Consiglio Nazionale delle Ricerche

Photonics

Key Enabling Technologies at CNR

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PHOTONICS
Key Enabling Technologies at CNR

The term Photonics was first introduced in 1967 by Pierre Aigrain, a French scientist, who gave the following definition: “Photonics is the science of the harnessing of light. Photonics encompasses the generation of light, the detection of light, the management of light through guidance, manipulation, and amplification, and most importantly, its utilisation for the benefit of mankind.” Indeed Photonics has a major impact in many interdisciplinary areas related to wellbeing and is one of the most pervasive KETs. Application sectors range from information and communication to industrial manufacturing and production, life sciences and health care, environmental monitoring, smart lighting, energy saving and production, food quality assessment, aerospace, safety and security, and the so-called “smart cities” and “smart communities” model.
Photonics, being intrinsically interdisciplinary, has strong interactions with most of the other KETs and allows synergic strategies. It can foster significant improvements in the state-of-the-art performances of any device or system, including those not “purely” photonic, but using photons at some stage of their operation, for signal generation, transmission, processing and/or detection, for light harvesting or production, for manufacturing, sensing, control purposes, visualisation or imaging, etc.
Moreover, photonic technologies have the potential of driving long-term innovation through new disruptive solutions where today’s conventional technologies are approaching their limits. Indeed, non-conventional approaches can be pursued through different strategies: new materials with unprecedented optical properties can be obtained through nanostructuring or by surface engineering; the quantum nature of photons can be exploited to realise integrated devices and system operating through quantum instead of classical processes; new wavelength ranges or extreme temporal features (e.g. ultrashort laser pulses) or extreme power characteristics can be used to explore radiation-matter interactions in new and unique conditions. This allows us to foresee a future where the performances of photonic components and systems will go much beyond what we can imagine today. Based on the Horizon 2020 strategy, Photonics is likely to play an important role in the three pillars: Excellent Science, Industrial Leadership, and Societal Challenges.
Thanks to the presence of several nodes of excellence in several Italian Regions, it can also be of major importance for the Smart Specialization Strategies through joint efforts and common development policies supported by local authorities, industries, and research institutions/universities (with CNR potentially in a leading position). The following booklet is reporting the main activities/results, within the Photonics KET, of CNR’s Institutes, where there is a potential capability to underpin value chains in strategic areas, and thus to contribute to the scientific knowledge, to support the industrial leadership and to accelerate the development of advanced innovative solutions addressing societal challenges.

dott. Corrado Spinella,
Director of the Department
of Physical Sciences and Technologies of Matter, CNR

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PHOTONICS - Key Enabling Technologies at CNR

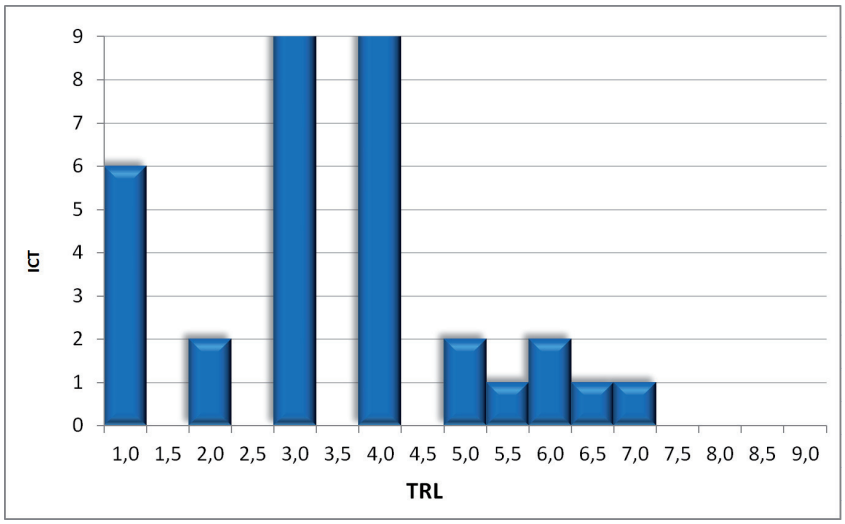
Technology Readiness Levels (TRL) in Horizon 2020

TRL 1 – basic principles observed
TRL 2 – technology concept formulated
TRL 3 – experimental proof of concept
TRL 4 – technology validated in lab
TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 7 – system prototype demonstration in operational environment
TRL 8 – system complete and qualified
TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

ICT

In the scenario of the profound transformations our society is passing through, ICT innovations are both a driver and a support.
Indeed, the ICT sector represents 4.8% of the European economy and investments in ICT account for 50% of all European productivity growth. In the H2020 framework the EU investment in ICT is supposed to increase of about 25% and support the whole chain from basic research to innovation that can deliver new business breakthroughs.
Nowadays our business-driven culture is moving to a more 'social-oriented' culture where user-generated innovation becomes more influential and models of production, social organization and value creation are changing. The connection of everyday devices (eg. home appliances) or of more specialised equipment (eg. medical devices) to the Internet, will create innovations and new business opportunities. In this perspective constant progress in miniaturisation of more powerful systems using less energy is needed. Furthermore the need for integration of more functionality on chips is increasing in order to support new advanced capabilities.
In this complex and challenging framework, CNR is deeply involved in the development of the ICT issues specifically related to photonics and nanophotonics. As it is highlighted in the following collection of contributions, great effort is spent among different Institutes in combining fundamental research with nanotechnology in order to provide a key to novel solutions for communications, new materials and devices, healthcare and security. Innovative micro-, nano-optical and -optolectronic components such as organic light-emitting transistors, polariton devices, solid-state lasers, photonic crystals, superconducting single-photon detectors are considered as enablers, multipliers and catalysts for other scientific and technological fields.
The developed expertise and know-how in ICT issues are implemented to generate breakthrough technologies and to translate them into new products and processes which are possibly taken up by industrial players. Thus, single photonic and optoelectronic components are integrated into functional devices in order to bring the well-assessed technology from lab to real settings, as in the case of innovative lab-on-a-chip devices for high throughput bio-diagnostics, sensing and food security.

number of contributions in this section



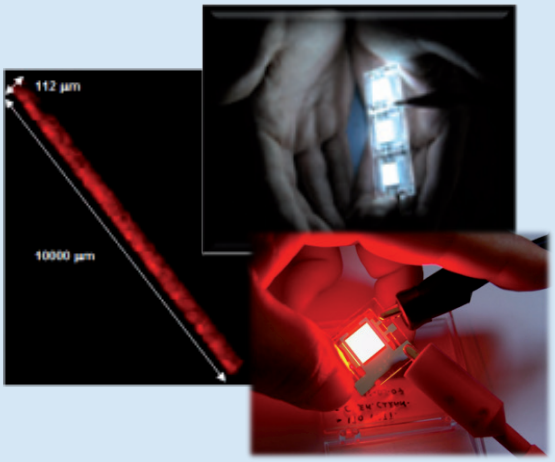
Organic light emitting devices: display and lighting applications

TRL: 6

Organic light-emitting diodes (OLEDs) are very promising type of technologies having a wide range of applications. In less than two decades, they have become a commercial reality in display technology (AMOLED). The development of large area white OLEDs (WOLEDs) for general lighting with an almost perfect Rendering Colour Index (CRI) near 100 and a theoretical efficiency of 200 lum/W has also become a priority.

We have demonstrated a new concept "p-i-n MC-OLED" structure for white and monochrome OLED, that offers the possibility to optimize the outcoupling efficiency and improve the output luminance, through the amplification of the light emission at the wavelength next to the resonance wavelength of the cavity, in the direction parallel to its axis, without changing its electrical behaviour. For red MC-OLED, operating at high luminance of 10000 cd/m^2, we report a current efficiency of 40 cd/A, ensuring a lifetime ($LT_{50\%}$) of 2000h.

More recently, we have demonstrated the first trilayer heterostructure of ambipolar "p-i-n Organic Light Emitting Field Effect Transistor" (p-i-n OLEFET) in a bottom contact/top gate configuration, featuring light emission across the whole channel area. It combines in a single device, the current modulation functions and electrical switching properties of a field effect transistor with light generation capabilities of an organic LED.



Photograph of p-i-n OLEFET and p-i-n MC-OLED in operation.

With regards to enterprises...

On this topic, we collaborate with STMicroelectronics, Tozzi Renewable Energy (TRE), Selex ES (partner of Mediteknology, CNR Spin-off), State Key Laboratory on Integrated Optoelectronics, Jilin University, China (bilateral cooperation)

We own a patent on p-i-n OLEFET (WO 2011110664 (A1) (15/09/2011)), on MC-OLED (WO 2009090248 (A1) (23/07/2009))

We can offer: OLED-OLEFET device fabrication, characterization and simulation.

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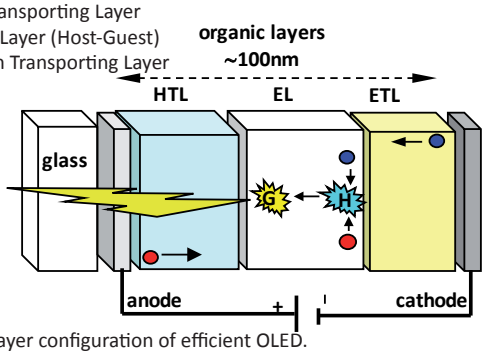
NANO - Lecce

OLED based on multi-emission by a single emitter

TRL: 4

OLEDs are electroluminescent devices constituted by one or more thin organic films of about 100 nm sandwiched between two electrodes. These devices require low working voltages (4-7 Volts) and do not need backlight. Due to all these advantages OLEDs are considered the future of display and lighting technology. OLED technology has application in visual communication devices, portable and fixed and can have an important role in environmental lighting and lighting panels for avionics, automotive, etc. also because OLEDs may be realized on flexible and conformable substrates. OLED prototypes realized in I.S.O.F. - CNR have a luminous area as large as 1 cm^2. They have a multilayered structure of about 130 nm thickness made by vacuum thermal evaporation of electro-active organic materials, which are sandwiched between two electrodes. The advantageous and innovative aspect of our devices is tuning of the color and coverage of the entire visible spectrum, as well as white light and NIR emission by using a single phosphor. The devices are encapsulated in glass to protect from deteriorating effects caused by humidity and oxygen. OLEDs fabricated in our lab are highly luminescent (>10000 cd/m2) and have external quantum efficiency up to 20%, which is the maximum efficiency that can be achieved in this device architecture. Currently our research is focused on the lifetime of the devices.

HTL : Hole Transporting Layer
EL : Emitting Layer (Host-Guest)
ETL : Electron Transporting Layer



Typical multi-layer configuration of efficient OLED.

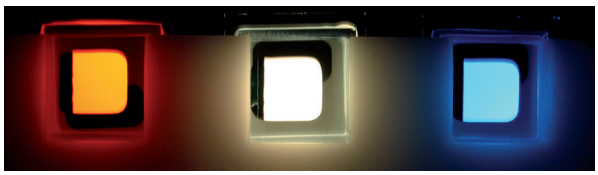


Photo of three OLEDs based on a single emitter at different concentration in the emitting layer.

With regards to enterprises...

On this topic, we collaborate with ISMN-CNR, Univ. of Milan, Univ. of Durham and Consortium MIST E-R scrl (Bologna).

We can offer: expertise to develop efficient OLED.

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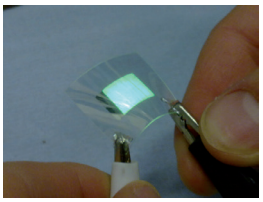
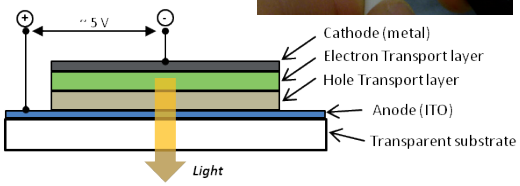
Joanna Malicka (joanna.malicka@isof.cnr.it)
Consorzio MIST E-R scrl

Low-cost and energy-efficient advanced OLEDs for decor lighting and signage

TRL: 6 - 7

OLED (*Organic Light Emitting Diode*) is expected to be the next generation lighting. It has possibilities to revolutionize the whole concept of lighting and space.
Indeed, OLED lighting is the first type of illumination that allows light emission by using the device itself as the emission surface, not depending on the particular single lighting device configuration. The luminescent active region of the device is mere 1/10,000mm thick so that the thickness of the overall OLED is almost the same as the thickness of the glass or plastic used to form the panel.
From the design perspective, OLED lightening is well-suited to the flat surfaces of interior décor offering surprising greater degree of design freedom.
Within this scenario, ISMN-CNR is currently developing research programs for developing new class of energy-efficient lighting systems for lighting by investigating i) combinations of advanced organic materials from major European suppliers with energy efficient and durable architectures, ii) flexible & shapeable low cost conformable substrates with integrated electric connections and iii) patterned full colors lighting systems for large area applications.





a) Image of a lit 1cm^{-2} –wide OLED deposited onto flexible substrate fabricated at ISMN-Bo. b) Sketch of the structure of a generic OLED. c) Lab facility available at ISMN-Bo for the fabrication of advanced light-emitting organic devices.

Possible industrial exploitation

INDUSTRIA 2015 ALADIN ; FIRB NODIS
Sirio Panel spa, Centro Ricerche Plastoptica,S.p.A., Artemide, Beng, GM Lightening

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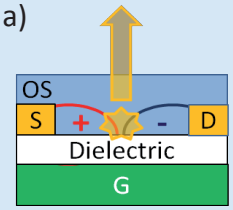
ISMN - Bologna

Organic light-emitting field-effect platform for innovative photonic biosensing

TRL: 5 - 6

a)



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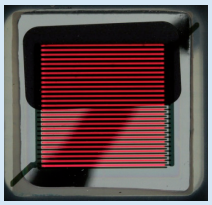
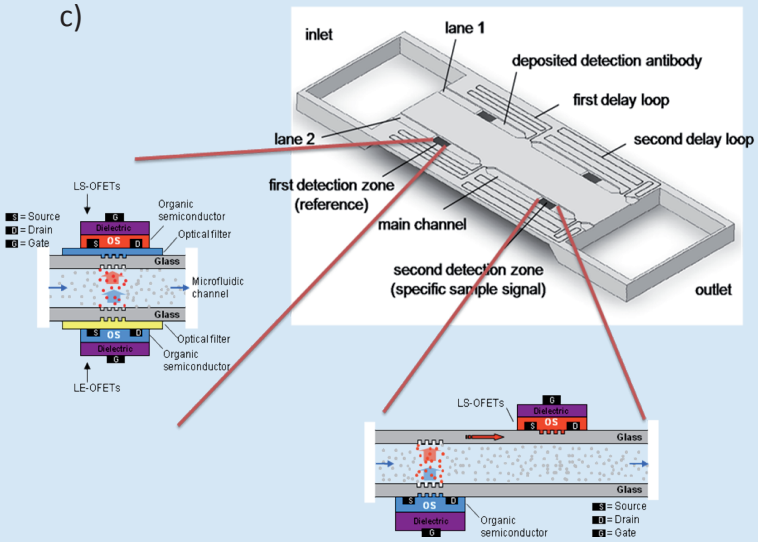


c)



Organic light-emitting field-effect transistors (OLETs) are emerging as an innovative class of multifunctional devices that integrate the electronic properties of a transistor, the light generation capability and the full potential of organic photonics. OLET technology is implemented in developing innovative portable photonic devices for bio-sensing capable of performing quantitative diagnostic tests.
OLETs:

- simplified manufacturing
- high efficiency
- high brightness
- on-chip integration

a) Sketch and working principle of OLET S: source electrode; D: drain electrode; G: gate electrode; OS: organic semiconductor b) Illuminated OLET realized at ISMN-CNR. c) Scheme of the Lab-on-a-Chip opto-fluidic device implementing OLET technology (PHOTO-FET courtesy).

Possible industrial exploitation

A synergic partnership between ISMN-CNR and innovation-driven company aims at realizing niche application in emerging organic photonic market:
EU PHOTO-FET project (FP6-IST-015034)
OLET industrial project ISMN-CNR/ETC srl
10 patents and patent applications

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Nanostructured highly conductive PEDOT:PSS films with 2D photonic crystals and quasi crystals for efficient OLED and WOLED devices

TRL: 4

Our group together with ENEA UTTP-NANO Laboratory in Portici Research Centre (Carla Minarini's team), has introduced for the first time an effective process based on the combination of Electron Beam Lithography and Plasma Etching techniques to fabricate a novel polymeric anode structure based on 2D nanopatterned highly conductive PEDOT:PSS layers. Our proposed ITO-free electrode structure can improve the outcoupling efficiency of OLEDs and demonstrate the great potential of PC-polymeric anodes for use in a wide variety of high-performance flexible organic optoelectronics. A 2D nanopatterned transparent anode was also fabricated onto a flexible polyethylene terephthalate (PET) substrate and it was integrated into an organic light emitting diode (OLED). The obtained results fully confirm the feasibility of the developed process of micro/nano patterning PEDOT:PSS.
ACS Applied Materials & Interfaces 5 (11), pp. 4777-4782 (2013); Nanotechnology 24 (31), (2013).

With regards to enterprises...

On this topic, we strongly collaborate with ENEA UTTP-NANO Laboratory in Portici Research Centre (Carla Minarini's team). This research has been financed by MIUR: RELIGHT- Research for LIGHT (lighting and sunlight) PON02_00556_3306937.

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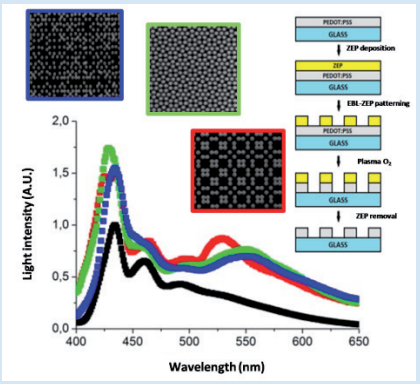

SEM images (up), light extracted (bottom) and schematic diagram-process (right) of the highly conductive PEDOT:PSS-PQC nanostructured films. J. Mater. Chem. C, 2014, DOI: 10.1039/C4TC01936A.

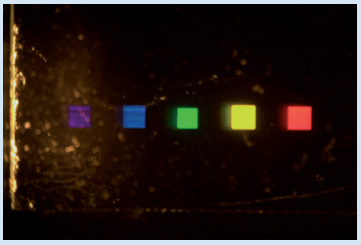

Photo of light extracted from air-cylinders PCs in polymer with diameter D= 180nm and increasing periods a = 265, 295, 325, 360, 410 nm from left to right. A white light is introduced from an edge of the glass and propagates inside the glass.

Novel organic laser devices by room temperature processing

TRL: 4

We have developed complementary processing approaches, working at room temperature, for the realization of patterns and lasers relying on (i) planar distributed feedback (DFB) geometries, (ii) integrated vertical microcavities and (iii) random systems. We have fabricated planar DFB cavities by nanoimprint lithography at room-temperature, a technique based on the deformation of a polymer film under the application of pressure (of the order of 100 Pa) onto hard, high resolution masters, fabricated by e-beam lithography. The emission of our DFB devices ranges from 600 to 920 nm, with linewidth <1 nm, a pumping threshold of the order of 30 μJ/cm^2, and strongly polarized emission. When nonlinear optical chromophores are embedded in the active layer, tunability of the emission of the order of 20 nm is achieved by applying an external electric field (typically in the range 50-100V). The vertical cavity surface emitting laser (VCSEL) and random laser devices feature emission in the whole visible range (400-700 nm) and pumping threshold as low as 10 μJ/cm^2. Applications of devices include high-sensitive chemical sensing, analytical spectroscopy and on-chip biomedical diagnostics.

With regards to enterprises...

On this topic we can design and develop patterning processes by nanoimprinting on polymers and organic multilayers, design and fabricate prototypes of planar and vertical organic lasers, and assess the lasing features of the devices.

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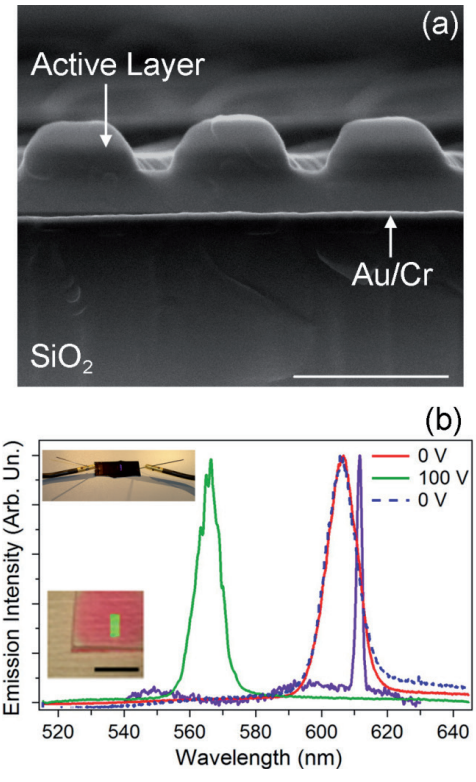
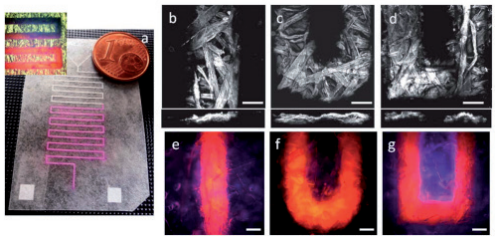


a) Scanning electron micrograph of polymer DFB device cross-section. The active layer is composed by a red-emitting conjugated polymer and a nonlinear optical chromophore. Scale bar: 400 nm. (b) Emission spectra of laser emission (violet continuos line) and ASE emission under different applied voltages.

Organic and Bio-mimetic Random Lasers



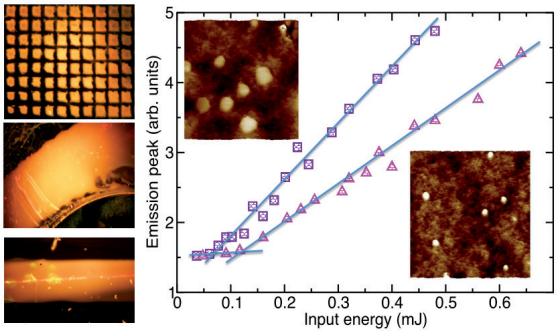
Paper microchannels used for random lasing.

The growing demand for innovative optical and photonic applications is motivating research towards the realization of soft, biocompatible and implantable photonic components that offer smart, low-cost and scalable interfaces which can be easily integrated. Here we report on different novel types of lasing devices without the presence of any optical cavity. We focus on a particular class of lasers, namely Random Lasers (RLs). RL consists of a random assembly of scattering structures dispersed into an optical gain medium in which the optical cavity is merely represented by multiple scattering processes of light.

TRL: 1

We consider lasing devices from paper flexible sheets by creating on the cellulose fibers micro- fluidic porous channels in which a fluorescent dye can flow by capillarity. We show how the emission properties depend crucially on the width, shape and curvature of the microchannels as well as on their functionalization with colloidal additives.

We also demonstrate the RL emission from scattering nano-aggregates of a thiophene oligomer, obtained by soft lithographic technique. We obtain organic mini-lasers of different shapes and we are able to tailor the structure of the random lasers at the nanoscale by finely tuning the supramolecular self assembly of the organic dye. Moreover we observe peculiar lasing emission from bio-mimetic materials. The transformations of the complete hierarchical structure of paper fibers into inorganic materials allow to obtain very efficient RLs with sub-nanometer localized lasing modes.



Lasing from lithographed thiophene organic dye T5COx!

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Claudio Conti (claudio.conti@cnr.it), ISC - Sapienza

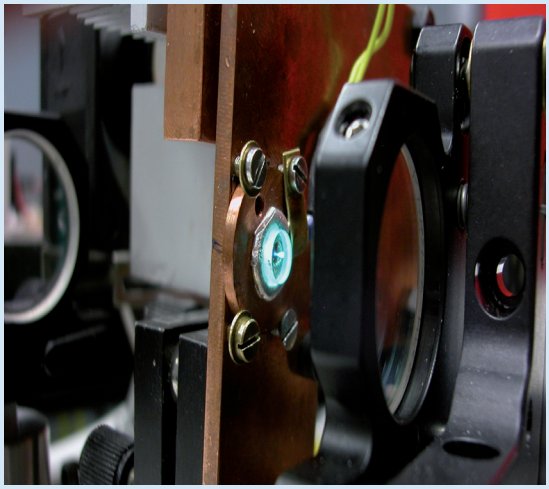
Development of innovative diode-pumped solid-state lasers based on ceramic materials

One of the most important achievements in recent years in the field of solid state lasers is the introduction of transparent polycrystalline materials, i.e. ceramics, doped with rare earths.

Ceramics are currently having an unquestioned success because of, if compared with single crystals, they support higher level of doping with more controlled distributions, and in turn, they can withstand higher thermo-mechanical stresses. Ceramics can be produced with complex structures and large size, which are difficult or impossible to obtain with monocrystals, and the same time, with a reduced cost.

TRL: 4

In the last years we have developed several laser prototypes based on Yb-doped ceramics as YAG, LuAG, Lu2O3, and Sc2O3, which are considered technological keystones for high power laser systems in the infrared region for many and many applications.



Yb:YAG ceramic element emitting laser radiation. Turquoise fluorescence is due to the pump up-conversion.

With regards to enterprises...

On this topic, we collaborate with: ISTEC-CNR, Faenza; Institute of Physics Academy of Sciences of the Czech Republic in Prague; Department of Physical Chemistry of Luminescent Materials, Claude Bernard University, Lyon, France.

We can offer well established experience in the development of solid state diode pumped lasers and their applications for sensors, environmental diagnostics and industrial applications.

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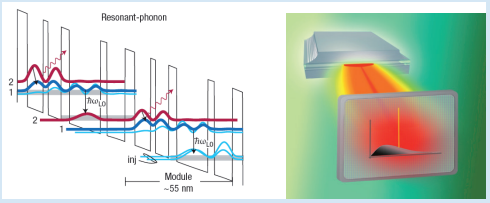
Matteo Vannini (matteo.vannini@ino.it) INO - Firenze

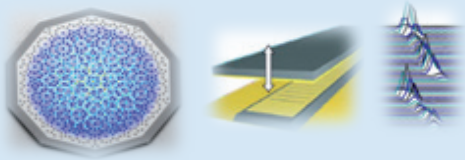
Terahertz Quantum Cascade Lasers

TRL: 4

Quantum Cascade Lasers (QCLs) represent one of the most impressive demonstration of the capabilities offered by band structure engineering, showing how artificial materials can be created by quantum design with tailor-made properties otherwise not existing in nature. Terahertz (THz) frequency QCLs have undergone rapid development in performance since their first demonstration and have potential to find application in a number of fields including astronomy, security screening, biomedicine, environmental sensing and cultural heritage. By operating across the 1.2–5 THz range, QCLs can provide high peak output powers (up to 1 W), a high spectral purity, frequency, phase and amplitude stability, and an ultra-broadband gain spanning an octave in frequency with operating temperatures ≤ 200 K, nowadays easily achieved through the use of small cryostats or Stirling coolers. The shape, the symmetry and the frequency of the optical resonator eigenmodes can be tailored by design, while simultaneously allowing single-mode operation. Vertical emission in the THz domain from QCLs based on a two-dimensional quasi-crystal photonic resonator has been recently achieved providing intense and highly collimated optical beam profiles. Also, second-order THz DFB QCLs, coupled to an external microcavity, allows achieving 55 GHz continuous tuning by mechanically changing the size of the external microcavity.



(Left) Schematic view of a portion of the conduction band structure of a THz QCL; moduli squared of the important states are drawn as thick lines. **(Right)** Schematic sketch of the ultra-narrow emission linewidth of a THz QCL.



(Left) Scanning electron microscope image of a double-metal vertical emitting THz QCL having a quasi period DFB Penrose patterning. **(Right)** Schematic drawing of the coupled cavity configuration and tuning range.

With regards to enterprises...

We can offer:
– High-Power CW THz QCLs (edge or surface -emitting)
– Widely tunable THz QCLs
– Waveguide-coupled THz QCLs

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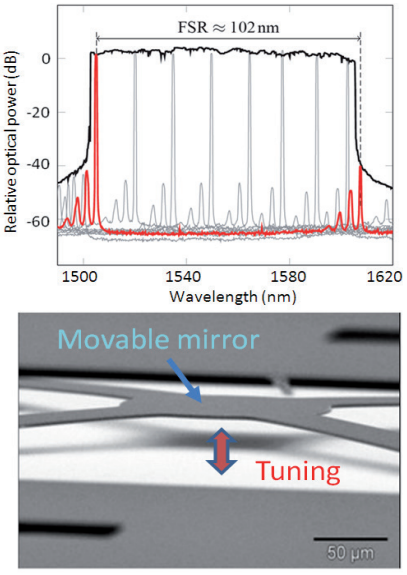
Vertical Cavity Surface Emitting Lasers: the light source for today and tomorrow photonics

TRL: 4 to 10

A VCSEL is a complex dielectric resonator, composed of hundreds of layers and with plenty of possible transverse geometries, to achieve different features, depending on its specific application. They are micro-lasers, driven by a few milliamps currents and delivering some milliwatts of optical power. Nowadays they represent more than 90% of the semiconductor laser market, with applications ranging from datacom to sensors. Their production volumes is exponentially growing and soon VCSELs will be indispensable part of smart-phones and in micro-processors for intra- and inter-chip data exchanges. Their success is due to smaller production costs, circular beam emission for best fiber coupling, small consumption (green electronics), high wall-plug efficiency, easy to have in linear of bi-dimensional arrays for higher powers, and on-silicon integration.

In 2002 IEIIT presented a model that allows the computation of their vectorial modes very efficiently: a few minutes on a normal PC instead of hours on supercomputers. This fully in-house developed code allowed us to design, realize and patent a technique to stabilize the emitted polarization, via a monolithically etched grating which is now found in all laser mice. In the European STREP project SUBTUNE (www.subtune.org) IEIIT lead the design and modeling of the tunable VCSELs, which ended up in 2011 with the record of 102nm continuous tuning (Fig. 1), still unbeaten.



Record VCSEL tuning features: top, spectra for different control parameter values, bottom, device image, showing the movable (tuning) top mirror.

With regards to enterprises...

Collaborations with academic (U-Ulm, TU-Berlin, TU-Munich) and commercial (Philips-photonics, Vertilas) producers. A contract is running with Camlin (Zuerich): develop VCSELs in the 3-4.2µm range, still not available on the market.
One granted and one pending patent on VCSELs.

Contact:
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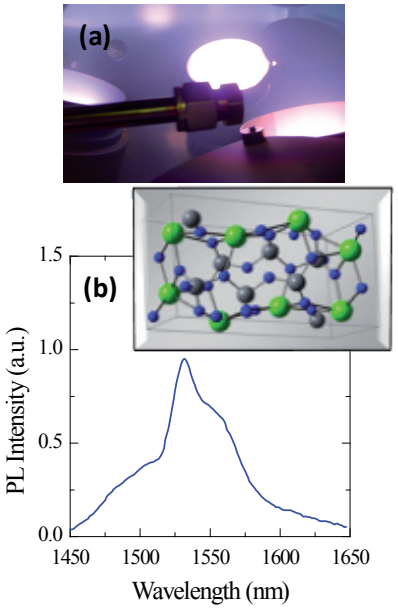
Rare earth compounds for optical amplification at 1,54 micron

TRL: 4

One of the main tasks in integrated silicon photonics is to develop a high gain material for compact amplifiers and coherent light sources totally integrated with Si platform. Erbium-containing materials are the ideal candidates due to the 1.54 micron emission from Er^{3+} ions. However Er density in a solid host is limited to only 10^{20} cm^{-3} due to the occurrence of clustering and segregation effects. Such a low Er density leads to only a few dB/cm optical gain, not useful in compact devices. To overcome this limit, we develop mixed rare-earth (RE) compounds thin films, in whose crystalline lattice Er can substitute the other RE ions, due to the similar chemical properties. Thus it is possible to insert gradually Er optically active ions with density above 10^{22} cm^{-3}. This structure allows a very accurate control of the dipole-dipole interactions between RE ions, and consequently a control of the optical properties of the system.

In this way the mixed RE compounds give exciting developments towards the realization of active photonic devices, such as optical amplifiers, slot waveguides and photonic crystal nanocavities, which include them as active medium. The implementation of these devices open the routes toward amplifiers and lasers at 1.54 micron totally compatible with Si platform. Moreover their peculiar optical properties permit light management interesting for photovoltaic applications as down-converters in the infrared region and upconverters in the visible one.



a) Photograph of plasma during the co-sputtering synthesis of thin films. (b) Typical Er emission at 1,54 micron. In the insert the crystalline structure schematic of a RE compounds. Green, grey and blue spheres are respectively RE, Si and O atoms.

With regards to enterprises...

We collaborate with University of Pavia and University of St. Andrews for the design and realization of active photonic devices, with STMicroelectronics for the realization of light emitting devices.

Contact:
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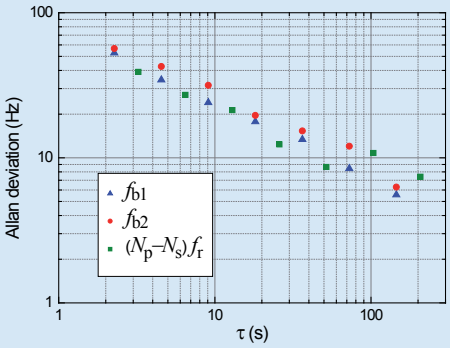
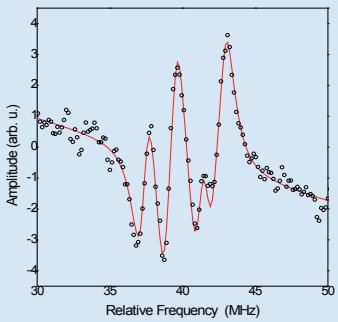
Mid-Infrared Optical Parametric Oscillator

TRL: 3

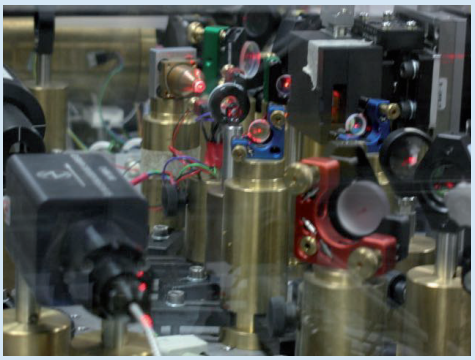
Continuous wave optical parametric oscillators (OPOs) are coherent sources of radiation having unique features, useful for a wide range of applications in high-resolution spectroscopy, frequency metrology, and fundamental physics. We developed a singly-resonant OPO emitting about 1 Watt of power in the range between 2.7 and 4.2 µm. Our activity is focused on improving the spectral features of the source: by using a frequency comb as a transfer oscillator and absolute reference we obtained an emission linewidth below 1 kHz and a long-term stability of 3×10^{-12} $\tau^{-1/2}$ between 1 and 200 s. This combination of high power, high spectral purity, and precise and absolute frequency control over a wide range of tunability makes our OPO a valuable tool for high-resolution molecular spectroscopy in the MIR, a spectral region of growing interest for precise measurements and accurate tests of fundamental theoretical models.



Allan deviation of the three relevant contributions to the idler frequency.



Example of saturation spectroscopy of CH_3I by means of OPO: sub-Doppler-resolved hyperfine structure of the v1 P(18,3) ro-vibrational transition.



Contact:
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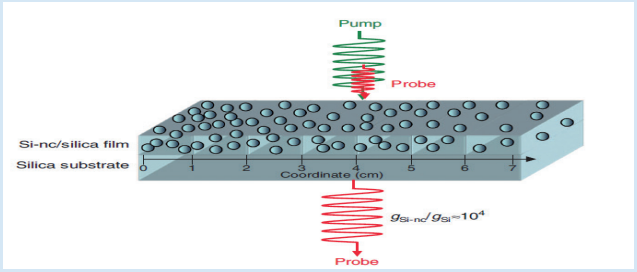
Simona Mosca (simona.mosca@ino.it), INO - Napoli
Iolanda Ricciardi (iolanda.ricciardi@ino.it), INO - Napoli

Light generation in silicon nanostructures

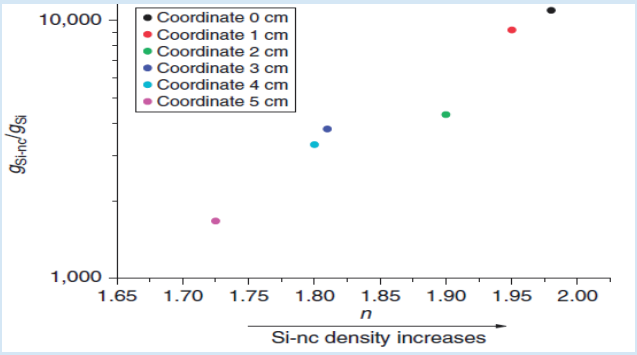
TRL: 3

Nanostructured silicon has generated a lot of interest in the past decades as a key material for silicon-based photonics. The low absorption coefficient makes silicon nanocrystals attractive as an active medium in waveguide structures, and their third-order nonlinear optical properties are crucial for the development of next generation nonlinear photonic devices.

Here we report the first observation of stimulated Raman scattering in silicon nanocrystals embedded in a silica matrix under non-resonant excitation at infrared wavelengths (B1.5 mm). Raman gain is directly measured as a function of the silicon content. A giant Raman gain from the silicon nanocrystals is obtained that is up to four orders of magnitude greater than in crystalline silicon. These results demonstrate the first Raman amplifier based on silicon nanocrystals in a silica matrix, thus opening new perspectives for the realization of more efficient Raman lasers with ultra-small sizes, which would increase the synergy between electronic and photonic devices.



The film has the Si concentration varying along the longer dimension of the sample, the highest Si concentration being at coordinate 0.



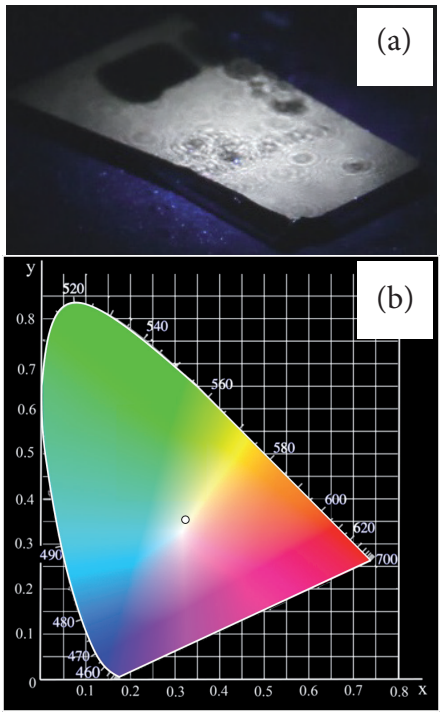
Ratio of the Raman gain coefficients of Si-nc in silica and crystalline silicon as a function of the refractive index of the film with different Si concentrations.

Contact:
Autori – M. A. Ferrara, I. Rendina. L. Sirleto (luigi.sirleto@cnr.it), IMM - Napoli

White light emission from Eu-doped Si oxycarbide

TRL: 4

Rare earth (RE) doped Si-based materials have recently attracted the interest of the scientific community as promising light sources. Among the various RE, a considerable attention has been devoted to Eu; both divalent and trivalent Eu ions are efficient emitting centers in the visible region and their luminescence is successfully employed in phosphors used in plasma display panels and in LEDs for solid-state lighting. Eu doped Si oxycarbide (SiO_xC_y) thin films have been grown by RF magnetron sputtering. We have demonstrated that Eu^{2+} luminescence is almost 3 orders of magnitude higher than Eu doped SiO_2 (in which Eu is excited through direct photon absorption), strongly suggesting that the SiO_xC_y matrix acts as a sensitizer for Eu excitation. Moreover, Eu^{2+} luminescence peak position strongly depends on the Eu content in the film. We have demonstrated that through a proper tuning of the Eu concentration and of the annealing temperature it is possible to obtain an intense white emission at room temperature (see (a)). The chromaticity coordinates for this sample are (0.33, 0.36), to be compared with those relative to an ideal white emission, which are (0.33, 0.33) (see open circle in (b)). Being Eu-doped SiOC a material fully compatible with Si CMOS technology and electrically excitable, it may find an application in the fabrication of light emitting devices to be employed in Si photonics or in solid-state lighting.



(a) Photograph of the Eu white emission under UV illumination. (b) CIE chromaticity coordinates for the Eu white emission.

With regards to enterprises...

We collaborate with STMicroelectronics for the realization of light emitting devices based on rare-earth doping of Si-based materials.

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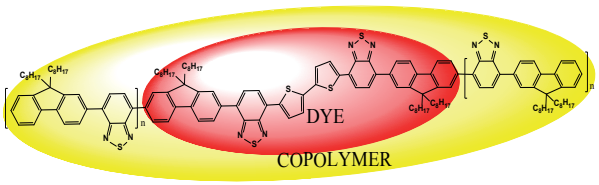
Fabio Iacona (fabio.iacona@ct.infn.it), IMM - Catania

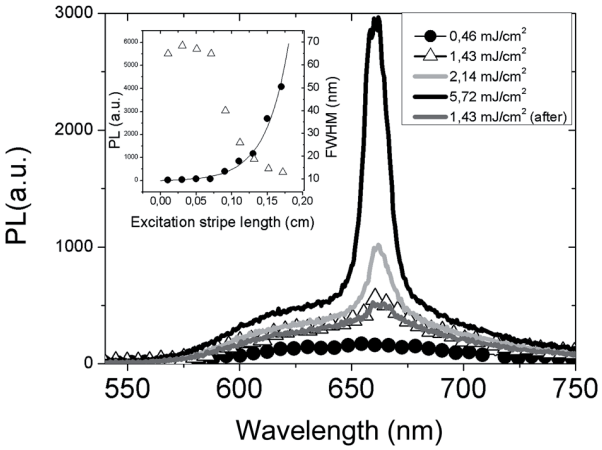
A core copolymer approach to improve the gain properties of emitting molecules

TRL: 3

Since their discovery, conjugated polymers are a growing area of interest for optoelectronic research such as transistors and photovoltaic applications. Their high optical gain, as well as their low cost processability and easily tunable optical properties, make them suitable as lasing materials or amplifying media. In particular organic materials have been recently used for signal regeneration in polymeric optical fibers. For these photonic applications it is very important to control the inter-chain charge photo-generation yield, which is often detrimental, as the charge absorption band overlaps spectrally with the stimulated emission. Therefore, charge generation acts to quench the stimulated emission, gain and lasing action. Different approaches have been
tried so far to control this mechanism. An attractive approach could be the "core polymer" strategy, where a molecular dye is inserted as core between two arms of semiconducting polymer This powerful strategy has been applied successfully in polymeric OLED materials and for the first time we are able to enhance optical gain for advanced applications

U. Giovanella, P. Betti, A. Bolognesi, S. Destri, M. Melucci, M. Pasini, W. Porzio and C. Botta, Org. Electron., 2010, 11, 2012





Spectral evolution of the PL from the polymeric film as a function of the excitation energy density. Inset: evolution of the FWHM (open triangles) and of the PL intensity at 660 nm (closed circles: experimental data, line: numerical fit) as a function of the stripe length. S. Bolis; M.Pasini,; T. Virgili; Chem. Commun., 2013, 49, 11761—11763

With regards to enterprises...

We collaborate with IFN-CNR

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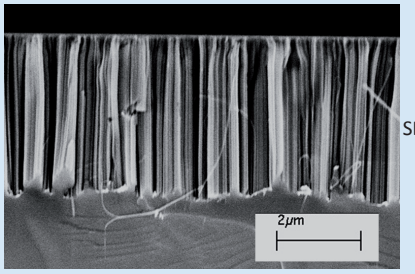
ISMAC-Milano
Tersilla Virgili IFN - Milano

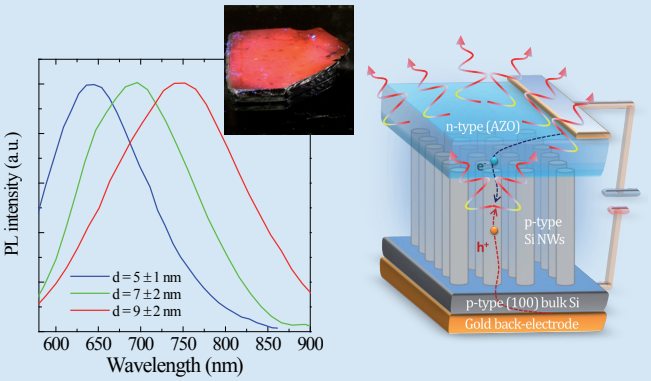
Room temperature light emission from silicon nanowires

TRL: 4

Si NWs are produced at room temperature, by using a metal-assisted wet etching process of Si substrates employing Au nanoparticles and an aqueous solution of HF + H_2O_2. The process is maskless, fast and cheap; moreover, it allows a tight control of the NW size, and very dense arrays (up to 10^{11} cm^{-2}) of NWs having an extremely small radius (about 5 nm) can be obtained. NWs maintain the same crystallographic structure and doping of the starting substrate and their length can be tuned inside a wide range, up to several µm, by increasing the etching time. NWs exhibit bright and tunable photoluminescence (PL) at room temperature, due to the occurrence of quantum confinement effects.
The external quantum efficiency of the system has been measured to be higher than 0.5%. Electroluminescence has been also obtained by realizing simple devices operating at room temperature and at low excitation voltage (2-6 V).



SEM cross section of Si NWs



Left: room temperature PL spectra of Si NWs as a function of the size; center: photograph of the intense red emission of Si NWs; right: schematic view of a device based on Si NW.

With regards to enterprises...

The synthesis process of Si NWs is compatible with an industrial environment, so that practical applications of this material are currently explored in collaboration with STMicroelectronics.

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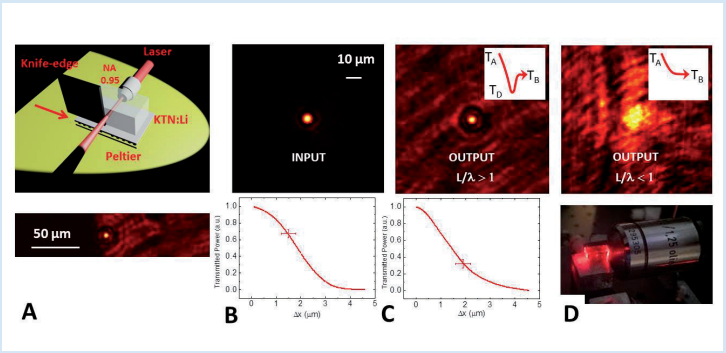
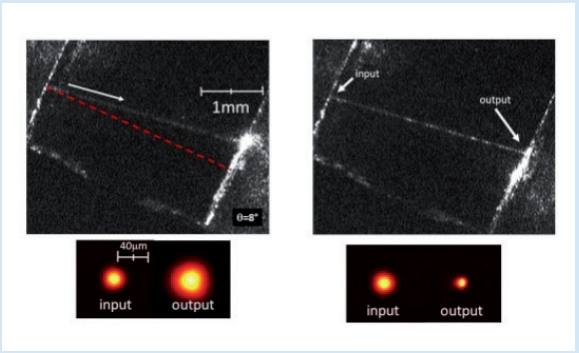
Subwavelength light beams in nanodisordered perovskites

TRL: 1

Diffraction causes light to spread as it propagates, and this limits the resolution of optical imaging systems, smearing out spatial details that are of the order of and below the optical wavelength.
For visible light, this means that all objects and features below the micrometer are not easily observed. Imaging then requires complicated super-resolution techniques. This fact places the frontier of nanoscale biology, electronics, and material fabrication beyond the grasp of direct vision. Here we report the observation of light behavior in out-of-equilibrium nanodisordered ferroelectric crystals that fundamentally violates this diffractive-wave picture. Beams are observed to propagate without diffraction, irrespective of size and intensity, and can even be made to shrink as they evolve, so that resolution is maintained and increased over macroscopic propagation lengths. In nanodisordered KTN:Li, we observe a non-paraxial propagation of a sub-micrometer-sized beam for over 1000 diffraction lengths, the narrowest visible beam to date reported. The effect is caused by the nonlinear response of a dipolar glass in a perovskite. Our findings, in collaboration with the Hebrew University of Jerusalem, open the way to high-resolution imaging over large depths-of-focus.



A micrometer-sized beam proagating for 3 mm in a sample of KTN:Li after the sample has been subject to a thermal shock.



Visible beams in thermalized (left) and supercooled (right) KTN:Li. Antidiffraction heralds the breaking of standard wave optics.

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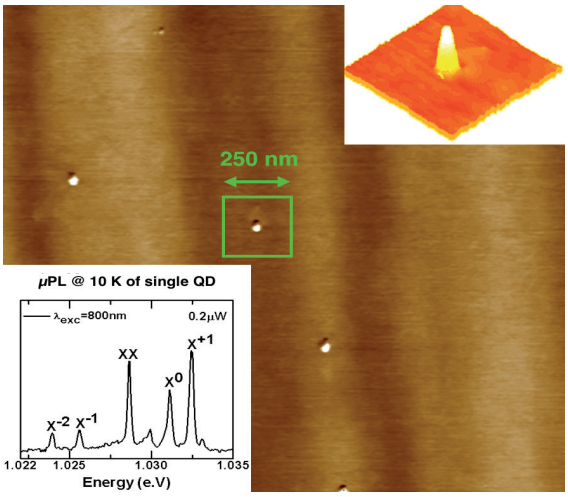
Epitaxial metamorphic quantum dots: single photon sources at telecom wavelengths

TRL: 2

We developed a method involving Molecular Beam Epitaxy for the preparation of quantum dot (QD) nanostructures with densities of few QDs per µm2: the structure design is based on InAs QDs grown on InGaAs metamorphic buffers and allows to control the emission wavelength in the telecom windows at 1.3 and 1.55 µm. Advanced micro-optical characterization showed that these QDs can act as single photon sources, for applications in quantum cryptography, communication and other quantum science areas.



AFM image of metamorphic InAs/In0.15Ga0.85As QDs grown by MBE. In the bottom inset µPL spectrum showing single QD emission in the 1.3 µm range

With regards to enterprises...
We have established preliminary contacts with leading semiconductor industries.

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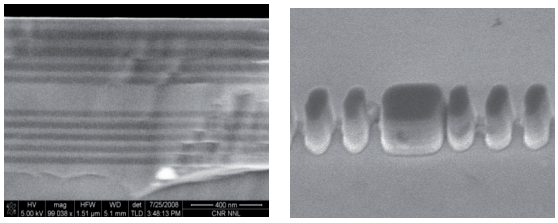
Giovanna Trevisi, Paola Frigeri, IMEM - Parma

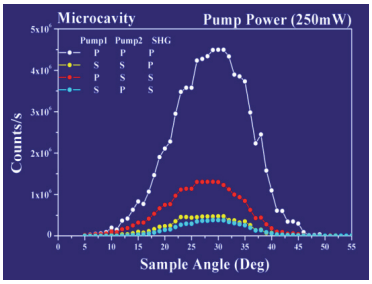
GaN based microcavities for enhancement of non linear optical effects

TRL: 3

Nonlinear optics is an important alternative for guided waves control in order to achieve higher speeds and powerful integrated optical circuits for all-optical communications and computing purposes. III-Nitride semiconductors are promising nonlinear materials exhibiting a non-centro symmetric structure which could provide second order nonlinear optical response comparable to conventional non linear crystals. Nevertheless, the large dispersion of bulk material implies too low quadratic nonlinear interaction. Properly designed heterostructures, such as AlGaN/GaN microcavities, combined with photonic crystal (PhC) technology, would allow to tailor exact phase-matching conditions and simultaneous field localization, enhancing nonlinear optical response. In order to enhance the non linear response of GaN, we designed, grew and fabricated a GaN-based microcavity centered in the UV spectral range ($\lambda \approx 400$ nm). The microcavity was epitaxially grown on sapphire by metal organic chemical vapour deposition and integrates a properly designed 1D-PhC grating, which amplifies the signal by exploiting the double effect of cavity resonance and non linear GaN enhancement. The integrated 1D-PhC microcavity was fabricated combing a high resolution e-beam writing with a deep etching technique. Measurements obtained as a function of incidence angle and polarization state of both fundamental and generated beams show an effective enhancement in the SGH emission.



SEM Cross Section of microcavity structure and view of a realized photonic crystal based on GaN/AlGaN microcavity.



Second Harmonic Generated signal as a function of pump polarization state from nitride-based microcavity .

With regards to enterprises...

Collaboration with SELEX S.I. and Università "La Sapienza", Rome.

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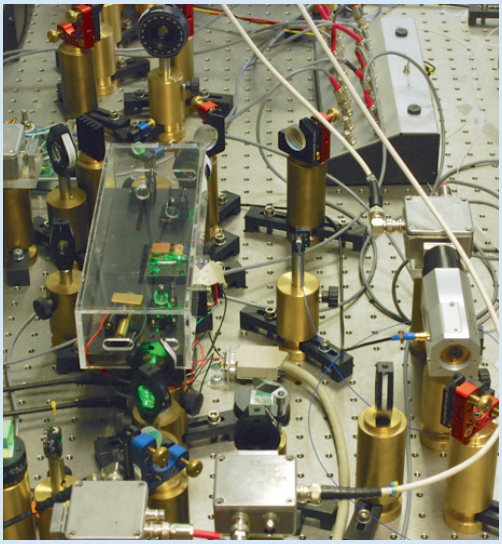
NANO - Lecce

Frequency Comb Generation in Quadratic Nonlinear Media

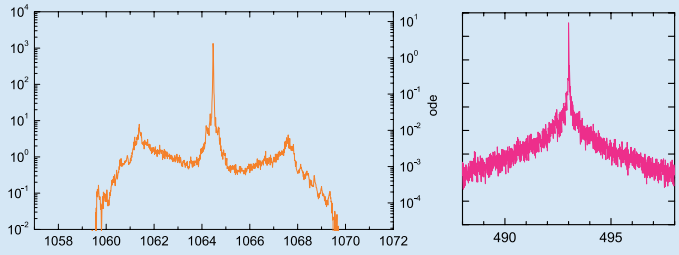
TRL: 3

Optical frequency combs are radiation patterns of discrete, equally-spaced frequencies. Although originally conceived for frequency metrology, optical frequency combs are currently used in many laboratories as a versatile tool for different applications. Ultrafast mode-locked lasers, first used for comb generation, have then been joined by continuously-pumped Kerr microresonators, exploiting the third-order nonlinearity of the materials, and quantum cascade lasers.

We demonstrated generation of optical frequency combs in a quadratic, $\chi^{(2)}$, nonlinear medium: a periodically-poled lithium niobate crystal, placed in an enhancement-cavity and continuously pumped by a single frequency laser. A dynamical model has been developed as well, describing the occurrence of $\chi^{(2)}$-combs as a results of cascaded nonlinear processes in nonlinear cavity, showing a striking resemblance to the FWM-based model for Kerr-combs in microresonators.



Nonlinear cavity pumped by a continuous wave laser generating frequency comb both in the IR and visible.



(Left) Optical spectrum of the IR comb around the pump wavelength. (Right) Radio-frequency intermodal beat note corresponding to the frequency spacing of comb teeth.

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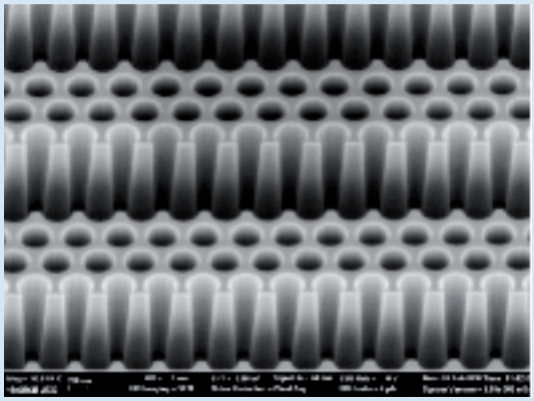
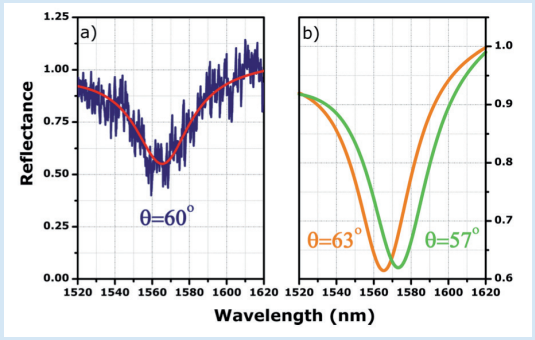
Metamaterials, Photonic Crystals & Plasmonics

TRL: 4

Metamaterials, Photonic Crystals (PhCs), and plasmonics have reshaped the landscape of photonics. In our laboratories, nanophotonic devices, and in particular PhCs with an effective negative refractive index, are designed, fabricated and characterized. They exploit the drastic change in group velocity, causing the light to bend away from the usual directions observed in conventional refracting medium. Owing to the fine control of the optical bandgap, "optical antimatter" behaviour was, for the first time, demonstrated on millimetric lenghts, opening to invisibility for cloaking applications, and to smart optical interconnections on silicon chips. A further interesting result carried out recently in our labs is the first demonstration of plasmonic-like behaviour in negative PhCs. In particular, sharp optical resonances have been excited in metal-less, absorption free, 2D-PhC nanostructures, paving the way to a next generation of high sensitivity, extremely low detection limit sensors for biomedicine.



"Optical antimatter" silicon metamaterial.



Plasmon-like optical resonances in a negative PhC.

Contact:
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Autori – I. Rendina, E. De Tommasi, P. Dardano, S. Romano

Deterministic coupling between site-controlled, nanometer-sized light emitters and photonic crystal structures

TRL: 3

The project aims to open a new route in the integration of nano-sized light emitters with photonic crystal devices by employing a novel method for the fabrication of site-controlled nano-emitters based on the hydrogen-induced passivation of N atoms in dilute-nitrides (e.g., GaAsN, InGaAsN, and GaPN). In this class of materials, the formation of stable N-H complexes following H irradiation wipes out the effects of nitrogen on the host crystal. In particular, H binding to N atoms in GaAsN leads to an increase in the band gap energy of the N-containing material (~1.33 eV for [N]=1% at T = 5 K) up to its GaAs value (1.52 eV at 5 K). Therefore, by allowing H incorporation only in selected regions of the sample (for example by deposition of H-opaque metallic or oxide masks prior to hydrogenation) it is possible to obtain a spatially controlled modulation of the band gap energy in the growth plane, thus tailoring the carrier-confining potential down to the nm level and enabling the fabrication of site-controlled, dilute nitride-based quantum dots (QDs); see Fig. 1. Coupled to the possibility of realignment within few nanometers allowed by electron beam lithography techniques, the fabricated QDs can be placed in any point of a photonic crystal (PhC) device: The latter being fabricated "*around*" a selected QD; see Fig. 2. This will allow studying the spectral coupling between emitters and PhC cavity modes as well as for the realization of complex photonic devices, e.g., single- and entangled-photon sources, optical switches, and delay lines.

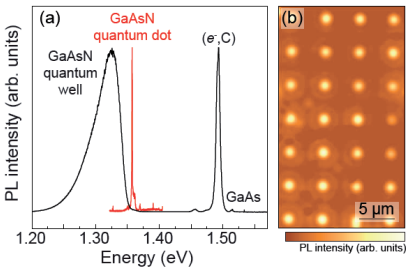

Figure 1. Photoluminescence spectra (a) and imaging (b) of GaAsN QDs fabricated by spatially selective hydrogen implantation.

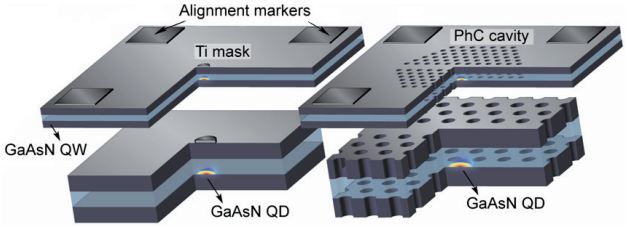

Figure 2. Sketch of the processing steps leading to a site-controlled GaAsN QD embedded in a photonic crystal micro-cavity.

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IFN - Roma, S. Birindelli, A. Polimeni,
L. Businaro, A. Gerardino, and M. Capizzi

Topological states in resonant photonic crystals

TRL: 1

The exchange of ideas and methods from atomic solids to their electromagnetic counterparts such as photonic crystals and metamaterials has led to extend to these structures the concept of topological order.

We propose a generalized Aubry-André-Harper model as an optical analogue of a topological insulator, given by a 1D sequence of sites with resonant excitations long-range coupled through an electromagnetic field .

Our photonic crystal consists of alternating resonant and non resonant layers A and B with a frequency-independent dielectric constant for the material B while the layer A is characterized by single-pole amplitude coefficients of light reflection.

This bichromatic resonant photonic crystal demonstrates topological properties as the existence of protected edge states for a compound non-centrosymmetric unit cell.

The dependence of the real part of the frequency of the left-edge (solid) and the right-edge (dashed) mode are shown as line in Fig.2. Circles indicate points where the edge modes are absent.

The radiative character of the system opens pathways to optical detection of the edge states and provides an important insight into the rapidly expanding field of the electromagnetic topological states in photonic crystals.

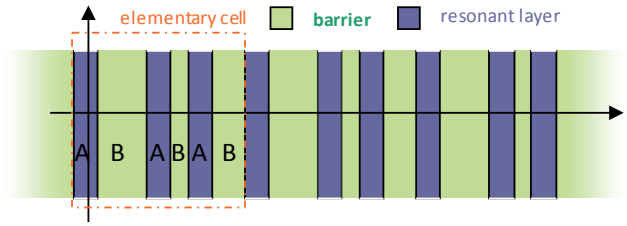

Fig. 1 Periodic structure with three resonant layers A in the unit cell.

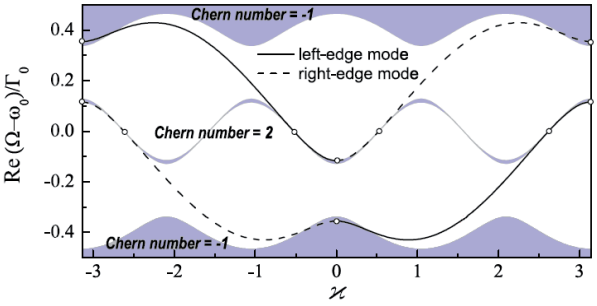

Fig. 2 Band structure as a function of the lattice wave vector characterizing the distribution of the A layers in the unit cell. The coloured regions are the allowed polariton zones, the white regions are the stop bands.

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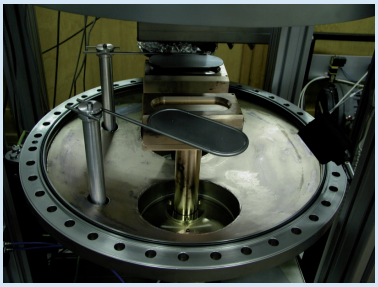
Laura Pilozzi (laura.pilozzi@isc.cnr.it) ISC - Monterotondo (RM)

A. V. Poshakinskiy, A. N. Poddubny, L. Pilozzi, and E. L. Ivchenko Phys. Rev. Lett. 112, 107403 (2014)

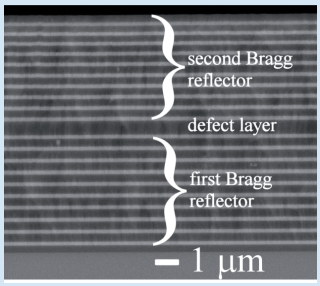
Photonics with RF-sputtering – High quality 1-D Er^{3+}-activated dielectric microcavity

TRL: 4

Rare earth-activated 1-D photonic crystals were fabricated by rf-sputtering technique. The cavity is constituted by an Er^{3+}-doped SiO_2 active layer inserted between two Bragg reflectors consisting of ten pairs of SiO_2/TiO_2 layers. A quality factor of 890 was measured. The influence of the cavity on the emission band of Er^{3+} ion is also demonstrated. The deposition protocol allows to fabricate 1-D photonic structures tuning the optical reflectance from visible to NIR regions.

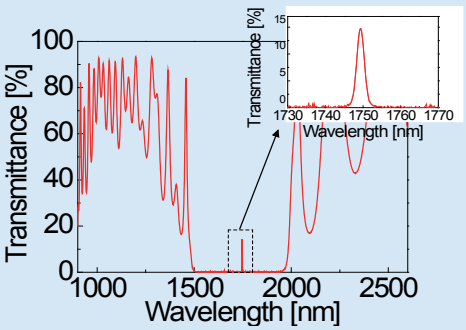


Rf-sputtering apparatus for deposition of dielectric systems. Resolution on the layers thicknesses of 1 Amstrong.



Transmittance spectrum of the cavity with two Bragg reflectors, each one consisting of ten pairs of SiO_2/TiO_2 layers, in the region between 1000 and 2600 nm. A quality factor of about 890 can be obtained.

SEM micrograph of the 1-D microcavity cross section. The bright and the dark areas correspond to TiO_2 and SiO_2 layers, respectively. The substrate is located on the bottom of the images and the air on the top.



With regards to enterprises...

Broad reflection coating on different substrates.

Rare earth activate multilayers systems

Dielectric microlaser.

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Alessandro Vaccari (FBK), Stefano Varas (IFN), Simone Normani (IFN), Sreeramulu Valligatla (UniHyderabad India – IFN), Francesco Scotognella (PoliMI-IFN), Giancarlo C. Righini (Centro Fermi), Roberta Ramponi (IFN), Maurizio Ferrari (IFN)

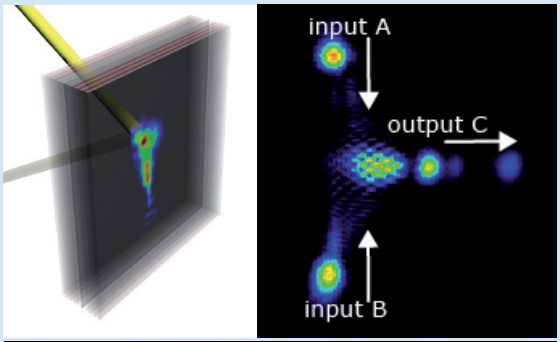
All optical polariton devices

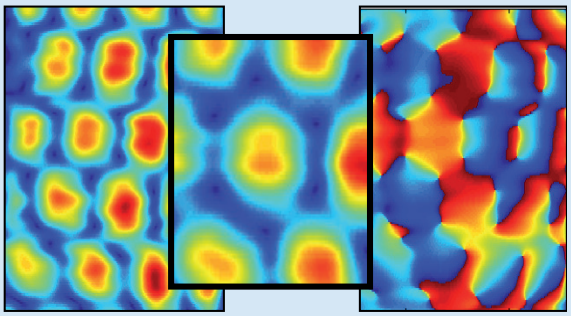
TRL: 1 - 2 - 3

The interaction of light and matter can be strongly enhanced in solid state heterostructurues (microcavities) which allow a coherent exchange of energy between photons and excitons. This coupled system is much more than the sum of its bare components, combining the best properties of the electronic and photonic realms to achieve outstanding performances in terms of fast switching times (few picoseconds), low power nonlinear operations, low heating transmission of information and new possibilities for the implementation of optical logics circuits integrated in semiconductor chips.

We have demonstrated the operation of a transistor which works with light signals as input and output, allowing for inter-connections of many transistors in the same microcavity chip realizing optical gates (AND, OR, NOT). The record switching time and activation energy are of 8 ps and few fJ, respectively.

Moreover, the propagation of fluids of polaritons allows the observation of lattices of quantum vortices (hexagonal shape, shown in the bottom figures in intensity and phase) which can be optically manipulated for their implementation in future all-optical devices.





With regards to enterprises...

On this topic, we collaborate with the Istituto Italiano di Tecnologia (IIT-CBN) –Italy, University of Salento, Universidad Autonoma de Madrid –Spain-, Université UPMC Paris (LKB) –France-, IESL-FORTH Crete –Greece-.

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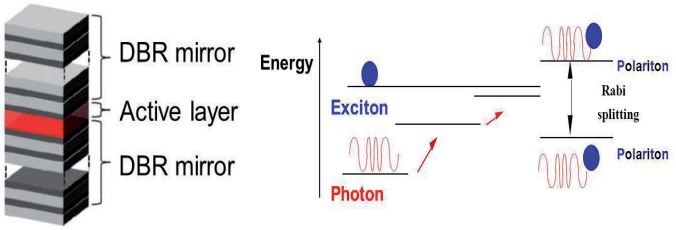
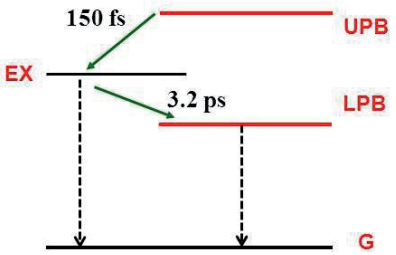
Organic polaritonic devices

TRL: 3

A semiconductor microcavity is fabricated by sandwiching a thin semiconductor active layer between two diffracting Bragg reflectors (DBRs) (see Figure). When the cavity mode is placed in resonance with the exciton absorption of the active layer, it is possible to achieve a strong coupling regime where two new states called Lower Polariton Branch (LPB), and Upper Polariton Branch (UPB) are separated by Rabi splitting energy. These new states are a quantum superposition between exciton and photon, they have very light mass and high speed due to their photonic part, but also a strong non linear response at low power thresholds due to the excitonic component. The peculiar characteristics of those new states can lead to the use of polaritons based devices in low-threshold lasers, diodes, transistors and logic element in integrated circuits. The understanding of the ultrafast processes in these kind of devices is one of the main purpose of our research together with the understanding of the role of the percentage of excitons not coupled to the photons (called excitons reservoir EX).



On the left: structure of the microcavity; On the right: schematic energetic diagram representing the formation of the two polaritonic states.



Ultrafast decays between the two polaritons states and the exciton reservoir. T. Virgili et al PRB 83, 245309 (2011)

With regards to enterprises...

We collaborate with the group from the Physics Department of the Politecnico di Milano led by Prof. G. Cerullo, with the group from the University of Sheffield led by Prof. D.G. Lidzey and the group in the IBM in Zurich. This research has been financed by European Union via FP7 ITN project Icarus (237900)

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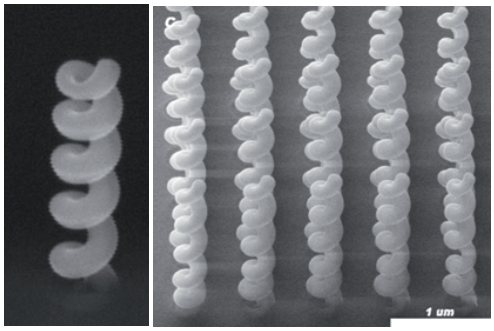
Three dimensional chiral metamaterial nanospirals in the visible range by focused ion beam induced-deposition

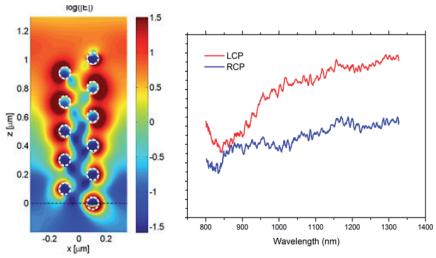
TRL: 4

Metamaterials have opened new paths in photonics applications introducing properties and functionalities such as negative refractive index (NRI), cloaking and nanolasing. Metamaterials are composed of engineered building blocks with subwavelength dimensions and exhibit properties of interaction with electromagnetic fields not found in nature. Chiral metamaterial is a new class of metamaterials offering a simpler route to negative refraction. Their optical properties exhibit a mixture of responses from electric and magnetic dipoles induced by the light field, leading to many exotic phenomena and applications, such as strong circular dichroism or optical rotatory dispersion, providing interesting solutions for applications as broadband circular polarizers or to enhance the optical response of chiral molecules by superchiral light. We have demonstrated the realization of platinum chiral metamaterials operating in the visible and near infrared ranges, consisting of a nanospiral-based meta-atom periodically repeated along the vertical direction realized by focused ion beam induced-deposition (FIBID). Uniform arrays of 3D nanospirals were realized on the different substrates by developing a scanning procedure that allows a high reproducibility of the nano-object structural features with resolution in the nm range. The optical transmittance measurements as a function of the degree of circular polarization of the incident light beam show a difference between the two transmitted circular polarizations up to 40%.

Adv. Optical Mater. 2014 doi: 10.1002/adom.201300323



Cross Section SEM images of 3D chiral nanostructures.



Simulated Distribution of E field around the nanostructures and measured transmission spectrum for right and left circular polarized light.

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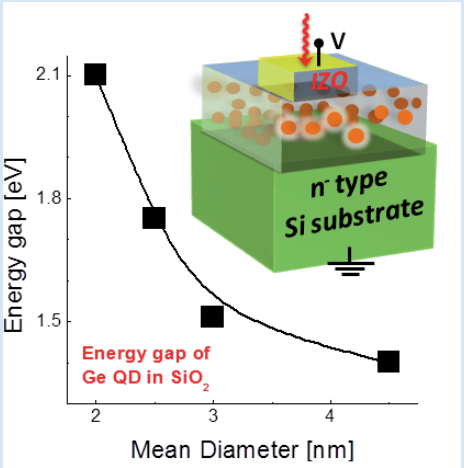
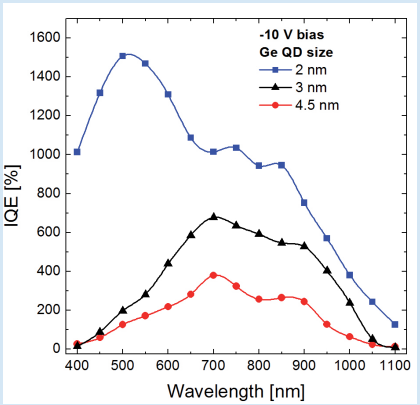
High-efficiency photodetectors based on Ge quantum dots

TRL: 4

Innovative materials allow to increase the resolution of commercially available photodetectors PD devices. Quantum confinement in nanostructures (NS), as quantum well and dots, pushes the technology into this direction as it allows to tailor many electronic properties, among which charge transport, optical bandgap, light absorption efficiency. In particular, Ge NS exhibit a large modulation of light absorption and offer high absorption coefficient values in the solar energy range, with possible successfully applications for light harvesting. We investigated the large effects on the light absorption of: Ge NS size and spacing, embedding matrix and synthesis technique. Absorption efficiency is increased and optical bandgap is largely modulated (0.8 - 2.5 eV), with promising application in UV-Vis detection with high resolution. By combining modulation of light absorption and charge trapping effects in Ge quantum dots, a very high efficient light detector has been fabricated with internal gain mechanism, able to detect visible light with responsivity as high as 10 A/W and internal quantum efficiency up to 1500%.



Variation of the optical bandgap with Ge QD size. Drawing of Ge QD based photodetector.



Spectral internal quantum efficiency at 10 V bias.

With regards to enterprises...
On this topic we have collaboration with: Univ. of Catania, Bilkent Univ. (TR), Brown Univ. (USA). We offer expertise to develop Ge QD based photodetectors.

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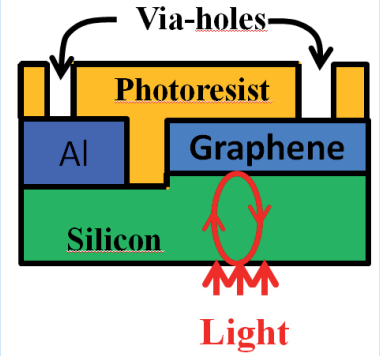
Antonio Terrasi, (antonio.terrasi@ct.infn.it), Univ. Catania

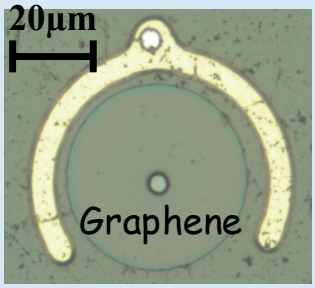
Graphene-silicon photodetectors at 1550 nm

TRL: 4

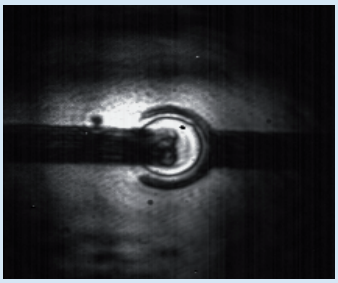
Graphene is an appealing material for photonics offering a wide palette of advantages compared to other materials. Most importantly, graphene is compatible with the highly mature silicon (Si) based platform for electronics and photonics, making it a strong contender for low-cost and large-scale integration into optoelectronic networks and multi-pixel CMOS read-out circuits. A variety of prototype optoelectronic devices have already been demonstrated. Recently, we have realized a new Graphene-Si photodetector (PD) working at 1550 nm, therefore in the transparency wavelength range of silicon, based on the internal photoemission effect (IPE) at the schottky graphene-Si junction. The device paves the way to new applications in on-chip optical interconnections and telecommunications. Future work will be aimed at enhancing responsivity by exploiting optical cavity resonance effects in microstructures compatible with VLSI technologies.



Sketch of the Graphene-Si PD.



Top view of the fabricated Graphene-Si PD.



Illuminated device at 1550 nm during efficiency measurements.

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G. Coppola, M. Iodice, L. Sirleto, I. Rendina

Nanowire and Graphene Terahertz photodetectors

TRL: 4

Photodetection of far-infrared radiation is relevant for a variety of strategic imaging applications, ranging from medical diagnostics to process control and homeland security. THz rays can penetrate commonly used dielectric materials, otherwise opaque for visible and mid-infrared light, allowing detection of substance-specific spectroscopic features and a sub-millimeter diffraction-limited lateral resolution.

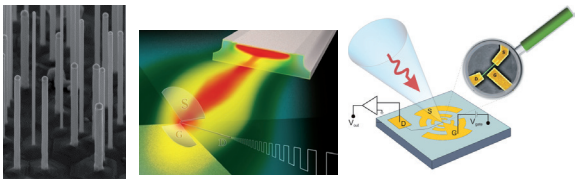
Recently, electronic devices based on the gate-modulation of the conductance channel by the incoming radiation have been realized in field effect transistors (FET), showing fast response times and high detectivities, as well as the possibility of implementing multi-pixel focal-plane arrays. THz detection in FETs is mediated by the excitation of plasma waves in the transistor channel.

During the last year, the described approach has been extended to semiconductor nanowires and graphene -based 1D or 2D FETs. Room temperature responsivities up to 150 V/W have been reached with impressive noise equivalent powers (NEP ~ 6 ×10-11 W/√Hz) and wide modulation bandwidths in the 0.3-3 THz range by playing with both material morphology/composition and antenna/impedance architectures, making the proposed technology already exportable for practical in-situ imaging or spectroscopic applications.

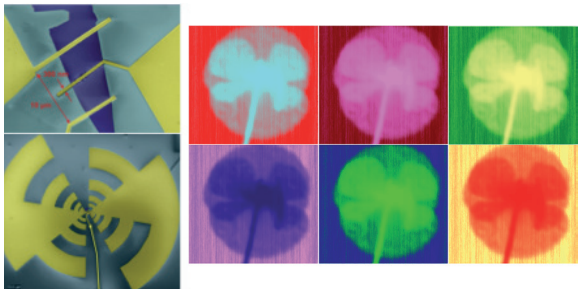
With regards to enterprises...

We can offer:

- Room temperature 1D nanowire FET photodetector (0.1 – 3 THz)
- Room temperature graphene photodetectors (0.3-0.6 THz)



(Left) Scanning electron micrograph of a set of InAs NWs **(Center)** Schematic draft showing the coupling of a THz QCLs with a nanowire THz FET with a patterned bow-tie antenna **(Right)** Experimental scheme describing the mechanism of detection of THz radiation in a NW- FET.



(Left) Scanning electron microscope pictures of a graphene FET detector showing the three electrodes and the coupling antenna **(Right)** Transmission THz images of poppy.

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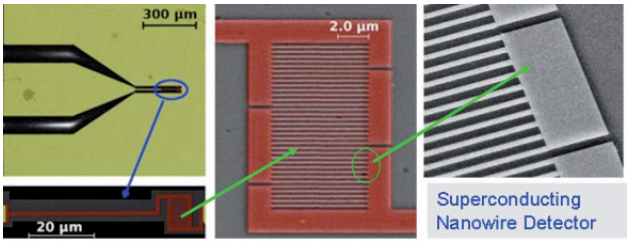
Lucia Sorba;
Istituto Nanoscienze - Pisa

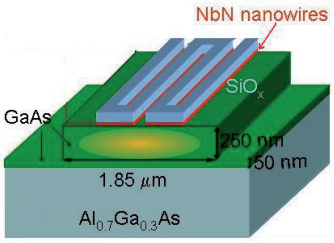
Superconducting Nanowire Single-Photon Detector

TRL: 4

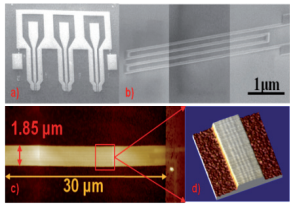
Quantum information QI and quantum cryptography are emerging new fields that will play a fundamental role in future security and information technologies. In most of the envisaged systems the information will be encoded in the form of single-photons and transmitted via optical fibers which use light at the infrared wavelength (1550 nm). In this context, the development of an integrated platform for QI, which is scalable and compatible with the standard optical telecommunication infrastructures is strongly needed. Single-photon detectors based on the semiconducting technology does not work with the necessary efficiency in the infrared region and cannot be integrated in Waveguide Photonic Circuits (WPC). This approach dramatically limits the complexity of the logical operations in terms of numbers of interacting photons, stability and scalability. Recently, the attention has been focused on Superconducting Nanowire Single-Photon Detectors (SNSPD) based on ultrathin nanostripes able to detect single photons of wavelength up to several micrometers with a few nanosecond response time, count rate in the GHz range and very few dark counts (few Hz in free-running mode). The use of SNSPDs can overcome a critical bottleneck in the development of a hardware platform for QI technology: the integration of efficient single photon detectors on a WPC.



Optical and SEM photographs of SNSPD.



Schematic of SNSPD integrated with waveguide photonic substrate.



SEM and Atomic force microscope images of SNSPD integrated with waveguide photonic substrate.

With regards to enterprises...

On this topic, we can offer: detector design, fabrication, diagnostics, simulations and service. We can also offer a partnership for the development of prototypes and demonstrators of both single devices and complete systems.

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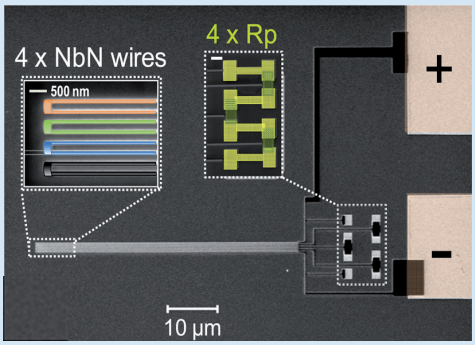
SPIN - Napoli
Roberto Leoni (Roberto.leoni@ifn.cnr.it) IFN-Roma

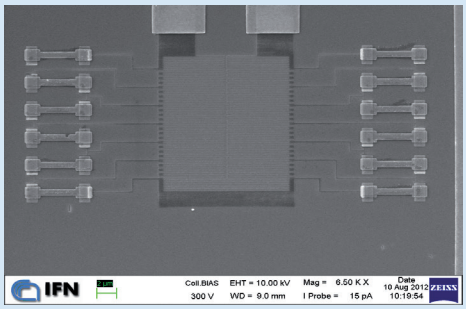
Counting single-photons with superconducting nanowires

TRL: 4

Photon-number-resolving (PNR) detectors are devices capable of measuring the number of photons contained in a single pulse at the single photon level. They play a key role in many fields such as linear-optics quantum computing and quantum communication. Ultimately, a PNR detector with a large dynamic range would represent an ideal photon detector combining single-photon sensitivity with a linear response. In this framework, Superconductive Nanowire Single-Photon Detectors (SNSPDs) based on ultrathin nanostripes are the best candidates. Different sections (up to twelve) are put in parallel with an on chip resistance: when the section absorbs a photon, the current is diverted into the parallel resistance.



Scanning electron micrograph of a PNR integrated on a WG, able to count up to 4 photons.



Scanning electron micrograph of a PNR able to count up to 12 photons.

The output pulse height is proportional to the number of firing sections. The detector has a few nanosecond response time, count rate in the GHz range and very few dark counts (few Hz in free-running mode). PNR detectors based on SNSPDs are promising to outpace the other existing PNR techniques. The picture on the left shows a practical realization of such a device which can count up to 12 photons at telecom wavelengths. PNR have also been integrated with waveguides.

With regards to enterprises...

On this topic, we can offer: detector design, fabrication, diagnostics, simulations and service. We can also offer a partnership for the development of prototypes and demonstrators of both single devices and complete systems.

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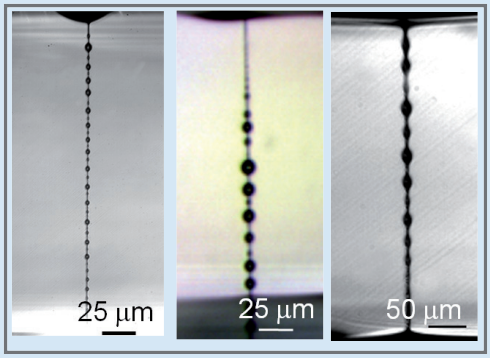
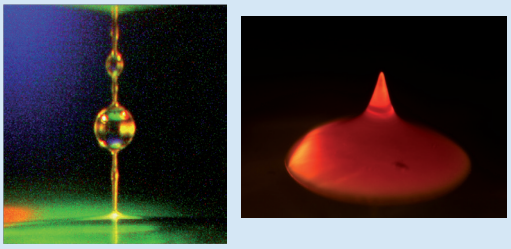
3D Microstructures for photonics applications

TRL: 5

The pyroelectric functionality of a Lithium Niobate (LN) substrate is used for non-contact manipulation of polymeric material. We introduced a novel approach for fabricating a wide variety of soft solid-like microstructures, leading to a new concept in 3D lithography. The method is twofold innovative thanks to the electrode-less configuration and to the rapid formation of a wide variety of 3D solid-like structures by exploiting polymer instabilities. The fabrication of polymer wires, needles, pillars, cones, or microspheres is demonstrated. Micro-axicons have been realized and used for generating Bessel beams (used as optical tweezers in microfluidics). Spherical polymer beads are another class of micro-optical elements and can be used as either passive or active whispering gallery mode (WGM) resonators for label-free detection of biosamples by classical evanescent field coupling; they can also be used as remotely excitable, active, microstructures if they are embedded with dye or quantum dots. In terms of micro-engineering the optical properties of this micro structures it would be possible to combine the use of a biopolymer and the 3D lithography approach to define a smart way of fabrication of biodegradable active microaxicon that as optical microelements could be inserted in lab-on-chip devices.



Typical polymeric wires with beads on a string.



(a) Typical spherical structures used as WGM optical resonators (b) Fluorescence image of a biopolymer microaxicon.

With regards to enterprises...

On this topic, we collaborate with the Photonics Centre, Tyndall National Institute, Prospect Row, Cork, Ireland.

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Veronica Vespini, (Veronica.vespini@cnr.it) ICIB - Pozzuoli (NA)

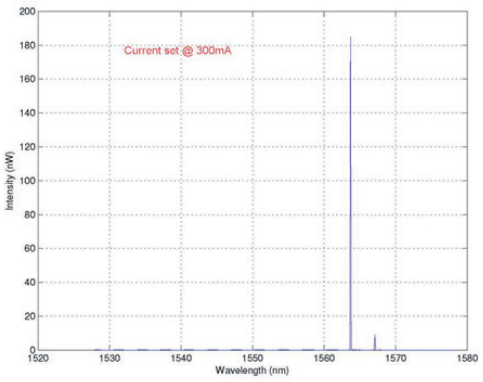
Coated microresonators: a viable tool to tailor whispering gallery modes photonic features

TRL: 4

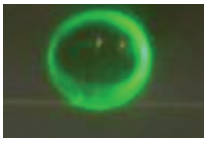
Whispering Gallery Modes (WGMs) represent a class of cavity devices with exceptional properties, like extremely small mode volume, very high power density, and very narrow spectral linewidth.

WGMs are known since more than 100 years, after the papers published by John William Strutt (Lord Rayleigh) about acoustic waves; in Photonics they represent a unique tool to study e.g. nonlinear optical phenomena or quantum electrodynamics and to obtain microlasers with very low threshold as well as high sensitive microsensors.

Coupling by means of tapered fiber of dimension about 3 µm on a glass microsphere coated with Er-activated silica hafnia film.



Lasing spectrum of glass microsphere coated with Er-activated silica hafnia film, diameter of about 150 µm. Inset: green upconversion of Er ions.



With regards to enterprises...

We offer the know-how on the realization of glass based microspheres and the development of tapered-fiber for their coupling. The activity is developed in the framework of a project with the French government space agency CNES.

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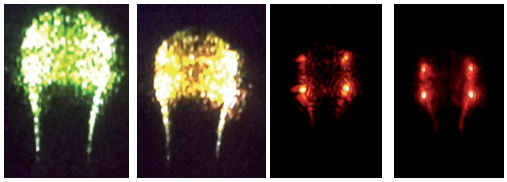
Davor Ristić (RBI Croatia), Maurizio Mazzola (IFN), Patrice Féron (ENSSAT France), Cristina Armellini (IFN-FBK), Anna Lukowiak (PAS Poland), Iustyna Vasilchenko (UniTN-IFN), Stefano Pelli (IFAC), Gualtiero Nunzi Conti (IFAC), Mile Ivanda (RBI Croatia), Giancarlo C. Righini (Centro Fermi), Gilles Cibiel (CNES France), Maurizio Ferrari (IFN)

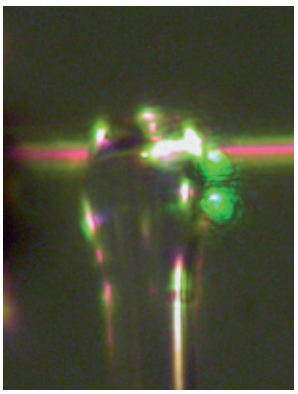
Whispering Gallery Mode Resonators (WGMR) for nonlinear optics

TRL: 3

Optical resonators play an ubiquitous role in modern optics. A particular class of optical resonators is constituted by spherical dielectric structures, where optical rays are total internal reflected. Due to minimal reflection losses and to potentially very low material absorption, these guided modes, known as whispering gallery modes, can confer the resonator an exceptionally high quality factor Q, leading to high energy density, narrow resonant-wavelength lines and a lengthy cavity ringdown. These attractive characteristics make these miniaturized optical resonators especially suited for nonlinear optics applications. We have demonstrated, experimentally and theoretically, a variety of $X^{(3)}$ nonlinear interactions in silica microspheres, consisting in third harmonic generation and Raman assisted third order sum-frequency generation (TSFG) in the visible. We have also demonstrated the feasibility of a non-linear optical switch based on hybrid WGMR, based on $X^{(3)}$ nonlinear interactions in organic coating.



Third harmonic signal generated in a silica WGMR, in this case the generated light is directional, as expected.



Third harmonic signal generated in a silica WGMR, in this case the generated light is directional, as expected.

With regards to enterprises...

On the nonlinear switch topic , we collaborate with Moscow State University (Prof. Murzina).
We can offer: fabrication of WGMR and characterization of the final devices.

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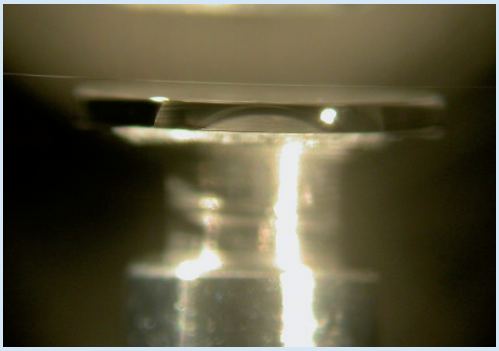
Gualtiero Nunzi Conti g.nunziconti@ifac.cnr.it

Ultra-high Q crystalline optical micro-resonators for RF photonics

TRL: 3

The combination of long cavity lifetime and small mode volume make Whispering Gallery Mode (WGM) optical micro-resonators an ideal device for enhancing light-matter interactions. Crystalline WGM resonators have gained increasing attention since the possibility of getting very high Q factors ($Q \geq 10^9$ in Calcium Fluoride, CaF_2) was demonstrated. Additional properties specific of crystals like for instance enhanced non linear or electro-optical properties have played an additional role for the implementation of high performance devices. Resonators made in lithium niobate, for instance, can be used for the realization of a number of specific components including single and multi-order tunable filters, electro-optic modulators, or frequency converters.
The optoelectronic oscillator (OEO) is a device that produces spectrally pure RF electrical signals at tens of gigahertz based on photonic techniques, and thus overcomes some of the inherent limitations of the conventional electronic devices. The use of optical storage elements allows for the realization of extremely high Qs and thus spectrally pure signals. The typical optical fiber delay line can be replaced by a high-Q WGM optical resonator in order to implement ultra-compact, low noise OEO.



CaF_2 disk with a Q factor close to 10^9 corresponding to a resonance linewidth of 200 KHz.

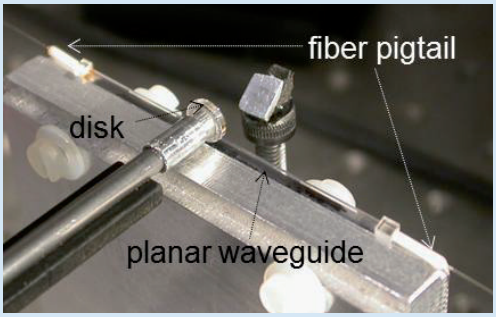


Photo showing a lithium niobate disk coupled to a fiber pigtailed lithium niobate waveguide.

With regards to enterprises...

We have joint R&D international projects with Selex ES (Italy) and Thales R&T (France) on high performances optoelectronic microwave oscillators.
We are able to provide high-Q crystalline disks fabricated in different materials like CaF_2 and Lithium Niobate.

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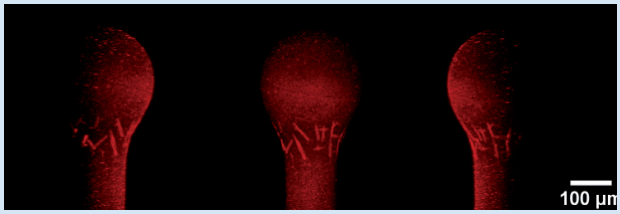
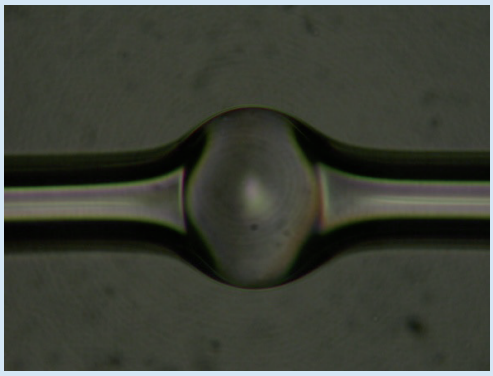
Whispering Gallery Mode Resonators (WGMR) based biosensors

TRL: 4

Optical microresonators are an efficient tool for the realisation of optical biochemical sensors, based on the measurement of the refractive index changes induced by the interaction of the investigated analyte with a selective layer immobilised on the microresonator surface. We have developed a sensor based on the DNA-aptamer sequence, able to recognize specifically thrombin or VEGF protein and an immunosensor. The protein binding was optically characterized in terms of specificity in buffer solution or in 10% diluted human serum. Simulation of the protein flow was found in good agreement with experimental data. The aptasensor was also chemically regenerated and tested again, demonstrating the reusability of our system.



Three different projections of aptamer-modified microsphere incubated with rhodamine-labelled thrombin.



Microbubble resonator with OD ~ 205 µm, created from a capillary with OD ~ 122 µm and wall thickness ~ 21 µm

With regards to enterprises...

On this topic , we collaborate with Fondazione Bruno Kessler (Dr. Pederzolli) at Trento, IQAC-CSIC (Dr. Marco, Barcelona, Spain), and we are partner of FIRB Sens4bio project. We can offer: fabrication of WGMR and characterization of the final device.

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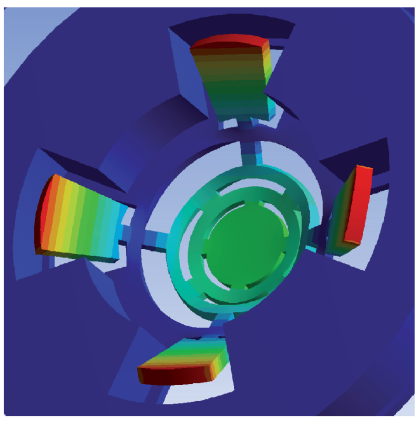
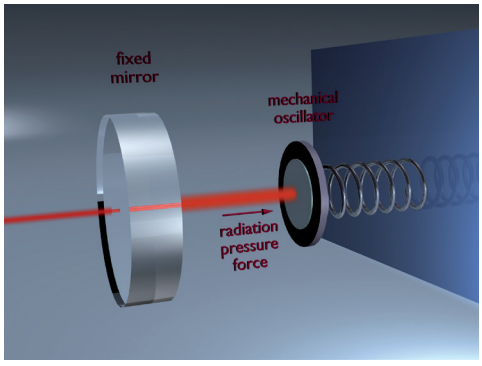
Optomechanical Manipulation of Squeezed Light

TRL: 1

In the last decade the new and interdisciplinary field of optomechanics has rapidly developed as a branch of quantum optics. The interplay between mechanical and cavity optical modes gives rise to a variety of effects which, in the quantum regime, may enable the exploration of quantum mechanics in entirely new ways. Quantum optomechanical oscillators could be used as an interface between microwave and photonic circuits and are also promising for quantum metrology and sensing applications beyond the standard quantum limit.
Our work (in collaboration with CNR-IMEM) aims at demonstrating the possibility of manipulating and controlling the spectral dependence of the field quadratures fluctuations of squeezed light by effect of opto-mechanical interaction. The activity is funded by a FIRB 'Futuro in ricerca' (P.I., S. Mosca) and is part of the Progetto Premiale QUANTOM (P.I., F. Marin, Università di Firenze e CNR-INO) in collaboration with INFN and other CNR institutes (NANO and IMEM).



FEM simulation of a SiN micromirror which constitutes the optomechanical element of the optical cavity.



Conceptual scheme of an optomechanical cavity.

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Simona Mosca (simona.mosca@ino.it), INO - Napoli
Iolanda Ricciardi (iolanda.ricciardi@ino.it), INO - Napoli

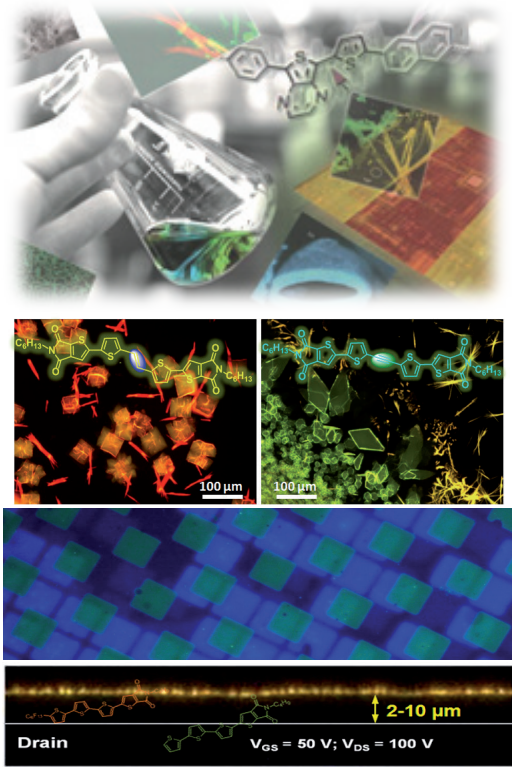
Synthetic technologies for photonics

TRL: 4

Tailoring of organic π-conjugated and hybrid materials is a milestone for driving innovation and development of advanced photonics. Chemical engineering and in-depth structure-property relationships are playing a pivotal role to empower, tune, target the properties and the performances of photonic materials.

The researchers at CNR-ISOF have internationally recognized expertise in materials design, synthesis and characterization. Multifunctional ambipolar and electroluminescent organic semiconductors, *ad-hoc* surface functionalization processes, fluorescent nanostructures and composites are successfully developed. A library of π-conjugated material-composites has been realized by discovering and implementing design principles and novel synthetic routes.

The research, at the forefront of chemistry, materials science, physics and bionanotechnology, provide tailored *material solutions* toward *multifunctional photonic platforms* ranging from lighting, biosensing and biomedical applications.



Tailored organic photonic materials and devices produced at CNR-ISOF.

With regards to enterprises...

The activities, carried out in collaboration with SMEs and multinational industries including ETC (CNR-SAES GETTERS group spin-off), have been exploited in several patent applications. The research is also developed within the Laboratory of Industrial Research and Technology Transfer of the High Technology Network of Emilia-Romagna.

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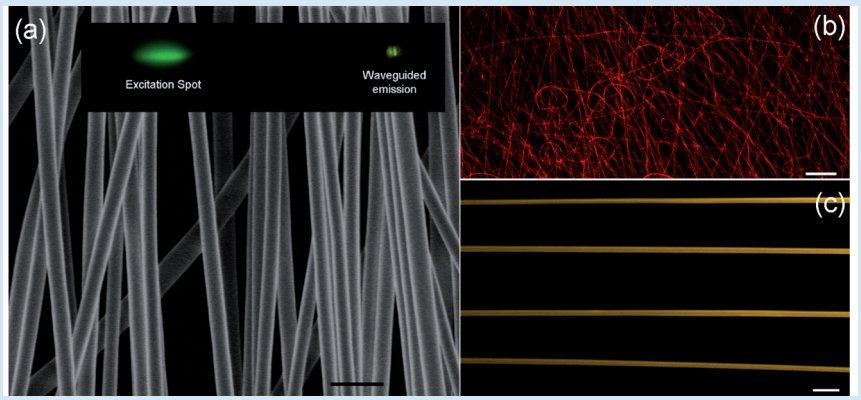
ISOF - Bologna

Electrospun nanofibers: novel multifunctional materials for photonic applications

TRL: 5

Polymer nanofibers are exploited in many applications, which span from filtration, to tissue engineering, to electronics and energy harvesting. The particular features of polymer nanofibers have recently stimulated their application in photonics, where such innovative nanomaterials can be used as miniaturized light sources, guides, amplifiers and detectors. We have developed light-emitting polymer nanofibers by the electrospinning technique, which allows fibers to be produced in continuous runs, arranged as either randomly or uniaxially oriented arrays. Our materials, based on conjugated polymers and organic dyes and quantum dots embedded in passive polymer matrices feature emission and optical gain in the visible and near-infrared range, waveguiding properties and emission polarized along the fiber axis, properties that often outperform the equivalent bulk materials. These features makes them ideal for optical sensing, lab-on-chip and laser applications.



(a) Scanning electron micrograph of light-emitting electrospun nanofibers embedding conjugated polymers. Scale bar: 1 µm. Inset: Example of a nanofiber waveguide. The emission excited by a focussed laser beam (left spot) is partially coupled into the fiber, waveguided and emitted by the fiber tip (right spot). (b)-(c) Light-emitting, randomly oriented and uniaxally aligned electrospun nanofibers.

With regards to enterprises...

On nanofiber related applications we can offer: production of nanofibers, design and development of optically active nanofibers for sensing, waveguiding, optical gain, amplification of light, microscale light sources and polarized emission. Research funded by ERC project NANO-JETS (306357).

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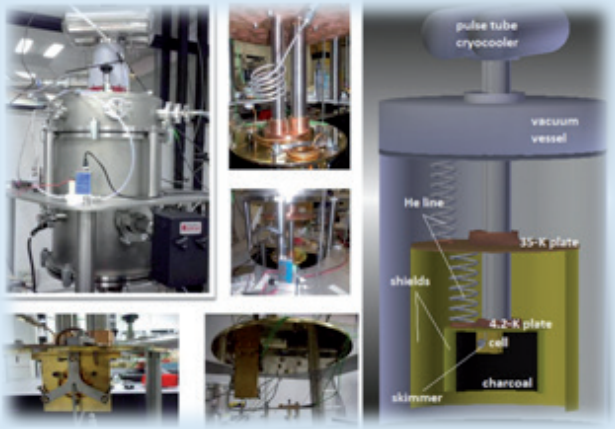
Dario Pisignano (ERC P.I.), NANO - Lecce

Precision Spectroscopy with Cold Stable Molecules

TRL: 1

Thanks to the advent of optical frequency comb (OFC) synthesizers based on femto-second mode-locked lasers, the field of precision spectroscopy is experiencing an extraordinary growth. This has allowed to devise more and more challenging experiments aiming at testing fundamental physics laws with unprecedented sensitivity. Since the ultimate resolution attainable in any spectroscopic measurement is limited by the interaction time between the particle under investigation with the radiation field, such experiments would draw enormous benefit from the ability of interrogating extremely slow molecules, as produced by the emerging cooling/trapping techniques. For this purpose, based on a two-stage pulse tube cryo-cooler, we have realized a buffer-gas-cooling machine where the molecular species of interest is brought to translational and rotational temperatures near 1 K via collisions with a helium buffer gas in a cryogenic cell. Then, by expansion in a high vacuum, a decelerated molecular beam is formed, subsequently further collimated by means of an electrostatic hexapole lens. In parallel, a second, chip-based source of Stark-decelerated molecular beams is under construction. For the spectroscopic interrogation of such samples, excitation of two-photon Ramsey fringes will be used, where an ultra-narrow-linewidth mid-infrared probe laser is phase-locked to a specially-developed OFC that is ultimately referenced to the Cs primary standard via the National Optical Fiber Link. In this frame, we envisage a new generation of low-energy tests of the Standard Model (time variation of fundamental constants and axion dark matter detection) as well as of high-precision studies of astrophysical phenomena on a laboratory scale.



Buffer-gas-cooling machine.

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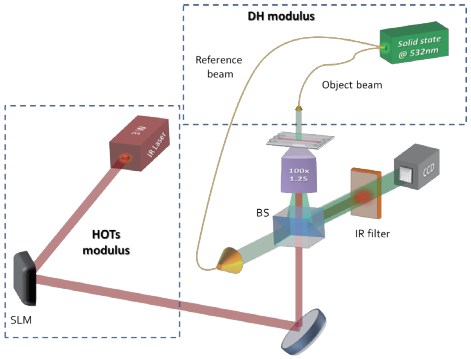
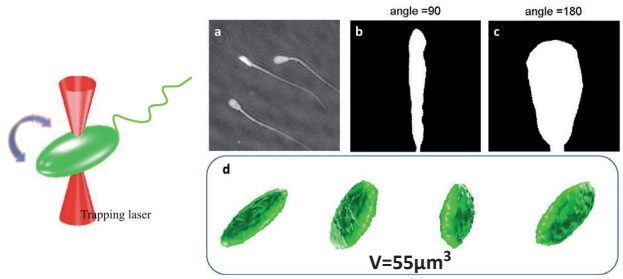
INO - Pozzuoli (NA)

3D imaging of cells by Digital Holography for lab-on-chip biophotonics

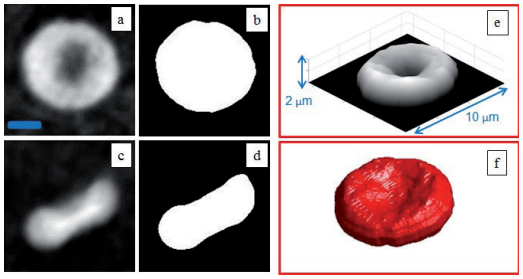
TRL: 4

Digital Holography (DH) is employed as powerful imaging technique for lab-on-chip applications allowing quantitative, high resolution, and marker-free investigation of biological unstained samples. The Optical Tweezers (OT) capabilities are combined with DH microscopy in a unique optofluidic platform, able to provide quantitative information about the morphology, the volume and the mechanical properties of different kinds of cells. In particular, 3D reconstruction provides accurate biovolume estimation and 3D rendering of spermatozoa and Red Blood Cells (RBCs), very important for biomedical and diagnostic purposes.





3D reconstruction and biovolume estimation of bovine spermatozoon.



3D reconstruction and biovolume estimation of discocyte RBC.

With regards to enterprises...

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CNR-IMM, Via P. Castellino 111, Napoli 80131, Italy
Istituto "Lazzaro Spallanzani", Rivolta d'Adda, Cremona 26027, Italy.

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Photonic Tasting of Food

Quality and safety inspection of intact food by means of absorption, fluorescence and Raman spectroscopies and multivariate data processing. The food is analyzed as it is, simply using a light beam, with these advantages:

- it is a green analytical approach which offers: multi-component analysis, non-destructive, real-time, and no-contact operation, no environmental impact because reagent-free;
- the same technology can be used along the entire supply chain, that is, *from-farm-to-fork*.

TRL: 4

Extra virgin olive oil: detection of geographic region of production, nutraceutic indicators (fatty acids, polyphenols), and fakes by lower quality oils.

Beer: detection of alcoholic content during brewing process, identification of beer characteristics (Ale, Lager, Lambic, Doppelbock .....), and distinction of Belgian beers.

Honey: distinction of the botanic origin, and detection of pollutants.

Others – Detection of: hogwash-oil in soybean oils for the Chinese market, aflatoxin M1 in milk, composition of artificial sweeteners, geographic region of production of single-malt Scotch whiskies.

With regards to enterprises...

Design, implementation and testing in industrial environments of photonic setups for online/real-time assessment of food quality&safety

- MIUR Projects: PON "Fingerimball", Cluster Agrifood "Safe&Smart"
- Patent: PCT #WO 2012/020440, 16 February 2012

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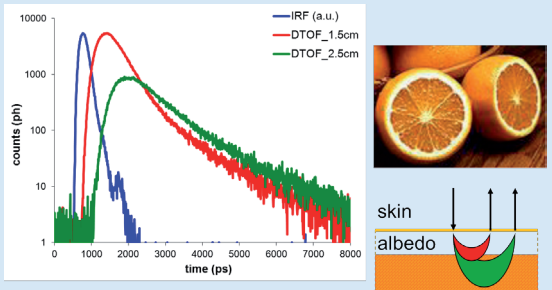
IFAC - Sesto Fiorentino (FI)

Nondestructive fruit quality assessment by diffuse optical methods

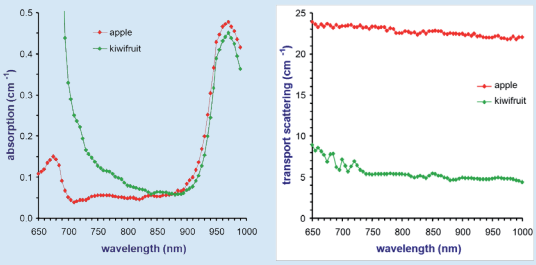
TRL: 6

Time-resolved reflectance spectroscopy (TRS) improves the classical approach to Vis/NIR spectroscopy. TRS measures the distribution of photon time-of-flight (related to photon path length by the speed of light in the medium) at the picosecond or nanosecond timescale and at a fixed source-detector distance (e.g. 15 mm). This is done with pulsed laser sources (duration of tens of picoseconds) and fast detection techniques (e.g. time-correlated single photon counting). The use of TRS, in combination with proper models of photon migration, enables the complete optical characterization and simultaneous non-destructive measurement of the optical properties (absorption and scattering) of a diffusive medium. This can be particularly important for most fruit and vegetables because information derived by TRS refers to the internal properties of the medium and is not so much concerned with surface features as is traditional spectroscopy. It is hypothesized that the absorption properties are related to the chemical composition, whereas the scattering properties are related to the microstructural features such as the topology of the intercellular space and the size and shape of the cells. This could enable a means for nondestructively assessing texture, as these features affect the overall mechanical properties.



Shorter distance: early photons travel in the albedo, late photons in the pulp
Longer distance: photon-path is mainly in the pulp

Distribution of time-of-flight (DTOF) for photon traveling inside a grapefruit for different source detector distances.



Absorption and reduced scattering spectra of apple and kiwifruit.

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Rinaldo Cubeddu, Alessandro Torricelli
Dipartimento di Fisica - Politecnico di Milano

Health

Nowadays, doctors and researchers use photonics to treat disease, get images from inside our bodies, diagnose and monitor pathologic conditions, provide cosmetic treatments, and more. Medical optics and photonics help in minimizing patient complaints and pain, not only diagnosing disease earlier for greater chance of cure, and reducing or eliminating hospital stays but taking part in the identification and/or administration of personalized therapy.

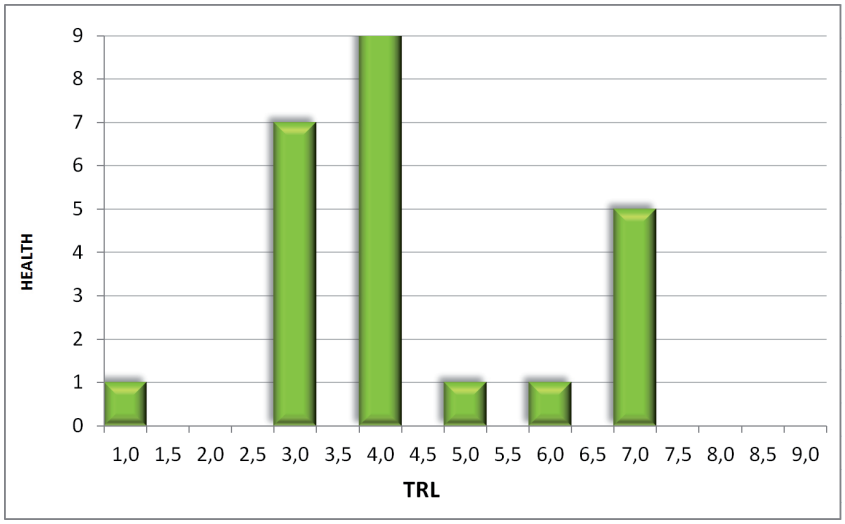
Technological advancements in key-areas such as sensing, optical engineering and nanotechnology are currently offering new opportunities for development and further optimization of different healthcare practices.

The collection of contributions reported in the following provides a description of the expertise and achievements recently attained in the health area at CNR, by means of photonics. Some product of research are already assembled for moving “from the lab to the clinics”, while others are rapidly progressing, both increasing R&D levels and laying the foundation of future practical applications.

Original proposals have been developed by capitalizing on different photonics technologies including fluorescence, plasmonics, optofluidics, label-free imaging and nonlinear spectroscopy and microscopy. These are remarkable examples of multidisciplinary approach that is particularly required when dealing with biomedical and healthcare aspects, which require the creation of highly interdisciplinary work-teams coming from different areas such as optoelectronics, chemistry, physics, engineering, biochemistry, and medicine, where photonics plays a fundamental and essential role.

The potential of the presented technologies paves the way toward valuable benefits on healthcare and quality of life of patients and introduces concrete perspectives in the industrial market.

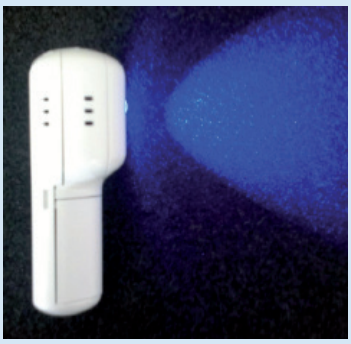
number of contributions in this section



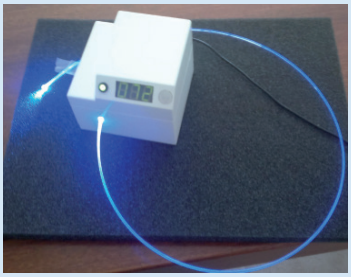
LED technologies for photocoagulation and wound healing

TRL: 6

We developed new technologies based on the use of high power blue-LEDs to repair abrasions and wounds. Haemostasis of superficial blood vessels is achieved through a photo-thermo-coagulation process, without any collateral damage to surrounding tissue.
We made two layouts of the photohaemostatic device based on LED technology: 1) a "Self-medication" layout, easily handled and ensuring high portability for first-aid situations; 2) a "Fiber" layout, where the LED source is coupled to a hand-held optical fiber, to be adopted in hospital environments by specialized personnel for ophthalmologic, dental and plastic surgery applications.
The main beneficiaries of the photo-haemostatic device are accidentally injured healthy people, as well as people suffering from bleeding disorders.



Miniaturized and engineered photohaemostasis device for self medication.



The photocoagulation device engineered for hospital use.

With regards to enterprises...

The photocoagulator device has been designed and developed in collaboration with the company Light4Tech and with the research center LENS, in the framework of two european projects (Light+ter, Development of a compact, low cost and easy to use device based on LED technology for non-invasive selective haemostasis to benefit the people suffering from coagulation problems; Light Patch, Led Technology in Photo Haemostasis).
The devices is patented: PCT/IB2007/054912, priority data: FI2006A000307, Applicant: Light4Tech Firenze S.r.l., title "LED DEVICE FOR THE HAEMOSTASIS OF BLOOD VESSELS". Authors: Roberto Pini, Francesca Rossi.

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- http://bnlab.ifac.cnr.it/

Time of flight based platform for human fall detection

TRL: 7

The problem of falls in the elderly has become a health care priority in all industrialized countries around the world due to the related high social and economic costs. The consequences of falls in elderly may lead to psychological trauma, physical injuries, hospitalization and death in the worst case. The 3D Position Detector (3D PD) is designed to support people living alone by detecting automatically the occurrence of critical events (falls) and gathering high level information (people position and body posture) helpful for caregivers to provide the needed help and for geriatricians to evaluate the autonomy level of elderly people.
The 3D PD is designed to guarantee the person's privacy preservation; the system provides only distance measures unable to reveal the person's identity or to compromise the feelings of intimacy.

3D Position Detector and related depth map.

The 3D PD is equipped with an innovative 3D Time of Flight sensor able to capture distances rather than traditional appearance images, allowing a whole real-time 3D reconstruction of the scene. The 3D sensor is provided with a near-infrared LEDs array (eye safe certified), assuring high efficiency and reliability in all illumination conditions (even in full darkness). The noiseless functioning (0-db noise) allows the usage of the 3D sensor even in silent environments such as bedrooms. The 3D PD technology overcomes the limitations of the traditional camera-based solutions, such as typical problems due to darkness or brightness variations, camouflage effects, poor textured surfaces, shadows, privacy violation and so on.

With regards to enterprises...

We can offer: consulting services and facilities on design of new materials and processing architecture for passive and active vision system and related smart devices.

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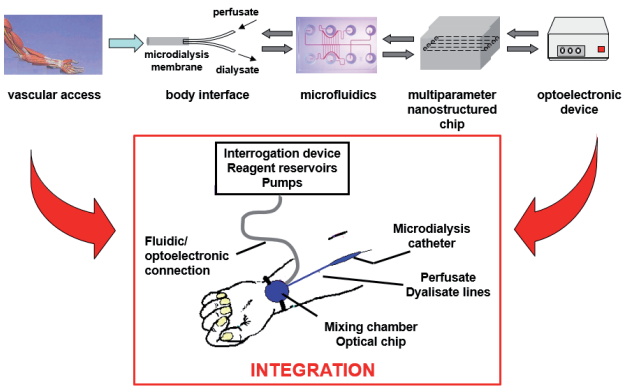
IMM - Lecce

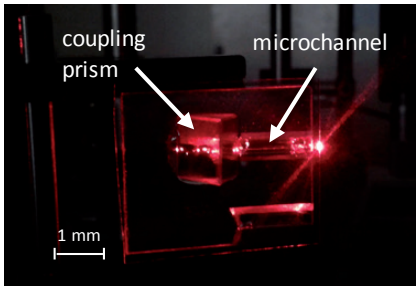
Novel point-of-care-testing (POCT) device for the immunosuppressant measurement in transplanted patients

TRL: 3

In transplanted patients, one of the most critical aspects is the correct dosage of the immunosuppressants, which have the difficult task of avoiding the transplant rejection by means of the partial inhibition of the immune response of the body to the transplanted organ. Standard of practice today is the discrete measurement of the drug plasma level measured just before each dose, generally administered every hour, by use of analytical techniques. Therefore there is a strong demand for a frequent and accurate monitoring of the immunosuppressants, characterized by a narrow therapeutic window, with a POCT device located close to the patient bed. On these bases, a novel therapeutic drug monitoring (TDM) POCT device for the *in-line* and *in-time* immunosuppressants measurement is under development. The transplanted patient will be connected to the device by an intravenous microdialysis catheter to allow 48-h online measurements. Heart of the device is a multi-parametric optical chip, which makes use of the recent developments in nanotechnology to convert the concentration changes of the analytes in detectable luminescent signals.



Flow diagram of the proposed TDM – POCT device.



First prototype of the optical chip with one microchannel illuminated by means of a coupling prism.

With regards to enterprises...

European Project NANODEM -Nanophotonic device for multiple therapeutic drug monitoring (contract 318372)involved companies: Datamed srl (Milano) and Chip & Shop GmbH (Jena, D).

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Romeo Bernini (bernini.r@irea.cnr.it) IREA - Napoli

Fluorescence optical platform for sepsis analysis for point of care application

TRL: 7

Sepsis is the first leading cause of mortality in intensive care units. Discrimination of viral and bacterial sepsis in intensive care patients and the fast identification of the origin of infections can be essential for the patient survival. It has been shown that every hour delay until administration of an effective calculated antibiotic treatment in septic shock increases mortality by 7%. Sepsis can be caused by numerous pathogens and the primary state of infection can be found in any major organ system. Therefore a single marker could not provide the high accuracy needed for fast and accurate guidance of treatment of sepsis patients, and a combination of markers should be considered the right approach. A novel optical platform, the channel array interrogation (CAI) system, was developed for multiparameter analysis and was applied to the simultaneous detection of procalcitonin (PCT), C-reactive protein (CRP) and neopterin, considered among the most important biomarkers for the sepsis. The heart of the system is a plastic multichannel chip, constituted by 13 microchannels (50 µm high, 600 µm wide, 10 mm long) through which the sample flows and which carries the necessary chemistry for the implementation of the assay on its surface. The chip is shown in Figure 1, and the the whole instrument is shown in Figure 2.

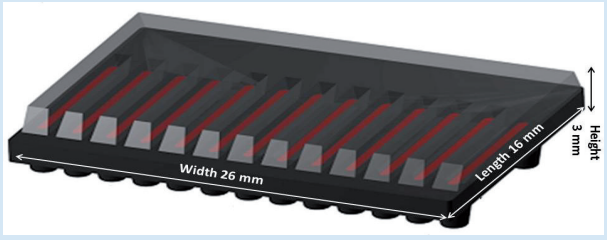

Fig.1. The PMMA optical chip.

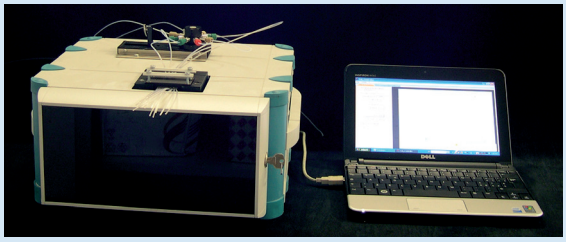

Fig.2. The CAI instrument.

With regards to enterprises...

Integrated European Project CARE-MAN - HealthCARE by biosensor Measurement And Networking (contract NMP4-CT-2006-017333). Prototype developed in strict collaboration with Datamed srl (Milano).

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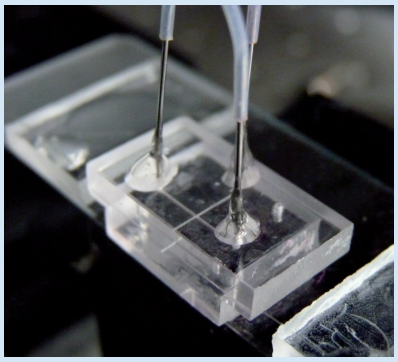
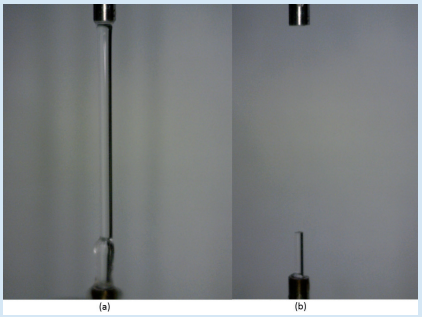
TRL: 4

Optofluidic micro-nanosensors

Optofluidics merges optics with microfluidics in order to realize optical devices in which fluids act as an optical material. This approach enables an unprecedented level of integration, tunability and reconfigurability of optical devices. In particular, the possibility to guiding light through a fluid offers very interesting applications especially in sensing field.
The research activity is focused on the development of micro-nanofluidic optical sensors for the detection of biological or chemical substances. The optofluidics approach permits a strong enhancement of the sensitivity with a simultaneous reduction of device sizes. The IREA group has developed innovative optofluidic waveguides and devices for sensing applications. In these waveguides the light and liquid under analysis are confined in the same microchannel with a strong enhancement of the light-matter interaction a great improvement of the limit of detection.
Liquid core waveguides using antiresonant reflecting optical confinement (ARROW) have been developed and used in order to realize complex optofluidic devices like, Cytometer, Mach-Zehnder interferometers and ring resonators. More recently, optofluidic jet waveguides have been developed and applied for the detection of organic pollutans in water at ppm and sub-ppm levels. This approach, exploiting the waveguide properties of a liquid jet stream enable high sensitivity Raman and fluorescence spectroscopy.



Integrated cytometer for cell analysis.



Detail of the liquid jet sensor with liquid jet waveguide formed (a) and without (b).

With regards to enterprises...

On this activity we collaborate with West Systems SRL (Firenze) in the project ACQUASENSE. We can offer: Design, fabrication and characterization of microfluidic sensor.

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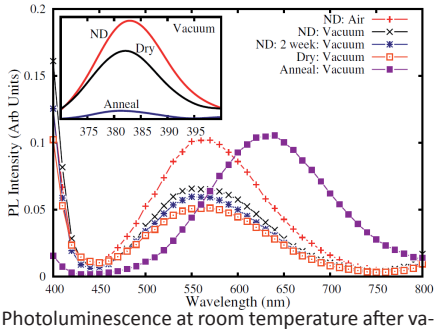
TRL: 4

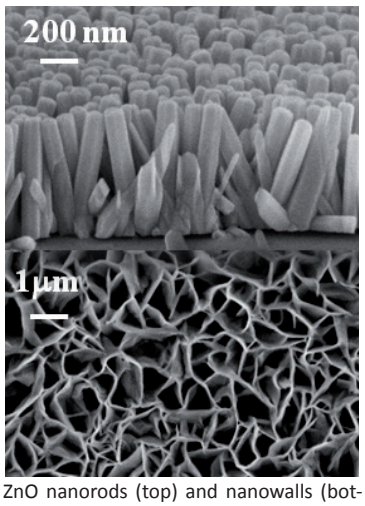
Low-cost ZnO nanostructures for disposable optical sensors

Given the abundancy, non-toxicity, and ease of synthesis, zinc oxide is largely used as transparent conductive oxide for solar cells, as building block for piezotronics, and as promising material for biosensing. Indeed, ZnO nanostructures (NS) can be synthesized with very low-cost methods on any kind of substrate, and offer a huge variety of applications.



Photoluminescence at room temperature after various surface treatments of ZnO nanorods.

Despite the low-cost method (chemical bath deposition at 90°C, on glass, metal or plastic substrates) ZnO nanorods and nanowalls exhibit good control of dimension, orientation and crystalline quality. Indeed, engineering of surface defects in ZnO NS leads to significant change in the visible light emission, whose spectrum greatly depends on surface adsorbates.



ZnO nanorods (top) and nanowalls (bottom) grown at 90 °C by chemical bath synthesis.

Efficient, flexible and disposable optical sensors can be fabricated for UV or gas detection (O_2, NH_3, alcohol vapors, ...).
A simple UV sensor based on ZnO NS was tested as well as the powerful light scattering ability was used to increase the conversion efficiency of thin solar cell in the NIR-visible range. More, a pH sensor was realized with ZnO nanowalls connected to a thin-film-transistor, showing an ideal response of 59 mV/pH.

With regards to enterprises...

On this topic we have collaboration with: Univ. of Catania, Tel Aviv Univ., Oslo Univ. We offer expertise to develop ZnO nanostructures for efficient optical sensing purposes.

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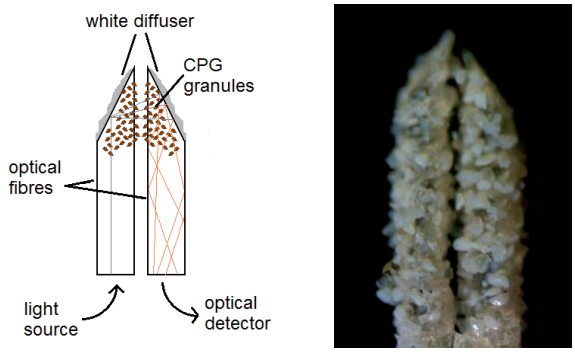
IMM - Catania

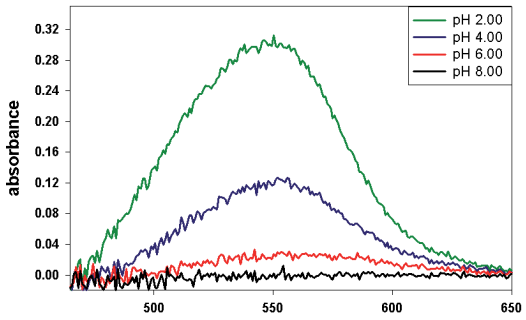
Miniaturized optical probe for invasive pH sensing in gastro-esophageal apparatus

TRL: 4

Monitoring pH for long periods, usually 24 h, in the stomach and in the esophagus may be essential in the diagnosis of gastro-esophageal diseases. The clinical range of interest is quite extended, between 1 to 8 pH units. Methyl red, after its covalent immobilization on controlled pore glass (CPG), is characterized by a working range which fits well with the clinical one. A novel probe, suitable for gastro-esophageal applications, was designed in order to optimize the performances of the colored CPG. Two plastic optical fibers (core diameter 250 µm) are used, one connected to the optical source and the other one coupled to a detector. The distal end of each fiber is cut at an angle capable to assure the total reflection of the optical radiation at the fiber tip and the CPG granules with methyl red immobilized on them are fixed on the lateral external surface of the distal end of the plastic fibers. The requirements of the physicians for pH gastric measurements, accuracy of 0.1 pH units and response time 30 seconds, are well satisfied by the realized probe.



Sketch (left) and photo (right) of the novel fiber tip sensor for pH measurement.



Absorption spectra vs pH.

With regards to enterprises...

- Tuscany regional project (POR CReO FESR 2007-2013) with Cecchi srl (Firenze) "Dispositivo per la misura combinata di pH e contenuto biliare nell'apparato gastroesofageo»
- Brev.It FI2010A000237, "Sonda a Fibra Ottica e sensore di misura utilizzante detta sonda", F.Baldini, C.Trono

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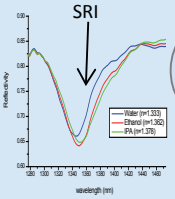
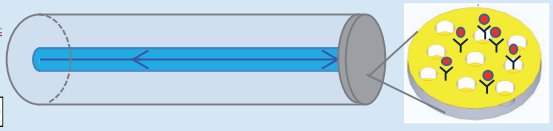
Nano optical fiber transducer as a point of care analysis device

TRL: 4

We developed a key enabling technology named "Lab-on-Fiber" based on the integration onto the optical fiber tip of two-dimensional hybrid metallo-dielectric nanostructures supporting Localized Surface Plasmon Resonances. The Nanostructured optical fiber transducers (NOFT)work effectively as an optical probe for label-free chemical and biological sensing and represents a new technology for Point Of Care Analysis applications.

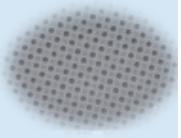


Optical signal read out.

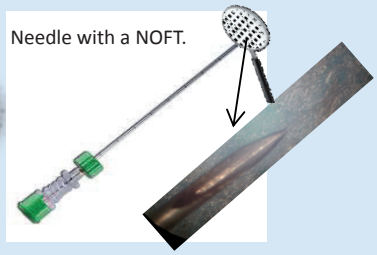


Patterned and functionalized tip.

Nanostructured Optical Fiber scheme.



Tip SEM top view.



Needle with a NOFT.

Once the metallo-dielectric nanostructured has been functionalized it works as a detector of a bio/chemo specific layer. The nanostructured surface is sensitive to a small variation of the surface refractive index SRI due to the interaction of the bio-functionalized layer with the specific marker, this interaction will be transduced in an optical signal read out through the OF itself.
NOFT can be optimized for the specific application, like to detect in vitro and in vivo the Papillifero Carcinoma of the thyroid gland (Smart Health Project_Pon4_a2), and can be exploited for many purposes.
NOFT could provide in addition to invaluable benefits on health care and quality of life of patients, a concrete perspectives in industrial market.

With regards to enterprises...

Smart Health Project PON4_a2
Tecnologie OPtoelettroniche per l'INdustria – Scarl.

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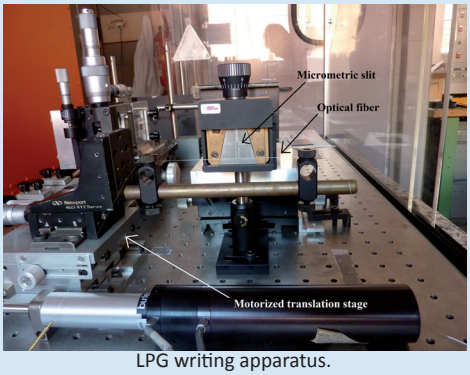
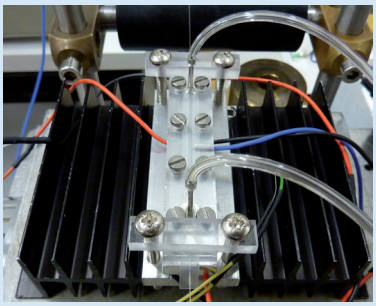
TRL: 4

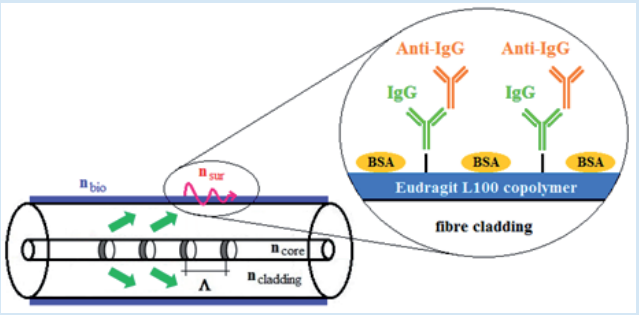
Optical fibre long period gratings for label free biosensing

Optical fibre gratings, especially long period gratings, have been recently proposed as optical devices for biochemical sensing. A biochemical interaction along the grating portion induces a refractive index change and hence a change in the fiber transmission spectrum. This provides an alternative methodology with respect to other label-free optical approaches, such as surface plasmon resonance, interferometric configurations and optical resonators. The fibre biofunctionalization has been carried out by means of a novel chemistry using Eudragit L100 copolymer as opposed to the commonly used silanization procedure. Antigen-antibody interaction has been analysed by means of an IgG/anti-IgG bioassay. The biosensor was fully characterised, monitoring the kinetics during the antibody immobilization and the antigen interaction and achieving the calibration curve of the assay.



LPG writing apparatus.


Thermostated flow cell for LPG characterization and bioassays development.



Sketch of an example of biosensor based on an optical fibre LPG

In collaboration with:

INDO-ITALY Collaborative Project: "Development of Long Period Grating based immunoassay for bio-sensing applications".

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TRL: 4

Integrated plasmonic-superhydrophobic device for biosensing

The device is aimed to IR vibrational spectroscopy of biomolecules highly diluited in a solution and that usually cannot be easily revealed , in particular to estimate the secondary structure of proteins providing insights into their structural properties. The device consists of, patterned superhydrophobic (SH) area (10mmx10mm) in the middle of which an hydrophilic area is realized (300umx300um). On this last area an array of plasmonic nanoantennas designed for Mid-IR is integrated (Fig.1). E-beam lithography has been used to define the different structures. The FTIR analysis of the nanontennas, shows a broad peak centered at 1650 cm-1 corresponding to the Mid-IR dipole bandwidth. When a drop of the solution containing the molecule to be revealed is released on the device, it sticks on the hydrophilic area and the SH ones forbid to the drop to escape. So when the drop dries all its solute remains on the central pad so on the nanoantennas. In Fig.2, the FTIR signal of 0.001 mg/ml Ferritin in 10 ml of DI on a 300x300 mm2 anchor point is shown. This concentration is on the same order of the ferritin content in a blood sample. The absorbance at 1650 cm-1 is clear and signs the presence of ferritin, a mainly helical protein.

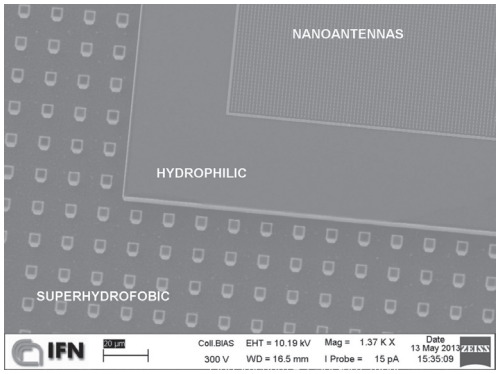

Fig. 1 SEM image of the device.

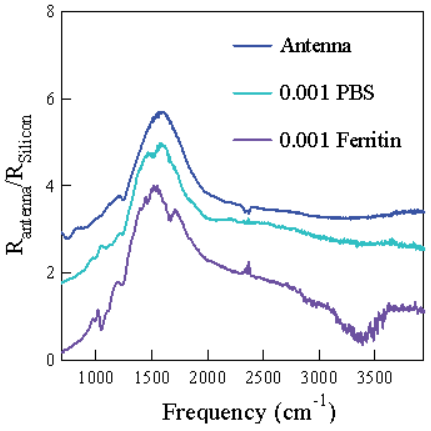

Fig. 2 Comparison of FTIR signals by antennas, PBS and Ferritin.

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Authors: L. Businaro , G. Ciasca , M. Ortolani , L. Baldassarre,A. Di Gaspare, A. De Ninno, F. Santoni, M. Papi, E. Giovine, A. Gerardino

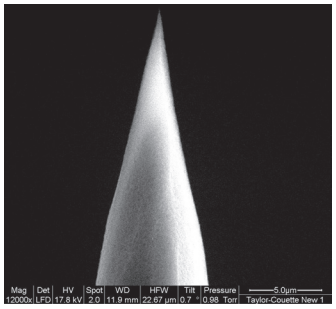
Silica nanotips for intracellular sensing

TRL: 1

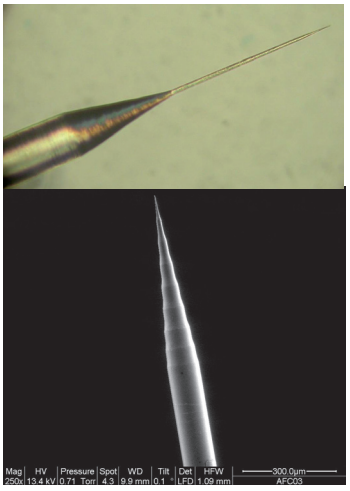
Detailed comprehension of cellular physiology is fundamental for the assessment of the interaction between cells and environmental pollutants or drugs, whose efficacy could therefore be better optimised and tailored.

Fibre nanotips can act as a flexible platform for intracellular applications: being able to guide excitation light inside the cells, they can probe single cells without inducing morphological damage or perturbing their physiological equilibrium, while their functionalised surface can act as high spatial resolution sensor.

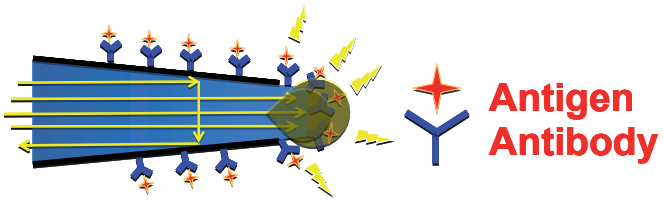
We have developed a technology to produce nanometric sized (down to 40 nm) silica tips from optical fibres by chemical etching (patent pending) and to effectively functionalise their surface for selective response to particular biomolecules.



nm sized tip



Customizable taper profile.



Tip surface functionalisation and antigen-antibody selective reaction.

With regards to enterprises...

The patent "*Method of Fabricating Structures, Starting from Material Rods*" has been deposited and is pending.

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Stefano Pelli, Andrea Barucci, Franco Cosi, Giancarlo Righini, Francesco Baldini, Ambra Giannetti, Cosimo Trono, Sara Tombelli

Optical manipulation of single cells

TRL: 5

Optofluidics defines a wide research field that is characterized by the synergic combination of optics and microfluidics. In biophotonic applications, optofluidic is generally exploited to increase the miniaturization of the devices towards integrated platforms called Lab-on-chips. These are microsystems aiming at the miniaturization onto a single substrate of several functionalities that would usually require an entire biological laboratory.

The technique of femtosecond laser irradiation followed by chemical etching (FLICE) proved to be ideally suited for lab-on-chip fabrication as it provides the integration of both microfluidic and optical functions on the same glass chip leading to monolithic, perfectly aligned, robust and portable optofluidic devices.

The combination of microfluidics and optical tweezers technologies allowed the fabrication of chips for single cell manipulation, trapping and stretching. Recently, the activity has been focused on the demonstration of a micro fluorescence activated cell sorter for single cell sorting and collection.

As regards enterprises...

We can offer a microfabrication technology on transparent materials (glass, plastic) that can produce 3D fluidic and optical circuits.

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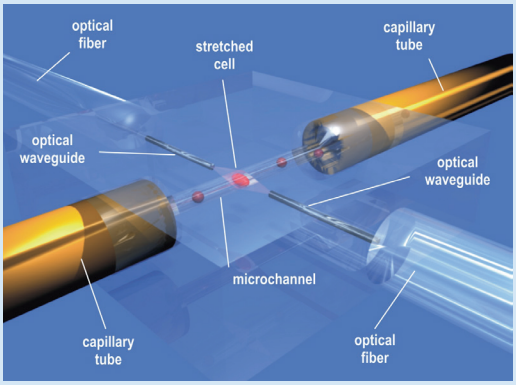
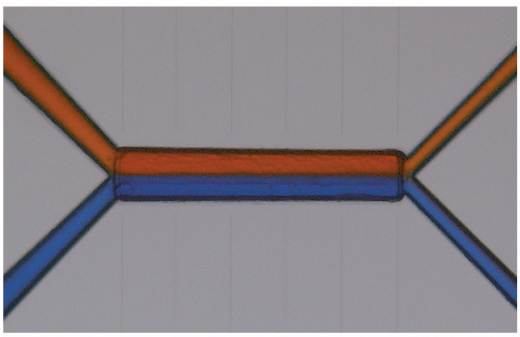


Monolithic chip for cell trapping and stretching by optical forces.



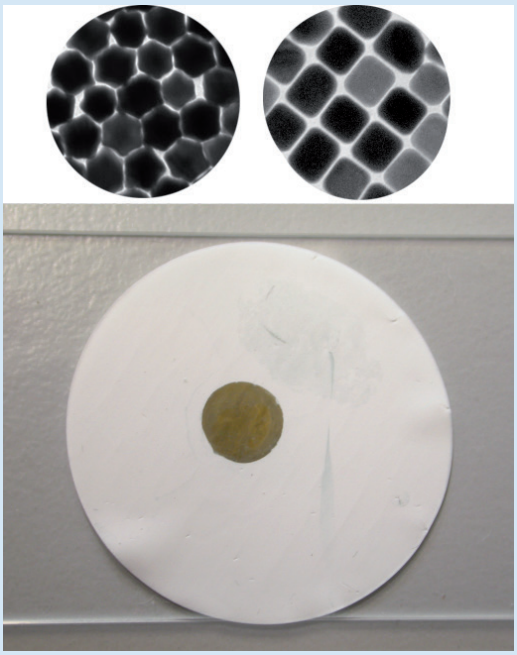
Laminar flow in microchannels avoids mixing of fluids and can be used for sorting cells.

SERS platform for detecting misfolded proteins

TRL: 3

We propose a reliable approach for determining chemical identity and structural information from given aberrant proteins in physiological conditions and in trace concentration. The unique combination of sensitivity, selectivity and spectral multiplexing of Surface Enhanced Raman Scattering (SERS) coupled with the use of novel and powerful signal-enhancing plasmonic substrates represents a valuable option for the effective analysis of aberrant species. These species may include different forms (nontoxic monomeric to toxic oligomeric and protofibrillar forms) of amyloid beta and protein tau proteins, which impair the cognitive function of Alzheimer's disease patients.

In general, the proposed platform can find application in the chemical and structural characterization of biomarkers and early diagnosis of neurodegenerative diseases. Additionally, the SERS detection may eventually offer a valuable support for monitoring the disease progress and the response to new treatments.



TEM micrographs (up) and appearance (bottom) of 2D organized superassemblies of dodecahedral and cubic gold nanocrystals used for ultrasensitive SERS detection of misfolded proteins.

With regards to enterprises...

IFAC-CNR can offer technological development of the SERS platform, including preparation of 2D organized superassemblies made of preformed gold and silver nanocrystals as powerful SERS substrates for effective detection of biomolecules at the nano- to femto-molar scale.

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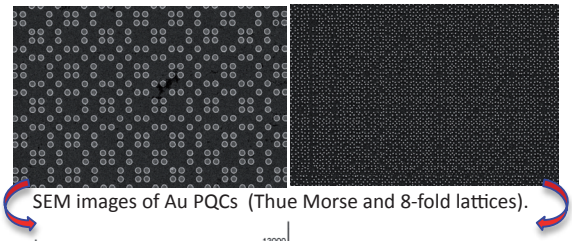
Photonic Quasi-Crystals for SERS nanobiosensing

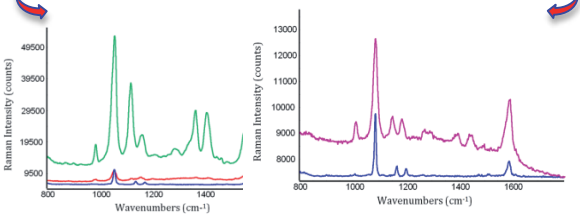
TRL: 3

The possibility of engineering complex metal nanoparticle arrays with distinctive plasmonic resonances extending across the entire visible spectrum can have a significant impact on the design and fabrication of novel nanodevices based on broadband plasmonic enhancement. With the use of PCs and PQCs, it is possible to synthesize novel artificial structures characterized by highly selective, sensitive, tunable in frequency EM response with significative amplification of the surface-enhanced Raman scattering (SERS) signal in presence of specific analytes.

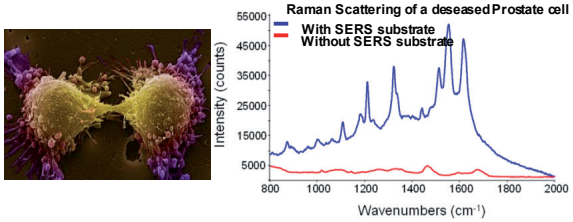
Our Team developed innovative plasmonic nanobiosensors based on SERS working in the visible frequency band. SERS on PQC arrays with precisely controlled size and spacing fabricated via electron beam lithography were investigated. The SERS substrates show high efficiency at 785 nm excitation in the detection of p-mercaptoaniline (pMA), and a SERS enhancement factor (EF) of 10^7 is achieved.



SEM images of Au PQCs (Thue Morse and 8-fold lattices).



RAMAN spectrum of bulk pMA (blue trace) compared with SERS spectrum of 10 µM pMA (red trace) adsorbed on the Au PQCs nano arrays.



SERS spectrum of a single Prostate cell (PC3) deposited on the gold nanostructure excited by a 632 nm laser.

With regards to enterprises...

- Cooperation with IPCB-CNR (Dr. P. Musto), IBBR-CNR, IZSM and with the Institute of Photonics, Ningbo University, Ningbo-China (Prof. Jun Zhou).
- Major International Joint Research Project (grant number 601320106014) funded by the NNSF of China. Duration: 01/2014-12/2018. Project title: "Study on the immunological detection technology of tumor marker based on SERS characteristics of gold nanoparticle array".
- P.O.R. Campania FESR 2007-2013 Call Innovation Window

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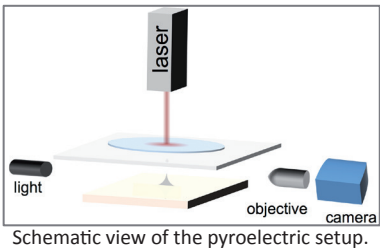
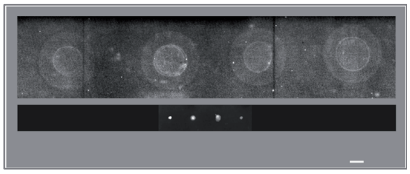
Pyroelectric charges for revealing gluten traces

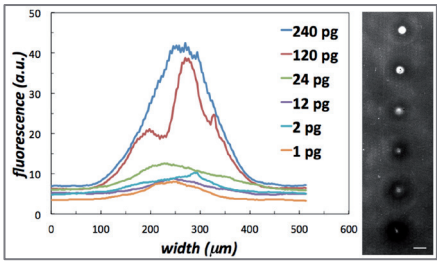
TRL: 3

Celiac disease (CD) is an immune mediated enteropathy triggered by the ingestion of gluten in genetically susceptible individuals. Treatment of CD is based on the complete avoidance of gluten proteins from the diet, the so called "gluten free diet" (GFD). However gluten contaminations are very common in food. Even products specifically targeted to dietary treatment of CD may contain tiny amounts of gluten proteins, either because of the cross-contaminations or due to the presence of wheat starch as a major ingredient. A subset of celiac patients, despite strictly adhering to a proper GFD, can react to trace amounts of gluten with even serious health consequences. Here we developed an innovative pyroelectric technique for accumulating proteins of gliadin, the main component of gluten, from high diluted solutions. The technique uses the pyroeletric effect for withdrawing extremely little volumes of solution (down to femto-litres) onto microscopic spots of functionalized supports (e.g. supernylon slides). The results show the possibility of revealing gliadin with 60 times improved sensitivity, compared to well-established methods of analysis (e.g. ELISA kit).



Schematic view of the pyroelectric setup.


Fluorescence signal from pipette spots (line above) and from "pyro-spots" (line below). Scale bar 800 µm.



Fluorescence signals from pyro-spots of gliadins at different challenging dilutions. Scale bar 300 µm.

With regards to enterprises...

- Cooperation with ISA-CNR, IBP-CNR, IMM-CNR.
- FIRB Project (Protocol RBFR10FKZH).
- PON Project (Protocol 1719).

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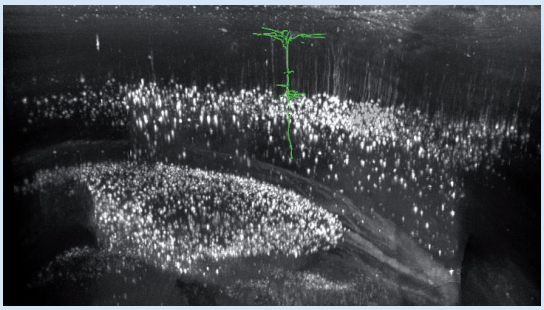
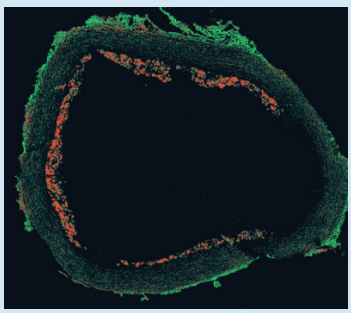
Advanced imaging methods in biophotonics

TRL: 4

We develop innovative imaging methodologies for an increased understanding of biological events in brain and heart. Novel implementations of light-sheet microscopy are applied to resolve neuronal anatomy in whole brains micrometric resolution. Moving to living samples, real-time dynamics of brain rewiring are visualized through non-photon microscopy with the spatial resolution of single synaptic contacts. Finally, random access microscopies in combination with novel fluorescence probes allow optical registrations of action potential and calcium release across population of neurons and cardiomyocytes.


Micron-scale neuroanatomy by confocal light sheet microscopy in a GFP-m transgenic fluorescence mouse.


Characterization of collagen and cholesterol deposition in atherosclerotic arterial tissue using SHG microscopy.

Our team is also performing super-resolution techniques based on single-molecule detection such as PALM and STORM. Single molecule localization methods are used to carry out 2D and 3D tracking in-vitro or in living cells. Optical methods are also performed for tissue diagnostics using microscopic and spectroscopic techniques. The development and integration of multiple laser scanning imaging techniques provides a high-resolution label-free alternative to standard histopathological methods for tissue diagnostics since it allows integrating morphological and functional information and correlating the observed molecular and cellular changes with disease behavior.

With regards to enterprises...

We can offer well established experience in the development of novel imaging methods for biomedical applications.

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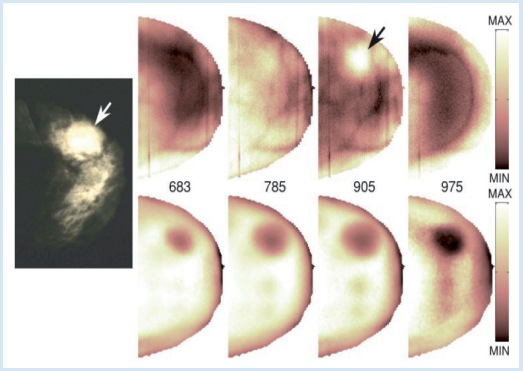
Time-resolved diffuse optical imaging and spectroscopy

TRL: 7

Optical biopsy (i.e. the in vivo examination of biological tissues using visible and near infrared light) is an attractive tool for clinical diagnostics because of the intrinsic non-invasiveness of at low-power light, and the richness offered by spectral measurements providing chemical, morphological, structural and functional information on the probed medium. In the 600-1100 nm range, the so called "therapeutic window", for most biological tissues the absorption coefficient is relatively low (< 0.5 cm^{-1}) and light propagation is dominated by the reduced scattering coefficient. Thus, light can penetrate or traverse few cm of tissue, permitting non-invasive, in vivo investigations into the human body. Different applications have been proposed, such as optical mammography, tissue oximetry, functional imaging of the brain, diagnosis of osteo-articular diseases.

Time resolved approach to diffuse optical spectroscopy based on pulsed laser sources, suitable detectors and electronics in order to achieve a temporal resolution down to the ps level, together with single-photon sensitivity, offers the great advantage of naturally uncoupling absorption from scattering contributions due to their different impact on the re-emitted photon temporal distribution.



Late gated intensity (top row) and scattering images (bottom row) at 683, 785, 905 and 975 nm obtained by an optical mammograph on the left breast of a patient bearing multiple cysts. X-ray mammogram is also reported.

SPM brain activation maps of O2Hb and HHb recorded by Time-Domain functional Near-Infrared Spectroscopy (TD-f-NIRS) on healthy subjects during right handgrip exercise.

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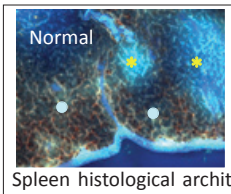
Autofluorescence in cell and tissue diagnosis

TRL: 4

Biomolecules naturally present in cells and tissues can act as endogenous fluorophores under suitable excitation light, giving rise to light emission in the visible range: AutoFluorescence (AF).

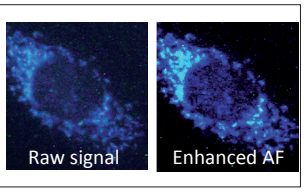
The overall AF emission properties depend strictly on the kind, amount and physicochemical state of endogenous fluorophores, in close relationship with cell and tissue morphofunctional properties. As a consequence endogenous fluorophores act as intrinsic biomarkers, the AF signal analysis providing direct, multiple information on structural organisation and biochemical composition of biological substrates, without alterations from exogenous agents.

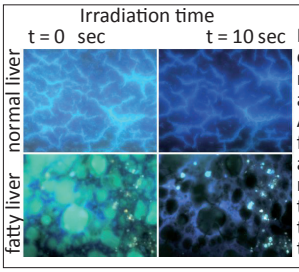
The AF signals can be collected *in vivo* from organs and tissues -spectra via fiber optic probe- or from living cultured cells -spectra and images via microscope. Focusing on the coenzymes NAD(P)H and flavins as biomarkers, AF spectral analysis even allows a monitoring of oxidative metabolism/ respiration transient events, otherwise undetectable or requiring complex assay procedures. *Ex vivo* AF imaging and microspectrofluorometric analysis of unfixed, unstained cryostatic tissue sections can then integrate data on tissue composition characterization. Self developed spectral fitting analysis procedures allow a subsequent estimation of the contribution of each endogenous fluorophore to the whole AF emission signal, similarly to an *in situ* biochemical analysis.



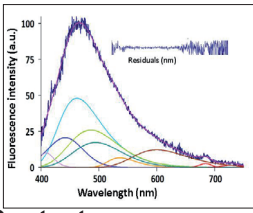
Spleen histological architecture, white (⋆) and red pulp (●)

The AF emission from NADH allows to appreciate mitochondria in a living cell in the absence of exogenous dyes.





Photosensitive endogenous fluorophores (fatty acids and vitamin A) prevailing in fatty liver cause a different tissue response to continuous irradiation with excitation light.



Example of liver AF spectrum recorded *in vivo* and fitting analysis: Measured & calculated curves proteins, bound and free NAD(P)H, vitamin A, fatty acids, flavins, lipopigments, porphyrins.

With regards to enterprises...

know-how is offered as to: i) endogenous fluorophore photophysical properties and biological meaning; ii) instrumental set-up and optimization for *in vivo*, *ex vivo* AF detection; iii) AF imaging and spectral analysis procedures; iv) AF data diagnostic interpretation. Expertise derives from a long time engagement in AF analysis application in diagnosis and functionality monitoring of cell/tissue normal and altered states. Instrumentation is also self assembled in collaboration with Italian R&D SMEs.

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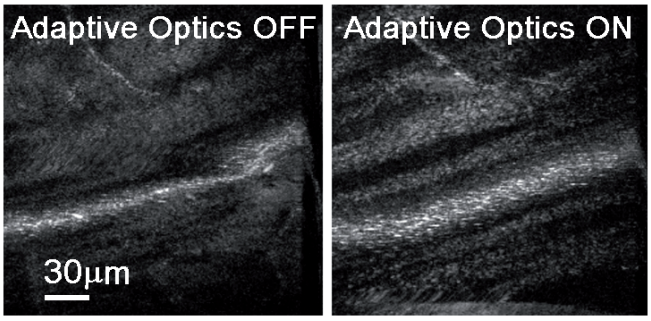
Adaptive optics high resolution OCT with an adaptive lens

TRL: 7

We demonstrate the use of an Adaptive Lens for in-vivo imaging of mouse retinas. The AL, recently realized at CNR-IFN, can generate aberrations up to the 4th order. The OCT data are processed with a Graphic Processing Unit (GPU) permitting real time extraction of image projection total intensity for arbitrarily selected retinal depth plane to be optimized. The image data were used to operate the Adaptive Lens using a wavefront sensorless control. We demonstrated that this is a viable option for imaging in-vivo biological structures for which AO-OCT cannot establish a reliable wavefront measurement. With respect to previous results obtained with deformable mirrors the use of the adaptive lens and of the sensorless optimization offers a possibility to decrease the system complexity and to access to new field of application where the use of the wavefront sensor is not possible.

Adaptive lens mounted on a camera objective.



In vivo OCT image of mice retina nerve fiber layer without and with adaptive optics .

With regards to enterprises...

Adaptive Lens was developed together with the spin-off Adaptica srl

Patent pending: TV2014A000014

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Stefano Bonora, Yifan Jian, Azhar Zam, Pengfei Zhang, Edward N. Pugh Jr., Marinko V. Sarunic and Robert J. Zawadzki

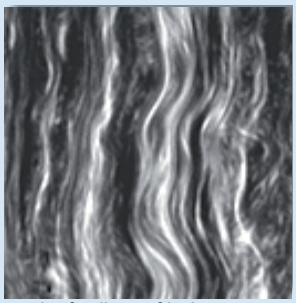
Advanced methods in laser biomedical imaging

TRL: 3

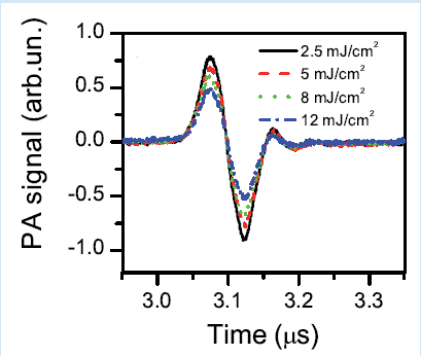
We have developed new non-invasive imaging and diagnostic techniques based on pulsed lasers for applications in biomedicine:

1) Multiphoton microscopy and in particular second harmonic generation (SHG) microscopy, which is a novel tool based on nonlinear light scattering. SHG imaging proves to be ideal to investigate pathological conditions of connective tissue such as the cornea and gain insight into the distribution and conformation of biological macromolecules of clinical relevance (in collaboration with INO and LENS).

2) Photoacoustic (PA) microscopy and tomography for a variety of biomedical applications, including early detection of cancer (in collaboration with IFC). These methods rely on the analysis of ultrasounds that are generated by the rapid photothermal heating and thermoelastic expansion occurring upon absorption of pulsed light. The combination of optical excitation and acoustic detection allows one to reach far deeper penetration into biological tissue than wholly optical imaging techniques, while maintaining the high contrast and spectroscopic specificity of optical imaging. In this context, we are also testing the use of plasmonic particles as contrast agents to increase the sensitivity and spectroscopic specificity of PA signals.



SHG micrograph of collagen fibrils in a porcine cornea.



photoacoustic transients induced by laser excitation of a biomimetic phantom embedded with gold nanorods.

With regards to enterprises...

These activities are being developed in collaboration with academic and corporate partners. We can offer expertise in the analysis of SHG signals and the characterization of materials by photoacoustics.

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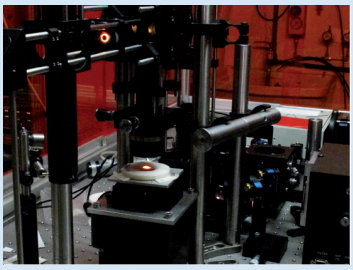
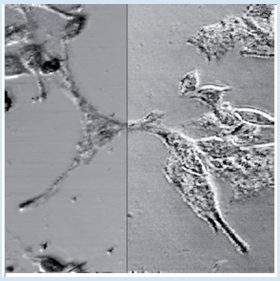
Silab– spectral imaging laboratory

TRL: 4

The laboratory is located at the Institute for Complex Systems, in the Tor Vergata Research Area. It has expertise in optics, spectroscopy and microscopy for the study of complex nanostructured and mesostructured materials. The activity is focused on the study of complex nano-structured and mesostructured materials with overall properties not easily comparable to homogeneous systems.
The laboratory is equipped with instruments for optical microscopy, confocal Hyperspectral-microscopy, reflection and transmission spectroscopy in the visible and near infrared range and atomic force microscopy. The systems are also studied with suitable theoretical models and numerical simulations developed ad hoc. The laboratory is also engaged in the design and characterization of optical measuring instruments for space missions for long term ESA missions.



The patented confocal hyperspectral microscope.



Melanoma confocal images compared at 1064 nm (left) vs. 550 nm (right).

With regards to enterprises...

Recently, Silab has been involved in projects dedicated to the development of optical and spectroscopic instrumentation for diagnostic assays of in vitro and in vivo biomedical samples (project "Skintarget", IDEAS European grant, carried on in collaboration with the NESMOS Department of Dermatology of the University "La Sapienza" and the Department of Dermatology, University of Tor Vergata). In this context, the research activity has led to the development and patent of a spectral confocal microscope powered by a continuous emission laser in the visible and near infrared. A second research line is presently dedicated to the development of advanced electronic and mechanical instrumentation for applications in aerospace technologies (BepiColombo Mission of the European Space Agency, ESA).

-Patent: Confocal, wide band spectral reflection microscope, and relevant spectral imaging method. International application number WO 2011148407.

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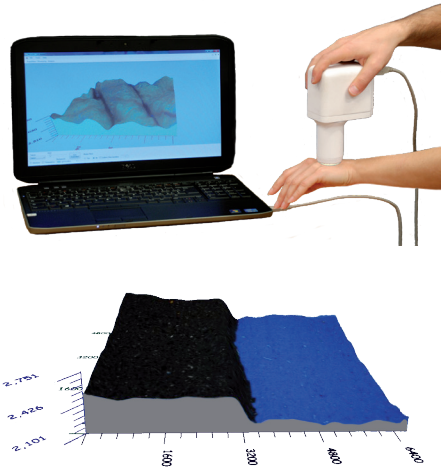
F.R. Bertani, F. Cilloco, M. D'Alessandro, L. Ferrari, V. Mussi

Portable 3D digital microscopes

TRL: 7

Compact 3D digital microscopes for in situ micro-morphological characterizations of a variety of surfaces have been developed. The novel devices exploit a simple set up including an optoelectronic group (CCD camera and objective), a translation stage, and a PC for data acquisition and elaboration. The 3D reconstruction of the surface under examination is achieved through the elaboration of a sequence of pictures (usually 50-100), which are collected while translating the focal point of the objective along the optical axis z. Fields of view range between 1-10 mm with corresponding vertical resolutions between some microns to some tens of microns can be achieved using suitable objectives. The microscope head can optionally be mounted on (x, y) translation axes in order to investigate wider zones by merging 3D reliefs of adjacent areas. The present low-cost micro-3D devices have a significant application potential in various fields: industry, health, environment, and cultural heritage. Thus for examples, in dermatology they can allow accurately examining and monitoring the micro-morphologies of the skin diseases, as well as assessing the effectiveness of surgical therapies. In archaeometry, 3D digital microscopes can provide information on the authenticity and the state of conservation of the object under study and support the assessment of the effectiveness of the cleaning treatments.



Palm-sized 3D digital microscope and application examples: a) examination of skin, b) observation of a painted surface during laser cleaning.

With regards to enterprises...

A PCT patent application has been submitted for the present class of 3D digital microscopes: "*Microscopy optoelectronic device with focus scanning*", by S. Siano, A. A. Mencaglia, I. Cacciari (PCT/IB2012/053905). Related collaborations have been established with El.En. S.p.A and Actis S.r.l of Calenzano, Italy. We are available for further partnerships.

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Simple *in vivo* models for nanomedicine

TRL: 3

Simple *in vivo* models are required to study the interactions of nano-materials with living matter. To this aim, we use aquatic invertebrates (*Hydra vulgaris and Nematostella vectensis*) as new models for nanomedicine, with respect to ethical and economic issues. The functional versatility of these animals make them useful for a variety of investigations, from bioimaging to high throughput testing of functional materials, to nanotoxicology. Here we report the most recent research interest in this field.

Colloidal semiconductor nanocrystals, such as Quantum Rods (QRs) are superior candidates for bioimaging. By using these nanoprobes we disclosed new *in vivo* dynamics of cell trafficking and embryo development (Fig 1). Beside bioimaging, functional nanomaterials are excellent platforms for biomolecule delivery. To this aim, we developed multifunctional gold nanoparticles (AuNPs) to deliver at high efficiency small-interfering RNA (siRNA) and tested its capability to elicit the dowregulation of myc proto-oncogene in *Hydra* (Fig 2).

The use of light holds great promise for new therapeutic approaches. Novel methods to induce hyperthermia-mediated cell ablation were successfully exploited *in vivo* by using Near Infrared (NIR) responsive gold nanoprims (Fig 3).

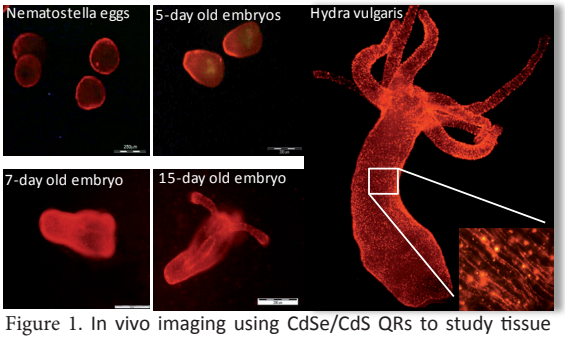

Figure 1. In vivo imaging using CdSe/CdS QRs to study tissue plasticity (H. vulgaris) and embryo development (N. vectensis).

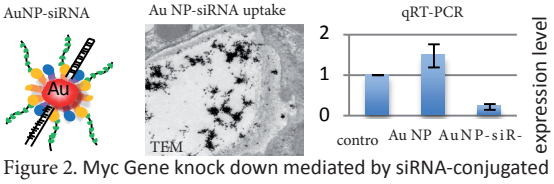

Figure 2. Myc Gene knock down mediated by siRNA-conjugated Au NPs in *H. vulgaris*.

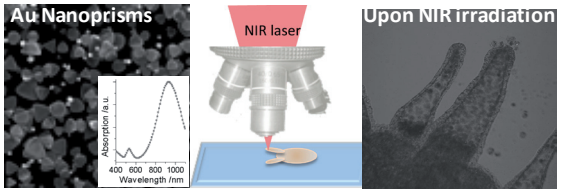

Figure 3. *In vivo* phototermal cell ablation mediated by Near infrared responsive Au nanoprims.

With regards to enterprises...

On this topic we can offer support for testing functional materials, providing new models and cell/molecular biology expertise to characterize their impact and functionality in vivo (nanotoxicology, drug delivery, remote control of cell fate).

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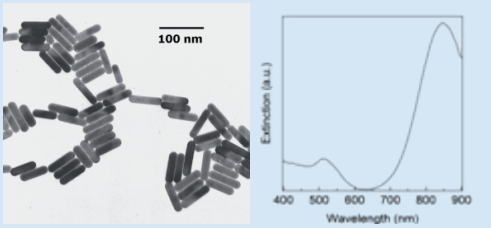
Laser-assisted nanomedicine for tumor theranostics

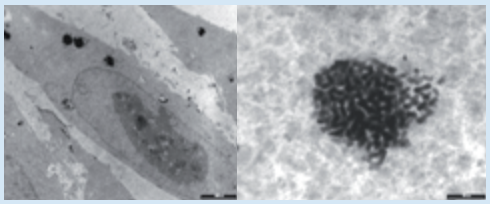
TRL: 3

The combination of pulsed and CW near-infrared laser light with plasmonic particles such as gold nanorods is gaining relevance for the photoacoustic imaging and photothermal ablation of cancer. Selective targeting of malignant cells with these contrast agents may rely on complementary biochemical and biological strategies, including the use of specific probes or the exploitation of cellular vehicles.

We have developed a platform of PEGylated gold nanorods with plasmonic bands around 800 nm, good biological profiles, stability and efficiency of photoacoustic and photothermal conversion as well as potential to passively accumulate into solid tumors by their enhanced permeability and retention. In order to enhance this potential, we are drawing advantage and inspiration from biological processes to modify these particles for active delivery. Examples include: (i) the conjugation with antibodies against cancer antigen 125 (CA125), which is a common biomarker for ovarian lesions; (ii) the termination with inhibitors of carbonic anhydrases 9 and 12 (CAIX and CAXII), which are expressed by hypoxic cells such as those found in the core of solid tumors; and (iii) by introducing macrophages as a versatile model of cellular vehicles that would phagocytose the particles and home to inflammatory lesions.



Gold nanorods with optical absorption bands around 850 nm.



Phagocytosis of targeted gold nanorods in cultured cancer cells.

With regards to enterprises...

These activities are being developed in collaboration with academic and corporate partners. The IP on the use of inhibitors of carbonic anhydrases in this context is owned by CNR. We can offer expertise in the design and development of any aspect of these activities.

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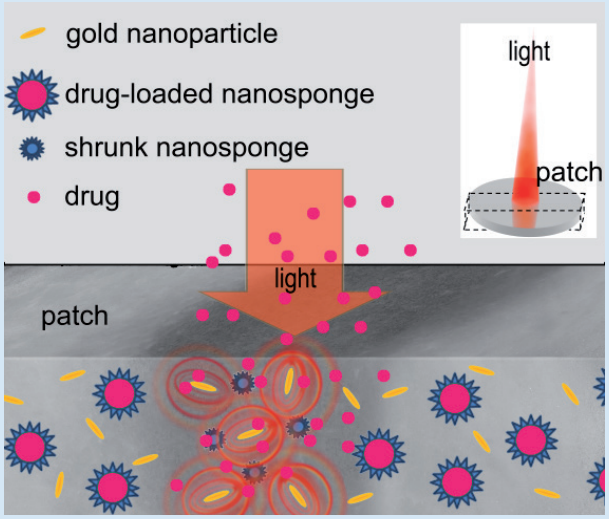
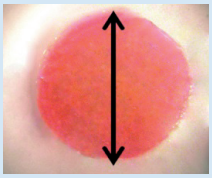
Light-sensitive implantable devices for “on demand“ drug release

TRL: 4

The system consists of a biocompatible film or patch containing a dispersion of gold nanoparticles, which act like light transducers, producing heat upon light stimulation, and of thermosensitive nanosponges, which serve as a reservoir for the drug molecules to be released. The temperature rise generated by the nanoparticles triggers a contraction in proximal nanosponges, thus promoting the expulsion of the drug to the external environment in a very controllable and localized way. The patches can be applied either on the skin or inside the body with high levels of safety and comfort.
The use of these devices may assist in performing advanced and personalized pharmacological therapies, in which the release of precise drug amounts to specific body regions is required.



Scheme of the light-sensitive device for controlled drug release.



Example of a biocompatible patch for the release of the anti-cancer drug Doxorubicin (1 cm in size).

With regards to enterprises...

The IP of this invention is owned by CNR, which filed a patent, now under PCT application: “Matrix and device and use thereof for optically controlled release of chemicals”, Inventors: P. Matteini, F. Ratto, R. Pini.
We can offer: technological development of the invention, as well as support for studies in vitro, in vivo and at clinical level.

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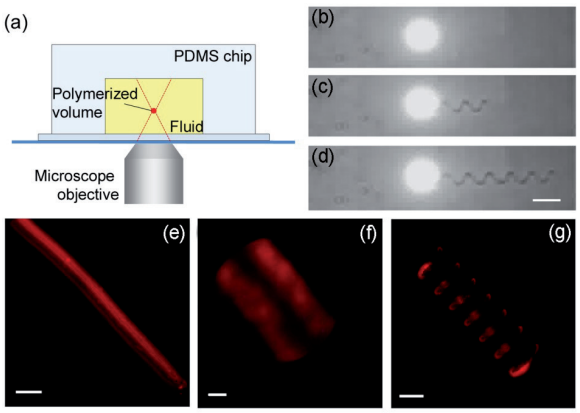
3D printing of micro-particles by two-photon continuous flow lithography

TRL: 4

3D printing technologies are attracting a growing interest for the production of complex objects. In particular, optical stereo-lithography allows 3D objects with micrometric resolution to be produced. We have developed a novel optical printing method by combining the high spatial resolution of two-photon stereo-lithography with microfluidics. 3D micro-object with feature size down to few hundreds of nanometers can be produced in continuous runs, overcoming some of the limitations of 3D optical printing in terms of feature size and throughput.
The process is based on a near-infrared pulsed laser, focused inside a micro-channel, where a continuous flow of a pre-polymer solution is maintained by external pumps. Two-photon absorption of the incident laser induces the polymerization of the pre-polymer solution in a small volume (typical size <400 nm) close nearby to the laser focus. The shape of the produced particles results from the composition of the flow motion and the movement of the laser spot. We can produce micro-objects with various shapes, such as polymer fibers, bow-tie and helical particles, by varying both the position and focusing conditions of the laser beam inside the microchannel. In addition, particles with chemical anisotropy (such as Janus particles) can be produced by moving the laser beam across the interface of co-flowing fluids, with different chemical composition, having interesting perspective for photonics and biotechnology applications.



(a) Schematics of the device geometry and TP-CFL set-up. (b-d) Sequence of frames imaging the synthesis of helical particles. Scale bar: 20 µm. Time interval between consecutive frames=600 ms. The bright spot in (b)-(d) corresponds to the laser beam, whereas the pre-polymer flows from left to right. (e-g) Confocal fluorescence microscopy images of fiber, bow-tie and helical particles, respectively. Scale bars: 10 µm.

With regards to enterprises...

On this topic we can design and develop prototype free-standing 3D micro-objects and 3D printing of high-resolution microscale systems.

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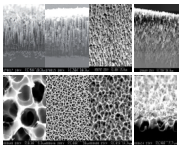
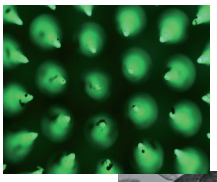
Optical Biochip for biomedical applications

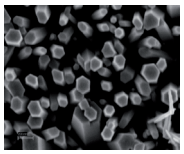
TRL: 4

Nanostructured, multifunctional, hybrid materials are biochemically modified and integrated within multi-purpose photonic devices.
Applications in medical diagnostic and imaging, but also in fundamental studies of biochemistry have been demonstrated.

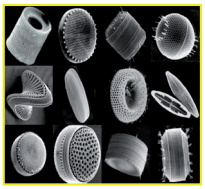


Porous silicon.



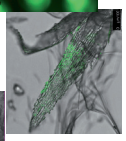


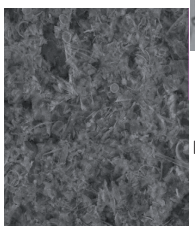
ZnO nanowires.



Diatoms.

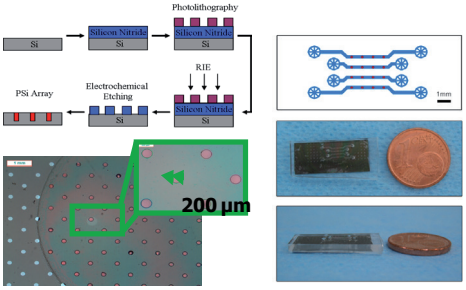
Polymer µ-needles.



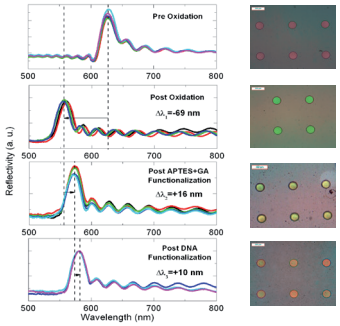


Diatomite.

Nanostructured supports.



Porous silicon based microfluidic assisted optical microarray.



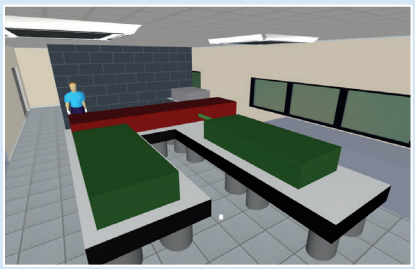
Naked-eye reading of the microsensor optical response in different activation steps of the porous silicon surface.

Contact:
Luca De Stefano, (luca.destefano@cnr.it)
Authors: L. De Stefano, I. Rea, I. Rendina
IMM - Napoli

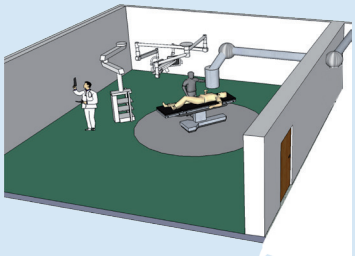
Extreme Laser Intensities: dense plasma and radiation sources

TRL: 4

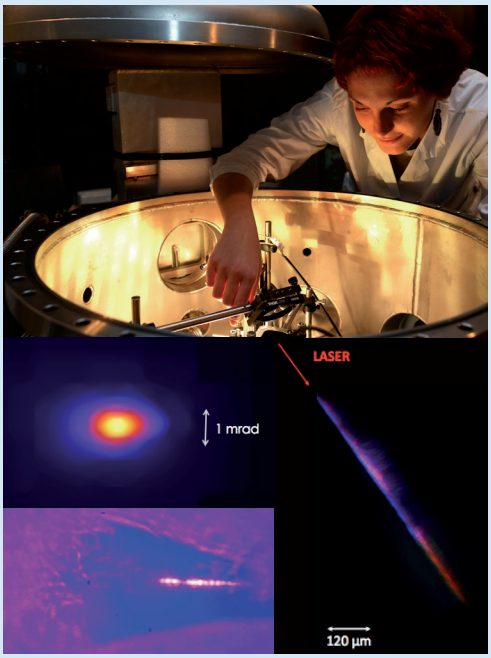
Laser pulses as short as 30 femtoseconds (10^{-15} sec), can now be amplified to the petawatt power (10^{15} W) using large, Titanium doped, Sapphire crystals. When these pulses are focused on gas or solid matter at intensities as high as 10^{21} W/cm^2, electrons are instantaneously accelerated to relativistic velocities enabling new mechanisms for miniature particle accelerators and the generation of extreme matter states typical of large planetary cores or Inertial Confinement Fusion plasmas. Based on these recent discoveries, we are developing revolutionary, all-optical radiation sources for medical radiotherapy and diagnostics and new schemes for the laboratory investigation of hot plasmas and warm dense matter.



ILIL-PW, the High power laser installation at INO, Pisa, a node of the Italian network on Extreme Light infrastructure.



Laser-LINAC, a revolutionary "all-optical" concept of accelerator for future medical applications.



Miniature laser-plasma accelerator: the high energy electron beam and the fingerprints of the laser propagating in the gas.

Projects funded by MIUR (PRIN, FIRB), INFN and Min. Salute, EU(FP7). Radiobiological validation of laser-linac in progress. Part of the European Network for Novel Accelerators.

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Leonida A. Gizzi, (la.gizzi@ino.it)
Intense Laser Irradiation Laboratory (ilil.ino.it)
INO - Pisa

Energy
Space & Transport

Eco-sustainable and abundant energy production is an ambitious objective not only justified by fundamental scientific interest but also urged by socio-economic issues. The Sun supplies free, abundant and clean energy, especially in Countries, like Italy, which benefit from naturally long solar exposure. CNR has an active role in identifying and researching eco-friendly energy production solutions to efficient sunlight harnessing. Here we present a summary of the CNR activity in the field of photovoltaic devices.

CNR researcher have exploited biomimetic self-assembled patterns aid coating for enhancing light absorption in photovoltaic devices and light extraction in OLED. In the field of Dye-Sensitized Solar Cells (DSSC) natural and synthetic dyes, mesostructured titania films with enhanced dye adsorption and with low thermal balance, plasmonic enhancement and innovative hybrid perovskite absorber materials are explored from different CNR groups towards clean and efficient energy. New material systems, such as solution processable hybrid perovskite with high efficiency or quantum dots and related barriers, to study photocarrier dynamics and improve trapping and collection, are also investigated to implement high efficiency devices.

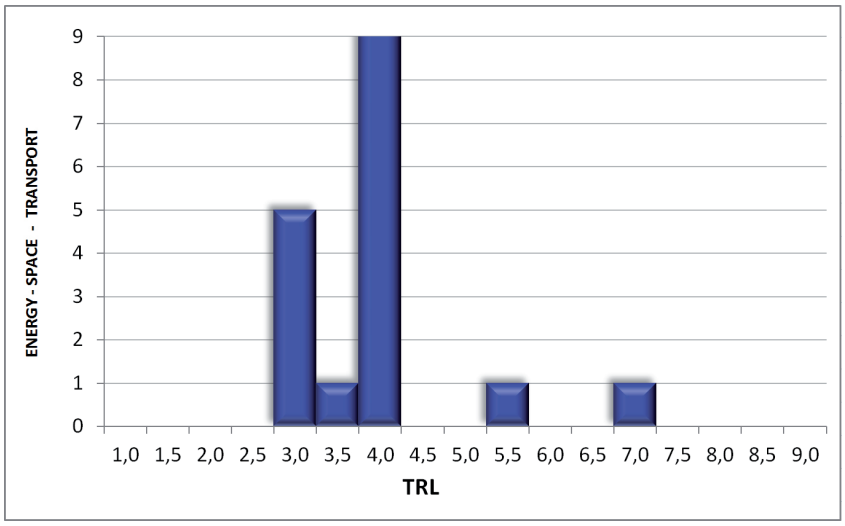
Concerning the research in space and transport, it addresses the major challenges of society in the fields of mobility, resource management, communication and information systems, the environment and safety. In this frame, here we report the resent achievement of CNR in the space and transport research field.

CNR has developed polycrystalline YAG (Y3Al5O12) doped with rare earth elements (REE) as a strategic functional material for high power Diode Pumped Solid State Lasers (DPSSL). The Laser-Induced Breakdown Spectroscopy (LIBS) technique has been implemented from CNR group to suit the on-line analysis of materials in industrial environment.

The space exploration plans of the European Space Agency include new ambitious space missions which foresee the participation also of the Italian Space Agency. For this activity CNR has developed solar probes operating in a harsh environment, rich of ion particles and characterized by high temperature. Optical coating are also developed as a key element to manipulate the radiation, both in spectral as well as in imaging systems. Moreover image interferometer for aerospace platforms and compressive sampling technology have been developed from CNR units in this frame.

Distributed fiber optic sensors and Quartz Enhanced Photoacoustic Gas Sensors have been implemented for safety and security from different CNR units. These sensors find an application to monitoring bridges, railways, pipeline deformations and leakeages. Distributed temperature measurements have been performed for geothermal applications and volcanic area monitoring. These sensors have been also used in aeronautical applications.

number of contributions in this section



Hybrid perovskite and colloidal nanocrystal based organic/inorganic photovoltaics

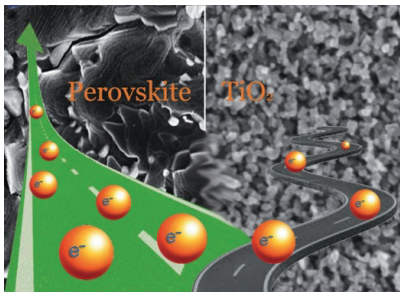
TRL: 3

In the quest of high efficiency energy sources, recent breakthroughs in the realization of solar cells that exploit wet-chemically prepared hybrid organic/inorganic composites as active functional elements have drawn the attention of the scientific community. We explore novel materials and device architectures based on polymeric/organic, hybrid organic inorganic perovskite, and colloidal nanocrystals.

Motivated by the recent results of perovskite based solar cells which boost the efficiency of solid state dye sensitized solar cells, we aim to exploit the peculiar properties of hybrid perovskites. Such materials are prepared by a simple self-assembly approach by solution processing. Our study involves the preparation, device fabrication, photo-physical characterization to explain the charge generation and collection processes.

In parallel, we exploit colloidal PbS/PbSe nanocrystals as active material in solar cells to harvest the infrared portion of solar spectrum. We report on the fabrication of high-efficiency all-inorganic solar cells by a novel approach that involves processing of colloidal PbS QDs and anisotropic TiO2 NCs under room-temperature conditions. Through these procedures we have realized solar cell devices on flexible PET substrates.

Both hybrid perovskite and collaidal nanocrystals are solution processable and can be potentially be implemented into flexible plastic technology and large-scale industrial manufacturing.



With regards to enterprises...

Energy & Environmental Science 6, 1565 (2013) doi: 10.1039/C3EE23928D
Chemistry of Matererials 25, 4613 (2013) doi: 10.1021/cm402919x
Energy & Environmental Science 7, 1889 (2014) doi: 10.1039/C3EE43991G

Contact:

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Silvia Colella (silvia.colella@nano.cnr.it)
Nano - Lecce

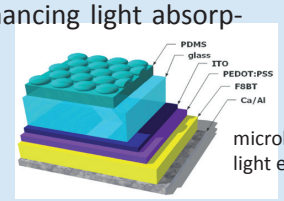
Biomimetic self-assembled patterns for efficient light utilization

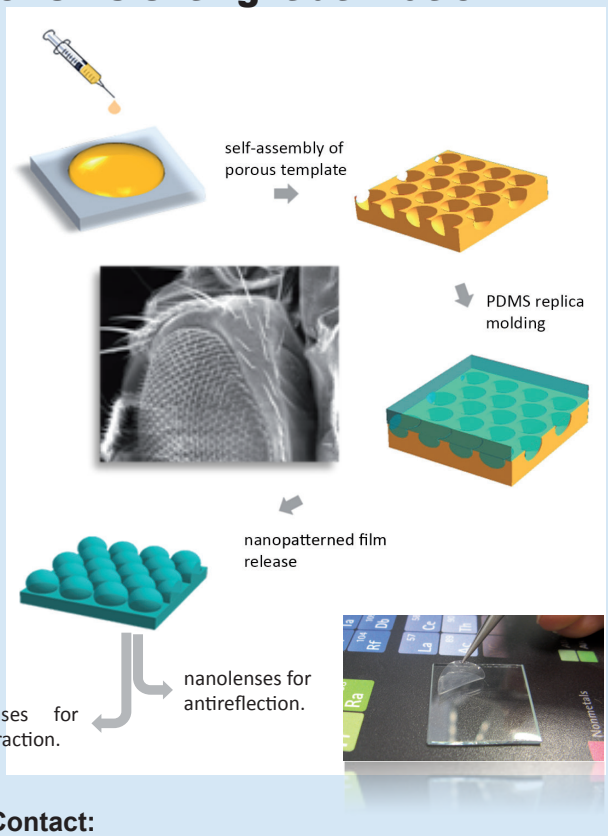
TRL: 4

Optical devices and many energy-related applications rely on glass as a protecting barrier from external agents and as a transparent window for light propagation. The transmittance through a glass window is limited by reflection losses that are always present at any interface separating different indices of refraction.

We employ a low cost manufacturing process based on self-assembly to create a single layer of nano-pores in a polymer film. By replica molding of these porous films we obtain elastomeric nano/micro-domes made of PDMS, with size tunable between 300 nm and 10 µm. Such patterned layers, easy to apply on any flat surface, are used for a dual scope depending on the feature size:

- as light extraction aid coating for enhancing an OLED effi ciency, in the case of the micrometric lenses
- as antireflection coating for enhancing light absorption in photovoltaic devices, in the case of nanometric lenses.





With regards to enterprises...

We collaborate with RSE SpA.

We can offer: broadband and crack-free antireflection coatings for glass windows; low cost elastomeric microlens arrays.

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Mariacecilia Pasini (m.pasini@ismac.cnr.it)
ISMAC - Milano

Plasmonic solar cells

TRL: 4

Plasmonic light trapping in thin film silicon solar cells is a promising route to achieve high efficiency with reduced volumes of semiconductor material. Distinct plasmonic back reflectors (PBR), which consists of subwavelength metallic nanoparticles (NPs) embedded in a Transparent Conductive Oxide (TCO) layer on a back mirror, were incorporated in the rear contact of thin film a-Si:H solar cells, as schematically shown in Fig 1.

The external quantum efficiency (EQE) spectra of the devices revealed a remarkable broadband enhancement, Fig 2, which is attributed not only to the plasmon assisted light scattering from the NPs but also to the front surface texture originated from the conformal growth of the cell material over the particles. The photocurrent enhancement achieved in the a-Si:H light trapping window (600 – 800 nm), measured on more than 40 devices deposited on distinct types of PBRs, stays in linear relation with the PBRs diffuse reflection. Remarkably high values of short circuit current density and open circuit voltage are achieved in comparison to those previously reported in the literature for the same type of devices.

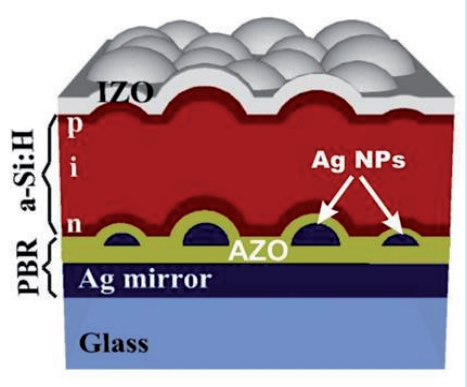

Fig.1: Structure of a-Si:H solar cell with PBR.

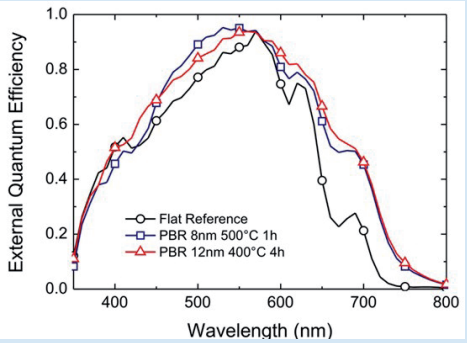

Fig 2: EQE curves of solar cells fabricated on two PBRs with NPs formed from 8 and 12 nm thick Ag films and on a flat back reflector for comparison.

With regards to enterprises...

Plasmonic solar cells are particularly attractive to photovoltaics enterprises. This research activity, performed within the EU FP7 Marie Curie Actions FP7-PEOPLE-2010-ITN through the PROPHET project (Grant No. 264687), is carried out in collaboration with several national and international academic laboratories and also industrial partners, as 3SUN, the largest italian photovoltaic factory.

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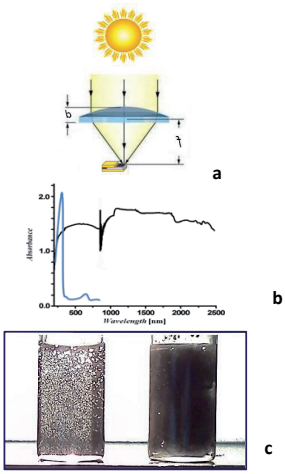
Francesco Priolo, (francesco.priolo@ct.infn.it), Univ. Catania

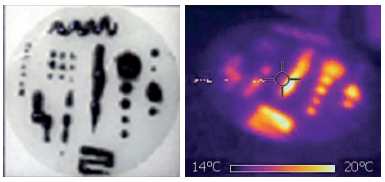
Pyro-electric solar energy harvesting

TRL: 4

Energy harvesting is the process by which energy is derived from external sources (e.g. solar power, thermal energy, wind energy, salinity gradients, and kinetic energy), captured and stored. The use of pyroelectricity for this pourpose has been widely investigated over the past years. Recently, a novel device able to harvest solar energy by means of on an optical system focusing solar radiation onto a ferroelectric crystal (i.e. lithium niobate) has been developed. The pyroelectric crystal's face exposed to the heating source is coated with a nano-composite material (i.e. carbon black and graphene particles). Even if this is only a first demonstrator device, we can find two big powerful aspects related to the proposed harvester. First of all, the presence of the polymer absorber (CB) coating and of a refractive focusing system is decisive to determine the achievement of a temperature onto the crystal that greatly exceeds that obtained with the crystal plainly exposed to solar radiation without any radiation concentration systems and so increasing the amplitude of temperature variation experienced. Moreover, the most important aspect to focus on, is the achievement of a wider spectral absorbance. Thanks to the presence of a CB coating with a higher absorbing coefficient and a wider spectral absorbance with respect to the lithium niobate pyroelectric crystal (transparent from 320 to 5000 nm), the whole visible and IR wavelengths of solar radiation are involved in the energy harvesting. This aspect, that allows the improvement of the efficiency of the proposed device, is a goal with respect to standard solar cells (up to 1000-1200 nm).



a: Our device;b: absorbance spectrum for CB (black) and LN (blue); c: radiation absorbing material (GO and CB in PDMS).



Thermal map of the pyroelectric element with CB coating.

With regards to enterprises...

Financial support from:
EFOR-CABIR CNR project
the Molecular NAnotechnology for HeAlth and EnvironmenT

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Veronica Vespini: (veronica.vespini@cnr.it)
ICIB - Pozzuoli (NA)

Natural and synthetic dyes for clean and efficient energy

TRL: 4

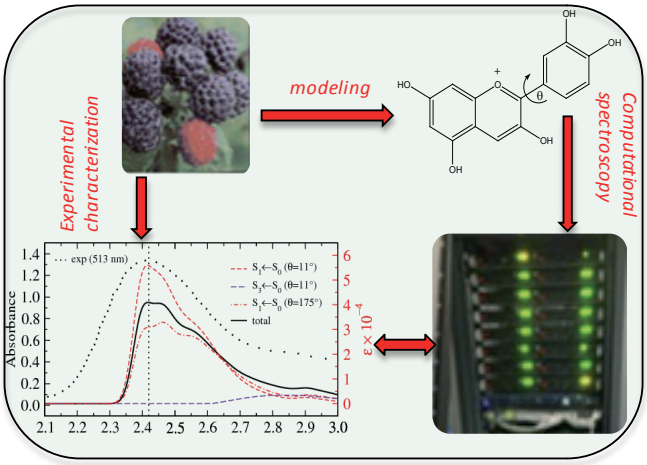
Within a plethora of renewable energy sources available today, photovoltaic cells surely sit among the most effective and usable ones. In this field, the possibility of exploiting organic dyes in the industrial production of dye-sensitized solar cells (DSSC) is very attractive, for the benefits in terms of cost and impact on the environment.

Computational approaches have been proved to contribute substantially in the whole DSSC field, by clarifying the mechanisms that determine their efficiency, unraveling the role of the dye-interface interactions and in the search of the most effective sensitizers, either of natural or artificial origin, including plasmonics effects.

In our lab (www.pi.iccom.cnr.it/ThC2-lab) state-of-the-art computational methods are developed and employed in modeling dyes optical properties, investigating energy transfer in complex supramolecular assemblies as multi-chromophoric systems for artificial photosynthesis, selecting among large sets of candidates the most efficient ones.

With regards to enterprises...

On this topic, we are pleased to collaborate with enterprises by offering our know-how, exploiting the insight offered by computational approaches to flank the effective synthesis with *in silico* screening protocols based on realistic models.



Modeling optical properties of natural and synthetic dyes for DSSC.

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(thc2_lab@pi.iccom.cnr.it)
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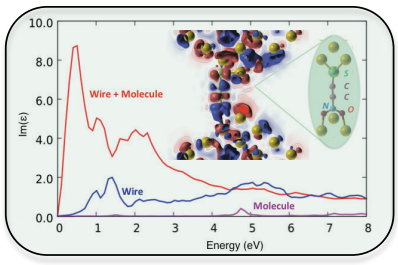
Alessandro Ferretti
Alessandro Fortunelli
Susanna Monti
Giacomo Prampolini
Fabrizio Santoro
Giovanni Villani
ICCOM - Pisa



Molecules connecting "hot spots" nano-gaps.

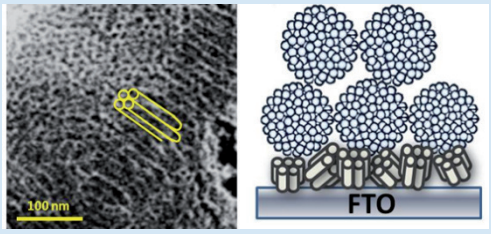
Mesostructured titania films with enhanced dye adsorption and with low thermal balance for solar cells

TRL: 4

Soft template assisted synthesis was used for the preparation of highly porous titania films with an ordered mesoporous structure. These films were used for the development of photoanode in dye sensitized solar cells. It was observed that the mesostructure allows to achieve superior performance with respect to commercial titania (Degussa P25). In collaboration with Luisa De Marco (Nano-CNR Lecce) hierarchical mesostructured titania films were developed and, in particular, by combining thin mesoporous titania buffer layers and thick films from mesoporous titania powder, the power conversion efficiency of solar cells was increased up to ~55% with respect to commercial titania P25 (9.67 and 6.17% by using mesostructured and P25 TiO_2, respectively).

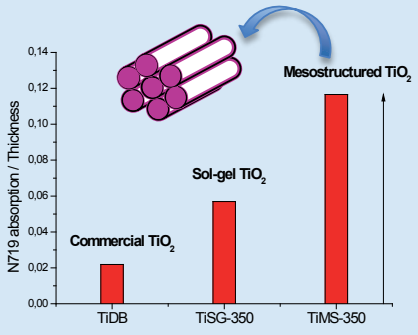
To decrease the thermal balance for the production of solar cells a low temperature route for the synthesis of mesostructured titania has been recently developed and crystalline anatase was obtained at temperature of about 100-150°C. The aim of this project is the realization of solar cells entirely produced at low temperature in collaboration with Giuseppe Calogero (IPCF-CNR Messina).

This work was supported by the EFOR project (Energy from renewable sources).



Titania-based fotoanodes with hierarchical meso-ordered structure for dye sensitized solar cells lead to an enhancement of light harvesting and DSSC efficiency with respect to devices from commercial P25 titania.

Enhancement of DSSC power conversion efficiency of ~55% with respect to P25.



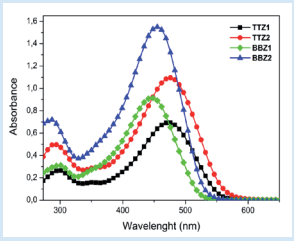
Enhanced dye adsorption by using mesostuctured titania.

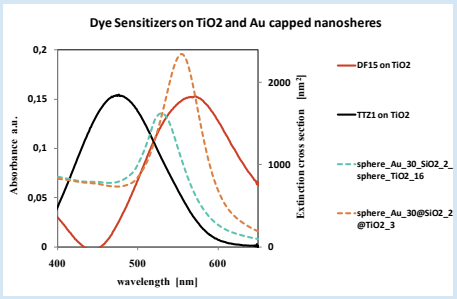
Contact:
Gabriella Di Carlo (gabriella.dicarlo@ismn.cnr.it) ISMN - Montelibretti (Roma)

P_DSSC Plasmonic enhancement in Dye-Sensitized Solar Cells

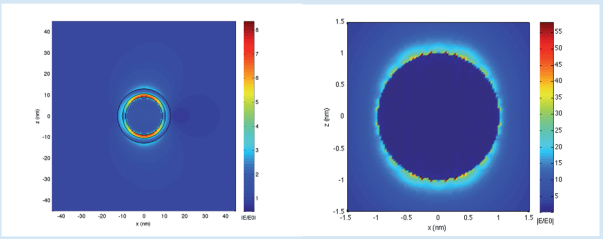
TRL: 3 - 4

Dye-sensitized solar cells (DSSCs) have emerged as one of the most promising technologies for the construction of cheap, silicon-free photovoltaic devices. DSSCs are based on the use of light-harvesting dyes to sensitize the surface of a nanocrystalline semiconductor (usually TiO_2).
Our research focuses on the device optical and chromatic properties simulation and optimization by plasmonic effects of selected dyes syntetized by ICCOM (G. Reginato, L. Zani). The extinction properties were simulated for several types of metallic nanoparticles by means of commercial and open source softwares, starting from gold nanospheres with dimensions and capping (Si and TiO_2) from realized compounds from literature and at ICCOM (A. Ienco). Disperse particles and aggregates were considered for best exploiting all the possible practical realizzations, over rigid, nanostructurated and flexible substrates.





Absorption extension of dyes by plasmonic effects produced by gold sheres capped with silica and titania, and capped with silica on titania nanosheres.



Near-field enhancement maps for gold nanospheres with different capping and dimensions at wavelengths of maximum extinction.

With regards to enterprises...

in collaboration with ICCOM, we have already presented projects with italian companies working on new generation PV (Tozzi, Renewable Energy, Aurel Innovation), and were selected for funding in Progetti Premiali for Made in Italy with the leadership of ITIA.

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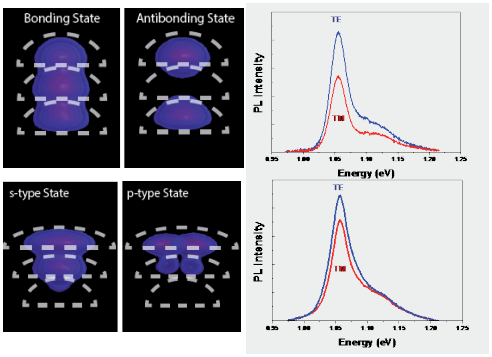
IFAC - Sesto Fiorentino (FI)

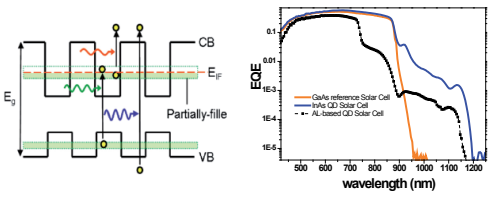
Tailoring quantum dot device properties

TRL: 4

Nanoscale islands of semiconductor inserted in a wider bandgap matrix represent a powerful tool to add new functionalities to optoelectronics devices such as laser, LEDs or optical amplifiers. These structures formed by self-organized growth process provide confined energy states available for photo/electro injected carriers. InAs quantum dots are a particular class of quantum dots which are studied for improving performances of telecom optoelectronic devices. Tailoring of electronic and optical properties of this material by proper material development approaches is the critical limit for the design of efficient quantum dot-based devices. We demonstrated the engineering of shape anisotropy and related polarization sensitivity of Stranski–Krastanov closely stacked InAs/GaAs quantum dot layers by overgrowth phenomena and surface kinetics. The study lead to a drastic increase of the TM/TE polarization ratio of emitted light up to 0.8. This polarization independence represents a critical issue when semiconductor optical amplifiers based on these nanostructures are envisioned. The insertion of quantum dots in conventional single junction solar cell can also provide an efficient way to enhance photocurrent along with photovoltage preservation in the new generation concept of Intermediate Band Solar Cells. Our activity in this field is based on the definition of new material systems (quantum dots and related barriers) to study photocarrier dynamics and improve their trapping and collection for photovoltaics.



Emission polarization control in vertically stacked quantum dot structures.



Control of subbandag level engineering in Intermediate Band Solar cells based on InAs and AlGaInAs quantum dots.

With regards to enterprises...

On these topics, we collaborate with Tyndall National Institute-Cork(IE), CNR-IMM Lecce, KACST-Riyhad-Saudi Arabia.

Nanotechnology 25 055207 (2014).

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Nano - Lecce

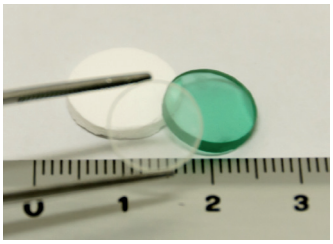
Transparent ceramics: Yttrium Aluminium Garnet (YAG)

TRL: 4

Polycrystalline YAG ($Y_3Al_5O_{12}$) doped with rare earth elements (REE) is a strategic functional material as laser source for high power Diode Pumped Solid State Lasers(DPSSL).
Compared to the more commonly used single crystals, transparent YAG ceramic can widen the laser applications:

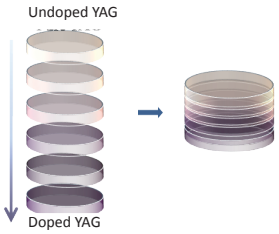
- It can be highly doped
- It is faster to produce
- It can be shaped in complex architectures.

Yb- doped YAG

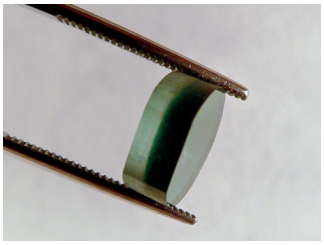


Nd-doped YAG

Exemple of a graded structure



Layered pure – Yb-doped YAG



With regards to enterprises...

Recent articles

- L. Esposito et al., Optical Materials, 35 761–765 (2013)
- L. Esposito et al., J. Eur. Ceram. Soc., 32 [10] 2012, 2273-2281
- L. Esposito et al., J. Eur. Ceram. Soc., 33 737–747 (2013)

Recent National and International Projects

1. European project LASERLAB-EUROPE" EC contract no. 284464.
2. Italian Flag project RITMARE, funded by Ministry of Educ..Univ. and Res. (MIUR)
3. European CRAFT Project NOVIGLAS COOP-CT-2004-5123182010-2011
4. Bilateral Project with INSA CNRS Lyon in france and with Kyushu University in Japan

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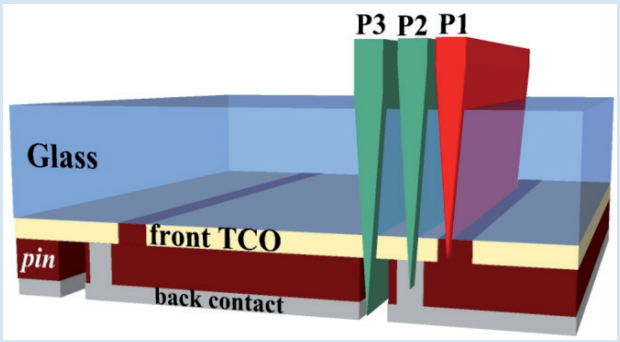
Ultra-thin transparent electrodes

TRL: 3

The coexistence of high electrical conductivity and optical transparency, in visible and near-infrared spectral regions, is the reason for the tremendous interest in Transparent Conducting Oxide (TCO) materials.
To reduce the TCO thickness and, at the same time, to get the desired electrical conductivity while maintaining high transmittance, inclusion of very thin metal film within TCO material has recently received a renewed interest as a highly promising route in the framework of ultra-thin devices. The main feature of these structures is the achieving of their high optical and electrical performances at room temperature, which avoids the problem related to TCOs, for which a heat treatment above 250° C during or after deposition is necessary. Lowering the thermal budget has the double advantage of reducing production costs and being compatible with plastic substrates, which is necessary for the development of flexible devices.
In particular, TCO/Ag/TCO electrode is a suitable candidate for use in large-area modules, liable to segmentation, such as for α-Si:H solar panels, as schematically shown in the figure on the right. The energy density threshold for the scribing of the transparent contacts can be significantly reduced by replacing the standard thick TCO single layer with a 10 times thinner TCO/Ag/TCO multilayer structure with better electrical and optical properties.



Typical interconnect scheme of an α-Si:H module in superstrate configuration. P1, P2 and P3 indicate the scribing steps for electrical isolation of the individual segments.

With regards to enterprises...

Due to their great potential of application in solar cells, flat screen displays, touch panels and energy saving windows, to name a few, ultra-thin transparent electrodes can be particularly attractive to several enterprises. In particular, this research activity is carried out in collaboration with STMicroelectronics and 3SUN.

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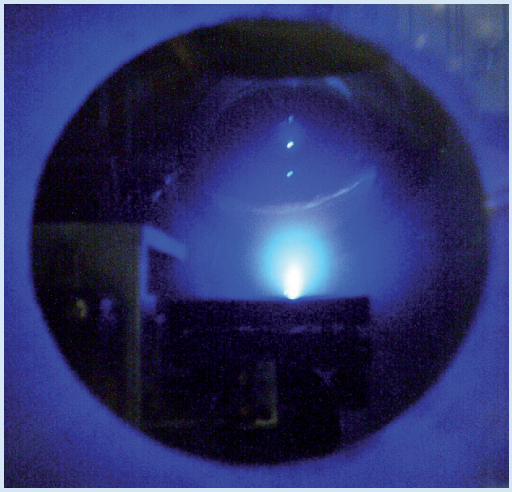
IMM - Catania

On line LIBS analysis of coal in industrial environment

TRL: 4

The LIBS (Laser-Induced Breakdown Spectroscopy) technique is particularly suited for the on-line analysis of materials in industrial environment.
The LIBS technique, in fact, can operate in stand-off mode, without treatment of the sample. The measurement time is extremely short (nanoseconds) and therefore LIBS is the election technique for the analysis of large quantities of materials. The development by the Laboratory of proprietary analytical techniques allows the accurate measurement of all the elements of interest in coal, including hydrogen, oxygen and nitrogen, which are normally impossible to quantify when operating in ambient air atmosphere.
An automated software, specifically tailored for being used by non-specialist operators, provides the composition of coal with measurements performed directly on the moving conveyor belt. The LIBS prototype for coal analysis has been successfully tested in laboratory-simulated industrial environment. The system will be soon moved to an operating coal power plant for monitoring in real time the quality of the combustible.



The laser spark in LIBS measurements.

ALS Lab
Applied and Laser Spectroscopy

With regards to enterprises...

This activity is performed in the framework of the research contract between ENEL S.p.a. and the Laboratory of Applied and Laser Spectroscopy of ICCOM-CNR for the On-line analysis of coal in electrical power plants.

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G. Lorenzetti *E. Grifoni*
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ICCOM - Pisa

Nonlinear time-resolved spectroscopy of surfaces and interfaces

TRL: 4

One of the natural phenomena that underpin modern society is surface physics and chemistry. Surface interactions determine how materials adhere to each other or may dramatically modify the physical properties of bulk materials. Recently, there has been growing interest in photoinduced processes at solid surfaces and interfaces for developing efficient solar energy conversion. For example, photoinduced charge transfer between adsorbates and semiconductor substrates at the surfaces of metal oxides induced by photogenerated holes and electrons is a core process in photovoltaics and photocatalysis. Understanding and control of surface interactions are then key to improve the functionality of surfaces and interfaces for achieving higher light-conversion efficiencies. Such processes often occur on ultrafast time-scales (femtoseconds). Therefore the use of optical probes that gather together surface specificity, high-temporal resolution and chemical selectivity is mandatory. In this respect processes that are nonlinear in the optical field add new potentialities to standard optical spectroscopy. For instance, by exploiting second-order processes (sum frequency generation and difference frequency generation) surface and interface may be investigated with vertical sub-nanometer resolution or single-cycle THz pulses, that couple to low-energy molecular excitations, may be generated. By combining in a pump-probe scheme both these techniques, it is possible to set up an invaluable investigation tool with unprecedented temporal, interfacial and chemical resolving power.

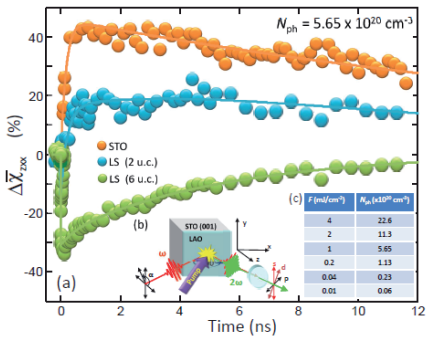

Fig1. Pump-probe surface second harmonic generation.

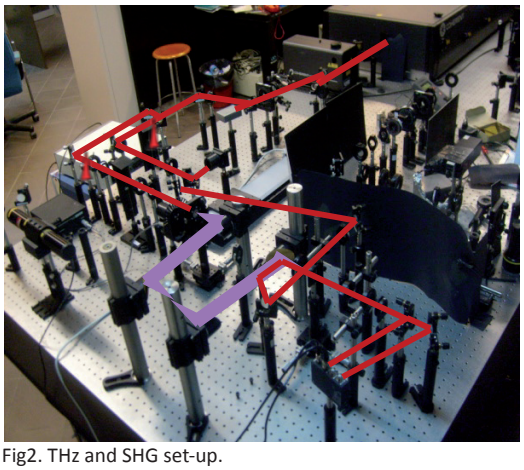

Fig2. THz and SHG set-up.

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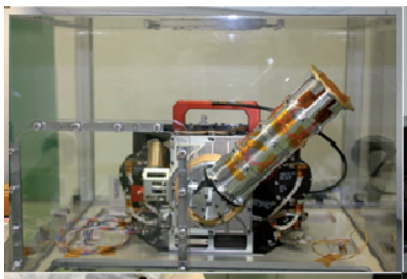
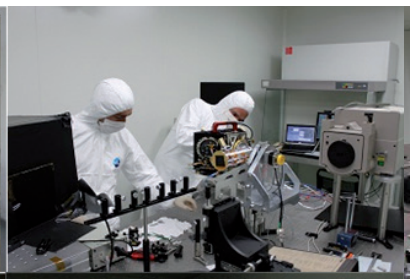
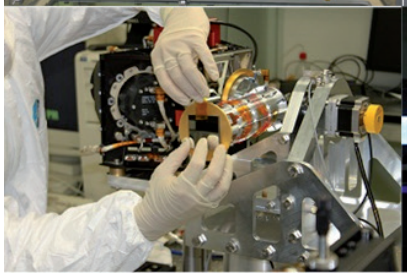
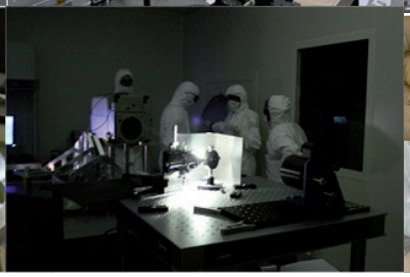
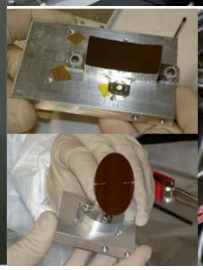
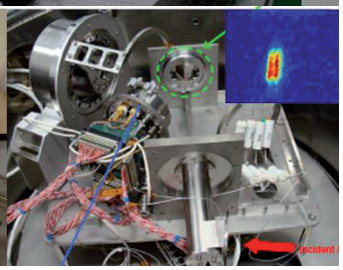
Space instrumentation

TRL: 3

The space exploration plans of the European Space Agency include new ambitious space missions which foresee the participation also of the Italian Space Agency. The BepiColombo mission will explore the Mercury planet and its environment. Solar Orbiter will be the closest mission to the Sun. CNR-IFN is involved with the realization of some instruments on board of these two missions.

Cleanroom activities.

Thermo mechanical testing facility.

With regards to enterprises...
Industrial collaborations: Selex ES Firenze OHB Germany
Collaborations – PI ships:
INAF Oato, INAF Oapd, CNES and CNRS Latmos, France

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IFN - Padova

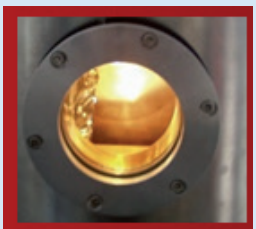
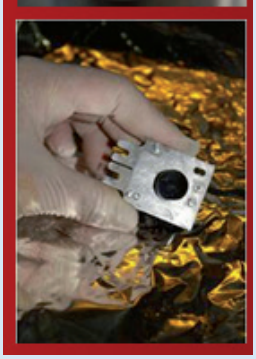
Optical components for space

TRL: 3

Space exploration is linked to the development of increasingly innovative instrumentation, able to withstand the operation environment. In particular, new missions foresee solar probes approaching the Sun as never before thus operating in a harsh environment, rich of ion particles and characterized by high temperature, or investigating planets operating in the close Jupiter and its satellites environment. Optical coating are key element in order to manipulate the radiation, both in spectral as well as in imaging systems. Beside having the required optical properties, novel optical coatings need to withstand the new space frontiers environments. Selection of best materials, capable to withstand the harsh space environment and/or to protect the structure underneath and realization of optimized and characterized prototype components is mandatory.
CNR-IFN Padova has the following capabilities:

- Deposition by e-beam evaporator and RF magnetron sputtering
- Optical characterization in EUV, VUV, UV, Visible and NIR spectral ranges
- Study of morphology of the surface by AFM and profilometry
- Interferomentric testing

Devices can be characterized and manipulated in cleanroom ISO6.

Cleanroom at CNR-IFN Padova.

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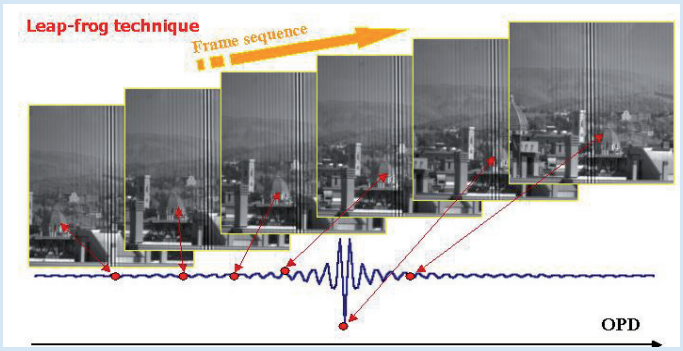
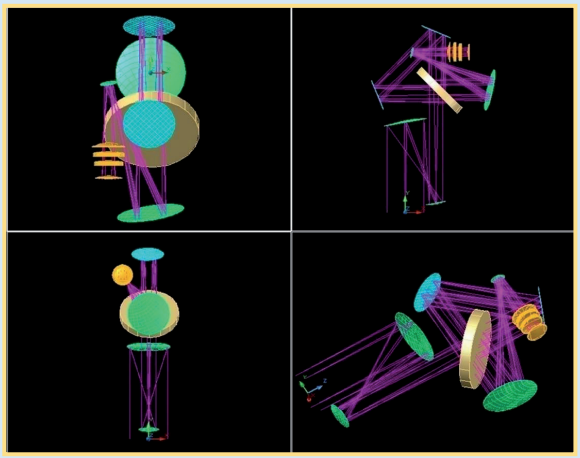
Image interferometer for aerospace platforms

TRL: 4

The stationary image interferometer ALISEO (Aerospace Leap-frog Imaging Stationary Interferometer for Earth Observation) - in-house developed at IFAC - is distinctive for its "leap-frog" configuration, in which the image of the observed scene is modulated by an optical path difference (OPD). In this configuration, each point of the scene is seen with different phase delays and the interferogram of each point is reconstructed through the acquisition of a temporal sequence of images. With respect to a push-broom configuration, this method offers the advantage of providing an image for each acquisition, although it requires a more complex data processing for the reconstruction of the interferogram.



Working principle of the ALISEO interferometer.



Optical design of the ALISEO demonstrator.

The applications are typically those related to Earth Observation (environmental monitoring, natural resources, catastrophic events, etc..).

With regards to enterprises...

The demonstrator has been developed within the MIOSAT program of the Italian Space Agency.

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IFAC - Sesto Fiorentino

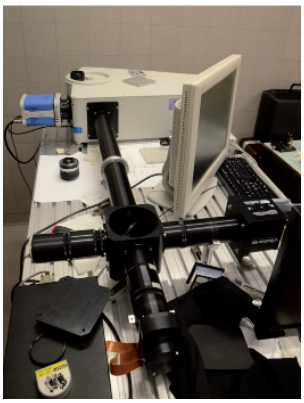
Compressive sampling technology for aerospace systems

TRL: 3

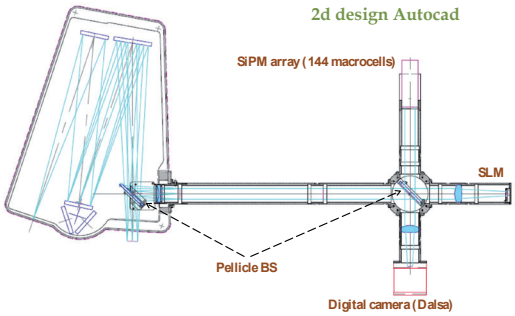
According to recent studies, the acquisition of a signal can be also performed at sampling rates much lower than the minimum frequency dictated by the Shannon's theorem: this concept is known as "compressive sampling" (CS). This technique can be applied to signals which show some correlation, that is they are sparse in some domain. The CS technique may offer many advantages for Earth Observation from aerospace platforms in order to obtain a high spectral/spatial resolution data even using a reduced number of detection elements, memory capacity and down-link bandwidth. For this purpose, a demonstrator has been implemented in the laboratory to assess the feasibility of the CS for Earth Observation and to investigate the main critical issues for the development of this technology. The demonstrator operates in push-broom configuration according to a scheme of direct modulation obtained with a 2D-array of mirrors or crystals or LCD controlled by electric actuators. The data acquisition - carried out using a single sensitive element - is repeated for different modulating spatial patterns; the image is then reconstructed by applying a suitable algorithm that takes advantage of the sparseness of the signal.

With regards to enterprises...

The demonstrator has been developed within an ITB project of the European Space Agency.



Experimental set-up for the CS demonstrator.



Optical design of the CS demonstrator.

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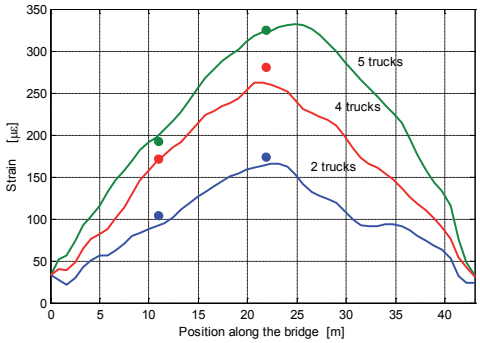
IFAC - Sesto Fiorentino (FI)

Distributed fiber optic sensors for safety and security

TRL: 7

Distributed fiber optic sensors, differently from standard point sensors, are able to continuously measure a parameter (e.g. strain, temperature,..) over kilometre distances with spatial resolution lower than 1m. In these sensors the sensing element is a standard telecommunication fiber. These measurements allow the values of the measurand of interest to be extracted, as a function of position, along the length of the sensing fiber. Distributed sensors are particularly attractive for use in applications where monitoring of the measurand is required at a large number of points or continuously over the path of the fiber. These sensors could be used for a wide range of applications starting from structural health monitoring of large infrastructures (Dams, bridges, highways, railways, and pipeline) to environmental monitoring.

In the last years we have developed distributed sensors based on stimulated Brillouin scattering and other optical scattering mechanism. These sensors have been applied to monitoring bridges, railways, pipeline deformations and leakeages. Distributed temperature measurements have been performed for geothermal applications and volcanic area monitoring. These sensors have been also used in aeronautical applications.



Distributed strain measurement along a bridge for different load conditions .

Brillouin distributed sensor prototype.

With regards to enterprises...

On this activity we have national and european project with Tecno-in, Alenia, Zodiac Aerospace. We have two patent IT n.0001398184, n. US20080013096 A1

We can offer: Design and application of distributed fiber sensors.

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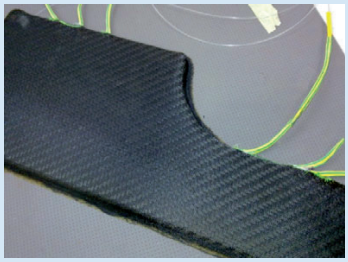
IREA - Napoli

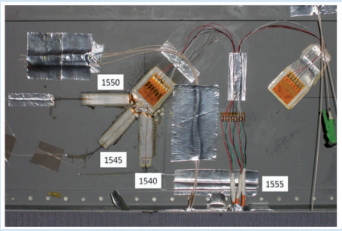
Fiber optic sensors for aerospace

TRL: 5 - 6

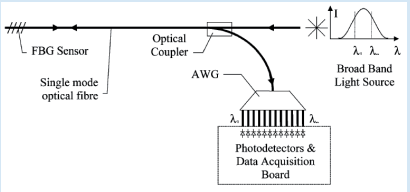
Fiber Bragg Gratings (FBGs), originally designed for the 'telecom revolution', have become a key enabling technology for the measurement of strain, vibration, acoustics, acceleration, pressure, temperature, moisture, and corrosion. It has gained rapid acceptance in civil, aerospace, chemical and petrochemical, medicine, aviation and automotive industries. The most prominent advantages of FBGs are: small size and light weight, distributed array of FBG transducers on a single fiber, and immunity to electro-magnetic interference. But their biggest benefit is the possibility to be easily attached to a surface or embedded in a component, to provide information on the state of an object under scrutiny. The process of implementing the damage detection and characterization strategy for engineering structures is referred to as Structural Health Management (SHM). The SHM process involves the observation of a system over time using periodically sampled dynamic response measurements from an array of sensors. FBG sensors are the most suitable platform for the SHM of aircraft structures because they can be embedded in composite materials during their manufacturing with no effect on their strength. In our labs we design, realize and test sensing set-up based on FBG sensors, and high speed interrogators based on Planar Lightwave Circuit (PLC) technology, where an Arrayed Waveguide Grating (AWG) acts as solid state spectrometer.



Carbon fiber composite panel with the embedded FBG sensor.



FBG sensors attached to the fuselage of an aircraft.



Functional block diagram of the FBG-AWG measurement system.

With regards to enterprises...

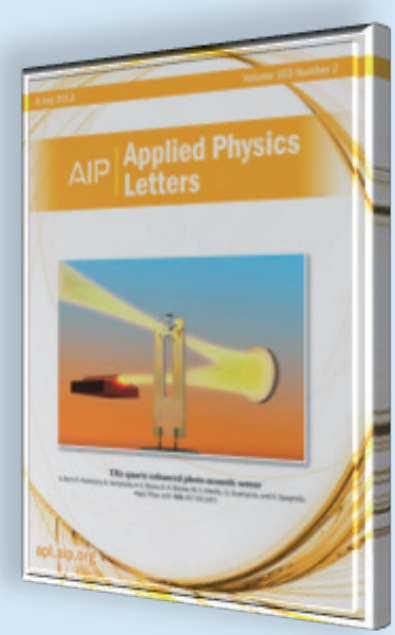
Activities carried out in cooperation with Alenia Aermacchi, Airbus, DEMA, Magnaghi, Telespazio and CGS, in the framework of several regional, national and European research project and Distretto Aerospaziale Campano (DAC).

We can offer: full design support, simulation, prototype interrogator fabrication, ground and flight test campaign support.

Contact:
Mario Iodice (mario.iodice@cnr.it) IMM - Napoli
Authors: M. Iodice, M. Indolfi, G. Coppola, I. Rendina

TRL: 4

Quartz enhanced photoacoustic gas sensors

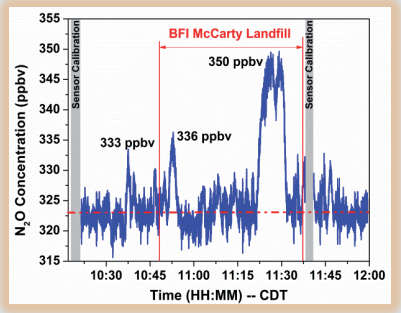


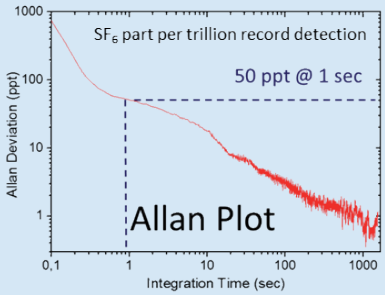
Quartz-enhanced photo-acoustic spectroscopy (QEPAS) is a robust and sensitive trace-gas detection technique, capable of record sensitivities with a compact and relatively low-cost acoustic detection module. The key innovation of this method is to invert the common photoacoustic approach and accumulate the acoustic energy in a sharply resonant quartz tuning fork with a very high quality factor, which acts as a piezoelectric acoustic transducer.

We have developed the first mid-IR fiber-coupled QEPAS sensor, the first intracavity QEPAS sensor and the first terahertz QEPAS sensor, all working with quantum cascade laser sources.

High sensitivity detection of several type of gas species, such as nitric oxide, nitric dioxide, methane, sulphur hexafluoride, methanol, hydrazine, etc., with record detection limit down to few tens of part per trillions (ppt) has been demonstrated.

QEPAS Sensor for N2O in a mobile laboratory.





With regards to enterprises...

We can offer:

- Development of gas sensor prototypes
- Development of leak detectors
- Design of custom quartz tuning fork transducers.

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Miriam S. Vitiello (miriam.vitiello@sns.it) NANO – Pisa

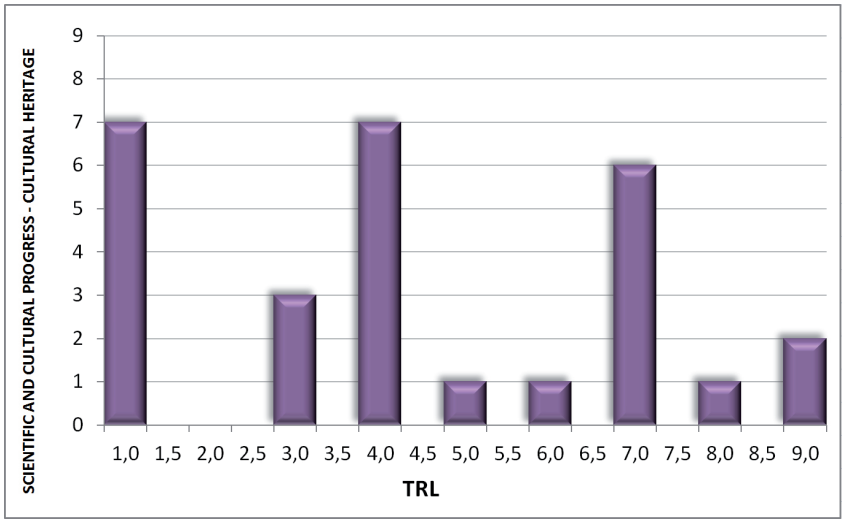
Scientific & Cultural Progress
Cultural Heritage

Lasers are important tools in several research fields. They are key elements at the forefront of scientific investigations of nature and have also found many applications in the preservation and analysis of cultural heritage. Here we present an overview of research topics currently being pursued at CNR in these two fields.

Ultrafast optics is an important topic in Photonics. The development of increasingly reliable and performing ultrafast lasers has recently boosted the field, enabling the introduction of ultra-sophisticated tools to probe the most basic mechanisms of nature. Advanced time and frequency resolved spectroscopy has allowed the analysis of the early stage of the mechanism of vision and the detection of gas molecules with ppb sensitivity. By exploiting high harmonic generation in noble gases, femtosecond lasers have opened the world of attosecond science. With the development of sophisticated technologies for handling these very energetic photons, molecular dynamics on attosecond timescales have been recorded with XUV radiation, allowing the reconstruction of images of the molecular orbital. This also required the development of sophisticated technologies for handling these very energetic photons. The unique interaction processes of ultrashort pulses with transparent materials can also be exploited to directly inscribe optical circuits in glass for integrated quantum optics experiments.

Photonics have a wealth of applications also in the Conservation and Analysis of Cultural Heritage; groups from CNR have developed new instrumentation, methods and strategies to address significant questions facing conservators, curators, archeologists, art historians and scientists. Novel instruments range from time-gated LIDAR devices for the analysis of stone and wall painting to hyperspectral imaging systems for probing the colour and underdrawings in paintings using remarkably high spectral and spatial resolution. Other expertise has focused on applications of time-resolved fluorescence imaging of cultural heritage. Portable spectroscopic devices employ laser-ablation for the creation of a plasma, analysed to determine the composition of artifacts, which is particularly useful for multi-layered alloys. Both spectral databases and new calibration-free methods have been developed for data analysis. Photonics has also been exploited to aid the cleaning of works of art, relying on the generation and optimization of laser pulse duration, aiding the removal of unwanted materials from paintings, plaster and sensitive metals surfaces.

number of contributions in this section

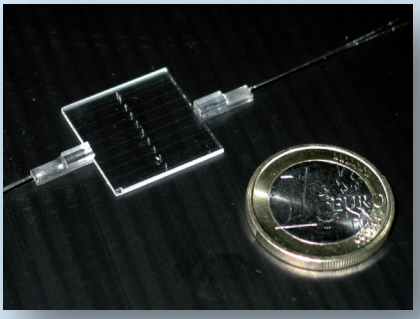


Integrated quantum photonics

TRL: 4

The emerging strategy to overcome the limitations of bulk quantum optics experiments consists of taking advantage of the robustness and compactness of the integrated waveguide technology. Indeed, high-quality quantum photonic circuits can be conveniently realized by femtosecond laser waveguide writing, exploiting the unique features of this fabrication technique.
Its three-dimensional capabilities empower the design of devices and circuit configurations with novel functionalities and enhanced compactness. Further, this direct writing technique enable to produce with low cost and rapid turnaround many different designs, easing the experimental testing of new ideas.
Several applications have been addressed up to now, ranging from quantum computing to quantum simulation and quantum metrology. Circuits integrating up to tens of optical components in a single chip have been realized, including an integrated quantum CNOT gate for polarization encoded qubits, multi-port interferometers employed in multi-photon quantum simulation experiments, optofluidic chips for quantum interferometry on biological samples.

Pictorial image of a three-dimensional waveguide circuit employed for a quantum simulation experiment.



Optofluidic chip for quantum interferometry on biological samples.

With regards to enterprises...

Two Italian patents are pending (n°PD2011A000140 and n° MI2013A000631) on technologies devised within this activity, related respectively to an integrated quantum logic gate and to waveguide-integrated polarization rotators. In the frame of a FP7/CP-STREP European project (QWAD - Quantum Waveguides Application and Development), we are also collaborating with qutools GmbH (Munich, Germany).

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SCIENTIFIC & CULTURAL PROGRESS
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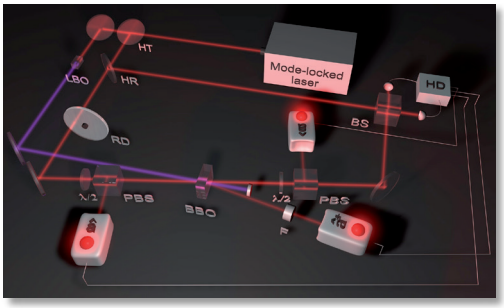
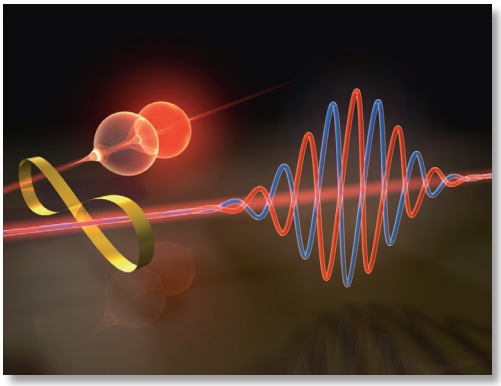
Advanced engineering of quantum light states and processes

TRL: 1 -3

Light is the perfect tool for exploring the foundations of quantum physics, and its quantum properties can be exploited for novel technologies that promise enhanced computational power, measurement precision and sensitivity, and information security.
In recent years, our group at INO-CNR has developed many new tools for generating light with tailor-made quantum characteristics, manipulating it with arbitrary quantum operations, and, finally, analyzing it with advanced quantum tomographic techniques. Single photons with arbitrary temporal and spectral shapes can be efficiently produced and detected, and basic quantum operations, like the addition and subtraction of single photons and their sequences and superpositions, can now be experimentally implemented in our lab with high fidelities.
Recent achievements include the realization of a noiseless amplifier for quantum light states, and the production of a new kind of hybrid quantum-classical entanglement that is the small-scale optical equivalent of the Schrödinger's cat case.
These unique capabilities are allowing us to perform world-class experiments on the foundations of quantum mechanics and provide an advanced and versatile toolbox for the development of emerging quantum technologies.



Testing quantum commutation rules in the lab.



Hybrid entanglement between a single photon and a classical light pulse.

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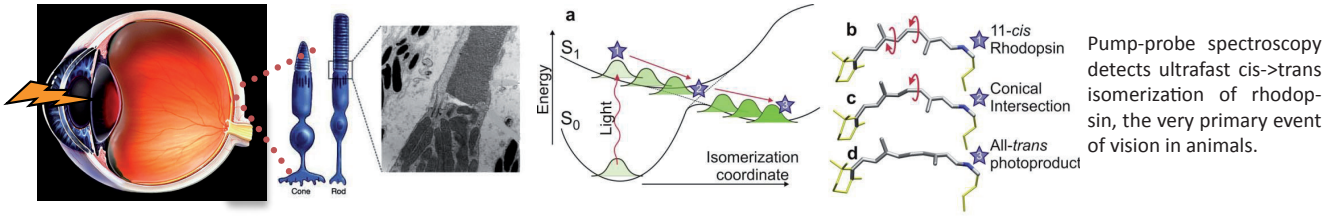
Femtosecond pulse generartion and ultrafast spectroscopy

TRL: 1

Many fundamental events in Nature, such as sunlight harvesting in leaf cells, light detection by cones and rods in retina, photoprotection mechanisms in DNA structures and biochemical reactions, occur on ultrafast time scales. These processes can nowadays be observed thanks to techniques such as time-resolved spectroscopy with ultrashort light pulses. Here, a short light pulse resonantly photoexcites a system; similarly to light flashes in photography, the following events are then probed by a second light pulse: the frames freezed by sequences of the probing pulses allow to reconstruct the evolution of the system. The resolution of time-resolved spectroscopy is given by the duration of the light pulses.

Ultrafast events can be freezed by shining ultrashort flashes of light.

Our main activity is the manipulation of laser light by linear and nonlinear optical processes to generate and characterize ultrashort pulses for spectroscopy; the request of high time resolution constantly pushes our pioneering research beyond the frontiers of light manipulation. The tunability of our laser pulses currently ranges from 0.25 to 3 microns wavelength; pulses as short as 5 fs allow extreme-temporal-resolution spectroscopy on organic and inorganic systems, including rhodopsin in retinal rods, carotenoids in leaf cells, and carbon nanotubes and graphene. The study of these fundamental mechanisms allows not only to get insight into fascinating biological processes, but also inspires the design of devices for light harvesting and ultrafast optoelectronics.



Pump-probe spectroscopy detects ultrafast cis->trans isomerization of rhodopsin, the very primary event of vision in animals.

With regards to enterprises...

Collaboration with companies for the development of devices for laser light manipulation.
Patents in UE (13168800.4-1562) and USA (13/490862) have been submitted.

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Femtosecond laser surface structuring with optical vortex beams

TRL: 4

Creation of patterns/structures on surfaces at micro- and nano-scale has many potential applications (e.g. in material processing, tailoring of optical properties, THz optics). Many patterns are obtained using direct laser structuring through femtosecond (fs) laser ablation, with Gaussian-like intensity of the beam spatial profile.

Recently, non-Gaussian laser beams are emerging as interesting candidates for strategic tailoring in material processing. We propose fs laser structuring using optical vortex (OV) beams. The OV is generated by a q-plate that allows producing beams carrying orbital angular momentum (OAM). Experimental findings show that fs OV beams can be exploited to fabricate interesting morphologies at micro- and nano-scales on semiconductors (silicon) and metals, suggesting the possibility of using an appropriate selection of polarization states and q-plate charges to obtain different surface micro- and nano-structures. Moreover, fs laser structuring is also useful to analyze distribution of focal intensity and polarization of unconventional laser beams.

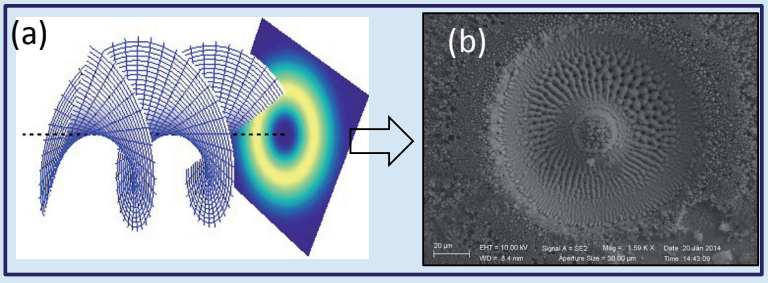

Fig. 1. (a) OV beam and corresponding annular spot on a target; (b) Example of the structure formed on a Si(100) surface for an azimuthally polarized OV beam. Interestingly, ripples normal to the local laser polarization forms in the annular beam region, and a micro-needle at the laser spot center, corresponding to the central singular region of the OV with nearly zero intensity, with a cauliflower-like NPs-assembled structure on the top.

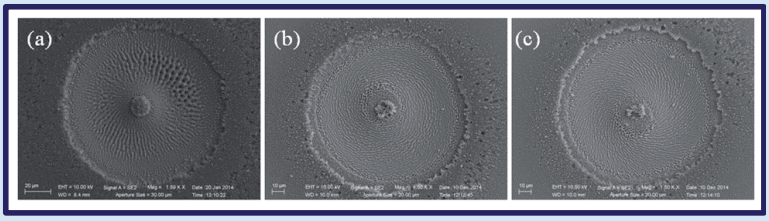

Fig. 2. Examples of SEM micrographs of Si surface for various laser polarizations: (a) Azimuthal (radial ripples); (b) Radial (azimuthal ripples) and (c) intermediate (spiral ripples).

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Pulsed laser ablation and deposition with ultrashort pulses for nanoparticles and nanoparticles-assembled films fabrication

TRL: 4

Direct ejection of nanoparticles (NP) is a striking feature of laser ablation with ultrashort laser pulses (ULA). Typically, NP constitute the major part of the material blowoff and ULA is a promising prospective physical technique for preparation of NPs and NPs-assembled (NPA) media, in controlled ambient conditions. We pursue ULA for deposition of NPA films of metals, semiconductors, oxides, etc. These NPA films show interesting physical properties related to their peculiar nanostructure, with Interesting examples observed in case of magnetic and optical properties of metals, wide bandgap semiconductors, transition metal oxides, etc. For example, striking features are observed in: i) iron NPA with peculiar magnetic response (see Fig. 1); ii) CdS and ZnS NPA film for photovoltaics (see Fig. 2); iii) TiO_2 NPA decorated with CdS NP for hydrogen production from water splitting.

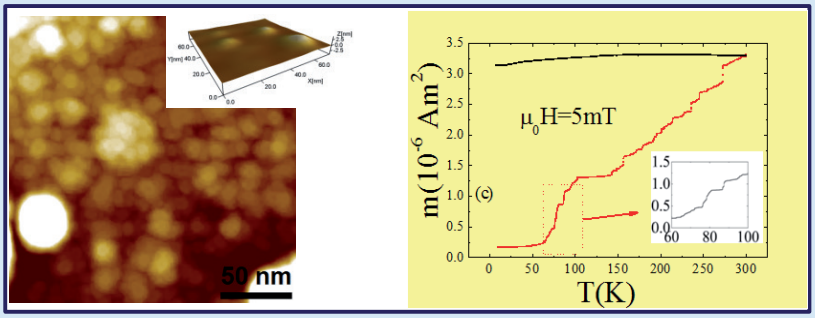

Fig. 1. Iron NPA dense films show an unusual stepwise behavior in the temperature dependence of the zero field cooled (ZFC) magnetization due to the This behavior, induced by the peculiar particle system's morphology, is due to the competition between Zeeman energy density, intracluster anisotropy energy density and intercluster exchange energy density.

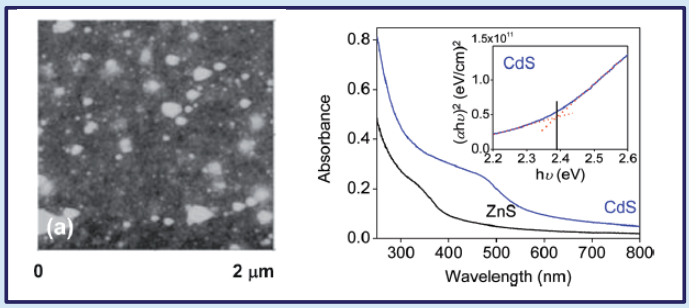

Fig. 2. (a) AFM image of a CdS NPA film; (b) absorbance spectra of CdS and ZnS NPA films.

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Ultrafast molecular imaging

TRL: 1

The physical and chemical properties of molecules are mostly determined by the outermost electronic structure, that is usually represented by a molecular orbital. The ability of directly imaging this orbital and following the dynamics induced by an electronic or vibrational excitation would allow to understand how molecules interact with the surrounding environment. This direct imaging can be achieved exploiting the interaction between very short laser pulses and the molecule itself.

When molecules are ionized by an intense femtosecond (1 femtosecond = 10^{-15} sec) laser pulse, the freed electron is accelerated in the external driving electric field and, because of the periodic oscillation of this field, is brought back to the parent ion, where it can recombine and give rise to the emission of XUV radiation.

This radiation has been shown to contain information on the electronic structure of the molecule, which can be interpreted as a projection of the molecular orbital. From the combination of several projections it is possible to reconstruct a picture of the molecular orbital in the same way as in tomographic imaging.

The activity at IFN aims to the development of time-resolved molecular orbital tomography for real-time imaging of evolving electronic structure in complex molecules.

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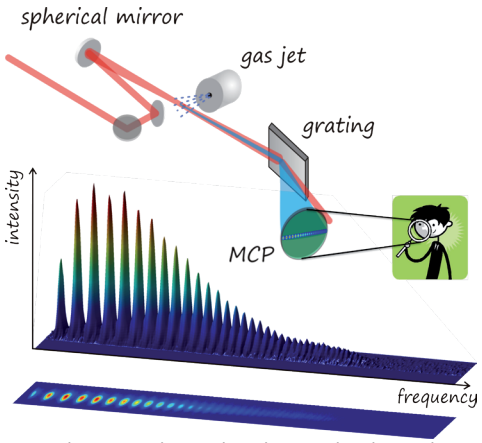
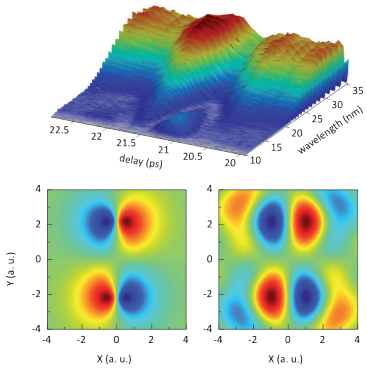


XUV radiation can be produced in a molecular gas by an intense and ultrashort laser pulse.



XUV Molecular Tomography captures an image of the CO_2 molecular orbital through the generation of XUV radiation.

Photon handling in the extreme-ultraviolet and soft X-rays

TRL: 8

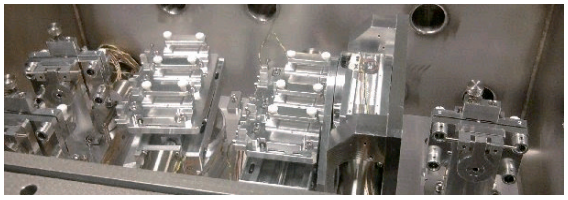
Extreme-ultraviolet (XUV) and X-Ray photons have been used for many fundamental discoveries and outstanding applications in basic science and medical diagnostics, as well as in industrial research and development. The most spectacular advance in the XUV and X-ray techniques since the last 40 years concerns on one side the brilliance of the radiation sources, that has been increased by more than 15 orders of magnitude thanks to the progresses in synchrotron and free-electron-lasers light technology, on the other side the duration of the light pulses, that has been decreased down to the attosecond (10-18 s) regime thanks to the progress in the ultrafast laser technology and through high-order laser harmonics generation. The handling of photon beams with such high peak intensity and short duration requires a multidisciplinary approach, which includes capabilities on the optical and mechanical design, optical properties of materials, vacuum technologies. The requirements on photon handling includes, e.g., beam transport, monochromatization, focusing, temporal stretching, measurement of spectrum and intensity.

CNR-IFN Padova has the following capabilities on photon handling instrumentation:

- beamlines for ultrashort XUV pulses (high-order laser harmonics);
- spectrometers and monochromators for ultrashort pulses;
- XUV beam stretchers;
- instrumentation for free-electron lasers.

Attosecond beamline (POLIMI, Italy).

Spectrometer for free-electron laser (FLASH, Hamburg).



Monochromator for ultrafast pulses (UNING, Slovenia).

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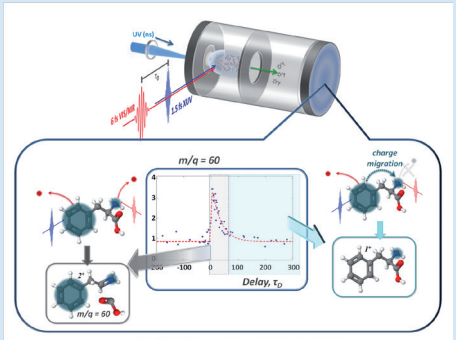
Attosecond physics

TRL: 1

Electron motion in matter occurs on a temporal scale of a few hundreds of attoseconds (1 attosecond = 10-18 s) , a time scale shorter then an optical period of the visible light. Attosecond science is nowadays a well-established research field and several techniques based on the use of attosecond pulses have been developed to investigate and control the electron dynamics initiated by photo-ionization in atoms, molecules and condensed matter.

Experimental setup for attosecond pulse generation.

Attosecond pulses are produced in the XUV spectral region by using an extremely non-linear process named high-order harmonic generation (HHG). Recently, it has been theoretically demonstrated that, after sudden removal of an electron from a biomolecule, charge migration along the molecular backbone can occur in a time scale of few hundreds attoseconds. This ultrafast charge dynamics precedes subsequent structural changing potentially leading to damage. XUV attosecond pulses are a powerful tool to track and control the charge migration process.



First experimental demonstration of charge migration in an amino acid using XUV attosecond pulses.

The activity at IFN aims to the development of state-of-the-art attosecond sources for the study of electron dynamics occurring in complex systems. Recently, we have obtained the first experimental demonstration of sub-3fs charge dynamics in the aminoacid Phenylalanine.

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Intracellular optical nanosensing

TRL: 3

The advent of optical nanoprobes for the quantitative determination of bioanalytes at the intracellular level is one of the most fascinating achievements in the field of nanoparticle and nanomaterial technology. Among this, oligonucleotide optical switches can work not only as nanoprobes but also as drugs capable to address specific RNA messengers thus preventing the overexpression of proteins associated with pathologic diseases. We focused our research on the use of carbon nanotubes (CNTs) and polymethylmethacrylate (PMMA) nanoparticles as intracellular nanocarriers for molecular beacons (MBs), selected fluorescent DNA probes as well as for the detection and localization of specific mRNAs. Survivin mRNA targeting MBs have been used with Atto647N and Blackberry 650 as fluorophore/quencher pair. The MB was anchored to the surface of CNTs and PMMA nanoparticles and the as obtained nano-composites were characterized in vitro.

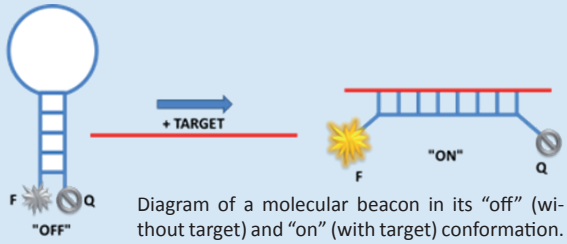
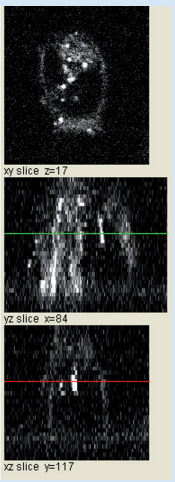
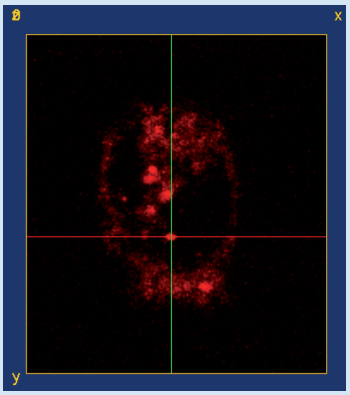
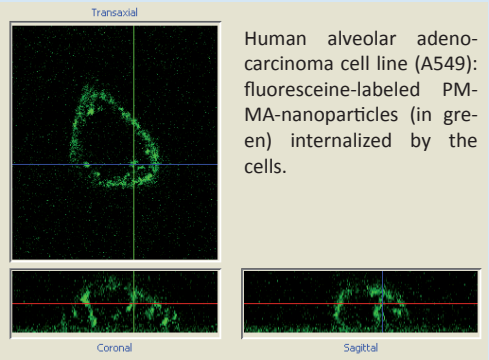


Diagram of a molecular beacon in its "off" (without target) and "on" (with target) conformation.





Human alveolar adenocarcinoma cell line (A549): molecular beacon (in red) delivered into the cells by using PMMA nanoparticles as intracellular carrier.



Human alveolar adenocarcinoma cell line (A549): fluoresceine-labeled PMMA-nanoparticles (in green) internalized by the cells.

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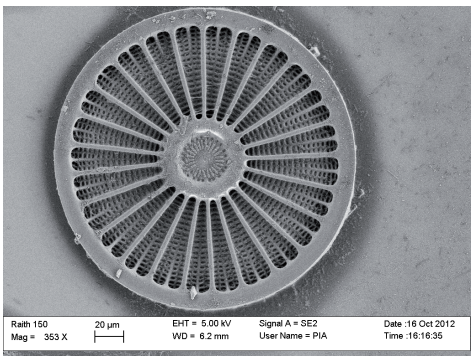
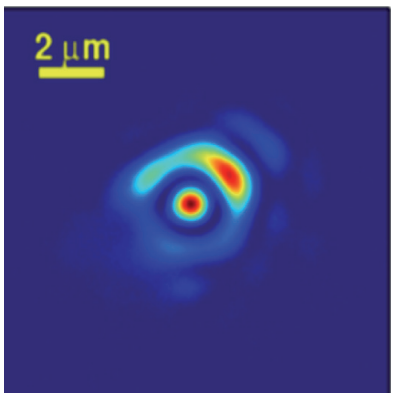
Photonic properties of diatoms

TRL: 4

Diatoms are ubiquitous, monocellular algae whose protoplasm is enclosed in a shell called frustule, made of hydrated amorphous porous silica. Being responsible of about 20-25% of the global oxygen produced by means of photosynthesis, but living in environments where sunlight is not easily accessible, it follows that they have been probably modelled by evolution in order to exploit at maximum light collection. We are indeed focused on the optical properties of the various components of diatoms, which, for the quasi-periodic dislocation of the pores all over the frustule, have been defined as "living photonic crystals". In particular we are studying a) the diffraction-driven collection of light in tiny spots by frustule valves, connected to chloroplasts relocation at different sunlight conditions; b) the dependence of this effect by wavelength; c) its conjunction with structured-light techniques for sub-diffraction light confinement; d) photoluminescence of frustules for sensing application; e) nanostructured frustules as substrate for plasmonics and SERS. In general, the aim of this activity is both to understand the biological meaning of the optical properties of diatoms and to exploit these properties in the design and fabrication of bio-inspired photonic devices.



SEM image of the inner plate of a *Arachnoidiscus* diatom valve.



Light-spot collected by a single diatom valve. The conjunction with optical eigenmodes technique guarantees sub-diffraction confinement of light.

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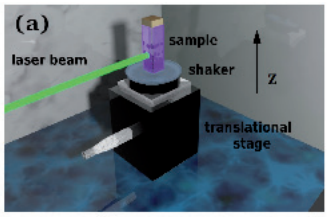
Authors: E. De Tommasi, L. De Stefano, P. Dardano, A. Ferrara, L. Lavanga, I. Rendina

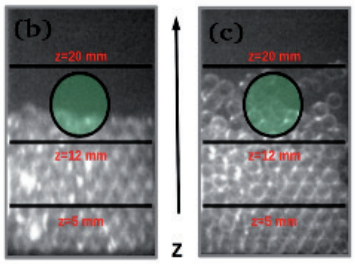
Random lasers: from macro to nano scales

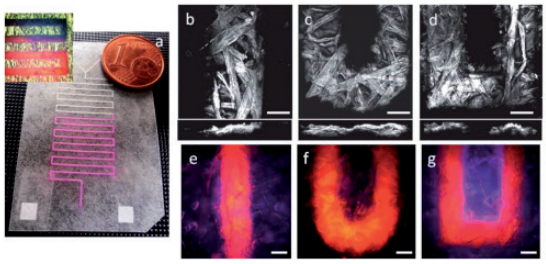
TRL: 1

The growing demand for innovative optical and photonic applications is motivating research towards the realization of components with photonic properties strictly dependent on the structure of the materials used. The manipulation of the materials gives a wide variety of tunable photonic devices. Here we report on different novel types of lasing systems without the presence of any optical cavity. We focus on a particular class of lasers, namely Random Lasers (RLs). RL consists of a random assembly of scattering structures dispersed into an optical gain medium in which the optical cavity is merely represented by multiple scattering processes of light. We realize a large variety of RLs where light is confined at length scales ranging from millimeter to nanometer.
1) We consider a lasing gravity-affected granular system, composed of dielectric grains with millimeter size, where the mechanical motion of the material dramatically affects the RL emission. 2) We realize devices from paper flexible sheets by creating on the cellulose fibers micro- fluidic porous channels in which a fluorescent dye can flow by capillarity. We show how the emission properties depend crucially on the width, shape and curvature of the microchannels as well as on their functionalization with colloidal additives. 3) We demonstrate the RL emission from scattering nano-aggregates of a thiophene oligomer, obtained in a controlled way by a simple soft lithographic technique. We obtain organic mini-lasers of different shapes and importantly we are able to tailor the structure of the random lasers at the nanoscale by finely tuning the supramolecular self assembly of the organic dye.



Shaken granular random laser.





Paper microchannels used for random lasing.

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Claudio Conti (claudio.conti@cnr.it), ISC - Sapienza

Frequency comb spectroscopy for trace gas sensing

TRL: 3 - 5

Frequency combs are a revolutionary radiation source made up of thousands of evenly spaced optical frequencies that act as a manifold of phase coherent cw lasers. They can be used to probe the absorption features of multiple molecular species with an unprecedented combination of sensitivity, speed and spectral resolution. The CNR-IFN in Lecco and Milano has developed such technology for applications to:
Gas sensing with part-per-billion sensitivity by comb-assisted cavity-enhanced spectroscopy in the near- and mid-infrared region;
Accurate determination of absorption profiles and spectroscopic parameters via absolute frequency calibrated measurements ;
Detection and identification of multiple molecular species in human breath as a non-invasive diagnostic tool of various kinds of diseases (activity under development).

With regards to enterprises...

We collaborate with IMRA America Inc. in the framework of NH3 comb-assisted spectroscopy. The results of this collaboration are two pending patents (n°PCT/US2013033989 and n° US61846459) related to precision optical frequency synthesis for molecular detection and cavity enhanced spectroscopy.

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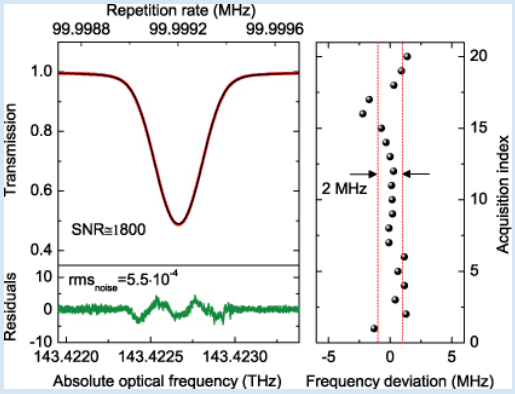
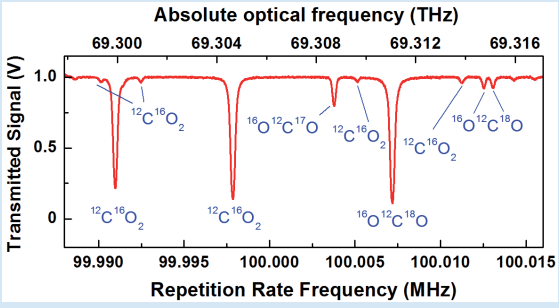


Averaging over several measurements allows for the retrieving of spectroscopical parameters with ultra high-resolution.



Several absorption lines of a CO_2 gas sample are simultaneously acquired in the mid-IR with high-resolution and calibrated frequency axis.

Shock waves in disordered media

TRL: 1

We study the formation of dispersive shock waves (DSWs) by the direct visualization of a laser beam propagating into two different random nonlinear media: i) aqueous solutions of rhodamineB (RhB) and ii) silica aerogels (SA). Both the samples present de-focusing nonlinearity of thermal origin due to the light absorption and temperature dependent refractive index. We investigate the liquid system by imaging both the fluorescence emission from the top of the samples (upper panels of Fig. 1) and the transmitted light at the exit of the samples (bottom panels of Fig. 1); we show that the disorder increase hampers shock waves formation, up to its total inhibition. Such a transition has been quantitatively characterized and results into the first measurements of the phase-diagram in terms of disorder and nonlinearity, obtained by evaluating the point of shock formation and the angular aperture of the far field measurements. Similar analysis was carried out also on the light transmitted at the exit of SA samples (Fig.2), revealing the same phase transition behaviour.

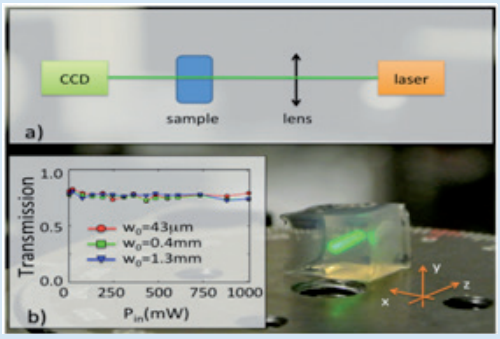


Figure 2. Picture of typical SA samples. (a) Sketch of the experimental setup. (b) Measured optical transmission vs laser input power obtained by impinging with different diameter laser beam.

N.Ghofraniha, S.Gentilini, V.Folli and C. Conti, Phys. Rev. Lett.109, 243902 (2012)

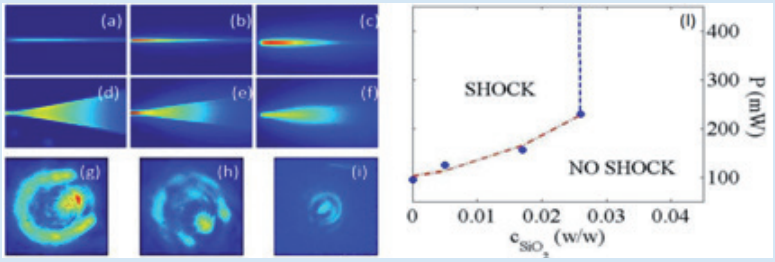


Figure 1. (a-f) Top view of the fluorescence emission from RhB samples of the laser beam for different power and disorder degree. (g-i) Images of the transmitted laser intensity for different disorder degree and fixed input power. (l) Disorder-power phase diagram of shock – noshock regimes as obtained analysing the shock point from the panels (a-f).

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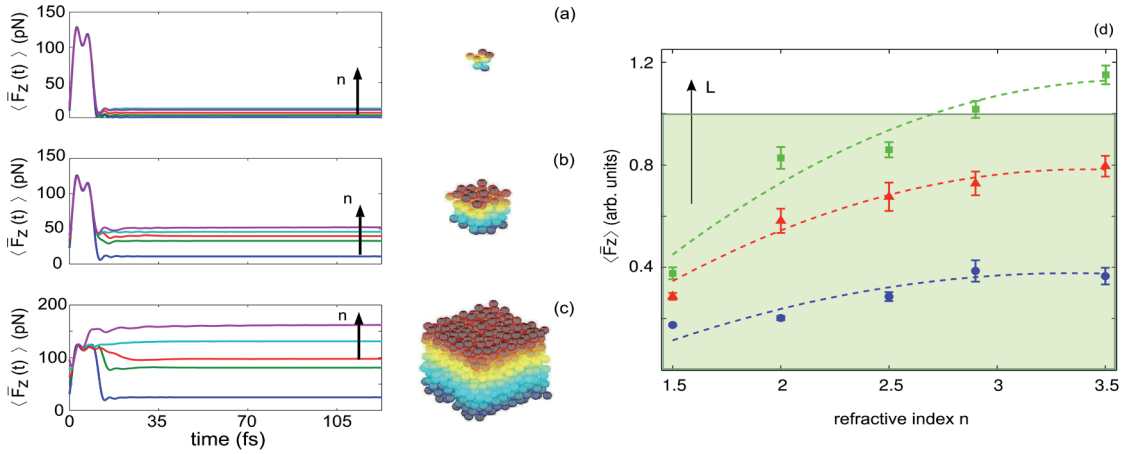
Optomechanics of random media

TRL: 1

Using light to control the movement of nano-structured objects is a great challenge. This challenge involves fields like optical tweezing, Casimir forces, integrated optics, bio-physics, and many others. However, when the complexity of the light-activated devices increases, disorder unavoidably occurs and induces a number of effects as multiple-scattering, diffusion and localization of light. We show that these effects radically enhance the mechanical effect of light. We theoretically determine the link between optical pressure and the light diffusion coefficient, and unveil that optical forces and their statistical fluctuations reach a maximum at the onset of the Anderson localization of light. Disorder may be hence exploited for increasing the mechanical action of light on complex objects.



(a-c) Disorder averaged optomechanical force (OMF) for three different system sizes. Each curve corresponds to a different particle refractive index. The 3D structures represent the simulated system. (d) Stationary value of the curves reported in panels (a-c), normalized with respect to the homogeneous case vs the refractive index n. Each curve refers to a different size of the system. The coloured box marks the transition at which the OMF z-component is enhanced by the disorder.

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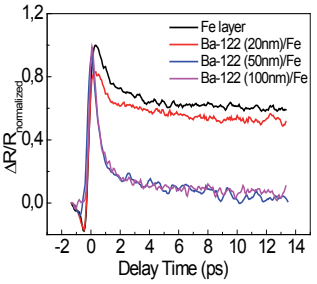
In Optical Spectroscopy of novel superconductors

TRL: 7

Optical Pump & Probe Technique

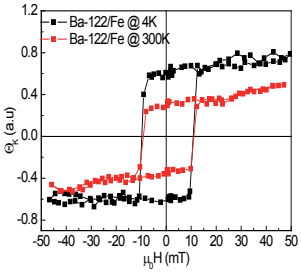
Time-resolved spectroscopy is considered an efficient and useful technique to study the nature of the electronic excitations in superconductors, and more recently also in Fe-pnictides. In a pump-probe experiment the system under study is suddenly brought out of equilibrium by a pump pulse, and, after a given time delay, the state of the system is measured by a probe pulse. This technique gives new and complementary information on the low-lying electronic structures, and potentially on the pseudogap, due to its capability to distinguish among scattering processes characterized by different relaxation dynamics. Femtosecond spectroscopy has been used to investigate the quasi-particle relaxation times in a nearly-optimally-doped pnictide superconductor $Ba(Fe_{1-x}Co_x)As_2$ (Ba-122) on a Fe buffer-layer grown on MgO substrate. The temperature dependence of quasi-particle recombination time in a superconducting state allows to estimate the temperature-dependent energy gap Δ(T) at T<Tc, and to investigate the presence of phase transition and pseudogap at T>Tc.



Photoinduced reflectivity vs delay time, at room temperature, for bilayer Ba-122/Fe changing the Ba-122 thickness: 20nm, 50nm and 100nm, compared with the Fe thin film 20nm thick.

Magneto-optical Kerr effect (MOKE) Technique

Magneto-optical Kerr effect (MOKE) method is a powerful technique to understand the local magnetic properties of thin films and nanostructured multylayers. MOKE technique utilizes the magneto-optical Kerr effect to detect the magnetization as a function of applied field. Hysteresis loop is obtained by detecting the rotation of the plane of polarization of the incident beam as a function of an external applied field. This technique is simple to implement, and can probe the magnetization in small regions of the thin film, unlike the conventional technique, e.g. vibrating sample magnetometer (VSM) and SQUID susceptometer. Investigation on the new class of superconductors, such as Fe-pnictides, have revealed a common phase diagram characterized by the existence of an antiferromagnetic spin density-wave (SDW) ground state as well as a strong antiferromagnetic (AFM) spin interactions. MOKE measurements could be carried out on this thin films, in the normal and superconducting state, to analyse the magnetic properties.



Hysteresis loop of Ba-122/Fe at 4K and 300K.

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Laser techniques for conservation of cultural heritage

TRL: 9

Significant contributions to the development and application of the laser treatments in conservation of cultural heritage have been made since the beginning of 1990's. Dedicated laser systems and suitable methodologies for addressing a variety of conservation problems have been developed, which have been validated on a number of unique masterpieces. A novel approach to the typical ablation problems encountered in the restoration of stone, metal, and painted artefacts has been demonstrated, which is based on the optimisation of the laser pulse duration. The laser prototypes developed according to this general criterion have been engineered and then marketed by El.En. S.p.A., Calenzano, Italy. At the same time, several conservation problems concerning important artworks have been successfully addressed, thus validating novel operative protocols and promoting the methodological transfer to institutional laboratories and restoration enterprises. Thus for examples of, successful applications were include the facades of the Palazzo Rucellai (Firenze) and Mausoleum of Theodoric (Ravenna), I. della Quercia's Fonte Gaia, Ghiberti's Porta del Paradiso, Porta Nord, and San Matteo, N. di Banco's Santi Quattro Coronati and Assunta, Donatello's Attis and David, the Arringatore, the wall paintings of S. Maria della Scala (Siena), Castello di Quart (Aosta), catacombs of Santa Tecla and Domitilla (Roma). Significant efforts have also been dedicated to the tutoring and dissemination activities.

Application examples of optimized laser treatments: a) plasterwork of the Loggia della Mercanzia (Siena); b) painted arcosolium in the cubicle "dei fornai", catacombs of Domitilla (Roma).

With regards to enterprises...

A laser system allowing to select the pulse duration between ~ 0.1-1 μm has been patented: "*Apparatus for the generation of variable duration laser pulses*", by R. Pini, R. Salimbeni, S. Siano (PCT/IT2001/000612, US6842474 B2). Related collaborations have been established with El.En. S.p.A, a number of restoration enterprises and conservation institutions.

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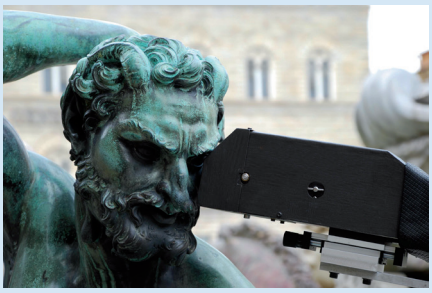
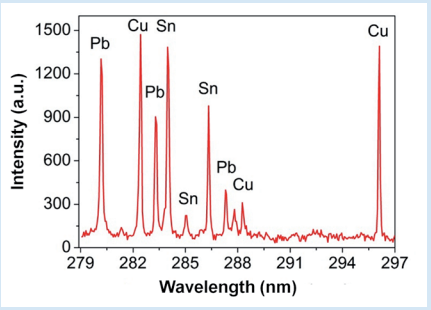
Portable laser induced plasma spectroscopy and authentication

TRL: 7

A novel compact Laser Induced Plasma Spectroscopy (LIPS)z device has been developed, which provides real time measurements of the elemental depth profiles of the outer material layers of any object, at a pulse repetition rate of 3 Hz. This analytical instrument has been carefully calibrated for characterizing copper, silver, and gold alloys and then used for investigating a variety of knowledge and conservation problems of metal artefacts of cultural interest. Important compositional studies have been carried out on unique masterpieces such as Donatello's David and Pulpito della Resurrezione, Rustici's Predica del Battista, Danti's Decollazione del Battista, the Arringatore from the Tasimene, the Chimera from Arezzo, and other. Furthermore, the device has been successfully used for the first time in authentication studies of metal artefacts through the development of a novel analytical methodology, which allows discriminating between natural alteration phenomenologies and fraudulent patinations. The technique, which is based on comparative analyses of elemental depth profiles, is being applied in an overall authentication study of small bronzes, jewels, and coins from Florence's National Museum of Archaeology and Egyptian Museum, which belong to the antiquary collections of the Houses of Medici and Lorraine. Recently, this approach has been used for authenticating the "Ombra della Sera" the famous bronze figurine of the Museum Guarnacci of Volterra. The present analytical tool has significant potential in material characterisations of industrial interest.





LIPS head (about 25x10 x 10cm) and a detail of a typical elemental spectrum of a copper alloy.

With regards to enterprises...

We are exploring potential collaborations with industrial partners. At the same time, the LIPS device is extensively used in characterisation services by conservation institutions and restoration enterprises.

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SCIENTIFIC & CULTURAL PROGRESS
CULTURAL HERITAGE

In situ LIBS analysis of cultural heritage

TRL: 9

The Applied and Laser Spectroscopy Laboratory has decades of experience in the development and application of laser techniques for in situ analysis of Cultural Heritage. The Laboratory is directed by Vincenzo Palleschi, Professor of Archeometry at Pisa University and Senior Researcher at CNR. The staff consists of six people: 2 researchers, 3 grants and a researcher associate. The team has experience in National and International projects, but the Laboratory also receives research contracts from the small and medium enterprises. The laboratory promoted and participated in research activities on the analysis of precious metals, bronzes, marble and stone of archaeological interest, the analysis of ink in manuscripts, the diagnostics of classical and contemporary frescoes and paintings. A proprietary method for spectra analysis, developed and patented by the Laboratory, allows for standard-less, stand-off Laser Induced Breakdown Spectroscopy (LIBS) measurements without need for reference materials which overcomes the matrix effect, one of the most important limiting factors on the feasibility and accuracy of quantitative LIBS measurements.

The Modì mobile instrument for LIBS analysis of Cultural Heritage.

LIBS analysis of archaeological objects (the Porticello philosopher head, roman silver coins).

With regards to enterprises...

The activity of the Laboratory is performed in close collaboration with Marwan Technology s.r.l., with whom the Modì istrument for in-situ LIBS analysis of Cultural Heritage has been developed and commercialized. The Laboratory also collaborates with Art-Test Pisa, a SME specialized in diagnostic services for Cultural Heritage.

ALS Lab
Applied and Laser Spectroscopy

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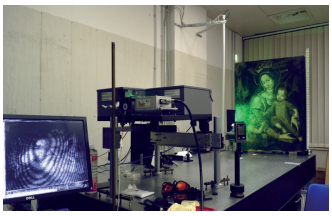
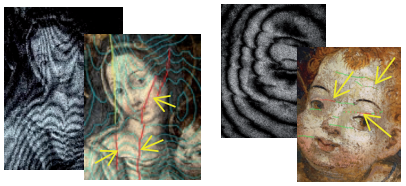
Electronic Speckle Pattern Interferometry for Cultural Heritage Diagnostics

TRL: 4

Electronic Speckle Pattern Interferometry (ESPI) is a high sensitivity, non-contact and non-destructive testing technique. Thanks to its features ESPI is a perfect diagnostic tool in the field of Cultural Heritage, on almost any surface and material. The object under examination is simply illuminated by a low intensity laser light and does not need any handling or sample collection.

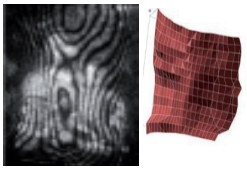


Optimal laboratory conditions.



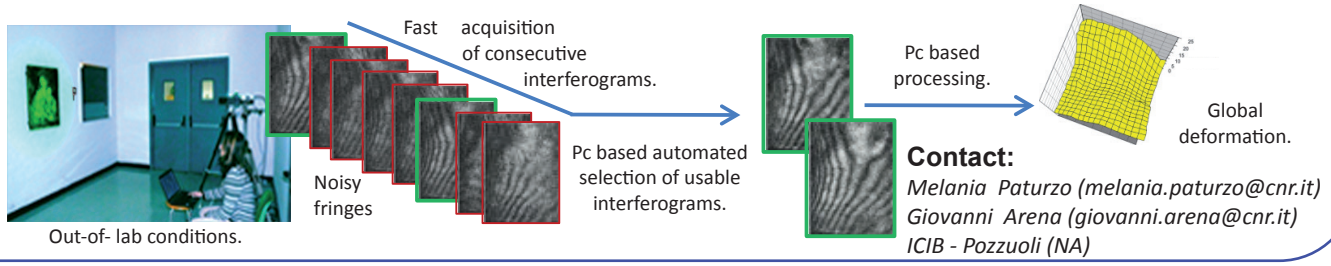
Localization of not visible damage. (Red lines).

ESPI provides sub-micrometric capacities in evaluating global structural distortions as well as localized displacements, micro-cracks, hidden detachments and flaws, usually produced by microclimate variations. The ESPI output consists of an interference fringes-pattern (Interferogram) overlaid onto the image of the object under testing. PC based numerical methods allow for, high spatial resolution, quantitative measurements. In our laboratory we are utilizing the ESPI technique for long-term survey on distinct objects of Cultural Heritage interest.



Global deformation.

Usually it is very difficult to move an art-work from its locations to a laboratory. We implemented a portable system intended for in-situ utilization. In this case the setting vibrations produce unpredictable fringe distortions. However, an adequate number of interferograms, usable for retrieving suitable measurements, can be randomly found. We carry out continuous acquisitions of a large number of consecutive interferograms. From the recorded sequences, useful frames are selected by a specific PC based method, that we developed.



Out-of- lab conditions.

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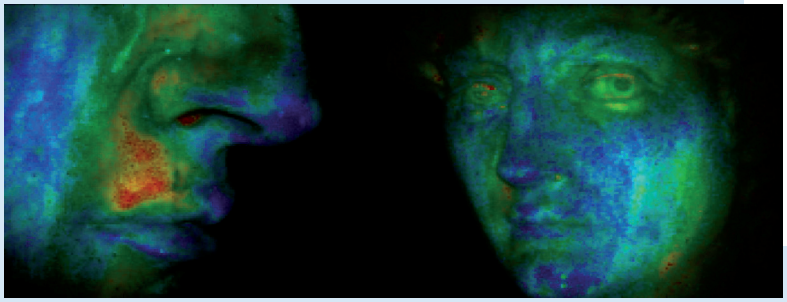
Advanced imaging of cultural heritage

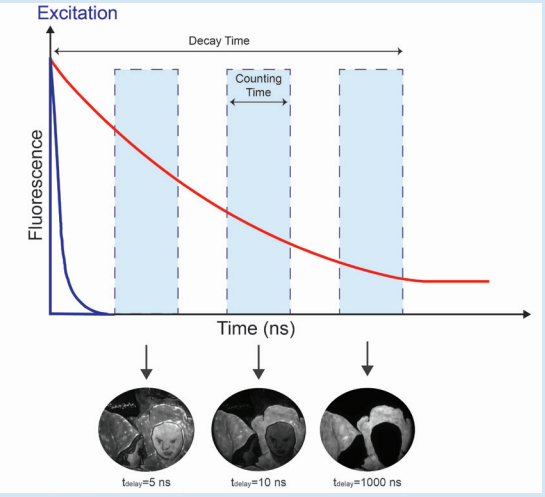
TRL: 6

The understanding of the materials present on the surface of a work of art is crucial for the treatment and long-term preservation of cultural heritage. A range of non-invasive portable instrumentation has been developed for the analysis of works of art using different light sources.



The Fluorescence emission from the surface of Michelangelo's David.

We present an instrument which is based on the detection of the time-resolved fluorescence lifetime of emissions from the surface of works of art known as Fluorescence Lifetime Imaging (FLIM). The device uses a pulsed laser source for excitation and a time-gated detector. Different applications of FLIM range from the detection of original materials in Renaissance wall paintings, the analysis of materials from the tomb of King Tutankhamun, to the detection of organic materials on the surface of sculptures and the analysis of the lifetime of the emissions from pigments in Impressionist paintings.



Images acquired at different decays after a laser pulsefrom a painting by Vincent Van Gogh.

With regards to enterprises...

An Italian patent has been registered for the application of Fluorescence Lifetime Imaging System (FLIM) to Cultural Heritage (MI2002A001361). We collaborate with XGLab S.R.L. in the development of portable instrumentation.

We offer: consultation on instrumentation development and in situ applications for the monitoring and analysis of cultural heritage.

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UV/Vis-IR-THz spectroscopy for conservation studies of ancient paper

TRL: 7

Some of the most famous masterpieces of our culture are stored on paper. Paper is mostly constituted of cellulose, the most abundant biopolymer on Earth. However, increasing fragility and yellowing , due to cellulose degradation processes, are commonly observed in ancient paper-based artifacts. Suitable diagnostic methods allowing an advanced knowledge of these degradation processes are indispensable for the preservation of these cultural properties. To this goal, an innovative diagnostic method based on non-destructive optical spectroscopy techniques combined with computational simulations based on ab-initio theoretical condensed matter methods has been set up in collaboration with the Physics Department of the University of Rome Tor Vergata and the Chemistry Department of the University of Krakow, Poland. In this way we were able to obtain the concentration of oxidized functional groups in cellulose acting as chromophores and responsible of paper yellowing. We have applied this method to the Leonardo da Vinci's self-portrait in order to quantify its present level of optical degradation which, compared with future measurements, will assess its degradation rate. We are presently extending this theoretical-experimental approach to the infrared (IR) and THz spectra of ancient paper. IR spectra allow extending the investigation on paper degradation also to the oxidized functional groups that are not directly involved in visual damage. THz spectra are instead correlated to structural degradation and crystallinity of ancient paper.

Fig. 1. Leonardo da Vinci's self-portrait as acquired during the diagnostic studies carried out at the ICR-CPAL (MIBACT) in Rome, Italy.

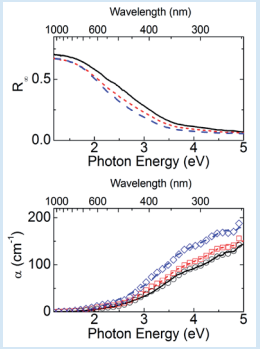

Fig. 2. Upper panel: reflectance spectra measured in the spots shown in Fig. 1. Lower panel: experimental (lines) and theoretical (symbols) absorption spectra of the spots.

With regards to enterprises...

We can offer our method for a wide range of applications for cellulose-based materials, like paper, textiles, and other manufactured products of great industrial and cultural interest. We are presently starting a collaboration with Fater S.p.A.

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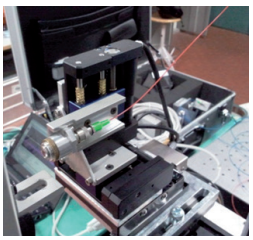
SCIENTIFIC & CULTURAL PROGRESS
CULTURAL HERITAGE

Non-invasive optical analysis of paintings: Vis-NIR reflectography and OCT

TRL: 7 - 4

Image analysis offers outstanding possibilities for diagnosis and study of artworks. Depending on the type of radiation, the different techniques allow us to reconstruct an image of the object that contains information other than that you may have from a simple vision. The results obtained are of extraordinary importance both for the study of artwork's conservation status, and for its storage, memory and/or attribution.

Scanner for multispectral Vis-NIR reflectography.

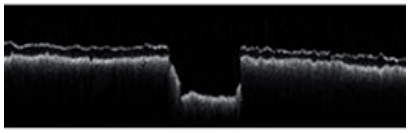


OCT device (TRL 4).

Caravaggio, Baccus reflectogram @2300 nm.

In particular, multispectral Vis-NIR reflectography (TRL 7), consisting in the acquisition of 16 Vis and 16 NIR nearly monochromatic images, allows both the spectro-photometric analysis (one spectrum for each pixel of the image) and the visualization of features underneath the surface of paintings, such as the underdrawing sketch, the "pentimenti" or subsequent repaintings, thanks to the properties of transparency of the pigments to the infrared radiation. Compared to the existing technologies, the scanner combines a huge spectral range (up to 2.5 micron) to the single-point detection that ensures the acquisition of aberration-free and self-registered images.

Optical Coherence Tomography (OCT, TRL 4) is a relatively new high resolution imaging technique that uses visible or infrared light to provide non invasive cross-sectional imaging of partially transparent or scattering media on the micrometers scale with probing depths up to 1-2 mm. In the cultural heritage field it can be profitably applied for measuring the varnish/overpainting thickness. This is particularly useful for monitoring the cleaning process.



Tomographic image where the varnish layer is visible, together with a hole corresponding to a micro-sampling.

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With regards to enterprises...

The multispectral scanner is part of the MoLab (Mobile Laboratory, http://www.charismaproject.eu/transnational-access/molab.aspx). OCT is commonly applied in oftalmology.

A prototype Vis-NIR hyper-spectral scanner for non-invasive investigation on artworks

TRL: 7

At IFAC-CNR laboratories a new prototype of a high-performance hyper-spectral scanner operating in the 400 - 1700 nm range has been recently assembled (Fig. 1). The extension of the sensitivity up to 1700 nm improves the capability of materials identification as well as the possibility of revealing hidden features. The system operates with both high spatial and spectral sampling rates, thus providing data with a spectral resolution of about 2.5 nm in the Vis and 8 nm in NIR range, and high- resolution images (about 300 ppi). This technique consists on the acquisition of series of reflectographic images at different wavelengths by capturing sequences of quasi-monochromatic images, registered on almost contiguous narrow spectral bands.

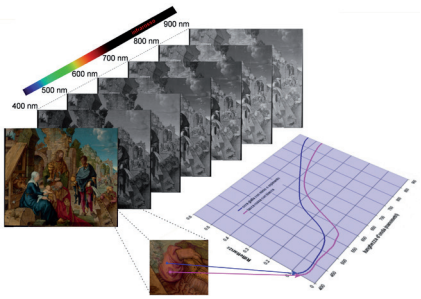

Fig. 2. From hyper-spectral data-set a sequence of quasi-monochromatic images and a collection of highly resolved reflectance spectra can be extracted.

The data-set acquired, contains both spatial and spectral information (Fig. 2). From each pixel of the imaged area it is possible to extract highly resolved reflectance spectra. Elaborated images and maps may be obtained by using statistical methods of data analysis. High spatial resolution is crucial to provide high-quality images usable for documentation and archiving. High spectral resolution is essential for discrimination and identification of pictorial materials.

Fig. 1. IFAC-CNR hyper-spectral scanner at the Uffizi Gallery, Florence.

With regards to enterprises...

We can offer our hands-on in designing spectral imaging systems and hyper-spectral data processing and interpretation for specific application on artworks.

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Hyperspectral fluorescence LIDAR imager

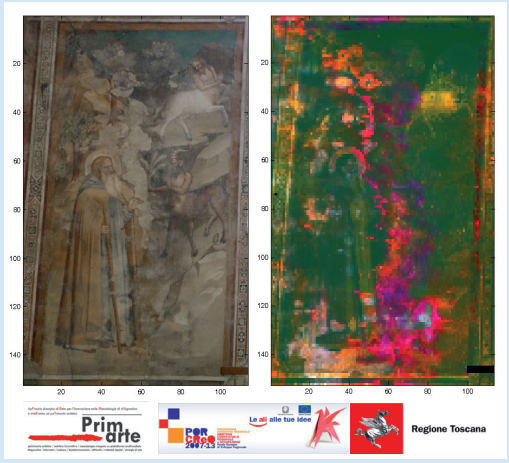
TRL: 7

The fluorescence LIDAR technique - thanks to the use of an UV pulsed laser as an excitation source - makes it possible to carry out remote Laser-Induced Fluorescence (LIF) spectroscopy in the outdoors. The IFAC prototype, in-house developed at IFAC in collaboration with El.En. S.p.A., is able to provide hyperspectral (more than 500 channels) fluorescence images of the investigated surface from a distance of several tens of meters, e.g. the façade of an outdoor monument or a wall painting. The fluorescence data acquired using the fluorescence LIDAR can be also resolved in the time domain in order to measure the fluorescence lifetime and extract additional information on the different compounds that constitute the examined surface. The fluorescence data are processed to generate thematic maps, which provide useful information to restorers and conservators for the detection and characterisation of biodeteriogens, of protective treatments, different lithotypes and, more generally, for the identification of materials in terms of their fluorescence spectral signatures and fluorescence lifetime.

With regards to enterprises...

The fluorescence LIDAR has been developed specifically for applications to the field of the cultural heritage in collaboration with El.En. S.p.A.. The prototype has been used to carry out fluorescence measurements in the frame of several international and national projects (Casa di Augusto, TDT-bioart, PRIMARTE) in close collaboration with several Italian SMEs (Laboratori ARCHA srl, Elab Scientific srl, Faberestauro snc, Nike restauro snc, ART-Test sas, Culturanuova srl, SOING Struttura e Ambiente srl).

The hyperspectral fluorescence LIDAR imager.



Hyperspectral fluorescence image of a mural painting.

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Revealing Letters in Herculaneum Papyri

TRL: 4

Hundreds of papyrus rolls, buried by the eruption of Mount Vesuvius in 79 AD and belonging to the only library passed on from Antiquity, were discovered 260 years ago at Herculaneum.

These carbonized papyri are extremely fragile and are inevitably damaged or destroyed in the process of trying to open them to read their contents.

In recent years, new imaging techniques have been developed to read the texts without unwrapping the rolls.

Until now, specialists have been unable to view the carbon-based ink of these papyri, even when they could penetrate the different layers of their spiral structure.

For the first time, we showed that X-ray Phase-Contrast Tomography (XPCT) can reveal various letters hidden inside the precious papyri without unrolling them.

This attempt opens up new opportunities to read many Herculaneum papyri, which are still rolled up, thus enhancing our knowledge of ancient Greek literature and philosophy. Indeed the impact of our discovery that XPCT can read writing inside carbonized papyrus rolls reaches far beyond the study of one particular Herculaneum papyrus. It holds out the promise that many philosophical works from the library of the 'Villa dei Papiri', the contents of which have so far remained unknown, may in future be deciphered without damaging the papyrus in any way.

This pioneering research opens up new prospects not only for the many papyri still unopened, but also for others that have not yet been discovered, perhaps including a second library of Latin papyri at a lower, as yet unexcavated level of the Villa.

Herculaneum Papyrus scroll.

Hyperspectral Reconstructed Letters sequences using XPCT Mocella, V. et al. Nat. Commun. 6:5895 (2015).

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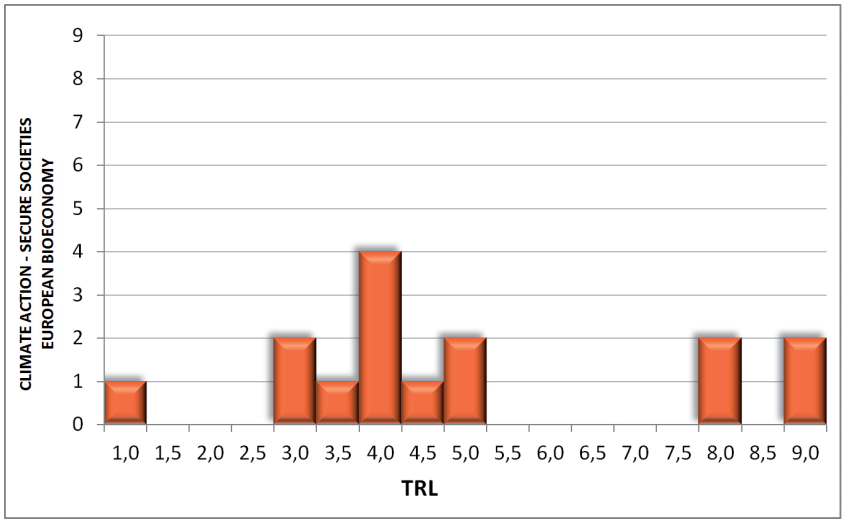
Climate Action
Secure Societies
European Bioeconomy

Optics and optoelectronics represent enabling technologies in different fields with prospective uses both in productive processes and as answers to individual and collective needs.
Methods, technologies and instrumentation combining essential optical and optoelectronical contents have several uses for applications that range from safety to agrofood, biomedical, environment, industrial diagnostics, consumers business.
The research subjects presented in this section belong to the branch of applications of modern photonics where innovative instrumentation and/or sensors are realized for climate actions, safety and bioeconomy. In these fields, the breakthrough is very fast due to the impact of new optical technologies and nonatechnologies with possibility of industrial and societal applications also in the short period.
The subjects here presented are representative of the broad range of expertise developed by several CNR Institutes in the field of photonics for climate action (see the applications to environmental monitoring), secure societies (see the applications to imaging and biosensors), bioeconomy (see the applications to process monitoring).

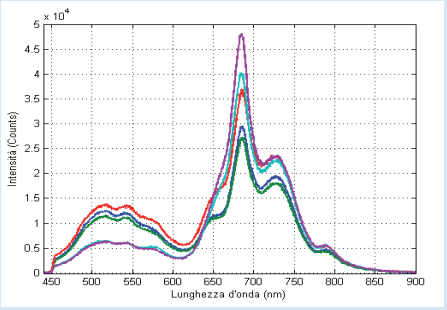
number of contributions in this section

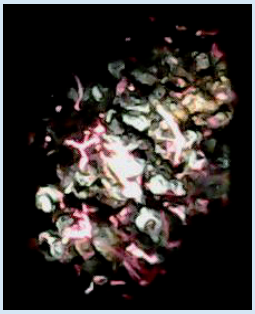


LIF technology for in situ measurements in extreme environments

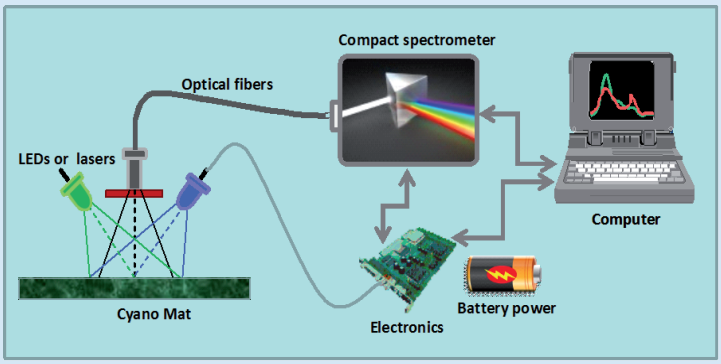
TRL: 5

The LIF spectroscopy is a versatile technique widely used in various scientific fields and for diverse applications. One of the advantages of the technique is to be suitable for the development of very compact instrumentation to be used in the field. We developed at IFAC a specific expertise in the design and prototyping of extremely compact and portable Laser Induced Fluorescence (LIF) instrumentation to make measurements in the field, even in particularly harsh environmental conditions (e.g. Antarctica).
The prototype, specifically developed for acquiring measurements of Arctic and Antarctic terrestrial cyanobacterial crusts, uses a diode laser emitting in the UV to excite the fluorescence in the visible spectral region. The system is battery-powered and can be transported inside a backpack.





LIF spectra and micro-LIF image of terrestrial microorganisms.



Portable spectrofluorimeter: principle of operation.

With regards to enterprises...

The instrument can be used to acquire LIF measurements in the field for diverse applications related to environmenal monitoring (e.g. Fluorescent pollutants, plants, lichens, etc.).
Possibility to develop dedicated prototypes for similar applications requiring in-field deployment of very compact instrumentation.

Contact:

Valentina Raimondi (v.raimondi@ifac.cnr.it)
Lorenzo Palombi (l.palombi@ifac.cnr.it)
IFAC - Sesto Fiorentino (FI)

Precision trace gas sensing with novel sources and techniques

TRL: 4

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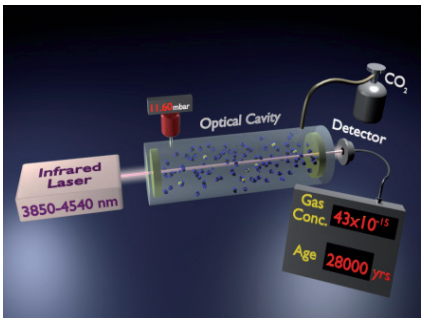
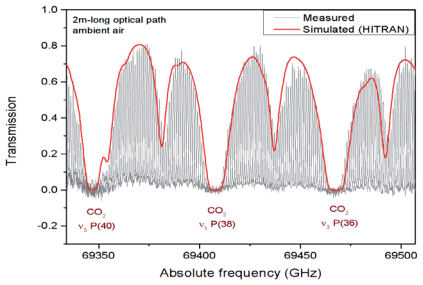
We developed an apparatus, named SCAR, based on mid-IR cavity ring-down spectroscopy, able to detect radiocarbon dioxide down to 43 ppq, well below the 1.2-ppt natural abundance. This result can play a crucial role for monitoring global fossil fuels emission and a collaboration with a USA company has already been started, to that purpose. This set-up, as other similar spectroscopic set-ups, benefits from several years of development and study of Quantum Cascade Lasers in the mid-IR. Indeed, schemes and specific hardware to reduce their frequency jitter have been implemented, putting our labs at the forefront of research on these specific lasers. On this subject we have, since about four years, a collaboration with Hamamatsu Photonics, a world leader in optoelectronics. In addition to QCL sources, we routinely use Comb frequency synthesizers both as reference for our lasers and directly as broadband, though highly coherent, sources. To this goal, we have also generated combs in the 4.2-5.0 µm wavelength interval by novel nonlinear mixing schemes.



SCAR apparatus for the optical detection of radiocarbon.

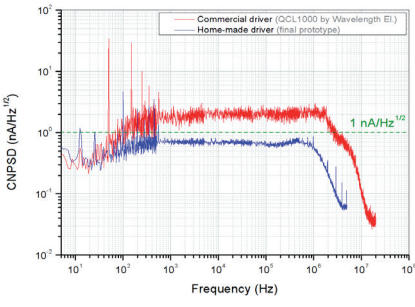


Direct absorption spectroscopy on atmospheric CO_2 by using a mid-IR comb as direct source.

With regards to enterprises...

Pending patents: "Apparatus and method for measuring the concentration of trace gases by scar spectroscopy"; "Low-noise current driver for QCLs"

Ongoing collaborations: PEM Inc. – USA; Hamamatsu Photonics Ltd. - Japan.



Comparison between the current noise figures of our patented driver and a commercial driver.

Contact:

Davide Mazzotti (davide.mazzotti@ino.it);
Saverio Bartalini (saverio.bartalini@ino.it);
Paolo De Natale (paolo.denatale@ino.it)
INO - Sesto Fiorentino (FI)

Laser Remote Sensing - LIDAR

TRL: 5

LIDAR—Light Detection and Ranging—is a remote sensing technology that measures distance by illuminating a target with a laser and analyzing the backscattered light.

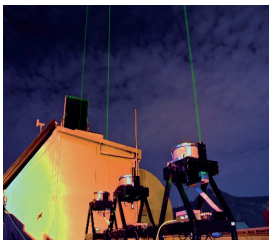
Atmospheric Remote Sensing

The lidar technique is one of the most important remote optical methods in atmospheric aerosol studies. Ground-based, air-borne and space-borne lidar can be applied. 3D distribution and time evolution of aerosol, natural or anthropogenic, or from volcanic eruption, can be constructed by 3D scanning lidar system. From the multiwavelength elastic, Raman scattering and depolarization measurements, aerosol concentration, size distribution and shape can be evaluated by applying deterministic and statistical inversion techniques based on regularization theory and realizing an optimal trade-off between stability and data fitting. High Spectral Resolution Lidar (HSRL) can also be used to characterize clouds and small particles in the atmosphere. The HSRL technique takes advantage of the spectral distribution of the lidar return signal to discriminate aerosol and molecular signals and thereby measure aerosol extinction and backscatter independently. Unlike Raman lidar, it can have take measurement both in day and night time.
From the analysis of Doppler shift of laser line by aerosol and/or molecular scattering, the wind speed can be measured.

Others Applications

Lidar can be used also in topographic and bathymetry applications.

Lidar for volcanic ash monitoring.



Lidar for metropolis air pollution.

(PM10, PM2.5, etc.) measurements.

With regards to enterprises...

We can design and implement aerosol lidar system and/or the lidar components, e.g. laser source, spectral analyzer, detectors and data acquisition and processing system, also for space applications.

Contact:

Lidar system: Dr. Xuan Wang (xuan.wang@spin.cnr.it)
Algorithm: Dr. Anna Maria Massone (annamaria.massone@spin.cnr.it), SPIN - Napoli

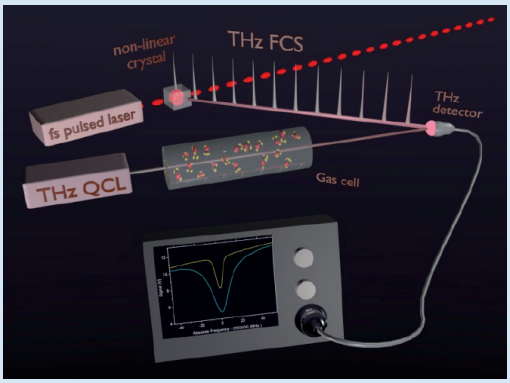
Terahertz sensing

TRL: 4

Access to the terahertz (THz) portion of the IR spectrum has been one of the most exciting frontiers of photonics for the last thirty years. Whereas fabricating efficient sources and detectors of THz radiation is intrinsically challenging, THz systems can ideally find application in several fields, including gas sensing and spectroscopy, heterodyne detection in astronomy, and advanced imaging techniques.

INO-CNR pioneered in development of THz sensing systems, in particular for spectroscopy and frequency metrology, and has a well established know-how on infrared imaging, in particular on holography; CNR-NANO demonstrated operation of the first quantum cascade laser (QCL) in the 1-10 THz frequency range, and is presently developing efficient THz detectors based on semiconductor nanowires and graphene nanostructures.

In the last years INO-CNR and CNR-NANO have shared the above know-hows with the aim of setting up advanced imaging systems and high resolution spectrometers in the THz range. Such THz systems are employed in fundamental physics experiments, such as for frequency metrology and molecule cooling, as well as in the frame of interdisciplinary collaborations, for eg the investigation of biological samples or of pieces of cultural heritage.



Scheme of a high resolution THz spectrometer based on a QCL and a THz frequency comb synthesizer (FCS).

IR speckle holography with a QCL: amplitude (left) and phase (right) image of a coin.

With regards to enterprises...

THz sensing systems are highly attractive for several industrial applications, in particular for non destructive quality control. We have established contacts with potential industrial partners interested in exploiting our technology.

Contact:

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Miriam S. Vitiello (miriam.vitiello@sns.it) NANO - Pisa
Saverio Bartalini (saverio.bartalini@ino.it) INO - Pisa

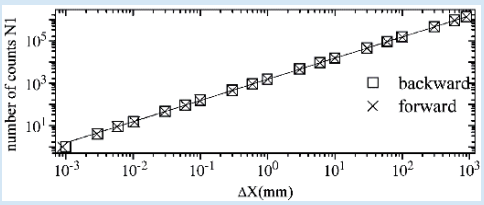
Optical feedback in terahertz quantum cascade lasers (QCLs) for imaging and metrology

TRL: 3 - 4

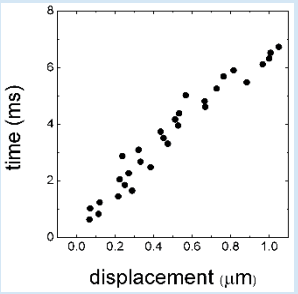
Partial re-injection of laser radiation reflected or diffused by a moving target back into the laser cavity interferes with the internal field and modulates the field phase and amplitude, the laser wavelength, the voltage drop across the active region. The analysis of this so called self-mixing interferometry (e.g. the voltage drop fringes) allows to determine the target displacement with sub-wavelength resolution. Also, by scanning the laser beam over a structured surface allows to assess the surface morphology. The main applications are:

- Coherent imaging in reflection mode with terahertz and mid-infrared QCLs: sensitivity to surface morphology by phase sign retrieval.
- Metrology: from 6 Dof measurement to nanoscale position-sensing.
- Multi-detection sensing capability: homodyne measurement of muktiple independently moving targets through nonlinear frequency mixing in a single semiconductor gain medium.
- Laser ablation monitoring for laser drilling real-time control.
- Virtually perfect common-mode rejection: QCLs are intrinsically stable against optical feedback, owing to the absence of relaxation oscillations (class-A laser) and small linewidth enhancement factor ($\alpha < 1$ in THz-QCLs).

Continuous-wave reflection imaging using optical feedback in QCLs.



Displacement measurement over 1 m with sub-micrometer resolution.



Displacement measurement with ~ λ/50 sub-micrometer resolution.

With regards to enterprises...

System for laser measurement of target motion: WO 2010/000283 A1
System for optical fiber strain measurement. No. 12/563,920
Laser system for ablation monitoring. No. EP11425016 (pending).

Contact:

Francesco P. Mezzapesa francesco.mezzapesa@uniba.it); Maurizio Dabbicco (maurizio.dabbicco@uniba.it); Gaetano Scamarcio (gaetano.scamarcio@uniba.it) IFN - Bari; Miriam S. Vitiello (miriam.vitiello@sns.it) NANO – Pisa

Opto-chemical detection of polluting gas and vapour species by MOX nanoparticles photoluminescence

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TRL: 4

Metal oxide (MOX) nanoparticles are at the basis of many important applications, including chemical sensing (e.g. SnO_2, ZnO) heterogeneous photocatalysis and environmental remediation (e.g. TiO_2) and solar energy conversion (e.g. ZnO, TiO_2). These properties are by MOX photophysical characteristics.

Ambient-controlled Photoluminescence (PL) analysis provides important information on these latter, while also representing a possible *multi-parametric route to chemical sensing*. Our research focuses on (A): fundamental studies on interactions between polluting gas molecules (e.g. O3, NOx, VOCs) with MOX nanoparticles and on (B): application of MOXs as optical nanosensors. These topics are investigated through different variants of PL technique (static, excitation-resolved, time-resolved) complemented with electro-optical approaches. Our recent investigations focusing on TiO_2 and ZnO nanoparticle systems produced by different chemical and physical (e.g. fs-PLD, ref. S. Amoruso, UniNa) routes. The optical approach to chemical sensing allows strengthening the standard sensing approaches based on single-parameter (conductivity) detection.

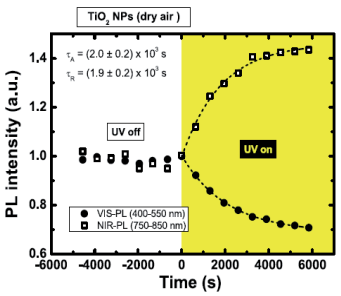


Fig. 1. Intensity of normalized visible and near-infrared emission bands in mixed rutile/anatase TiO2 nanoparticle systems under oxygen exposure. The yellow area indicates the presence of continuous illumination by the excitation UV laser. The experiment evidences multiple reactivity toward oxygen.

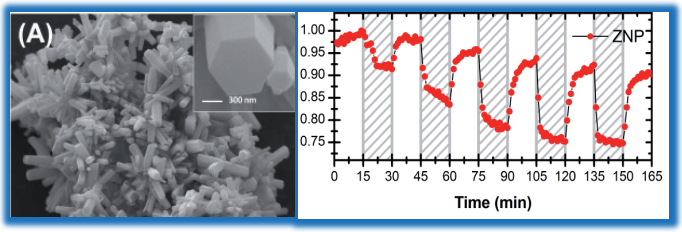


Fig. 2. Representative SEM images of ZnO micro-rods system and its excitonic PL response toward NO_2 (at concentration from 10 to 90 ppm).

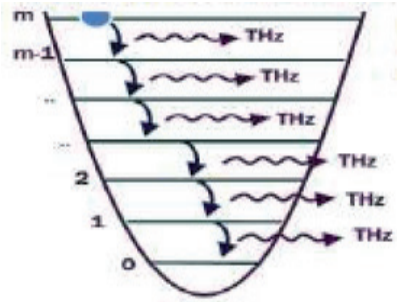
Contact:

Stefano Lettieri (stefano.lettieri@spin.cnr.it), Pasqualino Maddalena (pasmad@fisica.unina.it), SPIN - Napoli

Bosonic Cascade Lasers

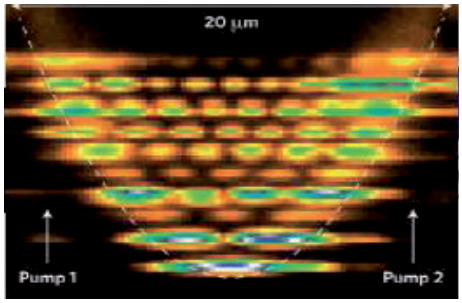
TRL: 1

Bosonic lasers represent a new generation of coherent light sources. They are based on a stimulated scattering of mixed light-matter quasiparticles into condensates which emit spontaneously the coherent and monochromatic light. Contrary to conventional lasers, bosonic lasers do not require the inversion of electronic population in the active media, which is why they are characterized by ultra-low thresholds. The first experimentally realized bosonic lasers are polariton lasers based on semiconductor microcavities. Recently, we came up with a concept of a new class of bosonic lasers termed Bosonic Cascade Lasers. Stimulated transitions of bosonic quasiparticles between equidistant levels in a parabolic trap result in the emission of a coherent terahertz radiation, which is of a major interest for applications in medicine, security and communication technologies. Bosonic cascade lasers are predicted to exhibit interesting fundamental properties: the population of steps of the cascade is expected to be quantized, the topology and spin properties of a bosonic liquid in the cascade lasers are expected to be very rich. This project is aimed at paying way to the experimental realization of Bosonic Cascade Lasers both with optical and electronic injection. Microcavity structures with GaAs and GaN parabolic quantum wells will be in the focus of our studies. The theoretical modelling results will be used to optimize samples for proof-of-concept experiments. Important theoretical challenges in the many-body systems of interacting bosons will be addressed.



(a) Bosonic cascades are based on quantization of exciton condensates in parabolic traps.

(b) The quantization of Bose-Einstein condensates of exciton-polaritons in optically induced traps has been recently demonstrated experimentally.

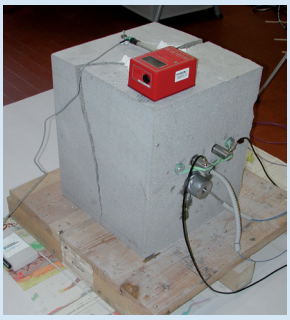


Contact:
Alexey Kavokin (alexey.kavokin@spin.cnr.it), SPIN - Roma

Fibre-optic sensors for rockfall monitoring

TRL: 4 - 5

Collapses of rock masses represent a major source of hazard in mountain areas, being the cause of rapid landslides. Differently from landslides occurring in earth or debris, which are usually surveyed by directed inspection of their surface, rockslides offer few, if any, visible signs. Furthermore rockslides apparently occur all of a sudden, making the application of early warning procedures very urgent. Rockslides are associated to processes of stress accumulation in unstable rocks, during which part of the accumulated energy is released in small internal cracks. These cracks generate acoustic emissions (AE) that can, therefore, be used as precursory signals, through which unstable rocks could be monitored.



Destructive laboratory tests with highly expansive mortar (note the induced crack).

With the collaboration of Vrije Universiteit Amsterdam in the Netherlands and the University of Padova in Italy, we have developed two interferometric fibre-optic sensors for use in such an application. With respect to standard legacy sensors (piezo-transducers and microphones), the fibre-optic sensors proposed provide a reliable solution offering the following features: more robustness to electromagnetic interference, smaller form factor, multiplexing capability, longer distance range (which lead to easiness of installation) and higher sensitivity.

On the left: Fibre Coil Sensor; on the right: front view and side view of the Ferrule-Top-Cantilever based sensor (the sensor is hosted inside the M10 bored bolt).

With regards to enterprises...

We can offer support to challenging and complex innovations from the problem phase to the development of fibre-optic sensing solutions for geo-hydrological applications.

Contact:
Luca Schenato (luca.schenato@cnr.it)
Alessandro Pasuto (alessandro.pasuto@cnr.it), IRPI - Padova

Mapping winegrape phenolic maturity by using a fluorescence optical sensor

TRL: 8

Non-destructive mapping of anthocyanins can be performed in the vineyard by using a fluorescence optical sensor. It is based on the measurement of grape berry chlorophyll fluorescence at different excitation wavelengths, more or less absorbed by pigments present on the berry external layers.

Once the anthocyanins optical index has been calibrated against wet chemistry, it can be used to report the spatial heterogeneity of anthocyanins concentration in the viineyard.

This technique allows for vineyard zoning to perform a selective harvest and consequently a separated vinification to produce high quality wines.

With regards to enterprises...
We have collaborated with various Italian wineries, as well as with the Force-A, Orsay, France optoelectronics company and with the Centro Analisi CAIM, Follonica (GR), Italy.

Contact:
Giovanni Agati (g.agati@ifac.cnr.it)
IFAC - Sesto Fiorentino (FI)

Portable fluorescence multiparametric sensor in the field.

Segmentation of a Cabernet Sauvignon vineyard for higher (red) and lower (green) anthocyanins content guided by in field non-destructive optical measurements.

Fluorescence wide-field and confocal microscopy localization of polyphenols in plant tissues

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TRL: 8

Multispectral fluorescence microimaging and microspectrofluorimetry represent useful tools to localize polyphenolic compounds in plant tissues. UV-excited blue autofluorescence can be used as proxy of hydroxycinnamic acids, while flavonoids can be detected as yellow fluorescence under blue excitation, once treated the sample with a specific fluorescence enhancer.

The information obtained are fundamental in eco-physiology studies to elucidate and understand the multifunctional role covered by these compounds in plants under different environmental conditions.

With regards to enterprises...
We collaborate with various academic groups (University of Florence, University of Pisa) and with Force-A, Orsay, France optoelectronics company.

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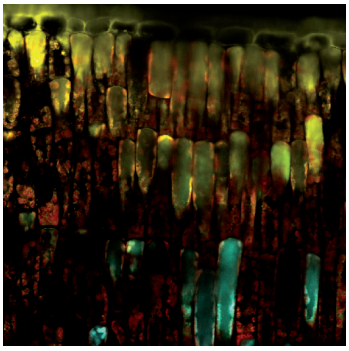
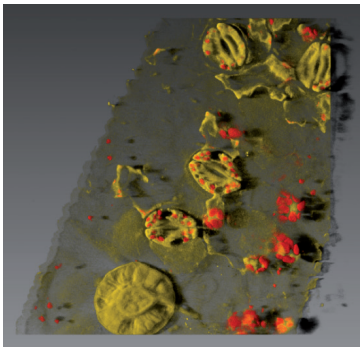


Multispectral fluorescence confocal microimaging of a *Phyllirea latifolia* leaf cross section (adaxial tissues) as recombination of hydroxycinnamic acid (light blue), flavonoid (yellow) and chlorophyll (red) fluorescence images.



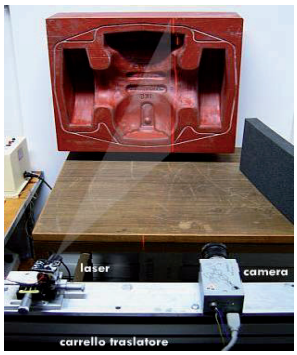
Confocal fluorescence image of the abaxial leaf surface showing flavonoids in the tricomes and guard cells (yellow) and chlorophyll in the chloroplasts (red).

Applied optics for industrial application

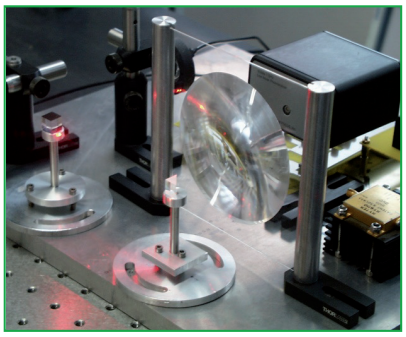
The term “applied optics” is here indicating a family of techniques using semiconductor low-power lasers for industrial applications, related particularly to metrology and gas detection. CNR-IFN Padova has a long-term expertise in industrial collaborations on:

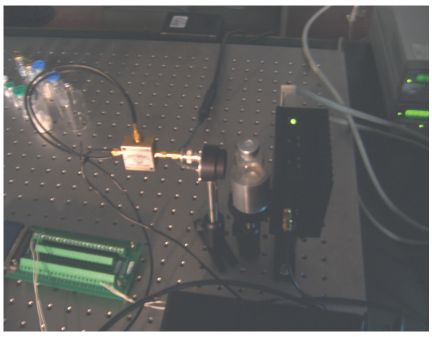
- Laser metrology applied to the position control of machining tools for manufacturing industries: measures of distance and of transversal and angular displacements for the control of 3D positioning.
- Laser metrology applied to the 3D modeling: laser mapping of complex objects, e.g. molds, to obtain the 3D model.
- Laser spectroscopy applied to non-invasive detection of gas pressure and content in close containers: applications to the detection of oxygen, carbon dioxide and water vapor in the food and beverage industry; applications to the detection of oxygen and water vapor in the pharmaceutical industry.

TRL: 9



3D mapping of molds.


Laser metrology: system for distance measurement.


Gas detection through laser spectroscopy applied to the pharmaceutical field.

On-going industrial collaborations (03-2014):
- Lpro srl, Padova
- FT System srl, Alseno (PC)
- FPT Industrie spa, Santa Maria di Sala (VE)

On-going projects (03-2014):
- SAFETYPACK, FP7 CE project (CNR-IFN project coordinator)
- EXTRACAL, Made in Italy Industria 2015 (CNR-IFN project partner)

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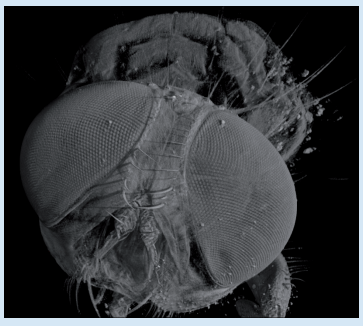
IFN - Padova

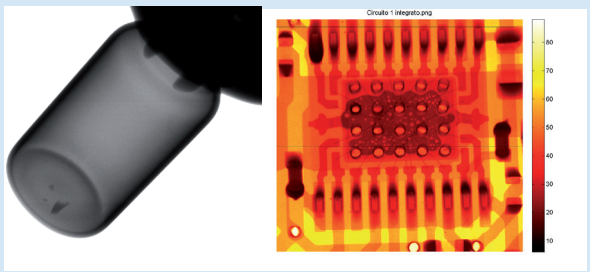
X-ray imaging techniques for industrial applications

X-ray imaging is a powerful method to look in a non-invasive way inside objects. Nowadays, X-ray imaging techniques are used in a wide range of industrial fields, from agrofood packaging to beverage, to mechanical manufacturing. CNR-IFN Padova has a long-term expertise in industrial collaborations on:

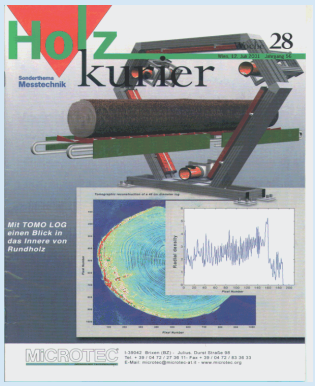
- X-ray radiography applied to the agro-food industry, for in line control of manufacturing and packaging processes
- X-ray radiography applied to the wood industry, for in line imaging of boards applied to saw optimization and metal detection
- X-ray 3D tomography applied to the wood industry, for in line quality control of logs
- X-ray radiography applied to the pharmaceutical industry , for in line quality control of sealing processes
- X-ray 3D tomography applied to the biology, for 3D reconstruction of biological specimens

TRL: 9


3D tomography of a Drosophila.


Examples of X-ray imaging: pharmaceutical vials and integrated circuit.

Tomohraph for logs.



Industrial collaborations:
- Microtec srl, Bressanone (BZ).
- Brevetti CEA, Sovizzo (VI).

Projects:
- Rotating tomograph for log analysis, Ministry of Economic Development.

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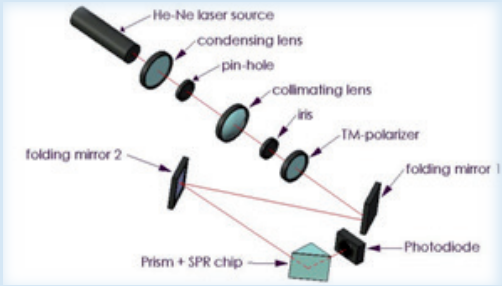
Surface plasmon resonance biosensors

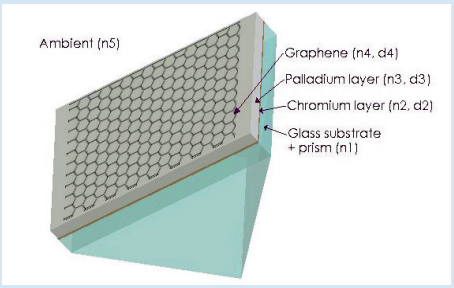
TRL: 3

Biosensors are devices capable of detecting bacteria, viruses and molecules, and can therefore be used in different applications. In particular, the food processing industry requires the use of biosensors for the detection of pollutants or toxic substances present in foods. Among the sensors based on bio-affinity, of great importance are those that use Surface Plasmon Resonance (SPR) as transducer systems. The advantages of this technique are the extreme rapidity of analysis (chemical manipulations are not required), the high reproducibility and sensitivity compared to other techniques. CNR-IFN Padova has the following capabilities:

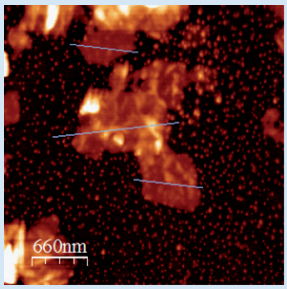
- Modelling and realization of metal chips for SPR and ISPR (Pd, Ir, Cr).
- Functionalization (es. thiols and graphene).
- Chips optical and physical properties characterization.
- SPR chips transducer (optical bench based on Kretschmann).
- Realization of optical trasducers capabilities.



Scheme of an SPR optical transducer.



Scheme of a Pd-GO chips on a prism for a Kretschmann configuration system.



AFM of a Pd-GO chips realized in Padova.

Collaborations:
- Next Step Engineering s.r.l., Padova
- University of Padova, Department of Chemestry

Contact:
Maria Guglielmina Pelizzo - (pelizzo@dei.unipd.it) IFN - Padova

Dielectric optical resonators for mechanical & chemical sensing

TRL: 3

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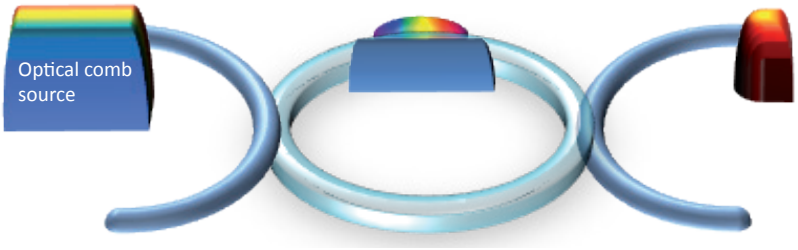
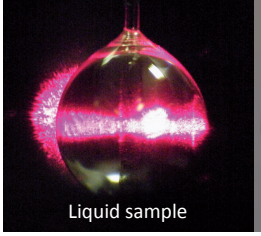
Optical fiber ring or FBG-based cavities are proven as ultra-sensitive tools for acoustic and inertial sensing based on optical combs (OC) as frequency references. Also, evanescent-wave fiber cavity-enhanced spectroscopy is achieved in the liquid phase using an OC as a broadband light source. Exploiting strong fiber-dispersion effects, liquid absorption spectra can be recorded without external dispersive elements.

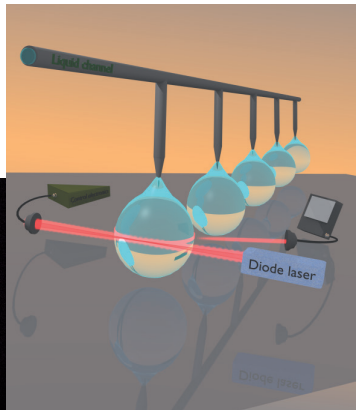


Optical fiber ring resonators for strain sensing & liquid spectrometry.

Refs: G. Gagliardi et al., Science 330, 1081 (2010); S. Avino et al., Appl. Phys. Lett. 102, 201116 (2013).

We recently explored the idea of liquid optical microcavities, i.e. a self-sustained drop of liquid where light can be trapped and resonate with very low loss (Q ~ 10^7), demonstrating, for the first time, the feasibility of droplets as passive sensors. We show evidence that simple oil droplets, vertically suspended thanks to surface tension, can be used in the same way as solid microspheres. The droplet itself serves as the sensor and the sample at the same time, where the internal optical field is directly used to probe dissolved analytes or nanoparticles.





Refs: S. Avino et al., Adv. Opt. Mat. 2, 1115, 2014;
M. R. Foreman et al., Eur. Phys. J. ST 223, 1971 (2014).

With regards to enterprises...

-PON BACKOP: «Backplane Ottico per Apparati ICT di Alta Capacità»;
-Patents: EP2021741-B1 «Method for laser-frequency locking to a fibre resonator»; WO2014102572-A1 "Frequency comb spectroscopy apparatus"; EP2014/071694 "High Voltage fiber optic sensor ".

Contact:
Gianluca Gagliardi, (gianluca.gagliardi@ino.it), INO - Napoli
S. Avino, A. Giorgini, P. Malara, R. Zullo, P. De Natale

Spectrally- and temporally-resolved fluorescence LIDAR technology

TRL: 4

The fluorescence LIDAR is a remote sensing instrument that permits to investigate the laser-induced fluorescence properties of a target from a distance. A pulsed UV laser beam is sent to the target: the radiation interacts with the target's constituents and the emitted fluorescence is collected by a telescope and sent to a suitable dispersion and detection system, usually a multi-channel detector. The acquired fluorescence spectra contain valuable information about the chemo-physical properties of the target.

The technique is widely applied for the investigation of the marine environment (pollutants like hydrocarbons, colored dissolved organic matter, phytoplankton, etc.), agro-forestry studies and for assessing the health status of vegetation since the red fluorescence of chlorophyll a is closely linked to the photosynthetic process.

The fluorescence data can be additionally resolved in the time domain in order to measure the fluorescence lifetime and to get additional information on the different compounds that constitute the target.

With regards to enterprises...

The fluorescence LIDAR has been already used within projects in close collaboration with Italian enterprises (e.g. FlyBY srl). It can be useful both for the characterisation of samples in the laboratory and for in-field deployment aimed at environmental studies.

Contact:
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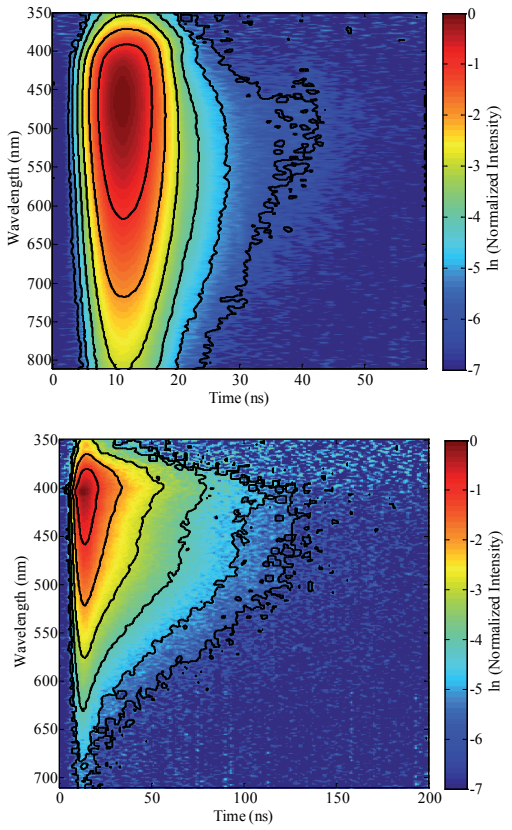

Wavelength-time fluorescence LIDAR diagrams of crude oil (above) and marine diesel (below).

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CNR Institutes: list of participants

DSCTM – Dipartimento di Scienze Chimiche e Tecnologie dei Materiali

ICCOM Istituto di chimica dei composti organo metallici
http://www.iccom.cnr.it/

Main branch:
Via Madonna del Piano 10 - 50019 Sesto Fiorentino FI
Pisa section: Via G. Moruzzi, 1 - 56124 Pisa

ISMAC Istituto per lo studio delle macromolecole
http://www.ismac.cnr.it

Main branch:
Via Edoardo Bassini, 15 - 20133 Milano MI

ISMN Istituto per lo studio dei materiali nano strutturati
http://www.ismn.cnr.it

Main branch:
c/o area della Ricerca di Roma 1 - Montelibretti
Via Salaria, Km 29,5 - 00015 Monterotondo RM
Bologna section: Via P. Gobetti, 101 - 40129 Bologna

ISOF Istituto per la sintesi organica e la foto reattività
http://www.isof.cnr.it

Main branch:
Via Piero Gobetti, 101 - 40129 Bologna

ISTEC Istituto di scienza e tecnologia dei materiali ceramici
http://www.istec.cnr.it

Main branch:
Via Granarolo, 64 - 48018 Faenza RA

DSFTM – Dipartimento di Scienze Fisiche e Tecnologie della Materia

ICIB Istituto di Cibernetica “Edoardo Caianiello”
http://www.cib.na.cnr.it

Main branch:
Via Campi Flegrei, 34 - 80078 Pozzuoli NA

IFN Istituto di Fotonica e Nanotecnologie
http://www.ifn.cnr.it

Main branch:
Piazza Leonardo da Vinci, 32 - 20133 Milano
Roma section:
v. Cineto Romano 42, 00156 Roma
Bari section:
c/o Dip. Interuniversitario Fisica “M. Merli Università degli Studi Di BARI ‘Aldo Moro’ Via Amendola, 173 - 70126 Bari
Padova section: - via Trasea, 735131 Padova
Trento section: - Via alla Cascata, 56/C, 38123 Povo (TN)
Lecco section: - c/o Polo di Lecco del Politecnico di Milano, Via Gaetano Previati, 1/c 23900 Lecco

IMM Istituto per la microelettronica e microsistemi
http://www.imm.cnr.it

Main branch: VII strada, 5 - 95121 Catania
Catania Section: Catania Università, Via S. Sofia, 64 - 95123 Catania
Lecce section: Via Monteroni c/o Campus Ekotecne, Palazzina A3 - 73100 Lecce
Napoli section: Via Pietro Castellino, 111 - 80131 Napoli

INO Istituto Nazionale di Ottica
http://www.ino.it

Main branch:
Largo Enrico Fermi, 6 - 50125 Firenze
Napoli section: Via Campi Flegrei 34 - 80078 Pozzuoli (NA)
Pisa section: Via G. Moruzzi, 1 - 56124 Pisa

IPCF Istituto per i processi chimico-fisici
http://www.ipcf.cnr.it/

Main branch:
Viale Ferdinando Stagno d’Alcontres, n. 37 - 98158 Messina

ISC Istituto dei Sistemi Complessi
http://www.isc.cnr.it

Roma Montelibretti section:
c/o Istituto dei Sistemi Complessi Via Salaria Km. 29,300 - C.P. 10 - 00016 Monterotondo RM
Roma Tor Vergata section:
c/o Istituto dei Sistemi Complessi Via del Fosso del Cavaliere, 100 - 00133 Roma
Roma Sapienza section:
c/o Istituto dei Sistemi Complessi c/o Dipartimento Fisica Nuovo Edifico Università La Sapienza

NANO Istituto Nanoscienze
http://www.nano.cnr.it

Lecce (NANO-NNLN) section:
Via Arnesano - 73100 Lecce
Pisa section: Piazza San Silvestro 12 - 56127 Pisa

SPIN Istituto superconduttori, materiali innovativi e dispositivi
http://spin.fisica.unina.it/

Napoli section:
Via Cinthia - 80126 Napoli
Roma section: CNR-SPIN, University Tor Vergata, Viale del Politecnico 1, I-00133 Rome, Italy

DIITET– Dipartimento di Ingegneria, ICT e Tecnologie per l'Energia e i Trasporti

IEIIT Istituto di Elettronica e di Ingegneria dell'Informazione e delle Telecomunicazioni
http://www.ieiit.cnr.it/

Main branch:
c/o Politecnico di Torino, corso Duca degli Abruzzi, 24 - 10129, Torino

IFAC Istituto di fisica applicata "Nello Carrara"
http://www.ifac.cnr.it

Main branch:
Via Madonna del Piano, 10 - 50019 Sesto Fiorentino FI

IMEM Istituto dei materiali per l'elettronica ed il magnetismo
http://www.imem.cnr.it

Main branch:
Parco Area delle Scienze 37/A - 43124 Parma

IREA Istituto per il Rilivamento Elettromagnetico dell'Ambiente
http://www.irea.cnr.it/

Main branch:
Via Diocleziano, 328, Napoli

DSB – Dipartimento Scienze Biomediche

IGM Istituto di Genetica Molecolare
http://www.igm.cnr.it

Main branch:
Via Abbiategrasso, 207 - 27100 Pavia

DTA – Dipartimento di Scienze del sistema Terra e Tecnologie per l'Ambiente

IRPI Istituto di ricerca per la protezione idrogeologica
http://www.irpi.cnr.it/

Padova section:
Corso Stati Uniti, 4 - 35127 Padova

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