WHITE PAPER AP1
DEVICES AND SYSTEMS FOR ICT

EXECUTIVE SUMMARY

The Project Area (PA) entitled "Devices and Systems for ICT" is a cross-cutting research area that focuses on the development of a broad range of devices and technologies, encompassing photonics, microwave/millimeter-wave technologies, micro/nano-electronics, and chemical electronics.

The objective of the PA is to make new components and technologies available to ICT applications, including next-generation 5G terrestrial and satellite networks, Internet of Things (IoT), environmental monitoring, diagnosis of civil structures and cultural heritage, Industry 4.0, automotive, nuclear fusion, and healthcare. In this context, the activities are aimed at increasing the Technology Readiness Level (TRL) of the components/systems/processes involved, from the concept and formulation (TRL 1-2) to the experimental verification in the operational environment (TRL 7), through proof-of-concept and bread-boarding (TRL 3-5).

Depending on the specific technology maturity, the activities at CNR are carried out within the framework of programs funded by agencies (European Commission, European Space Agency, Italian Space Agency, Fusion for Energy, MISE, MIUR) for more fundamental researches, and industrial contracts with national companies for industry-driven activities. In this scenario, CNR plays an important role in supporting the national industry by boosting knowledge transfer in fields relevant to many application domains.

The activities carried out in this PA can be clustered in three main topics, *i.e.* photonics, microwave and millimeter-wave technologies and devices, and micro and nano-electronics technologies.

1. STATE OF THE ART OF THE RELEVANT SCIENTIFIC AREA

Topic 1 Photonics

Photonics is one of the most pervasive KETs in ICT and has a major impact in many areas including classical and quantum information and communication, industrial manufacturing and production, life sciences and health-care, environmental and structural health monitoring, smart lighting, energy saving and production, food quality assessment, aerospace, safety and security, cultural heritage.

Optical sensors, classical and quantum light sources (from LEDs to VCELs and QDs), fiber, integrated and micro-optical devices (like micro or nano-resonators), are all example ok key technologies allowing the generation of light and its management through guidance and manipulation, and can apply to all types of societal challenges.

Sensors

Optical sensors are emerging to play a vital role in several areas, ranging from environmental monitoring to biomedical diagnostic. The wide range of wavelengths from UV to the Mid-IR now available, thanks to new laser technologies, permits a specific and quantitative analysis of the samples under investigation. The continuous miniaturization of optical components has led to the development of highly integrated optical sensing techniques and devices (from millimeter size gratings to nanotips), including additional functionalities, like microfluidics, and leading to self-contained microsystems and lab-on-chip.

Fiber grating based sensing is a well consolidated research field with application for the structural health monitoring and in all the fields in which low intrinsic invasiveness and immunity from electromagnetic fields are required. This technology is therefore extremely useful and convenient in harsh environments as compared to conventional non-dielectric sensing systems.

Sources

Recent developments in the solid-state-laser research area have been triggered by the availability of new host materials like transparent polycrystalline ceramics, because of the possibility to achieve a higher uniformity in the distribution and higher concentrations of dopants.

VCSELs cover 99% of the ICT optical sources, and are used for short range huge volume of data transmission and for a very broad range of sensing applications, ranging from OCT, to popular 3D applications for unmanned car driving or smart phone applications. The VCSEL production volume is exploding and more and more help from CAD-oriented simulation tools is requested.

Self-organized Quantum Dots (QDs) grown by epitaxial techniques offer unique opportunities to realize compact and high-efficiency photon sources for the continuously evolving field of information and communication technologies. Making use of the well-established semiconductor fabrication technology, epitaxial QDs can be integrated on a chip and coupled with waveguides and optical cavities.

Resonators

High-Q optical micro-resonators have recently gained great attention due to the possibility of using these devices for both fundamental studies and for practical applications. Beside studies in the field of non-linear optics, opto-mechanics, and quantum optics, several resonator-based devices have been implemented mainly in sensing and RF photonics.

Recent works have demonstrated that nanomechanical resonators can be coherently coupled and manipulated with optical and microwave cavity fields, exploiting peculiar quantum properties to enhance the efficiency of the measurement and/or to integrate the extracted information in quantum communication systems.

Topic 2 Microwave and Millimeter-Wave Technologies and Devices.

Antennas and passive assemblies are key building blocks of radio-frequency (RF) systems developed for a broad range of applications, encompassing terrestrial and satellite telecommunication, industrial sensors, automotive radar, Earth and Space observation. In very recent years, the way these devices are developed has started to be revolutionized by digital manufacturing, where parts are built by additive manufacturing processes, most commonly known as 3D-printing. These technologies allows for very high integration and miniaturization of components, thus enabling the implementation of new RF architectures aimed at next-generation 5G terrestrial and satellite networks, RF receivers with very high sensitivity, wearable and smart systems for IoT. Meanwhile, the experimental testing and monitoring of wireless systems have benefit from the use of new technologies, such as Unmanned Aerial Vehicles (UAVs) integrated with Tx and Rx capabilities. Connected to the antenna systems, microwave front-ends working at steadily increasing frequencies (millimeter-wave bands available for 5G connectivity from 24-86 GHz) are analog circuits that necessitate a design approach very different from the low-frequency counterparts due to propagation effects and have to be implemented according to the latest semiconductor technologies developments.

For fusion plasma heating applications, Mega-watt (MW) class Continuous-Wave (CW) gyrotrons are being developed. In plasma heating plants (such as ITER that will be composed of more than 20 gyrotrons and will deliver a combined heating power of 24 MW) dummy loads are essential components and very few commercial models of loads are capable of absorbing and measuring continuous-wave at MW level.

Sensing technologies perform non-invasive characterization of surface and subsurface features of materials or manmade objects thanks to the electromagnetic waves ability to interact with them. Among these, Ground Penetrating Radars (GPRs), working from 1 MHz to 100 GHz, are exploited in several applications and continuous efforts are towards the development of sophisticated data processing approaches. More recent sensing technologies relying on THz waves are currently under development because of higher resolution and material identification capabilities.

Topic 3 Micro and Nano-Electronics Technologies

During the last years, sensors have increased more and more their capabilities, thanks to the integration of different functionalities, typical of integrated circuits (ICs), allowing them to reach a level of smartness which goes beyond a simple measure and to be employed for a wider range of applications. Several industrial sectors are exploiting these innovative smart sensors, including automotive, production automation process, robotics and aeronautics. One of the most interesting field, that has a great potential of development in the future, regards human healthcare and wellness, which technology is giving a great contribution for. Nowadays a great effort is spent to the development of a variety of possible methods of integrating and packaging sensor/MEMS and IC components, and the technology of choice strongly depends on the device, the field of application and the commercial requirements.

Magnetic materials are used as active elements in micro-sensors based on fluxgate or Hall type electronic devices in which they act as magnetic flux concentrators. Besides miniaturization and increase of sensitivity, a very important requirement is the direct integration of magnetic materials in Si processing technologies that can enable multiple new functionalities.

Analysis of concentrations of gas components plays a crucial role in several applications, ranging from inspection of exhausted plumes in vehicles to the analysis of breath for assessing physiological parameters and assess health status. To achieve this goal several new technologies have been proposed either based on semiconductor sensors or remote sensing technologies (*e.g.*, differential optical absorption spectrography). Nevertheless, suitable algorithms for data processing are still deserved to analyze the response of such non selective sensors and to properly assess actual gas concentrations.
Both organic and inorganic systems integrating sensors and/or bioelectronic devices with logic architectures, based on memristive technology, are explored to overcome the current limits in biomedical and neurological applications. These devices and systems are also used as key elements for the development of unconventional computing approaches based on neuromorphic systems, such as novel fully hardware perceptrons demonstrating the ability to produce reliable and functional systems for complex tasks, including classifications of data.

2. CONTRIBUTION TO THE RELEVANT SCIENTIFIC AREA

Topic 1 Photonics
Contact Person: G. Nunzi Conti (g.nunziconti@ifac.cnr.it)

CNR institutes involved in the topic: IEIIT, IFAC, IMEM, IREA

Sensors

Subtopic 1.1 and subtopic 1.3 Optofluidic and Fiber optics distributed Sensors
Contact: R. Bernini (bernini.r@irea.cnr.it)
The activity of IREA is focused in the design, development and characterization of new sensing strategies and techniques that permits to push to limits of the performances of optical sensors. In particular hollow core and optofluidic waveguides able to confine in the same place the light used for sensing and the sample (liquid or gas) under analysis have been developed. These waveguides has been used in order to realize integrated optical devices like microresonator or enhanced spectroscopic techniques (UV, Raman). Novel fabrication techniques based on polymeric materials have been implemented in order to realize high performance and low cost disposable optical sensors. IREA is also involved in the development of distributed fiber optical sensor for physical and chemical measurements over large distances.

Subtopic 1.4 Fiber gratings.
Contact: Cosimo Trono (c.trono@ifac.cnr.it)
The main activities regard the project and development of advanced sensing systems based on fiber grating (Bragg gratings, FBG, and long period gratings, LPG) and fiber lasers. The possibility of realizing custom prototypes adapted and optimized for the particular application, makes IFAC a prominent actor in this field.

Subtopic 1.5 Silica nanotips.
Contact: Stefano Pelli (s.pelli@ifac.cnr.it).
A new technique to fabricate silica nanotips has been developed at IFAC and has been patented. The method is based on a special chemical etching process that can be applied to standard silica fiber and results in tips having controllable sizes down to 40 nm. These devices can be used in high spatial resolution intracellular sensing platforms as well as for studies in plasmonics and non-linear optics.

Sources

Subtopic 1.2 Vertical cavity surface emitting lasers (VCSEL).
Contact: Pierluigi Debernardi (pierluigi.debernardi@ieiit.cnr.it)
Given the unavailability of an adequate multiphysics VCSEL commercial simulations tool, IEIIT is developing an in-house software which can handle the optical, thermal, electric transport and optical gain interrelated problems.

Subtopic 1.7 High power blue LED for biomedical applications.
Contact: Roberto Pini (r.pini@ifac.cnr.it.)
High power blue LED based devices has been designed and optimized up to the maximum TRL level targeting the treatment of wounds. Indeed, the system has been proven in operational environment demonstrating that blue LED sources can induce a photothermal effect to immediately stop the bleeding of a superficial wound.

Subtopic 1.8 Development of innovative diode-pumped solid-state-laser based on transparent ceramics emitting in the IR and VIS regions.
Contact: Angela Pirri (a.pirri@ifac.cnr.it).
Our research has focused on the fabrication and characterization of gain ceramic materials doped with several trivalent rare-earth ions as Yb, Dy,Er, which allow emitting in the IR and VIS regions. Our work has contributed to clarify the influence on the laser behavior and performances of different spectroscopic and microstructural characteristics of the transparent ceramics we investigated.

Subtopic 1.9 Quantum Dot nanostructures for photon emission at telecom wavelengths.
Contact: Paola Frigeri (paola.frigeri@imem.cnr.it).
To address the need of efficient, bright and integrable light sources for laser applications and single-photon devices, we study the design and the preparation by Molecular Beam Epitaxy (MBE) of InAs/GaAs and metamorphic InAs/In(Ga)As Quantum Dot (QD) nanostructures grown on GaAs substrates.
We perform model simulations, photoluminescence (PL) and structural characterization of the MBE-grown nanostructures aimed to tune QD emission wavelength in the 1320 – 1550 nm telecom window and to improve QD optical light-emission properties. The accurate control of the experimental growth conditions allows obtaining in-plane QD densities low enough to enable single-dot characterization and processing.

Resonators

Subtopic 1.6 High-Q optical micro-resonators.
Contact: Gualtiero Nunzi Conti (g.nunziconti@ifac.cnr.it).
The activities include the design, fabrication, and characterization of high quality-factor (Q) optical micro-resonators based on whispering galley modes. More specifically resonators made in crystalline fluorides with ultrolow losses and very broad transparency windows are used into innovative low noise optoelectronic oscillators. Similarly, silica based microbubble resonators are used as innovative transducers in photoacoustic microscopy and for label free biochemical sensors.

Subtopic 1.10 Micro/nano optomechanical oscillators with low optical and mechanical loss.
Contact: Michele Bonaldi (mbonaldi@fbk.eu).
One of the major obstacle to the realization of exploitable sensors is the extreme delicacy of quantum effects that can be destroyed by thermal noise. In fact, all quantum effects observed to date have been obtained on

resonators placed in a cryogenic environment. We are progressing toward a new generation of optomechanical systems, able to maintain a quantum behavior even at room temperature. For this purpose, we are developing devices with low optical and mechanical losses, based on innovative designs and optical metamaterials.

Topic 2 Microwave and Millimeter-Wave Technologies and Devices.
Contact Person: O. A. Peverini (oscar.peverini@ieiit.cnr.it)

CNR institutes involved in the topic: IEIIT, IREA, IFP

Subtopic 2.1 Microwave and millimeter-wave passive systems and antennas.
Contact persons: G. Virone (giuseppe.virone@ieiit.cnr.it)
In this area, CNR is involved in the development of novel architectures of multi-beam antenna systems working form 50 MHz to 110 GHz aimed at HTS (High Throughput Satellite) communication platforms with Terabits aggregate capacity, Earth Observation (EO) instruments with high spatial resolution for next-generation MetOP-SG and Copernicus sentinels, radio-astronomy and astrophysical instrumentation. The outdoor experimental characterization of complex and large antenna arrays, such as Italian and European demonstrators of the Square Kilometer Array, is successfully tackled by integrating Tx sources in UAVs.

Subtopic 2.2 Active Circuits for Wireless-Communication Systems.
Contact persons: R. P. Paganelli (rudi.paganelli@ieiit.cnr.it)
This topic deals with investigation, modelling, design and realization of both integrated and hybrid circuits for RadioFrequency (RF) front-ends: power and low noise amplifiers, programmable phase shifter and attenuators, switching power converters, oscillators and mixers. The research is evoted to improve the best trade-off among the most important figure of merit as linearity, efficiency, dynamic range, bandwidth, sensitivity, long term stability and reliability. Various wireless power transfer (WPT) methods are also included in this topic.

Subtopic 2.3 RF Technologies for Nuclear Fusion Research.
Contact persons: A. Simonetto (simonetto@ifp.cnr.it) e A.Bruschi (bruschi@ifp.cnr.it)
CNR has developed a unique dummy load concept designed for 2 MW CW that, while more expensive than commercial alternatives, has shown outstanding performance in tests on different test-stands worldwide and can be easily scaled to future multi-MW CW plants.

Subtopic 2.4 Electromagnetic Diagnostics Systems and Technologies.
Contact Person: Ilaria Catapano (catapano.i@irea.cnr.it)
CNR has assessed skills regarding electromagnetic modelling of forward and inverse scattering problems as well as development and performance assessment of methodologies and technologies for acquisition, processing and interpretation of GPR and THz data. In particular, application oriented data-processing strategies, which are based on a proper modelling of the interaction among electromagnetic waves (microwave and THz) and materials, have been developed and exploited widely in different applicative contexts ranging from subsoil investigations, to security and diagnosis of civil structures and cultural heritage. These strategies usually combine noise-filtering procedures with approaches facing the imaging as an inverse scattering problem and allow accurate, reliable and easily interpretable images of the probed scenarios by properly managing large amount of data.

Topic 3 Micro and Nano-Electronics Technologies
Contact Person: F. Albertini (franca.albertini@imem.cnr.it)

CNR institutes involved in the topic: ISTI, IMEM, IEIIT

Subtopic 3.1 Hardware/Software Platforms for Gas Analysis
Contact Person: Davide Moroni (davide.moroni@isti.cnr.it)
The activity aims at designing and developing gas sensor-based platforms for gas analysis. In combination with robust and optimized methods of signal processing, the concentrations of the target volatile molecules can be assessed. Recently, a portable device for human breath analysis has been developed; it is based on an array of commercial, semiconductor gas sensors and a signal acquisition board. It is able to detect, in human breath, specific volatile compounds related to cardiometabolic risk.

Subtopic 3.2 Si-Integrated Magnetic and Magneto-Optical Sensors and Devices.
Contact Person: F. Albertini (franca.albertini@imem.cnr.it)
This activity aims at Si-integrated magnetic and magneto-optical materials and technologies for the production of current/magnetic field sensors, biosensors, magnetic MEMS, integrated inductors: preparation and characterization of materials and devices and technological transfer.

Subtopic 3.3 Electronic and electrochemical devices for sensing, radiation detection, unconventional computing and bioelectronics.
Contact Person: Victor Erokhin (victor.erokhin@fis.unipr.it)
Development of electrochemical devices (Organic Electrochemical Transistors (OECTs)) with customized performance and architectures, fabricated on Si and flexible substrates, for sensing, monitoring of systems activity (Lab on Chip configuration) and neuromorphic applications, prepared through different micro-scale technological processes and innovative features:

- 3D-OECTs fabricated by Additive Manufacturing (patent pending) to increase the Limit of Detection
- OECTs with nanometric channels for fast, miniaturized devices
- OECTs with functionalized graphene-based electrodes to improve selectivity towards specific analytes
- OECTs with nanostructured active layer based on electrospinned nanofibers for enhancing trasducer/ analyte interaction.

Development of memristive organic-based devices and logic circuits for the implementation of:

- 1 and 2 perceptrons
- Systems integrating sensing and memristive devices for the local sorting of as-collected signals.

Subtopic 3.4 MEMS and Smart Sensors based on Thermal Principles and Micro/Nano-Structured Materials
Contact Person: Lucanos Strambini (lucanos.strambini@ieiit.cnr.it)
In the framework of smart sensors the activities performed at CNR concern the design, fabrication and experimental characterization of micro-nanosensor/MEMS integrated on the same chip with the electronic interface necessary for signal acquisition and processing. Micro and nano-structuring of silicon and the employment of new materials (i.e. polymer) are the key elements involved for the development of a new class of devices with improved sense capabilities and integration potentialities with IC components. To this purpose both standard IC technology and silicon/polymer based new fabrication process techniques (i.e. porous silicon technology) are involved. Some results of such activities concern the design, fabrication and characterization of MEMS-based microsystems (e.g. thermal flow sensors, solid-state anemometers, acoustical sensors) porous silicon-based sensors for gas sensing and biosensing applications, and polymer-based transducers for the field of flexible devices. As parallel activity, the design and implementation of electronic interfaces, from both hardware and software point of view, are performed to connect (biasing and communication) such smart devices with the outside world.

3. IMPACT

Topic 1. Photonics

Sensors

The possibility to perform high performance measurements at low cost through optofluidic and fiber optics distributed sensors could represent a paradigm shift from snapshot measurements to continuous monitoring. This pervasive sensing could address current social challenges from environmental pollutions up to global healthcare.
The capability of implementing custom sensors (based for instance on fiber gratings and nanotips) can be strategic for specific applications in which commercial sensing systems cannot be employed.

Sources
By overcoming several simulation challenges in terms of models, accuracy and simulation speed a significant impact is expected in the exploding production volumes of VCSEL, whcih are becoming a pervasive and enabling technology.
The improvement of the fabrication techniques will enhance the optical quality of the ceramic material and improve the laser performances by obtaining shorter laser pulses and higher intensity sources.
The development of compact and integrable Quantum Dot (QD)-based photon sources with high quantum efficiency aims to explore novel solutions in nanophotonic science with technological breakthroughs in the fields of communications and information processing. These findings will impact on the future well-being and secure data communication. The tailoring of the light-emission properties of self-organized semiconductor QDs, performed by means of the material and growth design, represents one of the first fundamental steps of this technological evolution.

Resonators
Ultra-high Q optical micro-resonators are key components for the development of ultra-compact stable frequency combs for high-precision metrology and spectroscopy as well as for quantum communications. Single molecule detection in biomedical applications and ultra-broadband photoacoustic microscopy are targeted with hollow silica based micro-resonators.
An optomechanical platforms operating at the quantum level could be integrated both within existing “classical” networks and devices, and within the future quantum networks able to process quantum signals and information. This achievement will be relevant also to the much broader scenario of the MEMS and sensor industry which, as a fundamental technological player, is boosting the development of the Internet of Things for a more connected world.

Topic 2 Microwave and Millimeter-Wave Technologies and Devices.

Microwave and millimeter-wave antenna systems have a key role in the development of next-generation 5G networks of mobile internet connectivity, offering faster speeds and more reliable connections on smartphones and other devices than ever before. Digital divide between geographic areas will be reduced by integrating terrestrial and HTS communication systems.
At the same time, dense antenna focal planes allows for EO instruments with the sensitivity levels needed in climate-change monitoring missions (MetOP-SG, Copernicus) and cosmology studies. Finally, RF sensors for industrial applications can increase working safety conditions, such as in steel casting industry, where RF sensors can replace radiative sources that are commonly used for monitoring the level of the molten metal liquid.

RF front-end electronic circuits are particularly affected by the technologies advances in the field of semiconductor fabrication and assembly. Therefore, the impact of these circuits is high in many applications where their use is consolidated, while they can become enabling technologies for future applications not yet practical at present.

A successful production of a suitable dummy load is a necessary condition for the development of new gyrotrons, essential for ITER and for other present and future devices in which the fusion plasmas are heated with microwaves, as foreseen in future demonstrative (DEMO) and commercial fusion power reactors.

Microwave and THz systems (hardware device plus data processing) capable of performing non-invasive surveys are demanded in all those applications where is required to gather information about surface and subsurface features of a certain object and thus represent a possible technological solution for many open issues traced into national and international research programs.

Topic 3 Micro and Nano-Electronics Technologies

Automation for home and automotive applications, Internet of Things (IoT), Industry 4.0, Augmented and Virtual Reality (AR/VR), Artificial Intelligence (AI) are emerging/pervading Information and Communication Technologies (ICTs) with high impact at scientific, industrial, social and political level. All these technologies are strongly demanding of small devices that are able to integrate into a "simple element" the capabilities of computing, communication and monitoring systems. In this framework, the activities on sensor/MEMS and IC components integration and new silicon/polymer technology could have a high impact making available very small, low power, low cost and smart devices for several current emerging ICTs, with applications in the environmental monitoring as well as sensing and biosensing areas.

Hardware/software platforms for gas analysis can be exploited in multiple cases of use: from the monitoring of environmental gases to the investigation of human breath composition. The activity may also include the development and the characterization of ad-hoc gas sensors (i.e. polyaniline nanofiber – based gas sensors highly sensitive to specific odorants, such as cigarette smoke, present in human breath) in collaboration with other research centers.

The developments of contactless magnetic sensors and devices and their integration with Si-technologies can have a strong impact in several crucial field of application, including electrical mobility, consumer electronics and nano-medicine.
The short-term perspectives for OECT are focused on the accumulation of a robust and diversified technological experience in the fabrication of OECTs devices, through the combination of several advanced technological tools. In the medium-to-long term, OECTs will be customized with different structural properties and features to optimize the response with respect to specific application scenarios and to widen the portfolio of potential application fields.

4. EMERGING RESEARCH CHALLENGES

Specific research challenges for photonics devices and systems includes:

- Solving the complexity of implementing software for VCSELs design which requires multidisciplinary approaches, validations with experiments, and parameter fittings.
- Fabrication and characterization of transparent ceramics with emission in the VIS regions.
- Optimization of the emission efficiency and operating temperature of QD-based photon sources and integration of QD nanostructures with optical components at nm-scale to develop a complete on-chip quantum nanophotonic circuit.
- Controlling resonator dispersion to push the combs into the visible

Challenges are planned to be tackled by participating at research programmes, some of them already identified, focused on the relevant fields in conjunction with both research institutes/academy and industrial partners. The PA researchers are also participating in agencies and networks committees, so as to contribute to the roadmaps and harmonization dossiers (as the ones coordinated by ESA and ASI for the GSTP, ARTES, TRP, H2020 programmes) that will define the activities to be implemented in the incoming future, among which are,

- Digital manufacturing of microwave/millimeter-wave products.
- Flexible electromagnetic monitoring and testing through UAV-based RF systems.
- Active circuits implemented with the latest device technologies (GaN, pHEMT, mHEMT).
- Gyrotrons with dummy loads at powers up to a few MW (2 or more) in CW.
- GPR systems exploiting new observation platforms (UAVs).
- Consolidation of THz imaging systems.
- Polyaniline nanofiber, magneto-optical, Si-Integrated magnetic, and nanoelectronic sensors.
- Interfacing human and brain signaling for optimized, direct control of devices, prosthesis and health status.

5. CONCLUSIONS

The PA “Devices and Systems for ICT” is cross-cutting by nature, allowing for the technological development of ICT products to be used in many applications. As a consequence, the PA proves to be the cornerstone for several activities to be carried out in other PA’s, such as Earth Observation based on radiometric imaging, cultural heritage monitoring, healthcare, and internet of the future, just to mention a few.

The PA is well established at CNR level within the strategic area entitled “System and Telecommunication Engineering”, and at national and international level within the framework of several research programs and industrial contracts.

The competences of the researchers involved cover a wide spectrum of topics, from photonics to micro/nano-electronics, through millimeter-wave technologies. This interdisciplinary nature is an added value for the successful development of new ICT products, based on the implementation of concurrent-engineering methodologies.

The man-power effort and known-how of the CNR staff involved and the research facilities are relevant, thus guaranteeing a significant CNR impact in the research area. In this scenario, an adequate turn-over of the personnel would be beneficial so as not to lose the competences and the capabilities to manage advanced research laboratories.

Annex: RELEVANT FCILITIES

IREA *(Relevant subtopics: 1.1-1.3)*

Optical laboratory for a full characterization of optical/ microfluidic sensors equipped with:

- Tunable laser 1550nm, 780nm, Supercotinnum Broadband light source, Fluorescence/Raman spectroscopic microscope, Optical spectrum analyser (350nm-1100nm), High sensitivity spectrometer with EMCCD camera, Femtosecond Erbium Laser at 780nm, High Energy Q-switched Nd:YAG Lasers (1060nm, 532nm, 266nm), Time resolved fluorescence measurement system
- Optical laboratory for fabrication of polymeric sensor: equipped with: Photolithographic Laser direct system with 1 µm resolution, Spin coater, CNC micromilling with 5 µm resolution, Hot press, Optical profilometer, low-pressure plasma system
- Fiber optic laboratory equipped with: optical time domain reflectometer, Stimulated Brillouin Optical time domain reflectometer, Stimulated Brillouin Optical frequency domain reflectometer, fiber fusion splicer
- Electromagnetic diagnostic laboratory equipped with subsurface radar systems (GPR and holographic radar) covering different ranges of frequencies from 200MHz up to 4GHz; a time domain THz system (spectral range from 60GHz to 3THz) suitable to perform imaging and spectroscopy analysis both in transmission and reflection modes; proprietary software for data processing, among which Microwave Tomography approaches and THz imaging strategies.

IFAC

(*Relevant subtopics: 1.4-1.7)*

- Clean room multi-user environment of Class 100/Class 1000 (ISO 5 and 6) level space with equipment for photolithographic processes.
- Wide range of laser sources from the visible (Verdi G @532nm, 7W) to the NIR (laser diodes @ 830 nm, 980 nm, 1480 nm, 1.4 μm tuneable, 1.5 μm tuneable; narrow line laser at 1.5μm, 770 nm external cavity tuneable laser, solid state Ti:Sapph ultrashort pulsed laser, tuneable 690-980 nm), to the UV (excimer laser @ 248 nm, short pulsed laser). EDFA booster amplifier 2W. Detectors: photodiodes, fast PD, optical spectrum analyzer for 600-1700nm, hand-held spectrometers (low spectral resolution).

- Set of anti-vibration optical benches equipped with precision stages and optics mounts, manual and piezoelectric. Navitar imaging systems,
- Optical fabrication lab: polishing of waveguides, fabrication of crystalline WGMR, home made prototype for production of microbubbles. Equipment for cutting, splicing, tapering optical fibres.

***(**Relevant subtopics: 1.7)*

Advanced Microscopy laboratory:

- a confocal microscope Leica SP8 equipped with incubator to perform cell live imaging. Leica DM2500P transmission microscope equipped with polarization set-up in order to perform analysis about orientation of tissue, i.e. skin. Stereomicroscope Nikon SMZ1500 and Thermo Scientific Cryostat HM525.
- Equipment for cells extraction from human tissue, and cell cultures storage and observation. Micro-Raman Microscope for biological fluids investigation.

IEIIT

- Microwave and mm-wave laboratory equipped with vector network analyzers and spectrum analyzers up to 110 GHz for experimental characterization of passive components and antennas.
- Unmanned aerial vehicles integrating Tx sources up to 50 GHz for outdoor RF measurements.
- MEMS and smart sensors laboratory, equipped with 100/10000 Class Clean Room, Scanning Electron Microscope (SEM) Jeol JSM-6500F, wet and dry thermal oxidaon furnaces, thermal evaporation system, electron beam evaporation system, high vacuum evaporation system, chemical and laminar flow hoods, profilometer Veeco Dektak 150, optical microscope Leica DM2500 M.
- Electrical and noise characterization of electronic devices facilities: nanovoltmeter, multimeters, electrometer, parameter analyzer, LCR meter and C-Meter/C-V plotter, oscilloscopes, waveform generator.

IFP

Microwave and bolometry laboratories that can provide microwave reflection measurements at 170 GHz and a full set of hydraulic and vacuum qualification tests before delivery of bolometric loads.

IMEM

(Relevant subtopics: 1.9)

Laboratory devoted to epitaxial growth and study of semiconductor structures composed by

- Molecular Beam Epitaxy (MBE) modular growth system with two growth chambers for the deposition of III-V semiconductor heterostructures: quantum wells, quantum dots, multilayer heterostructures, metamorphic buffers, n- and p-doped layers, doping- and composition-graded epitaxial layers. The system is housed in a clean room and equipped with a chemical hood for the treatment of substrates.
- Setup for photoluminescence (PL), transmittance and reflectance in the 10 K - 300 K range composed by a Fourier Transform InfraRed Spectrophotometer, LN_2 cooled Ge detector (800-1600 nm), laser source at 532 nm (for PL) and lamp for reflectance / transmittance.
- Hall effect instrumentation for the electrical characterization of materials and devices.
- TiberCAD modeling of semiconductor heterostructures.

Laboratory for Micro- and Nano-Fabrication equipped with a FESEM-FIB (Field Emission Scanning Electron Microscope - Focused Ion Beam) system for: Ga^+ ion-beam milling, Ga^+ ion-beam litography, electron-beam and Ga^+ ion-beam metal deposition (Pt), Ga^+ ion-implantation, nanomanipulation, advanced SEM study.

- Growth of thin films, multilayers, granular systems, nanocomposites and nanostructures

- by means of sputtering r.f.
- AGFM, SQUID and VSM magnetometry (max magnetic field 12 T, temperature range 4-800K).
- Magneto-optical and magnetoplasmonic characterization.
- Characterization of electrical properties in magnetic fields: a.c.-d.c. resistivity, anomalous Hall effect, pirocurrents, dielectric constant measurements (max field 5 T, 4-600K).
- Scanning Probe Microscopy: AFM, MFM, Scanning Capacitance, Nanolithography and Nanomanipulation.
- Structural characterization by means of X-ray diffraction (LNT-500K) and reflectivity, SEM and HRTEM with analytical facilities.
- Characterization of magnetic domains in nanostructured materials with Lorentz microscopy.
- Langmuir-Schaefer deposition system.
- Focused Ion Beam (FIB)- SEM system (Zeiss).
- AFM (Dimension 3100 Scanning Probe Microscope, Veeco).
- Source meter units (National Instrument PXI Source Meter Unit, Agilent B2902A).
- Palmsens4 (electrochemical workstation).
- Laboratory based on photolithography, etching processes (both wet and dry - RIE), metallization, and wire bonding for the fabrication of prototype devices.
- Through the partnership with Politecnico di Torino (IMEM-CNR@PoliTo): Cleanroom composed of three different areas: an ISO 14644 Class 5 (U.S Fed-Std 209D Class 100) yellow area (15 m2); an ISO 14644 Class 6 (U.S Fed-Std 209D Class 1000) area (45 m2); a not classified grey area, but approximately an ISO 14644 Class 7 (U.S Fed-Std 209D Class 10000) area (90 m2). Several micromachining facilities available: Double side Mask Aligner, Laser Direct Writer, Deep Ractive Ion Etcher (Bosch(R) & Cryo), Chemical Bench for Lithographic processes & Wet Etching, Plasma Etcher, E-Gun Evaporator, Rapid Thermal Annealer (RTA), PECVD, LPCVD, Oxidation furnace, Graphene deposition furnace, Electroplating, Hot Embossing, Micro Injection Moulding, Microfluidic characterization setup, Micro Electro-Discharge Machining, 3D InkJet Printer, Microstereolithography, Polymeric powder 3D printing by Direct Laser Sintering, Electrospinning.

ISTI

BIO-ICT Lab, that is a joint Lab between ISTI and the Institute of Biophysics whose purpose is to promote advanced multidisciplinary research in areas ranging from bioplasmonic to image processing, from probe microscopy to computational intelligence.

PROJECT AREA 1: DEVICES AND SYSTEMS FOR ICT

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