

## Optical Characterization at the Nanoscale

Title:  
Optical  
Characterization  
at  
the  
Nanoscale.  
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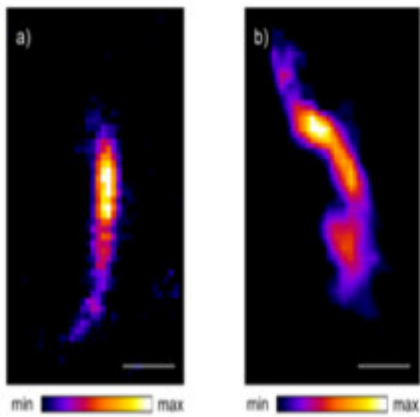


Figure.1 SNOM PL of individual CNT at room temperature. The white bar is 1  $\mu\text{m}$ .

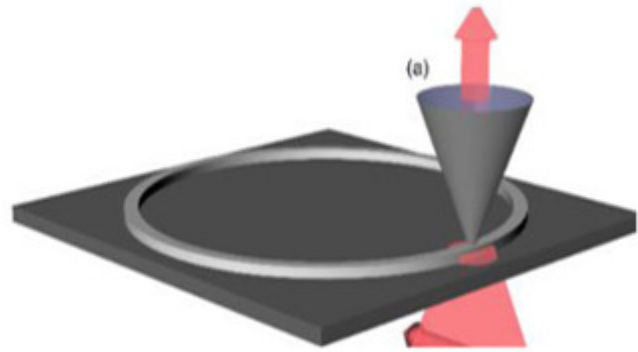


Figure.2 Scheme of the SNOM forward resonant scattering imaging

When: Wednesday, February 07, (2018), 15:00.

Place: Department of Theoretical Condensed Matter Physics, Faculty of Science, Module 5, Seminar Room (5th Floor).

Speaker: Massimo Gurioli, Department of Physics and Astronomy, University of Florence, Sesto Fiorentino (FI), Italy.

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he tremendous progress in nanophotonics towards efficient quantum emitters at the nanoscale requires investigation tools able to access the detailed features of the both sources and optical modes with deep-subwavelength spatial resolution. This scenario has motivated the development of different nanoscale optical imaging techniques.

In this contribution, we will overview our activity in exploiting near field microscopy for optical characterization at the nanoscale, both for semiconductor nanostructures and photonics nanoresonators. We will show that the scanning near field optical microscopy (SNOM) is a powerful method to access the excitons confined at the nanoscale and to image the electric-magnetic field in nanophotonics.

In the first part we will present experiments on carbon nanotubes where the confined excitons are mapped along the micrometer long tube extension, evincing localization and tube bending [1,2]. Examples are given in Figure 1.

In the second part we will discuss a novel technique involving the combination of scanning near-field optical microscopy with resonant scattering spectroscopy. The scheme of a RS-SNOM measurement on a microring is given in Figure 2. Our approach enables imaging the electric and magnetic field intensity (including phase, amplitude and polarization) in nano-resonators with sub-wavelength spatial resolution ( $\lambda/20$ ) [3-8].

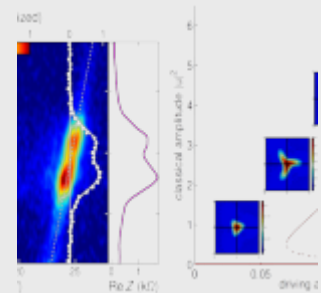
We conclude with recent results on the exploitation of our resonant scattering SNOM for addressing the exceptional points in photonics.

#### References

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- F. La China, et al. JAP, 120, 123110, (2016).
- F. Riboli, et al. Nat. Materials 13: 720 (2014).
- N. Caselli, et al. Light: Science & Applications 4, e326, (2015).
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- N. Caselli, et al. submitted to Nat. Materials.

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## Josephson Photonics: Quantum Optics Meets Quantum Electronics



Title: Josephson Photonics: Quantum Optics Meets Quantum Electronics.

When: Thursday, March 16, (2017), 12:00.

Place: Departamento de Física Teórica de la Materia Condensada, Facultad Ciencias, Module 5, Seminar Room (5th Floor).

Speaker: Joachim Ankerhold, Ulm University, Institute for Complex Quantum Systems, Germany.

**R**eal quantum systems never live in isolation but are embedded in surrounding media. An impressive example is cavity quantum electrodynamics and its more recent realization circuit-QED, where ‘artificial atoms’ in microwave cavities are implemented with superconducting circuits. Quantum electrodynamics, however, implies the interaction of bosonic with fermionic matter in general. For the latter, fascinating progress has been achieved in the field of quantum electronics to control charge transfer down to the level of individual charge carriers.

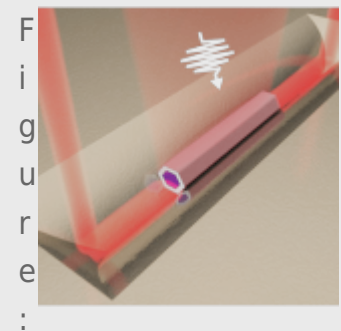
Activities to combine these two previously almost distinct fields, quantum optics and quantum electronics, have appeared only very recently with the advent of Josephson

photonics. This opens a new playground to study a wealth of phenomena far from equilibrium including non-classical light sources, ultra-strong charge-light interactions, and quantum phase transitions in steady state. In this talk I will discuss experimental developments in line with the theoretical background.

[More information on IFIMAC Website](#)

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## A Bright Nanolight for Plasmonic Circuitry



Schematic illustration of the proposed hybrid plasmonic platform for an on-chip nanolaser source. It consists of a GaAs nanowire positioned inside a 30 microns-long gold V-groove waveguide capable of coupling its lasing emission to the propagating plasmonic modes supported by the structure.

Article: published in [Nano Letters](#) by Javier Cuerda, [Jorge Bravo-Abad](#) and [Francisco J. Garcia-Vidal](#), Department of Theoretical Condensed Matter Physics and [IFIMAC](#) researchers.

**T**he need of ever faster and powerful data processing and communication technologies, as well as for ultrasensitive and compact sensors is playing a crucial role

in the advance of novel on-chip optical devices. It is a matter of time before integrated photonic circuits will become inherent in our daily lives in a similar way that electronic circuits did with the development of the transistor. Currently, one of the main goals in nano-photonics research is being able to integrate all the key necessary building blocks on a same chip, including the light source, transmission lines, modulators and detectors. Small on-chip lasers have emerged over the last decade as an ideal solution for the light source integration, however the main challenge is to efficiently couple their emission into the small footprint components.

Now, in a recent Nanoletters publication, a group of researchers from the [Departamento de Física Teórica de la Materia Condensada](#) and the [Condensed Matter Physics Center](#) (IFIMAC) at the [Universidad Autónoma de Madrid](#), together with researchers from the [Institute of Photonic Sciences](#) (ICFO), the [Laboratory for Semiconductor Materials](#) at the EPFL in Switzerland, the [Technical University of Denmark](#) and the [Center for Nano Optics](#) in Denmark, report on the realization of a novel ultracompact hybrid nanolaser source operating at room temperature consisting of semiconductor nanowire (NW) lasers directly integrated with wafer-scale lithographically designed plasmonic waveguides.

To achieve this, the researchers used epitaxially grown GaAs NWs with diameters at least ten times smaller than a human hair and a few microns in length, which provided both the gain medium and the cavity geometry required for the lasing emission. The NWs were then transferred from their host substrate onto a silicon chip containing gold V-groove (VG) plasmonic waveguides, which support a special type of surface plasmons with sub-wavelength lateral electromagnetic field confinements and good propagation characteristics, namely the channel plasmon polaritons (CPPs). Later, by means of micro and nanomanipulation techniques, the researchers deterministically positioned individual NWs at the bottom of the VG channels, forming the so-called NW-VG hybrid nanolaser.

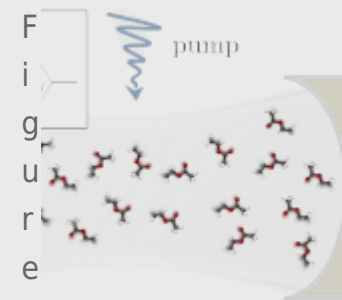
Lasing action and emission coupling to the plasmon CPP waveguide mode was observed upon pulsed illumination of the NW. Furthermore, rigorous theoretical simulations revealed that the lasing action in these devices was enabled by a hybrid photonic-plasmonic mode supported by the NW-VG geometry. The demonstrated system exhibited an unprecedented transfer efficiency of the lasing emission into the CPP waveguide mode of nearly 10%. This benchmark result was possible thanks to the good overlap between the hybrid plasmon lasing mode and the subwavelength confined CPP mode of the waveguide.

The authors envision that the unique features of the developed integrated source will provide the means to build high-sensitivity chemical or bio-sensing platforms powered by an integrated nanolaser. Future directions will also focus on the development of electrical injection as well as the integration of other on-chip components along the VG to build functional photonic circuitry, for example, in quantum optics experiments employing single quantum emitters coupled to the CPPs or integrating electro-optic

elements in high-speed plasmonic modulators for data communications, which overall can bring us one step closer to future hybrid photonic-plasmonic circuit platforms. [Full article]

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## Exploiting Vibrational Strong Coupling to Make an Optical Parametric Oscillator out of a Raman Laser



Sketch of the system. The blue arrow depicts the pump beam, while the green and red arrows show the two emitted laser beams. The inset shows the energy structure, with the vibropolaritons (purple) separated by the Rabi splitting.

Article: published in [Physical Review Letters](#) by Javier del Pino, [Francisco J. Garcia-Vidal](#) and [Johannes Feist](#), Department of Theoretical Condensed Matter Physics and IFIMAC researchers.

**R**aman scattering is a nonlinear optical process in which a photon is converted into two new excitations: a photon of a different color, as well as a material excitation such as a phonon (a quantum of vibrational energy). In a Raman laser, stimulated Raman scattering is exploited to create sources of coherent light with a wide range of achievable output wavelengths. This concept can be implemented in a variety of configurations, such as under pulsed or continuous operation, and using a wide range of

nonlinear media such as optical fibers, nonlinear crystals, gases, or semiconductor materials. However, all these devices share the same drawback: Only the photon resulting from Raman scattering is used, while the material excitation is “lost” and its energy deposited in the form of heat.

In a theoretical study published in [Physical Review Letters](#), a group of researchers from the [Departamento de Física Teórica de la Materia Condensada](#) and the [Condensed Matter Physics Center](#) (IFIMAC) at the [Universidad Autónoma de Madrid](#) present a proposal to circumvent this drawback of conventional Raman lasers. The crucial step is to modify the vibrational excitations in the material, converting them into hybrid light-matter excitations that have a photonic component, so-called vibropolaritons. This can be achieved through so-called “strong coupling”, which occurs when the coupling between the vibrational excitations and a resonant confined light mode becomes faster than the decay of either constituent. The resulting vibropolaritons then decay most efficiently through emission of light, which has two important consequences in the context of Raman lasers: First, the heat deposition is strongly reduced, as this energy is now emitted as photons. Second, and even more importantly, the Raman laser with only a single output beam is converted into a different type of nonlinear optical device, a so-called optical parametric oscillator with two output beams. These beams are coherent and have a stable phase relation, as well as providing possibly entangled pairs of photons with non-classical correlations.

In addition, the authors show that the coexistence of two vibropolariton modes with similar properties allows to operate the same device as an all-optical switch. Here, one (gate) pump beam can be used to switch on or off the Raman lasing of a second (signal) pump beam with slightly detuned frequency. In this mode of operation, both vibropolariton modes show stimulated emission as soon as the total pump power becomes large enough, such that the device produces three coherent output beams.

These results are an example of the great potential that hybrid light-matter states possess in manipulating light fields and providing novel light sources. The proposed setup could be used in novel solid-state microcavity devices for applications requiring mutually coherent and/or entangled beams in disparate frequency regions, such as quantum information transmission and storage. In addition, this approach could improve existing Raman lasers by lowering the operating threshold and reducing heat generation. [\[Full article\]](#)

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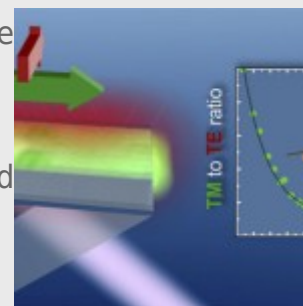
[Multi-scale Molecular Dynamics Simulations of Photoactive Molecules Strongly Interacting With Confined Light](#)

Title: Multi-scale Molecular Dynamics Simulations of Photoactive Molecules Strongly Interacting With Confined Light.

When: Friday, January 13, (2017), 12:00.

Place: Departamento de Física de la Materia Condensada, Facultad de Ciencias, Module 3, Seminar Room (5th Floor).

Speaker: Gerrit Groenhof, University of Jyväskylä, Finland.



**W**hen photoactive molecules strongly interact with confined light, for instance inside optical cavities or near (localised) surface plasmons, new hybrid light-matter states may form, the so-called polaritons or plexcitons. These polaritons are coherent superpositions (in the quantum mechanical sense) of the excitations on the molecules and the cavity photon or plasmon. Recent experiments suggest that access to these polaritons may provide a totally new paradigm for controlling chemical reactions [1]. However, to exploit strong light-matter coupling for steering chemistry we need a theoretical model that can accurately predict the effect of the coupling on the molecular dynamics. Because current models are based on phenomenological theories that are not easily inverted to design new systems, we have developed a new model based on molecular dynamics (MD) simulations, with which the dynamics of one or more photoactive molecules strongly interacting with confined light can be simulated in atomic detail. In addition to discussing this model, I will also show how the results of the simulations might explain the effect of the molecular Stokes shift on the SPP-molecule polariton emission in recent experiments [2].

#### References

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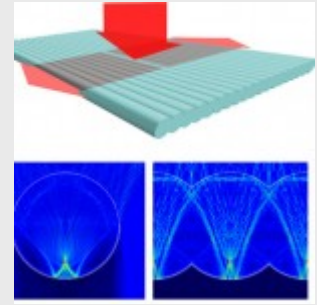
S. Baieva, O. Hakamaa, G. Groenhof, T. T. Heikkilä, and J. J. Toppari, *ACS Photonics*, [Article ASAP](#), (2016).

[More information on IFIMAC Website](#)

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[Intermittent Chaos for Ergodic Light Trapping in a Photonic Fiber Plate](#)

Article: published in [Light: Science & Applications](#) by Jorge Bravo-Abad, Department of Theoretical Condensed Matter Physics and IFIMAC researcher.



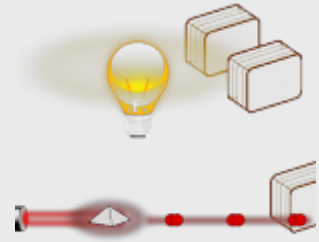
**L**ight trapping and guiding in thin films combined with efficient light extraction or insertion in the direction orthogonal to the guiding one is essential to obtain energy-efficient light harvesting or emission. In this context, one is faced with two seemingly incompatible constraints -namely, to let as much light in or out as possible at any point on the guiding film surface while maintaining the light effectively trapped across the film. For several decades, in an attempt to maximize sunlight energy harvesting, researchers of thin film solar cells have been searching for the optimal system architecture to achieve the most effective light path ‘bending’ into the cell absorber layer. In a collaboration between the [Departamento de Física Teórica de la Materia Condensada](#) and the [Condensed Matter Physics Center \(IFIMAC\)](#) at the [Universidad Autónoma de Madrid](#), the [Institute of Photonic Sciences \(ICFO\)](#) and the [Université Libre de Bruxelles \(ULB\)](#) , it has now been demonstrated that the paradoxical goal of letting as much light in or out while maintaining the wave effectively trapped can be achieved with a periodic array of interpenetrated fibers forming a photonic fiber plate. Photons entering perpendicular to that plate may be trapped in an intermittent chaotic trajectory, leading to an optically ergodic system. The researchers simulated and fabricated such a photonic fiber plate and showed that for a solar cell incorporated on one of the plate surfaces, light absorption is greatly enhanced. The interest in the novel light-guiding mechanism proposed in this work well exceeds photovoltaics and may contribute to many relevant applications in future illumination systems, displays or wearable devices. [\[Full article\]](#)

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[When Quantum Light Meets Matter](#)



Article: published in [Physical Review A](#) by J. C. López Carreño, C. Sánchez Muñoz, E. del Valle and F. P. Laussy, [Department of Theoretical Condensed Matter Physics](#) and IFIMAC researchers..



**A** theoretical analysis of the interaction between quantum light and matter shows that quantum light can offer advantages over its classical analog. Interactions between classical light and matter lie at the heart of a broad range of applications—think sunlight striking a solar panel or laser light scanning a barcode. But what happens when quantum light such as light made of “squeezed” or entangled photons interacts with matter? In two back-to-back papers, Fabrice Laussy from the [Autonomous University of Madrid](#), Spain, and colleagues now report a theoretical analysis of the interaction between quantum light and matter that, unlike most previous studies, doesn’t solely apply to specific types of quantum light. The researchers find that quantum light offers advantages over its classical counterpart for certain systems and applications. [\[Full article\]](#)

#### References

Excitation with quantum light. I. Exciting a harmonic oscillator, J. C. López Carreño and F. P. Laussy, *Phys. Rev. A* 94, 063825, (2016). [\[URL\]](#)

Excitation with quantum light. II. Exciting a two-level system, J. C. López Carreño, C. Sánchez Muñoz, E. del Valle, and F. P. Laussy, *Phys. Rev. A* 94, 063826, (2016). [\[URL\]](#)

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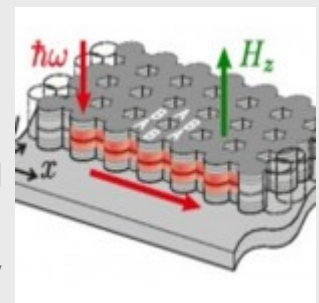
## [Spin-orbit Coupling in Photonic Systems: from Optical Spin Hall Effect to Z Topological Insulator Analog](#)

Title: Spin-orbit Coupling in Photonic Systems: from Optical Spin Hall Effect to Z Topological Insulator Analog.

When: Tuesday, July 19, (2016), 16:00-17:00h

Place: Departamento de Física de la Materia Condensada, Facultad Ciencias, Module 3, Seminar Room (5th Floor).

Speaker: Guillaume Malpuech, Institut Pascal, CNRS and University Blaise Pascal, France.



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he optical modes of photonic structures are the so-called TE and TM modes which bring intrinsic spin-orbit coupling and chirality to these systems. This, combined with the unique flexibility of design of the photonic potential, and the mixing with excitonic resonances, allows to achieve many phenomena, often analogous to other solid state systems. In this contribution, I will review several of these realizations, namely the optical spin Hall effect [1], Berry curvature for photons [2], and the photonic/polaritonic topological insulator [3,4].

## References

A.V. Kavokin, G. Malpuech, and M.M. Glazov, Phys. Rev. Lett. 95, 136601 (2005).

I. A. Shelykh, G. Pavlovic, D. D. Solnyshkov, and G. Malpuech Phys. Rev. Lett. 102, 046407 (2009).

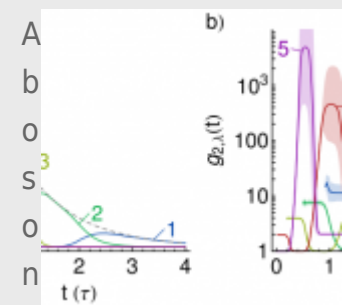
F.D.M. Haldane and S. Raghu, Phys. Rev. Lett. 100, 013904, (2008).

A. Nalitov, D.D. Solnyshkov, G. Malpuech, Phys. Rev. Lett. 114, 116401, (2015).

[More information on IFIMAC Website](#)

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## Quantum Statistics of Bosonic Cascades



c cascade, in population (a) and photon correlation (b). Superbunching plateaus are observed as the condensate falls through the cascade.

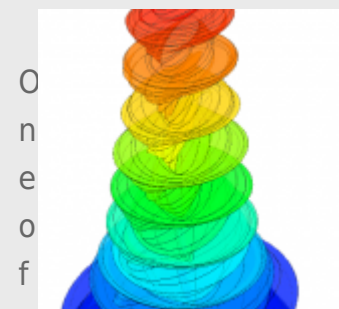
Article: published in [New Journal of Physics](#) by Fabrice P. Laussy, Department of Theoretical Condensed Matter Physics and IFIMAC researcher.

# Q

uantum cascade lasers brought a new architecture of light-amplification to laser engineering, allowing a single electron to trigger several photons by falling down a staircase of intersubband transitions. This inspired a similar design with fully bosonic systems [[Phys. Rev. Lett., 110:047402, 2013](#)] by confining Bose condensates in a parabolic trap. Such designs may have applications in the THz range. In these so-called bosonic cascades, the amplification of the signal had been studied at the level of its intensity only, leaving aside other important features of lasing such as the photon statistics of the emitted light. Recently, we have studied this aspect and found that the cascading results in strong correlations. Namely, the photons exhibit super-bunching, i.e., tend to be cluttered together. Our study reveals unsuspected aspects of photon correlations in such systems, for instance their magnitude, that grows in ideal conditions like the exponential of the population, and populations can easily be of the order of millions of particles. Also that two photons only are required to reach an arbitrary high bunching. Our text shows that bosonic cascades are new players in optics, with potential not only in hard-of-access frequency windows but also in photonics where unconventional photon states are called for. [[Full article](#)]

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## International Year of Light: Two New Kinds of Light



he two new kinds of light.

Title: [International Year of Light: Two New Kinds of Light](#)

When: Friday, 18 December (2015), 12:00h

Place: Departamento de Física Teórica de la Materia Condensada, Facultad Ciencias, Module 5, Seminar Room (5th Floor).

Speaker: Fabrice P. Laussy, Departamento de Física Teórica de la Materia Condensada and Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, E-28049, Spain.

**L**ight is the substratum of the universe since it became transparent in the photon epoch, c. ten seconds after the big bang. As a physical entity, it is the most fundamental and best understood theoretical object, and sets the standard for quantum field theories. It pervades not only humankind's science and technology, but also its history, culture and civilization ["Let there be Light", Genesis 1:3]. It has exerted fascination since the dawn of time and was at the heart of many of the major intellectual feasts to bring meaning to our surroundings, in particular shaping both the quantum and relativity theories that are the pinnacle of modern science. The interest for light in all its possible variations is ever increasing.

At the occasion of the International Year of Light and Light-based Technologies (2015)-a UNESCO observance that aims to raise awareness of the achievements of light science and its applications and its importance to humankind-we will give an overview of past and recent scientific achievements, covering such different aspects as astronomy, medicine and communication (classical and quantum), as well as the latest developments that take Light in always more remote corners. In particular, we will present in more details two new kinds of light proposed recently by the speaker and co-authors, one quantum light where the fundamental brick of the light field is upgraded from being an isolated photon to bundles of them [[Nature Photonics 8:550 \(2014\)](#)], and another classical one that takes all the states of polarizations in each emitted pulse [[Light: Science & Applications \(2015\)](#)]. Implications and applications for now and the future will conclude our brief overview of light.

[More information on IFIMAC Website](#)

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