COST ACTION MP1403

Nanoscale Quantum Optics—ESR Workshop

November 15-18, 2015, Malta

Inside Nature Materials

INVITED SPEAKER

Dr. Maria Marakou

Since its launch in 2002, Nature Materials remains a leading journal in the field of materials science across many disciplines, aiming at publishing cutting edge science for the relevant scientific communities as well as disseminating exciting results among the wider readership of materials scientists.

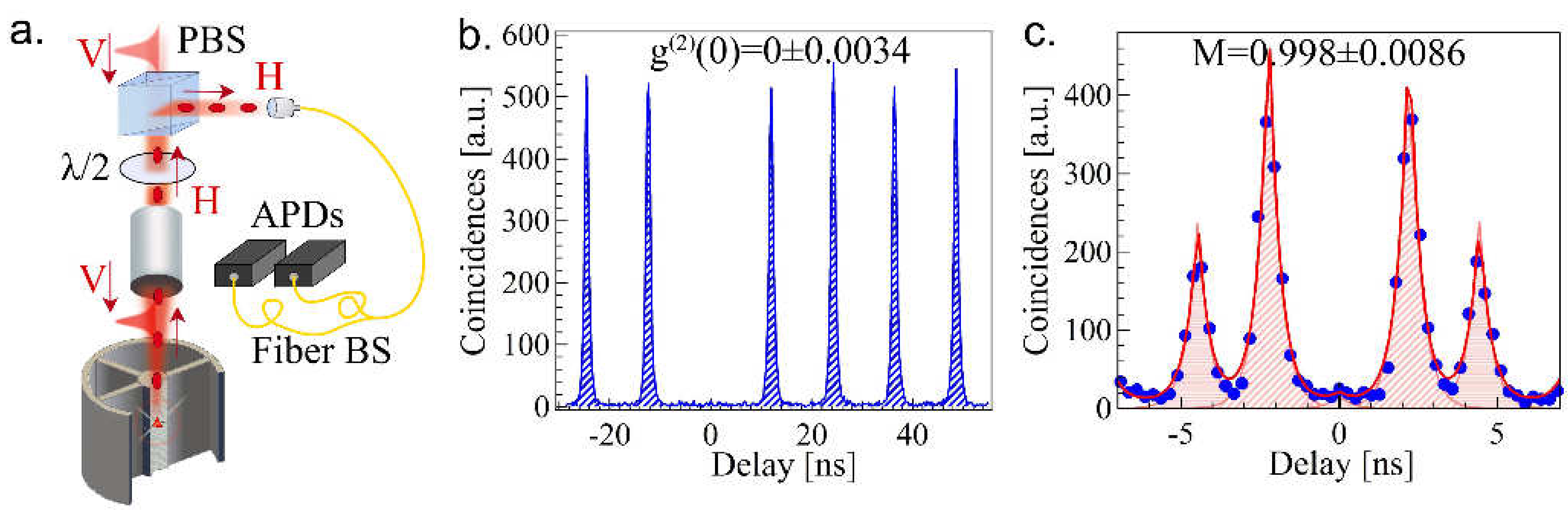
This talk will describe how these principles shape the editorial process in Nature Materials and other journals within the Nature family, amidst a rapidly changing scientific publishing landscape, underlining the key points from submission of original research papers to publication.

Solid State Bright Sources of Fully Indistinguishable Photons

Niccolo Somaschi niccolo.somaschi@lpn.cnrs.fr

Bright sources of single and indistinguishable photons are crucial for the scalability of linear optical quantum computing. Recent works have shown that semiconductor quantum dots (QDs) are very promising to fabricate such sources : QD deterministically emit true single photon states which can be efficiently collected if the QD is inserted in an optical structure. Recently, we demonstrated QD-based single photon sources with a brightness of 80% and indistinguishability as high as 92% [1].

Here we report on the fabrication and study of electrically tunable bright sources of fully indistinguishable single photons. We propose a novel cavity design which permits to apply an electric field while maintaining a 3D confinement for the photons. Specifically it consists of a micropillar cavity (2-3 μm) connected to a larger ohmic-contact surface with four 1D-bridges and a surrounding frame. Laterally, the fundamental cavity mode (CM) of the structure is confined in the centre of the connected pillar. Vertically, the GaAs cavity is surrounded by GaAs/AlGaAs Bragg mirrors, doped in a p-i-n diode configuration. A single QD is deterministically positioned at the center of the pillar by means of an advanced in-situ optical lithography [2, 3]. A strong Purcell effect is obtained with such a device when the QD transition is tuned into resonance with the CM, which in turn results in a very high brightness of the single-photon source, exceeding 55%. We study the device at first by mean of non-resonant excitation and report a photon indistinguishability in the 70−80% range. Subsequently we demonstrate that performing strictly resonant pumping in a excitation/detection cross polarization scheme (Fig.1 a) we can suppress completely any dephasing process thus obtaining near-unitary indistinguishability M = 0.998±0.0086 of the emitted single photons ($g^{(2)}(0) = 0\pm0.0034$) (Fig.1 b, c).



Exploring Multi-Photon States for Quantum Metrology

Merritt Moore merritt.moore@physics.ox.ac.uk

Quantum metrology uses quantum properties of a probe, particularly entanglement, to yield higher resolution and more sensitive measurements than possible with classical approaches. In an optical setup, many body entangled states have the ability to make precision phase measurements. Their quantum nature, when used in an interferometer, minimises the inherent uncertainty imposed by quantum mechanics. One of the main challenges is that these states are typically extremely fragile, particularly to loss, which prevents them from out-performing their classical counterpart. Hence quantum advantages in metrology have not been experimentally demonstrated before without post-selection. However, it has been theoretically shown that a particular state, the Holland-Burnett state HB(N), is a promising solution in the presence of experimental imperfections and losses. Experimentally we are now in the position to explore these states.

QED Description of Raman Scattering from Molecules in Plasmonic Cavities

Mikolaj Schmidt mikolaj_schmidt@ehu.es

Substrate Enhanced Raman Scattering (SERS) is a fundamental spectroscopic technique that allows us to access the rich vibrational structure of molecules. A variety of recent implementations of Raman experiments has been possible thanks to a better understanding of the interaction of light and Raman-active molecules, allowing for a more efficient engineering of the SERS substrates. Some of those results [1-3] appear to escape the standard description of the Raman process based on the classical treatment of the electromagnetic enhancement of fields inside a plasmonic cavity [4]. In our work [5] we present a quantum-mechanical model of the non-linear interaction between the quantized excitations of the plasmonic cavity, and the vibrational structure of the molecule. This approach readily describes effects which are not encompassed by the classical framework: (i) the onset of phonon-stimulated Raman scattering due to the interaction with the incoherent population of phonons, (ii) an unexpected dependence of the anti-Stokes scattering on the frequency of the incident laser and the local temperature. Furthermore, our exact formalism opens avenues to studying classical and quantum correlations of the photons emitted from the cavities. Finally, thanks to the resemblance of our interaction Hamiltonian to that commonly used to treat optomechanical systems [6], our approach allows to explore the vibration-plasmon coupling in a novel regime of interaction, characterized by relatively strong couplings observed previously only for the cold atoms, and low thermal populations.

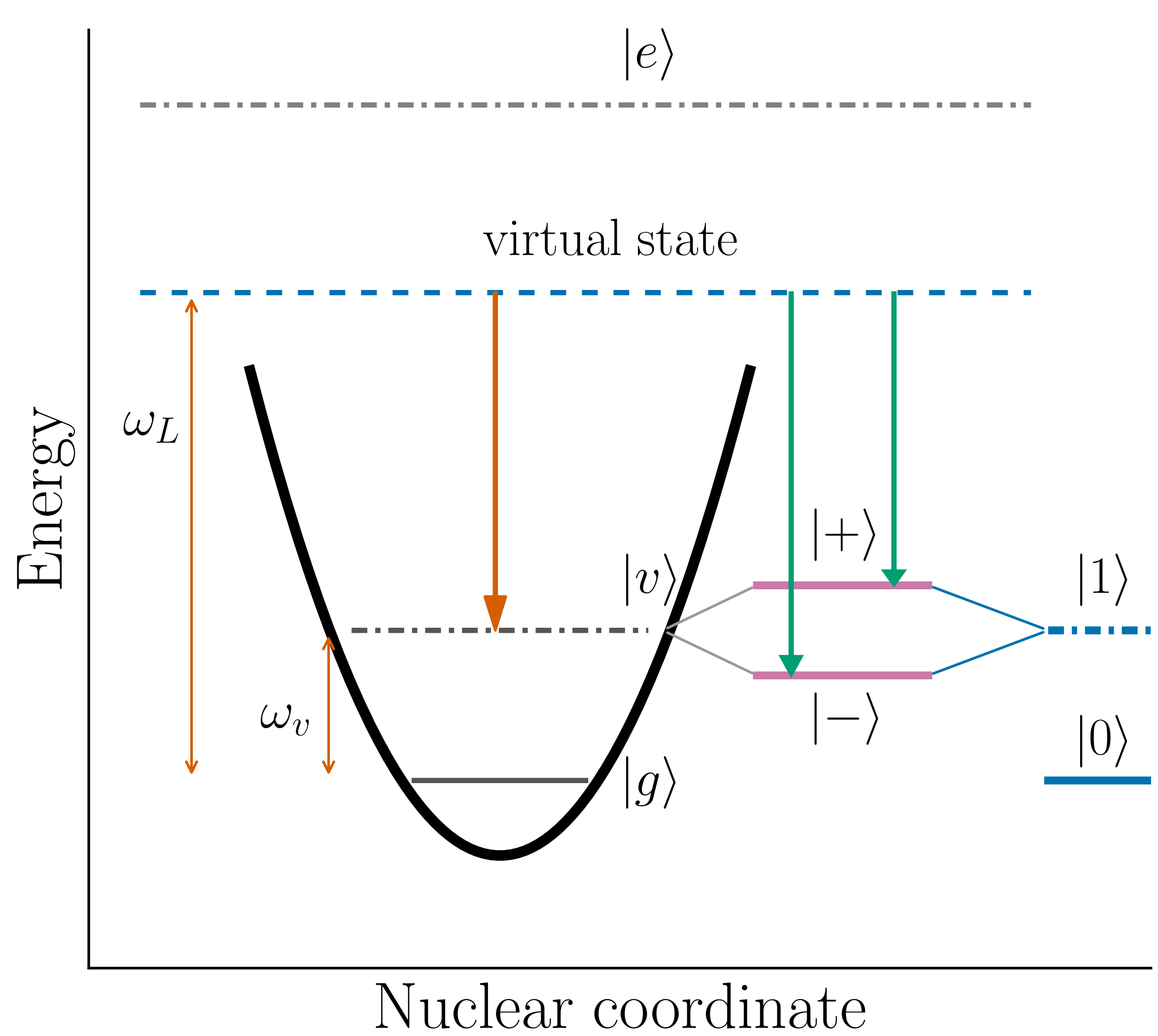
[1] W. Zhu, and K. Crozier, Nature Comm. 5, 5228 (2014).
[2] R. Zhang, Y. Zhang, Z.C. Dong, S. Jiang, C. Zhang, L.G. Chen, L. Zhang, Y. Liao, J. Aizpurua, Y. Luo, J.L. Yang, and J.G. Hou, Nature 498, 82 (2013).
[3] A. Shalabney, J. George, J.A. Hutchison, G. Pupillo, C. Genet, and T.W. Ebbesen, arXiv:1403.1050 (2014).
[4] H. Xu, X.-H. Wang, M.P. Persson, H.Q. Xu, M. Käll, and P. Johansson, Phys. Rev. Lett. 93, 243002 (2004); P. Johansson, H. Xu, and M. Käll, Phys. Rev. B 72, 035427, (2005).
[5] M.K. Schmidt, R. Esteban, A. Gonzalez-Tudela, G. Giedke, J. Aizpurua, arXiv:1509.03851.
[6] P. Roelli, Ch. Galland, N. Piro, and T.J. Kippenberg, arXiv:1407.1518 (2014).

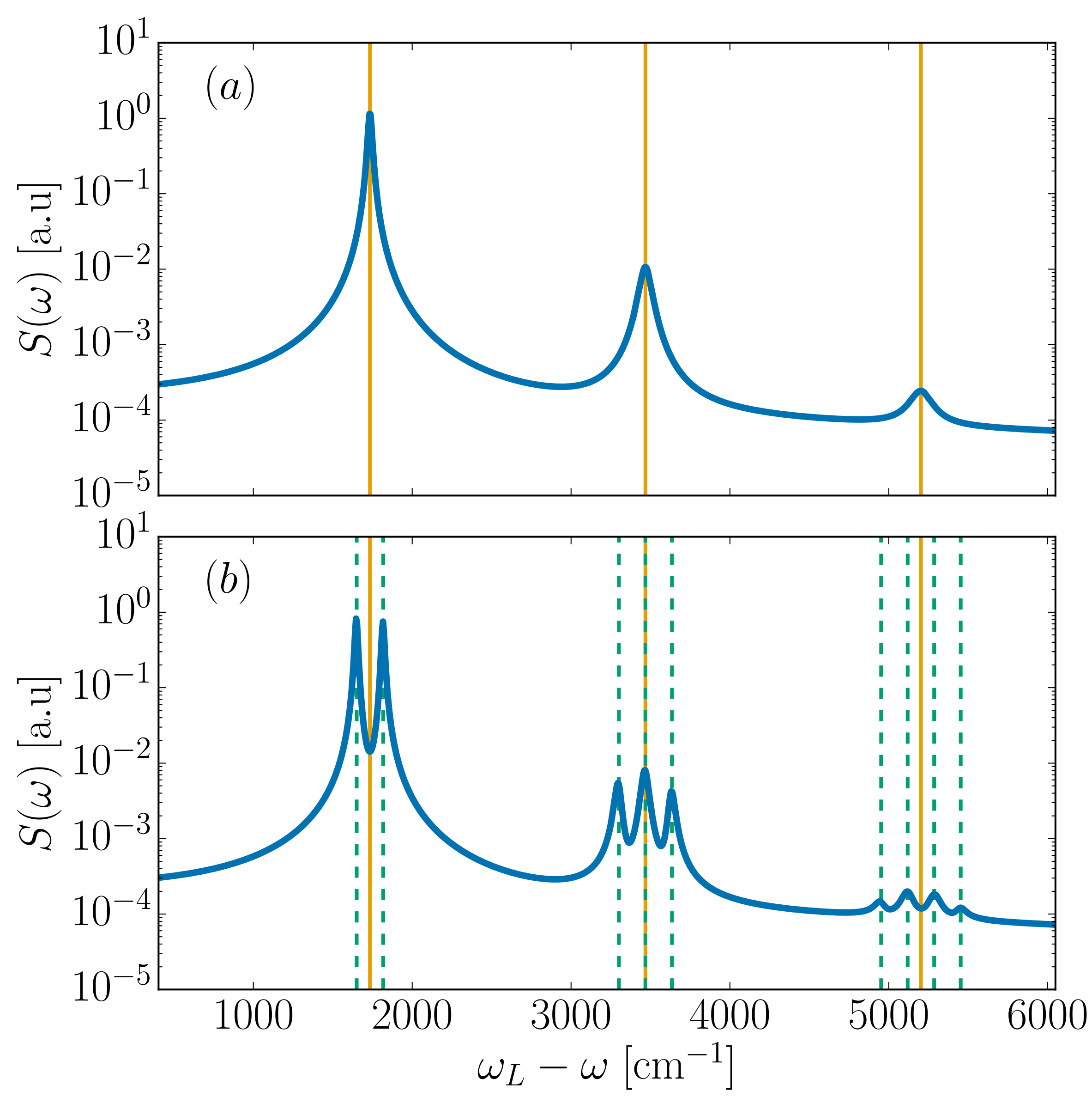
Signatures of Vibrational Strong Coupling in Raman Scattering

Javier Del Pino francisco.delpino@uam.es

When the coherent energy exchange between a light mode and quantum emitters is faster than the decay and decoherence of either constituent, the energy levels of both systems become inextricably linked. The excitations of the system are then hybrid light-matter quasiparticles, so-called polaritons, with an energy splitting given by the vacuum Rabi Splitting ΩR. A novel approach consists in coupling a photonic mode inside a Fabry-Pérot microcavity to to a collection of IR-active bond-stretching modes within a molecular ensemble, leading to vibrational strong coupling (VSC). In contrast to the well-known technique of surface- enhanced Raman scattering (SERS), which is based on the enhancement of the involved optical transitions, it is an open question whether Raman scattering is influenced by the modification of the vibrational levels under VSC. Recent experimental data on spontaneous Raman scat- tering (cf. Fig. 1) from the IR/Raman-active C=O bond in VSC within an ensemble of polymer molecules has been reported [1]. When the system achieves VSC, the first Stokes line of the Raman scattering from the weakly coupled (WC) system splits into 2 peaks, corresponding to the vibrational polaritons. These new lines, prominently asymmetric, are shifted by a significantly bigger amount in comparison with the splitting observed in transmission (ΩR) and remarkably, exhibit a 10^2-10^3 enhancement in the cross section of the coupled molecules relative to the uncoupled ones. We report a theory devoted to model the experiment in Ref. [1]. Using a series of successively more involved ap- proaches, we show that standard linear Raman scattering theory can not explain the observed signal enhancement. We discuss a number of possible further effects due to ultra-strong coupling (where counter-rotating terms in the Hamil- tonian become important) and the influence of permanent molecular dipole moments. We show that these effects are not significant under the experimental conditions, indicating that the observed signal can not be simply explained by Raman scattering from vibrational polaritons.

[1] A. Shalabney, J. George, H. Hiura, J. A. Hutchison, C. Genet, P. Hellwig, and T. W. Ebbesen, Angewandte Chemie 127, 8082 (2015).





Explicit Demonstration of How Path Interference Effect can Enhance Plasmonic Nonlinearity

Mehmet Emre Tasgin metasgin@hacettepe.edu.tr

It is well known to Plasmonics community that nonlinearities [e.g. second harmonic generation (SHG)] can be enhanced via Fano resonances. 2 to 3 orders of magnitude enhancement can be achieved on top of the enhancement due to field localization. We explicitly demonstrate --on an expression for the steady-state SHG amplitude-- how the presence of a Fano resonance leads to cancellation of nonresonant terms in a SHG process. Cancellation in the denominator gives rise to enhancement in the nonlinearity. The explicit demonstration, we present here, guides one to a method for achieving even larger enhancement factors by introducing additional coupling terms. The method is also applicable to Fano resonances induced by all-plasmonic couplings, which are easier to control in experiments.

[1] D. Turkpence, Gursoy B. Akguc, Alpan Bek, M. E. Tasgin, "Engineering nonlinear response of nanomaterials using Fano resonances," J. Opt. 16, 105009 (2014).
[2] B. C. Yildiz, M. E. Tasgin, M. K. Abak, S. Coskun, H. E. Unalan, Alpan Bek, "Enhanced Second Harmonic Generation from Coupled Asymmetric Plasmonic Metal Nanostructures", accepted in J. Opt.

Coupling Effects in Plasmonic Nanoparticle Arrays The Weak and the Strong Coupling Regime and the Effects of spin-orbit coupling

Tommi Hakala tommi.hakala@gmail.com

We study the spatial coherence properties of a system composed of periodic silver nanoparticle arrays covered with fluorescent organic molecule film [1]. The evolution of spatial coherence of the structure is investigated both in weak and strong coupling regimes by systematically varying the coupling strength between the localized molecular excitons and the collective, delocalized modes of the nanoparticle array known as surface lattice resonances (SLRs). In stark contrast to pure localized excitons, the high degree of spatial coherence is maintained in the strong coupling regime, even when the mode is very exciton-like (80 %). The effects of spin-orbit coupling are studied in periodic rectangular arrays of magnetic Ni nanoparticles [2]. We observe SLR modes in which the two directions of the lattice are coupled by the magnetic-field-controllable spin-orbit coupling in the nanoparticles. When breaking the symmetry of the lattice, we find that the optical response shows Fano-type surface lattice resonances whose frequency is determined by the periodicity orthogonal to the polarization of the incident field. In striking contrast, the magneto-optical Kerr response is controlled by the period in the parallel direction. The spectral separation of the response for longitudinal and orthogonal excitations provides versatile tuning of narrow and intense magneto-optical resonances.

[1] L. Shi, T. K. Hakala, H. T. Rekola, J.-P. Martikainen, R. J. Moerland, and P.Törmä, Phys. Rev. Lett. 112, 153002 (2014).
[2] M. Kataja, T. K. Hakala, A. Julku, M. J. Huttunen, S. van Dijken, and P. Törmä, Nature Communications 6, 7072 (2015).

Funding Opportunities in Horizon 2020

INVITED SPEAKER

Anthea Fabri

The presentation will focus on EU funding opportunities available in Horizon 2020 for Early Stage Researchers. Particular emphasis will be made on 2 specific programmes within Horizon 2020 – Marie Sklodowska Curie Actions (MSCA) and the European Research Council (ERC).

Detecting TE Plasmons and Bandgaps in Strained Graphene Atoms as a Universal Probe

Julia Werra julia.werra@physik.hu-berlin.de

We demonstrate how atoms and specifically their electric-dipole and magnetic-dipole transitions can be utilized for quantum-sensing of the electronic properties of strained graphene. For instance, strain caused by a lattice mismatch between graphene and a substrate, results in the opening of a bandgap in an otherwise gapless bandstructure. Besides probing this bandgap, atoms or atom-like systems (NV centers in diamond, quantum dots) are also very well suited probes for probing interesting unusual features such as the appearance of TE plasmons. This is mainly due to the enormous energy range covered by the various transitions, notably by the tunable magnetic Zeeman transitions, hyperfine transitions and various electronic transitions. We analyze in detail the changes in the lifetime of an emitter placed in direct proximity of a graphene sheet. Specifically, we isolate the role played by TE-plasmons and by the bandgap. Our results are relevant for atom-chip setups and in general for quantum technologies based on hybrid atom-field condensed-matter systems in particular.

Fabrication of Thin Diamond Films with Si-V Centers and Study of Their Temperature Dependent Photoluminescence

Štěpán Potocký potocky@fzu.cz

Outstanding photoluminescence properties of optical centers in diamond are characterized by high quantum yields, negligible photobleaching, no blinking and long lifetimes. Exceptionality of Si-V centers resides in spectrally narrow photo-luminescence with the zero-phonon line (ZPL) in the NIR spectral region (full width at half maximum down to 0.7nm at room temperature) and with the short lifetime of 1.2ns. The ZPL is very intensive at room temperature, and it is located at spectral window of biological tissues. Moreover, Si-V centers are highly photo-stable and their effective excitation by red light reduces tissue auto-fluorescence. Photoluminescence properties of such color centers localized near the surface are also sensitive to the surface termination. Due to carbon-carbon bonds diamond can be easily functionalized with various chemical groups and color center optical activity can be controlled. These properties predetermine application of Si-V centers in solid-state light emitters, especially single-photon sources, or fluorescent markers for bio-imaging. In this contribution, reproducible fabrication of a Si-related color centers in diamond lattice using microwave plasma CVD is investigated with a view to achieve a strong and controllable photoluminescence at 738nm. Particularly the influence of process conditions ($H_2/CH_4/CO_2$ gas mixture and deposition temperature) on the Si-V center photoluminescence activity is investigated. Temperature behaviour of steady-state photoluminescence of Si-V centres was studied within the range 11-300K. The photoluminescence properties are correlated with process parameters i.e. the addition influence of CO_2 up to 4.5% or N_2 up to 6.0% into the H_2/CH_4 gas mixture, and the substrate temperature during the film growth (350–1100°C). The growth temperature can tune the grain size from 50 to 200nm keeping good ZPL intensity. Adding of CO_2 or N_2 into the gas mixture monotonically suppressed the ZPL intensity. Moreover morphology change from well-faceted diamond film to a nanowire-like diamond structure with photoluminescence active Si-V center is induced by 1% N_2 addition. For all the samples, the temperature dependent PL study exhibited the blue shift in ZPL position with decreasing temperature and for selected samples, ZPL narrowing as well. This work was financially supported by research projects 14-04790S (CSF), SGS13/218/OHK4/3T/14 (CTU) and MSMT LD15003 (MPNS COST Action MP1403).

Numerical Studies of Out-of-Equilibrium Systems with Tensor Networks

INVITED SPEAKER

Mari Carmen Bañuls

Tensor network states have proven successful in describing ground states of quantum many body systems. The paradigmatic example is that of Matrix Product States (MPS), which underlie the celebrated DMRG method for the study of one dimensional systems. Using these methods it is also possible to simulate dynamics of pure quantum states. But MPS can be also extended to describe operators. This allows for different ways of numerically exploring out-of-equilibrium problems. For instance, we can study the steady state of a dissipative quantum system. Or we can construct the operators that exhibit the slowest dynamics in a given non-integrable problem.

Optical Control and Cooling of Nanoparticles in Vacuum

Towards Testing High-Mass Quantum Physics

INVITED SPEAKER

James Millen

By controlling nanoscale objects on the level where quantum effects become evident we can explore the limits of quantum physics. For example, we could test collapse models, whereby external influences such as gravity or fundamental noise prevents massive objects from being in a quantum superposition. By bringing the nanoscale object into the gas phase, and controlling it with light, we remove sources of noise and decoherence that are present in solid-state experiments. By cooling the motion of free nanospheres with the field of an optical cavity, we aim to perform interferometry in an entirely new mass regime.

It is not only the centre-of-mass motion that we can measure and control with light. We launch nanofabricated Silicon nanorods through an optical cavity and observe rotation rates of tens of MHz. The light in the cavity exerts a torque on the motion of the nanorods, and there is a coupling between the rotational and centre-of-mass motions, which we can measure with high-resolution. We will potentially be able to control and cool the rotational motion. Finally, to cool to the level where we can perform quantum experiments, we have developed arrays of open silicon microcavities with mode volumes of a few tens-of-femtolitres. This tiny mode volume will provide strong coupling between the light and the nanoparticles, and the ability to cool in several stages makes interferometry with masses over 10^6 amu feasible.

The Thermodynamics of Quantum Information Processing

INVITED SPEAKER

Philipp Kammerlander

How much heat is dissipated in a quantum computer? Just how small can thermal engines be? When does a system act as a heat bath towards a quantum device? As technology miniaturizes, we find that some approaches of traditional thermodynamics are inadequate to study heat and work in the regime of the very small. There are several aspects to this change, such as finite-size effects, subjectivity of information, emergence of quantum effects, the growing importance of correlations between small systems, and the fact that we are normally interested in single-shot results, as opposed to averages over a large number of experiments.

To tackle these challenges, a new theory of quantum thermodynamics is emerging, drawing from insights of quantum information theory. Quantum information theory has given us tools to model knowledge of quantum systems explicitly: we use it to analyse the security of cryptographic protocols, or how much information can be sent through a noisy channel, for example. In this talk, I will explore the connection between information theory and thermodynamics. We will start with the classic example of Maxwell's demon, and build up to the work cost of erasure of quantum information.

Analyzing Peer Review

INVITED SPEAKER

Dr. Manolis Antonoyiannakis

I will present an insider's view on peer review drawing from my experience at the journals of the American Physical Society (Physical Review B, Physical Review Letters, and Physical Review X) where I have worked since 2003. First, I will discuss the basic elements of peer review (editorial screening, rejection without external review, referee selection, consultation with Editorial Board Members, assessment of referee reports, handling of conflicting referee recommendations, selection of a subset of accepted papers for highlighting). In the process, I will present some commonly used arguments by authors that can actually backfire, and some anecdotal excerpts of correspondence. Second, I will discuss some recent trends in science publishing, from launching new journals to providing new services to authors. I will focus on one recent trend, the highlighting of select sets of papers by publishers. Third, I will discuss citation impact metrics for journals (Impact Factor, EigenFactor, h5 index) and for subsets of journals (e.g., Editors' Suggestions, papers highlighted in APS Physics, etc.). This leads naturally to the questions (a) whether editors and referees can pick out, at the time of acceptance, the papers destined to be highly cited or otherwise influential; and (b) whether such papers tend to be controversial at the time of publication and after. I will present some data on these questions. Overall, my aim is for the audience to appreciate the imperfect and imprecise nature of editorial decision-making that is sometimes unappreciated by a community trained in the hard sciences. Finally, for the benefit of the younger audience, I will present a brief outline of the editorial job and career prospects of editors.

Planar Optical Antenna to Direct Light Emission

Simona Checcucci checcucci@lens.unifi.it

The study of single emitter systems via detection of fluorescence photons is a widely used method in a multitude of situations, ranging from sensing to quantum information. However, the nearly isotropic nature of the radiation pattern makes the efficient collection of light problematic. The main approaches in overcoming this limit are substantially divided into two types: one is to increase the solid angle of collection through the use of high numerical aperture objectives, while the other involves the study and the implementation of appropriate devices able to directing and beaming the emission. Exactly this second approach is the guideline of this work, focused on the design, the implementation and the experimental observation of a multilayer planar structure able of beaming the fluorescence emission.

Injection Locking in the Quantum Regime

Steffen Holzinger steffen.holzinger@tu-berlin.de

Nonlinear oscillators can eventually synchronize to a periodic external force applied by a master oscillator, even if the strength of the external drive is orders of magnitude weaker than the amplitude of the nonlinear oscillator itself. We study this widely applied phenomenon of injection locking on quantum dot microlasers in the regime of cavity quantum electrodynamics with on average few tens of photons in the cavity. In contrast to classical predictions like Adler's theory and modifications thereof [1], a regime of partial locking is found where the laser simultaneously oscillates phase-synchronized to the external signal and at its solitary frequency. In the experiments we use electrically pumped micropillar lasers with a diameter of 5.3µm and a single layer of self-assembled InGaAs quantum dots as an active medium. Figure 1 (a) shows the input-output characteristics of the investigated microlaser emitting at a wavelength of 850nm. In principle, the laser exhibits two orthogonally polarized modes [2]. However, at in the operating region above threshold one mode is dominant and the laser is effectively single mode and emits a total power <1µW [3]. In this regime, the laser operates with a few tens of photons in the cavity. A commercial external cavity laser tunable in intensity Im is injected into the microlaser of emitting intensity Is [Fig 1(b)]. Synchronization between master and slave is proven by their ability to interfere on a fiber beam splitter. The amplitude of the interference fringes reflects the intensity of the phase locked slave laser emission. Figure 1(c) shows a map of this locked intensity, depending on injection rate $K = (Im/Is)^{1/2}$, with detuning Δ between master and solitary slave laser frequency. Fabry-Perot spectra for varying Δ are shown in figure 1(d). Strong emission at the master's frequency is evident for negative detuning as expected from the interference measurements. Surprisingly, this is accompanied by significant emission at the slave laser's solitary frequency. Only for very low detuning below 1 GHz, emission at the slave frequency is suppressed and very intense locking is observed. This behavior is attributed to the strong contribution of spontaneous emission in the investigated microlaser with a high spontaneous emission factor (β-factor) [3]. For further insight into the emission dynamics measurements of the second order autocorrelation function g(2)(τ) were performed with a Hanbury-Brown and Twiss setup. Our results pave the way for further studies on the dynamics of high-β lasers and the external quantum control of nanophotonics systems which promises exciting insight into the underlying physics of single photon nonlinearities.

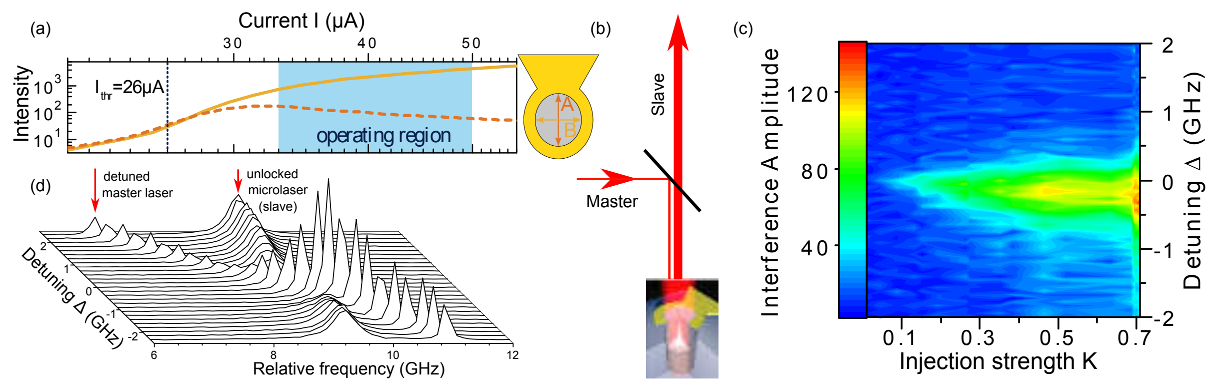


Fig. 1 (a) Double-logarithmic input-output characteristic for the two orthogonally polarized modes of the micropillar laser. The schematic inset shows the micropillar seen from top. The polarization of the two modes (called A and B) is indicated by arrows. (b) Sketch of the experiment: A tunable master laseris injected into a micropillar laser whose emitted signal is analyzed. (c) Colourmap showing the intensity of the phase locked slave laser emission in dependence on the detuning Δ between master and slave and injection strength K.
(d) High resolution spectra measured while the master laser is tuned over slave laser. The emission shows partial injection locking.

References [1] T. Erneux and P. Glorieux, Laser Dynamics, Cambridge 2010 [2] H.A.M. Leymann et al., Phys. Rev. A 87, 053819 (2013) [3] S. Reitzenstein et al., Appl. Phys. Lett. 93, 061104 (2006)

Optically Controlled Elastic Microcavities

Assegid Mengistu Flatae flatae@physik.uni-siegen.de

Solid-state optical microcavities are versatile photonic devices which come in a large variety of shapes. Of particular interest are whispering gallery mode (WGM) resonators which have small modal volume and ultra high quality (Q) factors. These resonators are highly attractive for applications like, bio- sensing, single photon sources as well as for fundamental physics studies like cavity quantum electrodynamics (cQED). However, tunability of these resonances is difficult to achieve for robust device applications. Here we present the fabrication of polymeric micro-goblet WGM resonators with an optically controlled tunability over a large spectral range. This tunability is achieved by integration of photo-responsive liquid crystalline elastomers (LCEs) into micro-goblet cavities.

Novel Topological States in Optomechanical and Nanophotonic Arrays

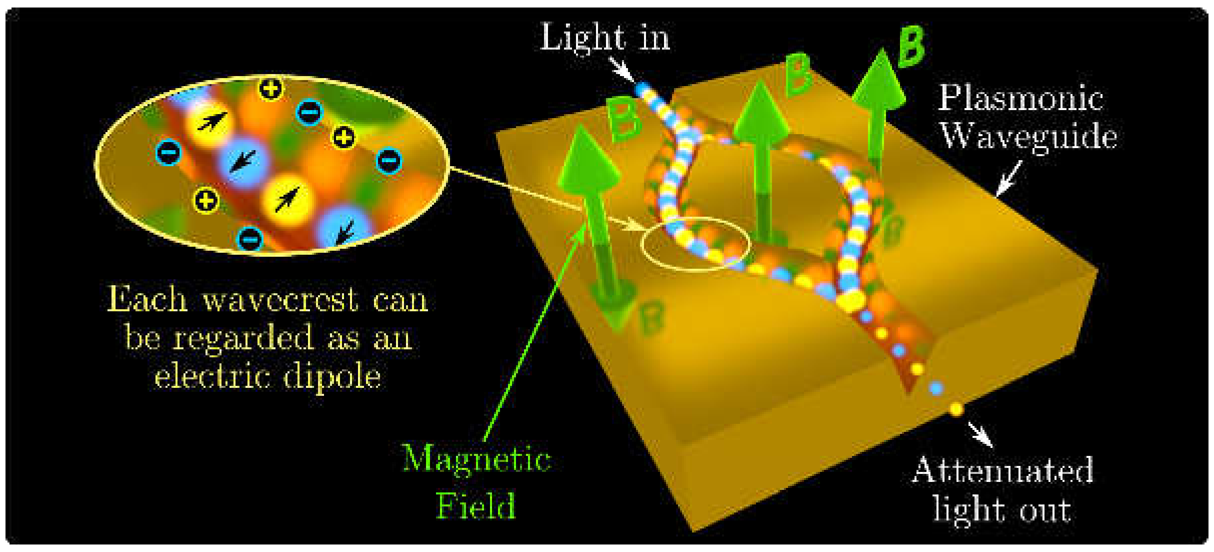
Vittorio Peano vittorio.peano@physik.uni-erlangen.de

Motivated by current experimental progresses in confining light and sound in photonic and optomechanical crystals, we investigate novel topological states of photons and phonons confined on a lattice of defect modes. We propose that the topological properties of the sound waves in an optomechanical array could be wholly tuned in situ via the amplitude and frequency of a driving laser. The resulting chiral, topologically protected phonon transport could be probed completely optically. Moreover, we identify a regime of strong mixing between photon and phonon excitations, which gives rise to a large set of different topological phases and offers an example of a Chern insulator produced from the interaction between two physically distinct particle species, photons and phonons. We also show how the squeezing of light can lead to the formation of topological states. Such states are characterized by non-trivial Chern numbers, and exhibit protected edge modes which give rise to chiral elastic and inelastic photon transport. These topological bosonic states are not equivalent to their fermionic (topological superconductor) counterparts and cannot be mapped by a local transformation onto topological states found in particle-conserving models. They thus represent a new type of topological system.

Quantum Topological Phase in Guided Surface Plasmon-Polaritons

Vassili Savinov vs1106@orc.soton.ac.uk

The Aharonov-Bohm effect is both one of the most celebrated and vigorously debated phenomena in quantum physics. In essence, it predicts that the phase of charged quantum mechanical particles, such as electrons, will be shifted as a result of encircling a region penetrated by magnetic field. The phase shift is topological in nature and will occur even if the electrons are confined to travel only through space where magnetic field is strictly zero, such as around an infinitely long solenoid. The modern view on this unusual phenomenon, is that the electrons can sense the vector potential that encircles the infinite solenoid, since it is the vector potential that enters the Schrödinger Equation and therefore affects the evolution of electron wavefunction. The Aharonov-Bohm effect is not unique; there exist several similar effects that arise as a result of the same physical laws. In particular, the He-McKellar-Wilkens (HMW) effect predicts additional phase gain for the particles with electric dipole that propagate through a region with uniform static magnetic field. First described in the beginning of 1990s, this effect has remained unconfirmed until just few years ago. Surface plasmon-polaritons, or simply plasmons, are coupled excitations of light and free electrons in solids. We will demonstrate that by viewing plasmons travelling along a V-groove plasmonic waveguide as a row of propagating electric dipoles with alternating orientation (see Fig. 1), one can predict a plasmonic equivalent of the HMW effect. Applying magnetic field perpendicular to the direction of plasmon propagation will cause a phase-shift in wavefunctions of the effective electric dipoles. Such a shift could be detected in an interferometer setup as attenuated light transmission that arises due to plasmon interference. We will provide numerical analysis to show that the effect will be observable under routinely accessible measurement conditions such as millitesla magnetic fields and microwatt optical power. Finally, we will discuss the implementation of the experiment to confirm the effect.



Coherent Polaron Pair Formation in a Conjugated Polymer

Antonietta De Sio antonietta.de.sio@uni-oldenburg.de

Combining high-time resolution two-dimensional spectroscopy and density matrix simulations we show that coherent vibronic coupling is the driving force for polaron pair formation in a reference conjugated polymer for photovoltaic applications. Semiconducting polymers have fascinating optical and electrical properties that, together with high mechanical flexibility and ease of processing, make them suitable for flexible, low cost, large area optoelectronic devices such as solar cells, transistors and light emitting diodes [1-3]. Because of their low dielectric constants compared to inorganic semiconductors, electron-phonon interactions cannot be neglected in the description of the optical excitations [4]. As a consequence a wealth of quasiparticles, e.g., excitons, charge-transfer excitons, polarons, polaron pairs and others contribute to the optical and transport properties. Polarons and polaron pairs are of fundamental importance for application of these materials in optoelectronic devices, since they are the precursors of charges [5]. However, still very little is known on their initial quantum dynamics in conjugated polymers. Here we use ultrafast two-dimensional optical spectroscopy with 10 fs temporal resolution to probe the dynamics of polaron pair formation in regioregular poly-3-hexyl-thiophene thin films at room temperature. This is the prototypical donor material in organic photovoltaics. Experimentally, we observe efficient polaron pair formation within 20fs after photoexcitation and long-lived oscillatory behavior on both the exciton and polaron pair dynamics with a period of 23fs, which corresponds to the breathing mode of the thiophene ring [6, 7]. These preliminary results suggest that the strong coherent coupling between electronic and vibrational degrees of freedom is the driving force for polaron pair formation and results in strongly correlated exciton and polaron dynamics.

1. G. Li, R. Zhu, Y. Yang, Nat Photon 6, 153, 2012
2. T. Sekitani, U. Zschieschang, H. Klauk, T. Someya, Nat Mater 9, 1015, 2010
3. S. Reineke et al., Nature 459, 234, 2009
4. S. Kilina, D. Kilin, S. Tretiak, Chemical Reviews 115, 5929, 2015
5. R. C. Huber et al., Science 348, 1340, 2015
6. S.M. Falke et al, Journal of Raman Spectroscopy 42, 1897, 2011
7. S.M. Falke, C.A. Rozzi, D. Brida, M. Maiuri, M. Amato, E. Sommer, A. De Sio, A. Rubio, G. Cerullo, E. Molinari, and C. Lienau, Science 344, 1001, 2014.

Conjugating Entrepreneurship and Research for Fun and Profit

INVITED SPEAKER

Dr. Simone De Liberato

I will use the time of this talk to tell you something about my experience in-between academia and entrepreneurship. I will try to focus both on the more mundane problems of funding, building a team, and managing bureaucracy, and on the more subtle change in perspective needed to successfully conjugate those two worlds.

Perspectives for Integrated Optics in Satellite Quantum Communications

Daniele Dequal dequal@dei.unipd.it

The development of integrated optics is a promising technique for the realization of quantum information protocols. This is for instance the case of the realization of complex structure which may be impractical, or even impossible, to build with bulk optical elements. Moreover, integrated optical circuits might play a crucial role in the realization of source of quantum state of light for long distance quantum communication (QC), as in the case of satellite QC that requires compact and lightweight components. We report recent results of Padua University in collaboration with the Matera Laser Ranging Observatory in the field of satellite QC. The collaboration recently realized the first transmission of a quantum state of light from an orbiting terminal in low Earth orbit (LEO) to a ground station. Moreover, a single photon transmission link from a medium Earth orbit (MEO) satellite to a ground station has been demonstrated as well. These results have been obtained exploiting passive devices, i.e. the corner cube retro-reflectors mounted on satellites of the laser ranging network. The next step toward the realization of satellite based quantum experiment is the realization of active payloads that can produce and modulate the quantum state of light in orbit. Perspective and challenges for the realization of payloads compliant for the implementation onboard of small satellites will be discussed, highlighting the possible implementation of integrated optics in next generation satellite quantum experiment.

Optomechanical Interaction and Strain Coupling in Diamond Resonators

Laura Kreiner laura.kreiner@uni-saarland.de

All platforms for realizing basic building blocks of quantum technologies known to date have different strengths and weaknesses. With the aim of benefitting from their individual advantages several dissimilar devices can be combined in a hybrid system. In order to develop new quantum technologies the interaction between different degrees of freedom needs to be studied. Here, we investigate a platform for mutual coupling between confined phonons, photons and the spin of color centers in diamond. Our platform consists of a diamond nanostructure hosting at the same time strongly confined optical and mechanical resonator modes as well as a color center in its center. This monolithic approach enables not only the well-studied Purcell enhancement of the emitter's spontaneous emission rate but also optomechanical interaction and strain coupling. Our study is based on a photonic crystal structure providing an optical cavity mode in resonance with a color center at visible wavelengths. Due to its design the device also functions as phononic crystal resonator confining a mechanical cavity mode at 10-20 GHz with a zero point fluctuation of 2.89fm. Optomechanical interaction in this structure is based on the photoelastic effect and the moving boundaries effect. We identify design rules that allow at the same time for good optical and mechanical quality factors in the range 107 and a considerable optomechanical interaction already on the single quantum level. With this approach overall single photon optomechanical coupling constants as high as $g_0/2\pi$=1.5*10MHz can be reached. In addition strain coupling between the mechanical cavity mode and a NV color center incorporated in the resonator material takes place. We describe the effect of longitudinal and transversal strain on the electronic ground states. To this end we consider the orientation of the phononic crystal structure with respect to the diamond crystal lattice taking into account commonly available sample surfaces and the alignment of the resonator axis in the surface plane. We find a splitting between the |0> and |1> states up to 400MHz and between the new eigenstates |1*> and |-1*> up to 520MHz per single confined phonon, respectively.

Cavity-Induced Modifcations of Molecular Structure in the Strong Coupling Regime

Javier Galego javier.galego@uam.es

Strong coupling in quantum electrodynamics is a well-known phenomenon that occurs when the coherent energy exchange between a light mode and quantum emitters is faster than the decay and decoherence of either constituent. The excitations of the system are then hybrid light-matter excitations, so-called polaritons, that combine the properties of both constituents. Organic molecules as quantum emitters are particularly suited to achieve strong coupling due to their large dipole moments and high densities, which enable Rabi splittings (the energy splitting between the polaritons) up to more than 1 eV. However, in most theoretical description of collective strong coupling of organic molecules to a cavity mode, the molecules are modeled as simple two-level systems. This picture fails to describe the rich structure provided by their internal rovibrational (nuclear) degrees of freedom. It has been experimentally demonstrated that strong coupling can modify this structure, in the sense that material properties and chemical reaction rates change [1]. Current theoretical approaches only provide limited insight into the effects of strong coupling on molecular structure. We investigate a first-principles model that fully takes into account both electronic and nuclear degrees of freedom, allowing an exploration of the phenomenon of strong coupling from an entirely new perspective. We will do so by taking advantage of the widely-used Born-Oppenheimer approximation, which allows to fully describe molecular structure and reactions. In the present work [2] we begin by demonstrating the limitations of applicability of the Born-Openheimer approximation in strongly coupled molecule-cavity structures due to the introduction of the Rabi splitting as a new additional intermediate timescale between electronic and nuclear motion. For the case of two molecules, we also show how dark states, which within the two-level picture are effectively decoupled from the cavity, are indeed affected by the formation of collective strong coupling. Finally, we discuss ground-state modications in the ultra-strong coupling regime and show that some molecular observables are affected by the collective coupling strength, while others only depend on the single-molecule coupling constant.

[1] James A. Hutchison, Tal Schwartz, Cyriaque Genet, Elose Devaux, and Thomas W. Ebbesen, "Modifying chemical landscapes by coupling to vacuum fields", Angew. Chem. Int. 51, 1592-1596 (2012).

[2] Javier Galego, Francisco J. Garcia-Vidal, and Johannes Feist, "Cavity-induced modications of molecular structure in the strong-coupling", Phys. Rev. X (submitted), arXiv:1506.03331 (2015).

Coherent Control and Readout of Single Spins in Silicon Carbide at Ambient Conditions

Matthias Widmann m.widmann@physik.uni-stuttgart.de

Coherent spin manipulation is a key for quantum information processing (QIP)[1] and quantum metrology (QM) [2,3]. Coherent spin manipulation has been performed in several systems such as quantum dots, Josephson junctions[4] and Rydberg atoms[5]. However all these systems need to be operated at low temperature. A promising candidate, which operates at room temperature is the nitrogen-vacancy (NV) center in diamond. This paramagnetic defect spin (S=1) has a high spin polarization in the ground state and very stable photon emission. This combined with long spin coherence times, up to a millisecond at ambient condition, allowed rapid growth of the related research fields towards applications to QIP and QM using the NV centers. However, it is hard to perform nanometer-scale fabrication, because of the mechanical and chemical inertness of diamond. Difficulty in the fabrication of spintronic devices based on electrical spin detection also hinder integration of diamond device into modern electronic devices. By switching the host to silicon carbide (SiC) both drawbacks can be compensated. Mature fabrication has been developed with SiC, which allows fabrication of optical cavities and various nanostructures. The smaller band gap compared to diamond even allows electrical access to spins, known as electrically detected magneto resonance (EDMR)[6] and tiny electronic devices like SiC nanowire field effect transistors (nwFETs)[7,8]. Besides the electrical access also the optical is possible. In 2014 Castelletto et al[9] reported the first single-photon source creation. Recently spin manipulation and detection from a single defect at ambient condition in SiC has been shown[10,11]. Here we present our research progress on the creation of single spin qubits based on the silicon vacancy (Vsi) in SiC. We show that that it is possible to realize a low defect density via 2 MeV low dose electron irradiation in order to resolve single Vsi. To prove the single photon emission from single defects created, we present 2nd order autocorrelation measurement of the photon emission. We also show that optically detected magnetic resonance (ODMR) on these single defects is possible. We find the lower limit of a spin coherence time T2 to be close to 200 µs which is comparable with that of the NV centers in natural abundant diamond. Generally, major decoherence source is caused by interactions with spin bath. These are paramagnetic impurities, and nuclear spins (29Si) which interact with the central electron spin via dipolar interaction. In the tested sample, the lowered impurity concentration and the suppressed hetero nuclear spin flip-flop by an externally applied magnetic field (~300 Gauss) allow long-lived electrons spin coherence[12,11]. The expected T2 time in the natural abundant SiC can be close or longer than 1 ms , which is similar to that of the NV centers in the isotope pure diamond. This theoretical work is confirmed by measurement of the coherence time of ensemble defects (divacancy) in SiC at cryogenic temperature[10]. Our report combined with the results from other research groups suggest SiC as a prospective platform for integrated spintronics, photonics and electronics in one material.

1. Morton, J. J. L. & Lovett, B. W. Hybrid solid state qubits: the powerful role of electron spins. 54 (2011). doi:10.1146/annurev-conmatphys-062910-140514
2. Balasubramanian, G. et al. Nanoscale imaging magnetometry with diamond spins under ambient conditions. Nature 455, 648–651 (2008).
3. Häberle, T., Schmid-Lorch, D., Karrai, K., Reinhard, F. & Wrachtrup, J. High-Dynamic-Range Imaging of Nanoscale Magnetic Fields Using Optimal Control of a Single Qubit. Phys. Rev. Lett. 111, 170801 (2013).
4. Shnirman, A., Schoen, G. & Hermon, Z. Quantum Manipulations of Small Josephson Junctions. Phys. Rev. Lett. 15 (1997).
5. Treutlein, P., Hommelhoff, P., Steinmetz, T., Hänsch, T. & Reichel, J. Coherence in Microchip Traps. Phys. Rev. Lett. 93, 219904 (2004).
6. Sato, T., Yokoyama, H. & Ohya, H. Electrically Detected Magnetic Resonance (EDMR) Measurements of Bulk Silicon Carbide (SiC) Crystals. Chem. Lett. 35, 1428–1429 (2006).
7. Seong, H.-K., Choi, H.-J., Lee, S.-K., Lee, J.-I. & Choi, D.-J. Optical and electrical transport properties in silicon carbide nanowires. Appl. Phys. Lett. 85, 1256 (2004).
8. Rogdakis, K. et al. 3C-silicon carbide nanowire FET: An experimental and theoretical approach. IEEE Trans. Electron Devices 55, 1970–1976 (2008).
9. Castelletto, S. et al. A silicon carbide room-temperature single-photon source. Nat. Mater. 12, 1–6 (2013).
10. Christle, D., Falk, A. & Andrich, P. Isolated electron spins in silicon carbide with millisecond-coherence times. Nat. Mater. 14, 25–27 (2015).
11. Widmann, M. et al. Coherent control of single spins in silicon carbide at ambient condition. Nat. Mater. 14, (2015).
12. Yang, L.-P. et al. Electron spin decoherence in silicon carbide nuclear spin bath. Phys. Rev. B 90, 1–6 (2014).

Shubnikov-De Haas Effect in a Light-Dressed Two Dimensional Electron Gas

Kevin Dini kevin.dini@laposte.net

During the last decades, the study of the electronic properties of semiconductors has become quintessential in the context of research of new materials for innovation in many applied fields like photovoltaics, lasers etc. Most of the interest is directed to the theory of two-dimensional systems partly because of their relevance of such theories to the properties of surfaces and thin films. Characteristic properties of two-dimensional system appear specially when a strong magnetic field is applied perpendicularly to the surface. The orbital motion of the electrons is quantized and the energy spectrum becomes discrete, formed by the so called Landau levels (LL). This kind of singular system clarify the characteristics of the quantum transport and are the basis of the famous Hall bar experiment . The study of such systems has to be done taking into account the broadening of the LLs due to disorder. At low temperatures, the broadening is caused by scatterers such as impurities, lattice defects, roughness of the surface etc. In calculating the quantum transport properties of 2D systems, one usually assumes scatterers with a delta potential which are randomly distributed in the x-y plane and according to some distribution in the z direction. The results are the so called Shubnikov-de Haas (SdH) effect and Hall effect which are nowadays used to determine such properties of semiconductors as the density of carriers or the relaxtion time of electrons. Experimentaly the level broadening, which strongly depend on the density of scatterers may be a problem for the clarity of the results and lead to a high uncertainty in dirty samples. The level broadening reduction would lead to the raise of the precision of measurements on such systems. The electron backscattering effect is the main result of the presence of scatterers in a two-dimensional electronic system. It has been shown recently that a strong coupling between a 2D electron gas (2DEG) and a high-frequency polarized electromagnetic wave has a huge effect on the transport properties of the system. The purpose of this paper is to show the impact of this effect on the SdH oscillations which is to raise their amplitudes which in turn leads to more clarity in the extraction of the electron concentration values. The results show a significant raise of the amplitude of the oscillations with a 1mW per cm^2 dressing field.