Cavity-enhanced nitrogen-vacancy ensemble magnetometry
We demonstrate magnetic-field sensing using the intrinsic nitrogen-vacancy concentration of a single-crystal diamond placed in an optical cavity resonant with the pump field. We investigate two approaches based on fluorescence detection and pump absorption, respectively.

Contributed review: camera-limits for wide-field magnetic resonance imaging with a nitrogen-vacancy spin sensor
Sensitive, real-time optical magnetometry with nitrogen-vacancy centers in diamond relies on accurate imaging of small (∼10−2), fractional fluorescence changes across the diamond sample. We discuss the limitations on magnetic field sensitivity resulting from the limited number of photoelectrons that a camera can record in a given time. Several types of camera sensors are analyzed, and the smallest measurable magnetic field change is estimated for each type. We show that most common sensors are of a limited use in such applications, while certain highly specific cameras allow achieving nanotesla-level sensitivity in 1 s of a combined exposure. Finally, we demonstrate the results obtained with a lock-in camera that paves the way for real-time, wide-field magnetometry at the nanotesla level and with a micrometer resolution.
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BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.686 SNIP 0.908 CiteScore 1.11
Web of Science (2015): Impact factor 1.336
Web of Science (2015): Indexed yes
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Scopus rating (2014): SJR 0.972 SNIP 1.261 CiteScore 1.45
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Web of Science (2013): Impact factor 1.584
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.017 SNIP 1.277 CiteScore 1.45
Web of Science (2012): Impact factor 1.602
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
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ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.218 SNIP 1.405
Web of Science (2010): Impact factor 1.601
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.001 SNIP 1.061
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.274 SNIP 1.344
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.922 SNIP 1.023
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.153 SNIP 1.297
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.883 SNIP 1.044
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 1.13 SNIP 1.393
Web of Science (2004): Indexed yes
We suggest a novel approach for wide-field imaging of the neural network dynamics of brain slices that uses highly sensitivity magnetometry based on nitrogen-vacancy (NV) centers in diamond. In vitro recordings in brain slices is a proven method for the characterization of electrical neural activity and has strongly contributed to our understanding of the mechanisms that govern neural information processing. However, this traditional approach only acquires signals from a few positions, which severely limits its ability to characterize the dynamics of the underlying neural networks. We suggest to extend its scope using NV magnetometry-based imaging of the neural magnetic fields across the slice. Employing comprehensive computational simulations and theoretical analyses, we determine the spatiotemporal characteristics of the neural fields and the required key performance parameters of an NV magnetometry-based imaging setup. We investigate how the technical parameters determine the achievable spatial resolution for an optimal 2D reconstruction of neural currents from the measured field distributions. Finally, we compare the imaging of neural slice activity with that of a single planar pyramidal cell. Our results suggest that imaging of slice activity will be possible with the upcoming generation of NV magnetic field sensors, while single-shot imaging of planar cell activity remains challenging.
Nitrogen-vacancy ensemble magnetometry based on pump absorption

We demonstrate magnetic-field sensing using an ensemble of nitrogen-vacancy centers by recording the variation in the pump-light absorption due to the spin-polarization dependence of the total ground-state population. Using a 532 nm pump laser, we measure the absorption of native nitrogen-vacancy centers in a chemical-vapor-deposited diamond placed in a resonant optical cavity. For a laser pump power of 0.4 W and a cavity finesse of 45, we obtain a noise floor of $\sim 100$ nT/$\sqrt{\text{Hz}}$ spanning a bandwidth up to 125 Hz. We project a photon shot-noise-limited sensitivity of $\sim 1$ pT/$\sqrt{\text{Hz}}$ by optimizing the nitrogen-vacancy concentration and the detection method.
Precision temperature sensing in the presence of magnetic field noise and vice-versa using nitrogen-vacancy centers in diamond

We demonstrate a technique for precision sensing of temperature or the magnetic field by simultaneously driving two hyperfine transitions involving distinct electronic states of the nitrogen-vacancy center in diamond. Frequency modulation of both driving fields is used with either the same or opposite phase, resulting in the immunity to fluctuations in either the magnetic field or the temperature, respectively. In this way, a sensitivity of 1.4 nT Hz$^{-1/2}$ or 430 μK Hz$^{-1/2}$ is demonstrated. The presented technique only requires a single frequency demodulator and enables the use of phase-sensitive camera imaging sensors. A simple extension of the method utilizing two demodulators allows for simultaneous, independent, and high-bandwidth monitoring of both the magnetic field and temperature.

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BFI (2015): BFI-level 2
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Scopus rating (2012): SJR 2.57 SNIP 1.739 CiteScore 3.76
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ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.814 SNIP 1.917 CiteScore 4.04
Narrow-bandwidth sensing of high-frequency fields with continuous dynamical decoupling

State-of-the-art methods for sensing weak AC fields are only efficient in the low frequency domain (<10 MHz). The inefficiency of sensing high-frequency signals is due to the lack of ability to use dynamical decoupling. In this paper we show that dynamical decoupling can be incorporated into high-frequency sensing schemes and by this we demonstrate that the high sensitivity achieved for low frequency can be extended to the whole spectrum. While our scheme is general and suitable to a variety of atomic and solid-state systems, we experimentally demonstrate it with the nitrogen-vacancy center in diamond. For a diamond with natural abundance of $^{13}\text{C}$, we achieve coherence times up to 1.43 ms resulting in a smallest detectable magnetic field strength of 4 nT at 1.6 GHz. Attributed to the inherent nature of our scheme, we observe an additional increase in coherence time due to the signal itself.

General information

State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology, University of Ulm, Hebrew University of Jerusalem
Authors: Stark, A. (Intern), Aharon, N. (Ekstern), Unden, T. (Ekstern), Louzon, D. (Ekstern), Huck, A. (Intern), Retzker, A. (Ekstern), Andersen, U. L. (Intern), Jelezko, F. (Ekstern)
Number of pages: 6
Publication date: 2017
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Publication information
Nitrogen-vacancy ensemble magnetometry based on pump absorption

We demonstrate magnetic field sensing by recording the variation in the pump light absorption with nitrogen-vacancy center ensemble. At a frequency of 10 mHz we obtain a noise floor of ~30 nT/\sqrt{Hz}.

General information
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Organisations: Department of Physics, Quantum Physics and Information Technology
Authors: Ahmadi, S. (Intern), El-Ella, H. A. (Intern), Hansen, J. B. (Ekstern), Huck, A. (Intern), Andersen, U. L. (Intern)
Pages: 1-2
Publication date: 2017
Optimised frequency modulation for continuous-wave optical magnetic resonance sensing using nitrogen-vacancy ensembles

Magnetometers based on ensembles of nitrogen-vacancy centres are a promising platform for continuously sensing static and low-frequency magnetic fields. Their combination with phase-sensitive (lock-in) detection creates a highly versatile sensor with a sensitivity that is proportional to the derivative of the optical magnetic resonance lock-in spectrum, which is in turn dependant on the lock-in modulation parameters. Here we study the dependence of the lock-in spectral slope on the modulation of the spin-driving microwave field. Given the presence of the intrinsic nitrogen hyperfine spin transitions, we experimentally show that when the ratio between the hyperfine linewidth and their separation is ≥ 1/4, square-wave based frequency modulation generates the steepest slope at modulation depths exceeding the separation of the hyperfine lines, compared to sine-wave based modulation. We formulate a model for calculating lock-in spectra which shows excellent agreement with our experiments, and which shows that an optimum slope is achieved when the linewidth/separation ratio is ≥ 1/4 and the modulation depth is less then the resonance linewidth, irrespective of the modulation function used.
Pump-Enhanced Continuous-Wave Magnetometry Using Nitrogen-Vacancy Ensembles

Ensembles of nitrogen-vacancy centers in diamond are a highly promising platform for high-sensitivity magnetometry, whose efficacy is often based on inefficiently generating and monitoring magnetic-field dependent infrared fluorescence. Here we report on an increased sensing efficiency with the use of 532-nm resonant confocal cavity and a microwave resonator antenna for measuring the local magnetic noise density using the intrinsic nitrogen-vacancy concentration of a chemical-vapor deposited single-crystal diamond. We measure a near-shot-noise-limited magnetic noise floor of 200 pT/√Hz spanning a bandwidth up to 159 Hz, and an extracted sensitivity of approximately 3 nT/√Hz, with further enhancement limited by the noise floor of the lock-in amplifier and the laser damage threshold of the optical components. Exploration of the microwave and optical pump-rate parameter space demonstrates a linewidth-narrowing regime reached by virtue of using the optical cavity, allowing an enhanced sensitivity to be achieved, despite an unoptimized collection efficiency of about 0.2 ppb.

General information
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Organisations: Department of Physics, Quantum Physics and Information Technology
Authors: Ahmadi, S. (Intern), El-Ella, H. A. R. (Intern), Hansen, J. O. B. (Ekstern), Huck, A. (Intern), Andersen, U. L. (Intern)
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BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 3.83 SJR 2.449 SNIP 1.602
Web of Science (2016): Impact factor 4.808
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
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Web of Science (2015): Impact factor 4.061
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Qudi: a modular python suite for experiment control and data processing
Qudi is a general, modular, multi-operating system suite written in Python 3 for controlling laboratory experiments. It provides a structured environment by separating functionality into hardware abstraction, experiment logic and user interface layers. The core feature set comprises a graphical user interface, live data visualization, distributed execution over networks, rapid prototyping via Jupyter notebooks, configuration management, and data recording. Currently, the
Coupling single emitters to quantum plasmonic circuits

In recent years, the controlled coupling of single-photon emitters to propagating surface plasmons has been intensely studied, which is fueled by the prospect of a giant photonic nonlinearity on a nanoscaled platform. In this article, we will review the recent progress on coupling single emitters to nanowires towards the construction of a new platform for strong light-matter interaction. The control over such a platform might open new doors for quantum information processing and quantum sensing at the nanoscale and for the study of fundamental physics in the ultrastrong coupling regime.
Determining the internal quantum efficiency of shallow-implanted nitrogen-vacancy defects in bulk diamond

It is generally accepted that nitrogen-vacancy (NV) defects in bulk diamond are bright sources of luminescence. However, the exact value of their internal quantum efficiency (IQE) has not been measured so far. Here we use an implementation of Drexhage's scheme to quantify the IQE of shallow-implanted NV defects in a single-crystal bulk diamond. Using a spherical metallic mirror with a large radius of curvature compared to the optical spot size, we perform calibrated modifications of the local density of states around NV defects and observe the change of their total decay rate, which is further used for IQE quantification. We also show that at the excitation wavelength of 532 nm, photo-induced relaxation cannot be neglected even at moderate excitation powers well below the saturation level. For NV defects shallow implanted 4.5 ± 1 and 8 ± 2 nm below the diamond surface, we determine the quantum efficiency to be 0.70 ± 0.07 and 0.82 ± 0.08, respectively.

General information

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Organisations: Department of Physics, Quantum Physics and Information Technology, Department of Photonics Engineering, Fiber Sensors and Supercontinuum Generation, University of Leipzig, University of Ulm
Authors: Radko, I. (Intern), Boll, M. (Intern), Israelsen, N. M. (Intern), Raatz, N. (Ekstern), Meijer, J. (Ekstern), Jelezko, F. (Ekstern), Andersen, U. L. (Intern), Huck, A. (Intern)
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BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.48 SJR 1.532 SNIP 1.544
Web of Science (2016): Impact factor 3.307
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.91 SNIP 1.674 CiteScore 3.78
Web of Science (2015): Indexed yes
Quantum enhanced optical sensing
The work in this thesis is embedded in the framework of quantum metrology and explores quantum effects in solid state emitters and optical sensing. Specifically, the thesis comprises studies on silicon vacancy centres in nanodiamonds, phase measurements and cavity optomechanics utilising optical squeezed states, and a theoretical study on quantum amplifiers.

Due to its similarity to single atoms, colour centres in diamond are ideal objects for exploring and exploiting quantum effects, because they are comparably easy to produce, probe and maintain. While nitrogen vacancy centres are the most renowned colour centres, we studied the silicon vacancy (SiV−) centre. In bulk diamond it features strong zero-phonon-line emission and, at cryogenic temperatures, a linewidth of hundreds of MHz, but it displays a weak spin coherence in the order of ns. To suppress the relaxation process which limits the coherence time, we utilised SiV− centres in nanodiamond. By means of confocal microscopy and resonant excitation at cryogenic temperatures, we measured linewidths in recently developed nanodiamond which were an order of magnitude smaller compared to previous studies on SiV− nanodiamonds. Furthermore, we identified spectral diffusion as the main hindrance in extending spin coherence times. Overcoming this issue will provide a promising candidate as an emitter for quantum information. Next, the question of how squeezed states of light can improve optical sensing was addressed. For this purpose, a squeezed light source was designed and built from scratch, which achieved a noise suppression of −8 dB at an optical pump power of 40mW. The generated squeezed light was first used to demonstrate how Gaussian states and detection can beat the shot noise limit and Rayleigh criterion in phase measurements simultaneously. Compared to quantum phase measurements based on single photon states, this approach is inherently deterministic. In addition, the applied homodyne detection enables close-to-unity detection efficiencies and thereby outperforms single photon state strategies which rely on comparably inefficient or demanding detection techniques.

A second experiment combined squeezed light and feedback control to cool an optomechanical system. This proof-of-principle study is the first reported squeezing enhanced optomechanical cooling experiment. Despite losses of more than 50% (a resulting noise suppression of −2 dB), the mechanical resonator was cooled from room temperature to 130K. This represents a 12% improvement compared to the use of a coherent state protocol. Finally, we theoretically investigated the fundamental properties of quantum amplifiers. Such devices can be used in information and sensing technology to amplify signals to overcome e.g. technical detection limitations. Amplified communication channels were characterised by applying the measure of mutual information $I$, as it offers strict bounds on the maximum achievable performance, which enabled a fair comparison between different applications scenarios. As a result, we identified two peculiar configurations: A configuration where amplification does not affect $I$, and a configuration where quantum correlations do not always lead to an enhanced $I$.

General information
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Authors: Schäfermeier, C. (Intern), Andersen, U. L. (Intern), Huck, A. (Intern)
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Quantum enhanced optical sensing
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Extraction of light from a quantum emitter by tailoring the photonic environment
Since the discovery of quantum mechanics it has been a physicists dream to test and exploit the fantastic prediction of entanglement. Applications based on entanglement are quantum key distribution and quantum computing which can exploit ying quantum bits based on single photons. To deterministically create this type of quantum bits single photons on demand are essential. This thesis presents the work on controlling the photonic environment of a quantum emitter in order to efficiently extract photons. We demonstrate increased photon collection efficiencies from single nitrogen vacancy (NV) centers by a factor of up to 1.76 when approaching it with a plane silver mirror made on an optical fiber facet. However, using this method we also show that the non-radiative decay rate of NV centers can be highly dependent on the excitation power, which makes this method a poor broadband approach for obtaining information on the photonic decay rate of the NV center. By further spectrally resolving emission from these systems we observe clear modulations which carry information related to the
We carry out three experiments where coupling NV centers to the highly confined mode fields of silver nano-wires (SNWs) are exploited. First, we demonstrate routing of single plasmons fed by a single NV center. Controlled routing is shown by facilitating different beamsplitter configurations where the routing itself is performed on a length scale less than 2 µm. We then measure the coupling between an NV center ensemble and single SNWs through 2-dimensional imaging of the NV center lifetime which outlines the SNW profiles confirmed by atomic force microscopy (AFM). Finally, an attempt to couple a single SNW to NV centers in a micro-fabricated diamond nano-pillar is presented.

The final part of the thesis address experiments on coupling colloidal quantum dots (CQDs) to the gap mode of two Si3N4 waveguides (DSNWs). We demonstrate evanescent-field coupling between spin-coated CQDs and the waveguide. However we are unable to deduce the coupling-related modification of the CQD lifetime due to apparent density dependent CQD interactions which dominate the lifetime distribution. We circumvent this by instead attaching CQDs to an AFM cantilever and scanning this across the DSNWs. By doing this, we obtain a 2-dimensional lifetime map showing an AFM-confirmed outline of the DSNW through the spatially-dependant lifetime variations.

**Demonstration of a variable plasmonic beam splitter**

In this contribution, we excite surface plasmon polaritons propagating along a silver nano-wire by a single nitrogen-vacancy center located in a diamond nano-crystal. By using the tip of an atomic force microscope, a second nano-wire is brought into the evanescent field of the first wire such that surface plasmons can evanescently couple. In our experiment, we are able to tune the coupling strength from one nano-wire to another by adjusting the gap with the aid of the atomic force microscope. Numerical calculations of the coupling strength are carried out, which support the values found in the experiment.
We demonstrate the excitation of single surface plasmon polaritons on a silver nanowire using a nitrogen vacancy center and the subsequent controlled coupling to a second silver nanowire. The coupling efficiency and thus the splitting ratio between the nanowires is controlled by adjusting the gap size between the wires with an atomic force microscope. By numerical methods, we estimate the splitting ratios for different gap sizes, and the results support the values obtained in the experiment.
In this paper, we demonstrate the applicability of MOVPE butt-joint regrowth for integration of all-active InP/AlGaInAs/InGaAsP optical components and the realization of high-functionality compact photonic devices. Planar high-quality MOVPE butt-joint integration of InP/AlGaInAs/InGaAsP-based all-active optical components
absorption modulator has been successfully performed and their optical and crystalline quality was experimentally investigated. The regrown multi-quantum well material exhibits a slight bandgap blue-shift of less than 20 meV, when moving away from the regrowth interface. In closest vicinity to the mask, the growth profile revealed a bent-up shape which is associated with an increase in the bandgap energy resulting from the combined effect of growth rate suppression and higher Ga concentration. This increase in bandgap energy makes the interface partially transparent (thus beneficial for unaffected light transmission) and forces carriers away from possible interfacial defects. The internal reflectivity below $2.1 \times 10^{-5}$ ensures minimization of detrimental intracavity feedback.

**General information**

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Organisations: Department of Photonics Engineering, Nanophotonic Devices, Center for Electron Nanoscopy, Department of Physics, Quantum Physics and Information Technology
Authors: Kulkova, I. (Intern), Kadkhodazadeh, S. (Intern), Kuznetsova, N. (Intern), Huck, A. (Intern), Semenova, E. (Intern), Yvind, K. (Intern)
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Web of Science (2017): Impact factor 1.742
Web of Science (2017): Indexed yes

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Scopus rating (2016): SJR 0.742 SNIP 1.113 CiteScore 1.69
Web of Science (2016): Impact factor 1.751

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Web of Science (2015): Impact factor 1.462

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Scopus rating (2014): SJR 0.786 SNIP 1.14 CiteScore 1.69
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Web of Science (2014): Indexed yes

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Scopus rating (2013): SJR 0.826 SNIP 1.191 CiteScore 1.78
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ISI indexed (2013): ISI indexed yes
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BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.954 SNIP 1.236 CiteScore 1.68
Web of Science (2012): Impact factor 1.552

ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.962 SNIP 1.407 CiteScore 1.89
Web of Science (2011): Impact factor 1.726

ISI indexed (2011): ISI indexed yes
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BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.157 SNIP 1.197
Web of Science (2010): Impact factor 1.746
Web of Science (2010): Indexed yes

BFI (2009): BFI-level 1
Increasing the photon collection rate from a single NV center with a silver mirror

In the pursuit of realizing quantum optical networks, a large variety of different approaches have been studied to achieve a single photon source on-demand. The common goal for these approaches is to harvest all the emission from a quantum emitter into a single spatial optical mode while maintaining a high signal-to-noise ratio. In this work, we use a single nitrogen vacancy center in diamond as a quantum emitter operating at ambient conditions and we demonstrate an increased photon count rate up to a factor of 1.76 by placing a silver mirror fabricated on the end facet of an optical fiber near the emitter.

General information
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Organisations: Department of Physics, Quantum Physics and Information Technology, Technical University of Denmark
Authors: Israelsen, N. M. (Intern), Kumar, S. (Intern), Tawfieq, M. (Ekstern), Neergaard-Nielsen, J. S. (Intern), Huck, A. (Intern), Andersen, U. L. (Intern)
Number of pages: 8
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Web of Science (2017): Indexed yes
Scopus rating (2016): CiteScore 1.63 SJR 0.715 SNIP 0.787
Web of Science (2016): Impact factor 1.741
Resonance Energy Transfer in Hybrid Devices in the Presence of a Surface

We have studied room-temperature, nonradiative resonant energy transfer from InGaN/GaN quantum wells to CdSe/ZnS nanocrystals separated by aluminum oxide layers of different thicknesses. Nonradiative energy transfer from the quantum wells to the nanocrystals at separation distances of up to approximately 10 nm was observed. By comparing the carrier dynamics of the quantum wells and the nanocrystals, we found that nonradiative recombination via surface states, generated during dry etching of the wafer, counteracts the nonradiative energy-transfer process to the nanocrystals and therefore decreases the process efficiency.
A Variable Single Photon Plasmonic Beamsplitter

Plasmonic structures can both be exploited for scaling down optical components beyond the diffraction limit and enhancing and collecting the emission from a single dipole emitter. Here, we experimentally demonstrate an adiabatic coupling between two silver nanowires using a nitrogen vacancy center as a probe source.

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Coupling of a single quantum emitter to end-to-end aligned silver nanowires

We report on the observation of coupling a single nitrogen vacancy (NV) center in a nanodiamond crystal to a propagating plasmonic mode of silver nanowires. The nanocrystal is placed either near the apex of a single silver nanowire or in the gap between two end-to-end aligned silver nanowires. We observe an enhancement of the NV-centers’ decay rate in both cases as a result of the coupling to the plasmons. The devices are nano-assembled with a scanning probe technique. Through simulations, we show that end-to-end aligned silver nanowires can be used as a controllable splitter for emission from a dipole emitter.

General information
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Organisations: Department of Physics, Quantum Physics and Information Technology, Department of Photonics Engineering
Authors: Kumar, S. (Intern), Huck, A. (Intern), Chen, Y. (Intern), Andersen, U. L. (Intern)
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Web of Science (2017): Impact factor 3.495
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.67 SJR 1.673 SNIP 1.249
Web of Science (2016): Impact factor 3.411
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.499 SNIP 1.226 CiteScore 2.47
Web of Science (2015): Impact factor 3.142
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.861 SNIP 1.492 CiteScore 3.25
Web of Science (2014): Impact factor 3.302
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.146 SNIP 1.633 CiteScore 3.77
Web of Science (2013): Impact factor 3.515
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.57 SNIP 1.739 CiteScore 3.76
Web of Science (2012): Impact factor 3.794
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.814 SNIP 1.917 CiteScore 4.04
Web of Science (2011): Impact factor 3.844
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.92 SNIP 1.775
Web of Science (2010): Impact factor 3.841
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 2.826 SNIP 1.834
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 2.894 SNIP 1.82
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 3.012 SNIP 1.916
Web of Science (2007): Indexed yes
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 3.755 SNIP 2.353
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 3.992 SNIP 2.367
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 3.897 SNIP 2.275
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 4.018 SNIP 2.414
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 4.281 SNIP 2.22
We demonstrate the coupling of a single nitrogen vacancy center in a nanodiamond to propagating plasmonic modes of mechanically etched silver nanowires. The mechanical etch is performed on single crystalline silver nanoplates by the tip of an atomic force microscope cantilever to produce wires with pre-designed lengths. We show that single plasmon propagation can be obtained in these wires, thus making these structures a platform for quantum information processing.
Design and geometry of hybrid white light-emitted diodes for efficient energy transfer from the quantum well to the nanocrystals

We demonstrate light color conversion in patterned InGaN light-emitting diodes (LEDs), which is enhanced via nonradiative exciton resonant energy transfer (RET) from the electrically driven diode to colloidal semiconductor nanocrystals (NCs). Patterning of the diode is essential for the coupling between a quantum well (QW) and NCs, because the distance between the QW and NCs is a main and very critical factor of RET. Moreover, a proper design of the pattern can enhance light extraction.

General information
State: Published
Organisations: Department of Photonics Engineering, Nanophotonic Devices, Department of Physics, Diode Lasers and LED Systems
Efficient coupling of a single diamond color center to propagating plasmonic gap modes.
We report on coupling of a single nitrogen-vacancy (NV) center in a nanodiamond to the propagating gap mode of two parallel placed chemically grown silver nanowires. The coupled NV-center nanowire system is made by manipulating nanodiamonds and nanowires with the tip of an atomic force microscope cantilever. An efficient coupling of an NV-center to an easily accessible gap plasmon mode is demonstrated and we measure an enhancement of the spontaneous emission decay rate by a factor of 8.3.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology
Authors: Kumar, S. (Intern), Huck, A. (Intern), Andersen, U. L. (Intern)
Pages: 1221-1225
Publication date: 2013
Main Research Area: Technical/natural sciences

Publication information
Journal: Nano Letters
Volume: 13
Issue number: 3
ISSN (Print): 1530-6984
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 13.07
Web of Science (2017): Impact factor 12.08
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 13.4
Web of Science (2016): Impact factor 12.712
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 14.76
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 14.04
Web of Science (2014): Impact factor 13.592
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 14.23
Web of Science (2013): Impact factor 12.94
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 13.78
Web of Science (2012): Impact factor 13.025
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 13.83
Web of Science (2011): Impact factor 13.198
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Web of Science (2010): Impact factor 12.219
Web of Science (2010): Indexed yes
Large Optical Nonlinearity of Surface Plasmon Modes on Thin Gold Films

We investigate the optical nonlinear effects of a long-range surface plasmon polariton mode propagating on a thin gold film. These effects may play a key role in the design of future nanophotonic circuits as they allow for the realization of active plasmonic elements. We demonstrate a significant enhancement of the transmission on a timescale below a millisecond as well as a phase shift exceeding $2\pi$ already for modest peak powers of 150 mW. On the contrary, slow effects suppress the transmission on a millisecond timescale.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology, University of Copenhagen
Authors: Huck, A. (Intern), Witthaut, D. (Ekstern), Kumar, S. (Intern), Sorensen, A. S. (Ekstern), Andersen, U. L. (Intern)
Number of pages: 9
Pages: 1597-1605
Publication date: 2013
Main Research Area: Technical/natural sciences

Publication information
Journal: Plasmonics
Volume: 8
Issue number: 4
ISSN (Print): 1557-1955
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): SNIP 0.791 SJR 0.679 CiteScore 2.13
Web of Science (2017): Impact factor 2.366
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.8 SJR 0.635 SNIP 0.701
Web of Science (2016): Impact factor 2.139
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.755 SNIP 0.824 CiteScore 2.07
Web of Science (2015): Impact factor 2.146
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.93 SNIP 0.925 CiteScore 2.32
Web of Science (2014): Impact factor 2.238
Web of Science (2014): Indexed yes
Continuous-wave spatial quantum correlations of light induced by multiple scattering

We present theoretical and experimental results on spatial quantum correlations induced by multiple scattering of nonclassical light. A continuous-mode quantum theory is derived that enables determining the spatial quantum correlation function from the fluctuations of the total transmittance and reflectance. Utilizing frequency-resolved quantum noise measurements, we observe that the strength of the spatial quantum correlation function can be controlled by changing the quantum state of an incident bright squeezed-light source. Our results are found to be in excellent agreement with the developed theory and form a basis for future research on, e.g., quantum interference of multiple quantum states in a multiple scattering medium.

General information
State: Published
Organisations: Nanophotonics, Department of Photonics Engineering, Structured Electromagnetic Materials, Quantum Physics and Information Technology, Department of Physics, University of Copenhagen
Authors: Smolka, S. (Intern), Ott, J. R. (Intern), Huck, A. (Intern), Andersen, U. L. (Intern), Lodahl, P. (Ekstern)
Number of pages: 8
Pages: 033814
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
Journal: Physical Review A
Volume: 86
Issue number: 3
ISSN (Print): 2469-9926
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 2.46 SJR 1.286 SNIP 0.886
Web of Science (2017): Impact factor 2.909
Web of Science (2017): Indexed yes
Scopus rating (2016): CiteScore 2.25 SJR 1.482 SNIP 0.985
Web of Science (2016): Impact factor 2.925
Coupling of a single nitrogen vacancy center to the gap modes of a dual silver nanowire system

We couple a nitrogen vacancy center in a diamond nano-crystal to a dual silver nanowire system by positioning the crystal in the gap between the two nanowires, and demonstrate a lifetime decrease of 8.3.

General information
Erratum: Observation of Spatial Quantum Correlations Induced by Multiple Scattering of Nonclassical Light [Phys. Rev. Lett. 102, 193901 (2009)]

General information
State: Published
Organisations: Nanophotonics, Department of Photonics Engineering, Quantum Physics and Information Technology, Department of Physics, FOM Institute for Atomic and Molecular Physics - AMOLF
Authors: Smolka, S. (Intern), Huck, A. (Intern), Andersen, U. L. (Intern), Lagendijk, A. (Ekstern), Lodahl, P. (Intern)
Number of pages: 1
Publication date: 2012
Source: Physical Review Letters
Journal: Physical Review Letters
Volume: 109
Issue number: 25
ISSN (Print): 0031-9007
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 7.58 SJR 3.622 SNIP 2.464
Web of Science (2017): Impact factor 8.839
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 6.33 SJR 4.196 SNIP 2.61
Web of Science (2016): Impact factor 8.462
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 4.656 SNIP 2.538 CiteScore 5.76
Web of Science (2015): Impact factor 7.645
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 5.232 SNIP 2.71 CiteScore 6.62
Web of Science (2014): Impact factor 7.512
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 5.675 SNIP 2.781 CiteScore 7.46
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 6.292 SNIP 2.867 CiteScore 7.19
We demonstrate propagation of plasmons in single crystalline silver nanostructures fabricated using a combination of a bottom-up and a top-down approach. Silver nanoplates of thickness around 65 nm and a surface area of about 100 μm² are made using a wet chemical method. Silver nanotips and nanowires are then sculptured by focused ion beam milling. The plasmons are excited by using the fluorescence from the redeposited silver clusters during the milling process. Propagation of plasmons in the nanowires is observed in the visible spectral region. We also observe a cavity effect by measuring the emission spectrum from the distal wire end.

Propagation of plasmons in designed single crystalline silver nanostructures

We demonstrate propagation of plasmons in single crystalline silver nanostructures fabricated using a combination of a bottom-up and a top-down approach. Silver nanoplates of thickness around 65 nm and a surface area of about 100 μm² are made using a wet chemical method. Silver nanotips and nanowires are then sculptured by focused ion beam milling. The plasmons are excited by using the fluorescence from the redeposited silver clusters during the milling process. Propagation of plasmons in the nanowires is observed in the visible spectral region. We also observe a cavity effect by measuring the emission spectrum from the distal wire end.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology
Authors: Kumar, S. (Intern), Lu, Y. (Intern), Huck, A. (Intern), Andersen, U. L. (Intern)
Pages: 24614-24622
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
Journal: Optics Express
Volume: 20
Issue number: 22
ISSN (Print): 1094-4087
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 3.74 SJR 1.519 SNIP 1.567
Web of Science (2017): Impact factor 3.356
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.48 SJR 1.532 SNIP 1.544
Web of Science (2016): Impact factor 3.307
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.91 SNIP 1.674 CiteScore 3.78
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.313 SNIP 2.124 CiteScore 4.18
Web of Science (2014): Impact factor 3.488
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.337 SNIP 2.196 CiteScore 4.38
Web of Science (2013): Impact factor 3.525
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.562 SNIP 2.108 CiteScore 3.85
Web of Science (2012): Impact factor 3.546
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.58 SNIP 2.572 CiteScore 4.04
Web of Science (2011): Impact factor 3.587
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.906 SNIP 2.428
Web of Science (2010): Impact factor 3.753
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 3.039 SNIP 2.679
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 3.204 SNIP 2.423
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 3.284 SNIP 2.11
Web of Science (2007): Indexed yes
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 3.313 SNIP 2.336
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 2.819 SNIP 2.472
Controlled Coupling of a Single Nitrogen-Vacancy Center to a Silver Nanowire

We report on the controlled coupling of a single nitrogen-vacancy (NV) center to a surface plasmon mode propagating along a chemically grown silver nanowire (NW). We locate and optically characterize a single NV center in a uniform dielectric environment before we controllably position this emitter in the close proximity of the NW. We are thus able to control the coupling of this particular emitter to the NW and directly compare the photon emission properties before and after the coupling. The excitation of single plasmonic modes is witnessed and a total rate enhancement by a factor of up to 4.6 is demonstrated.

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics
Authors: Huck, A. (Intern), Kumar, S. (Intern), Shakoor, A. (Intern), Andersen, U. L. (Intern)
Pages: 096801
Publication date: 2011
Main Research Area: Technical/natural sciences

Publication information
Journal: Physical Review Letters
Volume: 106
Issue number: 9
ISSN (Print): 0031-9007
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 7.58 SJR 3.622 SNIP 2.464
Web of Science (2017): Impact factor 8.839
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 6.33 SJR 4.196 SNIP 2.61
Web of Science (2016): Impact factor 8.462
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 4.656 SNIP 2.538 CiteScore 5.76
Web of Science (2015): Impact factor 7.645
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 5.232 SNIP 2.71 CiteScore 6.62
Controlling the Coupling of a Single Nitrogen Vacancy Center to a Silver Nanowire

Dipole emitters are expected to efficiently couple to the plasmonic mode propagating along a cylindrically shaped metallic nano-structure. Such a strongly coupled system could serve as a fundamental building block for a single photon source on demand and a device enabling strong non-linear interaction at the level of a few photons. In our contribution we demonstrate the controlled coupling of a single nitrogen vacancy (NV) center in a diamond nano crystal to a nanowire made of silver. This is in contrast to previous realizations, where the nanowire dipole system was assembled randomly. Ultimate control over the relative nanowire diamond nano-crystal position is achieved by using an atomic force microscope.
(AFM) in contact mode operation.

**General information**
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics
Authors: Huck, A. (Intern), Kumar, S. (Intern), Shakoor, A. (Intern), Andersen, U. L. (Intern)
Publication date: 2011

**Host publication information**
Title of host publication: Lasers and Electro-Optics Europe (CLEO EUROPE/EQEC), 2011 Conference on and 12th European Quantum Electronics Conference
Main Research Area: Technical/natural sciences
Diamond-like carbon, Photonics, Surface topography, Plasmons, Optical surface waves, Silver
DOIs:
10.1109/CLEOE.2011.5943589
Source: orbit
Source-ID: 314759
Publication: Research - peer-review › Article in proceedings – Annual report year: 2011

**Generation and Characterisation of Non-Classical Surface Plasmons**

**General information**
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics, Quantum Photonics, Department of Photonics Engineering
Authors: Huck, A. (Intern), Lodahl, P. (Intern), Andersen, U. L. (Intern)
Publication date: Mar 2010

**Publication information**
Place of publication: Kgs. Lyngby, Denmark
Publisher: Technical University of Denmark (DTU)
Original language: English
Main Research Area: Technical/natural sciences
Electronic versions:
phd_thesis_Alex_Huck.pdf
Source: orbit
Source-ID: 271206
Publication: Research › Ph.D. thesis – Annual report year: 2010

**Continuous-variable quantum erasure correcting code**
We experimentally demonstrate a continuous variable quantum erasure-correcting code, which protects coherent states of light against complete erasure. The scheme encodes two coherent states into a bi-party entangled state, and the resulting 4-mode code is conveyed through 4 independent channels that randomly erases the signal. We show experimentally that the transmitted state can be corrected by performing a syndrome measurement followed by a corrective transformation.

**General information**
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics
Authors: Lassen, M. Ø. (Intern), Sabuncu, M. (Intern), Huck, A. (Intern), Niset, J. (Ekstern), Cerf, N. (Ekstern), Leuchs, G. (Ekstern), Andersen, U. L. (Intern)
Pages: 1-2
Publication date: 2010

**Host publication information**
Title of host publication: 2010 Conference on Lasers and Electro-Optics (CLEO) and Quantum Electronics and Laser Science Conference (QELS)
Publisher: IEEE
ISBN (Print): 978-1-55752-890-2
Main Research Area: Technical/natural sciences
Conference: Conference on Lasers and Electro-Optics (CLEO)/International Quantum Electronics Conference (IQEC), San Jose, CA, United States, 16/05/2010 - 16/05/2010
Electronic versions:
Quantum optical coherence can survive photon losses using a continuous-variable quantum erasure-correcting code

A fundamental requirement for enabling fault-tolerant quantum information processing is an efficient quantum error-correcting code that robustly protects the involved fragile quantum states from their environment. Just as classical error-correcting codes are indispensable in today's information technologies, it is believed that quantum error-correcting code will play a similarly crucial role in tomorrow's quantum information systems. Here, we report on the experimental demonstration of a quantum erasure-correcting code that overcomes the devastating effect of photon losses. Our quantum code is based on linear optics, and it protects a four-mode entangled mesoscopic state of light against erasures. We investigate two approaches for circumventing in-line losses, and demonstrate that both approaches exhibit transmission fidelities beyond what is possible by classical means. Because in-line attenuation is generally the strongest limitation to quantum communication, such an erasure-correcting code provides a new tool for establishing quantum optical coherence over longer distances.
Continuous Variables Quantum Erasure-Correcting Code

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics
Authors: Lassen, M. Ø. (Intern), Sabuncu, M. (Intern), Huck, A. (Intern), Nisset, J. (Ekstern), Cerf, N. J. (Ekstern), Leuchs, G. (Ekstern), Andersen, U. L. (Intern)
Publication date: 2009
Event: Paper presented at ICSSUR'09, OLOMOUC.
Main Research Area: Technical/natural sciences
Source-ID: 267496

Correlation measurement of squeezed light
We study the implementation of a correlation measurement technique for the characterization of squeezed light which is nearly free of electronic noise. With two different sources of squeezed light, we show that the sign of the covariance coefficient, revealed from the time-resolved correlation data, is witnessing the presence of squeezing in the system. Furthermore, we estimate the degree of squeezing using the correlation method and compare it to the standard homodyne measurement scheme. We show that the role of electronic detector noise is minimized using the correlation approach as opposed to homodyning where it often becomes a crucial issue.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology
Authors: Krivitsky, L. (Intern), Andersen, U. L. (Intern), Dong, R. (Ekstern), Huck, A. (Intern), Wittmann, C. (Ekstern), Leuchs, G. (Ekstern)
Pages: 033828
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: Physical Review A
Demonstration of quadrature squeezed surface-plasmons in a gold waveguide

In this contribution we present an experiment demonstrating the generation of non-classical SPPs by exciting them with a squeezed optical light field generated using a bow-tie shaped optical parametric oscillator operating below threshold. Free space optics and end-fire coupling are used for the excitation of long-range SPPs (LR-SPPs) on gold stripes embedded in lossless transparent polymer BCB.

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics, Quantum Photonics, Department of Photonics Engineering, Plasmonics and Metamaterials
Authors: Huck, A. (Intern), Smolka, S. (Intern), Krivitsky, L. (Intern), Lodahl, P. (Intern), Sørensen, A. S. (Ekstern), Boltasseva, A. (Intern), Andersen, U. L. (Intern)
Number of pages: 1
Publication date: 2009

Host publication information
Title of host publication: Conference abstract series, CLEO/Europe - EQEC
Publisher: IEEE
Main Research Area: Technical/natural sciences
Electronic versions:
Huck.pdf
DOIs:
10.1109/CLEOE-EQEC.2009.5191638

Demonstration of quadrature-squeezed surface plasmons in a gold waveguide
We report on the efficient generation, propagation and reemission of squeezed long-range surface-plasmon polaritons in a gold waveguide. Squeezed light is used to excite the nonclassical surface-plasmon polaritons, and the reemitted quantum state is fully characterized by complete quantum tomographic reconstruction of the density matrix. We find that the plasmon-assisted transmission of nonclassical light in metallic waveguides can be described by a beam splitter relation. This result is explained theoretically.

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics, Quantum Photonics, Department of Photonics Engineering, Plasmonics and Metamaterials, Niels Bohr Institute
Authors: Huck, A. (Intern), Smolka, S. (Intern), Lodahl, P. (Intern), Sørensen, A. S. (Ekstern), Boltasseva, A. (Intern), Janousek, J. (Intern), Andersen, U. L. (Intern)
Publication date: 2009
Main Research Area: Technical/natural sciences
Excitation and characterization of non-classical surface plasmon polaritons

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics, Quantum Photonics, Department of Photonics Engineering, Plasmonics and Metamaterials
Authors: Huck, A. (Intern), Andersen, U. L. (Intern), Smolka, S. (Intern), Boltasseva, A. (Intern), Lodahl, P. (Intern)
Pages: Wed4f.28
Publication date: 2009

Host publication information
Title of host publication: Proceedings, NANOMETA
Main Research Area: Technical/natural sciences
Conference: 2nd European Topical Meeting on Nanophotonics and Metamaterials, Seefeld, Austria, 05/01/2009 - 05/01/2009
Source: orbit
Source-ID: 246665
Publication: Research - peer-review › Article in proceedings – Annual report year: 2009

Experimental demonstration of spatial quantum correlations in multiple scattering media
We demonstrate that spatial quantum correlations are induced by multiple scattering of squeezed light. The correlation relates multiple scattered photons at different spatial positions, and is tunable by varying photon fluctuations of the illuminating beam.

General information
State: Published
Organisations: Quantum Photonics, Department of Photonics Engineering, Quantum Physics and Information Technology, Department of Physics, FOM Institute for Atomic and Molecular Physics - AMOLF
Authors: Smolka, S. (Intern), Huck, A. (Intern), Andersen, U. L. (Intern), Lagendijk, A. (Ekstern), Lodahl, P. (Intern)
Pages: 1-2
Publication date: 2009

Host publication information
Title of host publication: Conference proceedings, CLEO/IQEC
Publisher: IEEE
ISBN (Print): 978-1-55752-869-8
Main Research Area: Technical/natural sciences
Electronic versions:
Observation of spatial quantum correlations induced by multiple scattering of nonclassical light

We present the experimental realization of spatial quantum correlations of photons that are induced by multiple scattering of squeezed light. The quantum correlation relates photons propagating along two different light paths through the random medium and is infinite in range. Both positive and negative spatial quantum correlations are observed when varying the quantum state incident to the multiple scattering medium, and the strength of the correlations is controlled by the number of photons. The experimental results are in excellent agreement with recent theoretical proposals by implementing the full quantum model of multiple scattering.
Spatial quantum correlations generated by multiple scattering of squeezed light

General information
State: Published
Organisations: Quantum Photonics, Department of Photonics Engineering, Quantum Physics and Information Technology, Department of Physics, FOM Institute for Atomic and Molecular Physics - AMOLF
Authors: Smolka, S. (Intern), Huck, A. (Intern), Andersen, U. L. (Intern), Lagendijk, A. (Ekstern), Lodahl, P. (Intern)
Publication date: 2009

Host publication information
Title of host publication: Proceedings, ETOPIM
Main Research Area: Technical/natural sciences
Demonstration of a Quantum Nondemolition Sum Gate

The sum gate is the canonical two-mode gate for universal quantum computation based on continuous quantum variables. It represents the natural analogue to a qubit C-NOT gate. In addition, the continuous-variable gate describes a quantum nondemolition (QND) interaction between the quadrature components of two light modes. We experimentally demonstrate a QND sum gate, employing the scheme by R. Filip, P. Marek, and U. L. Andersen [Phys. Rev. A 71, 042308 (2005)], solely based on off-line squeezed states, homodyne measurements, and feedforward. The results are verified by simultaneously satisfying the criteria for QND measurements in both conjugate quadratures.

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics
Authors: Yoshikawa, J. (Ekstern), Miwa, Y. (Ekstern), Huck, A. (Intern), Andersen, U. L. (Intern), van Loock, P. (Ekstern), Furusawa, A. (Ekstern)

Publication information
Journal: Physical Review Letters
Volume: 101
Issue number: 25
ISSN (Print): 0031-9007
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 7.58 SJR 3.622 SNIP 2.464
Web of Science (2017): Impact factor 8.839
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 6.33 SJR 4.196 SNIP 2.61
Web of Science (2016): Impact factor 8.462
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 4.656 SNIP 2.538 CiteScore 5.76
Web of Science (2015): Impact factor 7.645
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 5.232 SNIP 2.71 CiteScore 6.62
Web of Science (2014): Impact factor 7.512
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 5.675 SNIP 2.781 CiteScore 7.46
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 6.292 SNIP 2.867 CiteScore 7.19
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 6.314 SNIP 2.905 CiteScore 7.02
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Electronic noise-free measurements of squeezed light

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology
Authors: Krivitsky, L. (Intern), Andersen, U. L. (Intern), Dong, R. (Ekstern), Huck, A. (Intern), Wittmann, C. (Ekstern), Leuchs, G. (Ekstern)
Pages: 2395-2397
Publication date: 2008
Main Research Area: Technical/natural sciences

Publication information
Journal: Optics Letters
Volume: 33
Issue number: 20
ISSN (Print): 0146-9592
Ratings:
BFI (2018): BFI-level 2
Demonstration of deterministic and high fidelity squeezing of quantum information

By employing a recent proposal [R. Filip, P. Marek, and U.L. Andersen, Phys. Rev. A 71, 042308 (2005)] we experimentally demonstrate a universal, deterministic, and high-fidelity squeezing transformation of an optical field. It relies only on linear optics, homodyne detection, feedforward, and an ancillary squeezed vacuum state, thus direct interaction between a strong pump and the quantum state is circumvented. We demonstrate three different squeezing levels for a coherent state input. This scheme is highly suitable for the fault-tolerant squeezing transformation in a continuous variable quantum computer.
Polarization squeezing with photonic crystal fibers

General information
State: Published
Organizations: Department of Physics
Authors: Milanovic, J. (Ekstern), Huck, A. (Intern), Heersink, J. (Ekstern), Marquardt, C. (Ekstern), Andersen, U. L. (Intern), Leuchs, G. (Ekstern)
Publication date: 2007

Host publication information
Title of host publication: Technical Digest
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 210313
Publication: Research - peer-review › Article in proceedings – Annual report year: 2007

Polarization squeezing with photonic crystal fibers
We report on the generation of polarization squeezing by employing intense, ultrashort light pulses in a single pass method in photonic crystal fibers. We investigated the squeezing behavior near the zero-dispersion wavelength and in the anomalous dispersion regime by using two distinct fibers. We observed a maximal squeezing at 810 nm of -3.3 +/- 0.3 dB with an excess noise of +16.8 +/- 0.3 dB in the anomalous regime. Correcting for linear and interference losses between the polarization modes, this corresponds to -6 +/- 1 dB. The ratio of squeezing to excess noise indicates the creation of a much purer state; this ratio indeed lies an order of magnitude below those squeezing experiments that exploit traditional fibers [1]. We attribute this increased state of purity to increased effective nonlinearity and to the reduction of scattering on acoustic modes in the fiber.
Quantum optics in multiple scattering random media

General information
State: Published
Organisations: Quantum Photonics, Department of Photonics Engineering, Department of Physics
Authors: Smolka, S. (Intern), Huck, A. (Intern), Andersen, U. L. (Intern), Lodahl, P. (Intern)
Publication date: 2007
Projects:

**Quantum Thermodynamics and Quantum Information**

Department of Physics  
Period: 15/09/2018 → 14/09/2021  
Number of participants: 3  
Phd Student:  
Jørgensen, Mathias Rønnow (Intern)  
Supervisor:  
Huck, Alexander (Intern)  
Main Supervisor:  
Brask, Jonatan Bohr (Intern)

**Financial sources**  
Source: Internal funding (public)  
Name of research programme: Forskningsrådsfinansiering  
Project: PhD

**Highly sensitive quantum magnetometry using Nitrogen-Vacancy centers in diamond**

Department of Physics  
Period: 01/09/2018 → 31/08/2021  
Number of participants: 4  
Phd Student:  
Poulsen, Andreas Feldt Lomholt (Intern)  
Supervisor:  
Andersen, Ulrik Lund (Intern)  
Berg-Sørensen, Kirstine (Intern)  
Main Supervisor:  
Huck, Alexander (Intern)

**Financial sources**  
Source: Internal funding (public)  
Name of research programme: Institut stipendie (DTU)  
Project: PhD

**Coherent interaction between a solid-state spin and a mechanical oscillator**

Department of Physics  
Period: 01/08/2018 → 31/07/2021  
Number of participants: 3  
Phd Student:  
Berrig, Christian (Intern)  
Supervisor:  
Andersen, Ulrik Lund (Intern)  
Main Supervisor:  
Huck, Alexander (Intern)

**Financial sources**  
Source: Internal funding (public)  
Name of research programme: Grundforskningsfonden  
Project: PhD
Highly sensitive quantum magnetometry using Nitrogen-Vacancy centers in diamond

Department of Physics
Period: 01/08/2018 → 31/07/2021
Number of participants: 4
Phd Student: Clement, Joshua David (Intern)
Supervisor: Berg-Sørensen, Kirstine (Intern)
Huck, Alexander (Intern)
Main Supervisor: Andersen, Ulrik Lund (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Fonde
Project: PhD

Cavity-modified dynamics of Nitrogen-Vacancy centers in Diamond

Department of Physics
Period: 15/02/2016 → 14/03/2019
Number of participants: 3
Phd Student: Jensen, Rasmus (Intern)
Supervisor: Huck, Alexander (Intern)
Main Supervisor: Andersen, Ulrik Lund (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)
Project: PhD

Experimental solid state Nano-Optics

Department of Physics
Period: 01/11/2015 → 31/10/2018
Number of participants: 3
Phd Student: Boll, Mads Kjær (Intern)
Supervisor: Huck, Alexander (Intern)
Main Supervisor: Andersen, Ulrik Lund (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

Improved collection efficiency of photons from NV centers for applications in magnetometry

Department of Physics
Period: 15/12/2014 → 15/09/2018
Number of participants: 3
Phd Student: Ahmadi, Sepehr (Intern)
Supervisor: Huck, Alexander (Intern)
Main Supervisor:
Andersen, Ulrik Lund (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

Development of measurement protocols for quantum magnetometry

Department of Physics
Period: 01/12/2014 → 09/02/2018
Number of participants: 7
Phd Student:
Stark, Alexander (Intern)
Supervisor:
Huck, Alexander (Intern)
Jelezko, Fedor (Ekstern)
Main Supervisor:
Andersen, Ulrik Lund (Intern)
Examiner:
Wubs, Martijn (Intern)
Balasubramanian, Gopalakrishnan (Ekstern)
Maletinsky, Patrick (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering

Relations
Publications:
Development of measurement protocols for quantum magnetometry
Project: PhD

Entanglement Enhanced Quantum Communication and Bio-sensing

Department of Physics
Number of participants: 6
Phd Student:
Jacobsen, Christian Scheffmann (Intern)
Supervisor:
Berg-Sørensen, Kirstine (Intern)
Main Supervisor:
Andersen, Ulrik Lund (Intern)
Examiner:
Huck, Alexander (Intern)
Alléaume, Romain (Ekstern)
Villoresi, Paolo (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.

Relations
Publications:
Quantum Information Protocols with Gaussian States of Light
Project: PhD

Quantum Protocols with a Colour Centre in a Microcavity

Department of Physics
Number of participants: 6
Phd Student:
Schäfermeier, Clemens (Intern)
Supervisor:
Huck, Alexander (Intern)
Main Supervisor:
Andersen, Ulrik Lund (Intern)
Examiner:
Berg-Sørensen, Kirstine (Intern)
Treps, Nicolas (Ekstern)
Vitali, David (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.

Relations
Publications:
Quantum enhanced optical sensing
Project: PhD

Coherent Coupling of a Nitrogen-Vacancy Center to Gap Modes in Intergrated Structures
Department of Physics
Period: 01/04/2012 → 13/08/2015
Number of participants: 6
Phd Student:
Israelsen, Niels Møller (Intern)
Supervisor:
Huck, Alexander (Intern)
Main Supervisor:
Andersen, Ulrik Lund (Intern)
Examiner:
Wubs, Martijn (Intern)
Bozhevolnyi, Sergey I. (Intern)
Jelezko, Fedor (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut, samfinansiering
Project: PhD

Generation and Characterisation of Non-Classical Surface Plasmons
Department of Physics
Period: 01/02/2007 → 31/03/2010
Number of participants: 7
Phd Student:
Huck, Alexander (Intern)
Supervisor:
Lodahl, Peter (Intern)
Sørensen, Anders S (Ekstern)
Main Supervisor:
Andersen, Ulrik Lund (Intern)
Examiner:
Kneipp, Katrin (Intern)
Bozhevolnyi, Sergey I. (Intern)
Jelezko, Fedor (Ekstern)

Financing sources
Activities:

**Dansk Optisk Selskabs Årsmøde 2008**
Alexander Huck (Participant)
Department of Physics

**Description**
Observing spatial quantum correlations induced by multiple scattering of non-classical light

We investigate the transport of non-classical light through multiple scattering random media. So far almost all experiments in the multidisciplinary field multiple light scattering have concentrated on the transport of light intensity. In recent years the quantum nature of multiple scattered light has been considered by studying the photon fluctuations of the light [1]. It was predicted that fluctuations below the classical limit can survive multiple scattering and novel spatial quantum correlations can be induced [2]. In accordance with the Heisenberg uncertainty principle, photon fluctuations smaller than the classical limit can only be generated with non-classical light sources. Using squeezed light we performed the first experimental demonstration that non-classical fluctuations survive multiple scattering of light. The experiments are in excellent agreement with theory. Moreover we demonstrate experimentally that multiple scattering induces novel spatial quantum correlations, cf. Fig. 1.

Fig 1. Illustration of multiple scattering process leading to spatial quantum correlations. A non-classical light source illuminates a medium consisting of a random distribution of scatterers. The incoming light is split into a multitude of different trajectories that perform a random walk through the medium. The number of photons exiting the medium in a specific direction can be anti-correlated with the number of photons in another direction, and this correlation depends on the quantum state of light illuminating the medium.

Place: Dops Annual Meeting, Nyborg, Denmark
Degree of recognition: National

**Related event**

**Dansk Optisk Selskabs Årsmøde 2008**
17/06/2008 → 18/06/2008
Nyborg, Denmark
Activity: Attending an event › Participating in or organising workshops, courses, seminars etc.