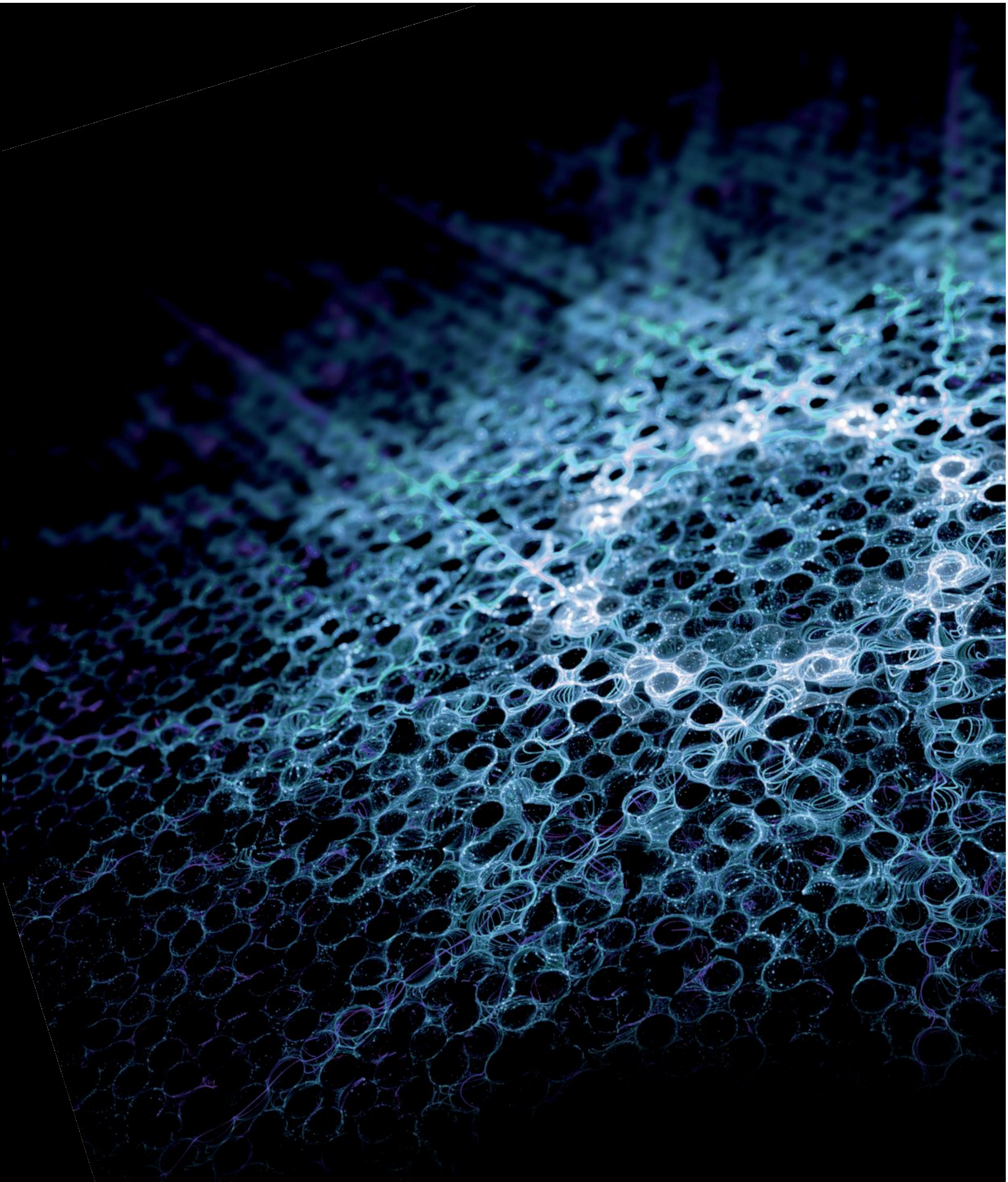

IMM Institute for Microelectronics and Microsystems

National Research Council of Italy

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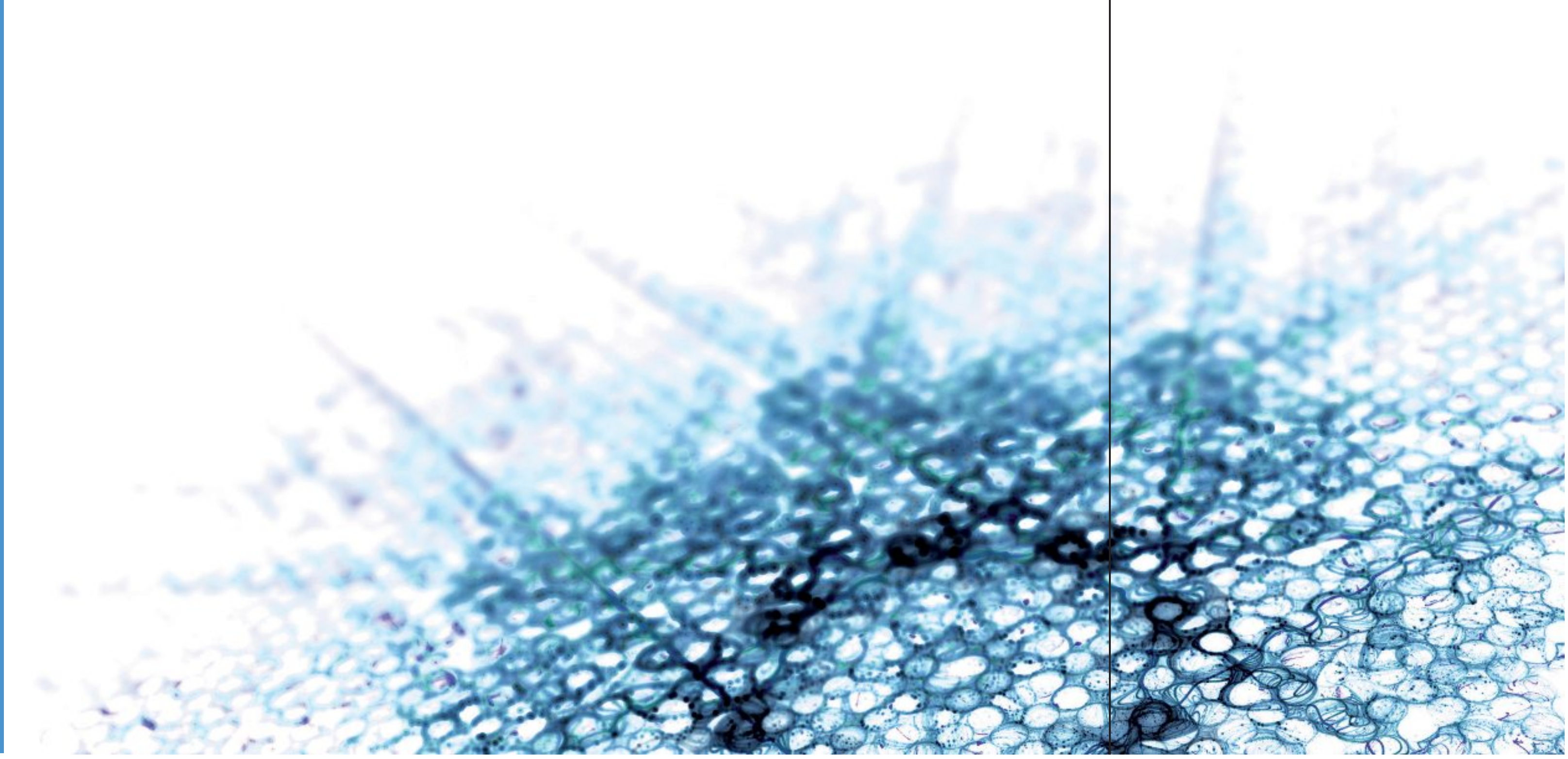


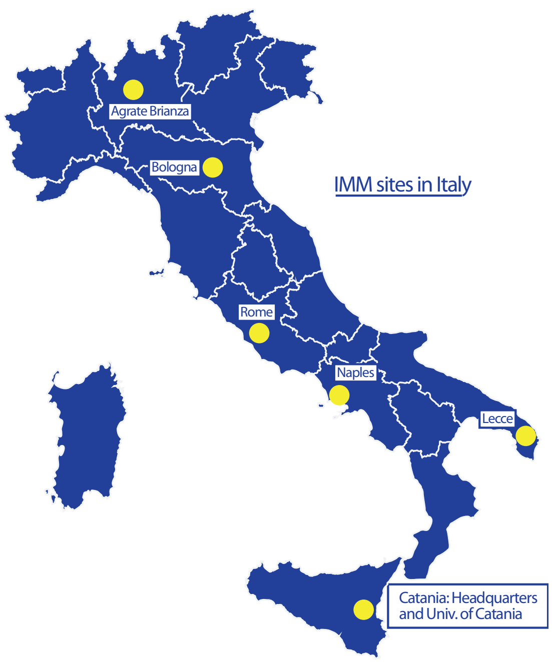
The Institute for Microelectronics and Microsystems (IMM),

belonging to the Physics and Matter Technologies Department of CNR, is organized in 7 Sections, with the Headquarters in Catania and the other Units located in Agrate Brianza (Mi), Bologna, Rome, Naples, Lecce and the University of Catania. The Institute has a permanent staff of 219 people (139 of them Researchers) and a temporary staff including around 40 post-docs and 60 PhD students. In addition, the IMM research activities are further supported by 14 Research Associates (Professors) and 32 Associated Collaborators.

The research activities

The research activities are focused on three main application areas and each one of the application areas is organized in workgroups, which coordinate the scientific activities on specific subjects involving the different IMM Sections:

1. **Micro-Nanoelectronics**
   - a. Power and high frequencies devices
   - b. Flexible and Large area electronic
   - c. Devices for classic and quantum information storage and processing

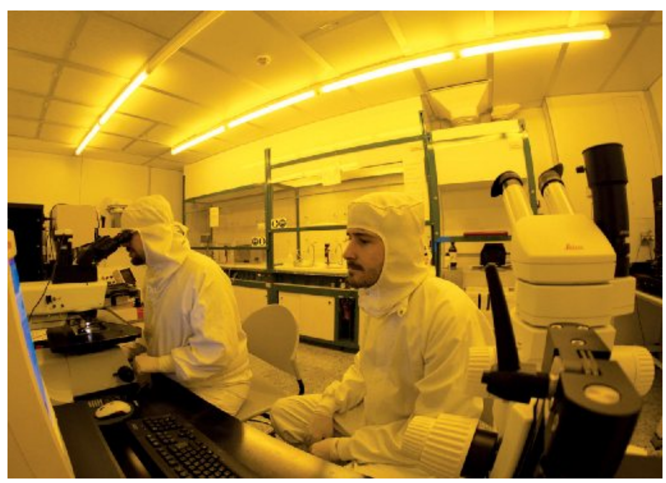


2. **Functional materials and devices**
   - a. MEMS and MOEMS
   - b. Chemical, physical and biological sensors
   - c. Multifunctional micro/nanosystems
   - d. Functional nanostructured materials
3. **Photonics**
   - a. Energy conversion devices
   - b. Optoelectronics
   - c. Plasmonics and Nanophotonics

The IMM expertise, instrumentation and facilities are coordinated into 4 technological areas, which support the activities of the application areas, and are:

1. **Micro-nanofabrication**
2. **Characterizations**
3. **Theoretical modeling**
4. **Synthesis of advanced materials**

In general, the activities span from material science and process development to device fabrication and system integration, thanks to the micro-nanofabrication facilities present at the different sites (clean-room areas totaling >1500 m^2).



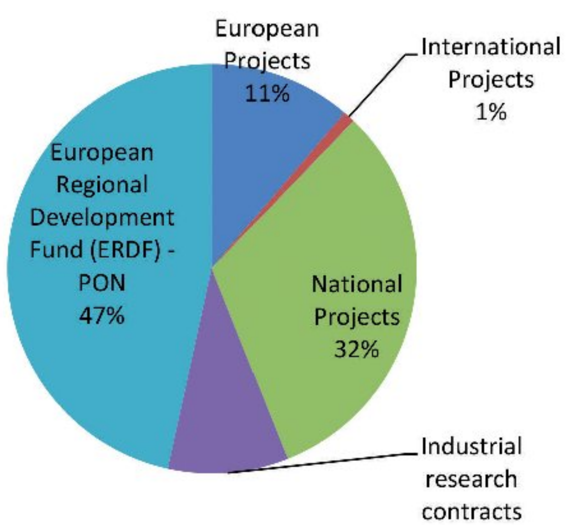
Through the participation to many European projects, IMM benefits from collaboration with prestigious international research institutions, such as Laboratoire d'Electronique de Technologie et d'Instrumentation (LETI), Interuniversity MicroElectronics Center (IMEC), European Synchrotron Radiation Facility (ESRF), Centro Nacional de Microelectrónica (CNM), and with many semiconductor industries, including STMicroelectronics (ST), Leonardo-Finmeccanica, Micron, Enel Green Power (EGP), LFoundry, Philips, SILVACO, AMD and ABB.

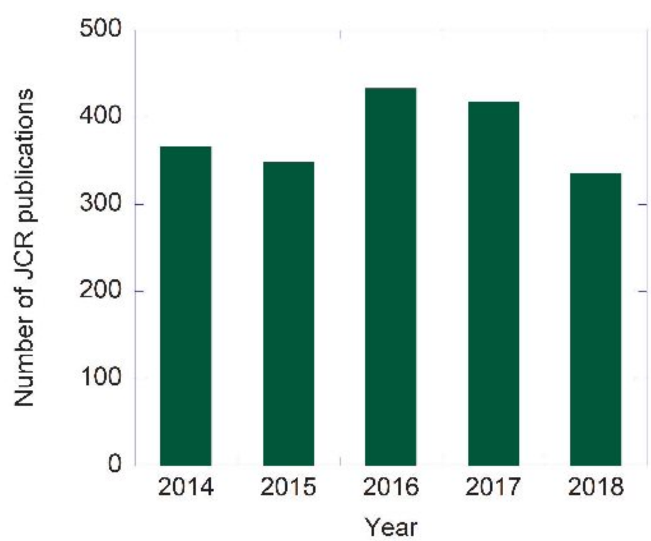
Particularly effective is the collaboration with STMicroelectronics, with two IMM Sections embedded in ST plants in Catania and Agrate Brianza, allowing the successful development of public-private initiatives. More recently IMM has also established a joint lab on solar cell characterization with EGP (Passo Martino, Catania) and another joint lab on the heteroepitaxy of GaN has been planned with Leonardo-Finmeccanica (Rome), adopting the successful public-private collaboration scheme experimented for many years with ST. Furthermore, IMM has a close collaboration with many Universities (one of its Section being located within the Physics Dept. of the University of Catania) and also carries out an important role in the formation, coordinating many PhD and graduate student activities. As a result, IMM effectively bridges the Academic Institution research activities with the Industrial applications.

IMM is currently involved in 20 European Projects, 4 of them coordinated by IMM researchers, including H2020 ICT (5), ECSEL (5), FETPROACT (2). Among the European Projects it is worth mentioning the ERC-Consolidator Grant XFab (coordinated by A. Molle), dealing with the development of two dimensional materials for nanotechnology applications. In addition, IMM is partner of the European Network for Electron Microscopy (ESTEEM3) and of the ESFRI initiative EuroNanoLab, a European initiative aiming to establish a large scale distributed nanofabrication research infrastructure.

IMM is also involved in many National and Regional projects, including relevant infrastructural projects funded by Regione Campania (project CIRO), Regione Lazio (project NanoMicroFab) and Regione Sicilia (project BeyondNano Upgrade). IMM has an annual operating budget, averaged over three fiscal years, around €24 million, including €9.8 million of personnel costs and €1.4 million of running costs supported by CNR and €12.8 million arising from European Regional Development Funds, European, International, National projects and Industrial research contracts (see the pie chart below on left).

Scientific results are presented to many International Conferences and an average of 380 articles are published by IMM researchers on JCR journals every year.





Micro/Nano Electronics

The research activities in the area of Micro/Nano Electronics at IMM cover the full electronic "value-chain" from advanced materials and innovative technological processes, to emerging logic and non-volatile memory nanodevices exploiting both classical and quantum phenomena, as well as systems and novel computing paradigms beyond von-Neumann.
In particular, the Institute is active and has a long and recognized expertise in materials, advanced technological process and modeling/simulation in various sectors related to:

- Enabling technologies for energy efficient high-power and high-frequency devices based on advanced materials (such as SiC, GaN, GaAs, graphene, etc.) and high frequency components for aerospace applications.

- Device and electronic circuits on flexible substrates based on organic/inorganic thin film transistors.

- Novel devices with logic and non-volatile memory applications exploiting emerging concepts and advanced materials.

- Enabling technologies for the nanofabrication and processing of devices.

- 2D materials for nanoelectronics and spintronics.

- Devices and methodologies towards neuromorphic and quantum computation systems, and More than Moore applications.

Power and High Frequency Devices

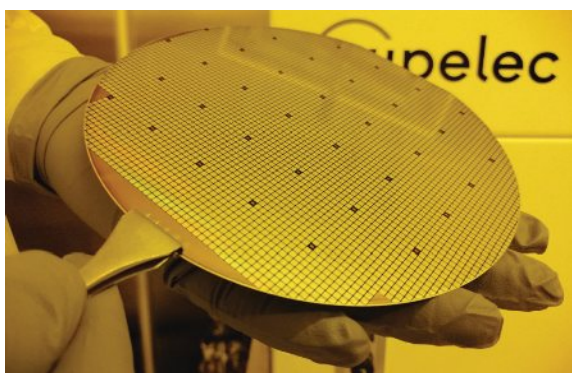
Today, power and high-frequency devices find application in different fields, e.g., consumer electronics, automotive, photovoltaic, telecommunications, transportations, etc.
The main objective of the "Power and High Frequency Devices" group is the development of key enabling technologies for a new generation of energy efficient power and high-frequency devices, with a reduced power consumption, able to overcome the current limitation of silicon.
Wide band gap semiconductors (e.g., SiC and GaN) are the semiconductors of choice to satisfy these requirements. Hence, a large part of the activities are focused on SiC and GaN, where the Institute has a long term recognized experience. Moreover, the research covers other emerging technologies based on polycrystalline diamond, GaAs, graphene and related 2D-materials, etc.. The activities are currently focused on the following topics:

- Epitaxial growth of 4H-SiC and 3C-SiC for power devices and new applications (e.g., MEMS, detectors, etc.).

- Advanced processing and characterizations for SiC and GaN devices (interfaces with metals and insulators, implantation and annealings for SiC selective doping, normally-off HEMTs, new dielectrics and nano-laminates, etc.).

- High-frequency components (e.g., filters, oscillators, antennas, interferometric systems, electromagnetic sensors, etc.) based on Si, hydrogenated diamond or other materials (dielectrics, metamaterials, polymers, etc.).

- Novel devices integrating 2D-materials on WBG semiconductors for RF applications.



Flexible and Large Area Electronics

Flexible electronics represents a new branch of electronics in which circuits are deployed on bendable and even stretchable substrates.

Flexible electronics offers several advantages over rigid backplane, such as lower production cost, lightness and robustness. Moreover, this field opens new designs and concepts and it provides the possibility to realize specific applications in numerous markets: in particular aerospace, biomedical and environmental companies, consumer electronics, sportswear represent the principal stakeholders since key properties such as lightness, transparency and competitiveness can favor the rise of breakthrough products.

Nowadays a series of technologies related to conventional microelectronic processes or innovative printing techniques offer a wide range of possibilities for fabricating novel devices with different materials, depending by the specific properties that are requested. In fact, circuits' performances often have to be balanced with production costs. In IMM two technological platforms are available to fabricate devices based on:

- Polycrystalline Silicon, obtained by excimer laser annealing, providing devices with high electrical performance and complex integrated circuits.
- Organic semiconductors, deposited by solution process or printing techniques, for large-area and low-cost applications.

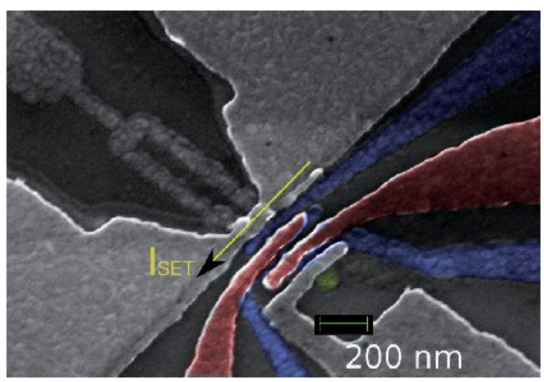
In addition, new ultra-thin and two-dimensional materials, such as transparent conductive oxides, graphene, transition metal dichalcogenides, are investigated. Indeed, thanks to their properties (high carrier mobility, optical transparency, stability of structural and electronic characteristics upon bending or stretching), are particularly promising for flexible electronic applications.

Devices for Classic and Quantum Information Storage and Processing

Nowadays, micro-nanoelectronic research addresses on one side the continuous scaling of logic and memory devices, also in view of targeting low power electronics. On the other side, there is an increased interest to develop new systems and new computing paradigms, which can address the current emerging societal challenges. IMM is at the forefront of emerging technologies in the nanoelectronics area and the research activities are carried out in collaboration with leading Industries in the field, as well as Italian/international Universities and Research Centers.

The research activities are currently focused on the following macro-areas:

- Materials and devices towards next generation non-volatile memory devices, with focus on phase change memory (PCM) and resistive switching memory (RRAM).
- Electronic devices based on 2D (graphene, silicene, phosphorene, MoS_2 and related materials) and 1D (Si nanowires) materials for low power nanotechnology applications.
- Dielectrics for CMOS and metal-insulator-metal capacitors for power management.
- Spintronics based on topological insulators and TMDs.
- Development of advanced nanofabrication tools based on self-assembled materials.
- Memristive devices as key elements for neuromorphic systems and artificial intelligence
- Quantum computation systems: modeling/simulation of semiconducting and superconducting qubits. Electrical characterization of Si-based devices as qubit.

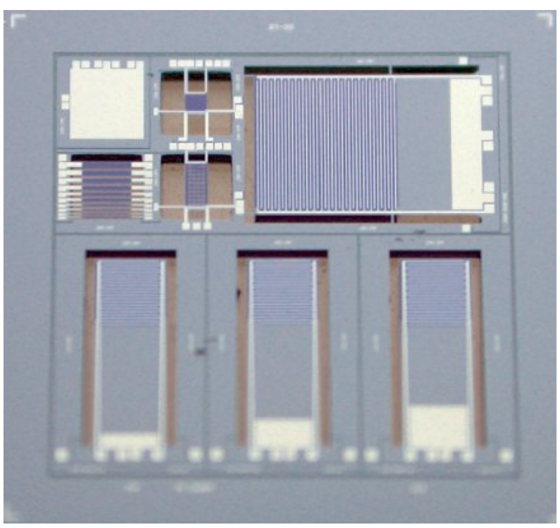


Functional Materials and Devices

The research activities in the "Functional Materials and Devices" thematic area are organized in a multidisciplinary perspective, exploiting the consolidated skills in the different IMM Units on innovative micro- and nanostructured functional materials, the advanced instrumentation and technological facilities for the development, characterization and prototyping of sensors, integrated systems and devices with applicative impacts in various sectors such as aerospace, energy and sustainable mobility, health, agri-food and biology. The research activities are structured into 4 workgroups: 1) MEMS and MOEMS 2) Chemical, Physical and Biological Sensors 3) Multifunctional micro-nano Systems and 4) Functional Nanostructured Materials.

By integrating design expertise and excellent characterization and microfabrication facility IMM can develop and validate multifunctional devices with TRL up to 6. The fabricated devices and materials related to present area can be classified into the following categories:

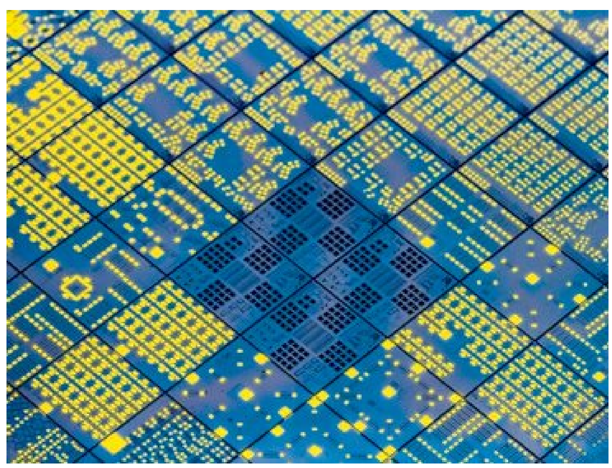
- Physical sensors
- Chemical sensors
- Biosensors
- MEMS sensors and actuators
- Devices for energy harvesting
- Low-dimensional and nanostructured materials
- Microphysiological systems



MEMS and MOEMS

The workgroup related to MEMS and MOEMS devices is focused on activities related to advanced design, development of enabling technologies for different applications and the fabrication of complex devices and systems. The activities are currently focused on the following topics:

- Manufacturing and characterization of devices and MEMS sub-systems for microwave and millimeter-wave integrated telecommunications on Si, alumina, SiC and GaAs substrates
- Development of MOEMS-type microfluidic platforms for Lab-On-Chip systems suitable for pharmaceutical applications in radiotherapy
- Integration of innovative materials deposited with advanced synthesis technologies (ALD, MOCVD) in MEMS devices, for piezoelectric, thermoelectric, chemical transduction and protective coatings deposition
- Development of MOEMS SiC sensors for the measurement of pressure in the cylinders of endothermic engines
- Development of MOEMS technology optical fibre ultrasonic probes for minimally invasive medical diagnostics
- Fabrication of MEMS devices for energy harvesting from heat sources and other semiconductor materials manufactured with top-down technologies, even on flexible substrates.
- Development of MEMS sensors for the measurement of physical parameters of automatic machines
- Fabrication of new MEMS/NEMS devices based on 2D materials (graphene, MoS_2).

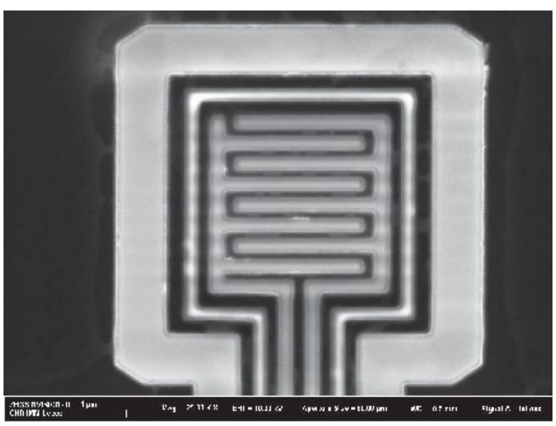


Chemical, Physical and Biological Sensors

The sensors for chemical, biological and physical detection represent one of the fundamental research activities at IMM, confirming the mission of scientific innovation and the ability to transfer new materials into high performance devices and sensors. The main research activity of this Workgroup is focused on modeling, design, devices manufacturing with micro-nanoelectronic techniques and their functional characterization in different application domains.

The different devices, systems and related enabling technologies concern chemical, physical and biological sensors applied in strategic sectors such as aerospace and the environment, energy and sustainable mobility, health and agri-food, omics sciences and intelligent systems. In these sectors, innovation pushed by the development of new materials and their integration into high performance platforms has revolutionized and continuously innovates the society, contributing to the improvement of the quality of life. The activities have a strong interaction of expertises and a multidisciplinary approach with the other workgroups of the applicative areas. The strategic research activities currently being developed are oriented to the study of nanostructured and low-dimensional materials and the investigation of disruptive transduction techniques. The current development roadmap includes the following advanced materials and devices, classified into following categories:

- Sensors and sensor arrays based on nanostructured materials for chemical detection
- Nanogap sensor devices
- Physical sensors and photodetectors
- Biosensors



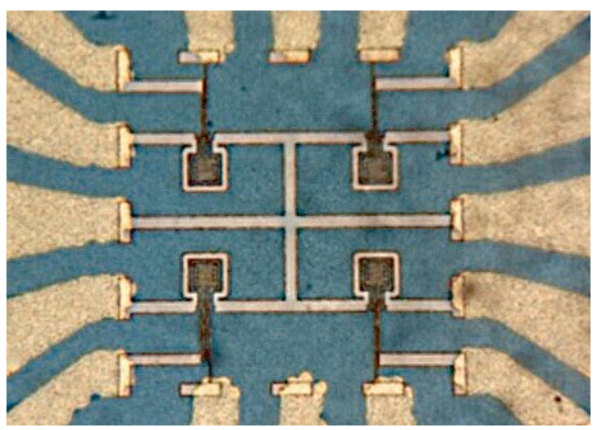
Multifunctional Micro-Nano Systems

In the framework of national strategic research roadmap, IMM owns engineering know-how and strategic technological facilities needed for the development of multifunctional systems.

The IMM research activities on sensors and multifunctional sensing systems are related to both basic research and application-driven developments; the main aim is to enforce the technological transfer, merging MEMS/NEMS components with the broad expertise and capabilities about nanostructured materials into the framework of Smart Systems Integration (SSI).

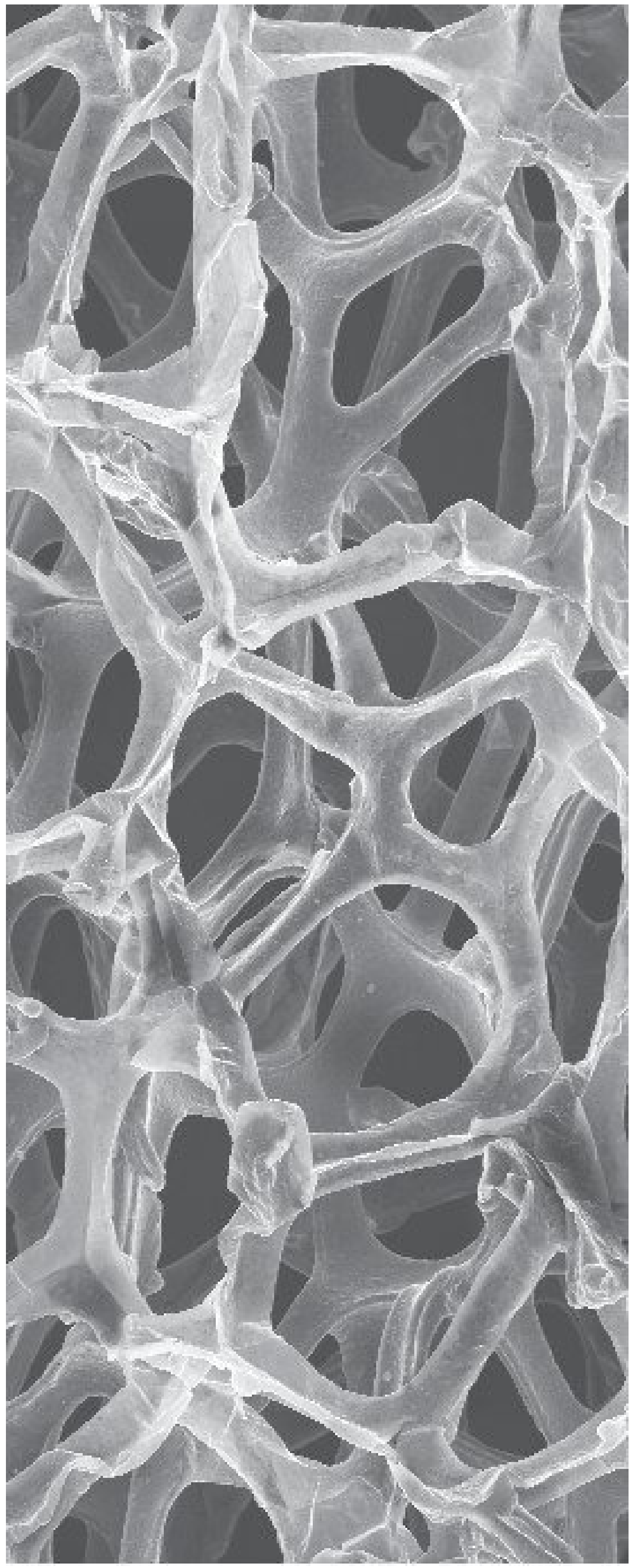
Main research activities are in the areas of:

- Smart, Secure and Inclusive Communities: autonomous multisensory systems of chemical and physical parameters, even on unmanned platforms
- Technologies for living environments: multifunctional and multisensorial systems for assistance to the elderly people / Ambient Assisted Living (AAL), advanced and autonomous analytical systems for air quality
- Agri-food and agriculture: advanced electronic noses and multisensorial systems for food quality and safety; microsensors on drones for precision agriculture applications
- Multifunctional systems based on functionalized optical fibers and silicon integration of photonic devices
- Flexible sensor systems related to wearable devices: devices for power generation and implantable sensors for artificial organs
- Multifunctional systems for biological applications: biosensing and micro-release of drugs, multisensor systems for medical diagnosis



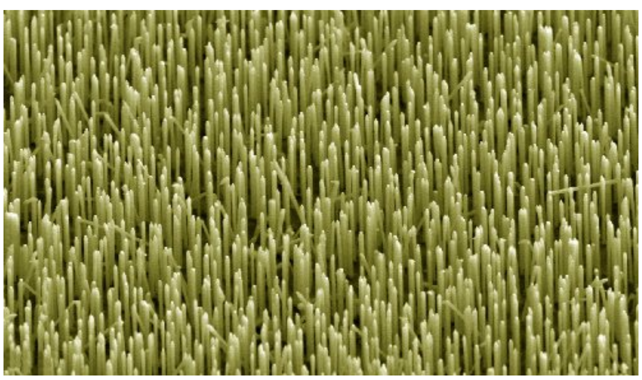
Functional Nanostructured Materials

The workgroup active on the functional nanostructured materials is focused on the research and development of innovative materials with specific functional properties such as electrical, optical, magnetic and/or chemical, through the control of the nanoscale structure. The activity carried out has a remarkable impact into fields such as sensors, photonics, catalysis, medicine and water purification. The competencies available at IMM range from the growth of different classes of nanostructured functional materials, to the accurate control of synthesis through sophisticated techniques (ALD, Sputtering, CVD, Pulsed laser deposition, MOVPE, MBE) and/or low-cost chemical and electrochemical processes, potentially scalable at the industrial level. Particular attention is paid to the development of advanced characterization techniques and methods of investigation and manipulation.



The main classes of investigated materials are:

- Semiconductor nanostructures for medical and biological applications aimed to improve the availability and targeting of drug molecules by reducing their toxicity; silicon nanostructures, III-V and III-N-V core-shell and core-multishell nanostructures;
- Metal oxides for water purification and disinfection, for concentrating solar systems, supercapacitors and lithium batteries;
- Two- and three-dimensional carbon-based materials for water purification and their integration with photo-active polymers
- 2D materials, such as TMDC and BN with high quality and structural purity
- Superconducting and magnetic materials
- Low temperature of compounds metal thin films for contacts on 1D structures.



Photonics

Photonics has a multidisciplinary character and provides the technological bases for the development of high-impact electronic devices and systems for the society of the future.
The research activities at IMM in this area are mainly devoted to:

- developing photonic devices to be integrated into next-generation micro and nanoelectronic chips, in which the interconnections are optical rather than electrical, overcoming the current limits of power dissipation and data processing speed. These activities are part of the broad scenario that looks forward to the realization of nanoelectronic systems increasingly intelligent, fast, miniaturized and cheap (also based on the exploration of quantum technologies), as well as of optical networks for ultra-wide band and cryptographic data transmission.
- developing photonic devices, sensors, micro and nanosystems, advanced diagnostic and imaging techniques for biomedicine, cultural heritage, agri-food, environment control, smart secure and inclusive communities, industrial processes, aerospace, sustainable mobility.
- developing next-generation solar cells characterized by low cost and high efficiency, so to make the most of the planet's main renewable energy source.

Devices for Energy Conversion

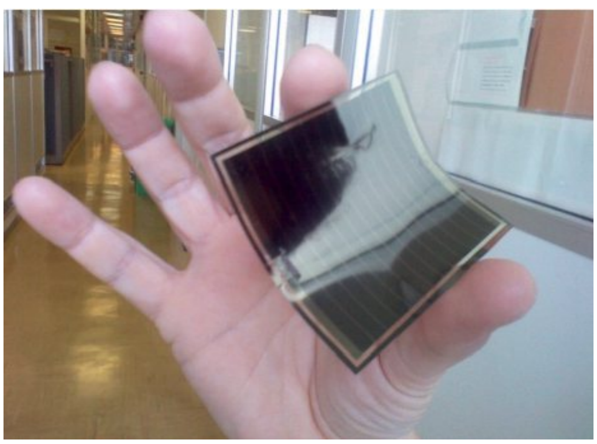
The field of Energy Conversion Devices is facing a huge growth thanks to the increasing interest towards renewable energies, due to the need at the worldwide level to reduce carbon emission for energy production. Photovoltaics (PV) is also a major technology for energy harvesting, to power novel generation of silicon microsystems, systems on chip (SoC) and systems in package (SiP) devices. The dominant PV technology is silicon based, but novel PV technologies may become very important in future, for example coupled with Si PV technology in utility scale plants, or for building integrated PV, or for powering nomadic or wearable electronics, etc.

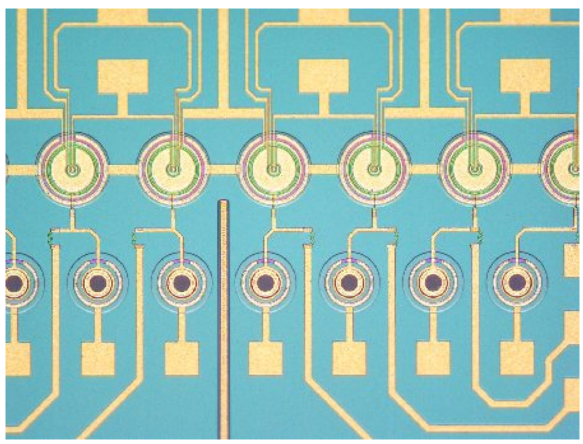
Our work is performed in many cases in strict collaboration with companies but with focus on novel approaches with strong potential for industrial application. The major areas of activity at IMM are:

- Efficiency enhancement and reliability of new generation high performance solar cells.
- Hybrid architectures for dye sensitized and perovskite solar cells.
- Photo-electrochemical water splitting for hydrogen production.
- Si, Ge, and metallic nanostructures
- development of high vacuum flat thermal solar panel.

Optoelectronics

Silicon photonics is pushing industrial research, and IMM is engaged in this field with the main objective of 1) overcoming the intrinsic inability of silicon to emit light, 2) studying original configurations (i.e., dielectric metasurfaces and photonic crystals) for light manipulation on a sub-micron scale, and 3) developing high performance photodetectors based on resonant structures and innovative materials (i.e., graphene). Devices and technologies are designed for optical inter- and intra-chip interconnections, for the transmission of ultrafast data in next-generation fiber optic networks, and for sensing.





New Si- and SiC-based UV-visible avalanche photodiodes and Si photomultipliers with high sensitivity (up to single photon) and/or internal gain are also developed for applications ranging from biomedicine to nuclear physics.
Nanophotonic biological structures, such as diatoms, are studied for the realization of new bio-inspired devices for smart light manipulation, such as super-lenses, and sensors.
Non-destructive imaging and diagnostic systems for biomedicine, materials science, and micro / nanoelectronics are developed. They are based on digital holography, linear and non-linear raman effects, interferometric and spectroscopic technologies.
New fiber optic sensors are developed, a first family being based on linear and non-linear optical Raman and Brillouin effects, while a second one looks at lab-on-fiber configurations through the realization of innovative plasmonic nanostructures and metasurfaces at the fiber tip.
A new objective concerns the development of quantum technologies and integrated quantum devices on chip.

Plasmonics and Nanophotonics

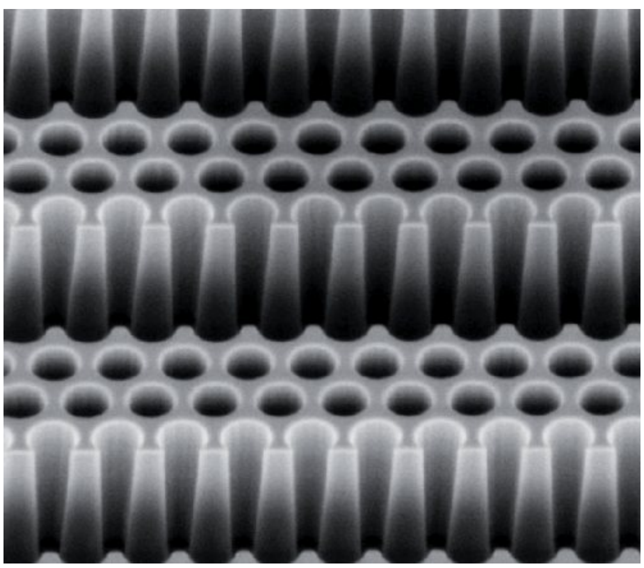
The research activity is focused on the realization of new optically passive and active nanostructures, differently organized in periodic arrays or randomized, for different applications.

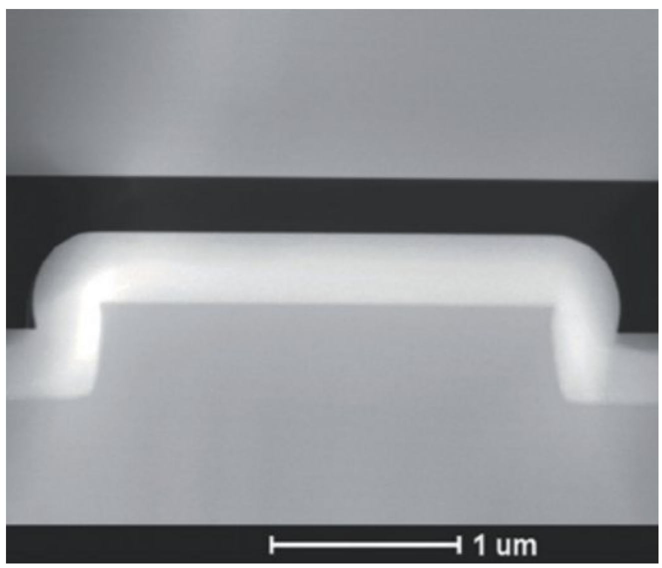
One of the main aim is the dynamic control of light propagation in plasmonic and nanophotonic circuits. Expertise includes: i) design, supported by various calculation tools for theoretical modeling; ii) development and implementation of new nanofabrication strategies with different approaches, both top-down and bottom-up, on conventional substrates and not (i.e., optical fibers); iii) optical characterization.

Main research topics are:

- Fabrication of nanostructured plasmonic materials: noble metal nanoparticles (gold, silver), plasmonic nanostructures on planar supports from top-down and bottom-up approaches, and unconventional substrates (optical fiber tip), silicon nanowires and titanium oxide decorated with noble metal nanoparticles.
- Development of bio-inspired nanostructured plasmonic devices or of biological derivation.
- Development of magneto-plasmonic nanomaterials.
- Development of metasurfaces: plasmonics and dielectrics.
- Development of theoretical-numerical methods for the study of light-matter interaction in plasmonic structures.

Principal applications are in bio-chemical sensing, light sources (in a wide spectrum range), solar energy conversion, photo-electro catalysis, integrated nanophotonics.





Micro and Nano Fabrication (MNF)

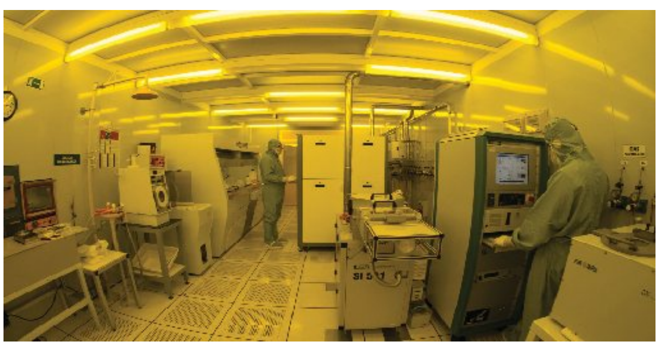
The MNF network is a state-of-the-art Micro/Nano fabrication research infrastructure that offers a number of cutting-edge facilities for the manufacturing of microelectronic devices and microsystems.
Conventional microelectronic production equipment are combined with large area electronics processes to meet the needs of scholars and entrepreneurs who want to investigate new device properties or boost new applications in the market.
Infrastructures, instruments and skills constitute a complex of the highest level and value, which has no equal at the national level.
With over 1400 m^2 from ISO 4 to ISO 8 Clean Room, 170 equipment distributed over 7 locations in Italy and more than 60 researchers and technicians operating in the Clean Rooms, IMM MNF network represents a reference network for basic, applied and industrial research for the development of:

- MEMS, MOEMS, Micro sensors and actuators, photonic devices, flexible electronics with the ability to manufacture prototypes with TRL 6 - TRL 7
- Devices for micro / nano electronics: study of processes and materials, power devices

The high number of Italian and European projects with the most important research centers at European level, demonstrate the potential of the MNF network to contribute to carrying out scientific research of excellence.
Thanks to its strong orientation towards applications and its distribution across Italy, the MNF network provides an optimal interface towards the national industrial partners. The numerous collaborations in research activities and service contracts with both Italian and foreign industrial companies, highlight the potential capacity of the MNF Lab of favoring and encouraging technology transfer to small, medium and large companies, and support a small and medium custom production.
IMM, thanks to the equipment and skills in the field of micro- and nano-fabrication present in the MNF network, represents a reference to the national excellence of key enabling technologies (KET).
The distributed Clean Room has a complete CMOS compatible 4-inch substrate line manufacturing processes, and a partial ability to process 6-inch substrates and has facilities such as:

- Design and simulation process software
- Lithography: Near and DUV Optical contact lithography with resolution down to 700 nm and laser lithography (<500 nm);
- Dry Etching processes: RIE and ICP etching with high aspect ratio for different materials (eg Silicon, III-V, GaN, AlN, and SiC);
- Growth and deposition: metallic, dielectric thin films and 2D materials by Hot wall tube, PCV, LPCVD, PECVD, ALD, electroplating, and printing system;
- Annealing: thearmal and Laser Annealing, RTP and UH-RTP process for Si and SiC
- Wet anistropic silicon etching by TMAH and KOH
- Wafer bonding
- Doping processes by solid and liquid phase, Medium and High energy ion implantation
- Nanolithography by EBL, Nano Imprint and block copolymer thin film

MNF Network is an active part of It-Fab, an infrastructure consortium of research in the micro and nanotechnology field connected to the EuroNanoLab project, which will significantly increase the possibility to access projects on a European scale.



Characterizations

Characterization plays a crucial role in the research activities at IMM. Investigating the physical and chemical properties of materials is of fundamental importance also to understand the operation of devices.
IMM has recognized and consolidated tradition in the characterization of materials and devices. The multidisciplinary nature of the Institute always required techniques for the morphological, structural, analytical, optical and electrical characterization. As such, some techniques are developed to a maturity to become a full research activity and the experience of researchers allows the organization of educational events.
The characterization facilities, widespread among the IMM units, can be classified in two groups: (i) Structural, Morphological and Analytical techniques and (ii) Electrical and Optical ones.

Structural, Morphological and Analytical Characterization

IMM houses a variety of instruments for morphological and structural characterization including transmission and scanning electron microscopes, probe microscopes and multi-purpose X-rays diffractometers.

Electron probe analysis includes 5 TEMs, 7 SEMs and 2 FIBs (with electron and ion columns). Catania HQ hosts the first aberration probe corrected TEM installed in Italy. The instruments are also available for external customers.

Up to 4 circle X-ray diffractometers and X-ray beam instruments are available for structural and analytical investigations, including XRD, XRR, XRF, TXRF and XPS.

Scanning probe analysis instruments are installed at almost all IMM units. The methods include AFM, EFM/MFM, KPFM, TUNA, SCM, CAFM, SSRM. Roma Unit has developed analysis methods using microwaves.

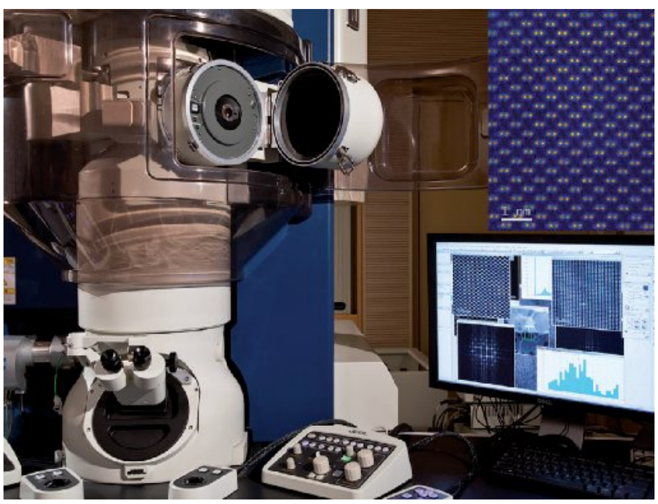
Mössbauer, EPR and ToF-SIMS (at Agrate Unit) complete the list of analytical techniques.

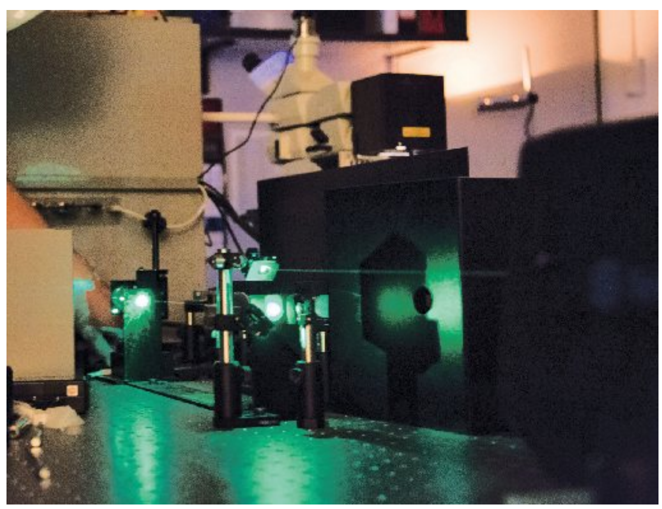
Electrical and Optical Characterization

Electrical and optical analyses are often strictly related and in IMM are applied to a wide range of samples, from Si and SiC based materials and devices, to bio-materials, 2D materials, solar cells, and much more to characterize defects, charge transport dynamics, interfaces, etc..

Lecce Unit hosts two laboratories (NPAL and ELPHO) devoted to Nanophotonics, Plasmonics and Electro and Electro-optical analysis. At Napoli Unit a Non-linear and Ultrafast Optics lab allows optical analysis of bio- and nano-materials.

The electrical and optical facilities are spread at almost all IMM Units and include several Probe stations (for up to 12" wafers) with temperature controlled chucks; Magnetic measurements; Ellipsometry; Optical spectrometry; Electro- and Photo-luminescence; FTIR and Raman spectroscopy; Reflectivity, QE, Transmittance, Spectral irradiance measurements.





Synthesis of Advanced Materials

The synthesis of new and technologically advanced materials represents a strategic field in terms of scientific endeavor and industrial perspectives. IMM has a deep knowledge and experience in the field and is equipped with a broad variety of sophisticated deposition systems, based on physical and chemical methods. The research activity stretches from the synthesis of thin-films to nanoscale structures with novel functional properties. Several state-of-the-art systems along with innovative deposition methodologies are employed and developed for various applications, from energetics to nanoelectronics, photonics, biomedicine, sensing, and environmental/cultural heritage protection. This wide range of applications ensures the as-synthetized advanced materials to play a key role in the development of hi-tech products and sophisticated devices.

All Application Areas of IMM are involved in the functionalization and exploitation of advanced materials, which can be grouped into two main classes: ultra-thin films (down to atomic monolayers) and nanostructures of several geometries.

Thin films/monolayers:

- oxides: ultra-thin films of transition metal oxides/rare earths
- transparent conductive oxides and materials
- nanostructured functionalized semiconductor oxides
- Selenium- and Tellurium-based chalcogenides
- hybrid perovskites, manganites, ruthenium, nitrides
- flexible conductors and semiconductors
- new nanocomposite materials based on nanostructured polymers, titanium and zinc oxide, graphene oxide.

Low dimensional structures:

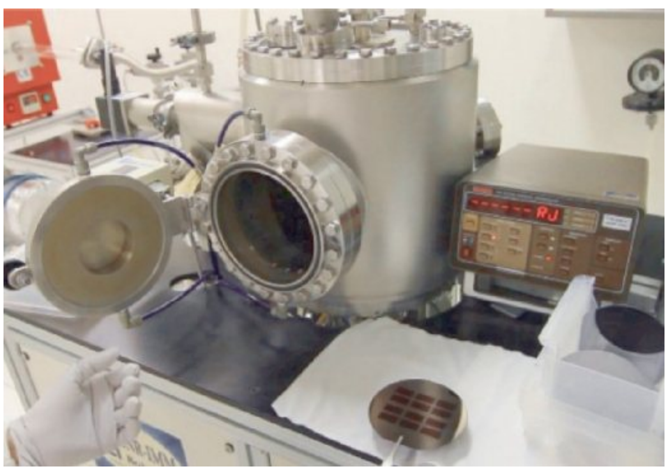
- 0D: Silicon, Germanium and Silicon Carbide nanoparticles, colloidal nanocrystals of metal oxides, pure, doped and in core-shell configuration;
- 1D: nanowires and nanotubes of Carbon, Silicon, Titanium, Zinc and Copper oxides, chalcogenide and core (multi) shell nanowires based on III-V compound semiconductors;
- 2D: graphene, silicene, phosphorene or hexagonal boron nitride, antimonene and transition metal dichalcogenides;
- 3D: graphene foams;
- Biocompatible and biodegradable nanomaterials.

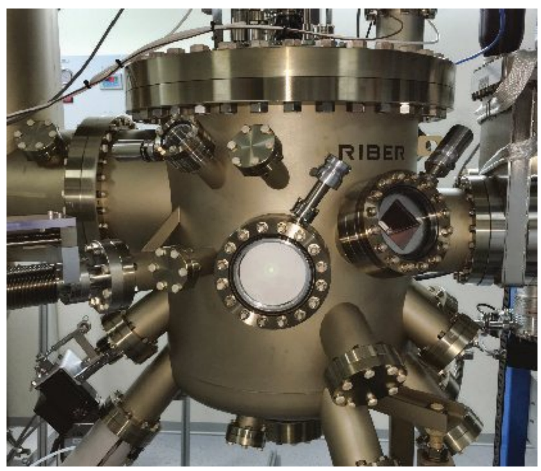
The synthesis techniques are mainly based on Chemical and Physical methods:

- Chemical Vapor Deposition, CVD
- Metalorganic Chemical Vapor Deposition, MOCVD
- Atomic Layer Deposition, ALD
- Molecular Beam Epitaxy, MBE
- Sputtering and Evaporation
- Low-cost chemical and physical synthesis

These techniques are compatible with ultra/large-scale integration processes, allowing IMM to keep strict and fruitful collaborations with world leader microelectronic industries.

(for further details visit the website)





Theoretical Modeling

The theoretical-computational activity at IMM aims at bridging the gap between quantum phenomena at the nanoscale and devices and processes with macroscopic dimensions. To this end several approaches at different scale are developed and employed, starting from quantum mechanics schemes for the description of materials up to the realization of advanced algorithms for the simulation of real-world processes and devices.

Applications include:

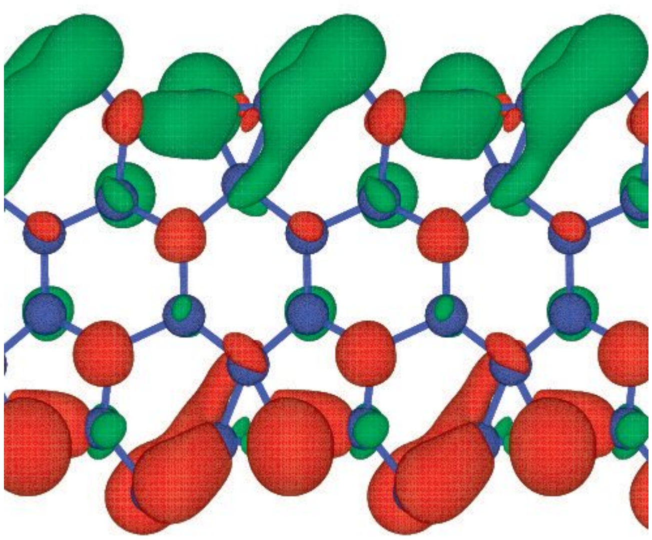
- ab-initio modeling , using Density Functional Theory (DFT) and beyond, of the structural, electronic, optical, and magnetic properties of materials and nanosystems;
- electronic transport modeling in high-frequency devices, large-area electronics, memristors;
- finite elements methods (FEM) multiphysics modeling of electronic, microelectro-mechanical, microfluidic, sensing, and mechanical devices;
- electromagnetic modeling of photonics devices, plasmonic and magneto-plasmonic nanosystems, multilayer structures and complex 3D systems;
- modeling of two-dimensional systems (graphene, silicene, germanene, phosphorene) and hybrid perovskites;
- modeling of phase-transitions and thermal modeling of nanostructures and solar absorbers;
- simulations of semiconductor devices and processes;
- statistical methods for image analysis.

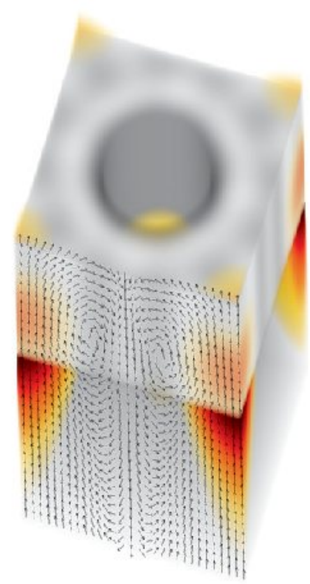
The IMM researchers have a large expertise in using software for modeling of devices (COMSOL, FEniCS, SILVACO, SYNOPSIS, CADENCE, DESSIS, DIOS-TCAD, Microwave Office, MEMS-Pro, Lumerical) and for atomistic electronic structure simulations (Quantum Espresso, TURBOMOLE, Yambo, Wien2K, PROFESS, Siesta).

Fundamental research includes developments of:

- new functionals (both exchange-correlation and kinetic energy) for DFT;
- methods for strongly-correlated quantum systems (Hubbard models, quantum-control, Density Matrix Renormalization Group);
- non-equilibrium Green-function methods;
- kinetic Montecarlo on lattice and super-lattice for material processing;
- quantum-computation and technologies (quantum-control, quantum-noise, circuit-QED);

IMM is also involved in the development of commercial software, namely TURBOMOLE (COSMOLOGIC), a quantum-chemistry package, and LIAB (LASSE Innovation Application Booster) a FEM tool for laser annealing simulations.





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