Deterministic phase measurements exhibiting super-sensitivity and super-resolution

Phase super-sensitivity is obtained when the sensitivity in a phase measurement goes beyond the quantum shot noise limit, whereas super-resolution is obtained when the interference fringes in an interferometer are narrower than half the input wavelength. Here we show experimentally that these two features can be simultaneously achieved using a relatively simple setup based on Gaussian states and homodyne measurement. Using 430 photons shared between a coherent and a squeezed vacuum state, we demonstrate a 22-fold improvement in the phase resolution, while we observe a 1.7-fold improvement in the sensitivity. In contrast to previous demonstrations of super-resolution and super-sensitivity, this approach is fully deterministic.
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 \(\sim 100\ \text{nT/\sqrt{Hz}}\) spanning a bandwidth up to 125 Hz. We project a photon shot-noise-limited sensitivity of \(\sim 1\ \text{pT/\sqrt{Hz}}\) by optimizing the nitrogen-vacancy concentration and the detection method.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology
Number of pages: 6
Publication date: 2018
Main Research Area: Technical/natural sciences

Publication information
Journal: Physical Review B
Volume: 97
Issue number: 2
Article number: 024105
ISSN (Print): 1098-0121
Ratings:
Web of Science (2018): Indexed yes
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.16
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.933 SNIP 0.94 CiteScore 2.8
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.667 SNIP 1.262 CiteScore 3.3
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.785 SNIP 1.339 CiteScore 3.55
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 3.206 SNIP 1.394 CiteScore 3.57
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 3.382 SNIP 1.438 CiteScore 3.61
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 3.417 SNIP 1.451
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 3.109 SNIP 1.474
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 2.982 SNIP 1.524
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 2.923 SNIP 1.546
Web of Science (2007): Indexed yes
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 $^{13}$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
Main Research Area: Technical/natural sciences

**Publication information**

Journal: Nature Communications
Volume: 8
Issue number: 1
ISSN (Print): 2041-1723
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 11.8 SJR 6.399 SNIP 2.995
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/√Hz.

Optimally cloned binary coherent states
Binary coherent state alphabets can be represented in a two-dimensional Hilbert space. We capitalize this formal connection between the otherwise distinct domains of qubits and continuous variable states to map binary phase-shift keyed coherent states onto the Bloch sphere and to derive their quantum-optimal clones. We analyze the Wigner function and the cumulants of the clones, and we conclude that optimal cloning of binary coherent states requires a nonlinearity above second order. We propose several practical and near-optimal cloning schemes and compare their cloning fidelity to the optimal cloner.
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 than the resonance linewidth, irrespective of the modulation function used.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology
Authors: El-Ella, H. (Intern), Ahmadi, S. (Intern), Wojciechowski, A. (Intern), Huck, A. (Intern), Andersen, U. L. (Intern)
Number of pages: 13
Pages: 14809-14821
Publication date: 2017
Main Research Area: Technical/natural sciences

Publication information
Journal: Opt. Express
Volume: 25
Issue number: 13
ISSN (Print): 1094-4087
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.48 SJR 1.487 SNIP 1.589
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.976 SNIP 1.755 CiteScore 3.78
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.349 SNIP 2.166 CiteScore 4.18
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.358 SNIP 2.226 CiteScore 4.38
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
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 a 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.
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 included modules are focused on confocal microscopy, quantum optics and quantum information experiments, but an expansion into other fields is possible and encouraged. Qudi is available from https://github.com/Ulm-IQO/qudi and is freely useable under the GNU General Public Licence.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology, University of Ulm
Authors: Binder, J. M. (Ekstern), Stark, A. (Intern), Tomek, N. (Ekstern), Scheuer, J. (Ekstern), Frank, F. (Ekstern), Jahnke, K. D. (Ekstern), Müller, C. (Ekstern), Schmitt, S. (Ekstern), Metsch, M. H. (Ekstern), Unden, T. (Ekstern), Gehring, T. (Intern), Huck, A. (Intern), Andersen, U. L. (Intern), Rogers, L. J. (Ekstern), Jelezko, F. (Ekstern)
Number of pages: 6
Pages: 85-90
Publication date: 2017
Main Research Area: Technical/natural sciences

Publication information
Journal: SoftwareX
Volume: 6
ISSN (Print): 2352-7110
Ratings:
Scopus rating (2016): SJR 1.753 SNIP 5.802 CiteScore 4.43
Original language: English
Towards an integrated squeezed light source

Since its first generation more than 30 years ago, squeezed light has developed towards a tool for high precision measurements as well as a tool for quantum information tasks like quantum key distribution. Miniaturization of sensors is an active field of research with the prospect of many applications. The precision of optical sensors based on interferometric measurements is often limited by the fundamental shot noise. While shot noise can be reduced by increasing the employed light power, integrated sensors pose limitations on the maximum possible amount due to damaging effects of high intensity as well as power consumption. Bright quadrature squeezed light produced by the optical Kerr effect in a nonlinear medium offers an opportunity to overcome these limitations. Here, we present first steps towards a bright quadrature squeezed light source produced by the optical Kerr effect in race-track resonators in silicon nitride by presenting characterizations of the chip. Using standard fabrication techniques this source will have the potential of seamless integration into on-chip optical sensors.
Ultrasensitive and broadband magnetometry with cavity optomechanics

We achieved sensitivity of 30 pT/Hz$^{1/2}$ and working bandwidth larger than 100 MHz, using cavity optomechanical magnetometry, and also demonstrated quantum light enhanced sensitivity in such a magnetometer.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology, University of Queensland, Defense Science and Technology Group
Authors: Li, B. (Ekstern), Bulla, D. (Ekstern), Bilek, J. (Intern), Prakash, V. (Ekstern), Forstner, S. (Ekstern), Sheridan, E. (Ekstern), Madsen, L. (Ekstern), Rubinsztein-Dunlop, H. (Ekstern), Foster, S. (Ekstern), Schafermeier, C. (Intern), Gehring, T. (Intern), Andersen, U. (Intern), Bowen, W. (Ekstern)
Number of pages: 2
Publication date: 2017

30 years of squeezed light generation

Squeezed light generation has come of age. Significant advances on squeezed light generation have been made over the last 30 years—from the initial, conceptual experiment in 1985 till today’s top-tuned, application-oriented setups. Here we review the main experimental platforms for generating quadrature squeezed light that have been investigated in the last 30 years.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology, Friedrich-Alexander University Erlangen-Nuremberg
Authors: Andersen, U. L. (Intern), Gehring, T. (Intern), Marquardt, C. (Intern), Leuchs, G. (Ekstern)
Number of pages: 11
Publication date: 2016
Main Research Area: Technical/natural sciences
Continuous-variable quantum computing on encrypted data

The ability to perform computations on encrypted data is a powerful tool for protecting a client's privacy, especially in today's era of cloud and distributed computing. In terms of privacy, the best solutions that classical techniques can achieve are unfortunately not unconditionally secure in the sense that they are dependent on a hacker's computational power. Here we theoretically investigate, and experimentally demonstrate with Gaussian displacement and squeezing operations, a quantum solution that achieves the security of a user's privacy using the practical technology of continuous variables. We demonstrate losses of up to 10 km both ways between the client and the server and show that security can still be achieved. Our approach offers a number of practical benefits (from a quantum perspective) that could one day allow the potential widespread adoption of this quantum technology in future cloud-based computing networks.

General information
Correlated classical states outperform squeezed states in communication over Gaussian channels
Using a quantum amplifier in a Gaussian channel, we show that classically correlated input states can outperform the mutual information of squeezed states.
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.
In a direct detection scheme, we observed 7.8 dB of twin-beam squeezing for multi-mode two-color squeezed vacuum generated via parametric downconversion. Applying postselection, we conditionally prepared a sub-Poissonian state of light containing $6.3 \cdot 10^5$ photons per pulse on the average with the Fano factor 0.63 +/- 0.01. The scheme can be considered as the heralded preparation of pulses with the mean energy varying between tens and hundreds of fJ and the uncertainty considerably below the shot-noise level. Such pulses can be used in metrology (for instance, for radiometer calibration), as well as for probing multi-mode non-linear optical effects. (C) 2016 Optical Society of America
Measurement-Induced Macroscopic Superposition States in Cavity Optomechanics

A novel protocol for generating quantum superpositions of macroscopically distinct states of a bulk mechanical oscillator is proposed, compatible with existing optomechanical devices operating in the bad-cavity limit. By combining a pulsed optomechanical quantum nondemolition (QND) interaction with nonclassical optical resources and measurement-induced feedback, the need for strong single-photon coupling is avoided. We outline a three-pulse sequence of QND interactions encompassing squeezing-enhanced cooling by measurement, state preparation, and tomography.
Nanodiamonds carrying silicon-vacancy quantum emitters with almost lifetime-limited linewidths

Colour centres in nanodiamonds are an important resource for applications in quantum sensing, biological imaging, and quantum optics. Here we report unprecedented narrow optical transitions for individual colour centres in nanodiamonds smaller than 200 nm. This demonstration has been achieved using the negatively charged silicon vacancy centre, which has recently received considerable attention due to its superb optical properties in bulk diamond. We have measured an ensemble of silicon-vacancy centres across numerous nanodiamonds to have an inhomogeneous distribution of 1.05 nm at 5 K. Individual spectral lines as narrower than 360 MHz were measured in photoluminescence excitation, and correcting for apparent spectral diffusion yielded an homogeneous linewidth of about 200 MHz which is close to the lifetime limit. These results indicate the high crystalline quality achieved in these nanodiamond samples, and advance the applicability of nanodiamond-hosted colour centres for quantum optics applications.

General information

State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology, University of Ulm, Jagiellonian University, Russian Academy of Sciences, Universite Francois Rabelais
Authors: Jantzen, U. (Ekstern), Kurz, A. B. (Ekstern), Rudnicki, D. S. (Ekstern), Schäfermeier, C. (Intern), Jahnke, K. D. (Ekstern), Andersen, U. L. (Intern), Davydov, V. A. (Ekstern), Agafonov, V. N. (Ekstern), Kubanek, A. (Ekstern), Rogers, L. J. (Ekstern), Jelezko, F. (Ekstern)
Number of pages: 7
Publication date: 2016
Main Research Area: Technical/natural sciences

Publication information

Journal: New Journal of Physics
Volume: 18
Issue number: 7
Article number: 073036
ISSN (Print): 1367-2630
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.97 SJR 1.788 SNIP 1.031
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.938 SNIP 1.047 CiteScore 2.8
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Parsing polarization squeezing into Fock layers

We investigate polarization squeezing in squeezed coherent states with varying coherent amplitudes. In contrast to the traditional characterization based on the full Stokes parameters, we experimentally determine the Stokes vector of each excitation subspace separately. Only for states with a fixed photon number do the methods coincide; when the photon number is indefinite, we parse the state in Fock layers, finding that substantially higher squeezing can be observed in some of the single layers. By capitalizing on the properties of the Husimi Q function, we map this notion onto the Poincare space, providing a full account of the measured squeezing.
Phase measurements exhibiting super sensitivity and super resolution features

By using an optical squeezed state and a post-processed homodyne detection scheme we show that phase measurements can overcome Rayleigh's resolution criterion and beat the quantum shot noise limit simultaneously.

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.
Quantum Information Protocols with Gaussian States of Light

Quantum cryptography is widely regarded as the most mature field within the context of quantum information in the sense that its application and development has produced companies that base their products on genuine quantum mechanical principles. Examples include quantum random number generators and hardware for secure quantum key distribution. These technologies directly exploit quantum effects, and indeed this is where they offer advantages to classical products. This thesis deals with the development and implementation of quantum information protocols that utilize the rather inexpensive resource of Gaussian states. A quantum information protocol is essentially a sequence of state exchanges between some number of parties and a certain ordering of quantum mechanical unitary operators performed by these parties. An example of this is the famous BB84 protocol for secret key generation, where photons in different polarization states are sent from one party to the other and subsequently detected.

In particular we introduce the idea of measurement device independence for continuous variable states and we present a proof-of-principle implementation of this protocol. Measurement device independence with Gaussian states is a promising avenue for the development of practical quantum key distribution with a relay network structure in environments where the distances are relatively short and there is a high number of users, such as an urban environment.

In addition to this we consider various point-to-point configurations that utilize Gaussian states to achieve security. Notably, we also present a novel experiment demonstrating the feasibility of delegated quantum computing on encrypted data, where we show that we can reliably encrypt and decrypt input and output states when a server with quantum computing capabilities performs Gaussian operations.
considers a specific attack using asymmetric preparation and excess noise. We find that this protocol is considerably more sensitive to noise than other CVQKD schemes, as a consequence of the simplified implementation. A single-quadrature modulation approach renders the need for a costly amplitude modulator unnecessary, and thus facilitates commercialization of continuous-variable quantum key distribution, provided that the low noise requirement can be achieved.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Techology
Authors: Gehring, T. (Intern), Jacobsen, C. S. (Intern), Andersen, U. L. (Intern)
Number of pages: 15
Pages: 1081-1095
Publication date: 2016
Main Research Area: Technical/natural sciences

Publication information
Journal: Quantum Information & Computation
Volume: 16
Issue number: 13-14
ISSN (Print): 1533-7146
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.51 SJR 0.789 SNIP 0.828
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.701 SNIP 0.895 CiteScore 1.25
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.789 SNIP 0.909 CiteScore 1.4
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.868 SNIP 0.892 CiteScore 1.73
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.07 SNIP 0.886 CiteScore 1.69
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.008 SNIP 0.812 CiteScore 1.53
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 2.188 SNIP 1.52
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 2.449 SNIP 1.526
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 2.262 SNIP 1.321
Scopus rating (2007): SJR 1.986 SNIP 1.019
Scopus rating (2006): SJR 1.627 SNIP 0.913
Scopus rating (2005): SJR 2.329 SNIP 1.197
Scopus rating (2004): SJR 2.106 SNIP 1.308
Scopus rating (2003): SJR 2.542 SNIP 1.852
Scopus rating (2002): SJR 2.106 SNIP 1.055
Original language: English
Electronic versions:
1507.01003.pdf
Links:
Source: FindIt
Source-ID: 2342852852
Publication: Research - peer-review › Journal article – Annual report year: 2016
Ab initio quantum-enhanced optical phase estimation using real-time feedback control

Optical phase estimation is a vital measurement strategy that is used to perform accurate measurements of various physical quantities including length, velocity and displacements (1,2). The precision of such measurements can be greatly enhanced by the use of entangled or squeezed states of light as demonstrated in a variety of different optical systems (3-8). Most of these accounts, however, deal with the measurement of a very small shift of an already known phase, which is in stark contrast to ab initio phase estimation where the initial phase is unknown (9-12). Here, we report on the realization of a quantum-enhanced and fully deterministic ab initio phase estimation protocol based on real-time feedback control. Using robust squeezed states of light combined with a real-time Bayesian adaptive estimation algorithm, we demonstrate deterministic phase estimation with a precision beyond the quantum shot noise limit. The demonstrated protocol opens up new opportunities for quantum microscopy, quantum metrology and quantum information processing.

General information

State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology, Leibniz Universität Hannover, Università degli Studi di Milano
Authors: Berni, A. (Intern), Gehring, T. (Intern), Nielsen, B. M. (Intern), Händchen, V. (Ekstern), Paris, M. G. A. (Ekstern), Andersen, U. L. (Intern)
Pages: 577-582
Publication date: 2015
Main Research Area: Technical/natural sciences

Publication information

Journal: Nature Photonics
Volume: 9
Issue number: 9
ISSN (Print): 1749-4885
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 21.32 SJR 15.831 SNIP 9.983
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 14.556 SNIP 9.494 CiteScore 17.25
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 13.612 SNIP 9.461 CiteScore 16.32
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 13.418 SNIP 8.003 CiteScore 13.46
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 10.754 SNIP 8.328
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 8.577 SNIP 11.176
Algebraic and algorithmic frameworks for optimized quantum measurements

von Neumann projections are the main operations by which information can be extracted from the quantum to the classical realm. They are, however, static processes that do not adapt to the states they measure. Advances in the field of adaptive measurement have shown that this limitation can be overcome by “wrapping” the von Neumann projectors in a higher-dimensional circuit which exploits the interplay between measurement outcomes and measurement settings.

Unfortunately, the design of adaptive measurement has often been ad hoc and setup specific. We shall here develop a unified framework for designing optimized measurements. Our approach is twofold: The first is algebraic and formulates the problem of measurement as a simple matrix diagonalization problem. The second is algorithmic and models the optimal interaction between measurement outcomes and measurement settings as a cascaded network of conditional probabilities. Finally, we demonstrate that several figures of merit, such as Bell factors, can be improved by optimized measurements. This leads us to the promising observation that measurement detectors which - taken individually - have a low quantum efficiency can be arranged into circuits where, collectively, the limitations of inefficiency are compensated for.
Assessments of macroscopicity for quantum optical states
With the slow but constant progress in the coherent control of quantum systems, it is now possible to create large quantum superpositions. There has therefore been an increased interest in quantifying any claims of macroscopicity. We attempt here to motivate three criteria which we believe should enter in the assessment of macroscopic quantumness: The number of quantum fluctuation photons, the purity of the states, and the ease with which the branches making up the state can be distinguished. © 2014.
Continuous Variable Quantum Key Distribution with a Noisy Laser

Existing experimental implementations of continuous-variable quantum key distribution require shot-noise limited operation, achieved with shot-noise limited lasers. However, loosening this requirement on the laser source would allow...
for cheaper, potentially integrated systems. Here, we implement a theoretically proposed prepare-and-measure continuous-variable protocol and experimentally demonstrate the robustness of it against preparation noise stemming for instance from technical laser noise. Provided that direct reconciliation techniques are used in the post-processing we show that for small distances large amounts of preparation noise can be tolerated in contrast to reverse reconciliation where the key rate quickly drops to zero. Our experiment thereby demonstrates that quantum key distribution with non-shot-noise limited laser diodes might be feasible.
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 photonic decay rate where the quantum efficiency can be deduced from.

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.

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.
Hybrid discrete- and continuous-variable quantum information

Research in quantum information processing has followed two different directions: the use of discrete variables (qubits) and that of high-dimensional, continuous-variable Gaussian states (coherent and squeezed states). Recently, these two approaches have been converging in potentially more powerful hybrid protocols.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology, Johannes Gutenberg-Universität, University of Tokyo
Authors: Andersen, U. L. (Intern), Neergaard-Nielsen, J. S. (Intern), van Loock, P. (Ekstern), Furusawa, A. (Ekstern)
Number of pages: 7
Pages: 713-719
Publication date: 2015
Main Research Area: Technical/natural sciences

Publication information
Journal: Nature Physics
Volume: 11
Issue number: 9
ISSN (Print): 1745-2473
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 10.44 SJR 12.032 SNIP 7.052
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 12.499 SNIP 7.072 CiteScore 10.81
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 14.719 SNIP 6.174 CiteScore 11.09
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 15.593 SNIP 5.678 CiteScore 12.26
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 15.512 SNIP 5.422 CiteScore 12.44
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 14.918 SNIP 5.371 CiteScore 11.03
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 11.951 SNIP 5.065
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 10.014 SNIP 4.58
Web of Science (2008): Indexed yes
Integrated Quantum Optics: Experiments towards integrated quantum-light sources and quantum-enhanced sensing

The work presented in this thesis is focused on experimental application and generation of continuous variable quantum correlated states of light in integrated dielectric structures. Squeezed states are among the most exploited continuous variable optical states for free-space quantum-enhanced sensing and communication protocols, but for these developments to be applicable for future technologies they must be transformed to an integrated architecture compatible with current electro-optical technology. So far only little work has been done in this direction, but two such contributions are made in this thesis: Firstly, we present proof-of-principle demonstration of interfacing squeezed light with an on-chip optomechanical resonator, demonstrating a quantum-enhanced sensitivity to the vibrations of the micromechanical object. Secondly, work on developing an integrated source of squeezed light is presented and an optimized device design is proposed. The devices have been fabricated and tested optically and preliminary interrogations of the output quantum noise have been performed.

Integrated source of broadband quadrature squeezed light

An integrated silicon nitride resonator is proposed as an ultracompact source of bright single-mode quadrature squeezed light at 850 nm. Optical properties of the device are investigated and tailored through numerical simulations, with particular attention paid to loss associated with interfacing the device. An asymmetric double layer stack waveguide geometry with inverse vertical tapers is proposed for efficient and robust fibre-chip coupling, yielding a simulated total loss of -0.75 dB/facet. We assess the feasibility of the device through a full quantum noise analysis and derive the output squeezing spectrum for intra-cavity pump self-phase modulation. Subject to standard material loss and detection efficiencies, we find that the device holds promises for generating substantial quantum noise squeezing over a bandwidth exceeding 1 GHz. In the low-propagation loss regime, approximately -6 dB squeezing is predicted for a pump power of only 75 mW.
Quantum cryptography with an ideal local relay

We consider two remote parties connected to a relay by two quantum channels. To generate a secret key, they transmit coherent states to the relay, where the states are subject to a continuous-variable (CV) Bell detection. We study the ideal case where Alice's channel is lossless, i.e., the relay is locally in her lab and the Bell detection is performed with unit efficiency. This configuration allows us to explore the optimal performances achievable by CV measurement-device-independent quantum key distribution. This corresponds to the limit of a trusted local relay, where the detection loss can be re-scaled. Our theoretical analysis is confirmed by an experimental simulation where $10^{-4}$ secret bits per use can potentially be distributed at 170km assuming ideal reconciliation.
Squeezing-enhanced feedback cooling of a microresonator

Since its inception, quantum mechanics have not ceased to fascinate the scientific world, and especially the fundamental question about the famous Schrödinger's cat being alive or dead, or both, is still far from being answered. Although superposition states have been achieved with small particles, such as photons or atoms, they have not yet been observed on large and massive objects consisting of billions of atoms. With the advance of cavity optomechanics, the quantum behavior of massive mechanical oscillators is becoming accessible and a major key requirement in this direction is the ability to cool such oscillators into their quantum ground state. In the present work we investigate a cold damping scheme relying on the ultra-sensitive measurement of mechanical displacements, provided by a cavity-enhanced optomechanical interaction with quadrature squeezed states of light, to control strong dielectric gradient forces actuating the motion of a toroidal microresonator within a feedback loop. We first determine theoretically the conditions and limits to squeezing-enhanced measurement sensitivity of mechanical displacements, provided by a cavity-enhanced optomechanical interaction with quadrature squeezed states of light, to control strong dielectric gradient forces actuating the motion of a toroidal microresonator within a feedback loop. We first determine theoretically the conditions and limits to squeezing-enhanced measurement sensitivity of mechanical displacements, provided by a cavity-enhanced optomechanical interaction with quadrature squeezed states of light, to control strong dielectric gradient forces actuating the motion of a toroidal microresonator within a feedback loop. We first determine theoretically the conditions and limits to squeezing-enhanced measurement sensitivity of mechanical displacements, provided by a cavity-enhanced optomechanical interaction with quadrature squeezed states of light, to control strong dielectric gradient forces actuating the motion of a toroidal microresonator within a feedback loop. We first determine theoretically the conditions and limits to squeezing-enhanced measurement sensitivity of mechanical displacements, provided by a cavity-enhanced optomechanical interaction with quadrature squeezed states of light, to control strong dielectric gradient forces actuating the motion of a toroidal microresonator within a feedback loop. We first determine theoretically the conditions and limits to squeezing-enhanced measurement sensitivity of mechanical displacements, provided by a cavity-enhanced optomechanical interaction with quadrature squeezed states of light, to control strong dielectric gradient forces actuating the motion of a toroidal microresonator within a feedback loop.
Squeezing-enhanced measurement sensitivity in a cavity optomechanical system

We determine the theoretical limits to squeezing-enhanced measurement sensitivity of mechanical motion in a cavity optomechanical system. The motion of a mechanical resonator is transduced onto quadrature fluctuations of a cavity optical field and a measurement is performed on the optical field exiting the cavity. We compare measurement sensitivities obtained with coherent probing and quantum-enhanced probing of the mechanical motion, i.e. the coherent probe field carries vacuum states and quadrature squeezed vacuum states at sideband frequencies, respectively. We find that quantum-enhanced probing provides little to no improvement in motion sensing for resonators in the unresolved sideband regime but may significantly increase measurement sensitivities for resonators in the resolved sideband regime.
Continuous Variables Quantum Information in Noisy Environments

The technological progress of the last few decades has brought us the ability of exploiting quantum effects to accomplish a variety of relevant tasks. Yet, quantum phenomena are fragile, and with the ability to engineer quantum information protocols comes the problem of keeping such information safe from the detrimental effects of noise and losses. In the present work we investigate continuous variables Gaussian quantum information in noisy environments, studying the effects of various noise sources in the cases of a quantum metrological task, an error correction scheme and discord-type correlations. We engage each of the topics from a theoretical point of view, successively delving into the details of the experimental realizations and concluding with a survey of the results. In particular, we present experimental implementation of an ab initio, deterministic, real-time adaptive phase estimation protocol in a realistic thermalized scenario, we investigate the performance of an error correction scheme for elimination of correlated noise in a quantum channel, and we study the robustness of discord-type quantum correlations when subject to additive noise and attenuation.

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.
Generation of picosecond pulsed coherent state superpositions

We present the generation of approximated coherent state superpositions-referred to as Schrödinger cat states-by the process of subtracting single photons from picosecond pulsed squeezed states of light. The squeezed vacuum states are produced by spontaneous parametric down-conversion (SPDC) in a periodically poled KTiOPO4 crystal while the single photons are probabilistically subtracted using a beamsplitter and a single photon detector. The resulting states are fully characterized with time-resolved homodyne quantum state tomography. Varying the pump power of the SPDC, we generated different states which exhibit non-Gaussian behavior. (C) 2014 Optical Society of America
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
State: Published
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
Pages: 114017
Publication date: 2014
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Optics
Volume: 16
Issue number: 11
ISSN (Print): 2040-8978
Ratings:
Web of Science (2018): Indexed yes
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.63
Web of Science (2016): Indexed yes
Adaptive phase estimation with squeezed thermal light

Summary form only given. The use of quantum states of light in optical interferometry improves the precision in the estimation of a phase shift, paving the way for applications in quantum metrology, computation and cryptography. Sub-shot noise phase sensing can for example be achieved by injecting a squeezed vacuum into an interferometer. However, this approach leads to enhanced sensitivity only for small phase shifts. In this work we aim for ab initio sub-shot noise estimation of an unknown phase shift using a pre-determined squeezed probe and an adaptive measurement approach. We experimentally investigate the performances of such protocol under the realistic assumption of thermalization of the
probe state. Indeed, adaptive phase estimation schemes with squeezed states and Bayesian processing of homodyne data have been shown to be asymptotically optimal in the pure case, thus approaching the quantum Cramér-Rao bound. In our protocol we take advantage of the enhanced sensitivity of homodyne detection in proximity of the optimal phase which maximizes the homodyne Fisher information. A squeezed thermal probe state (signal) undergoes an unknown phase shift. The first estimation step involves interference on a beam splitter of the signal and a local oscillator followed by homodyne detection. Homodyne data is then processed to compute a rough estimation of the phase through Bayesian inference. The rough estimation is fed back to the local oscillator in order to match the optimal relative phase with the signal. A second estimation step leads to the final estimation of the phase shift. Thermalization of the probe state prevents the attainability of the quantum Cramér-Rao bound. Nevertheless, we show that the studied adaptive scheme still saturates the classical Cramér-Rao bound, showing sub-shot noise behaviour and therefore extracting the maximum available information from homodyne data. In contrast to previous approaches, our scheme is optimized for Gaussian states.

**General information**
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology, Università degli Studi di Milano
Authors: Berni, A. A. (Intern), Madsen, L. S. (Intern), Lassen, M. Ø. (Intern), Nielsen, B. M. (Intern), Paris, M. G. A. (Ekstern), Andersen, U. L. (Intern)
Number of pages: 1
Publication date: 2013

**Host publication information**
Title of host publication: CLEO/Europe 2013 - European Conference on Lasers and Electro-Optics
Main Research Area: Technical/natural sciences
Conference: 2013 Conference on Lasers & Electro-Optics Europe & the International Quantum Electronics Conference (CLEO/Europe-IQEC), Munich, Germany, 12/05/2013 - 12/05/2013
DOIs: 10.1109/CLEOE-IQEC.2013.6801233
Source: FindIt
Source-ID: 266824561
Publication: Research - peer-review › Conference abstract in proceedings – Annual report year: 2013

**Amplification of realistic Schrödinger-cat-state-like states by homodyne heralding**
We present a scheme for the amplification of Schrödinger cat states that collapses two smaller states onto their constructive interference via a homodyne projection. We analyze the performance of the amplification in terms of fidelity and success rate when the input consists of either exact coherent state superpositions or of photon-subtracted squeezed vacua. The impact of imprecise homodyne detection and of impure squeezing is quantified. We also assess the scalability of iterated amplifications.

**General information**
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology, Friedrich-Alexander University Erlangen-Nuremberg, Technical University of Denmark
Authors: Laghaout, A. (Intern), Neergaard-Nielsen, J. S. (Intern), Rigas, I. (Ekstern), Kragh, C. (Ekstern), Tipsmark, A. (Intern), Andersen, U. L. (Intern)
Pages: 043826
Publication date: 2013
Main Research Area: Technical/natural sciences

**Publication information**
Journal: Physical Review A
Volume: 87
Issue number: 4
ISSN (Print): 2469-9926
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
Applications of hybrid measurements with discrete and continuous variables

The main topic of this thesis revolves around quantum measurement. We illustrate how two different views of quantum objects, the discrete-and continuous-variable views, can be combined to more effectively distinguish between orthogonal states. Such combined measurements are referred to as hybrid. The discrete-variable view is more appropriate to probe energy eigenstates. However, when two or more energy eigenstates are superposed, accurate measurements in the energy eigenbasis require rotations in phase space which are very unwieldy as they require strong nonlinearities and elaborate interactions between light and matter. On the other hand, energy eigenstate superpositions carry a continuous
relative phase which is easily probed by continuous-variable interference measurements such as homodyning. The
tradeoff between photon counting and homodyning is in practice determined by feasibility studies. This is what we do for
two particular applications of quantum measurements: Bell tests and the amplification of Schrödinger cat states. This
project also had an experimental component which was supposed to produce high-fidelity Schrödinger cat states. This
goal turned out to be hampered by noise from the laser as well as a series of anomalous behavior of the nonlinear crystal
whereby no classical de-amplification, and therefore no squeezing, could be observed.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology
Authors: Laghaout, A. (Intern), Andersen, U. L. (Intern)
Number of pages: 131
Publication date: 2013

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 adiabatic
coupling between two silver nanowires using a nitrogen vacancy center as a probe source.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Sensors and Supercontinuum Generation, Quantum Physics and Information Technology, Department of Physics
Authors: Israelsen, N. M. (Intern), Kumar, S. (Intern), Huck, A. (Intern), Neergaard-Nielsen, J. S. (Intern), Andersen, U. L. (Intern)
Number of pages: 1
Publication date: 2013
Main Research Area: Technical/natural sciences
Electronic versions:
Compilation_Abstracts_SSOP3_25juin.pdf
Source: PublicationPreSubmission
Source-ID: 111775019
Publication: Research - peer-review › Paper – Annual report year: 2013

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
State: Published
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)
Pages: 103106
Publication date: 2013
Main Research Area: Technical/natural sciences

Publication information
Volume: 102
Coupling of single quantum emitters to plasmons propagating on mechanically etched wires

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.
Deterministic superresolution with coherent states at the shot noise limit

Interference of light fields plays an important role in various high-precision measurement schemes. It has been shown that superresolving phase measurements beyond the standard coherent state limit can be obtained either by using maximally entangled multiparticle states of light or using complex detection approaches. Here we show that superresolving phase measurements at the shot noise limit can be achieved without resorting to nonclassical optical states or to low-efficiency detection processes. Using robust coherent states of light, high-efficiency homodyne detection, and a deterministic binarization processing technique, we show a narrowing of the interference fringes that scales with $1/\sqrt{N}$ where $N$ is the mean number of photons of the coherent state. Experimentally we demonstrate a 12-fold narrowing at the shot noise limit.

**General information**

State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology, Università degli Studi di Milano
Authors: Distante, E. (Ekstern), Jezek, M. (Intern), Andersen, U. L. (Intern)
Pages: 033603
Publication date: 2013
Main Research Area: Technical/natural sciences

**Publication information**

Journal: Physical Review Letters
Volume: 111
Issue number: 3
ISSN (Print): 0031-9007
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 6.33 SJR 3.56 SNIP 2.133
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 3.823 SNIP 2.205 CiteScore 5.76
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 5.027 SNIP 2.646 CiteScore 6.62
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 5.674 SNIP 2.796 CiteScore 7.46
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 6.243 SNIP 2.845 CiteScore 7.19
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 6.252 SNIP 2.886 CiteScore 7.02
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 6.418 SNIP 2.764
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 6.342 SNIP 2.94
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 6.223 SNIP 2.854
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 6.14 SNIP 2.862
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 5.645 SNIP 2.807
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 5.35 SNIP 2.938
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 5.312 SNIP 2.976
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 5.33 SNIP 2.93
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 5.441 SNIP 3.089
Web of Science (2002): Indexed yes
Web of Science (2001): Indexed yes
Scopus rating (2000): SJR 5.92 SNIP 3.111
Web of Science (2000): Indexed yes
Scopus rating (1999): SJR 6.185 SNIP 2.979
Original language: English
Coherent light, Complexation, Phase measurement, Shot noise, Quantum entanglement
Electronic versions:
PhysRevLett.111.033603.pdf
Displacement-enhanced entanglement distillation of single-mode-squeezed entangled states

It has been shown that entanglement distillation of Gaussian entangled states by means of local photon subtraction can be improved by local Gaussian transformations. Here we show that a similar effect can be expected for the distillation of an asymmetric Gaussian entangled state that is produced by a single squeezed beam. We show that for low initial entanglement, our largely simplified protocol generates more entanglement than previous proposed protocols. Furthermore, we show that the distillation scheme also works efficiently on decohered entangled states as well as with a practical photon subtraction setup.
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.
Experimental determination of the degree of polarization of quantum states

We demonstrate experimental excitation-manifold-resolved polarization characterization of quantum states of light ranging from the few-photon to the many-photon level. In contrast to the traditional characterization of polarization that is based on the Stokes parameters, we experimentally determine the Stokes vector of each excitation manifold separately. Only for states with a given photon number do the methods coincide. For states with an indeterminate photon number, for example Gaussian states, the employed method gives a richer and more accurate description. We apply the method both in theory and in experiment to some common states to demonstrate its advantages. © 2013 American Physical Society.
Gaussian Error Correction of Quantum States in a Correlated Noisy Channel
Noise is the main obstacle for the realization of fault-tolerant quantum information processing and secure communication over long distances. In this work, we propose a communication protocol relying on simple linear optics that optimally protects quantum states from non-Markovian or correlated noise. We implement the protocol experimentally and demonstrate the near-ideal protection of coherent and entangled states in an extremely noisy channel. Since all real-life channels are exhibiting pronounced non-Markovian behavior, the proposed protocol will have immediate implications in improving the performance of various quantum information protocols.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology, Palacky University
Authors: Lassen, M. Ø. (Intern), Berni, A. (Intern), Madsen, L. S. (Intern), Filip, R. (Ekstern), Andersen, U. L. (Intern)
Pages: 180502
Publication date: 2013
Main Research Area: Technical/natural sciences

Publication information
Journal: Physical Review Letters
Volume: 111
Issue number: 18
ISSN (Print): 0031-9007
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 6.33 SJR 3.56 SNIP 2.133
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 3.823 SNIP 2.205 CiteScore 5.76
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 5.027 SNIP 2.646 CiteScore 6.62
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 5.674 SNIP 2.796 CiteScore 7.46
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 6.243 SNIP 2.845 CiteScore 7.19
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 6.252 SNIP 2.886 CiteScore 7.02
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 6.418 SNIP 2.764
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Heralded generation of a micro-macro entangled state

Using different optical setups based on squeezed state and photon subtraction we show how optical entanglement between a macroscopic and a microscopic state—the so-called Schrödinger cat state or micro-macro state—can be generated. The entangled state is heralded and is thus produced a priori in contrast to previous proposals. We define the macroscopicity of the macroscopic part of the state as their mean distance in phase space and the success rate in discriminating them with homodyne detection, and subsequently, based on these measures we investigate the macroscopicity of different states. Furthermore, we show that the state can be used to map a microscopic qubit onto a macroscopic one thereby linking a qubit processor with a qumode processor.
High-fidelity teleportation of continuous-variable quantum States using delocalized single photons.

Traditional continuous-variable teleportation can only approach unit fidelity in the limit of an infinite (and unphysical) amount of squeezing. We describe a new method for continuous-variable teleportation that approaches unit fidelity with finite resources. The protocol is not based on squeezed states as in traditional teleportation but on an ensemble of single
photon entangled states. We characterize the teleportation scheme with coherent states, mesoscopic superposition states, and two-mode squeezed states and we find several situations in which near-unity teleportation fidelity can be obtained with modest resources.

**General information**

*State:* Published  
*Organisations:* Department of Physics, Quantum Physics and Information Technology, University of Queensland  
*Authors:* Andersen, U. L. (Intern), Ralph, T. C. (Ekstern)  
*Pages:* 050504  
*Publication date:* 2013  
*Main Research Area:* Technical/natural sciences

**Publication information**

*Journal:* Physical Review Letters  
*Volume:* 111  
*Issue number:* 5  
*ISSN (Print):* 0031-9007  
*Ratings:*  
  - BFI (2018): BFI-level 2  
  - Web of Science (2018): Indexed yes  
  - BFI (2017): BFI-level 2  
  - Web of Science (2017): Indexed yes  
  - BFI (2016): BFI-level 2  
  - Scopus rating (2016): CiteScore 6.33 SJR 3.56 SNIP 2.133  
  - Web of Science (2016): Indexed yes  
  - BFI (2015): BFI-level 2  
  - Scopus rating (2015): SJR 3.823 SNIP 2.205 CiteScore 5.76  
  - Web of Science (2015): Indexed yes  
  - BFI (2014): BFI-level 2  
  - Scopus rating (2014): SJR 5.027 SNIP 2.646 CiteScore 6.62  
  - Web of Science (2014): Indexed yes  
  - BFI (2013): BFI-level 2  
  - Scopus rating (2013): SJR 5.674 SNIP 2.796 CiteScore 7.46  
  - ISI indexed (2013): ISI indexed yes  
  - Web of Science (2013): Indexed yes  
  - BFI (2012): BFI-level 2  
  - Scopus rating (2012): SJR 6.243 SNIP 2.845 CiteScore 7.19  
  - ISI indexed (2012): ISI indexed yes  
  - Web of Science (2012): Indexed yes  
  - BFI (2011): BFI-level 2  
  - Scopus rating (2011): SJR 6.252 SNIP 2.886 CiteScore 7.02  
  - ISI indexed (2011): ISI indexed yes  
  - Web of Science (2011): Indexed yes  
  - BFI (2010): BFI-level 2  
  - Scopus rating (2010): SJR 6.418 SNIP 2.764  
  - Web of Science (2010): Indexed yes  
  - BFI (2009): BFI-level 2  
  - Scopus rating (2009): SJR 6.342 SNIP 2.94  
  - Web of Science (2009): Indexed yes  
  - BFI (2008): BFI-level 2  
  - Scopus rating (2008): SJR 6.223 SNIP 2.854  
  - Web of Science (2008): Indexed yes  
  - Web of Science (2007): Indexed yes  
  - Scopus rating (2006): SJR 5.645 SNIP 2.807  
  - Web of Science (2006): Indexed yes  
  - Scopus rating (2005): SJR 5.35 SNIP 2.938
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.
Measurement-induced amplification of optical cat-like states

Coherent state superpositions, also known as Schrödinger cat states, are widely recognized as promising resources in quantum information, quantum metrology, as well as fundamental tests. These states are hard to produce deterministically and most schemes for their probabilistic generation can only attain amplitudes too small for practical use. This is for example the case for photon-subtracted squeezed vacuum (PSSV), which can be used to approximate cat states of amplitude no larger than $y = 1.5$ if the fidelity is to be maintained above 95%. One way to reach larger amplitudes is to start with pairs of small cats and then to interfere them on a balanced beam splitter. The projective measurement of one of the outputs is used to herald a larger cat resulting from the constructive interference of the initial states. The scheme proposed here uses the projection $|x = 0\rangle\langle x = 0|$ as the heralding condition. Homodyning is proposed, as opposed to photon counting, because homodyne detection has high a quantum efficiency, and - as demonstrated in the paper - can be tuned to increase the success probability of the amplification without heavily compromising the output's fidelity.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology, Friedrich-Alexander University Erlangen-Nuremberg
Authors: Laghaout, A. (Intern), Neergaard-Nielsen, J. S. (Intern), Rigas, J. (Ekstern), Kragh, C. (Intern), Tipsmark, A. (Intern), Andersen, U. L. (Intern)
Number of pages: 1
Publication date: 2013

Host publication information
Title of host publication: Proceedings of Conference on Lasers and Electro-Optics Europe (CLEO EUROPE) and International Quantum Electronics Conference
ISBN (Print): 978-1-4799-0593-5
Main Research Area: Technical/natural sciences
Conference: Conference on Lasers and Electro-Optics Europe 2013 (CLEO Europe), München, Germany, 12/05/2013 - 12/05/2013
amplication, homodyne detection, light coherence, light interference, optical beam splitters, optical squeezing, Aerospace, Bioengineering, Communication, Networking and Broadcast Technologies, Components, Circuits, Devices and Systems, Engineered Materials, Dielectrics and Plasmas, Engineering Profession, Fields, Waves and Electromagnetics, General Topics for Engineers, Nuclear Engineering, Photonics and Electrooptics, Power, Energy and Industry Applications, balanced beam splitter, Cats, coherent state superpositions, constructive interference, homodyning, measurement-induced amplification, optical cat-like states, Optical variables measurement, Optimized production technology, photon-subtracted squeezed vacuum, Photonics, PSSV, quantum efficiency, quantum information, Quantum mechanics, quantum metrology, Schrödinger cat states, Stimulated emission
DOIs:
10.1109/CLEOE-IQEC.2013.6801670
Source: FindIt
Source-ID: 266826833
**Numerical Modelling of Spontaneous Emission in Optical Parametric Amplifiers**

Fiber optical parametric processes offer a wide range of applications including phase sensitive as well as phase insensitive amplification, wavelength conversion and signal regeneration. One of the difficult challenges is any of these applications is to predict their associated noise performance. However, it is well accepted that one contribution to the noise performance originates from vacuum fluctuations. In this work we show a novel approach to predict the spontaneous radiation from a parametric amplifier. In the approach the propagating fields are treated as a sum of a classical mean field and a perturbation defined from quantum optics relations.

**General information**

State: Published

Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Department of Physics, Quantum Physics and Information Technology

Authors: Friis, S. M. M. (Intern), Andersen, U. L. (Intern), Rottwitt, K. (Intern)

Number of pages: 4

Pages: Tu.B2.2

Publication date: 2013

**Host publication information**

Title of host publication: 2013 15th International Conference on Transparent Optical Networks (ICTON)

Publisher: IEEE

ISBN (Print): 978-1-4799-0683-3

DOI: 10.1109/ICTON.2013.6602790

Source-ID: u::7987

Publication: Research - peer-review › Article in proceedings – Annual report year: 2013

**Quantum-enhanced micromechanical displacement sensitivity**

We report on a hitherto unexplored application of squeezed light: for quantum-enhancement of mechanical transduction sensitivity in microcavity optomechanics. Using a toroidal silica microcavity, we experimentally demonstrate measurement of the transduced phase modulation signal in the frequency range 4–5.8 MHz with a sensitivity −0.72(±0.01) dB below the shot noise level. This is achieved for resonant probing in the highly undercoupled regime, by preparing the probe in a weak coherent state with phase squeezed vacuum states at sideband frequencies.

**General information**

State: Published

Organisations: Department of Physics, Quantum Physics and Information Technology, University of Queensland

Authors: Hoff, U. B. (Intern), Harris, G. I. (Ekstern), Madsen, L. S. (Intern), Kerdoncuff, H. (Intern), Lassen, M. Ø. (Intern), Nielsen, B. M. (Intern), Bowen, W. P. (Ekstern), Andersen, U. L. (Intern)

Pages: 1413-1415

Publication date: 2013

Main Research Area: Technical/natural sciences

**Publication information**

Journal: Optics Letters

Volume: 38

Issue number: 9

ISSN (Print): 0146-9592

BFI (2018): BFI-level 2

Web of Science (2018): Indexed yes

BFI (2017): BFI-level 2

Web of Science (2017): Indexed yes

BFI (2016): BFI-level 2

Scopus rating (2016): CiteScore 3.54 SJR 1.864 SNIP 1.658

Web of Science (2016): Indexed yes
Quantum optics: Squeezing more out of LIGO

Further sensitivity improvements are required before advanced optical interferometers will be able to measure gravitational waves. A team has now shown that introducing quantum squeezing of light may help to detect these elusive waves.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology
Authors: Andersen, U. L. (Intern)
Pages: 589
Publication date: 2013
Main Research Area: Technical/natural sciences

Publication information
Journal: Nature Photonics
Volume: 7
Issue number: 8
ISSN (Print): 1749-4885
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 21.32 SJR 15.831 SNIP 9.983
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 14.556 SNIP 9.949 CiteScore 17.25
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 13.612 SNIP 9.461 CiteScore 16.32
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 13.418 SNIP 8.003 CiteScore 13.46
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 10.754 SNIP 8.328
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 8.577 SNIP 11.176
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 6.481 SNIP 6.9
Web of Science (2007): Indexed yes
Original language: English
Source: dtu
Squeezing-enhanced optomechanical transduction sensitivity
High-sensitivity interferometric detection of mechanical displacements has received much attention over the past decades, due to its vast field of applicability, e.g. in gravitational wave detection, cantilever-based single spin detection, and the quest to reveal quantum effects in mesoscopic mechanical systems. Following the proposal of Caves we have experimentally proven the applicability of squeezed light-enhanced interferometric displacement detection in the domain of micromechanical oscillators. The technique has previously been demonstrated for table-top interferometer setups and GW-interferometers, but to the best of our knowledge never in microcavity optomechanics.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology, University of Queensland
Authors: Hoff, U. B. (Intern), Harris, G. I. (Ekstern), Madsen, L. S. (Intern), Kerdoncuff, H. (Intern), Lassen, M. Ø. (Intern), Nielsen, B. M. (Intern), Bowen, W. P. (Ekstern), Andersen, U. L. (Intern)
Number of pages: 1
Publication date: 2013

Host publication information
Title of host publication: Proceedings of the Conference on Lasers and Electro-Optics Europe (CLEO EUROPE) and International Quantum Electronics Conference (IQEC)
ISBN (Print): 978-1-4799-0593-5
Main Research Area: Technical/natural sciences
Conference: Conference on Lasers and Electro-Optics Europe 2013 (CLEO Europe), Munich, Germany, 12/05/2013 - 12/05/2013

Continuous variable quantum key distribution with modulated entangled states.
Quantum key distribution enables two remote parties to grow a shared key, which they can use for unconditionally secure communication over a certain distance. The maximal distance depends on the loss and the excess noise of the connecting quantum channel. Several quantum key distribution schemes based on coherent states and continuous variable measurements are resilient to high loss in the channel, but are strongly affected by small amounts of channel excess noise. Here we propose and experimentally address a continuous variable quantum key distribution protocol that uses modulated fragile entangled states of light to greatly enhance the robustness to channel noise. We experimentally demonstrate that the resulting quantum key distribution protocol can tolerate more noise than the benchmark set by the ideal continuous variable coherent state protocol. Our scheme represents a very promising avenue for extending the distance for which secure communication is possible.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology, Palacky University
Authors: Madsen, L. S. (Intern), Usenko, V. C. (Ekstern), Lassen, M. (Intern), Filip, R. (Ekstern), Andersen, U. L. (Intern)
Pages: 1083
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
Journal: Nature Communications
Volume: 3
ISSN (Print): 2041-1723
Ratings: BFI (2018): BFI-level 2
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.
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.
Coupling of Quantum Emitters in Nanodiamonds to Plasmonic Structures

This PhD thesis describes work towards the enhancement and efficient channeling of photons emitted from a single photon emitter. The emitter used is a defect center, the Nitrogen-Vacancy (NV) center, in diamond. The NV-center has many unique properties, such as long coherence time of its electronic spin states and the possibility of the optical readout of the spin states, which makes it a possible candidate for quantum computing applications. Efficient channeling in combination with enhancement of the emission from the NV-centers will be useful for its application in quantum optics and other applications such as sensing of the magnetic field. In this work, NV-centers in nanodiamond crystals smaller than 100 nm were used.

For enhancing and channeling emission from the NV-centers, metallic waveguides are used in this work. In such waveguides, electromagnetic waves are guided at the interface between metallic and dielectric structures. These electromagnetic waves are known as surface plasmon polaritons. The metallic waveguides, and in general plasmonic waveguides, can confine light far beyond the diffraction limit known for the dielectric waveguides. This confinement of light enables the enhancement and channeling of the emission from an emitter into the plasmonic waveguide. Plasmonic waveguides can have many structures, which can guide and confine light. For instance, a straight cylindrical nanowire made of silver is a plasmonic waveguide, which is used for coupling to an NV-center in this thesis. Another structure used for the coupling is two nanowires placed in parallel, which supports plasmonic modes in the gap between nanowires. The distribution of electromagnetic field in the plasmonic mode depends on the structure of the waveguide. The coupling between an emitter and the plasmonic mode, in turn, depends on the confinement of the plasmonic mode. The coupling between a single NV-center and a single silver nanowire was obtained controllably, by moving the nanodiamonds across the sample near to a silver nanowire.

Due to the coupling between the emitter and the plasmonic waveguide, the decay rate of the emitter is enhanced. An enhancement of the NV-center's decay rate by a factor of 4.6 was observed. Using the gap modes of two parallel silver nanowires for coupling to an NV-center, an increased efficiency of coupling was obtained. In this case, a decay rate enhancement by a factor of 8.3 was observed. Coupling of the NV-centers to the plasmonic mode of silver nanowires was also achieved by placing the emitter at the end of a nanowire and in the gap between two end-to-end aligned nanowires. All these coupled systems were assembled using an atomic force microscope (AFM), by manipulating the nanodiamonds containing the NV-centers and the silver nanowires.

Silver nanowires used for the experiments mentioned above were chemically synthesized. Predesigned silver structures were also fabricated, using two methods. In the first method, structures were sculptured with focused ion beam (FIB) milling of chemically synthesized single crystalline silver nanoplates. The silver nanowire made using this technique was characterized optically, and the propagation of plasmons was observed. In the second method, the silver nanowires were fabricated by carving them from the silver nanoplates with the tip of an AFM cantilever. These nanowires were subsequently used for coupling to an NV-center.

A drawback of the plasmonic waveguides is their high propagation loss. This makes it necessary to couple out photons, e.g. channeled from an emitter, into a dielectric waveguide. The numerical simulation of evanescent coupling between a plasmonic waveguide and a dielectric waveguide made of silicon nitride suggest that the two waveguides can be coupled with a coupling loss of around 30 percent. Evanescent coupling between two plasmonic waveguides is also studied which can be useful for all integrated quantum plasmonic circuits.
Deterministic teleportation using single-photon entanglement as a resource
We outline a proof that teleportation with a single particle is, in principle, just as reliable as with two particles. We thereby hope to dispel the skepticism surrounding single-photon entanglement as a valid resource in quantum information. A deterministic Bell-state analyzer is proposed which uses only classical resources, namely, coherent states, a Kerr nonlinearity, and a two-level atom. © 2012 American Physical Society.
Experimental Investigation of the Evolution of Gaussian Quantum Discord in an Open System

Gaussian quantum discord is a measure of quantum correlations in Gaussian systems. Using Gaussian discord, we quantify the quantum correlations of a bipartite entangled state and a separable two-mode mixture of coherent states. We experimentally analyze the effect of noise addition and dissipation on Gaussian discord and show that the former noise degrades the discord, while the latter noise for some states leads to an increase of the discord. In particular, we experimentally demonstrate the near death of discord by noisy evolution and its revival through dissipation.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology
Authors: Madsen, L. S. (Intern), Berni, A. (Intern), Lassen, M. (Intern), Andersen, U. L. (Intern)
Pages: 030402
Experimental test of the strongly nonclassical character of a noisy squeezed single-photon state

We experimentally verify the quantum non-Gaussian character of a conditionally generated noisy squeezed single-photon state with a positive Wigner function. Employing an optimized witness based on probabilities of squeezed vacuum and squeezed single-photon states, we prove that the state cannot be expressed as a mixture of Gaussian states. In our experiment, the non-Gaussian state is generated by conditional subtraction of a single photon from a squeezed vacuum state. The state is probed with a homodyne detector and the witness is determined by averaging a suitable pattern function over the measured homodyne data. Our experimental results are in good agreement with a theoretical fit obtained from a simple yet realistic model of the experimental setup.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology, Palacky University
Authors: Jezek, M. (Ekstern), Tipsmark, A. (Intern), Dong, R. (Intern), Fiurášek, J. (Ekstern), Mista, Jr., L. (Ekstern), Filip, R. (Ekstern), Andersen, U. L. (Intern)
Pages: 043813
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
Journal: Physical Review A
Volume: 86
Issue number: 4
ISSN (Print): 2469-9926
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
Scopus rating (2016): CiteScore 2.25 SJR 1.281 SNIP 0.852
Web of Science (2016): Indexed yes
Scopus rating (2015): SJR 1.451 SNIP 0.903 CiteScore 2.06
Web of Science (2015): Indexed yes
Scopus rating (2014): SJR 2.121 SNIP 1.146 CiteScore 2.46
Web of Science (2014): Indexed yes
Scopus rating (2013): SJR 2.317 SNIP 1.179 CiteScore 2.86
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
Scopus rating (2012): SJR 2.515 SNIP 1.239 CiteScore 2.81
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
Feedback-enhanced sensitivity in optomechanics: Surpassing the parametric instability barrier

The intracavity power, and hence sensitivity, of optomechanical sensors is commonly limited by parametric instability. Here we characterize the degradation of sensitivity induced by parametric instability in a micron-scale cavity optomechanical system. Feedback via optomechanical transduction and electrical gradient force actuation is applied to suppress the parametric instability. As a result a 5.4-fold increase in mechanical motion transduction sensitivity is achieved to a final value of $1.9 \times 10^{-18} \text{ mHz}^{-1/2}$. 

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology, University of Queensland
Authors: Harris, G. I. (Ekstern), Andersen, U. L. (Intern), Knittel, J. (Ekstern), Bowen, W. P. (Ekstern)
Pages: 061802
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
Journal: Physical Review A
Volume: 85
Issue number: 6
ISSN (Print): 2469-9926
Ratings:
Four-state discrimination scheme beyond the heterodyne limit

We propose and experimentally demonstrate a hybrid discrimination scheme for the quadrature phase shift keying protocol, which outperforms heterodyne detection for any signal power. The discrimination is composed of a quadrature measurement, feed forward and photon detection.
Generation of optical coherent state superpositions for quantum information processing

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology
Authors: Tipsmark, A. (Intern), Andersen, U. L. (Intern)
Number of pages: 150
Publication date: 2012

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Electronic versions:
ATipsmark_Phd_Thesis.pdf

Bibliographical note
PhD thesis
Source: dtu
Source-ID: u::4204
Publication: Research › Ph.D. thesis – Annual report year: 2012

On quantum amplifiers, quantum discrimination and adaptive phase estimation

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology
Authors: Castaneda, M. A. U. (Intern), Andersen, U. L. (Intern)
Number of pages: 120
Publication date: 2012

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Electronic versions:
Theesis MARIO USUGA.pdf
Source: dtu
Source-ID: u::4202
Publication: Research › Ph.D. thesis – Annual report year: 2012

Probabilistic cloning of coherent states without a phase reference

We present a probabilistic cloning scheme operating independently of any phase reference. The scheme is based solely on a phase-randomized displacement and photon counting, omitting the need for nonclassical resources and nonlinear materials. In an experimental implementation, we employ the scheme to clone coherent states from a phase covariant alphabet and demonstrate that the cloner is capable of outperforming the hitherto best-performing deterministic scheme. An analysis of the covariances between the output states shows that uncorrelated clones can be approached
asymptotically. This simultaneously demonstrates how the effect of loss on coherent states can be compensated via noiseless preamplification.

**General information**

State: Published

Organisations: Department of Physics, Quantum Physics and Information Technology, Max Planck Institute, Palacky University, University of Erlangen-Nuremberg

Authors: Müller, C. R. (Ekstern), Wittmann, C. (Ekstern), Marek, P. (Ekstern), Filip, R. (Ekstern), Marquardt, C. (Ekstern), Leuchs, G. (Ekstern), Andersen, U. L. (Intern)

Pages: 010305

Publication date: 2012

Main Research Area: Technical/natural sciences

**Publication information**

Journal: Physical Review A

Volume: 86

Issue number: 1

ISSN (Print): 2469-9926

Ratings:

BFI (2018): BFI-level 1

Web of Science (2018): Indexed yes

BFI (2017): BFI-level 1

Web of Science (2017): Indexed yes

Scopus rating (2016): CiteScore 2.25 SJR 1.281 SNIP 0.852

Web of Science (2016): Indexed yes

Scopus rating (2015): SJR 1.451 SNIP 0.903 CiteScore 2.06

Web of Science (2015): Indexed yes

Scopus rating (2014): SJR 2.121 SNIP 1.146 CiteScore 2.46

Web of Science (2014): Indexed yes

Scopus rating (2013): SJR 2.317 SNIP 1.179 CiteScore 2.86

ISI indexed (2013): ISI indexed yes

Web of Science (2013): Indexed yes

Scopus rating (2012): SJR 2.515 SNIP 1.239 CiteScore 2.81

ISI indexed (2012): ISI indexed yes

Web of Science (2012): Indexed yes

Scopus rating (2011): SJR 2.31 SNIP 1.261 CiteScore 2.79

ISI indexed (2011): ISI indexed yes

Web of Science (2011): Indexed yes

Scopus rating (2010): SJR 2.403 SNIP 1.22

Web of Science (2010): Indexed yes

Scopus rating (2009): SJR 2.475 SNIP 1.305

Web of Science (2009): Indexed yes

Scopus rating (2008): SJR 2.559 SNIP 1.241

Web of Science (2008): Indexed yes

Scopus rating (2007): SJR 2.618 SNIP 1.259

Web of Science (2007): Indexed yes

Scopus rating (2006): SJR 2.342 SNIP 1.257

Web of Science (2006): Indexed yes

Scopus rating (2005): SJR 2.017 SNIP 1.286

Web of Science (2005): Indexed yes

Scopus rating (2004): SJR 2.168 SNIP 1.1

Web of Science (2004): Indexed yes

Scopus rating (2003): SJR 2.05 SNIP 1.078

Web of Science (2003): Indexed yes

Scopus rating (2002): SJR 2.037 SNIP 1.191

Web of Science (2002): Indexed yes

Scopus rating (2001): SJR 2.204 SNIP 1.521
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.
We propose and experimentally demonstrate a near-optimal discrimination scheme for the quadrature phase shift keying (QPSK) protocol. We show in theory that the performance of our hybrid scheme is superior to the standard scheme—heterodyne detection—for all signal amplitudes and underpin the predictions with our experimental results. Furthermore, our scheme provides hitherto the best performance in the domain of highly attenuated signals. The discrimination is composed of a quadrature measurement, a conditional displacement and a threshold detector.

**General information**

State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology, Max Planck Institute, Japan National Institute of Information and Communications Technology
Authors: Müller, C. R. (Ekstern), Castaneda, M. A. U. (Intern), Wittmann, C. (Ekstern), Takeoka, M. (Ekstern), Marquardt, C. (Ekstern), Andersen, U. L. (Intern), Leuchs, G. (Ekstern)
Pages: 083009
Publication date: 2012
Main Research Area: Technical/natural sciences
Quantum information processing with mesoscopic photonic states

The thesis is built up around a versatile optical experimental setup based on a laser, two optical parametric amplifiers, a few sets of modulators and two sets of homodyne detectors, which together with passive linear optics generate, process and characterize various types of Gaussian quantum states. Using this setup we have experimentally and theoretically investigated Gaussian quantum discord, continuous variable quantum key distribution and quantum polarization.

The Gaussian discord broadens the definition of non-classical correlations from entanglement, to all types of correlations which cannot be extracted by local measurements due to the limitations dictated by the Heisenberg's uncertainty principle. We experimentally characterize the evolution of the discord of EPR states and mixtures of coherent states in an attenuating channel. We demonstrate that the discord can grow by local dissipation in the mixture of coherent states. Further we investigate the robustness of the discord of a broader range of states and suggest a toolbox of states which can be used to test if a protocol is discord based, before performing a rigid proof.

Gaussian quantum key distribution can be implemented with current commercially available equipment. However the performance in terms of achievable distance is highly limited. We first experimentally demonstrate that the boundaries of coherent states can be surpassed using modulated entangled states. A simplified experiment is also presented where the modulation of a single-mode squeezed state gives a very reconciliation efficiency robust protocol. All of this is done to achieve higher key rates at the current limits of the coherent state protocols and to extend the boundaries for tolerable channel noise, loss and reconciliation efficiency. As any degree of squeezing improves the performance the extra effort of implementing squeezing in commercial devices is overshadowed by the extended range and increased security margin achieved.

Still using the same experimental setup, but now in the context of polarization we have experimentally bridged the gap between the states with very low photon numbers and the states where one of Stokes parameters is highly excited. To describe the polarization of these states we introduce several new polarization measures which take into account the covariance of the polarization and resolve the polarization manifolds. We experimentally demonstrate states for which the polarization is hidden in the unresolved measures and as well a state which is unpolarized for both first order polarization measures. Finally we illustrate the polarization with SU2 Wigner functions to give a richer picture, not only of the degree of polarization but also its distribution among the manifolds.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology
Authors: Madsen, L. S. (Intern), Andersen, U. L. (Intern)
Number of pages: 97
Publication date: 2012

Squeezed light in optomechanical systems

Squeezed light enhanced optomechanical measurements are demonstrated in both intra-cavity and biological contexts, with respective enhancements of 1.0 and 2.7 dB. Quantum enhanced microrheology of the cytoplasm of a yeast cell is thereby realized.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology, University of Queensland, Australian National University
Authors: Harris, G. I. (Ekstern), Taylor, M. A. (Ekstern), Hoff, U. B. (Intern), Janousek, J. (Ekstern), Daria, V. (Ekstern), Knittel, J. (Ekstern), Kerdoncuff, H. (Intern), Hage, B. (Ekstern), Andersen, U. L. (Intern), Bachor, H. (Ekstern), Bowen, W. P. (Ekstern)
Continuous Variable Quantum Communication and Computation
We use squeezed states of light to implement a robust continuous variable quantum key distribution scheme and an optical Hadamard gate based on coherent state qubits.

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.
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.

Entangling different degrees of freedom by quadrature squeezing cylindrically polarized modes
Quantum systems such as, for example, photons, atoms, or Bose-Einstein condensates, prepared in complex states where entanglement between distinct degrees of freedom is present, may display several intriguing features. In this Letter we introduce the concept of such complex quantum states for intense beams of light by exploiting the properties of cylindrically polarized modes. We show that already in a classical picture the spatial and polarization field variables of these modes cannot be factorized. Theoretically it is proven that by quadrature squeezing cylindrically polarized modes one generates entanglement between these two different degrees of freedom. Experimentally we demonstrate amplitude squeezing of an azimuthally polarized mode by exploiting the nonlinear Kerr effect in a specially tailored photonic crystal fiber. These results display that such novel continuous-variable entangled systems can, in principle, be realized.© 2011 American Physical Society.
Experimental demonstration of a Hadamard gate for coherent state qubits

We discuss and make an experimental test of a probabilistic Hadamard gate for coherent state qubits. The scheme is based on linear optical components, nonclassical resources, and the joint projective action of a photon counter and a homodyne detector. We experimentally characterize the gate for the coherent states of the computational basis by full tomographic reconstruction of the transformed output states. Based on the parameters of the experiment, we simulate the fidelity for all coherent state qubits on the Bloch sphere.
Experimental Demonstration of a Hadamard Gate for Coherent State Qubits

In recent years coherent state qubits, |α⟩ ± |−α⟩, have gained much interest. The main reason is the promise to realize a universal set of coherent state quantum gates with a relative low overhead using only linear optics and photon counters. A universal set of gates consists of a single mode and a two mode phase gate and a Hadamard gate. The Hadamard is the gate that transforms one set of basis states into the conjugate basis, e.g., |±α⟩ - |−α⟩. Here we present an experimental demonstration of a Hadamard gate for coherent state qubits. The implementation is based on the scheme proposed by Marek and Fiurasek (2010).

Experimental Realization of Continuous-Variable Quantum Error Correction Codes

Quantum information processing relies on the robust and faithful transmission, storage and manipulation of quantum information. However, since different decoherent processes are inherent to any realistic implementation, the future of quantum information systems strongly relies on the ability to detect and perform error code correction and noise filtration. We present two different schemes to eliminate erasure errors and channel excess noise in continuous-variable quantum channels.
Probabilistic amplification and cloning of phase-covariant coherent states

Quantum Light from a Whispering-Gallery-Mode Disk Resonator

Quantum Light from a Whispering-Gallery-Mode Disk Resonator

Quantum Light from a Whispering-Gallery-Mode Disk Resonator
Realistic limits on the nonlocality of an N-partite single-photon superposition

A recent paper revealed that a single quantum symmetrically delocalized over N modes, namely a W state, effectively allows for all-versus-nothing proofs of nonlocality in the limit of large N. Ideally, this finding opens up the possibility of using the robustness of the W states while realizing the nonlocal behavior previously thought to be exclusive to the more complex class of Greenberger-Horne-Zeilinger states. We show that in practice, however, the slightest decoherence or inefficiency of the Bell measurements on W states will degrade any violation margin gained by scaling to higher N. The nonstatistical demonstration of nonlocality is thus proved to be impossible in any realistic experiment. © 2011 American Physical Society.
Quantum correlations and light localization in disordered nanophotonic structures

This thesis reports results on quantum properties of light in multiple-scattering nano-structured materials. Spatial quantum correlations of photons are demonstrated experimentally that are induced by multiple scattering of squeezed light and of purely quantum origin. By varying the quantum state of the light source, positive and negative spatial quantum correlations are observed. Angular-resolved measurements of multiply scattered photons show the infinite range of the correlation function in the diffusive regime. The multiply scattered light is characterized in frequency-resolved quantum noise measurements as well as in time-resolved photon coincidence measurements and the experimental results are in excellent agreement with the quantum theory of multiple scattering. Probing the noise properties of light in the coherent backscattering cone reveals an enhancement factor of the multiply scattered photon fluctuations that is larger than the predicted enhancement of the backscattered light intensity. Characterizing the quantum properties of multiply scattered light forms the basis for studies of quantum interference and quantum entanglement in disordered media. Anderson localization of light is demonstrated in disordered photonic crystal waveguides. Transmission measurements show that the localization length is strongly dispersive, allowing the control of one-dimensional Anderson localization of light. The statistical properties of Anderson localization are probed by embedding quantum dot light sources in disordered photonic crystal waveguides. From photoluminescence measurements, the spectral distribution of Anderson-localized modes is determined. Comparing the experimental data with one-dimensional analytical calculations provides a novel method to unambiguously distinguish Anderson localization from losses.

General information
State: Published
Organisations: Quantum Photonics, Department of Photonics Engineering, Quantum Physics and Information Technology, Department of Physics
Authors: Smolka, S. (Intern), Lodahl, P. (Intern), Andersen, U. L. (Intern)
Number of pages: 157
Publication date: Sep 2010

Publication information
Place of publication: Kgs. Lyngby, Denmark
Publisher: Technical University of Denmark (DTU)
ISBN (Print): 87-92062-48-2
Original language: English
Main Research Area: Technical/natural sciences
Electronic versions: 403DDd01.pdf
A generator for unique quantum random numbers based on vacuum states

Random numbers are a valuable component in diverse applications that range from simulations(1) over gambling to cryptography(2,3). The quest for true randomness in these applications has engendered a large variety of different proposals for producing random numbers based on the foundational unpredictability of quantum mechanics(4-11). However, most approaches do not consider that a potential adversary could have knowledge about the generated numbers, so the numbers are not verifiably random and unique(12-15). Here we present a simple experimental setup based on homodyne measurements that uses the purity of a continuous-variable quantum vacuum state to generate unique random numbers. We use the intrinsic randomness in measuring the quadratures of a mode in the lowest energy vacuum state, which cannot be correlated to any other state. The simplicity of our source, combined with its verifiably unique randomness, are important attributes for achieving high-reliability, high-speed and low-cost quantum random number generators.

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics
Pages: 711-715
Publication date: 2010
Main Research Area: Technical/natural sciences

Publication information
Journal: Nature Photonics
Volume: 4
Issue number: 10
ISSN (Print): 1749-4885
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 21.32 SJR 15.831 SNIP 9.983
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 14.556 SNIP 9.949 CiteScore 17.25  
Web of Science (2014): Indexed yes  
BFI (2013): BFI-level 2  
Scopus rating (2013): SJR 13.612 SNIP 9.461 CiteScore 16.32  
ISI indexed (2013): ISI indexed yes  
Web of Science (2013): Indexed yes  
BFI (2012): BFI-level 2  
Scopus rating (2012): SJR 13.418 SNIP 8.003 CiteScore 13.46  
ISI indexed (2012): ISI indexed yes  
Web of Science (2012): Indexed yes  
BFI (2011): BFI-level 2  
ISI indexed (2011): ISI indexed yes  
Web of Science (2011): Indexed yes  
BFI (2010): BFI-level 2  
Scopus rating (2010): SJR 10.754 SNIP 8.328  
Web of Science (2010): Indexed yes  
BFI (2009): BFI-level 2  
Scopus rating (2009): SJR 8.577 SNIP 11.176  
BFI (2008): BFI-level 2  
Scopus rating (2008): SJR 6.481 SNIP 6.9  
Web of Science (2007): Indexed yes  
Original language: English  
DOIs:  
10.1038/NPHOTON.2010.197  
Source: orbit  
Source-ID: 270041  
Publication: Research - peer-review › Journal article – Annual report year: 2010

**A novel method for polarization squeezing with Photonic Crystal Fibers**

Photonic Crystal Fibers can be tailored to increase the effective Kerr nonlinearity, while producing smaller amounts of excess noise compared to standard silicon fibers. Using these features of Photonic Crystal Fibers we create polarization squeezed states with increased purity compared to standard fiber squeezing experiments. Explicit we produce squeezed states in counter propagating pulses along the same fiber axis to achieve near identical dispersion properties. This enables the production of polarization squeezing through interference in a polarization type Sagnac interferometer. We observe Stokes parameter squeezing of $-3.9 \pm 0.3$ dB and anti-squeezing of $16.2 \pm 0.3$ dB.

**General information**

State: Published  
Organisations: Quantum Physics and Information Technology, Department of Physics, Max Planck Institute  
Authors: Milanovic, J. (Ekstern), Lassen, M. Ø. (Intern), Andersen, U. L. (Intern), Leuchs, G. (Ekstern)  
Pages: 1521-1527  
Publication date: 2010  
Main Research Area: Technical/natural sciences

**Publication information**

Journal: Optics Express  
Volume: 18  
Issue number: 2  
ISSN (Print): 1094-4087  
Ratings:  
BFI (2018): BFI-level 2  
Web of Science (2018): Indexed yes  
BFI (2017): BFI-level 2  
Web of Science (2017): Indexed yes  
BFI (2016): BFI-level 2  
Scopus rating (2016): CiteScore 3.48 SJR 1.487 SNIP 1.589  
Web of Science (2016): Indexed yes
Assessing the Polarization of a Quantum Field from Stokes Fluctuations

We propose an operational degree of polarization in terms of the variance of the Stokes vector minimized over all the directions of the Poincaré sphere. We examine the properties of this second-order definition and carry out its experimental determination. Quantum states with the same standard (first-order) degree of polarization are correctly discriminated by this new measure. We argue that a comprehensive quantum characterization of polarization properties requires a whole hierarchy of higher-order degrees.

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics, Universidad de Guadalajara, KTH - Royal Institute of Technology, Max Planck Institute
Authors: Klimov, A. B. (Ekstern), Björk, G. (Ekstern), Söderholm, J. (Ekstern), Madsen, L. S. (Intern), Lassen, M. Ø. (Intern), Andersen, U. L. (Intern), Heersink, J. (Ekstern), Dong, R. (Intern), Marquardt, C. (Ekstern), Leuchs, G. (Ekstern), Sánchez-Soto, L. L. (Ekstern)
Pages: 153602
Publication date: 2010
Main Research Area: Technical/natural sciences

Publication information
Journal: Physical Review Letters
Volume: 105
Issue number: 15
ISSN (Print): 0031-9007
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 6.33 SJR 3.56 SNIP 2.133
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 3.823 SNIP 2.205 CiteScore 5.76
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 5.027 SNIP 2.646 CiteScore 6.62
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 5.674 SNIP 2.796 CiteScore 7.46
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 6.243 SNIP 2.845 CiteScore 7.19
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 6.252 SNIP 2.886 CiteScore 7.02
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 6.418 SNIP 2.764
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 6.342 SNIP 2.94
Continuous-variable entanglement distillation of non-Gaussian mixed states

Many different quantum-information communication protocols such as teleportation, dense coding, and entanglement-based quantum key distribution are based on the faithful transmission of entanglement between distant location in an optical network. The distribution of entanglement in such a network is, however, hampered by loss and noise that is inherent in all practical quantum channels. Thus, to enable faithful transmission one must resort to the protocol of entanglement distillation. In this paper we present a detailed theoretical analysis and an experimental realization of continuous variable entanglement distillation in a channel that is inflicted by different kinds of non-Gaussian noise. The continuous variable entangled states are generated by exploiting the third order nonlinearity in optical fibers, and the states are sent through a free-space laboratory channel in which the losses are altered to simulate a free-space atmospheric channel with varying losses. We use linear optical components, homodyne measurements, and classical communication to distill the entanglement, and we find that by using this method the entanglement can be probabilistically increased for some specific non-Gaussian noise channels.

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics, Max Planck Institute, Palacky University
Authors: Dong, R. (Intern), Lassen, M. Ø. (Intern), Heersink, J. (Ekstern), Marquardt, C. (Ekstern), Filip, R. (Ekstern), Leuchs, G. (Ekstern), Andersen, U. L. (Intern)
Pages: 012312
Publication date: 2010
Main Research Area: Technical/natural sciences

Publication information
Journal: Physical Review A
Volume: 82
Issue number: 1
ISSN (Print): 2469-9926
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
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.

Continuous-variable quantum information processing
Observables of quantum systems can possess either a discrete or a continuous spectrum. For example, upon measurements of the photon number of a light state, discrete outcomes will result whereas measurements of the light's quadrature amplitudes result in continuous outcomes. If one uses the continuous degree of freedom of a quantum system for encoding, processing or detecting information, one enters the field of continuous-variable (CV) quantum information processing. In this paper we review the basic principles of CV quantum information processing with main focus on recent developments in the field. We will be addressing the three main stages of a quantum information system; the preparation stage where quantum information is encoded into CVs of coherent states and single-photon states, the processing stage where quantum information is manipulated to carry out a specified protocol and a detection stage where CV information is measured using homodyne detection or photon counting.
We experimentally demonstrate a new measurement scheme for the discrimination of two coherent states. The measurement scheme is based on a displacement operation followed by a photon-number-resolving detector, and we show that it outperforms the standard homodyne detector which we, in addition, prove to be optimal within all Gaussian operations including conditional dynamics. We also show that the non-Gaussian detector is superior to the homodyne detector in a continuous variable quantum key distribution scheme.
Discrimination of binary coherent states using a homodyne detector and a photon number resolving detector

We investigate quantum measurement strategies capable of discriminating two coherent states probabilistically with significantly smaller error probabilities than can be obtained using nonprobabilistic state discrimination. We apply a postselection strategy to the measurement data of a homodyne detector as well as a photon number resolving detector in order to lower the error probability. We compare the two different receivers with an optimal intermediate measurement scheme where the error rate is minimized for a fixed rate of inconclusive results. The photon number resolving (PNR) receiver is experimentally demonstrated and compared to an experimental realization of a homodyne receiver with postselection. In the comparison, it becomes clear that the performance of the PNR receiver surpasses the performance of the homodyne receiver, which we prove to be optimal within any Gaussian operations and conditional dynamics.
Discrimination of optical coherent states using a photon number resolving detector

The discrimination of non-orthogonal quantum states with reduced or without errors is a fundamental task in quantum measurement theory. In this work, we investigate a quantum measurement strategy capable of discriminating two coherent states probabilistically with significantly smaller error probabilities than can be obtained using non-probabilistic state discrimination. We find that appropriate postselection of the measurement data of a photon number resolving detector can be used to discriminate two coherent states with small error probability. We compare our new receiver to an optimal intermediate measurement between minimum error discrimination and unambiguous state discrimination.

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics
Authors: Wittmann, C. (Ekstern), Andersen, U. L. (Intern), Leuchs, G. (Ekstern)
Pages: 213-217
Publication date: 2010
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Modern Optics
Volume: 57
Issue number: 3
ISSN (Print): 0950-0340
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.491 SNIP 0.697 CiteScore 1.2
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.514 SNIP 0.676 CiteScore 1.12
Environment-assisted quantum-information correction for continuous variables

Quantum-information protocols are inevitably affected by decoherence which is associated with the leakage of quantum information into an environment. In this article we address the possibility of recovering the quantum information from an environmental measurement. We investigate continuous-variable quantum information, and we propose a simple environmental measurement that under certain circumstances fully restores the quantum information of the signal state although the state is not reconstructed with unit fidelity. We implement the protocol for which information is encoded into conjugate quadratures of coherent states of light and the noise added under the decoherence process is of Gaussian nature. The correction protocol is tested using both a deterministic as well as a probabilistic strategy. The potential use of the protocol in a continuous-variable quantum-key distribution scheme as a means to combat excess noise is also investigated.
Experimental demonstration of squeezed-state quantum averaging

We propose and experimentally demonstrate a universal quantum averaging process implementing the harmonic mean of quadrature variances. The averaged variances are prepared probabilistically by means of linear optical interference and measurement-induced conditioning. We verify that the implemented harmonic mean yields a lower value than the corresponding value obtained for the standard arithmetic-mean strategy. The effect of quantum averaging is experimentally tested for squeezed and thermal states as well as for uncorrelated and partially correlated noise sources. The harmonic-mean protocol can be used to efficiently stabilize a set of squeezed-light sources with statistically fluctuating noise levels.
Experimental Quantum Averaging of Squeezed Quadratures
We demonstrate an averaging process, corresponding to the harmonic-mean, that average quantum noise sources better than the basic arithmetic-mean strategy. Using simple linear optics, homodyne detection and feedforward, and it is tested on squeezed states.

Hybrid Long-Distance Entanglement Distribution Protocol
We propose a hybrid (continuous-discrete variable) quantum repeater protocol for long-distance entanglement distribution. Starting from states created by single-photon detection, we show how entangled coherent state superpositions can be generated by means of homodyne detection. We show that near-deterministic entanglement swapping with such states is possible using only linear optics and homodyne detectors, and we evaluate the performance of our protocol combining these elements.
Low-Threshold Optical Parametric Oscillations in a Whispering Gallery Mode Resonator

In whispering gallery mode (WGM) resonator light is guided by continuous total internal reflection along a curved surface. Fabricating such resonators from an optically nonlinear material one takes advantage of their exceptionally high quality factors and small mode volumes to achieve extremely efficient optical frequency conversion. Our analysis of the phase-matching conditions for optical parametric down-conversion (PDC) in a spherical WGM resonator shows their direct relation to the sum rules for photons’ angular momenta and predicts a very low parametric oscillation threshold. We realized such an optical parametric oscillator (OPO) based on naturally phase-matched PDC in lithium niobate. We demonstrated a single-mode, strongly nondegenerate OPO with a threshold of 6.7 μW and linewidth under 10 MHz. This work demonstrates the remarkable capabilities of WGM-based OPOs.
Naturally Phase-Matched Second-Harmonic Generation in a Whispering-Gallery-Mode Resonator

We demonstrate for the first time natural phase matching for optical frequency doubling in a high-Q whispering-gallery-mode resonator made of lithium niobate. A conversion efficiency of 9% is achieved at 30 μW in-coupled continuous wave pump power. The observed saturation pump power of 3.2 mW is almost 2 orders of magnitude lower than the state-of-the-art value. This suggests an application of our frequency doubler as a source of nonclassical light requiring only a low-power pump, which easily can be quantum noise limited. Our theoretical analysis of the three-wave mixing in a whispering-gallery-mode resonator provides the relative conversion efficiencies for frequency doubling in various modes.

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics, Max Planck Institute
Authors: Fürst, J. U. (Ekstern), Strekalov, D. (Ekstern), Elser, D. (Ekstern), Lassen, M. Ø. (Intern), Andersen, U. L. (Intern), Marquardt, C. (Ekstern), Leuchs, G. (Ekstern)
Pages: 153901
Publication date: 2010
Main Research Area: Technical/natural sciences

Publication information
Journal: Physical Review Letters
Volume: 104
Issue number: 15
ISSN (Print): 0031-9007
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
Noise-powered probabilistic concentration of phase information

Phase-insensitive optical amplification of an unknown quantum state is known to be a fundamentally noisy operation that inevitably adds noise to the amplified state (1-5). However, this fundamental noise penalty in amplification can be circumvented by resorting to a probabilistic scheme as recently proposed and demonstrated in refs 6-8. These amplifiers are based on highly non-classical resources in a complex interferometer. Here we demonstrate a probabilistic quantum amplifier beating the fundamental quantum limit using a thermal-noise source and a photon-number-subtraction scheme (9). The experiment shows, surprisingly, that the addition of incoherent noise leads to a noiselessly amplified output state with a phase uncertainty below the uncertainty of the state before amplification. This amplifier might become a valuable quantum tool in future quantum metrological schemes and quantum communication protocols.
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.

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics, Universite Libre de Bruxelles, Max Planck Institute
Authors: Lassen, M. Ø. (Intern), Sabuncu, M. (Intern), Huck, A. (Intern), Niset, J. (Ekstern), Leuchs, G. (Ekstern), Cerf, N. (Ekstern), Andersen, U. L. (Intern)
Pages: 700-705
Publication date: 2010
Main Research Area: Technical/natural sciences

Publication information
Journal: Nature Photonics
Volume: 4
Issue number: 10
ISSN (Print): 1749-4885
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 21.32 SJR 15.831 SNIP 9.983
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 14.556 SNIP 9.949 CiteScore 17.25
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
We demonstrate liquid core waveguides defined by UV to enable selective water infiltration in nanoporous polymers, creating an effective refractive index shift $\Delta n=0.13$. The mode confinement and propagation loss in these waveguides are presented.

We demonstrate an averaging process, corresponding to the harmonic-mean, that average quantum noise sources better than the basic arithmetic-mean strategy. Using simple linear optics, homodyne detection and feedforward, and it is tested on squeezed states.

**General information**
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics
Authors: Lassen, M. Ø. (Intern), Madsen, L. S. (Intern), Sabuncu, M. (Ekstern), Filip, R. (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:
Lassen.pdf

**Bibliographical note**
Copyright 2010 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.

Source: orbit
Source-ID: 265505
Publication: Research - peer-review › Article in proceedings – Annual report year: 2010
Colloquium: The Einstein-Podolsky-Rosen paradox: From concepts to applications

This Colloquium examines the field of the Einstein, Podolsky, and Rosen (EPR) gedanken experiment, from the original paper of Einstein, Podolsky, and Rosen, through to modern theoretical proposals of how to realize both the continuous-variable and discrete versions of the EPR paradox. The relationship with entanglement and Bell's theorem are analyzed, and the progress to date towards experimental confirmation of the EPR paradox is summarized, with a detailed treatment of the continuous-variable paradox in laser-based experiments. Practical techniques covered include continuous-wave parametric amplifier and optical fiber quantum soliton experiments. Current proposals for extending EPR experiments to massive-particle systems are discussed, including spin squeezing, atomic position entanglement, and quadrature entanglement in ultracold atoms. Finally, applications of this technology to quantum key distribution, quantum teleportation, and entanglement swapping are examined.

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics
Authors: Reid, M. (Ekstern), Drummond, P. (Ekstern), Bowen, W. (Ekstern), Cavalcanti, E. (Ekstern), Lam, P. K. (Ekstern), Bachor, H. (Ekstern), Andersen, U. L. (Intern), Leuchs, G. (Ekstern)
Pages: 1727-1751
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: Reviews of Modern Physics
Volume: 81
Issue number: 4
ISSN (Print): 0034-6861
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 35.68 SJR 23.543 SNIP 18.377
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 23.708 SNIP 19.026 CiteScore 32.79
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 34.257 SNIP 17.508 CiteScore 36.89
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 39.436 SNIP 17.844 CiteScore 43.19
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 48.103 SNIP 23.141 CiteScore 49.44
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 42.822 SNIP 21.819 CiteScore 42.45
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 43.665 SNIP 20.23
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 33.676 SNIP 18.036
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 35.796 SNIP 18.886
Scopus rating (2006): SJR 27.88 SNIP 16.18
Scopus rating (2005): SJR 25.64 SNIP 17.169
Scopus rating (2004): SJR 25.394 SNIP 17.104
Continuous Variable Entanglement and Squeezing of Orbital Angular Momentum States

We report the first experimental characterization of the first-order continuous variable orbital angular momentum states. Using a spatially nondegenerate optical parametric oscillator (OPO) we produce quadrature entanglement between the two first-order Laguerre-Gauss modes. The family of orbital angular momentum modes is mapped on an orbital Poincaré sphere, where the mode’s position on the sphere is spanned by the three orbital parameters. Using a nondegenerate OPO we produce squeezing of these parameters, and as an illustration, we reconstruct the “cigar-shaped” uncertainty volume on the orbital Poincaré sphere.

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics, Max Planck Institute
Authors: Lassen, M. Ø. (Intern), Leuchs, G. (Ekstern), Andersen, U. L. (Intern)
Pages: 163602
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: Physical Review Letters
Volume: 102
Issue number: 16
ISSN (Print): 0031-9007
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 6.33 SJR 3.56 SNIP 2.133
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 3.823 SNIP 2.205 CiteScore 5.76
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 5.027 SNIP 2.646 CiteScore 6.62
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 5.674 SNIP 2.796 CiteScore 7.46
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
Continuous variable entanglement distillation of non-Gaussian states

We experimentally demonstrate distillation of continuous variable entangled light that has undergone non-Gaussian attenuation loss. The continuous variable entanglement is generated with optical fibers and sent through a lossy channel, where the transmission is varying in time. By employing simple linear optical components, a measurement induced operation and classical communication, we demonstrate that the entanglement is probabilistically increased. ©2009 American Institute of Physics
Continuous Variable Entanglement Distillation of Non-Gaussian States
Continuous Variable Entanglement of Orbital Angular Momentum States

We have generated a new quantum state of light composed of quadrature entangled Laguerre-Gaussian (LG) modes. For the generation we used an OPO operating in a new regime where all field parameters are degenerate except for its spatial degree of freedom for which it is two-fold degenerate. The entanglement is manifested in the squeezing of the rotated modes in the Hermite-Gauss (HG) basis, measured with a specially tailored local oscillator. The most promising application of CV orbital angular momentum (OAM) states is their compatibility with atoms, thus allowing for storage of CV quantum information.
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.
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.
Excitation and characterization of non-classical surface plasmon polaritons

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. (Extern), 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: Smolka.pdf

Bibliographical note
Copyright: 2009 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE
Source: orbit
Source-ID: 246501
Publication: Research - peer-review › Article in proceedings – Annual report year: 2009

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.

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. (Extern), Lodahl, P. (Intern)
Pages: 193901
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: Physical Review Letters
Volume: 102
Issue number: 19
ISSN (Print): 0031-9007
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 6.33 SJR 3.56 SNIP 2.133
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Quadrature measurements of a bright squeezed state via sideband swapping
The measurement of an arbitrary quadrature of a bright quantum state of light is a commonly requested action in many quantum information protocols, but it is experimentally challenging with previously proposed schemes. We suggest that the quadrature be measured at a specific sideband frequency of a bright quantum state by transferring the sideband modes under interrogation to a vacuum state and subsequently measuring the quadrature via homodyne detection. The scheme is implemented experimentally, and it is successfully tested with a bright squeezed state of light.

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics
Authors: Schneider, J. (Ekstern), Glockl, O. (Ekstern), Leuchs, G. (Ekstern), Andersen, U. L. (Intern)
Pages: 1186-1188
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: Optics Letters
Volume: 34
Issue number: 8
ISSN (Print): 0146-9592
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.54 SJR 1.864 SNIP 1.658
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 2.142 SNIP 1.642 CiteScore 3.53
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.497 SNIP 2.056 CiteScore 3.86
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.458 SNIP 2.095 CiteScore 3.95
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.596 SNIP 1.95 CiteScore 3.52
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.518 SNIP 2.475 CiteScore 3.69
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.669 SNIP 2.293
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 3.167 SNIP 2.665
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 3.408 SNIP 2.378
Web of Science (2008): Indexed yes
Quantum Feed-Forward Control of Light

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics
Authors: Andersen, U. L. (Intern)
Pages: 365-415
Publication date: 2009

Host publication information
Title of host publication: Progress in optics
Publisher: Elsevier
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 254069
Publication: Research - peer-review › Book chapter – Annual report year: 2009

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
Source: orbit
Source-ID: 246503
Publication: Research - peer-review › Conference abstract in proceedings – Annual report year: 2009

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
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.
Demonstration of Near-Optimal Discrimination of Optical Coherent States
The optimal discrimination of nonorthogonal quantum states with minimum error probability is a fundamental task in quantum measurement theory as well as an important primitive in optical communication. In this work, we propose and experimentally realize a new and simple quantum measurement strategy capable of discriminating two coherent states with smaller error probabilities than can be obtained using the standard measurement devices: the Kennedy receiver and the homodyne receiver.

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics
Authors: Wittmann, C. (Ekstern), Takeoka, M. (Ekstern), Cassemiro, K. N. (Ekstern), Sasaki, M. (Ekstern), Leuchs, G. (Ekstern), Andersen, U. L. (Intern)
Pages: 210501
Publication date: 2008
Main Research Area: Technical/natural sciences

Publication information
Journal: Physical Review Letters
Volume: 101
Issue number: 21
ISSN (Print): 0031-9007
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 6.33 SJR 3.56 SNIP 2.133
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 3.823 SNIP 2.205 CiteScore 5.76
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
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.54 SJR 1.864 SNIP 1.658
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 2.142 SNIP 1.642 CiteScore 3.53
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.497 SNIP 2.056 CiteScore 3.86
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.458 SNIP 2.095 CiteScore 3.95
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.596 SNIP 1.95 CiteScore 3.52
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.518 SNIP 2.475 CiteScore 3.69
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.669 SNIP 2.293
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 3.167 SNIP 2.665
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 3.408 SNIP 2.378
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 3.489 SNIP 2.102
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 3.143 SNIP 2.334
Web of Science (2006): Indexed yes
Experimental continuous-variable cloning of partial quantum information

The fidelity of a quantum transformation is strongly linked with the prior partial information of the state to be transformed. We illustrate this interesting point by proposing and demonstrating the superior cloning of coherent states with prior partial information. More specifically, we propose two simple transformations that under the Gaussian assumption optimally clone symmetric Gaussian distributions of coherent states as well as coherent states with known phases. Furthermore, we implement for the first time near-optimal state-dependent cloning schemes relying on simple linear optics and feedforward.

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology, Friedrich-Alexander University Erlangen-Nuremberg
Authors: Sabuncu, M. (Intern), Leuchs, G. (Ekstern), Andersen, U. L. (Intern)
Pages: 052312
Publication date: 2008
Main Research Area: Technical/natural sciences

Publication information
Journal: Physical Review A
Volume: 78
Issue number: 5
ISSN (Print): 2469-9926
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
Scopus rating (2016): CiteScore 2.25 SJR 1.281 SNIP 0.852
Web of Science (2016): Indexed yes
Scopus rating (2015): SJR 1.451 SNIP 0.903 CiteScore 2.06
Web of Science (2015): Indexed yes
Scopus rating (2014): SJR 2.121 SNIP 1.146 CiteScore 2.46
Web of Science (2014): Indexed yes
Scopus rating (2013): SJR 2.317 SNIP 1.179 CiteScore 2.86
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
Scopus rating (2012): SJR 2.515 SNIP 1.239 CiteScore 2.81
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
Experimental entanglement distillation of mesoscopic quantum states

The distribution of entangled states between distant parties in an optical network is crucial for the successful implementation of various quantum communication protocols such as quantum cryptography, teleportation and dense coding(1-3). However, owing to the unavoidable loss in any real optical channel, the distribution of loss-intolerant entangled states is inevitably afflicted by decoherence, which causes a degradation of the transmitted entanglement. To combat the decoherence, entanglement distillation, a process of extracting a small set of highly entangled states from a large set of less entangled states, can be used(4-14). Here we report on the distillation of deterministically prepared light pulses entangled in continuous variables that have undergone non-Gaussian noise. The entangled light pulses(15-17) are sent through a lossy channel, where the transmission is varying in time similarly to light propagation in the atmosphere. By using linear optical components and global classical communication, the entanglement is probabilistically increased.

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics
Authors: Dong, R. (Ekstern), Lassen, M. Ø. (Intern), Heersink, J. (Ekstern), Marquardt, C. (Ekstern), Filip, R. (Ekstern), Leuchs, G. (Ekstern), Andersen, U. L. (Intern)
Pages: 919-923
Publication date: 2008
Experimental evidence for Raman-induced limits to efficient squeezing in optical fibers

We report new experiments on polarization squeezing using ultrashort photonic pulses in a single pass of a birefringent fiber. We measure what is to our knowledge a record squeezing of -6.8 +/- 0.3 dB in optical fibers which when corrected for linear losses is -10.4 +/- 0.8 dB. The measured polarization squeezing as a function of optical pulse energy, which spans a wide range from 3.5-178.8 pJ, shows a very good agreement with the quantum simulations and for the first time we see the experimental proof that Raman effects limit and reduce squeezing at high pulse energy.
Experimentally feasible quantum erasure-correcting code for continuous variables

We devise a scheme that protects quantum coherent states of light from probabilistic losses, thus achieving the first continuous-variable quantum erasure-correcting code. If the occurrence of erasures can be probed, then the decoder enables, in principle, a perfect recovery of the original light states. Otherwise, if supplemented with postselection based on homodyne detection, this code can be turned into an efficient erasure-filtration scheme. The experimental feasibility of the proposed protocol is carefully addressed.

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics
Authors: Nisset, J. (Ekstern), Andersen, U. L. (Intern), Cerf, N. (Ekstern)
Pages: 130503
Publication date: 2008
Main Research Area: Technical/natural sciences

Publication information
Journal: Physical Review Letters
Volume: 101
Issue number: 13
ISSN (Print): 0031-9007
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 6.33 SJR 3.56 SNIP 2.133
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 3.823 SNIP 2.205 CiteScore 5.76
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 5.027 SNIP 2.646 CiteScore 6.62
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 5.674 SNIP 2.796 CiteScore 7.46
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 6.243 SNIP 2.845 CiteScore 7.19
ISI indexed (2012): ISI indexed yes
Generation of Non-Classical Surface-Plasmon Polaritons

State: Published
Organisations: Department of Physics, Quantum Photonics, Department of Photonics Engineering, Plasmonics and Metamaterials
Authors: Huck, A. (Intern), Smolka, S. (Intern), Lodahl, P. (Intern), Boltasseva, A. (Intern), Andersen, U. L. (Intern)
Publication date: 2008

Host publication information
Title of host publication: Metamaterials'2008 : 2nd international congress on advanced electromagnetic materials in microwaves and optics
Generation of Non-Classical Surface-Plasmon-Polaritons

General information
State: Published
Organisations: Department of Physics, Quantum Photonics, Department of Photonics Engineering, Plasmonics and Metamaterials
Authors: Huck, A. (Intern), Smolka, S. (Intern), Lodahl, P. (Intern), Boltasseva, A. (Intern), Janousek, J. (Ekstern), Andersen, U. L. (Intern)
Publication date: 2008

Quantum filtering of optical coherent states
We propose and experimentally demonstrate nondestructive and noiseless removal (filtering) of vacuum states from an arbitrary set of coherent states of continuous variable systems. Errors, i.e., vacuum states in the quantum information are diagnosed through a weak measurement, and on that basis, probabilistically filtered out. We consider three different filters based on on-off detection, phase stabilized, and phase randomized homodyne detection. We find that on-off detection, optimal in the ideal theoretical setting, is superior to the homodyne strategy also in a practical setting.

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics
Authors: Wittmann, C. (Ekstern), Elser, D. (Ekstern), Andersen, U. L. (Intern), Filip, R. (Ekstern), Marek, P. (Ekstern), Leuchs, G. (Ekstern)
Pages: 032315
Publication date: 2008
Main Research Area: Technical/natural sciences

Publication information
Journal: Physical Review A
Volume: 78
Issue number: 3
ISSN (Print): 2469-9926
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
Scopus rating (2016): CiteScore 2.25 SJR 1.281 SNIP 0.852
Web of Science (2016): Indexed yes
Scopus rating (2015): SJR 1.451 SNIP 0.903 CiteScore 2.06
Web of Science (2015): Indexed yes
Scopus rating (2014): SJR 2.121 SNIP 1.146 CiteScore 2.46
Web of Science (2014): Indexed yes
Scopus rating (2013): SJR 2.317 SNIP 1.179 CiteScore 2.86
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
Scopus rating (2012): SJR 2.515 SNIP 1.239 CiteScore 2.81
Simulations and experiments on polarization squeezing in optical fiber

We investigate polarization squeezing of ultrashort pulses in optical fiber, over a wide range of input energies and fiber lengths. Comparisons are made between experimental data and quantum dynamical simulations to find good quantitative agreement. The numerical calculations, performed using both truncated Wigner and exact +P phase-space methods, include nonlinear and stochastic Raman effects, through coupling to phonon variables. The simulations reveal that excess phase noise, such as from depolarizing guided acoustic wave Brillouin scattering, affects squeezing at low input energies, while Raman effects cause a marked deterioration of squeezing at higher energies and longer fiber lengths. We also calculate the optimum fiber length for maximum squeezing.
Main Research Area: Technical/natural sciences

Publication information
Journal: Physical Review A
Volume: 78
Issue number: 2
ISSN (Print): 2469-9926
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
Scopus rating (2016): CiteScore 2.25 SJR 1.281 SNIP 0.852
Web of Science (2016): Indexed yes
Scopus rating (2015): SJR 1.451 SNIP 0.903 CiteScore 2.06
Web of Science (2015): Indexed yes
Scopus rating (2014): SJR 2.121 SNIP 1.146 CiteScore 2.46
Web of Science (2014): Indexed yes
Scopus rating (2013): SJR 2.317 SNIP 1.179 CiteScore 2.86
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
Scopus rating (2012): SJR 2.515 SNIP 1.239 CiteScore 2.81
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
Scopus rating (2011): SJR 2.31 SNIP 1.261 CiteScore 2.79
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
Scopus rating (2010): SJR 2.403 SNIP 1.22
Web of Science (2010): Indexed yes
Scopus rating (2009): SJR 2.475 SNIP 1.305
Web of Science (2009): Indexed yes
Scopus rating (2008): SJR 2.559 SNIP 1.241
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 2.618 SNIP 1.259
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 2.342 SNIP 1.257
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 2.017 SNIP 1.286
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 2.168 SNIP 1.1
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 2.05 SNIP 1.078
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 2.037 SNIP 1.191
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 2.204 SNIP 1.521
Web of Science (2001): Indexed yes
Scopus rating (2000): SJR 2.494 SNIP 1.33
Web of Science (2000): Indexed yes
Scopus rating (1999): SJR 2.696 SNIP 1.366
Web of Science (1999): Indexed yes
Original language: English

PULSES, STATES, NONLINEAR INTERFEROMETER, SELF-FREQUENCY SHIFT, GENERATION, QUANTUM-NOISE, LIGHT, SUPERFLUORESCENCE, SOLITONS, PHOTONIC CRYSTAL FIBERS

Electronic versions:
Joel.pdf
Accessing the phase quadrature of intense non-classical light states

General information
State: Published
Organisations: Department of Physics
Authors: Glöckl, O. (Ekstern), Andersen, U. L. (Intern), Leuchs, G. (Ekstern)
Pages: 215-232
Publication date: 2007

Host publication information
Title of host publication: Quantum information with continuous variables of atoms and light
Publisher: Imperial College Press
Editors: Cerf, N., Leuchs, G., Polzik, E.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 209796
Publication: Research - peer-review › Book chapter – Annual report year: 2007

An efficient source of continuous variable polarization entanglement
We have experimentally demonstrated the efficient creation of highly entangled bipartite continuous variable polarization states. Exploiting an optimized scheme for the production of squeezing using the Kerr non-linearity of a glass fibre we generated polarization squeezed pulses with a mean classical excitation in S3. Polarization entanglement was generated by interfering two independent polarization squeezed fields on a symmetric beam splitter. The resultant beams exhibit strong quantum noise correlations in the dark S1-S2 polarization plane. To verify entanglement generation, we characterized the quantum correlations of the system for two different sets of conjugate Stokes parameters. The quantum correlations along the squeezed and the anti-squeezed Stokes parameters were observed to be -4.1 ±0.3 and -2.6 ±0.3 dB below the shot noise level, respectively. The degree of correlations was found to depend critically on the beam-splitting ratio of the entangling beam splitter. Carrying out measurements on a different set of conjugate Stokes parameters, correlations of -3.6 ±0.3 and -3.4 ±0.3 dB have been observed. This result is more robust against asymmetries in the entangling beam splitter, even in the presence of excess noise. © IOP Publishing Ltd and Deutsche Physikalische Gesellschaft.

General information
State: Published
Organisations: Department of Physics
Authors: Dong, R. (Ekstern), Heersink, J. (Ekstern), Yoshikawa, J. (Ekstern), Gloeckl, O. (Ekstern), Andersen, U. L. (Intern), Leuchs, G. (Ekstern)
Pages: 410
Publication date: 2007
Main Research Area: Technical/natural sciences

Publication information
Journal: New Journal of Physics
Volume: 9
Issue number: 11
ISSN (Print): 1367-2630
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 2
Continuous variable polarization entanglement via the Kerr nonlinearity in an optical fiber

General information
Continuous variable quantum information protocol

**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.
Experimental demonstration of continuous variable cloning with phase-conjugate inputs

We report the first experimental demonstration of continuous variable cloning of phase-conjugate coherent states as proposed by Cerf and Iblisdir [Phys. Rev. Lett. 87, 247903 (2001)]. In contrast to this proposal, the cloning transformation is accomplished using only linear optical components, homodyne detection, and feedforward. As a result of combining phase conjugation with a joint measurement strategy, superior cloning is demonstrated with cloning fidelities reaching 89%.
We witness experimentally the presence of macroscopic coherence in Gaussian quantum states using a recently proposed criterion [E. G. Cavalcanti and M. D. Reid, Phys. Rev. Lett. 97 170405 (2006)]. The macroscopic coherence stems from interference between macroscopically distinct states in phase space, and we prove experimentally that a coherent state contains these features with a distance in phase space of 0.51 +/- 0.02 shot noise units. This is surprising because coherent states are generally considered being at the border between classical and quantum states, not yet displaying any nonclassical effect. For squeezed and entangled states the effect may be larger but depends critically on the state purity.
Experimental polarization squeezing and entanglement

General information
State: Published
Organisations: Department of Physics
Authors: Josse, V. (Ekstern), Dantan, A. (Ekstern), Bramati, A. (Ekstern), Pinard, M. (Ekstern), Giacobino, E. (Ekstern), Heersink, J. (Ekstern), Andersen, U. L. (Intern), Glockl, O. (Ekstern), Leuchs, G. (Ekstern)
Pages: 233-264
Publication date: 2007

Host publication information
Title of host publication: Quantum information with continuous variables of atoms and light
Publisher: Imperial College Press
Experimental quantum cloning with continuous variable

General information
State: Published
Organisations: Department of Physics
Authors: Andersen, U. L. (Intern), Josse, V. (Ekstern), Lutkenhaus, N. (Ekstern), Leuchs, G. (Ekstern)
Pages: 305-322
Publication date: 2007

Generation of Polarization Squeezing with Periodically Poled KTP at 1064 nm

We report the experimental demonstration of directly produced polarization squeezing at 1064 nm from a type I optical parametric amplifier (OPA) based on a periodically poled KTP crystal (PPKTP). The orthogonal polarization modes of the polarization squeezed state are both defined by the OPA cavity mode, and the birefringence induced by the PPKTP crystal is compensated by a second, but inactive, PPKTP crystal. Stokes parameter squeezing of 3.6 dB and anti squeezing of 9.4 dB is observed. (c) 2007 Optical Society of America.
Measurement induced decoupling of Gaussian Noise for quantum communication

General information
State: Published
Organisations: Department of Physics
Authors: Sabuncu, M. (Intern), Filip, R. (Ekstern), Leuchs, G. (Ekstern), Andersen, U. L. (Intern)
Publication date: 2007

Host publication information
Title of host publication: Technical Digest
Main Research Area: Technical/natural sciences
Conference: The QIPC 2007 International Conference on Quantum Information Processing and Communication, 01/01/2007
Noiseless filtering of non-Gaussian noise from continuous variable quantum information

General information
State: Published
Organisations: Department of Physics
Authors: Wittmann, C. (Ekstern), Elser, D. (Ekstern), Leuchs, G. (Ekstern), Andersen, U. L. (Intern), Filip, R. (Ekstern), Marek, P. (Ekstern)
Publication date: 2007

Host publication information
Title of host publication: Technical Digest
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 210312
Publication: Research - peer-review › Article in proceedings – Annual report year: 2007

Nonunity gain minimal-disturbance measurement
We propose and experimentally demonstrate an optimal nonunity gain Gaussian scheme for partial measurement of an unknown coherent state that causes minimal disturbance of the state. The information gain and the state disturbance are quantified by the noise added to the measurement outcomes and to the output state, respectively. We derive the optimal trade-off relation between the two noises and we show that the tradeoff is saturated by nonunity gain teleportation. Optimal partial measurement is demonstrated experimentally using a linear optics scheme with feedforward.

Nonunity gain minimal-disturbance measurement

General information
State: Published
Organisations: Department of Physics, Quantum Physics and Information Technology
Authors: Sabuncu, M. (Intern), Mišta, L. (Ekstern), Fiurášek, J. (Ekstern), Filip, R. (Ekstern), Leuchs, G. (Ekstern), Andersen, U. L. (Intern)
Pages: 032309
Publication date: 2007
Main Research Area: Technical/natural sciences

Publication information
Journal: Physical Review A
Volume: 76
Issue number: 3
ISSN (Print): 2469-9926
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
Scopus rating (2016): CiteScore 2.25 SJR 1.281 SNIP 0.852
Web of Science (2016): Indexed yes
Scopus rating (2015): SJR 1.451 SNIP 0.903 CiteScore 2.06
Web of Science (2015): Indexed yes
Scopus rating (2014): SJR 2.121 SNIP 1.146 CiteScore 2.46
Web of Science (2014): Indexed yes
Scopus rating (2013): SJR 2.317 SNIP 1.179 CiteScore 2.86
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
Scopus rating (2012): SJR 2.515 SNIP 1.239 CiteScore 2.81
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
Scopus rating (2011): SJR 2.31 SNIP 1.261 CiteScore 2.79
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
Scopus rating (2010): SJR 2.403 SNIP 1.22
Web of Science (2010): Indexed yes
Scopus rating (2009): SJR 2.475 SNIP 1.305
Web of Science (2009): Indexed yes
Scopus rating (2008): SJR 2.559 SNIP 1.241
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 2.618 SNIP 1.259
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 2.342 SNIP 1.257
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 2.017 SNIP 1.286
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 2.168 SNIP 1.1
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 2.05 SNIP 1.078
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 2.037 SNIP 1.191
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 2.204 SNIP 1.521
Web of Science (2001): Indexed yes
Scopus rating (2000): SJR 2.494 SNIP 1.33
Web of Science (2000): Indexed yes
Scopus rating (1999): SJR 2.696 SNIP 1.366
Original language: English
INFORMATION, QUANTUM TELEPORTATION, VARIABLES
Electronic versions:
Metin.pdf
DOIs:
10.1103/PhysRevA.76.032309
Links:

Bibliographical note
Copyright 2007 American Physical Society
Source: orbit
Source-ID: 209738
Publication: Research - peer-review › Journal article – Annual report year: 2007

Optical Amplification at the Quantum Limit

General information
State: Published
Organisations: Department of Physics
Authors: Andersen, U. L. (Intern), Leuchs, G. (Ekstern)
Pages: 2351
Publication date: 2007
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Modern Optics
Volume: 54
ISSN (Print): 0950-0340
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Polarization squeezing with photonic crystal fibers

General information
State: Published
Organisations: 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
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 dynamics of polarization squeezing in optical

General information
State: Published
Organisations: Department of Physics
Authors: Corney, J. (Ekstern), Drummond, P. (Ekstern), Andersen, U. L. (Intern), Heersink, J. (Ekstern), Dong, R. (Ekstern), 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: 210314
Publication: Research - peer-review › Article in proceedings – Annual report year: 2007

Quantum interferometry

General information
State: Published
Organisations: Department of Physics
Authors: Glöckl, O. (Ekstern), Andersen, U. L. (Intern), Leuchs, G. (Ekstern)
Pages: 575-589
Publication date: 2007

Host publication information
Title of host publication: Lectures on quantum information
Publisher: Wiley-VCH
Editors: Bruss, D., Leuchs, G.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 209783
Publication: Research - peer-review › Book chapter – Annual report year: 2007

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
Event: Poster session presented at Danish Optical Society annual meeting 2007, Risø, Denmark.
Main Research Area: Technical/natural sciences
Quantum reconstruction of an intense polarization squeezed optical state

We perform a reconstruction of the polarization sector of the density matrix of an intense polarization squeezed beam starting from a complete set of Stokes measurements. By using an appropriate quasidistribution, we map this onto the Poincare space, providing a full quantum mechanical characterization of the measured polarization state.
Quantum state filtering of noisy coherent states

General information
State: Published
Organisations: Department of Physics
Authors: Wittmann, C. (Ekstern), Elser, D. (Ekstern), Andersen, U. L. (Intern), Filip, R. (Ekstern), Marek, P. (Ekstern), Leuchs, G. (Ekstern)
Publication date: 2007

Host publication information
Title of host publication: Technical Digest
Main Research Area: Technical/natural sciences
Conference: The QIPC 2007 International Conference on Quantum Information Processing and Communication, 01/01/2007
Source: orbit
Source-ID: 209703
Publication: Research - peer-review › Journal article – Annual report year: 2007

Reduction of guided acoustic wave Brillouin scattering in photonic crystal fibers

General information
State: Published
Organisations: Department of Physics
Authors: Elser, D. (Ekstern), Marquardt, C. (Ekstern), Gloeckl, O. (Ekstern), Lorenz, S. (Ekstern), Leuchs, G. (Ekstern), Andersen, U. L. (Intern)
Publication date: 2007
Squeezing by self induced transparency in Rb filled hollow core fibers

General information
State: Published
Organisations: Department of Physics, University of Erlangen-Nuremberg, University of Bath
Authors: Zhong, W. (Ekstern), Marquardt, C. (Ekstern), Leuchs, G. (Ekstern), Andersen, U. L. (Intern), Light, P. (Ekstern), Couny, F. (Ekstern), Benabid, F. (Ekstern)
Publication date: 2007

Superiority of entangled measurements over all local strategies for the estimation of product coherent states

It is shown that the ensemble \{P(\alpha), |\alpha >| > |\alpha(\ast) >\}, where \(P(\alpha)\) is a Gaussian distribution of finite variance and \(|\alpha >\) is a coherent state, can be better discriminated with an entangled measurement than with any local strategy supplemented by classical communication. Although this ensemble consists of products of quasiclassical states without any squeezing, it thus exhibits a purely quantum feature. This remarkable effect is demonstrated experimentally by implementing the optimal local strategy on coherent states of light together with a global strategy that yields a higher fidelity.

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics
Authors: Nisset, J. (Ekstern), Acin, A. (Ekstern), Andersen, U. L. (Intern), Cerf, N. (Ekstern), García-Patrón, R. (Ekstern), Navascues, M. (Ekstern), Sabuncu, M. (Ekstern)
Pages: 260404
Publication date: 2007
Main Research Area: Technical/natural sciences
Optimal cloning of coherent states with linear optics
Squeezing based on nondegenerate frequency doubling internal to a realistic laser

We investigate theoretically the quantum fluctuations of the fundamental field in the output of a nondegenerate second-harmonic generation process occurring inside a laser cavity. Due to the nondegenerate character of the nonlinear medium, a field orthogonal to the laser field is for some operating conditions independent of the fluctuations produced by the laser medium. We show that this fact may lead to perfect squeezing for a certain polarization mode of the fundamental field. The experimental feasibility of the system is also discussed.
Four modes of optical parametric operation for squeezed state generation

We report a versatile instrument, based on a monolithic optical parametric amplifier, which reliably generates four different types of squeezed light. We obtained vacuum squeezing, low power amplitude squeezing, phase squeezing and bright amplitude squeezing. We show a complete analysis of this light, including a full quantum state tomography. In addition we demonstrate the direct detection of the squeezed state statistics without the aid of a spectrum analyser. This technique makes the nonclassical properties directly visible and allows complete measurement of the statistical moments of the squeezed quadrature.
Observations of continuous wave bright squeezed light from an intra-cavity periodically poled KTP second harmonic generator are presented. The experiment includes characterization of the classical as well as the quantum properties of the system.
Modelling a singly resonant, intracavity ring optical parametric oscillator

We study theoretically and experimentally the dynamics of a single-frequency, unidirectional ring laser with an intracavity nonlinear singly resonant OPO-crystal in a coupled resonator. We find for a range of operating conditions good agreement between model results and measurements of the laser and OPO power output and of the temporal development of complex dynamic phenomena such as pulse shape, pulse duration, oscillatory transients and Q-switched operation of the laser.
Polarization squeezing and entanglement produced by a frequency doubler

The quantum mechanical polarization properties of a nondegenerate second harmonic generator, where a nonlinear type II crystal is placed inside a cavity, are investigated theoretically. We demonstrate the possibility of strong squeezing of the continuous Stokes parameters as well as strong entanglement between them.

General information
State: Published
Organisations: Department of Physics
Authors: Andersen, U. L. (Intern), Buchhave, P. (Intern)
Pages: S486-S491
Publication date: 2003
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of optics b-quantum and semiclassical optics
Volume: 5
Issue number: 4
Squeezing and entanglement in doubly resonant, type II, second-harmonic generation

We investigate, theoretically, the generation of bright and vacuum-squeezed light as well as entanglement in intracavity, type II, phase-matched second-harmonic generation. The cavity in which the crystal is embedded is resonant at the fundamental frequency but not at the second-harmonic frequency. A simple model for the process using semiclassical theory is derived, and quadrature-squeezing spectra of the involved fundamental fields are deduced. The analysis shows that vacuum squeezing reminiscent of subthreshold optical parametric oscillator squeezing is present and, in the ideal case, perfect. Under slight modifications of the operational conditions, the system is shown to produce efficient bright, squeezed light. Furthermore, we investigate the degree of polarization squeezing and find that three Stokes parameters can be squeezed simultaneously. Finally, we gauge the process for possible entanglement.
General information
State: Published
Organisations: Department of Physics
Authors: Andersen, U. L. (Intern), Buchhave, P. (Intern)
Pages: 1947-1958
Publication date: 2003
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of the optical society of america b-optical physics
Volume: 20
Issue number: 9
ISSN (Print): 0740-3224
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.81 SJR 0.894 SNIP 1.015
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.023 SNIP 1.002 CiteScore 1.78
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.188 SNIP 1.156 CiteScore 2.09
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.354 SNIP 1.281 CiteScore 2.33
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.517 SNIP 1.273 CiteScore 2.2
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.527 SNIP 1.495 CiteScore 2.33
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.47 SNIP 1.356
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.763 SNIP 1.59
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.645 SNIP 1.33
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.737 SNIP 1.29
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.644 SNIP 1.411
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 2.071 SNIP 1.686
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 1.974 SNIP 1.626
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 1.742 SNIP 1.414
Green bright squeezed light from a cw periodically poled KTP second harmonic generator

We present the experimental observation of bright amplitude squeezed light from a singly resonant second harmonic generator (SHG) based on a periodically poled potassium titanyl phosphate (KTP) crystal. Contrary to conventional SHG, the interacting waves in this device couple efficiently using quasi phase matching (QPM) and more importantly QPM allows access to higher valued elements of the nonlinear tensor than is possible under the constraint of birefringence phase matching. We observe a noise reduction of 13% below the shot noise limit in the generated second harmonic field. This noise reduction is greater than what could be expected using normal birefringence phase matched KTP with the same experimental parameters. Excellent agreement between experiment and theory is found. (C)2002 Optical Society of America.
Quantum nondemolition measurement with a nonclassical meter input and an electro-optic enhancement

Optical quantum nondemolition measurements are performed using a beamsplitter with a nonclassical meter input and an electro-optic feedforward loop. The nonclassical meter input is provided by a stable 4.5 dB amplitude squeezed source generated by an optical parametric amplifier. We show that the implementation of a feedforward loop gives a substantial improvement in the signal transfer efficiency. With a 92% reflective beamsplitter we measure a transfer coefficient of $T_{s+m} = 1.81$. The quantum state preparation ability of our system is evaluated using two-dimensional correlation plots. This technique allows the direct visualization of the quantum correlations between the outputs of the QND system.

General information
State: Published
Organisations: Department of Physics
Authors: Andersen, U. L. (Intern), Buchler, B. (Ekstern), Bachor, H. (Ekstern), Lam, P. (Ekstern)
Pages: S229-S237
Publication date: 2002
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of optics b-quantum and semiclassical optics
Volume: 4
Issue number: 3
ISSN (Print): 1464-4266
Ratings:
BFI (2018): BFI-level 2
Reduction of spatial quantum noise and measurement of small shifts in optics

**General information**

State: Published
Organisations: Department of Physics
Authors: Treps, N. (Ekstern), Maitre, A. (Ekstern), Fabre, C. (Ekstern), Andersen, U. L. (Intern), Buchler, B. (Ekstern), Lam, P. (Ekstern), Bachor, H. (Ekstern)
Pages: 153-154
Publication date: 2002
Main Research Area: Technical/natural sciences

**Publication information**
Squeezing more from a quantum nondemolition measurement

We use a stable, 5 dB, amplitude squeezed source for a quantum nondemolition (QND) experiment. The performance of our QND system is enhanced by an electro-optic feedforward loop which improves the signal transfer efficiency. At best, we measure a total signal transfer of 1.81 and conditional variance of 0.55.
Surpassing the standard quantum limit for optical imaging using nonclassical multimode light

Using continuous wave superposition of spatial modes, we demonstrate experimentally displacement measurement of a light beam below the standard quantum limit. Multimode squeezed light is obtained by mixing a vacuum squeezed beam and a coherent beam that are spatially orthogonal. Although the resultant beam is not squeezed, it is shown to have strong internal spatial correlations. We show that the position of such a light beam can be measured using a split detector with an increased precision compared to a classical beam. This method can be used to improve the sensitivity of small displacement measurements.

Bibliographical note
Copyright (2002) American Physical Society
Source: orbit
Source-ID: 21790
Publication: Research - peer-review › Journal article – Annual report year: 2002

Surpassing the standard quantum limit for optical imaging using nonclassical multimode light

Using continuous wave superposition of spatial modes, we demonstrate experimentally displacement measurement of a light beam below the standard quantum limit. Multimode squeezed light is obtained by mixing a vacuum squeezed beam and a coherent beam that are spatially orthogonal. Although the resultant beam is not squeezed, it is shown to have strong internal spatial correlations. We show that the position of such a light beam can be measured using a split detector with an increased precision compared to a classical beam. This method can be used to improve the sensitivity of small displacement measurements.

General information
State: Published
Organisations: Quantum Physics and Information Technology, Department of Physics
Authors: Treps, N. (Ekstern), Andersen, U. L. (Intern), Buchler, B. (Ekstern), Lam, P. (Ekstern), Maitre, A. (Ekstern), Bachor, H. (Ekstern), Fabre, C. (Ekstern)
Pages: 203601
Publication date: 2002
Main Research Area: Technical/natural sciences

Publication information
Journal: Physical Review Letters
Volume: 88
Issue number: 20
ISSN (Print): 0031-9007
Ratings:
BFI (2018): BFI-level 2
Control of ring lasers by means of coupled cavities

Summary form only. Coupling of optical cavities offers a means of controlling the properties of one cavity (e.g. a laser) by making adjustments to another, external cavity. In this contribution we consider a unidirectional ring laser (bow-tie laser) coupled to an external ring cavity. Using different configurations we can control the out-coupling from the ring laser thereby influencing the threshold and the circulating power in the different ring cavities. This may be used to obtain the best balance between the passive losses and a nonlinear loss such as e.g. conversion to the second harmonic or operation of an optical parametric oscillator.
Projects:

**Development of ultra-high quality mechanical oscillators**
Department of Physics  
Period: 01/11/2017 → 31/10/2020  
Number of participants: 3  
Phd Student: Høj, Dennis (Intern)  
Supervisor: Sigmund, Ole (Intern)  
Main Supervisor: Andersen, Ulrik Lund (Intern)  
Financing sources  
Source: Internal funding (public)  
Name of research programme: Grundforskningsfonden  
Project: PhD

**Non-Gaussian Cluster States**
Department of Physics  
Period: 01/10/2017 → 30/09/2020  
Number of participants: 3  
Phd Student: Larsen, Mikkel Vilsbøll (Intern)  
Supervisor: Neergaard-Nielsen, Jonas Schou (Intern)  
Main Supervisor: Andersen, Ulrik Lund (Intern)  
Financing sources  
Source: Internal funding (public)  
Name of research programme: Institut stipendie (DTU)  
Project: PhD

**Error Reconciliation Protocols for Continuous-Variable Quantum Key Distribution**
Department of Physics  
Period: 01/09/2017 → 31/08/2020  
Number of participants: 4  
Phd Student: Mani, Hossein (Intern)  
Supervisor: Gehring, Tobias (Intern)  
Pacher, Christoph (Ekstern)  
Main Supervisor: Andersen, Ulrik Lund (Intern)  
Financing sources  
Source: Internal funding (public)  
Name of research programme: Fonde  
Project: PhD

**Quantum Communication with non-Gaussian states**
Department of Physics  
Period: 01/04/2017 → 31/03/2020  
Number of participants: 3  
Phd Student: Breum, Casper Rubæk (Intern)
Supervisor:
Neergaard-Nielsen, Jonas Schou (Intern)
Main Supervisor:
Andersen, Ulrik Lund (Intern)

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

**Quantum-optical networks with solid state spins and photons**
Department of Physics
Period: 01/02/2017 → …
Number of participants: 3
Phd Student:
Yakovlev, George (Intern)
Supervisor:
Huck, Alexander (Intern)
Main Supervisor:
Andersen, Ulrik Lund (Intern)

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

**Implementation of fiber-based continuous-variable quantum key distribution protocols**
Department of Physics
Period: 01/10/2016 → 30/09/2019
Number of participants: 3
Phd Student:
Nikolic, Dino Solar (Intern)
Supervisor:
Gehring, Tobias (Intern)
Main Supervisor:
Andersen, Ulrik Lund (Intern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Offentlig finansiering
Project: PhD

**Generation of Macroscopic Squeezed States for Quantum Sensing**
Department of Physics
Period: 01/08/2016 → …
Number of participants: 3
Phd Student:
Pedersen, Mikkel Maag (Intern)
Supervisor:
Gehring, Tobias (Intern)
Main Supervisor:
Andersen, Ulrik Lund (Intern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)
Project: PhD
On-Chip quantum communication
Department of Physics
Period: 01/08/2016 → 31/07/2019
Number of participants: 3
Phd Student: Kordts, Arne (Ekstern)
Supervisor: Gehring, Tobias (Intern)
Main Supervisor: Andersen, Ulrik Lund (Intern)

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

Highly Sensitive Magnetic Sensing of Neural Activity
Department of Electrical Engineering
Period: 01/02/2016 → 31/01/2019
Number of participants: 4
Phd Student: Karadas, Mürsel (Intern)
Supervisor: Andersen, Ulrik Lund (Intern)
Hanson, Lars G. (Intern)
Main Supervisor:
Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

Squeezed-light enhanced quantum opto-mechanics
Department of Physics
Period: 15/12/2015 → 14/12/2018
Number of participants: 2
Phd Student:
Bilek, Jan (Intern)
Main Supervisor:
Andersen, Ulrik Lund (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
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 → 30/11/2017
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
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

**First-principles theory of Light-matter Interaction in Low-dimensional Materials**
Department of Physics
Period: 01/09/2013 → 15/03/2017
Number of participants: 5
Phd Student:
Gjerding, Morten Niklas (Intern)
Main Supervisor:
Thygesen, Kristian Sommer (Intern)
Examiner:
Andersen, Ulrik Lund (Intern)
Peres, Nuno M. R. (Ekstern)
Wirtz, Ludger (Ekstern)

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

**Relations**
Publications:
Light-matter interaction in low-dimensional materials. A theoretical study

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

Plasmon supported optical nanosensors and their application for probing artificial and biological micro- and nanochannels

Department of Physics
Period: 01/08/2013 → 26/10/2016
Number of participants: 6
Phd Student:
Palanco, Marta Espina (Intern)
Supervisor:
Hélix-Nielsen, Claus (Intern)
Main Supervisor:
Berg-Sørensen, Kirstine (Intern)
Examiner:
Andersen, Ulrik Lund (Intern)
Dholakia, Kishan (Ekstern)
Kleinschmidt, Jörg Helmut (Ekstern)

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

Relations
Publications:
Optical sensors and their applications for probing biological systems
Project: PhD

Graphene Plasmonics

Department of Photonics Engineering
Period: 01/10/2012 → 17/02/2016
Number of participants: 7
Phd Student:
Christensen, Thomas (Intern)
Supervisor:
Jauho, Antti-Pekka (Intern)
Wubs, Martijn (Intern)
Main Supervisor:
Mortensen, N. Asger (Intern)
Examiner:
Andersen, Ulrik Lund (Intern)
Engheta, Nader (Ekstern)
Koppens, Franks (Ekstern)

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

**Relations**
Publications:
From Classical to Quantum Plasmonics in Three and Two Dimensions
Project: PhD

---

**Quantum control of a mechanical system**
Department of Physics
Period: 01/09/2012 → 21/01/2016
Number of participants: 5
Phd Student:
Kerdoncuff, Hugo (Intern)
Main Supervisor:
Andersen, Ulrik Lund (Intern)
Examiner:
Hansen, Jørn Otto Bindslev (Ekstern)
Filip, Radim (Ekstern)
Marquardt, Christoph Dirk (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Eksternt finansieret virksomhed
Project: PhD

---

**Coherent Coupling of a Nitrogen-Vacancy Center to Gap Modes in Integrated 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

---

**Continuous variable quantum metrology and information processing**
Department of Physics
Integrated quantum sensing with squeezed light

Department of Physics
Period: 01/08/2011 → 19/06/2015
Number of participants: 5
Phd Student:
Hoff, Ulrich Busk (Intern)
Main Supervisor:
Andersen, Ulrik Lund (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Dantan, Aurélien (Ekstern)
Fabre, Claude (Ekstern)

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

Relations
Publications:
Integrated Quantum Optics: Experiments towards integrated quantum-light sources and quantum-enhanced sensing
Project: PhD

Quantum Information Processing with Schrödinger Cat States

Department of Physics
Period: 15/03/2010 → 30/08/2013
Number of participants: 5
Phd Student:
Laghaout, Amine (Intern)
Main Supervisor:
Andersen, Ulrik Lund (Intern)
Examiner:
Brusch, Anders (Ekstern)
Bourennane, Mohamed (Ekstern)
Marquardt, Christoph Dirk (Ekstern)

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

Optical quantum feedback systems for applications in biosensing and quantum information processing

Department of Physics
Period: 01/11/2009 → 30/04/2012
Number of participants: 5
Phd Student:
Usuga Castaneda, Mario A. (Intern)
Main Supervisor:
Andersen, Ulrik Lund (Intern)
Examiner:
Hansen, Jørn Otto Bindslev (Ekstern)
Korolkova, Natalia (Ekstern)
Thomsen, Jan Westenkær (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: 1/3 DTU-stip, 2/3 FUR/andet
Project: PhD

Quantum information processing with mesoscopic photonic states
Department of Physics
Period: 01/05/2009 → 25/10/2012
Number of participants: 5
Phd Student:
Madsen, Lars Skovgaard (Intern)
Main Supervisor:
Andersen, Ulrik Lund (Intern)
Examiner:
Hald, Jan (Ekstern)
Paris, Matteo G. A. (Ekstern)
Schnabel, Roman (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Anden EU-finansiering
Project: PhD

Strong nonlinear effects in a diamond-plasmon system
Department of Physics
Period: 01/02/2009 → 28/09/2012
Number of participants: 5
Phd Student:
Kumar, Shailesh (Intern)
Main Supervisor:
Andersen, Ulrik Lund (Intern)
Examiner:
Wubs, Martijn (Intern)
Benson, Oliver (Ekstern)
Lodahl, Peter (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Eksternt finansieret virksomhed
Project: PhD

Generation of Optical Shrödinger Cat-States
Department of Physics
Period: 01/01/2009 → 21/06/2012
Number of participants: 6
Phd Student:
Tipsmark, Anders (Intern)
Supervisor:
Tidemand-Lichtenberg, Peter (Intern)
Main Supervisor:
Andersen, Ulrik Lund (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Chekhova, Maria V. (Ekstern)
Filip, Radim (Ekstern)

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

Strongly coupled diamond-plasmon system using nanowires
Department of Physics
Period: 01/08/2008 → 01/03/2010
Number of participants: 4
PhD Student:
Shakoor, Abdul (Intern)
Supervisor:
Hansen, Jørn Otto Bindslev (Ekstern)
Andersen, Ulrik Lund (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Eksternt finansieret virksomhed
Project: PhD

Fotonisk Krystal en-fotonkileder
Department of Photonics Engineering
Period: 15/04/2008 → 24/08/2011
Number of participants: 5
PhD Student:
Nielsen, Henri Thyrrestrup (Intern)
Main Supervisor:
Lodahl, Peter (Intern)
Examiner:
Mortensen, N. Asger (Intern)
Andersen, Ulrik Lund (Intern)
Vos, Willem L. (Ekstern)

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

Quantum Optics in Nano-Structured Materials
Department of Photonics Engineering
Period: 01/07/2007 → 29/09/2010
Number of participants: 6
PhD Student:
Smolka, Stephan (Intern)
Supervisor:
Andersen, Ulrik Lund (Intern)
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
Source: Internal funding (public)
Name of research programme: DTU-lønnet stipendie
Project: PhD

Reduktion af kvantefluktuationer ved brug af optiske X(2)-processer

Department of Physics
Period: 01/09/1999 → 06/03/2003
Number of participants: 5
Phd Student:
Andersen, Ulrik Lund (Intern)
Main Supervisor:
Buchhave, Preben (Intern)
Examiner:
Tromborg, Bjarne (Intern)
Leuchs, Gerd (Ekstern)
Polzik, Eugene (Ekstern)

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

Activities:

International Conference on Quantum Information Processing and Communication
Period: 21 Sep 2009 → 25 Sep 2009
Ulrik Lund Andersen (Speaker)
Department of Physics
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. 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.