Book of Abstracts
The Nanoscale Quantum Optics (NQO) Workshop
Prague, February 13th until 16th

Session 1: General Session
(all WGs, focus on GB and ESR)

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Challenge, advances and perspective on nanoscale quantum optics applications using color centers in carbon related materials

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Color centers in wide band semiconductors most notably diamond [1] and recently silicon carbide[2], boron nitride[3] and gallium nitride[4], have emerged as a robust room temperature source of single photons, that can be integrated in nanophotonics platforms for application in quantum technologies such as quantum communication, optical quantum computation and quantum metrology. Additionally some of these color centers, specifically in diamond and silicon carbide, also possess optical read-out of their spin state preparation and manipulation, that lends to applications in quantum sensing such as magnetometry[5, 6], due to their long coherence time at room temperature. The optical and spin properties of some color centers can also be applied in methods such as superresolution imaging (STED-ODMR and STORM/PALM ODRM)[7-9], providing magnetic sensing and imaging at the nanoscale. The major challenge in converting these atomic probes into useful applications is related to their scalability at the nanoscale and their consequent engineering in devices to improve current methods/devices sensitivity. Presently color centers photo-physics and atomistic properties are by far better known when embedded in bulk material rather than in their nanomaterial counterpart, where coherence time and spectral diffusion are still a limitation. In this talk I will address the challenges, advances and perspective of the integration of the above color centers and their useful properties within nanoscale systems such nano/micro cavities, metamaterials, nano-optical mechanical systems.

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Women and Men in Nanoscale Quantum Optics: Is there a difference in our career opportunities?

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Gender balance is an important topic for the COST Nanoscale Quantum Optics Action. At 15% women are in a clear minority, and at first glance, it appears unclear why this is. Some blame the lack of women taking physics and engineering at high school and university. However, while in a similar subject, biology, the numbers taking the subject at undergraduate level are approximately equal, the numbers of physics and biology professors remains equally low. Something else is going on: fewer women make it up through the ranks. Why this happens is the subject of much debate, but much research has been done on the subject. There is clear evidence that implicit bias, the perceived lack of ease of combining work and family life and a lack of mentorship and networks for women all play a role.

To understand the perception of the difficulties faced by women in the field, and how this compares to sociological research, we conducted a survey [1] of both men and women in the Action. I will present the findings of this survey and explain what we have subsequently done to address the findings. In the Action we have run information sessions which give an overview of the research that has already been done, but we also run discussion sessions in a safe environment where all participants have the opportunity to discuss in an equal setting their own experiences and perceptions of key issues, such as sexual harassment, the role of affirmative action, and the issues that arise with combining a family and a scientific career.

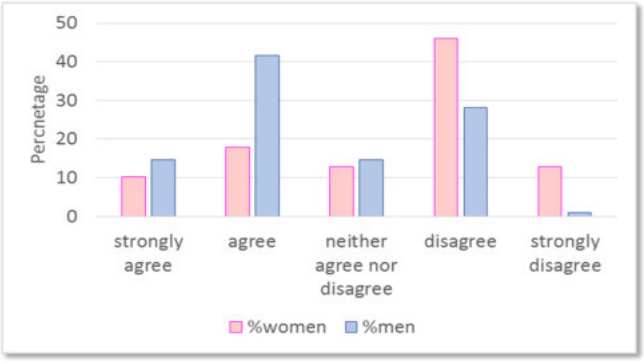

Figure 1. Responses of women and men to the question "Women and men in your field have equal opportunities for career advancement"

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[1] See report on the survey, and all references therein: http://www.cost-nqo.eu/wp-content/uploads/2016/10/COST-NQO-Gender-Survey_1010.pdf

Session 2: WG1

Isolating and enhancing the emission of single erbium ions using a silicon nanophotonic cavity

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The ability to distribute quantum entanglement over long distances is a vital ingredient for quantum technologies. Single atoms and atom-like defects in solids are ideal quantum light sources and quantum memories to store entanglement. However, a major obstacle to developing long-range quantum networks is the mismatch between typical atomic transition energies in the ultraviolet and visible spectrum, and the low-loss propagation band of optical fibers in the infrared, around 1.5 μm. A notable exception is the Er^{3+} ion, whose 1.5 μm transition is exploited in fiber amplifiers that drive modern communications networks. However, an optical interface to single Er^{3+} ions has not yet been achieved because of the low photon emission rate, less than 100 Hz, that results from the electric dipole-forbidden nature of this transition. Here, we demonstrate that the emission rate of single Er^{3+} ions in a solid-state host can be enhanced by a factor of more than 300 using a small mode-volume, low-loss silicon nanophotonic cavity. This enhancement enables the fluorescence from single Er^{3+} ions to be clearly observed for the first time. Tuning the excitation laser over a small frequency range allows dozens of distinct ions to be addressed, and the splitting of the lines in a magnetic field confirms that the optical transitions are coupled to the Er^{3+} ions' spins. These results are a significant step towards long-distance quantum networks and deterministic quantum logic for photons, based on a scalable silicon nanophotonics architecture.

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Superconducting nanowire single-photon detectors in a racetrack cavity

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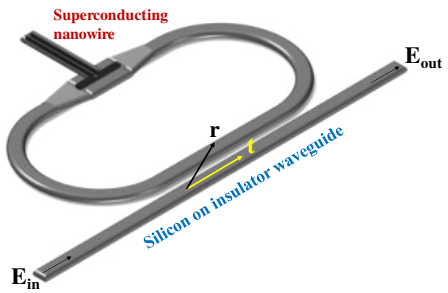
Single photon detectors (SPDs) and photon filters are amongst the fundamental building blocks of quantum photonic circuits [1]. Silicon with the availability of existing foundries offers a promising platform for the circuitries. To date, superconducting nanowire single-photon detectors (SNSPDs) offer unprecedented performance in detection efficiencies, dead times and timing jitter [2]. As SNSPDs can be integrated with waveguides, they are an ideal technology for quantum optics [3]. In our previous work, we have studied a cavity-enhanced SNSPD design on the silicon-on-insulator (SOI) platform [4]. The design utilizes a critically coupled racetrack ring resonator and a bus waveguide, which traps the photon in the cavity and enables it to make multiple round trips to be absorbed. This results in high detection efficiencies >95% with niobium nitride (NbN) nanowires. Here, we expand on this work for practical implementations. We study a multi-mode interferometer (MMI) based crossing in a SOI ring cavity as presented in the figure. The MMI-based crossing can be etched in the same step as the waveguides and allows NbN nanowires to be connected to contact pads for electrical bias and readout without introducing significant backscattering (-40 dB). The characteristic focal-point (self-imaging point) of an MMI forms in the centre of the design where we place the nanowires and at the second self-imaging point is connected to a waveguide (see Fig. 1). By using this design, we can transmit the light with a transmission loss as small as 0.05 dB and a crosstalk of -28 dB. Due to a large region of electric field at the focal point, various lengths of detector can be designed in the ring cavity at critical



Superconducting nanowire detector in cavity

coupling regime by tuning the coupling ratio between the bus and the ring waveguides at various reflectivities, r (or transmissivities, t=1-r). This allows tuning of the cavity linewidth through the NbN detector length for single-photon spectrometer [4]. Furthermore, since high detection efficiencies can be reached with small nanowires in the cavity, this scheme is expected to improve aspects of NbN SNSPDs such as yield, which generally arises from inhomogeneity when using longer nanowires [5]. I will also discuss our recent study on short wavelength infrared (SWIR) detectors around 2.1 μm which are promising for silicon photonics to eliminate two-photon absorption as well as leading to a high dispersive nonlinearity.

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The Influence of Electron-Phonon Interaction on Single Photon Emission from Defects in Hexagonal Boron Nitride

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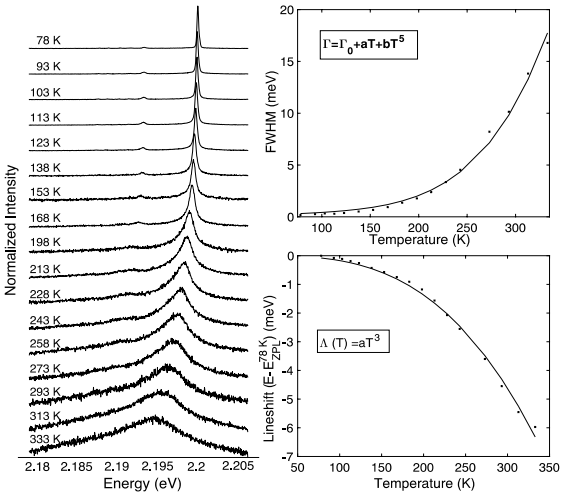
Single photon sources are important building blocks for several applications in the field of quantum information technologies. Solid-state systems including semiconductor quantum dots, defects in bulk 3D crystals such as diamond, and 2D transition metal di-chalcogenides are widely used materials as single photon sources. Recently, defect centers in hexagonal boron nitride (hBN) have attracted great attention due to its narrow and bright emission at room temperature [1].

In this work, we present the results of our study on zero-phonon line (ZPL) and its acoustic phonon sidebands in the emission spectra of a single defect in hBN. Photon correlation experiments at room temperature revealed a clear photon anti-bunching from ZPL emission, which proves the single quantum emitter nature of the defect. Emission spectrum also shows characteristic features of phonon density of states of hBN crystal even at room temperature. To understand the emission mechanism of defects in hBN, we performed temperature dependent micro-photoluminescence experiments and observed a clear linewidth narrowing and lineshift of the ZPL emission. A phonon assisted lineshape model with continuum of phonon modes interacting with electronic states of a single defect is applied to the observed spectra [2]. Excellent agreement between the experimental results and the theoretical calculations reveals that the theoretical model can be used to calculate the Debye-Waller and Huang-Rhys factors accurately, both of which are used to determine the potential of ZPL emission from a solid-state system.



Temperature dependent spectra of a defect in hBN

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Single photon sources for integrated quantum photonics based on organic molecules

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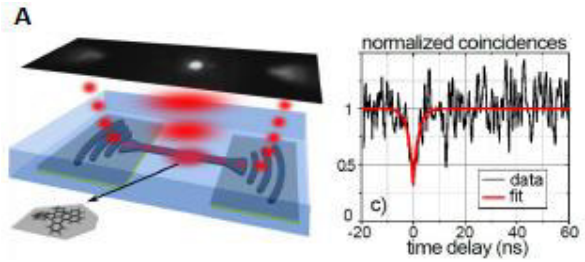
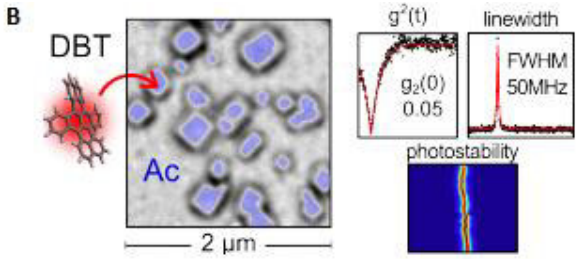
Efficient quantum light sources are basic ingredients for photonic quantum technologies. On the other hand, on-chip integration is necessary to envision a scalable platform for quantum information and communication. In the first part of this contribution we demonstrate the potential of a novel hybrid technology which combines single organic molecules as quantum emitters and dielectric chips, consisting of ridge waveguides and grating far-field couplers [1] (panel A in figure). Dibenzoterrylene molecules (DBT) in anthracene crystals (Ac) are particularly suitable quantum systems for this task, due to outstanding photophysical properties [2,3] demonstrated both in bulk and in samples as thin as few tens of nanometers. Here the emitters are integrated by spin-coating onto the photonic chip. We demonstrate at room temperature the emission of single photons from DBT molecules into ridge waveguides with a branching ratio up to 40%, corresponding to an estimated on-guide brightness around 50MHz for CW pumping at saturation. These results are competitive with state-of-the-art single photon emission into propagating guided modes from solid state systems [4,5], while offering a novel platform with high versatility.

In order to surpass evanescent coupling and address the challenge of deterministic positioning, we have developed a single-photon source based on Ac nanocrystals [6] (average size of 200 nm) doped with DBT molecules (panel B). Nanocrystals (NC) are naturally prone to the integration in hybrid devices, including heterostructures and complex photonic devices, and can be useful for quantum technologies in general. In the second part of our contribution, we report

on the unprecedented performances of single-photon emission from NCs in terms of spectral and intensity stability and emission purity, both at room and at cryogenic temperature. Moreover, when cooled down to 3 K, the 00-zero phonon line shows linewidth values (50 MHz) close to the lifetime-limit [7].



A: non-classical light detected from couplers



B: optical characterization of DBT:Ac nanocrystals

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Photon statistics beyond $g^{(2)}$ for quantum dot ensembles

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The intensity autocorrelation function $g^{(2)}$ is a powerful tool to characterize the statistical properties of light, and is frequently used to characterize single photon emitters. The light emission of a mesoscopic ensemble of emitters, e.g. quantum dots, coupled to a cavity can result in the emission of a complex non-classical light field, which requires more statistical information for a valid description. We show that the application of quantum state tomography to an ensemble of emitting quantum dots allows us to reconstruct the Wigner function, i.e. quantum-optical quasi-phase space distribution of the emitted light [1]. Equivalently, we can extract the full photon statistics from our data, which contains $g^{(2)}$ as one of its moments. We apply the technique characterize the thermal to coherent emission transition of an electrically pumped quantum dot semiconductor optical device amplifying a coherent input laser pulse [2]. We show that our technique reaches a resolution of <3 photons, making it a complimentary option to standard Hanbury Brown-Twiss experiments in the characterization of few-emitter systems.

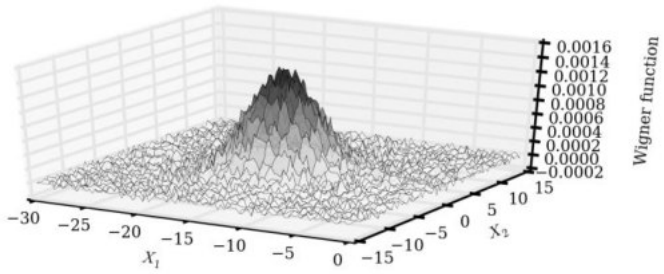

FIGURE: WIGNER FUNCTION OF A COHERENT STATE OF LIGHT AFTER PROPAGATING THROUGH AN ELECTRICALLY PUMPED QUANTUM DOT AMPLIFIER**.**

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A fiber-coupled source of identical single photons

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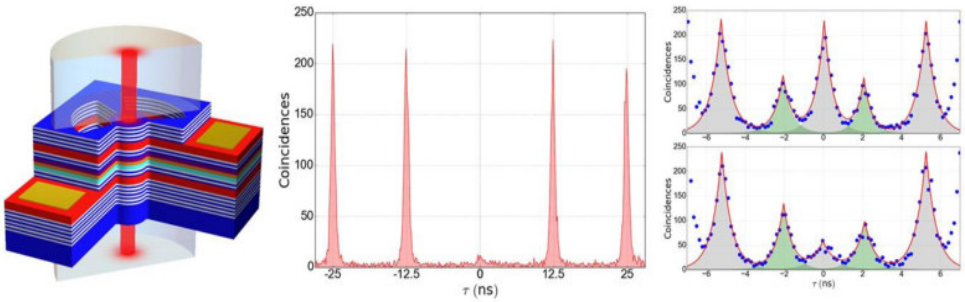
Photonic quantum networks require high quality single photon sources for parallel quantum information processing. To enable the use of many single photon sources in complex photonic networks, it is essential that these sources can be integrated easily and efficiently with optical fiber technology. Here, we demonstrate such a fiber-coupled single-photon source, in the form of an InGaAs quantum dot coupled to a resonant optical cavity [2]. The source is operated by resonant optical pumping through an excitation fiber; single photons are collected in a single-mode fiber attached to the transmission channel of the cavity (see left hand figure). Polarization and voltage tuning are used to optimize the device and remove the pump light.

The performance of any single photon source is characterized by three measurable quantities [1]: (i) the single-photon purity, characterized by the intensity correlation function $g^{(2)}(0)$, (ii) the photon indistinguishability, characterized by two-photon interference, and (iii) the brightness (= absolute probability to have a single photon). We obtain a stream of single photons with a purity of 97%, 90% indistinguishability and a brightness of 4%, which corresponds to a single photon rate of 3 MHz.



Scheme of the fiber-coupled device (left), single photon purity measurement (middle), photon indistinguishability measurement (bottom right), and control measurement (top right)

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Quantum Communications protocols

aimed to photonics integration

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The paradigm shift that Quantum Communications represent vs. classical counterpart allows envisaging the global application of Quantum Information protocols as the cryptographic key distribution as well as of the use of the qubits as a probe for fundamental tests of Quantum Mechanics and Gravity on a scale beyond terrestrial limits. In parallel, the genuine randomness that may be extracted using elementary quantum processes is expected to provide gigabit rate of random numbers suitable for valuable applications.

Moreover, Quantum Communications on planetary scale require complementary channels including ground and satellite links. As the fibre QKD progressed up to commercial stage using fiber-cables, it's crucial the study of links for space QC and eventually the demonstration of protocols such as quantum-key-distribution (QKD) and quantum teleportation along satellite-to-ground or intersatellite links.

We shall report on the protocols of the Quantum Communications and Quantum Random Number Generators suitable to be scaled to microoptics using integrated optical technologies and made suitable for the space payloads for the long distances links. Temporal modes were also used to demonstrate the quantum interference along a Space channel will be also described. The recent results on the extension to Space of the Gedankenexperiment proposed by John Wheeler on the wave-particle duality, then about the very nature of the quantum entities, will be described and the technique introduced there exploited in practical applications.

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Session 3: WG3

Quantum Maxwell's demon, quantum information and weak values in scattering and elementary interactions

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Quantumness of correlations in its various facets [1] (e.g. quantum discord, entanglement, quantum Maxwell's demon, measurement induced disturbance, etc.) provide novel insights in quantum-information processing, quantum thermodynamics, nanoscaled quantum systems, complex materials, etc.

In the theoretical part of the talk, we explore a new effect of quantumness of correlations accompanying a sufficiently fast collision of two quantum systems *A* and *B*, the latter interacting with (or being "actively observed" by) an environment (or a *"Maxwell's demon"*) *D* [1]. In clear contrast to a classical *D* , the quantum case can exhibit new counter-intuitive features, e.g. momentum and/or energy transfer which contradict every conventional expectation.

As an example, the experimental part of the talk shows experimental evidence of a *quantum deficit of momentum transfer* and/or *enhanced energy transfer (*or, equivalently: *reduced effective mass*) in an elementary neutron-molecule collision. The experimental method is incoherent inelastic neutron scattering (INS), available at neutron spallation sources (e.g., SNS, Oak Ridge, USA). This INS-effect was recently observed [2] on single H_2 molecules confined and physisorbed in multi-walled carbon nanotube channels with diameter ~10 Å. The INS results, if interpreted within conventional theory, reveal a strikingly reduced effective mass for the recoiling H_2 molecule, i.e. M = 0.64 ± 0.07 amu (atomic mass units). This is in blatant contrast to that of a completely free recoiling H_2 for which the mass must be 2 amu.

In contrast, the finding has a "first principles" qualitative interpretation within modern theory of quantumness of correlations [1].Namely, erasure of quantum correlations by the "participating" Maxwell's demon --- here: between the collisional neutron-H system and the „bath " of degrees of freedom of the C-sheets interacting with H_2 --- may have *negative* energetic costs [3,1]. Thus this phenomenon supports once more the well-known *Landauer's Principle*: "Information is physical". A semi-qualitative

analysis of the measurement reveals, for the first time, *the number of (erased) quantum bits* of information describing the H_2-C-sheet interaction.

Moreover, a quantum-mechanical interpretation based on Aharonov's theory of *Weak Values* (WV; see e.g. [4]) can shed additional light on the considered experimental observation. Analysed in the WV-theoretical context, the experimental result determines experimentally (or: measures), for the first time, the *overlap* of the initial-state wavepacket with that of the final-state of the recoiling H_2 (in momentum space).

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Color Centers as Atomic-sized Sensors for Nanoscale Fields

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Nitrogen vacancy (NV) centers in diamond are versatile, atomic-sized sensors for magnetic fields and optical near fields [1]. They offer the highly-advantageous combination of an optically-readable electronic spin for magnetic sensing and stable, bright, dipole-based photoluminescence even from individual centers. Truly nanoscale sensing demands scanning probe techniques that reliably position an NV in a distance of less than 50 nm to the investigated sample [2]. Furthermore, high photon rates from single NVs enable sensing with high sensitivities.

Consequently, nanoscale sensing demands NV centers close to diamond surfaces (shallow NV centers) placed inside tip-like photonic nanostructures like e.g. pyramids [3] and nanopillars (Fig. 1). Here, we present our recent results on simulating, fabricating and characterizing nanostructures enabling high photon rates for shallow NVs. We use numerical simulations to optimize scanning probe and pillar geometry and consider fabrication effects like, e.g., trenches forming around the pillar during reactive ion etching. We investigate PL lifetimes, coherence times and photoluminescence intensity for individual NV centers in our nanostructures. For the first time, we demonstrate the near-field interaction of shallow NVs in an un-structured single crystal diamond with graphene flakes spin coated onto the surface leading to lifetime and fluorescence reduction of the NVs.

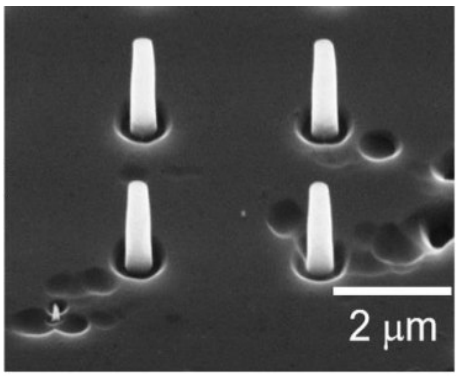

Fig. 1: Diamond nanopillars sculpted from single crystal diamond.

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Geometric phases in weak measurements using a quantum eraser and their Bloch sphere representation

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In a weak measurement, an ensemble of systems is pre-selected in an initial state which then interacts weakly with a device probing an observable $\hat{A}$. Afterwards, a final state is coherently post-selected by a strong measurement of another observable of the systems. In the usual configuration, the observed deflection of the measuring device (as in a Stern-Gerlach experiment, for example) is related to the real part of the weak value $A_w = \langle f | \hat{A} | i \rangle \langle f | i \rangle^{-1}$, which is a complex, unbounded number that can fall outside the range of the eigenvalues of the observable $\hat{A}$. Using polarization-entangled photons pairs produced by spontaneous parametric downconversion, we measured and provided an interpretation of the weak values of Pauli observables in terms of their modulus and argument. The modulus is linked to the visibility in our interferometric experiment exploiting a quantum eraser, while the argument corresponds to a geometric phase similar to the Pancharatnam phase of classical optics [1], which we relate to a solid angle on the Bloch sphere.

Furthermore, we extended our theoretical description to *n*-level systems using the Majorana representation. This allowed us to describe the measurements of pre- and post-selected *n*-level systems in terms of symmetric states of *n*–1 qubits. This provided us with a geometric description on the Bloch sphere of the topological phase acquired in weak measurements that use qubit meter systems [2]. Besides the investigation of fundamental questions, we are currently working towards exploiting these methods to probe interfaces and other nanoscale structures.

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Construction and driving of robust qubits in the solid state

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The reliable and efficient construction and manipulation of qubits is necessary for the implementation of quantum technology applications and quantum information processing. Ambient field fluctuations constitute a serious impediment, which usually limits the coherence time to a small fraction of the lifetime limit. Dynamical decoupling has been proven to be very useful in prolonging the coherence time, but typically such schemes suffer from technical noise. In order to mitigate both, environmental and technical noise, very rapid and composite pulse sequences must be applied, but their incorporation with other operations is challenging and requires a large field strength. Another possibility to suppress environmental noise is offered by continuous dynamical decoupling [1].

In this contribution, we present a novel scheme for the construction of a qubit from the three-level system [2]. A combination of on-resonant and off-resonant drive fields serves as concatenated continuous dynamical decoupling, producing doubly dressed qubit states for which robustness to environmental noise is achieved and driving noise is eliminated. We demonstrate our scheme on the paramagnetic ground state of the negatively charged nitrogen-vacancy center in diamond. With moderate Rabi-frequencies, we demonstrate that drive noise is completely eliminated and that an improvement of two orders of magnitude in the coherence time can be obtained. Our theoretical model predicts that with stronger drive fields the coherence time may be extended by three orders of magnitude and approach the lifetime limit of the system.

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Entanglement generation in mesoscopic photonic systems

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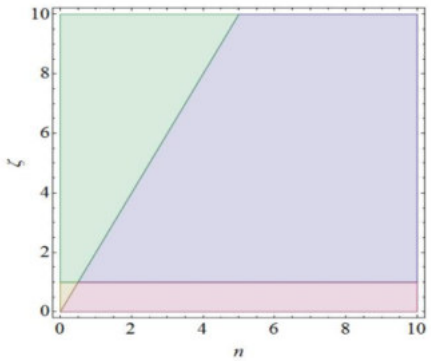
We report on the study of the generation and amplification of entanglement in photonic mesoscopic systems, such as a nano-ring ressonator, coupled to a parametric coherent source. Our model, considers evolution equations for the state of the systems are obtained using a Lindblad master equation and solved analytically and numerically for some specific parametric modulations, considering Gaussian states, thus allowing the identification of the best conditions for the generation of entanglement, in terms of the parameters of the thermal bath and of the modulation. Indeed and although entanglement is perhaps the most relevant resourse behind quantum technologies, from quantum computation to metrology, the generation, transmission and manipulation of entanglement in nanoscale photonic and plasmonic systems and devices at high or room temperature and devices constitutes an important conceptual and experimental challenge, mainly due to nefarious impact of decoherence and losses.



Regions displaying different dynamical regimes as a function of the average number of thermal photons, n, and the parameter ζ, that corresponds to the relative coupling of the system to parametric source and to the bath. Each region corresponds to a different dynamical regime, and in particular in the green region there is amplification of entanglement.

R&D of diamond technology for optics and photonics

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Synthetic polycrystalline diamond (PCD) films are routinely grown not only for basic research but also for industrial uses in multi-disciplinary fields such as life science, mechanics, sensorics or bio-chemistry [1]. The high optical transparency in the infrared (IR) region, the high refractive index and low optical absorption open the way to the implementation of diamond films as optical elements operating in extreme conditions. In this work we will present novel diamond based optical elements suitable for IR spectroscopy, optical waveguides and photonic crystals with enhanced directional PL for visible and near IR region. First, the PCD coated Au mirrors revealed an excellent optical transparency in IR spectral region [2,3]. We have shown that Au mirrors coated with nanostructured diamond enhanced the detection sensitivity. Ultra-thin molecular layers of organic molecules (<5 nm) were easily detectable using grazing angle reflectance IR spectroscopy [4]. Moreover, the absorption sensitivity has been also enhanced by multiple reflections in the attenuated total reflection regime using PCD-coated Si or Ge prisms [3,5]. Next, PCD based planar optical waveguides were fabricated on SiO_2/Si substrates with a potential uses as multimode interference demultiplexer [6]. Their high-index-contrast optical waveguiding properties were confirmed by prism coupling technique. Such a device guided one fundamental mode for five measured wavelengths. Finally, PCD-based photonic crystal (PhC) slabs with broadband and efficient directional light emission were fabricated. Employing electron beam or microsphere lithography and reactive ion etching, PhCs with subwavelength lattice constants were fabricated and successfully used not only to enhance the light emission but also to collimate it in the direction normal to the sample plane [7,8].

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Super-Radiance, Lasing and (Beyond) Strong Coupling in Plasmonic Nano-Structures

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Hybridisation of quantum emitters and plasmonic nano-structures has attracted much attention over the last years, due to their interest in the design of plasmon-based nano-lasers [1,2] or to achieve long-range qubit entanglement [3,4]. Recent theoretical studies [5,6] suggest a plasmonic super-radiant mechanism to increase the rate of emitters, similar to Dicke super-radiance [7].

In this talk, we will report a review of our work in these domains and explain the salient features of the involved effects. As such, i) we provide experimental evidence of plasmonic super-radiance of organic emitters close to a metal nanosphere at room temperature. This observation of plasmonic super-radiance at room temperature opens questions about the robustness of these collective states against decoherence mechanisms which are of major interest for potential applications.

ii) We propose a new type of nano-device, capable of both path-selectivity and anisotropic lasing that is based on loss- compensation and amplification by a localized plasmon polariton [8]. The nano-device is a Y-shaped plasmonic nanostructure embedded in an anisotropic host medium with gain. The anisotropy leads to the path selectivity, an effect which is more pronounced once gain is included. The path-selectivity may be coupled with activation of a rotation of the anisotropic host medium for inducing a light-guiding switching functionality.

Finally, iii) we demonstrate both experimentally and theoretically how to manipulate strong coupling between the Bragg-plasmon mode supported by an organo-metallic array and molecular excitons in the form of J-aggregates dispersed on the hybrid structure [9]. We observe experimentally the transition from a conventional strong coupling regime exhibiting the usual upper and lower

polaritonic branches to a more complex regime, where a third nondispersive mode is seen, as the concentration of J-aggregates is increased. The numerical simulations confirm the presence of the third resonance. We attribute its physical nature to collective molecule-molecule interactions leading to a collective electromagnetic response. It is shown that at the energy of the collective mode molecules oscillate completely out of phase with the incident radiation acting as an effective thin metal layer.

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Session 4: Industry &

COST Actions

Commercialising Quantum Components: Optical microcavities for sensing applications

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In experimental quantum science we put a lot of effort into developing new techniques and apparatus that will give the control and sensitivity required to observe interesting new quantum effects or to harness quantum effects in the study of new materials. These developments can sometimes provide quite fundamental capabilities which can find applications beyond those originally envisaged. This talk will describe our efforts towards commercialising quantum components in the form of optical microcavities for use in chemical and nanoparticle sensing.

In Oxford our interest in quantum science and technology using quantum dots and diamond colour centres motivated us to develop new techniques for the precise fabrication of tunable open microcavities to control the light-matter interaction. Via some exploratory work we have been able to show that these resonators make excellent sensors for chemicals and nanoparticle in fluids which could be used in a wide range of applications, and that the fabrication methods meet the requirements for manufacturing robust commercial products. We have identified target markets and are now in the process of spinning out a company, Oxford HighQ Ltd, to develop these sensors commercially. As well as sensor instruments and devices, Oxford HighQ will bring to market the components themselves, so that they can become part of the toolbox for micro-optics and quantum technology research labs.

In this talk I will introduce the technology, describe the rationale for spinning out a company as the preferred route for commercialisation, and discuss some of the application areas that we anticipate the technology will address.

Efficient solid-state Quantum light sources for Quantum Technologies

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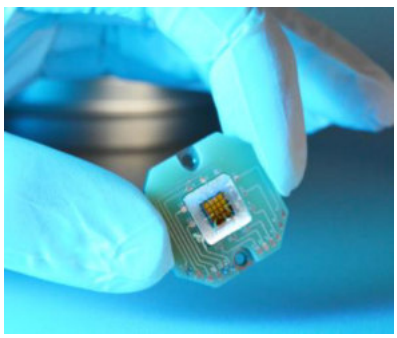
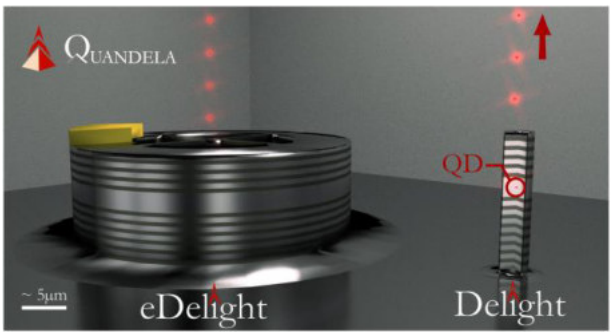
Quandela is a spinoff company from the Center for Nanoscience and Nanotechnology (C2N - CNRS/Univ. Paris-Sud) founded in 2017. Our objective is to commercialize top-class quantum light sources to boost the research in quantum optics, to allow the emergence of further innovations in photonics and to participate to the scaling up of quantum technologies outside the academic world.

One of our first products is **Delight**, a single-photon source device based on solid-state technology: it emits single photons in the infrared with an exceptional efficiency--- typically 75% against few percent for competitive technologies--- providing an effective rate of single photons up to 300 MHz. This technology could be applied to obtain record rates of on-demand photons even at telecom wavelength for future quantum communications.

By designing a unique architecture of the photonic structure, which allows for the insertion of electrical contacts, we also built **eDelight:** an electrically controlled source of ultra-pure photons. By means of an applied voltage, we reduced the charge noise and obtained bright emission of highly identical photons, an essential requirement for the development of the most advanced quantum applications (quantum simulations, computation, sensing…). Such source permits the exponential scaling up of quantum protocols requiring a large number of identical photons

In this talk I will give a brief overview about the technology at the core of Quandela, discuss how our devices can allow scaling up optical quantum technologies confirming the increasing importance of solid state single-photon source as cornerstone for the forthcoming developments of quantum technologies.





Introduction to deep tech hardware Venture Capital

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Venture Capital (VC) is a sub-class of Private Equity financing and is characterized by investments made for the purpose of developing, launching, and expanding the commercialization of new products or services.

Venture Capital has long been a necessary lubricant in the success stories of high-tech business initiatives and a key ally for technologists turned entrepreneurs. The presentation will provide an introduction to the world of Venture Capital, and will address issues related to how VC can positively impact the lifecycle of high-tech startups and support a business initiative in its early days.

Special attention is paid to quantum technology related startups and use cases based on hands-on experience of Quantum Wave Fund, investor of 10+ deep tech startups including ID Quantique (Switzerland, quantum communication developer).

Quantum Technologies in Space

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The scientific and technological legacy of the 20th century includes milestones such as quantum mechanics and pioneering space missions. Both endeavours have opened new avenues for the furthering of our understanding of Nature, and are true landmarks of modern science. Quantum theory and space science form building blocks of a powerful research framework for exploring the boundaries of modern physics through the unique working conditions offered by experimental tests performed in space.

Space-based sources of entangled photons promise the formation of global quantum communication networks, long-distance tests of quantum theory and the interplay between relativity and quantum entanglement.
Long free-fall times enable high-precision tests of general relativity and tests of the equivalence principle for quantum systems.
Harnessing microgravity, high vacuum and low temperature of deep space promises allowing the study of deviations from standard quantum theory or high-mass test particles. Space-based experiments of metrology and sensing will push the precision of clocks, mass detectors and transducers towards the engineering of novel quantum technologies**.**
Such an exciting framework is what "Quantum Technologies in Space (QTSpace)" aims at providing. QTSpace will embody a visionary opportunity for furthering the comprehension of fundamental mechanisms of physics in an entirely new context.

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www.qtspace.eu

COST Action MP1302 Nanospectroscopy

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The COST Action MP1302 Nanospectroscopy aimed at gathering European expertise in order to further develop UV/Vis/NIR/Raman nanospectroscopic techniques and modelling with (ultra-)high spatial, temporal, and spectral resolution and sensitivity, and the application of these techniques to novel (hybrid) (in)organic nanomaterials, complex device structures, and biosystems. With interdisciplinary efforts the Action targeted progress in designing new nanospectroscopic techniques, further technical development of established techniques, theoretical understanding and data processing, basic knowledge of light-matter interaction and energy flow at the nanoscale, and a boost in the manipulation of complex nanosystems. It encompassed the following Working Groups:

- WG 1 - System Design and Nanofabrication
- WG 2 - Physical Processes and Modelling
- WG 3 - Improving Spectroscopic Techniques
- WG 4 - Preparation of a Coherent Textbook on Optical Nanospectroscopy

The Action hosted a joint Training School with the COST Action NQO in 2017. It recently ended after a running time from November 15, 2013 to November 14, 2017. This presentation by the Action Chair will summarize the Action's goals and activities. An overview over the Action events will be given, discussing the merits of different networking tools. The outcomes of the COST Action will be highlighted.

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Molecular spins for quantum technologies

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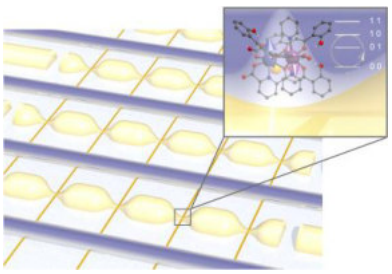

Magnetic quantum processor

Molecules are microscopic, yet they remain "tuneable". Their relevant properties can be set at the molecular scale by the tools of chemical design and chemical synthesis. This ability opens prospects in the field of spintronics [1], for instance to replace an inorganic material with an organic one showing enhanced properties (e.g. a higher electron coherence length) or to modify the interfaces between different components and eventually introduce additional electronic, magnetic, or optical functionalities. It is also possible to think of individual molecules as electronic components and devices in themselves.

In this talk, I'll focus on the application of artificial magnetic molecules to quantum technologies. A first goal is to create molecular analogues for the elementary units of a quantum computer. In the past few years, it has been shown that simple molecules, embodying a single paramagnetic ion, perform as spin qubits with long coherence times, approaching the ms scale. Realizations of two- and three-qubit gates, and even of simple quantum algorithms, have been achieved in molecules with multiple inequivalent spin centers and/or profiting from the internal (nuclear or electronic) spin degrees of freedom of these centers. Even more challenging is to create a scalable architecture for quantum computation and simulation, as it necessarily implies the controlled integration of individual molecules into quantum circuits. A promising scheme is based on circuit QED, that is, on "wiring-up" molecular spins via microwave photons trapped in superconducting on-chip resonators [2].

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Session 5: WG4

Correlated dissipation: inhibiting atomic decay via cooperative dynamics

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Dissipation is a pervasive problem in many areas of physics. In quantum optics, losses curb our ability to realize controlled and efficient interactions between photons and atoms, which are essential for many technologies ranging from quantum information processing to metrology. Spontaneous emission - in which photons are first absorbed by atoms and then re-scattered into undesired channels - imposes a fundamental limit in the fidelities of many quantum applications, such as quantum memories and gates. Typically, it is assumed that this process occurs at a rate given by a single isolated atom. However, this assumption can be dramatically violated: interference in photon emission and absorption generates correlations and entanglement among atoms, thus making dissipation a collective phenomenon. In this talk, I will provide a comprehensive look into the physics of subradiance, an emergent form of correlated dissipation in which interference is destructive and atomic decay is inhibited. In atomic arrays in free space, subradiant states acquire an elegant interpretation in terms of optical guided modes, which only emit due to scattering from the ends of the finite system. By interfacing atomic chains with nanophotonic structures, these states can be excited straightforwardly. Exploiting their radiative properties allows for the realization of a quantum memory with a photon retrieval fidelity that performs exponentially better with number of atoms than previously known bounds.[1]

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Tunable optical analogues using quantum optical systems

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In the paraxial approximation, the propagation of light in a bulk nonlinear media is well described by a Nonlinear Schrödinger equation which, by taking the Madelung transformation, can lead to the well-known hydrodynamic description of light. This interpretation maps the laser intensity into a fluid density and the spatial phase gradient into a fluid velocity. In the recent years, the similarity of the hydrodynamic interpretation and the mean field theory of Bose Einstein Condensates opened new perspectives in different branches of physics and in particular in the field of the optical analogues. Indeed, in theory, this analogy seems to offer tabletop experiments of analogue many-body quantum systems with unprecedented control of the interactions which can be used to mimic a wide range of phenomena in physics, from superfluidity[1] to Black Holes[2].

Still, the realization of these tabletop optical analogue experiments relies on the engineering of suitable optical media, with specifically tailored optical properties. In this work we explore theoretically how quantum atomic optical systems, and in particular a 4-level quantum optical system[3], can constitute a highly tunable optical media, with enhanced nonlinear properties due to quantum coherence phenomena. Moreover, we also investigate the hydrodynamic description of light and the concepts of superfluidic behavior of light, as well as reviewing some of computational tools developed using GPU-enhanced platforms. Finally, we discuss how the versatility of such systems can be used to develop new optical analogue experiments and address other phenomena yet to be explored, such as the case of persistent currents[3].

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“Mechano-optics”: Role-reversal in optomechanical quantum simulators

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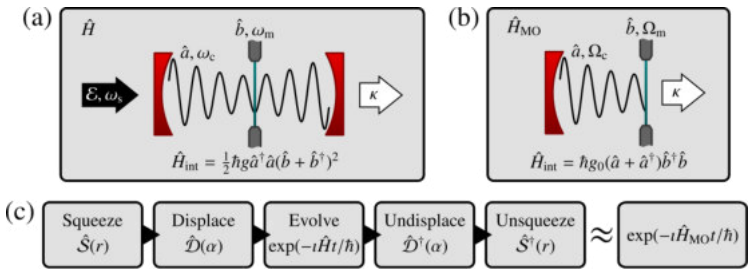
A widely-known paradigm in optomechanical systems involves coupling the square of the position of a mechanical oscillator to an electromagnetic field. We discuss how, in the so-called resolved sideband regime, this system allows to simulate dynamics similar to ordinary optomechanics, where the position of the oscillator is coupled to the field, but with the roles of the oscillator and the field interchanged. We show that realisation of this system is within reach, and that it opens the door to an otherwise inaccessible

One of the long sought-after goals of optomechanics is to demonstrate manifestly quantum-mechanical behavior in the motion of a macroscopic mechanical oscillator. This has given rise to proposals discussing how, for example, one may observe jumps in the occupation number of the mechanical oscillator by monitoring the electromagnetic field leaking out of a cavity [1]. The standard model within which this is explored is the so-called membrane-in-the-middle system [2], where a reflective membrane is placed at a node or antinode of a cavity field. This is the model that will form the basis of our work. It stands in contrast to the more widely-studied linear optomechanics model [3], where the most significant limitation is that the coupling strength is typically very small compared to the other frequency scales of the problem. This requires considering the case where the cavity field has a macroscopic coherent component. The key drawback of operating under these conditions is that the resulting Hamiltonian is, to a very good approximation, quadratic in the operators. As a result, initially Gaussian states (which are ubiquitous in nature and which tend to be quasi-classical) remain Gaussian at all times, making it exceedingly difficult to observe non-classical behavior. This is the problem that we will tackle in this paper.



We introduce a mechanical quantum simulator based on a quadratically-coupled optomechanical system. This system can effectively reproduce the dynamics of a standard optomechanical system, but where the roles of the optical and mechanical fields are switched, and where the single-photon coupling strength can be chosen by driving the system appropriately. As an example, we show how to apply our system to simulate the single-photon strong coupling regime, and have discussed its role in exploring instabilities in quantum systems. Our work opens the door to an entirely new use case for optomechanical systems.

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Photonic and Optomechanical Sensors for Nanoscaled and Quantum Thermometry

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Photonics and Quantum Optomechanics are two disruptive technologies which are experiencing an unstoppable progress that could help in facing up current metrology challenges. Photonic sensors use the light-matter interaction to measure temperature and other physical quantities via temperature-dependent material properties. A particularly exciting new development is the possibility of using nano-photonic devices in combination with nano-mechanical systems (optomechanical sensors) to produce quantum primary standards that use the scale of quantum energies determined by Planck's constant to measure the size level of thermal motion. [1] Here we will show some proposal aiming at developing photonic and optomechanical sensors for nanoscale and quantum metrology.

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Critical behaviour of laser-driven ultracold atoms in optical resonators

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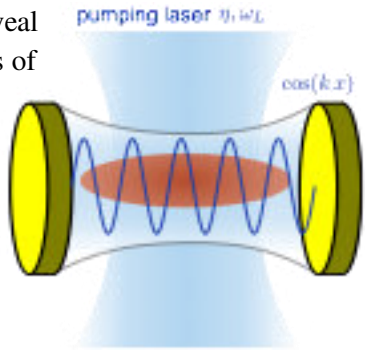
We demonstrate that criticality in a driven-dissipative system is strongly influenced by the spectral properties of the bath [1,2]. We study the open-system realization of the Dicke model, where a bosonic cavity mode couples to a large spin formed by two motional modes of an atomic Bose-Einstein condensate [3]. The cavity mode is driven by a high-frequency laser and it decays to a Markovian bath, while the atomic mode interacts with a colored bath. We reveal that the soft mode fails to describe the characteristics of the criticality. We calculate the critical exponent of the superradiant phase transition and identify an inherent relation to the low-frequency spectral density function of the colored bath. We show that a finite temperature of the colored bath does not modify qualitatively this dependence on the spectral density function.



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Super- and sub-radiance of coupled quantum emitters in confined light fields

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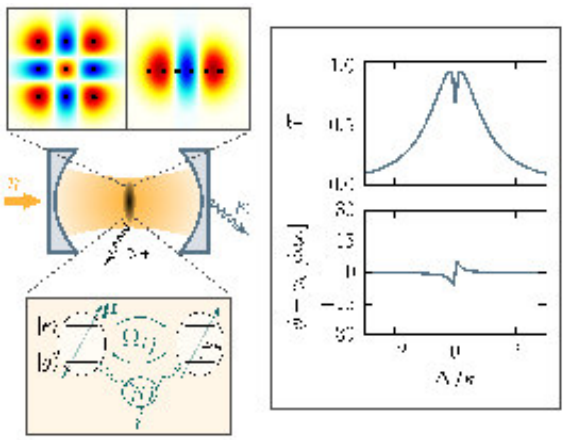
Spontaneous emission of atoms is modified by the presence of other atoms in close vicinity inducing collective super- as well as sub-radiance. The most sub-radiant states of pairs of two-level emitters are maximally entangled anti-symmetric singlet states. Selective addressing of these states can be the basis of improved precision spectroscopy. The idea can be generalized to atomic states with N > 1 independent spontaneous decay channels, where similar highly entangled states of at least N+1 particles can be found, which completely decouple from the vacuum radiation field. These will not decay spontaneously nor absorb any resonant laser light. Optimizing the geometry of dark states with respect to the spatial profile of a near resonant optical cavity mode allows to increase the ratio between collective light scattering into the cavity mode and free space by several orders of magnitude. The optimal effective collective cooperativity here exhibits a highly nonlinear particle number scaling increasing much faster than the typical linear scaling of independent emitters.



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Cavity QED in the non-perturbative regime

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We study a generic cavity-QED system where a set of (artificial) two-level dipoles is coupled to the electric field of a single-mode LC resonator. This setup is used to derive a minimal quantum mechanical model for cavity QED, which accounts for both dipole-field and direct dipole-dipole interactions. The model is applicable for arbitrary coupling strengths and allows us to extend the usual Dicke model into the non-perturbative regime, which can be associated with an effective finestructure constant of order unity. In this regime we identify and characterize three distinct classes of normal, superradiant and subradiant vacuum states and study the transitions between them. Our findings reconcile many of the previous, often contradictory predictions on this topic and provide a unified theoretical framework to describe ultrastrong coupling phenomena in a large variety of physically very different cavity-QED platforms.

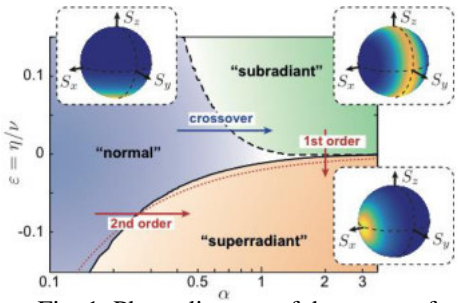

Fig. 1 Phase diagram of the vacua of cavity QED. For each of the three phases we show the corresponding dipole state represented on the Bloch sphere.

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Session 6: WG2

Light-Field-Driven Currents in Graphene

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Nonperturbative electron dynamics inside of solids under strong optical fields has recently found particular attention. Light-field driven effects such as high-harmonic generation and sub-optical-cycle interband population transfer have been reported for dielectrics and semiconductors. However, much less is known about strong-field phenomena in conducting materials. Graphene is an ideal playground for studying strong-field phenomena in a conductor because of its broadband optical response and its much weaker screening compared to conventional metals. Here we report a transition from a perturbative to a non-perturbative mechanism in generating optical-phase sensitive currents in graphene illuminated with few-cycle laser pulses [1]. We observed a carrier-envelope-phase (CEP) dependent current in graphene stripes excited with linearly polarized two-cycle laser pulses parallel to the graphene stripe with a peak field of up to 3 V/nm. The CEP dependent current changes its sign at around 1.8 V/nm with increasing the field strength.

We interpret this change in current direction as the result of a transition from a weak perturbative nonlinear response to optical-field-driven non-perturbative electron dynamics. For the weak field limit, odd-order multi-photon interference accounts for the generation of a CEP-dependent current, similar to well-known □-2□ interference. On the other hand, when the influence of the intraband dynamics to the interband transition cannot be neglected, this combined dynamics turns into a novel non-perturbative regime. In this strong-field regime, electron dynamics is governed by electron quantum-path interference that takes place on the 1-femtosecond timescale, causing changes in direction of the current. The process can be categorized as Landau-Zener-Stückelberg interferometry. In summary, light-field control of electrons in graphene is demonstrated, and a novel non-perturbative mechanism for conduction current generation is identified.

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Nanoscale amplification of high order laser harmonics in semiconductors

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We will present recent results in strong laser field science and nanoplasmonics. Our research is at the frontier of two large and highly successful fields of modern research: ultrafast laser science and nanoscale physics. It is motivated by the novel fundamental processes occurring while a semiconductor is submitted to a strong laser field. Electrons start to oscillate in coherence with the laser field. High order harmonics are emitting, carrying with them precious informations about the fundamental process[1-3]. Strategies to boost and control at a nanoscale this coherent phenomena is of recent focus[4-6]. We propose new routes in boosting the non-linear response using nanostructured photonic crystals. This is a very vast domain of research that encompasses all sorts of nano-objects, as well as meta-materials whose structure can be engineered so as to display some particular electromagnetic properties. Here, we present strong field amplification of a laser field in the terawatt regime to generate high order harmonics. Using our novel "nano-amplifiers", we have observed the amplification of high harmonics from mi-infrared laser-crystal interaction by up to 2 orders of magnitude. Field amplification through light confinement in nano-structured semiconductor 3D waveguides is demonstrated. Compared to previous works[6], high harmonic nano-converter consists of an array of zinc-oxide nanocones. Here, we extend enhancement of high harmonic generation in semiconductors to the highly non-perturbative regime. Amplification of up the 15th harmonic order is reported[7].

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arXiv:1709.09153

Nonlinear optical response of graphene and graphene derivatives

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During the past few years, graphene and graphene derivatives have greatly attracted the interest of the scientific community for their appealing mechanical, structural, chemical, electrical, and optical properties which can be exploited in numerous applications. Among the various fascinating properties they exhibit, their nonlinear optical properties are of high interest for photonic and optoelectronic applications as they are expected to find applications in lasers as mode-lockers, in optical limiting, in optical switching, for optical data storage devices, for optical computing applications, in solar cells and several other emerging needs. Among the most attractive features of these 2D carbon based nanomaterials is the tunability of their electronic/optoelectronic properties which can be achieved through the modulation of their bandgap. Today, it is well established that the bandgap of graphenes can be easily and effectively modulated following different strategies, providing photonic materials with custom tailored linear and nonlinear optical properties.

In the present work, we will present a summary of some recent results from our group concerning the nonlinear optical properties of different graphenes and graphene derivatives under nanosecond and picosecond laser excitations. In particular, the nonlinear optical response in terms of the corresponding nonlinear absorption and refraction of graphene (G), graphene oxides (GOs), some fluorographenes (CFs), some hydrogenated fluorographenes (CFHs) and some graphenes decorated with different linear chain- or aromatic ring- type organic molecules will be presented and discussed. In all cases the physical origins of the observed NLO response will be analyzed and discussed.

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Giant resonant ultrashort pulse polarisation rotation in a charged quantum dot – micropillar system

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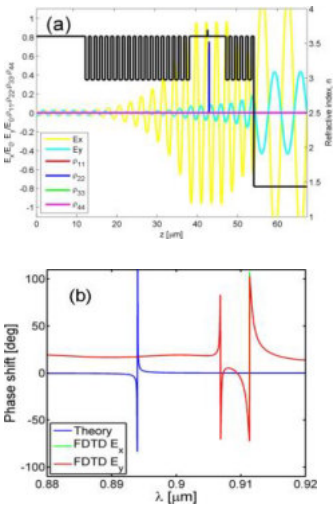
Realisation of a deterministic spin-photon entanglement in semiconductor quantum dots (QDs) is a major goal towards integrated quantum photonics. One promising approach is using the optical polarisation rotation induced by a single spin to prepare photon polarisation states with high-fidelity. Recently, a macroscopic Kerr rotation (~6°) has been observed using a CW excitation in both strong- and weak-coupling regimes [1] in a charged QD-micropillar system. This is, however, a modest achievement compared to predicted π phase shift [2].

We employ our Maxwell-pseudospin master equations [3] to compute the time evolution of an equivalent 4-level quantum system (mapping the trion transitions) under a resonant ultrashort circularly polarised pulse, taking into account the dominant spin relaxation processes. The system is initially prepared in either $|\downarrow\rangle$ or $|\uparrow\rangle$ state by optical pumping and a σ^- π-pulse (T_p ~ 100 fs) is injected through an optical fibre.



(a) Refractive-index profile of a QD-micropillar cavity; (b) phase shift of a σ^- pulse's E_x, E_y components

We demonstrate a giant (~±π/2) phase shift (b) in the circularly polarised pulse transmission spectrum in a realistic micropillar (a) in the weak-coupling regime. By contrast, when the trion transition is driven by a resonant *x*-linearly polarised pulse, a build-up of the pulse's E_y –component with time is shown resulting in a polarisation rotation and a spectral red shift leading to an effective rotation angle decrease. Such large rotation angles allow reliable detection of the initial spin state.

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White Light 2D Coherent Spectroscopy Reveals Crossed Excitons and State Coupling in InAs/InGaAs Nanostructures

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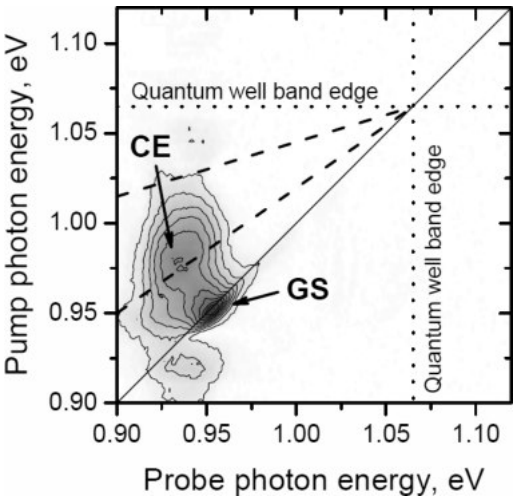
InAs/GaAs nanostructures are an established material system for the fabrication of opto-electronic devices. Beyond the excitonic transitions of quantum dots (QDs) and quantum wells (QWs), Crossed Excitons (CEs) are formed by a carrier confined in the QD and one in the surrounding QW [1] or bulk [2]. As optical transitions, CEs modify the excitation spectrum of the device [1,2], and as localized states, CEs have crucial impact on carrier diffusion dynamics and gain recovery [2]. Nanostructures in devices are convenient for the investigation of fundamental processes as they offer inversion control by electrical carrier injection [3].



2D spectrum of the unbiased SOA. Dashed lines indicate CE energies [2].

The contributing transitions are spread over a wide spectral range of more than 200 meV. To retrieve a detailed map of states and couplings, we developed a setup for two-dimensional coherent spectroscopy based on white supercontinuum-laser pulses and frequency-resolved heterodyne detection [3]. The method does not require active phase stabilization and can be applied in collinear geometry. We find pronounced signatures of CEs in the two-dimensional maps that allow for a quantitative determination of CE energies that is not possible based on simple pump-probe experiments [1].

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Quantum emitters coupled to pre-plasmonic and/or plasmonic nanostructures for quantum efficiency enhancement

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Single quantum emitters (QE) have become a common tool for the development of new light sources, such as lasers, LEDs, and single-photon sources, for electronic nanodevices. Among different possible QEs, rare-earth (RE) ions are particularly interesting for their intense room temperature emission as a two-level system. For instance Er^{3+} ions in silica emit at λ=1.54 μm where silica fibers exhibit the minimum losses. To this respect, the consistent development of a quantum network based on silica fibers strongly relies on the availability of single-photon sources at that wavelength. This demand makes Er^{3+} ions in silica a very interesting and promising quantum system for single-photon source development.

In this work, we studied the coupling of QEs with (i) pre-plasmonics and (ii) fully plasmonic nanostructures to achieve quantum emission enhancement. In the first case, we have investigated the non-resonant, non-radiative energy-transfer coupling between Er^{3+} ions in silica and quantum clusters (QC) of Ag or Au made of 10-30 atoms obtained by ion implantation [1-3], with a resulting enhancement of the Er^{3+} effective excitation cross section by 2-3 orders of magnitude. In the case of fully plasmonic nanostructures, we investigated the coupling between Er^{3+} ions with ordered arrays like Au NanoHole Arrays (NHA). By exploiting a tailored coupling with the extraordinary optical transmission (EOT) and the lattice modes, a reduction of the emission lifetime by a factor 2-3 is achieved (in quantitative agreement with FEM simulations), together with external quantum efficiency of about 0.9, with reduced losses and a high directionality in the emission pattern [4,5]. Finally, we demonstrated also a synergistic effect by combining the two approaches.

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SHG response in gold and aluminium antennas: where do non-local contributions play a major role?

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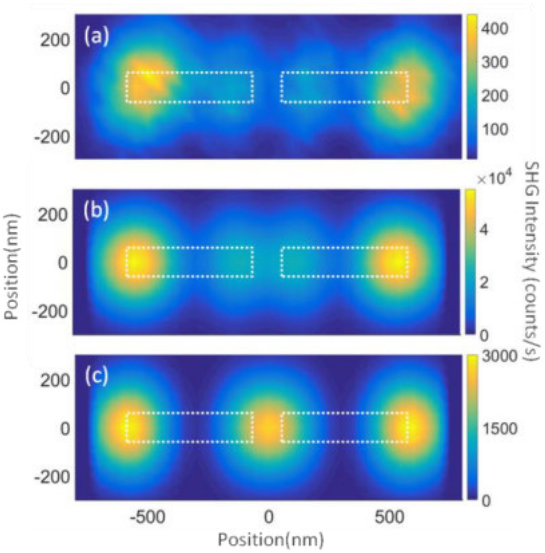
Abstract: We have investigated the origin of the optical second harmonic generation (SHG) process from gold and aluminum nanoantennas by comparing experimental and simulated far-field SHG maps. We demonstrate that the non-local contribution, linked to bulk nonlinear currents, can have a major impact in the SHG process in gold, in contrast with aluminum. This challenges many theoretical works using surface contribution only.

The second harmonic generation (SHG) is a second order nonlinear process in which two fundamental photons are converted into one at the incident half wavelength. Although centrosymmetric, metallic nanostructures exhibit a strongly SHG response which can be significantly enhanced thanks to localized surface plasmons resonances [1]. In single aluminum nanoantenna, we have shown that a doubly resonant regime can be achieved, enhancing the SHG signal by a factor of 36 [2].

The origin of nonlinear signal in metallic nanostructures is due to two different contributions: a local one due to the breaking of symmetry at the surface of the nanostructure and a non-local one due to the presence of field gradients in the bulk of the material [3]. In this work, we use rectangular, 35 nm high and 100 nm wide, aluminum and gold nanoantennas to investigate the origin of this second order nonlinear process in these two materials. We have performed



Experimental far-field SHG map of a 500 nm-long gold dimer (a). Panels (b) and (c) correspond to the simulated SHG signal for the bulk and the surface contributions respectively.

numerical simulations [2] in order to separate the two contributions [Fig. b and c] and compared with experimental single particle measurements [Fig. a]. Results obtained for 500nm-long gold dimers show a clear agreement between the measured SHG map and the simulated one when non-local bulk currents are considered. This contrasts with investigations in aluminum nanoantennas [2] in which surface contribution largely dominate the SHG process.

In conclusion, we have shown that the origin of SHG signal is intrinsically linked to the material and especially that the non-local contribution, often neglected to estimate SHG intensity in plasmonic nanostructures, can play a major role and even dominate the nonlinear response.

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Poster Session WG1

Towards Ultrafast Single-Photon Sources based on Color Centers in Diamond

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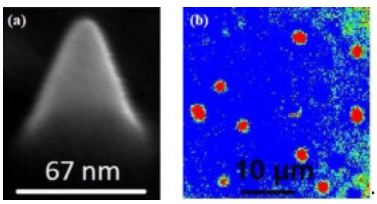
A narrow-band ultrafast solid-state single-photon source would play an important role in quantum technologies. We currently develop techniques for the fabrication and optical characterization of single-photon sources based on the silicon vacancy (SiV) color center in diamond [1] and introduce resonant structures to modify the photonic environment of the SiV center for ultrafast single-photon emission [2].



. B) SIV COLOR CENTERS

The SiV center is a promising candidate as most of the fluorescence signal is concentrated in a narrow zero-phonon line (> 90 %) at 738 nm, with a room temperature line-width down to about 1 nm. Moreover, it exhibits a short excited-state life-time (~ 1 ns) and a very small inhomogeneous broadening [1]. The photonic environment around a SiV color center can be manipulated using plasmonic nanocones to control the emission rate, the quantum efficiency, the angular distribution and the polarization of the emitted photons.

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Amorphous MoSi SNSPDs with a low time jitter and a high detection efficiency

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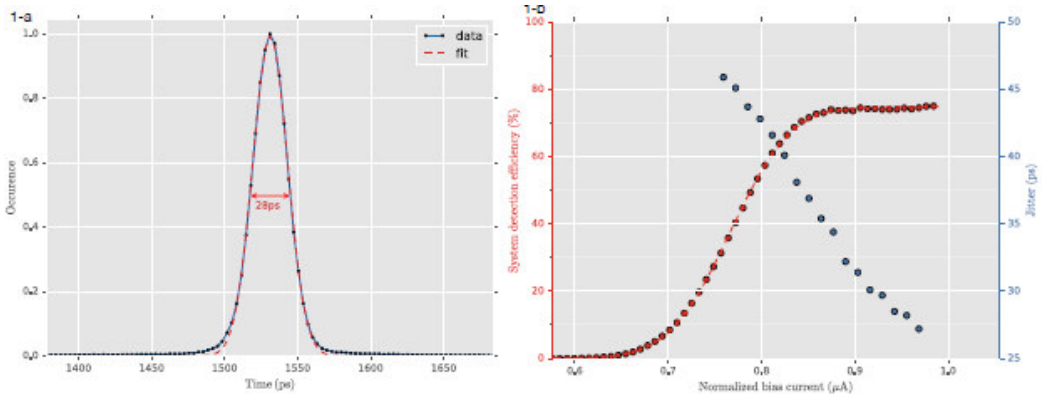
Superconducting nanowire single-photon detectors (SNSPDs) are a key technology for optical quantum information processing [1]. Their low dark count rate, fast response time, small jitter, and high system detection efficiency (SDE) favours their use in various demanding quantum optics applications such as high-speed or long-distance quantum key distribution, quantum networking, device-independent quantum information processing and deep-space optical communication. One recent advance in the SNSPD field has been the introduction of amorphous superconductors such as tungsten silicide (WSi), molybdenum silicide (MoSi) and molybdenum germanium (MoGe). SNSPDs based on these materials currently have the highest reported detection efficiencies (93 % with WSi [2]), as well as a high fabrication yield, favouring their use in complex structures such as detectors arrays. One limitation is that they typically operate at lower bias currents, in particular with nanowire geometries that lead to a saturated detection efficiency (a plateau). As a result, high-efficiency amorphous SNSPDs reported so far have a higher detection jitter, because the latter is essentially limited by the electronic noise of the amplification chain. Some previously reported values are 150 ps with 93 % detection efficiency with WSi [2], and 76 ps with 87 % detection efficiency for MoSi [3].

Obtaining a low jitter and a high detection efficiency requires finding an appropriate nanowire geometry in order to maximise the critical current while keeping a plateau, as well as the use of an optical stack to maximise absorption. In this talk we will report on high-efficiency SNSPDs based on amorphous MoSi exhibiting time jitters lower than 30 ps. For this we fabricated and characterised a series of devices with varying nanowire widths and fill factors. Fig.1-a shows a jitter histogram for one device having a full-with at half maximum value of 28 ps at a temperature of 0.8 K. The corresponding detection efficiency curve is shown on Fig.1-b; this device

reaches a 75 % detection efficiency with a clear detection plateau. Another device with a larger fill factor resulted in a detection efficiency of 85 % with a jitter of 40 ps. The influence of the nanowire and meander geometries on the jitter and efficiency will be discussed.



Timing jitter and effiency of a MoSi SNSPD.

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Toward a fast and sensitive nanowire based photodetector

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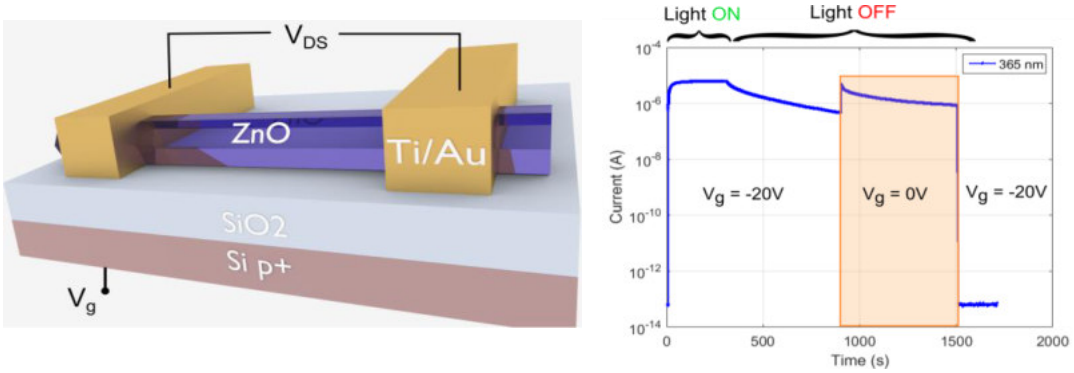
Due to the high surface to volume ratio, nanowire based components benefit from new properties typical of the nanoscale. ZnO nanowires have already proved their usefulness in the realization of multiple electronic components, such as FET transistors, gas detectors, photodetectors, LEDs or even solar cells.

ZnO nanowires have also shown themselves to be very promising UV detectors thanks to their significant photoconductive gain, as high as G =10^8 [1]. This makes them suitable for single photon detection, or at least detection of very dim light. The main current drawback is the recovery time (minimum time between 2 detections) which we develop last hours.

The device we developed is a good candidate for opto-electronic applications. Our device is a photodetector with ohmic contact and it behaves like a transistor. Our experiments stress out the importance of surface effect on the electrical by taking measurements in different atmospheres (oxygen, air, vacuum and argon). These surface states are the reason for the existence of a photoconductive gain, we obtain a maximum gain of G =5.10^6. In counterpart of this great gain, the persistence of the photocurrent (which can last up to several hours) prevents the device from operating at high frequency. We propose a method to reduce this time by applying a gate voltage.



[Left] Scheme of the photodetector with the electrical bias. [Right] Temporal dynamics of return to the initial state after illumination, in the oxygen and at room temperature. The persistence of the photocurrent can be shunted by changing the gate voltage.

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Polycrystalline diamond-based photonic crystal slabs for enhanced light emission

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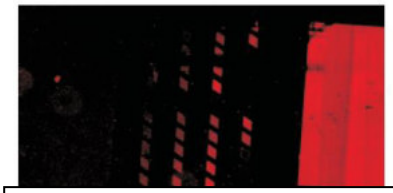
Photonic nanostructures can be employed to control propagation of light on nanoscale. For example, two-dimensional (2D) periodic patterns, 2D photonic crystals (PhCs), prepared on a surface of a thin layer with optical centers can be used to enhance light emission from these centers (Fig.1, [1]) and to direct the extracted light into desired direction. Particularly important for practical applications is extraction into normal or near-normal direction. Furthermore, PhCs can be simultaneously used to couple the excitation laser into the structure which enables more efficient excitation of the centers.



Red photoluminescence from the unstructured (on the left) diamond layer and the PhC structure (on the right).[1]

In this work, 2D PhCs prepared on a surface of thin polycrystalline diamond layers with light-emitting defects were investigated. Taking into account excitation laser and the diamond emission wavelength, respectively, dimension of the PhCs were designed by computer simulations in order to achieve both high excitation and extraction efficiencies. Then the PhC structures were fabricated employing various diamond deposition conditions and fabrication techniques. By this approach, in total around 120-fold emission enhancement was obtained for a fundamental TE mode at the wavelength of around 650 nm. From the total emission enhancement, the improvement of light extraction was approximately 24-fold and the excitation laser in-coupling enabled additional 5-fold increase of emission intensity. The extraction wavelength can be easily shifted by tuning dimensions of the PhC using our recently developed bottom-up fabrication technique of polycrystalline diamond-based PhCs [2].

This work has been supported by grants No. 16-09692Y (GACR), SGS17/179/OHK4/3T/13 (CTU) and by the COST Action MP1403.

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Optical Transitions for Single-Photon Emitters in Two-Dimensional hBN defect centers:

A Computational DFT-1/2 Study

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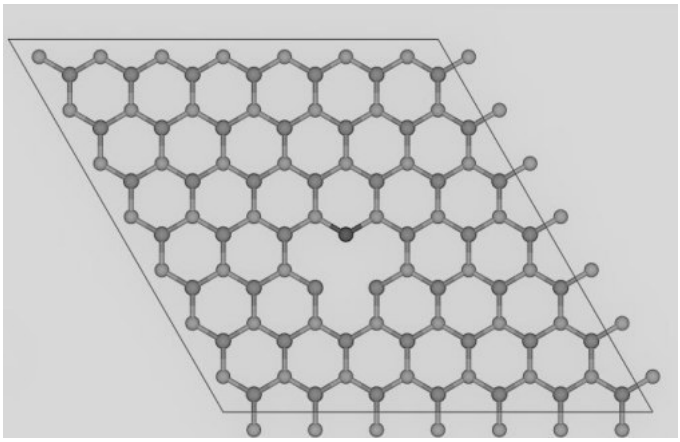
The single photon emitters are indispensable devices for realizing quantum secure protocols. As the name suggests, it promises to pass information without any cluttered signals. Systems with defects are one of the candidates for such systems [1]. In this work 2D materials with defects are focused for this purpose. The defect in a large system is isolated from the background and makes only local changes, so it can be used as a qubit. 2D hBN with defect is a promising material in this sense [2]. Spin orbit interactions as well as an external magnetic field split the spin degeneracies which can be used in magnetometry [3]. In this work, a study for understanding the optical transitions is done for 2D hBN with a Carbon vacancy defect, further adding the spin-orbit coupling effects. For this numerical work, a new method called as DFT-1/2 is used based upon its low computational cost and high accuracy [4].



hBN supercell with a C-vacancy defect

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Bloch Surface waves as a platform for integration of single photon emitters based on 2D materials

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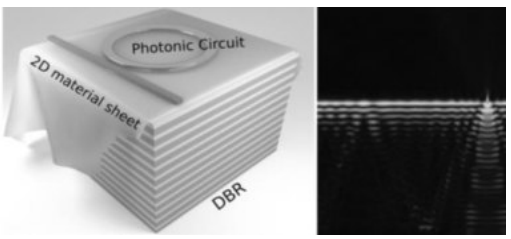
Single photon emission of two dimensional materials (2DM) has raised as a promising and complementary alternative to better stablished single photon emitter (SPE) technologies [1]. However, 2DM integration with current photonic devices remains a challenge, specially when the growth of SPE such as defects on hBN or 2D chalcogenides is not yet fully developed [2]. A key challenge towards the integration of such single photon sources is the difficulties to overlap the photonic modes of a waveguide/cavity with the position of the atomically thin layer. Here we present a feasible alternative to overcome these challenges.



Sketch of a 2DM-BSW system and simulation of SPE-BSW coupling.

Bloch Surface Waves are photonic modes tightly confined to the surface of a truncated dielectric photonic crystal [3]. The best known case is a Bragg reflector on which light is confined very close to the surface of the multilayer. Here we will discuss what are the possible advantages and best strategies of BSW for the enhancement of light-matter interaction between the 2DM-SPE and the optical mode in general. We will show that a simple structure such as dielectric multilayer could be a suitable platform for the integration of single emitters into photonic circuits based on BSW. Our preliminary data on experimental demonstrations will also be presented.

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Poster Session WG2

Stimulated emission of phonons and plasmons by ballistic electrons in nanoscale contacts

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It was shown [1,2] that biased nanoscale mesoscopic contact (constriction of nanowires) with ballistic transport of electrons can serve as electrically driven plasmonic nanoantenna for future plasmonic nanochips. Possible mechanism of plasmon emission by electrons in these nanostructures is the *bremsstrahlung* effect in collisions of electrons with the effective potential, defined by the transverse shape of nanocontact, and with the wall of nanostructure.

In this work, we study the stimulated emission of plasmon-polaritons by ballistic electrons in nanoscale contacts of various shapes. We show that the emission rate in nanoconstriction with slowly varying radius (and correspondingly, with more slightly sloping effective potential) can be much larger than in nanocontacts with sharply changing radius. This result can be interpreted as follows: the electron, colliding with more slightly sloping effective potential, has longer time to emit a quantum of electromagnetic oscillations. Since the rates of spontaneous and stimulated emission are related to each other with Einstein's relationships, the results of the work indicate that the spontaneous emission in nanocontacts with proper design can also be increased.

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Enhanced off-axis directional emission with Bulls-eye Nano-antennas

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Enhancing the photon collection efficiency and narrowing the emission directivity of such light sources are two critical aspects for their practical applications. Here, we propose a new design of bulls-eye antenna by introducing a metallic sub-plate and dielectric layer below conventional structure which is named as metal sub-plate antenna. Our proposed design provides high degree of directionality and enhanced out-coupled field intensity of nano-emitter sources as compared to conventional designs.

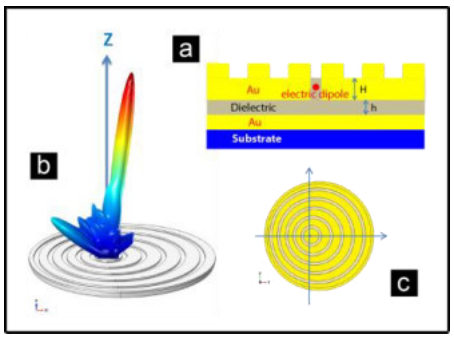

Fig. 1 a) The scheme of the designed bulls-eyes antenna with metal sub-plate. **b)** 3D far-field intensity distribution for a Bulls-eye plasmonic antenna with one main asymmetry plane and ridge asymmetry. The scheme of the asymmetric configuration is presented in **c**.

In addition, we study asymmetric optimized structures to steer emitted beam. Our results show that spatial off-axial steering angle over a cone is approachable by applying optimal asymmetries to grooves and ridges of the plasmonic antenna. The steered light retains out-coupled beam intensity even higher than conventional symmetric structures.

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Amplification of high harmonics in semiconductor waveguides

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We report enhancement of high harmonic generation in nano-structured semiconductors using nanoscale amplification of a mid-infrared laser in the sample rather than using large laser amplifier systems. Field amplification is achieved through light confinement in nano-structured semiconductor 3D waveguides. The high harmonic nano-converter consists of an array of zinc-oxide nanocones [1]. They exhibit a large amplification volume, 6 orders of magnitude larger than previously reported [2] and avoid melting observed in metallic plasmonic structures. The amplification of high harmonics is observed by coupling only 5-10 nano-joules of a 3.2 μm high repetition-rate OPCPA laser at the entrance of each nanocone. Harmonic amplification (factor 30 for H7) depends on the laser energy input and nanocone geometry [3].

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Resonant absorption and chiral effects in GaAs-based nanowires

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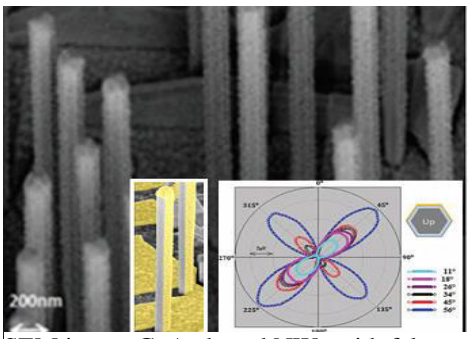
GaAs-based nanowires (NWs) were fabricated using a novel, lithography-free self-catalyzing approach that enabled the production of high-quality samples with desired geometric features on low-cost Si substrates [1]. Resonant absorption due to the excitation of discrete modes is experimentally characterized by means of photo-acoustic spectroscopy (PAS) technique. This direct, scattering-free, non-destructive, and low-cost technique is stable and sensitive enough to be proposed for the characterization of such nanodevices [2].

The optical response of such samples can be additionally controlled by the symmetry breaking by asymmetrically covering the NWs with Au (three out of six sidewalls). Extrinsic chiral effects are characterized by PAS and shown to produce circular dichroism (CD) [3]. All the experimental data are in great agreement with the numerical work, which can be used for the optimization of resonance or CD, and, further, for the investigation of chiral near fields [4]. Current efforts are dedicated to using these chiral effects for specific applications: enhanced enantioselectivity based on near chiral field manipulation, and circularly polarized field emission from the NWs.



SEM image GaAs-based NWs with false color SEM of the Au-covered NWs and the polar plot of CD measured by PAS.

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(The Road to) Understanding Localization of Light in Nanosponges

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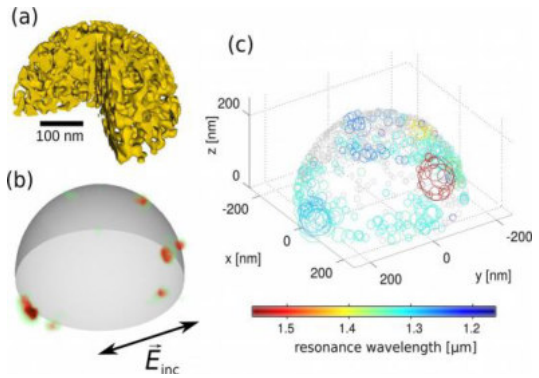
Disorder on the nanometer scale can lead to localization of light and huge electromagnetic field enhancement, which in turn can be used for non-linear optics and for the study and exploitation of quantum optical processes. We reported recently long-lived, highly localized plasmons on the surface of nanoporous gold-nanoparticles (nanosponges) with an unmatched excitation efficiency[1] based on photoemission, a process with a nonlinearity of n ≈ 7-8.

Our calculations show that localization takes place on the length scale given by the typical pore size. We systematically examine the influence of the specific disorder: Far-field and near-field properties are calculated for different correlation functions and filling fraction of the sponges. A multiscale approach is presented, where parts of the surface can be simulated with increased resolution while the antenna resonances are evaluated in an effective-medium picture. Very good agreement with experimental data regarding the field enhancement and lifetime is reported.



a) Cut-open model geometry of a nanosponge, revealing the percolating porestructure. b) Near Field intensity of long-lived fields for a representative sponge (FDTD calculations). c) Spectral analysis of long living near fields. Circles denote near field measurement points, the diameter of each circle encodes the encountered intensity, the color shows the frequency of the dominating long-lived resonance mode. Grey circles denote insignificant contributions.

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General expression of Poynting vector for evanescent wave region: inherent output from the method of single expression

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In unbounded region of evanescent waves, where electric and magnetic fields are diminishing values, Poynting vector becomes purely imaginary indicating impossibility of energy transfer. However, a confined region of evanescent wave permits transferring energy through it, e.g. at frustrated total internal reflection. In quantum mechanics, where time-independent Schrödinger equation is similar to Helmholtz's equation, the tunneling, i.e. transmission through a potential barrier is observed [1]. In confined regions a traditional expression for Poynting vector is useless as evanescent waves are inhomogeneous waves. Traditional methods of boundary problems solution operate with Poynting vector only outside of the evanescent waves region. In opposite, in the method of single expression (MSE) [2], in any boundary problem solution Poynting vector is calculated also within the media under analysis. In the MSE, where an assumption of counter-propagating waves is not used, the general expression for Poynting vector at any point of a medium is an integrable value and expressed as:

$$\vec{P}_z(z) = \frac{c^2}{8\pi\omega} U^2(z) \frac{dS(z)}{dz},$$

where $U(z)$ and $S(z)$ are real values describing resultant amplitude and phase of an electromagnetic wave in a medium. Outside of the region of evanescent waves full agreement with Poynting vector in a traditional form is obtained. The general expression of Poynting vector permits to monitor energy transfer process within any confined wavelength-scale evanescent wave media that is crucial for a correct design of nano-optical devices. The relevant expression for the probability flow density valid within the potential barrier in quantum mechanics has been obtained recently [3].

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Second harmonic generation reveals extrinsic chirality in Au coated GaAs-based nanowires

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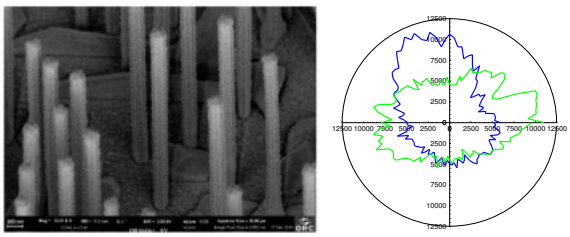
Nanostructures with broken symmetry can interact with circularly polarized light in a way that mimics the chiral response, thus raising the phenomenon called extrinsic chirality [1]. This can be evidenced with extreme visibility by using the second harmonic generation (SHG) technique, since the chirality is the lack of mirror symmetry and SHG are very sensitive to symmetry breaking [2]. Here we present the SHG measurement on Au partially covered GaAs nanowires fabricated on Si substrate by a self-catalyzing approach [3,5]. Comparison with the same sample without asymmetric gold covering gives rise to a dramatic circular dichroism enhancement.



SEM image oa Au coated GaAs-based NWs. the polar plot of SHG for L and R pol. state as a function of sample orientation.

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Nonlocal hydrodynamical models in nanoplasmonics – analytical and numerical approaches

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Apart from the conventionally applied approach used in plasmonics, for analyzing the resonant behavior of light interaction with plasmonic nanostructures, i.e. the local-response approximation (LRA), recently, however, more complex models based on the nonlocal response (NOR), or even quantum interaction, of free electrons have become necessary, as the characteristic dimensions of such structures have scaled down. This has also brought novel effects, such as new resonances, blue spectral shifts, etc. Newly emerging approaches describing the complexity of interactions at nanoscale, connected with emerging new physics, are shown and discussed in this contribution, in comparison with the standard LRA. In particular, in our studies, we have concentrated on understanding the interaction and developing a simple model capable of predicting the longitudinal nonlocal response based on the linearized hydrodynamic model, applied to simple structures, such as a spherical nanoparticle [1]. Within our model, we have generalized the description of the damping process, including liquid-viscosity type of damping. In parallel, as an alternative (and more general) approach, to our model, based on our previous experience with Fourier modal methods, we have considered and developed the extension of the rigorous coupled wave analysis technique capable of treating nonlocal response numerically, for more general structures. Some examples of the application will be shown and discussed. Finally, as an extension, we have considered the quantum description of the interaction using the quantum corrected model approach where the quantum characteristics of the interaction (e.g. between two nanoplasmonic particles) are modeled with the specific classical permittivity profiles, as a part of the numerical approach.

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Silver nanocrystal metamaterials fabrication by ink-jet printing

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In this study, we present the inkjet printing of silver colloidal nanocrystals for the functional metamaterials fabrication. The silver nanocrystal dispersion are used as printing ink, and the flexible PET film is used as the substrate. Using the ink-jet printing process, the few micron featured silver nanocrystal-based patterns were fabricated over large areas of up to a 10cm x10cm centimeters of complex patterns. For coupling between nanocrystals, the long ligand of the original nanocrystal was exchanged to –SCN, short conducting ligand by chemical process with low temperature. [1] The ink-jet printing and curing process with low temperature process allows for the demonstration of these metamaterial patterns on the rigid substrates as well as, on the various flexible polymers substrates. The optical and electromagnetic property of the metamaterial patterns were tuned by the choice of pattern size and shapes, the dielectric function of the nanocrystals.

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Tunable Plasmon Induced Transparency with Gold Strips on Graphene.

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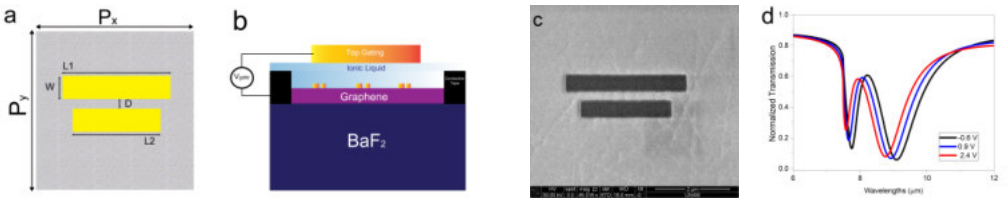
Plasmon induced transparency (PIT) reduces the absorption of optically thick material for narrow spectrum by quantum interference effect [1]. PIT can be used for slow light applications [2] and optical switching [3]. In this work we have investigated tunable PIT for mid infrared spectrum by two gold strips on graphene, is shown in; Fig. 1 (a). When these two strips are excited by incident light, they provide two bright modes. The weak hybridization between these two bright modes with different resonance frequency give PIT response. Resonance frequency of each strip is tuned by changing charge density of graphene layer by top gating method, method (Fig. 1 (b)).

Commercially available CVD grown graphene on Cu was transferred on BaF_2 substrates by wet transfer method and spin coated with positive photo resist and aqua save. Coated sample was exposed to E-beam lithography to form strips. The exposed samples were developed. 5/65 nm of Ti/Au were deposited by E-beam evaporator, structures appeared after liftoff process of 24 hours in acetone, SEM images of fabricated unit cell is shown in Fig. 1 (c). Normalized transmission of were obtained by Fourier Transform Infrared (FTIR) spectroscopy. By changing the gate voltage surface carrier concentration of graphene was changed and tuning was observed in PIT phenomena (Fig. 1 (d)). For the measurement samples were excited by *x* polarized field. Background measurement were taken from graphene on BaF_2 substrates with no PIT structures.



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Solving the Schrödinger-Newton equation with GPGPU supercomputing

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In the recent years the realization of optical analogue experiments of many-body physical systems has captured some interest of the optical sciences community. The validity of the analogy of these experiments is deeply connected with the similarity of the mathematical models that describe both physical systems. As an example, two of the most studied models in this field are the well-known Nonlinear Schrödinger equation and the Schrödinger-Newton equation, which constitute models that describe both optical phenomena, such as light beam propagation in nonlinear media, and many-body physical systems, such as Bose-Einstein condensates.

In the particular case of the Schrödinger-Newton equation, the model can be interpreted as the coupling between the Schrödinger equation and a Newtonian potential, where the mass-density term is related to the intensity of the wave function. In physics, a wide range of phenomena can be described using this model, including the propagation of light in thermo-optical media[1] and in Nematic Liquid Crystals[2] and gravitational phenomena[3]. Unfortunately, the analytical solution of this equation even in the one dimension is quite challenging and many times it is only possible to obtain approximate numerical solutions. In this work, we present the development of a solver of this equation for multi-dimensional systems based on General Purpose Graphical Processing Unit (GPGPU) supercomputing. Moreover, we also discuss some preliminary results of numerical simulations of the propagation of light in nonlocal optical media and analyze them in the context of optical analogue experiments.

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Exploring Dissipative Nonlinear optical media with GPGPU supercomputing

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Although at a fundamental level the physical laws describing light-matter interaction are linear, when one considers open systems and the feedback of the response of matter into the optical field, an effective model arises including typically both nonlinear and dissipative processes. A well-known model typically employed to describe such systems is the Complex Ginzburg-Landau Equation. However, while the model is well studied in the literature, its higher order nonlinearities and dissipative characteristic make any analytical solutions very parameter-specific and thus numerical methods are useful when studying such systems. In this work we present the current state of development of a solver Complex Ginzburg-Landau Equation based on GPGPU supercomputing, analyze its performance and explore some applications in physical systems, namely the propagation of an optical pulse in a 4-level atomic optical system.

Study of Nitro Group Symmetric Stretch Mode Splitting by Non-Collinear Phase-Sensitive Sum Frequency Generation

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We report an investigation of symmetric stretch mode splitting and dipole moment orientation of NO_2 nitro group of azo-phenyl-carbazole dyes on Au surface using non-collinear Phase-Sensitive Sum Frequency Generation Spectrometer (PS-SFGS) which was developed exploiting the nonlinear second order surface susceptibility of Au substrate. In general most of metals have surface nonlinearity which consequently results in optical components such as mirrors and filters not being applicable for collinear and non-collinear PS-SFGS systems due to noise generation or spectral limitations. Here this drawback was taken into our advantage and Au substrate local oscillator was used as a sum frequency source for PS-SFGS measurements. The system was tested using self-assembled monolayer of azo-phenyl-carbazole dyes on Au substrate. The origin of NO_2 symmetric stretch mode splitting and formation of doublet feature around 1335 cm^{-1} was attributed to appearance of in-phase and out-phase stretch modes. The orientation of the dipoles of these doublet modes with respect to the surface of the substrate was defined.

High Harmonic Generation in Graphene

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Graphene is a single atomic layer of carbon arranged in a honeycomb structure. It has attracted significant attention in recent years due to its extraordinary mechanical, electronic and optoelectronic properties such as a zero but tunable band gap energy, high electron mobility and ultrahigh mechanical strength. We study high harmonic generation from graphene of a mid-infrared femtosecond laser. We report for the first time on the generation of high harmonics, up to the 9^{th}, from free-standing graphene. We explore the influence of the number of graphene layers on the generated harmonics and investigate the laser polarization effects on the harmonic spectra [1]. We emphasize the effect of the in-plane and out-of-plane polarization on the harmonic cut-off, since we believe that the harmonic behaviour changes from atomic-like for out-of-plane polarizations to semiconductor-like for in-plane polarizations. Bearing in mind that the band gap of graphene is influenced by the substrate it rests on, we study the efficiency of the harmonics generated from free-standing graphene versus the harmonics generated from graphene on a substrate.

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Formation of methane and of (per)chlorates on Mars

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Rovers examining the composition of Mars have detected the presence of methane, perchlorates and chlorinated alkanes. The origin of these species has so far only been sought independently with separate chemistries. Here we show, that a UV-initiated photochemistry of CO_2 and HCl on various mineral catalysts can produce all of the mentioned compounds under one mutual reaction network. To strengthen the interconnection with Martian chemistry, we have used the Nakhla Martian meteorite and proved that its photochemical activity can initiate methanogenesis processes, and that both methane and perchlorates was formed. The comparison of the mineral composition and chemistry of the Martian regolith, as well as the other surface conditions of the planet fully satisfy the requirements for these reactions to occur, and infers that the process must inevitably take place on a global scale on Mars, and that it can significantly contribute to the explanation of the currently observed atmospheric composition of the Red planet. The concentration of perchlorates on the surface can be used as a signature to observe the methanogenesis process in situ.

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Ultrafast electron-hole dynamics in the surface layer of silicon upon femtosecond laser irradiation in modification regime

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During the last decades, intensive studies of interaction of ultrafast laser radiation with materials have led to emergence of various applications based on functionalization of surfaces at the nano- and microscale. By inducing periodic modifications of material surfaces (band gap modification, nanostructure formation, crystallization or amorphization), optical and mechanical properties can be tailored, thus turning femtosecond lasers to one of the key technological tools for rapid development of nanophotonics, bionanoengineering, and nanomechanics fields.

Although the interaction of femtosecond laser pulses with semiconductor surfaces has been studied for more than two decades, the dynamics of coupling of intense laser light with excited matter is far from complete understanding. In particular, swift formation of a transient overdense electron-hole plasma dynamically modifies optical properties in the surface layer of irradiated semiconductors and induces large gradients of hot charge carriers, resulting in ultrafast charge-transport phenomena.

In this work, the dynamics of ultrafast laser excitation of semiconductor materials are studied theoretically on the example of silicon. A special attention is paid to the electron-hole pair dynamics, taking into account ambipolar drift effects, temperature-induced diffusive flows, and transient band-gap modification. Modeling data on optical response are in agreement with pump-probe reflectivity measurements available in literature [1]. Based on the simulation results, ultrafast processes such as non-thermal melting and scattering of light on the homogeneously nucleating liquid are analyzed.

Achieving a predictive stage in describing the effects of intense laser light interaction with semiconductors enables the preparation of accurate modeling tools for the laser processing community [2,3].

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Long-range plasmon cavity assisted quantum emitter coupling

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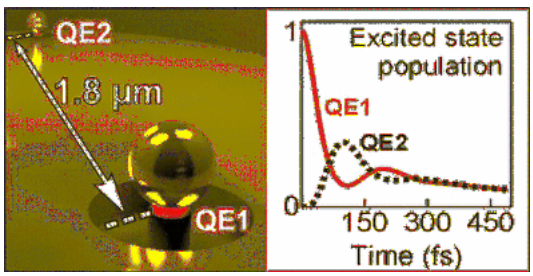
Diverse phenomena such as light harvesting, nanoscale quantum entanglement, or photonic mode hybridization rely on efficient coupling. Usually, these coupling phenomena are efficient only for separations much shorter than the optical wavelength. Recently, we demonstrated in theory and experiment an all-plasmonic device which facilitates coherent coupling between selectively addressable nanoantennas separated by more than twice the exciting light wavelength [1]. Such plasmon-mediated strong coupling between spatially separated and thus selectively addressable nanoantennas forms a basis to efficiently couple spatially separated quantum emitters (Figure. left panel). Here it is shown that strong coupling between spatially separated quantum emitters can be achieved. Based on FDTD simulations a quantum emitter-plasmon coupling strength $\hbar g = 16.7$ meV is reached while simultaneously keeping a small plasmon resonance line width $\hbar\gamma_s = 33$ meV. This facilitates strong coupling, and quantum dynamical simulations reveal an oscillatory exchange of excited state population (Figure, right panel) between the quantum emitters spatially separated by 1.8 µm [2]. Based on this efficient coupling scheme for selectively addressable quantum emitters the prospects of coherent quantum control and multidimensional coherent spectroscopy of excitation, photon correlation, and entanglement dynamics are explored.



Strong quantum emitter coupling. Plasmon polaritons in an elliptical cavity mediate strong coupling between quantum emitters.

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Poster Session WG3

Discussing recent progress in development of controllable sources of the entangled photon pairs

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In 1991 Artur Ekert, a Polish scientist working in Oxford, offered a secure quantum key distribution protocol based on entangled photon pairs [1]. Presently this technology is developing with huge steps and the spaceborne links with record distance 1203 km between the ground stations has been recently realized by Chinese scientists [2].

In [3] an idea of hypothetical communication link based on statistically manipulated entangled photon pairs was presented using the ideas from experimental works by N. Gisin's group in Geneve [4] and A. Zeilinger's group in Vienna [5]. The main bottleneck resisting the testing of the proposed idea is the availability of the efficient sources of entangled photon pairs. During the recent years a remarkable progress have been achieved in development of efficient sources based both on parametric down-conversion crystals and quantum dots [6]. The latter approach seems especially promising if considering affordable compact solid-state (semiconductor) realizations.

The presentation will analyze the recent progress in realization of quantum key distribution systems based on entangled photon pairs and progress in development of entangled photon pair sources.

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Slowing probe and conjugate pulses in potassium vapor using Four Way Mixing

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We used four-way mixing (FWM) phenomena to slow light pulses in hot potassium vapor. The atomic scheme for FWM was off-resonant double-Lambda scheme that was previously used to study slow light in Rb [1] and Na vapors [2]. At high atom density and strong pump laser power, this atomic system is a parametric amplifier which generates probe and conjugate photons with gain. The goal of this work was to find how fractional delays and pulse broadenings obtained in K vapor compare with those obtained in other alkali vapors.

We measured and calculated fractional delays and pulse broadening of probe and conjugate for different gas densities, different pump one photon detuning, and two photon Raman detuning. In the experiment phase matching was established at the small angle between probe and pump at the entrance. Probe and conjugate waveforms are detected and placed on the time scale whose zero corresponds to tthe maximum of the reference pulse. Theoretically we calculated waveforms of transmitted probe and conjugate by solving optical Bloch-Maxwell equations for the four-level system.

We present fractional delays and broadening, and gains of probe and conjugate, as a function of two photon detuning for incident probe pulse between 20 and 120 ns, at K densities between 10^{11} and 10^{12} cm^{-3}, for several values of one photon (pump) detuning. Parameters for optimum results will be discussed and will be compared to those reported for Rb and Na.

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Method for analytical calculations of the second-order autocorrelation function g_2

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Second-order autocorrelation function g_2 is very convenient tool for characterization of statistics and for investigations of weak or quantum light. The light source is coherent at $g_2=1$, thermal ($g_2=2$), exhibits quantum ($0< g_2<1$) or collective ($g_2>2$) properties; measurements of g_2 help to detect modulations and other features of small signals, this is why g_2 is very often measured in experiments with micro- and nano-scaled lasers. Theoretical calculations of g_2 is carried out mostly by complicated numerical procedures hiding the physics behind the interesting variations of g_2 as, for example, how collective effects are related with super-thermal light at $g_2>2$. Analytical models and analysis of g_2 are necessary for clear relations of statistical and other properties of weak or quantum lights with parameters of nano-emitters. We present and discuss such a method, where laser equations are replaced by equations for quantum harmonic oscillators coupled with each other and with noise reservoirs. Then we apply well-known results of the input-output theory, which facilitates calculations of diffusion coefficients and the derivation of g_2 considerably. We test the method in the limit with adiabatically eliminated polarization, reproduce well-known results for g_2 for "open" (i.e. pumped from outside) two-level laser [1], derive g_2 for "close" two-level laser with pump blocking and show how to apply the method to our generalized rate equations [2] outside the adiabatic limit and describe statistical properties of the light from lasers with collective effects.

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Tunable Plasmon Induced Transparency with Gold Strips on Graphene.

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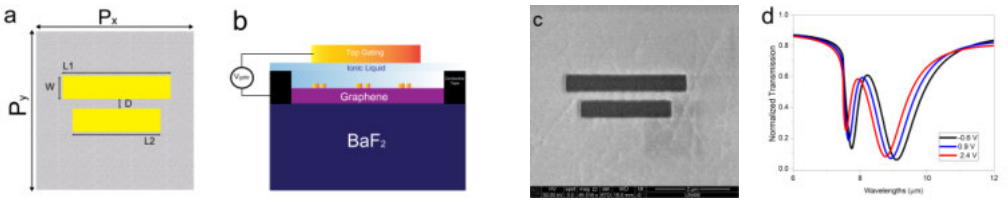
Plasmon induced transparency (PIT) reduces the absorption of optically thick material for narrow spectrum by quantum interference effect [1]. PIT can be used for slow light applications [2] and optical switching [3]. In this work we have investigated tunable PIT for mid infrared spectrum by two gold strips on graphene, is shown in; Fig. 1 (a). When these two strips are excited by incident light, they provide two bright modes. The weak hybridization between these two bright modes with different resonance frequency give PIT response. Resonance frequency of each strip is tuned by changing charge density of graphene layer by top gating method, method (Fig. 1 (b)).

Commercially available CVD grown graphene on Cu was transferred on BaF_2 substrates by wet transfer method and spin coated with positive photo resist and aqua save. Coated sample was exposed to E-beam lithography to form strips. The exposed samples were developed. 5/65 nm of Ti/Au were deposited by E-beam evaporator, structures appeared after liftoff process of 24 hours in acetone, SEM images of fabricated unit cell is shown in Fig. 1 (c). Normalized transmission of were obtained by Fourier Transform Infrared (FTIR) spectroscopy. By changing the gate voltage surface carrier concentration of graphene was changed and tuning was observed in PIT phenomena (Fig. 1 (d)). For the measurement samples were excited by *x* polarized field. Background measurement were taken from graphene on BaF_2 substrates with no PIT structures.



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Silicon vacancy color centers in ultra-thin nanocrystalline diamond films; impact of thickness and surface chemistry on SiV photoluminescence properties

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Color centers in diamond have shown excellent potential for applications in quantum information processing, photonics, and biology. Here we report chemical vapor deposition (CVD) growth of as thin as 5-6 nm nanocrystalline diamond (NCD) films with photoluminescence (PL) from silicon-vacancy (SiV) centers at 739 nm. Instead of conventional 4-6 nm detonation nanodiamonds (DNDs) we prepared and employed hydrogenated 2 nm DNDs to form extremely dense (~ 1.3×10^{13} cm^{-2}) and thin (2 ± 1 nm) nucleation layers on Si/SiO_x substrate which enabled the CVD growth of such ultra-thin NCD films (S. Stehlik et al., *ACS Appl. Mater. Interfaces* 2017, 9, 38842−38853). We demonstrate on/off switching of the SiV center PL in the NCD films thinner than 10 nm by oxygen/hydrogen surface chemistry variations. Several oxygen/hydrogen surface chemistry modification approaches such as thermal and plasmatic processes are used and discussed.

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Metamaterials perfect absorber for Vis-NIR wavelength

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Metamaterials (MM) are the artificial materials rationally designed from subwavelength nanostructures to engineer novel optical properties and control the interaction of electromagnetic radiation with matter [1]. Recently, metamaterials have been greatly interested in various applications such as cloaking, superlens, perfect absorber and so on.

In this study, we present optical metamaterials perfect absorber using silver nanocrystals. The optical metamaterial with nanocrystals can be fabricated by nanoimprinting process for large area application. [1, 2] In this work, the nanoscale silver nanocrystal based metamaterial perfect absorber were fabricated by nanoimprinting of colloidal nanocrystals for tunable optical properties from the visible to the near infrared wavelength. It was fabricated over large areas of up to a few centimeters in scale with high resolution for various nanostructure geometries of nano-pillars, nano-rods, and nano-holes composed of nanocrystals. The optical properties of the metamaterial perfect absorber were tuned by the choice of nanocrystal building block, the dielectric function of the nanocrystal nanostructure, and the nanostructure geometry and periodicity.

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A plasmonic approach towards optical poling enhancement of azophenylcarbazole molecules

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Induced molecular orientation breaks the initial centrosymmetric structure inside a material creating quasi-phase-matched grating of nonlinear second-order susceptibility $\chi^{(2)}$ applicable to second harmonic generation (SHG). That's the basis for all-optical poling – a method used to investigate optical storage materials. Key point for optical storage application is to fix molecules oriented in the host matrix. To enhance the interaction with host matrix genuine molecular glasses were investigated [1]. Highest values of $\chi^{(2)}$ (0.72 pm/V) and lowest mobility for azophenylcarbazoles were obtained for most branched derivatives [2]. To increase the efficiency of poling and to reach $\chi^{(2)}$ values of the best SHG materials the light-matter interaction has to be enhanced. We proposed a technological way to increase the interaction, means the plasmonic effect. Gold nanoparticles were synthesized and mixed with azophenylcarbazole tiol derivatives and all together dispersed into a polycarbonate matrix. A 1.5 times higher optical poling effect was registered demonstrated the tendency not the expected plasmonic enhancement. Adjustment of the nanoparticle size to the wavelength of light used in the experiments (532 nm) is needed. Other issues, like the material of the nanoparticles, the size dispersion of the nanoparticles, concentration of the nanoparticles in the matrix and accordance with the dilution of the azophenylcarbazole derivatives have to be overcome and optimized. To conclude, an important new approach towards optical poling enhancement has been demonstrated.

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Poster Session WG4

Manipulating heat flow in quantum devices

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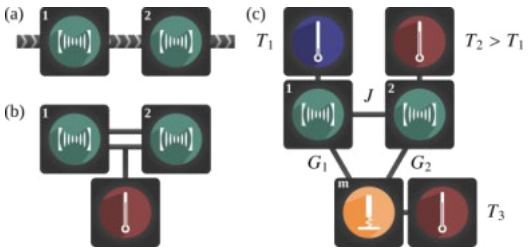
There has been significant interest recently in using complex quantum systems to create effective non-reciprocal dynamics. Proposals have been put forward for the realization of artificial magnetic fields for photons and phonons; experimental progress is fast making these proposals a reality. Much work has concentrated on the use of such systems for controlling the flow of signals, e.g., to create isolators or directional amplifiers for optical signals. In this paper, we build on this work but move in a different direction. We develop the theory of and discuss a potential realization for the controllable flow of thermal noise in quantum systems. We demonstrate theoretically that the unidirectional flow of thermal noise is possible within quantum cascaded systems. Viewing an optomechanical platform as a cascaded system we here that one can ultimately control the direction of the flow of thermal noise. By appropriately engineering the mechanical resonator, which acts as an artificial reservoir, the flow of thermal noise can be constrained to a desired direction, yielding a thermal rectifier. The proposed quantum thermal noise rectifier could potentially be used to develop devices such as a thermal modulator, a thermal router, and a thermal amplifier for nanoelectronic devices and superconducting circuits.



(a) A cascaded system model of two cavities, which can be realized (b) by means of a common bath. We detail (c) an optomechanical implementation of this model.

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GPU simulation of nonlinear and quantum many-body optical and atomic systems

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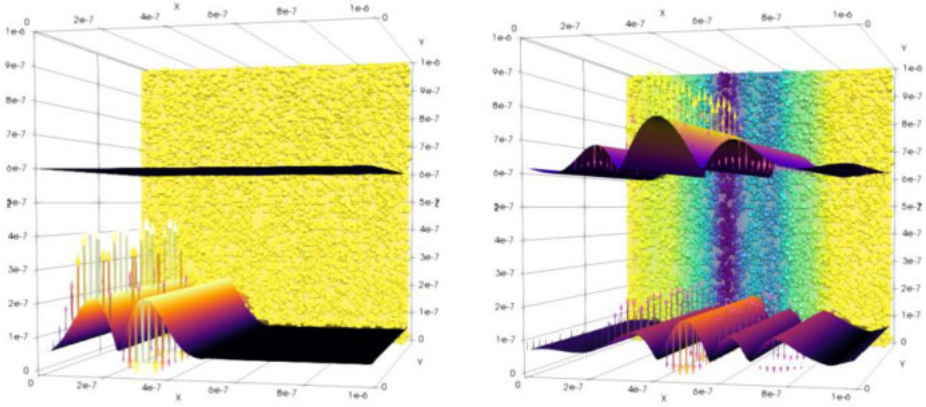
We report on the development of a modular scientific simulation platform based on GPGPU computing technologies focused on simulating quantum and nonlinear optics in nanoscale and atomic systems, including mesoscale many-body systems and their interaction with the electromagnetic field. This platform combined solvers of the Maxwell-Bloch equations, Coupled Generalized Nonlinear Schrödinger equation, Plasma Fluid equations (Vlasov-Maxwell equations) based on particle in cell methods (PIC), among others. We discuss the key concepts of GPGPU computing alongside with the design and implementation details of the solvers, while comparing the performance of the solver using multiple GPU and CPU backends and test the numerical stability of the implementation. Finally, we present several test cases of this platform to physical scenarios including two and three-level atomic gases and combine our software with a PIC code to demonstrate its modularity and applicability in studying coherent and nonlinear phenomena in nanoscale quantum systems.



Evolution of pulse propagating through a two-level atomic gas. The lower part represents the amplitude of the electric field, the middle part illustrates the amplitude of the polarization field and the back plane contains the information regarding the local population of the ground state of the atoms. (a) and (b) represent the state of the system at t = 0 and at the end of the simulation, respectively.

Electron-vibrational theory of Frenkel exciton-polaritons in organic dye structures

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Strong coupling between excitons and photons in condensed matter results in the formation of new quasi-particles, exciton polaritons, which combine exciton and photon properties. Recently organic dye nanofibers demonstrated long-range Frenkel exciton polariton (FEP) propagation at room temperature [1] owing to a considerably larger oscillator strength compared to inorganic semiconductors. To realize such long-range propagation, the FEPs should be stable. Their stability is governed by splitting between two branches of the polariton dispersion, the correct calculation of which is of decisive importance. The latter necessitates the proper description of the Frenkel exciton line shape that is impossible without taking the electron-vibrational interaction into account (especially for H-aggregates, as it took place in experiment [1]). In this work we have developed a mean-field electron-vibrational theory of FEPs in organic dye structures. Our theory contains experimentally measured quantities that makes it closely related to experiment. Between other things, we explain for the first time the additional red shift of the H-aggregate experimental absorption spectra [2] (that are blue-shifted as a whole). We apply the theory to experiment [1] on fraction of a millimeter propagation of FEPs in photoexcited organic dye nanofibers made of thiacyanine dye. Our theory correctly describes experimental absorption spectra [3] of both thiacyanine H-aggregates and monomers. Then using the values of parameters obtained by comparison between experimental and theoretical spectra, we calculate the polariton dispersion. We evaluate splitting between two branches of the polariton dispersion in thiacyanine fibers that is about 6300 cm^{-1}. This value agrees with measurements of Ref.[1]. The fluorescence spectrum of a nanofiber ($\sim 2.5\ eV$) is out of the splitting range under discussion, which is why it is amplified well. The polariton dispersion shows also the leaky part in the splitting range between two branches. The theory can be applied also to FEP lasers and BE condensation of FEPs.

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One-dimensional bi-periodic photonic structures based on ternary photonic crystals

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The transmittivity spectra, fields and energy distribution of the electromagnetic eigenwaves propagating in one-dimensional dielectric photonic crystal $[(TiO_2/SiO_2)^N Al_2O_3]^M$ with two periods formed by unit cells (TiO_2/SiO_2) and $[(TiO_2/SiO_2)^N Al_2O_3]$ are theoretically investigated.

Spectra of TE- and TM-modes depend on the geometric parameters of the structure and undergo modifications with the change of the period numbers, layer thicknesses and incidence angle of light. Special attention is paid to the applicability of the hybrid effective medium approximation comprising the long-wave approximation and two-dimensional (2×2) transfer matrix method.

We demonstrate spectral peculiarities of the bi-periodic structure and show the differences between the bandgap spectra of the bi-periodic and ternary one-dimensional dielectric photonic crystals. The presented photonic crystal structure can find its applications in optoelectronics and nanophotonics areas as omnidirectional reflectors, optical ultra-narrow bandpass filters and antireflection coatings.

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Dynamics of strongly coupled modes between surface plasmon polaritons and photoactive molecules: the effect of the Stokes shift

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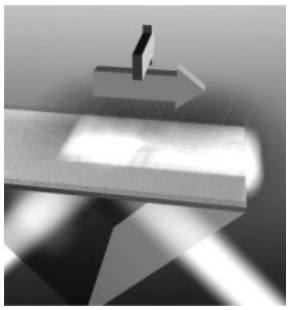
The strong coupling between surface plasmon polaritons (SPP) and molecules manifests itself by the appearance of an avoided crossing, i.e. Rabi splitting, in the SPP dispersion at the energy of the molecular absorption, due to the formation of new hybrid SPP-molecule polariton states [1]. We have studied the dynamics of these polaritons by analyzing their scattered emission [2]. While the emission of SPP is purely transverse magnetic (TM), the strong coupling with molecules induces transverse electric (TE) component to the emission of the polariton via the partial molecular nature. The TM/TE ratio of the emission clearly follows the molecular contribution, determined by the wavevector and the coupling strength. In addition, we show that the Stokes shift of the molecule influences the emission - the larger the shift the lower the TE emission.



The measurements are carried out via prism coupling in Kretschmann geometry. Arrows point the polarizations of interest: TM (left to right) & TE (front to back).

We argue that in case of randomly oriented molecules, the emission of a fully coherent SPP-molecule polariton is purely TM, like SPP. However, as a result of the unique micro-environments of the molecules in combination with thermal motion, this symmetry may break, providing a route to the TE emission. Furthermore, the relaxation rate of the polariton correlates with the Stokes shift, so that the TE emission can only occur if the Stokes shift is small and consequently the polariton lifetime is long enough. The experimental results agree with the model, but more accurate models will be essential to systematically exploit strong coupling.

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Surface exciton polaritons in J-aggregate thin films

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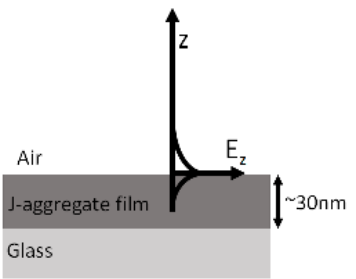
J-aggregates are self-assembling molecules whose absorption band is red-shifted upon aggregation. This red-shift occurs due to the collective behavior of the monomers in the aggregate: in an aggregate, the electronic orbitals of the constituent monomers are coupled together, and the first excited state of the aggregate is a Frenkel exciton [1].

This collective effect can be used to create materials with novel optical properties. A PVA thin film doped with J-aggregate can have extreme electric permittivity in the vicinity of the Frenkel exciton absorption: with sufficient doping, the real part of the electric permittivity is negative on the high-energy side of the absorption. In this region the thin film has high reflectance and supports a surface exciton polariton (SEP) mode, in which light is confined at the film-air interface [2].



The surface exciton polariton mode confines light at the air-film interface.

We demonstrate absorption into the SEP mode for three films doped with different J-aggregates. This new group of materials can be engineered using the tools of supramolecular chemistry to control the optical properties. J-aggregate thin films can be used to investigate exciton-photon many-body physics in an on-chip platform, shedding light on the influence of nanophotonic modes on energy transport processes in organic systems.

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Metrics as a sensitive test of the degree of adiabaticity in quantum dynamics

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Characterizing adiabaticity is vital for understanding adiabatic quantum computing and maximising quantum work among other applications, and is still an open fundamental problem. Likewise the one-to-one mapping of electron densities and wavefunctions in quantum systems is not fully understood. Here we show how the metric space approach to quantum mechanics [1] naturally allows the study of both problems at once. Considering a group of random external potentials, we see the ground-state relationship between wavefunction and density distances is quasi-linear. This is confirmed analytically for harmonic oscillators. When applying a liner time-dependent perturbation, this quasi-linear relationship breaks down away from the adiabatic limit. Therefore we propose using this ground-state relationship to provide an appealingly visual tool for characterizing adiabaticity in the dynamics of a group of systems, as well as developing understanding of the one-to-one mapping between densities and wavefunctions.

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Steady state entanglement beyond thermal limits

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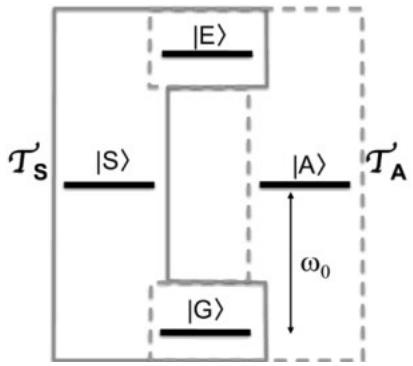
Classical engines turn thermal resources into work, which is maximized for reversible operations. The quantum realm has expanded the range of useful operations beyond energy conversion, and incoherent resources beyond thermal reservoirs. This is for example the case of entanglement generation in a driven-dissipative protocol, which we analyze as a continuous quantum machine. We show that for such machines the more irreversible the process the larger the concurrence. Maximal concurrence and entropy production are reached for the hot reservoir being at negative effective temperature, beating the limits set by classic thermal operations on an equivalent system. Irreversibility is quantified by the steady state entropy production rate, a concept derived from the field of stochastic thermodynamics and extended to a quantum case in which effective temperatures are involved. A practical implementation is discussed in a quantum optical model of a pair of incoherently driven non-interacting qubits resonantly coupled to a quantized and strongly dissipative cavity mode, and special attention is paid to realistic parameters in view of realizations and experimental tests in solid state cavity QED systems. The international scientific collaboration leading to this work was naturally embedded within the Cost framework and received support from Action MP1403 for a Short Term Scientific Mission.



Elementary model of a driven-dissipative quantum thermal machine for steady state entanglement generation. S and A are symmetric and antisymmetric entangled combinations of locally excited states.

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Electromechanical quantum simulators

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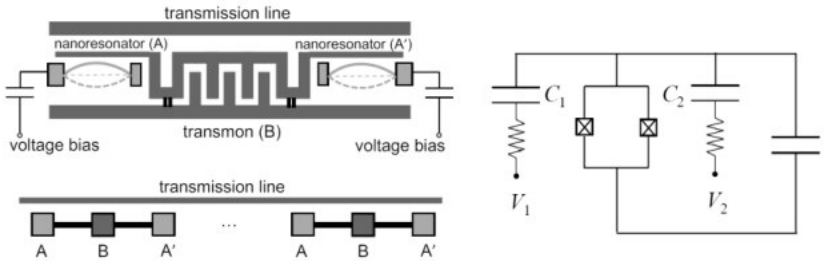
Quantum simulators are one of the most appealing applications of a quantum computer. Here we propose a universal, scalable, and integrated quantum computing platform based on tunable qubits encoded in electromechanical nano-



Fundamental building block of the circuit architecture proposed in this work and corresponding analog circuit model.

oscillators within a superconducting microwave circuit. It is shown that very high operational fidelities can be achieved in a minimal architecture where qubits are encoded in the anharmonic vibrational modes of mechanical nanoresonators, whose effective coupling is mediated by virtual fluctuations of an intermediate superconducting artificial atom. We explicitly show, by using realistic parameters, the digital quantum simulation of the transverse field Ising model as a paradigmatic example, displaying very large theoretical fidelities, and discuss its potential scalability to simulate more complex model Hamiltonians.

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Collective effects in Casimir-Polder forces

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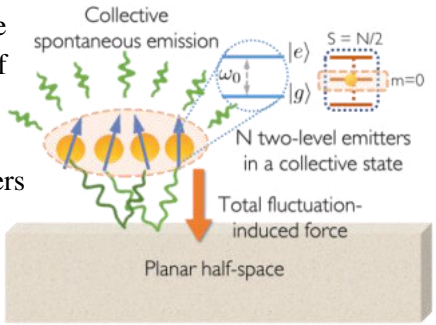

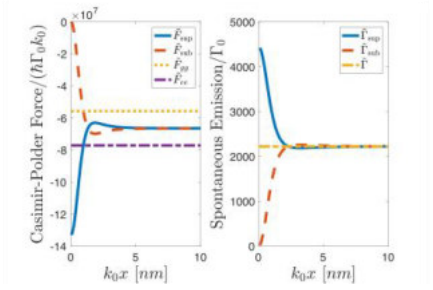

We study cooperative phenomena in the fluctuation-induced forces between a system of neutral two-level quantum emitters prepared in a coherent collective state and a surface. We find that the total Casimir-Polder force on the emitters can be modified via the mutual correlations between the dipoles, particularly showing that a collection of emitters prepared in a super- or sub-radiant state [1] experiences an enhanced or suppressed collective vacuum-induced force, respectively. Such collective fluctuation forces can be understood as the dispersive counterpart to collective spontaneous emission, and depend singularly on the surface response at the resonance frequency of the emitters, thus being readily maneuverable. Our results demonstrate the potential of collective phenomena as a tool to selectively tailor vacuum forces -- for example, super-radiant states could be used to boost and probe fluctuation forces that are otherwise too weak to be observable [2], while sub-radiant states that suppress undesirable Casimir-Polder attraction and exhibit long lifetimes can be potentially useful for trapping particles near surfaces.

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