Quantitative evaluation of standard deviations of group velocity dispersion in optical fibre using parametric amplification

A numerical model for parametric amplifiers, which include stochastic variations of the group velocity dispersion (GVD), is presented. The impact on the gain is investigated, both with respect to the magnitude of the variations and by the effect caused by changing the wavelength of the pump. It is demonstrated that the described model is able to predict the experimental results and thereby provide a quantitative evaluation of the standard deviation of the GVD. For the investigated fibre, a standard deviation of 0.01 ps/(nm km) was found.

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Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects
Contributors: Rishøj, L. S., Svane, A. S., Lund-Hansen, T., Rottwitt, K.
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Experimental investigation of saturation effect on pump-to-signal intensity modulation transfer in single-pump phase-insensitive fiber optic parametric amplifiers

We present an experimental characterization of how signal gain saturation affects the transfer of intensity modulation from the pump to the signal in single-pump, phase-insensitive fiber optic parametric amplifiers (FOPAs). In this work, we demonstrate experimentally for the first time, to our knowledge, how gain saturation of a FOPA reduces the noise contribution due to the transfer of pump power fluctuations to the signal. In a particular example, it is shown that the transferred noise is significantly reduced by a factor of 3, while the FOPA gain remains above 10 dB.

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Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, High-Speed Optical Communication, Nanophotonics
Contributors: Cristofori, V., Lali-Dastjerdi, Z., Lund-Hansen, T., Peucheret, C., Rottwitt, K.
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Original language: English
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Pump-To-Signal Intensity Modulation Transfer Characteristics in FOPAs: Modulation Frequency and Saturation Effect
This paper reports a comprehensive study of pump-to-signal intensity modulation transfer (IMT) in single-pump fiber optic parametric amplifiers (FOPAs). In particular, the IMT is studied for the first time for high-frequency fluctuations of the pump as well as in the saturated gain regime. The IMT cut-off frequency in typical single-pump FOPAs is around 100–200 GHz. The possibilities to shift this frequency based on dispersion and nonlinearities involved in the parametric gain are discussed. The severe IMT to the signal at low modulation frequencies can be suppressed by more than 50% in the gain saturation regime with respect to the linear gain operation. Experimental results confirm the validity of the numerical study.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, High-Speed Optical Communication, Fiber Optics, Devices and Non-linear Effects, Nanophotonics
Contributors: Lali-Dastjerdi, Z., Cristofori, V., Lund-Hansen, T., Rottwitt, K., Gallili, M., Peucheret, C.
Pages: 3061-3067
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Keywords: Optical fiber, Four-wave mixing, Optical parametric amplifiers, Intensity modulation, Optical saturation
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Experimental Investigation of Pump-to-Signal Noise Transfer in One-Pump Phase Insensitive Fibre Optic Parametric Amplifiers
This paper presents a detailed experimental characterization of the relative intensity noise (RIN) transferred from the pump to the signal in one-pump phase insensitive fibre optic parametric amplifiers. We extend an existing experimental and theoretical work towards higher frequencies, showing for the first time a strong wavelength dependence of the RIN transfer over a 30 GHz modulation frequency range. Good agreement is obtained between the measured RIN transfer and the predictions of a simple theoretical model.

General information
Publication status: Published
Organisations: Fiber Optics, Devices and Non-linear Effects, Department of Photonics Engineering, High-Speed Optical Communication
Contributors: Cristofori, V., Lund-Hansen, T., Peucheret, C., Rottwitt, K.
Pages: Tu.C1.4
Publication date: 2011
Extinction Ratio and Gain Optimization of Dual-Pump Degenerate-Idler Phase Sensitive Amplifiers

Numerical optimization of dual-pump degenerate-idler phase sensitive amplifiers is performed for Al-doped and standard highly nonlinear fibers. Design considerations for operating the PSAs at an optimum combination of gain and extinction ratio are discussed.

High-Frequency RIN Transfer in Fibre Optic Parametric Amplifiers

Fibre optic parametric amplifiers (FOPAs) are versatile devices for amplification at arbitrary wavelengths, as well as a wide range of optical signal processing applications, including switching, wavelength conversion, regeneraton, pulse generation etc [1]. Transfer of intensity fluctuations from the pump to the signal (hereafter referred to as relative intensity noise transfer, RINT) affects the quality of the amplified signal due to the pump power dependence of the gain and the ultrafast nature of the Kerr nonlinearity [1–4]. For high-speed signal processing applications, the pump may be modulated at several hundreds of GHz or Gbit/s and it is therefore important to quantify the RINT at such high frequencies. To the best of our knowledge, the frequency dependence of pump-to-signal RINT has only been investigated theoretically and experimentally in single-pump FOPAs for low intensity modulation frequencies (IMFs) (
Low-loss tunable all-in-fiber filter for Raman spectroscopy

We show a novel in-line Rayleigh-rejection filter for Raman spectroscopy, based on a solid-core Photonic Crystal Fiber (PCF) filled with a high-index material. The device is low-loss and thermally tunable, and allows for a strong attenuation of the Rayleigh line at 532nm and the transmission of the Raman lines in a broad wavenumber range.

General information
Publication status: Published
Organisations: Fiber Optics, Devices and Non-linear Effects, Department of Photonics Engineering
Contributors: Brunetti, A. C., Scolari, L., Lund-Hansen, T., Rottwitt, K.
Pages: SWA3
Publication date: 2011

Non-Markovian spontaneous emission from a single quantum dot

We observe non-Markovian dynamics of a single quantum dot when tuned into resonance with a cavity mode. Excellent agreement between experiment and theory is observed providing the first quantitative description of such a system.

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Publication status: Published
Organisations: Quantum and Laser Photonics, Department of Photonics Engineering, Universität Würzburg
Pages: FThE2
Publication date: 2011
Observation of non-Markovian dynamics of a single quantum dot in a micropillar cavity
We measure the detuning-dependent dynamics of a quasi-resonantly excited single quantum dot coupled to a micropillar cavity, and under resonant conditions we observe non-Markovian dynamics leading to nonexponential decays in time.

General information
Publication status: Published
Organisations: Quantum Photonics, Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Universität Würzburg
Pages: EA2.3 SUN
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Publisher: IEEE
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URLs:
http://www.cleoeurope.org/
Source: orbit
Source-ID: 277369
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2011 › Research › peer-review

Observation of Non-Markovian Dynamics of a Single Quantum Dot in a Micropillar Cavity
We measure the detuning-dependent dynamics of a quasiresonantly excited single quantum dot coupled to a micropillar cavity. The system is modeled with the dissipative Jaynes-Cummings model where all experimental parameters are determined by explicit measurements. We observe non-Markovian dynamics when the quantum dot is tuned into resonance with the cavity leading to a nonexponential decay in time. Excellent agreement between experiment and theory is observed with no free parameters providing the first quantitative description of an all-solid-state cavity QED system based on quantum dot emitters.

General information
Publication status: Published
Organisations: Quantum Photonics, Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Universität Würzburg
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Scopus rating (2011): CiteScore 7.02 SJR 6.314 SNIP 2.911
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
Original language: English
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Copyright (2011) American Physical Society.
Source: orbit
Pump-to-Signal Intensity Modulation Transfer in Saturated- Gain Fiber Optical Parametric Amplifiers

The pump-to-signal intensity modulation transfer in saturated degenerate FOPAs is numerically investigated over the whole gain bandwidth. The intensity modulation transfer decreases and the OSNR improves when the amplifier operates in the saturation regime.

Saturation Effect on Pump-to-Signal Intensity Modulation Transfer in Single-Pump Phase-Insensitive Fibre Optic Parametric Amplifiers

A numerical and experimental characterization of how signal gain saturation affects the transfer of the intensity modulation of the pump to the signal in single-pump phaseinsensitive fibre optic parametric amplifiers is presented.

Wavelength Conversion by Cascaded FWM in a Fiber Optical Parametric Oscillator

We report on a continuous-wave fiber optical parametric oscillator utilizing selective filtering on cascade four wave mixing (CFWM). Oscillations of distinct CFWM terms are obtained, extending wavelength conversion outside the parametric gain region.
Pump to signal noise transfer in parametric fiber amplifiers: [invited]

Fiber optic parametric amplifiers have been suggested due to their potential low spontaneous emission. However, by nature the parametric amplifier only work in a forward pumped configuration, which result in transfer of relative intensity noise in the pump to the signal.

Time-resolved spectroscopy of quantum dot single-photon sources

Coherent optical spectroscopy of a single quantum dot (non)-resonantly coupled to a high-q microcavity
Publication date: 2009

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Title of host publication: Workshop proceedings
Place of publication: Turun, Turkey
Source: orbit
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Research output: Chapter in Book/Report/Conference proceeding – Annual report year: 2009 – Research: peer-review

Direct measurement of the coupling between a single quantum dot and a photonic crystal waveguide by temperature tuning

General information
Publication status: Published
Organisations: Quantum Photonics, Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects
Contributors: Nielsen, H. T., Lund-Hansen, T., Lodahl, P.
Publication date: 2009

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Title of host publication: Proceedings, PECS VIII
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Source-ID: 251741
Research output: Chapter in Book/Report/Conference proceeding – Annual report year: 2009 – Research: peer-review

Sub-threshold investigation of two coupled photonic crystal cavities
The behavior of two coupled photonic crystal membrane cavities with quantum dots separated by different number of holes is investigated. The measured spectral splitting with increased coupling is verified by 3D calculations and discussed.

General information
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Organisations: Nanophotonic Devices, Department of Photonics Engineering, Quantum and Laser Photonics, Quantum Photonics, Technische Universität München
Number of pages: 183
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Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 2009 – Research: peer-review

Sub-threshold wavelength splitting in coupled photonic crystal cavity arrays
Coupled photonic crystal (PhC) cavity arrays have recently been found to increase the output power of nanocavity lasers by coherent coupling of a large number of cavities [1]. We have measured the sub-threshold behaviour of such structures in order to gain better understanding of the mode structure. PhC structures defined by circular holes placed in a quadratic lattice with pitch \( a = 280 \text{ nm} \) were fabricated in a GaAs membrane and cavity arrays were realized by introducing single missing holes with intracavity hole distances of two, three, five and seven holes. Arrays with different number of coupled cavities were fabricated and characterized using photoluminescence measurements of quantum dots embedded in the GaAs PhC membrane. Since the collection spot size was \( \sim 2.5 \text{ μm} \) and therefore small compared to the arrays, spectra
were taken at several positions of each array.

**Tuning the coupling of a single quantum dot to a photonic crystal waveguide**

We present time-resolved spontaneous emission measurements of a single quantum dot that is temperature tuned around the band edge of a photonic crystal waveguide. 85% efficient coupling to the slow-light waveguide mode is obtained.

**Coupling of single quantum dots to a photonic crystal waveguide**

Efficient and high quality single-photon sources is a key element in quantum information processing using photons. As a consequence, much current research is focused on realizing all-solid-state nanophotonic single-photon sources. Single photons can be harvested with high efficiency if the emitter is coupled efficiently to a single enhanced mode. One popular approach has been to couple single quantum dots to a nanocavity but a limiting factor in this configuration is that in order to apply the photon it should subsequently be coupled out of the cavity, reducing the overall efficiency significantly. An alternative approach is to couple the quantum dot directly to the propagating mode of a photonic waveguide. We demonstrate the coupling of single quantum dots to a photonic crystal waveguide using time-resolved spontaneous emission measurements. A pronounced effect is seen in the decay rates of dots coupled to the waveguide compared to dots not coupled to the waveguide. The frequency dependence of the coupling is compared to theoretical calculations and a good agreement is found. From the decay rates the efficiency of emission into the waveguide mode is estimated and values from 50% to 90% are found demonstrating the high efficiency of the coupling.
Efficient radiative coupling of single quantum dots to a photonic crystal waveguide
We present time-resolved spontaneous emission measurements of quantum dots in photonic crystal waveguides. Pronounced decay enhancement is observed for quantum dots coupled to the waveguides.

Efficient radiative coupling of single quantum dots to a photonic crystal waveguide
We present time-resolved spontaneous emission measurements of quantum dots in photonic crystal waveguides. Pronounced decay enhancement is observed for quantum dots coupled to the waveguides.

Experimental realization of highly efficient broadband coupling of single quantum dots to a photonic crystal waveguide
We present time-resolved spontaneous emission measurements of single quantum dots embedded in photonic crystal waveguides. Quantum dots that couple to a photonic crystal waveguide are found to decay up to 27 times faster than uncoupled quantum dots. From these measurements -factors of up to 0.89 are derived, and an unprecedented large bandwidth of 20 nm is demonstrated. This shows the promising potential of photonic crystal waveguides for efficient single-photon sources. The scaled frequency range over which the enhancement is observed is in excellent agreement with recent theoretical proposals taking into account that the light-matter coupling is strongly enhanced due to the significant slow-down of light in the photonic crystal waveguides.
**Fabrication and measurements on coupled photonic crystal cavities**

Quasi-three dimensional photonic crystals can be realized by fabricating thin membranes of high index material hanging in air patterned with sub-micron holes to create a photonic band gap for optical confinement in plane and total internal reflection for out of plane confinement. Introducing defects into the photonic crystal gives rise to defect states in the form of small confined modes. By embedding an active gain medium like quantum dots into the membrane makes it possible to realize lasers with ultra-small mode volumes and low thresholds. Unfortunately single cavity photonic crystal lasers have also a low output power. A promising way to increase the output power while keeping a low threshold is to couple a large number of cavities. We successfully fabricated several coupled cavity systems and measured on them in order to investigate the behaviour of the coupled systems and the interaction between coupled cavities depending on their relative coupling to each other.

**General information**

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Organisations: Nanophotonic Devices, Department of Photonics Engineering, Quantum Photonics, Quantum and Laser Photonics
Publication date: 2008
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Event: Poster session presented at DOPS Årsmøde, Nyborg, Denmark.
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Source-ID: 228126

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**Size dependence of the wavefunction of self-assembled InAs quantum dots from time-resolved optical measurements**

The radiative and nonradiative decay rates of InAs quantum dots are measured by controlling the local density of optical states near an interface. From time-resolved measurements, we extract the oscillator strength and the quantum efficiency and their dependence on emission energy. From our results and a theoretical model, we determine the striking dependence of the overlap of the electron and hole wavefunctions on the quantum dot size. We conclude that the optical quality is best for large quantum dots, which is important in order to optimally tailor quantum dot emitters for, e.g., quantum electrodynamics experiments.

**General information**

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Web of Science (2008): Indexed yes
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Stobbe.pdf
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**Bibliographical note**

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Accurate measurement of the transition dipole moment of self-assembled quantum dots

Here we present quantitative measurements of the dipole moment of an ensemble of self-assembled quantum dots employing a modified optical local density of states (LDOS). The LDOS is controlled by varying the distance from the QDs to a semiconductor/air interface.

Detailed investigation of spontaneous emission decay rates of self-assembled InAs quantum dots

Dynamic and spontaneous emission from quantum dots coupled to a photonic crystal nano-cavity
Investigating spontaneous emission from quantum dots coupled to a photonic crystal cavity

General information
Publication status: Published
Organisations: Nanophotonics, Department of Photonics Engineering
Contributors: Nielsen, H., Lund-Hansen, T., Julsgaard, B., Lodahl, P.
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Event: Abstract from 3rd Annual meeting Danish Physical Society, Nyborg, Denmark.
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Research output: Contribution to conference › Conference abstract for conference – Annual report year: 2007 › Research › peer-review

Investigating spontaneous emission from quantum dots to a photonic crystal cavity

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Organisations: Nanophotonics, Department of Photonics Engineering
Contributors: Nielsen, H., Lund-Hansen, T., Julsgaard, B., Lodahl, P.
Publication date: 2007
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Event: Abstract from 3rd Annual meeting Danish Physical Society, Nyborg, Denmark.
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Source-ID: 205481
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Measuring dipole moment and quantum efficiency of self-assembled InAs/GaAs quantum dots using a modified electromagnetic vacuum

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Publication date: 2007
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Event: Abstract from 3rd Annual meeting Danish Physical Society, Nyborg, Denmark.
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Quantum efficiency of self-assembled quantum dots determined by a modified optical local density of states
We have measured time-resolved spontaneous emission from quantum dots near a dielectric interface with known photonic local density of states. We thus experimentally determine the quantum efficiency and the dipole moment, important for quantum optics.

General information
Publication status: Published
Organisations: Nanophotonics, Department of Photonics Engineering
Pages: 1-2
Publication date: 2007

Host publication information
Title of host publication: Proceedings CLEO/QELS
Publisher: IEEE
ISBN (Print): 978-1-55752-834-6
Time- and energy-resolved measurements of spontaneous emission from ordered quantum dots

Highly Efficient Spontaneous Emission from Self-Assembled Quantum Dots

Investigating and manipulating the light-matter interaction of self-assembled semiconductor quantum dots