Dispersion tailoring of a silicon strip waveguide employing Titania-Alumina thin-film coating
We numerically demonstrate dispersion tailoring of a silicon strip waveguide employing Titania-Alumina thin-film coating using a finite-difference mode solver. The proposed structure exhibits spectrally-flattened near-zero anomalous dispersion within the telecom wavelength range. We also numerically predict the wavelength conversion efficiency for degenerate four-wave mixing, and obtain a 3 dB bandwidth of 80 nm.
All-fiber photon-pair source at telecom wavelengths

Single photon sources are a key element for quantum computing, quantum key distribution (QKD) and quantum communications. In particular, producing single photons at telecommunications wavelengths is valuable for QKD protocols and would enable realizing the quantum internet. The preferred method for their generation has long been spontaneous down conversion in bulk crystals, which suffers from connection loss to fiber networks. In-fiber spontaneous four-wave mixing provides a viable alternative as a photon pair source due to being compatible with existing fiber networks. We present an all-fiber photon pair source based on degenerate four-wave mixing in a 400 m Highly-Nonlinear fiber, with signal and idler wavelengths generated at 1552.5 nm and 1557 nm respectively. The source consists of CW pump laser operating at 1554.75 nm, which is slightly detuned from the zero group velocity dispersion wavelength into the normal dispersion regime. After pair generation in the highly-nonlinear fiber, three arrayed waveguide gratings are employed to spatially separate signal and idler, and provides a 120 dB pump power reduction. Firstly the source is modelled and experimentally characterized in the well known classical regime of stimulated four-wave mixing. The effect of fiber cooling on spontaneous Raman scattering is modelled and characterized, and a 30% reduction in spontaneous emission is found when cooling the fiber to ~77 °C. In the low power regime the coincidence to accidental count ratio is simulated and measured. An increase in the coincidence to accidental count ratio is observed when cooling the fiber.
Azimuthal asymmetry in HE11,X modes analyzed
An analytical study of higher-order modes in step-index fibers has been conducted with the aim of justifying the circular asymmetry experimentally observed in the intensity of higher-order Bessel-like modes.

Decoy-state BB84 protocol using space division multiplexing in silicon photonics
Quantum key distribution (QKD), a technique based on quantum physics, provides unconditional secure quantum keys to be shared between two or more clients (Alice and Bob) [1]. Most QKD systems are implemented in a point-to-point link using bulky and expensive devices. Consequently a large scale deployment of this technology has not been achieved. A solution may be integrated photonic circuits, which provide excellent performances (compact, good optical phase stability, new degrees of freedom), and are particularly suitable for the manipulation of quantum states in compact chips. Some recent experiments have already demonstrated conventional binary QKD systems, using polarization and phase reference degrees of freedom [2, 3]. In this paper, we show the first silicon chip-to-chip decoy-state BB84 protocol based on spatial degrees of freedom (the cores of a multi-core fiber-MCF.). By tuning cascaded Mach-Zehnder interferometers (MZIs), it is possible to prepare the quantum states in two mutually unbiased basis (MUBs) sets: basis X = {A, B}, and basis Z = {A + B, A − B}. A and B are the quantum states related to two individual cores of the MCF, while A + B and A − B represent the superposition of the quantum state between cores, combined with a positive/negative phase relation. A train of weak coherent pulses (5 kHz repetition and 10 ns wide) are injected into the transmitter chip (Alice), where multiple variable optical attenuators (VOAs) are used to decrease the number of photons per pulse (μ < 1) [4]. Moreover, by using a combination of MZIs and VOAs, a decoy state-technique is implemented. Alice, by using an FPGA board, (Fig. 1(a)) randomly chooses one of the two bases and one of the two states to transmit to Bob. The qubits are matched to two cores of a multi-core fiber, through a highly efficient MCF grating coupler. After 3 meters link, the quantum states are coupled into Bob's chip (Fig. 1(a)) through the MCF coupler, and randomly measured in one of the two bases. In the subsequent distillation process, counts measured in the wrong basis are discarded. In Fig. 1(b) and (c) the experimental data acquired within 11 minutes of measurement. In particular, Fig. 1(b) shows the gain of the decoy state technique (Qu). In Fig. 1(c) a stable bit error rate, well below the threshold limit for coherent attacks of 11%, is measured for more than 11 minutes.
Determining the group velocity dispersion by field analysis for the LP0X, LP1X, and LP2X mode groups independently of the fiber length: applications to step-index fibers

By knowing the electric field distribution of a guided mode in an optical fiber, we are able to evaluate the group velocity dispersion in a weakly guiding step-index fiber for a pure mode in the LP0X, LP1X, and LP2X mode groups independently of the fiber length. We demonstrate the method numerically for all three mode groups.
Effects of noninstantaneous nonlinear processes on photon-pair generation by spontaneous four-wave mixing

We present a general model, based on a Hamiltonian approach, for the joint quantum state of photon pairs generated through pulsed spontaneous four-wave mixing, including nonlinear phase modulation and a finite material response time. For the case of a silica fiber, it is found that the pair-production rate depends weakly on the waveguide temperature, due to higher-order Raman scattering events, and more strongly on pump-pair frequency detuning. From the analytical model, a numerical scheme is derived, based on the well-known split-step method. This scheme allows computation of joint states where nontrivial effects are included, such as group-velocity dispersion and Raman scattering. In this work, the numerical model is used to study the impact of the noninstantaneous response on the prefiltering purity of heralded single photons. We find that for pump pulses shorter than 1 ps, a significant detuning-dependent change in quantum-mechanical purity may be observed in silica. This shows that Raman scattering not only introduces noise, but can also drastically change the spectral correlations in photon pairs when pumped with short pulses.
Effects of Raman scattering and attenuation in silica fiber-based parametric frequency conversion

Four-wave mixing in the form of Bragg scattering (BS) has been predicted to enable quantum noise-less frequency conversion by analytic quantum approaches. Using a semi-classical description of quantum noise that accounts for loss and stimulated and spontaneous Raman scattering, which are not currently described in existing quantum approaches, we quantify the impacts of these effects on the conversion efficiency and on the quantum noise properties of BS in terms of an induced noise figure (NF). We give an approximate closed-form expression for the BS conversion efficiency that includes loss and stimulated Raman scattering, and we derive explicit expressions for the Raman-induced NF from the semi-classical approach used here. We find that Raman scattering induces a NF in the BS process that is comparable to the 3-dB NF associated with linear amplifiers.
Fiber Amplifiers

The chapter provides a discussion of optical fiber amplifiers and through three sections provides a detailed treatment of three types of optical fiber amplifiers, erbium doped fiber amplifiers (EDFA), Raman amplifiers, and parametric amplifiers. Each section comprises the fundamentals including the basic physics and relevant in-depth theoretical modeling, amplifiers characteristics and performance data as a function of specific operation parameters. Typical applications in fiber optic communication systems and the improvement achievable through the use of fiber amplifiers are illustrated.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Centre of Excellence for Silicon Photonics for Optical Communications
Authors: Rottwitt, K. (Intern)
Pages: 585-627
Publication date: 2017

Host publication information
Title of host publication: Fibre Optic Communication
Publisher: Springer
Flexible cross-correlated (C2) imaging method for the modal content characterization in a broad range of wavelengths

We demonstrate a flexible cross-correlated (C2) imaging method in the time domain by application of a tunable and highly flexible light source. An advantage of the flexible C2 method is shown by characterization of the step-index fiber (SMF28) over a broad range of wavelengths from 870nm to 1090nm and by the modal analysis of the distributed modal filtering (DMF) rod fiber within a wavelength range from 1050nm to 1090nm. Also, the influence of the spectral shape and bandwidth on the imaging trace is investigated by deliberately adjusting the input spectrum of the light source. The modal intensity as well as the phase distribution are extracted by the alternative method of 2D FT filtering. Being exceptionally tunable the flexible C2 method gives an ability to adapt the system's parameters in a desired manner satisfying even measurements of very specific fiber designs opening up new possibilities for advanced modal characterization of fibers over broad range of wavelengths.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Centre of Excellence for Silicon Photonics for Optical Communications, NKT Photonics A/S
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Pages: 5521-5535
Publication date: 2017
Main Research Area: Technical/natural sciences

Publication information
Journal: Optics Express
Volume: 25
Issue number: 5
Article number: 281618
ISSN (Print): 1094-4087
Ratings:
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
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.587 SNIP 2.145 CiteScore 3.85
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.579 SNIP 2.606 CiteScore 4.04
We derive from Maxwell's equations full-vectorial nonlinear propagation equations of four-wave mixing valid in straight semiconductor-on-insulator waveguides. Special attention is given to the resulting effective mode area, which takes a convenient form known from studies in photonic crystal fibers, but has not been introduced in the context of integrated waveguides. We show that the difference between our full-vectorial effective mode area and the scalar equivalent often referred to in the literature may lead to mistakes when evaluating the nonlinear refractive index and optimizing designs of new waveguides. We verify the results of our derivation by comparing it to experimental measurements in a silicon-on-insulator waveguide, taking tolerances on fabrication parameters into account. (C) 2017 Optical Society of America

Full-vectorial propagation model and modified effective mode area of four-wave mixing in straight waveguides

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<tr>
<th>State</th>
<th>Published</th>
</tr>
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<tr>
<td>Organisations</td>
<td>Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Centre of Excellence for Silicon Photonics for Optical Communications, Nanophotonic Devices, High-Speed Optical Communication, Diode Lasers and LED Systems, National University of Defense Technology, Technical University of Denmark</td>
</tr>
<tr>
<td>Authors</td>
<td>Guo, K. (Ekstern), Friis, S. M. M. (Intern), Christensen, J. B. (Intern), Christensen, E. N. (Intern), Shi, X. (Ekstern), Ding, Y. (Intern), Ou, H. (Intern), Rottwitt, K. (Intern)</td>
</tr>
<tr>
<td>Pages</td>
<td>3670-3673</td>
</tr>
<tr>
<td>Publication date</td>
<td>2017</td>
</tr>
<tr>
<td>Main Research Area</td>
<td>Technical/natural sciences</td>
</tr>
</tbody>
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Generation of two-temporal-mode photon states by vector four-wave mixing

Photon pair states and multiple-photon squeezed states have many applications in quantum information science. In this paper, Green functions are derived for spontaneous four-wave mixing in the low-and high-gain regimes. Nondegenerate four-wave mixing in a strongly-birefringent medium generates signal and idler photons that are associated with only one pair of temporal (Schmidt) modes, for a wide range of pump powers and arbitrary pump shapes. The Schmidt coefficients (expected photon numbers) depend sensitively on the pump powers, and the Schmidt functions (shapes of the photon wavepackets) depend sensitively on the pump powers and shapes, which can be controlled. (C) 2017 Optical Society of America
High coincidence-to-accidental ratio continuous-wave photon-pair generation in a grating-coupled silicon strip waveguide: 
Letters
We demonstrate a very high coincidence-to-accidental ratio of 673 using continuous-wave photon-pair generation in a silicon strip waveguide through spontaneous four-wave mixing. This result is obtained by employing on-chip photonic-crystal-based grating couplers for both low-loss fiber-to-chip coupling and on-chip suppression of generated spontaneous Raman scattering noise. We measure a minimum heralded second-order correlation of \(g(2) = 0.12\), demonstrating that our source operates in the single-photon regime with low noise. (C) 2017 The Japan Society of Applied Physics

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Centre of Excellence for Silicon Photonics for Optical Communications, High-Speed Optical Communication, Nanophotonic Devices, Diode Lasers and LED Systems, National University of Defense Technology
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Number of pages: 5
Publication date: 2017
Main Research Area: Technical/natural sciences

Publication information
Journal: Applied Physics Express
Volume: 10
Issue number: 6
Article number: 062801
ISSN (Print): 1882-0778
Ratings:
BFI (2017): BFI-level 1
High-dimensional quantum key distribution based on multicore fiber using silicon photonic integrated circuits

Quantum key distribution provides an efficient means to exchange information in an unconditionally secure way. Historically, quantum key distribution protocols have been based on binary signal formats, such as two polarization states, and the transmitted information efficiency of the quantum key is intrinsically limited to 1 bit/photon. Here we propose and experimentally demonstrate, for the first time, a high-dimensional quantum key distribution protocol based on space division multiplexing in multicore fiber using silicon photonic integrated lightwave circuits. We successfully realized three mutually unbiased bases in a four-dimensional Hilbert space, and achieved low and stable quantum bit error rate well below both the coherent attack and individual attack limits. Compared to previous demonstrations, the use of a multicore fiber in our protocol provides a much more efficient way to create high-dimensional quantum states, and enables breaking the information efficiency limit of traditional quantum key distribution protocols. In addition, the silicon photonic circuits used in our work integrate variable optical attenuators, highly efficient multicore fiber couplers, and Mach-Zehnder interferometers, enabling manipulating high-dimensional quantum states in a compact and stable manner. Our demonstration paves the way to utilize state-of-the-art multicore fibers for noise tolerance high-dimensional quantum key distribution, and boost silicon photonics for high information efficiency quantum communications.
High precision Cross-correlated imaging in Few-mode fibers

The trend of increasing data traffic in conventional communication systems demands utilizing new methods for data transmission, which in combination with traditional techniques, enable overcoming the predicted capacity limit. Mode division multiplexing (MDM), where higher-order modes (HOMs) in a few-mode fiber (FMF) are used as multiple spatial communication channels, comes in this context as a viable approach to enable the optimization of high-capacity links. From this perspective, it becomes highly necessary to possess a diagnostic tool for the precise modal characterization of FMFs. Among existing approaches for modal content analysis, several methods as S2, C2 in time and frequency domain are available. In this contribution we will present an improved time-domain cross-correlated (C2) imaging technique for the experimental evaluation of modal properties in HOM fibers over a broad range of wavelengths. Our modified setup makes it possible to adjust the time resolution of the system according to the needs of the required fiber measurement. We show that by tuning the spectral shape of the source (SuperK EXTREME filtered by SuperK Select), we enhance the time resolution of the system, which allows us to distinguishing differential time delays between HOMs in the picosecond timescale. Broad wavelength scanning in combination with spectral shaping, allows us to estimate the modal behavior of FMF without prior knowledge of the fiber parameters. We performed our demonstration at wavelengths from 850nm to 1100nm which can be easily extended to other wavelengths of interest just by replacing components with the appropriate coating. The method presented here aims to serve as flexible diagnostic tool that can be implemented in MDM systems for judicious evaluation of modal dispersion in FMFs.
Raman amplification of OAM modes

The set of fibre modes carrying orbital angular momentum (OAM) is a possible basis for mode division multiplexing. In this regard, fibres supporting OAM modes have been fabricated [1], and optical communication using these fibres, has been demonstrated [2]. A vital part of any long range communication system is an optical amplifier. Here we demonstrate, for the first time, Raman amplification of OAM modes.

Space division multiplexing chip-to-chip quantum key distribution

Quantum cryptography is set to become a key technology for future secure communications. However, to get maximum benefit in communication networks, transmission links will need to be shared among several quantum keys for several independent users. Such links will enable switching in quantum network nodes of the quantum keys to their respective destinations. In this paper we present an experimental demonstration of a photonic integrated silicon chip quantum key distribution protocols based on space division multiplexing (SDM), through multicore fiber technology. Parallel and independent quantum keys are obtained, which are useful in crypto-systems and future quantum network.
Spectrally pure heralded single photons by spontaneous four-wave mixing in a fiber: reducing impact of dispersion fluctuations

We model the spectral quantum-mechanical purity of heralded single photons from a photon-pair source based on nondegenerate spontaneous four-wave mixing taking the impact of distributed dispersion fluctuations into account. The considered photon-pair-generation scheme utilizes pump-pulse walk-off to produce pure heralded photons and phase matching is achieved through the dispersion properties of distinct spatial modes in a few-mode silica step-index fiber. We show that fiber-core-radius fluctuations in general severely impact the single-photon purity. Furthermore, by optimizing the fiber design we show that generation of single photons with very high spectral purity is feasible even in the presence of large core-radius fluctuations. At the same time, contamination from spontaneous Raman scattering is greatly mitigated by separating the single-photon frequency by more than 32 THz from the pump frequency. (C) 2017 Optical Society of America

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Centre of Excellence for Silicon Photonics for Optical Communications
Authors: Koefoed, J. G. (Intern), Friis, S. M. M. (Intern), Christensen, J. B. (Intern), Rottwitt, K. (Intern)
Pages: 20835-20849
Publication date: 2017
Main Research Area: Technical/natural sciences

Publication information
Journal: Optics Express
Volume: 25
Issue number: 17
ISSN (Print): 1094-4087
Ratings:
Split-step scheme for photon-pair generation through spontaneous four-wave mixing

The rapid development of quantum information technology requires the ability to reliably create and distribute single photons [1]. Photon-pair production through spontaneous four-wave mixing (SpFWM) allows heralded single photons to be generated at communication wavelengths and in fiber, compatible with conventional communication systems, with small losses. Creating single photons in desired quantum states require careful design of waveguide structures. This is greatly facilitated by a general numerical approach as presented here. Additionally, such a numerical approach allows detailed analysis of real systems where all relevant effects are included.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Centre of Excellence for Silicon Photonics for Optical Communications
Authors: Koefoed, J. G. (Intern), Christensen, J. B. (Intern), Rottwitt, K. (Intern)
Number of pages: 1
Pages: 1-1
Publication date: 2017

Host publication information
Title of host publication: 2017 Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference
Publisher: IEEE
ISBN (Print): 9781509067367
Main Research Area: Technical/natural sciences
Conference: CLEO®/Europe-EQEC 2017, Munich, Germany, 25/06/2017 - 25/06/2017
Dispersion, Photonics, Four-wave mixing, Delays, Jacobian matrices, Information technology, Reliability engineering
DOIs:
10.1109/CLEOE-EQEC.2017.8087370
Source: FindIt
Source-ID: 2392694338
Publication: Research - peer-review › Article in proceedings – Annual report year: 2017

Study of Raman-free photon pair generation using inter-modal four-wave mixing in a few-mode silica fiber

Single-photon sources are key components in applications of photonic quantum technologies such as quantum key distribution (QKD) [1]. One way of realizing single-photon sources is generation of photon pairs (PP) using spontaneous four-wave mixing (FWM): two photons from a pump p annihilate and create two side-band photons at frequencies determined partly by the energy conservation 2ω = ω1 + ω2, where ωp,ω1,ω2 are the frequencies of the pump and the two side-bands, respectively, and partly by the phase-matching condition. PP generated spontaneously arrive at indeterministic times but even so, they are useful for QKD because one of the photons can be heralded by detecting the other. The heralded photons are then used for transmitting the quantum key.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Centre of Excellence for Silicon Photonics for Optical Communications
Authors: Friis, S. M. M. (Intern), Christensen, J. B. (Intern), Koefoed, J. G. (Intern), Rottwitt, K. (Intern)
Number of pages: 1
Pages: 1-1
Publication date: 2017

Host publication information
Title of host publication: 2017 Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference
Publisher: IEEE
ISBN (Print): 9781509067367
Main Research Area: Technical/natural sciences
Conference: CLEO®/Europe-EQEC 2017, Munich, Germany, 25/06/2017 - 25/06/2017
Photonics, Optical frequency conversion, Silicon compounds, Indexes, Refractive index, Four-wave mixing
DOIs:
10.1109/CLEOE-EQEC.2017.8086542
Source: FindIt
Temporal mode selectivity by frequency conversion in second-order nonlinear optical waveguides: Erratum (Optics Express (2013) 21 (13840-13863) DOI: 10.1364/OE.21.013840)

We correct typographical errors in four equations showing the integral forms of the equations of motion and the corresponding perturbative approximation. Subsequently presented derivations, results, and conclusions remain unchanged.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Centre of Excellence for Silicon Photonics for Optical Communications, University of Oregon, Applied Communication Sciences
Authors: Reddy, D. V. (Ekstern), Raymer, M. G. (Ekstern), Mckinstrie, C. J. (Ekstern), Andersen, L. M. (Intern), Rottwitt, K. (Intern)
Number of pages: 1
Pages: 7998
Publication date: 2017
Main Research Area: Technical/natural sciences

Publication information
Journal: Optics Express
Volume: 25
Issue number: 7
ISSN (Print): 1094-4087
Ratings:
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
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.587 SNIP 2.145 CiteScore 3.85
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.579 SNIP 2.606 CiteScore 4.04
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.943 SNIP 2.466
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 3.092 SNIP 2.669
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 3.195 SNIP 2.393
Temporal mode selectivity by frequency conversion in second-order nonlinear optical waveguides (vol 21, 13840-13863, 2013)

We correct typographical errors in four equations showing the integral forms of the equations of motion and the corresponding perturbative approximation. Subsequently presented derivations, results, and conclusions remain unchanged. (C) 2017 Optical Society of America

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Centre of Excellence for Silicon Photonics for Optical Communications, University of Oregon, Applied Communication Sciences
Authors: Reddy, D. V. (Ekstern), Raymer, M. G. (Ekstern), Mckinstrie, C. J. (Ekstern), Andersen, L. M. (Intern), Rottwitt, K. (Intern)
Pages: 7998-7998
Publication date: 2017
Main Research Area: Technical/natural sciences

Publication information
Journal: Optics Express
Volume: 25
Issue number: 7
ISSN (Print): 1094-4087
Ratings:
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
We suggest a new scheme to create chirped micro bend long period gratings. Employing this scheme, the bandwidth of mode conversion between LP01 to LP11 is increased 4.8-fold with a conversion efficiency of 20 dB. This scheme includes a first time demonstration of a non-linearly chirped long period grating. The scheme is investigated both numerically using coupled mode equations as well as experimentally. (C) 2016 Optical Society of America
Detailed phase matching characterization of inter-modal four-wave mixing in a two-mode fiber

We experimentally characterize the phase matching properties of two inter-modal four-wave mixing processes in a graded index fiber guiding the LP01 and LP11 mode-groups.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Centre of Excellence for Silicon Photonics for Optical Communications, University of Southampton
Authors: Friis, S. M. M. (Intern), Jung, Y. (Ekstern), Begleris, I. (Ekstern), Horak, P. (Ekstern), Rottwitt, K. (Intern), Petropoulos, P. (Ekstern), Richardson, D. (Ekstern), Parmigiani, F. (Ekstern)
Number of pages: 2
Publication date: 2016

Host publication information
Title of host publication: CLEO: Science and Innovations 2016
Publisher: Optical Society of America (OSA)
Article number: JTu5A.49
ISBN (Print): 978-1-943580-11-8
Main Research Area: Technical/natural sciences
Conference: Conference on Lasers and Electro-Optics 2016, San Jose, California, United States, 05/06/2016 - 05/06/2016
DOIs:
10.1364/CLEO_AT.2016.JTu5A.49

Bibliographical note
From the session: Poster Session - Tuesday (JT u5A)
Source: PublicationPreSubmission
Source-ID: 124009030
Publication: Research - peer-review » Article in proceedings – Annual report year: 2016

Differential phase-time shifting protocol for QKD (DPTS)
We explore the implementation of a novel protocol for fiber-based high-dimensional quantum key distribution (QKD) which improves over the traditional DPS-QKD and COW protocols.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Centre of Excellence for Silicon Photonics for Optical Communications, High-Speed Optical Communication, Nanophotonic Devices
Authors: Usuga Castaneda, M. A. (Intern), Bacco, D. (Intern), Christensen, J. B. (Intern), Ding, Y. (Intern), Rottwitt, K. (Intern), Oxenløwe, L. K. (Intern)
Number of pages: 2
Publication date: 2016

Host publication information
Title of host publication: Proceedings of QCMC 2016
Experimental characterization of Raman overlaps between mode-groups

Mode-division multiplexing has the potential to further increase data transmission capacity through optical fibers. In addition, distributed Raman amplification is a promising candidate for multi-mode signal amplification due to its desirable noise properties and the possibility of mode-equalized gain. In this paper, we present an experimental characterization of the intermodal Raman intensity overlaps of a few-mode fiber using backward-pumped Raman amplification. By varying the input pump power and the degree of higher order mode-excitation for the pump and the signal in a 10km long two-mode fiber, we are able to characterize all intermodal Raman intensity overlaps. Using these results, we perform a Raman amplification measurement and demonstrate a mode-differential gain of only 0.25dB per 10dB overall gain. This is, to the best of our knowledge, the lowest mode differential gain achieved for amplification of mode division multiplexed signals in a single fiber.
Generation of pure heralded single-photon states by cross-polarized spontaneous four-wave mixing

We propose a novel scheme which employs cross-polarized pumps to generate temporally and spectrally uncorrelated signal-idler photon-pairs through spontaneous four-wave mixing in a birefringent third-order nonlinear waveguide.

Lower Order Mode Fibers

This PhD thesis considers higher order modes (HOMs) in optical fibers. That includes their excitation and characteristics. Within the last decades, HOMs have been applied both for space multiplexing in optical communications, group velocity dispersion management and sensing among others. The research presented in this thesis falls in three parts. In the first part, a first time demonstration of the break of the azimuthal symmetry of the Bessel-like LP_{0X} modes is presented. This effect, known as the bowtie effect, causes the mode to have an azimuthal dependence as well as a quasi-radial polarization as opposed to the linear polarization of the LP_{0X} modes. The effect is investigated numerically in a double cladding fiber with an outer aircladding using a full vectorial modesolver. Experimentally, the bowtie modes are excited using a long period grating and their free space characteristics and polarization state are investigated. For this fiber, the onset of the bowtie effect is shown numerically to be LP_{011}. The characteristics usually associated with Bessel-likes modes such as long diffraction free length and selfhealing are shown to be conserved despite the lack of azimuthal symmetry. In the second part of the thesis, a new scheme for constructing chirped microbend long period gratings is presented. The method presents a versatile platform for tailoring the chirp to the phase matching profile of the targeted HOM conversion in the fiber under test. The scheme introduces the ability to implement a nonlinear chirp which is a first time demonstration. The results are modelled using coupled mode theory and it is shown that the conversion bandwidth may be increased more than four fold. In the final part of the thesis, imaging as a characterization tool for HOMs is considered. Three different characterization methods are considered. First, the divergence angle is introduced as a quality parameter to replace the conventional M^2 which compares the diffraction of the investigated fiber mode to that of a Gaussian and suffers from ambiguity when considering mode mixtures. Secondly, the phase retrieval method is used to retrieve the phase profile of a mode mixture in fewmodeled fiber based on volume intensity measurement. A mixture of LP_{01} and LP_{11} is considered both using a numerical example to establish the workings of the method and experimental investigations. In the experimental investigation, both a 50/50- and 88/12-mixture is considered, and in both cases the method shows reliable results. Last, a new method for determining the group velocity dispersion of modes in the LP_{0X} , LP_{1X} , and LP_{2X} mode groups based on an analysis of the field profile is presented. The method is independent of the fiber length. The method reproduces the group velocity dispersion spectra obtained analyzing a test fiber with a scalar mode solver.
Inter-modal four-wave mixing study in a two-mode fiber

We demonstrate efficient four-wave mixing among different spatial modes in a 1-km long two-mode fiber at telecommunication wavelengths. Two pumps excite the LP01 and LP11 modes, respectively, while the probe signal excites the LP01 mode, and the phase conjugation (PC) and Bragg scattering (BS) idlers are generated in the LP11 mode. For these processes we experimentally characterize their phase matching efficiency and bandwidth and find that they depend critically on the wavelength separation of the two pumps, in good agreement with the numerical study we carried out. We also confirm experimentally that BS has a larger bandwidth than PC for the optimum choice of the pump wavelength separation.
Light interaction with nano-structured diatom frustule, from UV-A to NIR

Diatoms are found in nearly every aqueous environment and play a vital part of the global primary production system contributing with up to 25% and are efficient light harvesting organisms. Unique to diatoms are the hard cell wall, called the frustule surrounding the single cell. The frustule is made from bio-synthesized silicate, perforated by wavelength sized features where the morphology of the nano-structured “greenhouse” is species dependent. Diatoms would therefore make for one of the most interesting “green” resources since it has not only potential as a biomass production system but also for nano-structured inorganic material. To understand the biological significance and to integrate diatomic frustules as active material in devices a fundamental understanding of how light interacts with the frustule is needed. In this study we focus on centric diatoms, i.e. having rotational symmetry where morphological parameters vary between the different investigated species. We report how light interacts with the frustule in the wavelength range from UV-A (320-380 nm) to NIR (900 nm). High resolution spectroscopy and CCD images are used to identify photoluminescence (PL) and variations in the transmitted light caused by the nano-structured frustule. Furthermore we show, by placing the frustule on a quartz half sphere how light transmission is a function of the angle of incidence and wavelength.

General information
State: Published
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Number of pages: 6
Pages: 3811-3816
Publication date: 2016
Conference: 2015 MRS Fall Meeting and Exhibit, Boston, United States, 29/11/2015 - 29/11/2015
Main Research Area: Technical/natural sciences

Publication information
Journal: MRS Advances
Volume: 1
Issue number: 57
Original language: English
DOIs:
10.1557/adv.2015.15
Source: PublicationPreSubmission
Source-ID: 118983077
Publication: Research - peer-review › Conference article – Annual report year: 2015

The stagnating increase in data transmission capacity in optical communication systems combined with the ever growing demand of transmission bandwidth is leading to an impending capacity crunch, referring to the point in time after which the available bandwidth of the individual user starts to decrease. To postpone this point in time, existing technologies in terms of data transmission through optical fibers must be optimized and new degrees of freedom must be introduced to continue the exponential increase in available bandwidth; space-division multiplexing is believed to be the strongest candidate for another degree of freedom in transmission fibers. This thesis is two-fold: firstly, starting at Maxwell’s equations and basic principles of quantum mechanics, a semi-classical model of the noise properties of fiber optical parametric amplifiers and
frequency converters is presented. The model accounts for multiple effects present in nonlinear fibers such as four-wave mixing, Raman scattering, distributed loss, and dispersion, and it is valid in the depleted pump regime. After validating the model against well-known results of quantum models, the model is used to predict the impacts of Raman noise, loss, and pump depletion on the noise properties of parametric frequency conversion and phase-insensitive and phase-sensitive parametric amplification. An important part of realizing space-division multiplexing is the ability of optical signal processing so the second part of this thesis addresses few-mode Raman fiber amplifiers and parametric amplifiers and frequency converters. A model of weak random linear mode coupling in the pump of a two-mode distributed Raman fiber amplifier is presented and it is shown that an amplification noise figure induced by mode coupling increases with the degree of mode coupling and that this tendency increases as the pump depletes. Also, a very low mode-dependent gain of 0.25 dB per 10 dB gain is experimentally demonstrated in a two-mode distributed Raman fiber amplifier by exciting the pump in a combination of two modes. A comprehensive model of four-wave mixing in two-mode fibers acvi counting for six simultaneous processes is derived, and the conversion efficiency from signal to idler in the four-wave mixing processes of phase conjugation and Bragg scattering in two two-mode fibers with different phase matching properties are experimentally investigated. A conversion efficiency of $> -2.70$ dB is demonstrated for Bragg scattering in the conversion of a signal in the LP01-mode to the idler in the LP11-mode; the signal-to-idler separation is $\sim 25$ nm. Good qualitative agreement between experiments and theory is found for both processes in both fibers.
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Pages: 301-303
Publication date: 2016

**Host publication information**
Title of host publication: Proceedings of 42nd European Conference and Exhibition on Optical Communications
Publisher: VDE Verlag
ISBN (Print): 978-3-8007-4274-5
Main Research Area: Technical/natural sciences
Source: PublicationPreSubmission
Source-ID: 128071098
Publication: Research - peer-review › Article in proceedings – Annual report year: 2016

**Temporally uncorrelated photon-pair generation by dual-pump four-wave mixing**
We study the preparation of heralded single-photon states using dual-pump spontaneous four-wave mixing. The dual-pump configuration, which in our case employs cross-polarized pumps, allows for a gradual variation of the nonlinear interaction strength enabled by a birefringence-induced walk-off between the pump pulses. The scheme enables the preparation of highly pure heralded single-photon states, and proves to be extremely robust against the effect of nonlinear phase modulation at the required photon-pair production rates.

**General information**
State: Published
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Number of pages: 12
Publication date: 2016
Main Research Area: Technical/natural sciences

**Publication information**
Journal: Physical Review A
Volume: 94
Issue number: 1
Article number: 013819
ISSN (Print): 2469-9926
Ratings:
- BFI (2017): BFI-level 1
- Web of Science (2017): Indexed yes
- BFI (2016): BFI-level 1
- Scopus rating (2016): CiteScore 2.25 SJR 1.281 SNIP 0.852
- Web of Science (2016): Indexed yes
- BFI (2015): BFI-level 1
- Scopus rating (2015): SJR 1.451 SNIP 0.903 CiteScore 2.06
- Web of Science (2015): Indexed yes
- BFI (2014): BFI-level 1
- Scopus rating (2014): SJR 2.121 SNIP 1.146 CiteScore 2.46
- Web of Science (2014): Indexed yes
- BFI (2013): BFI-level 1
- Scopus rating (2013): SJR 2.317 SNIP 1.179 CiteScore 2.86
- ISI indexed (2013): ISI indexed yes
- Web of Science (2013): Indexed yes
- BFI (2012): BFI-level 1
- Scopus rating (2012): SJR 2.515 SNIP 1.239 CiteScore 2.81
- ISI indexed (2012): ISI indexed yes
- Web of Science (2012): Indexed yes
The fascinating diatom frustule—can it play a role for attenuation of UV radiation?

Diatoms are ubiquitous organisms in aquatic environments and are estimated to be responsible for 20–25 % of the total global primary production. A unique feature of diatomis the silica wall, called the frustule. The frustule is characterized by species-specific intricate nanopatterning in the same size range as wave lengths of visible and ultraviolet (UV) light. This has prompted research into the possible role of the frustule in mediating light for the diatoms' photosynthesis as well as into possible photonic applications of the diatom frustule. One of the possible biological roles, as well as area of potential application, is UV protection. In this review, we explore the possible adaptive value of the silica frustule with focus on research on the effect of UV radiation on diatoms. We also explore the possible effect of the frustules on UV radiation, from a theoretical, biological, and applied perspective, including recent experimental data on UV transmission of diatom frustules.
Two-dimensional distributed-phase-reference protocol for quantum key distribution

Quantum key distribution (QKD) and quantum communication enable the secure exchange of information between remote parties. Currently, the distributed-phase-reference (DPR) protocols, which are based on weak coherent pulses, are among the most practical solutions for long-range QKD. During the last 10 years, long-distance fiber-based DPR systems have been successfully demonstrated, although fundamental obstacles such as intrinsic channel losses limit their performance. Here, we introduce the first two-dimensional DPR-QKD protocol in which information is encoded in the time and phase of weak coherent pulses. The ability of extracting two bits of information per detection event, enables a higher secret key rate in specific realistic network scenarios. Moreover, despite the use of more dimensions, the proposed protocol remains simple, practical, and fully integrable.

General information
State: Published
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Number of pages: 7
Publication date: 2016
Main Research Area: Technical/natural sciences

Publication information
Journal: Scientific Reports
Volume: 6
Article number: 36756
ISSN (Print): 2045-2322
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 4.63 SJR 1.625 SNIP 1.401
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 2.057 SNIP 1.684 CiteScore 5.3
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 2.103 SNIP 1.544 CiteScore 4.75
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.886 SNIP 1.51 CiteScore 4.06
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.458 SNIP 0.896 CiteScore 2.44
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
ISI indexed (2011): ISI indexed no
Original language: English
Electronic versions:
srep36756.pdf
DOIs: 10.1038/srep36756
10.1038/srep36756
Source: FindIt
Source-ID: 2350107822
Publication: Research - peer-review › Journal article – Annual report year: 2016

Challenges in higher order mode Raman amplifiers

A higher order Raman amplifier model that take random mode coupling into account is presented. Mode dependent gain and signal power fluctuations at the output of the higher order mode Raman amplifier are discussed.
Comparing optical properties of different species of diatoms

Diatoms are single cellular algae encapsulated in an external wall of micro-structured porous silica called the frustule. Diatoms are present in all water environments and contribute with 20-25% of the global primary production of oxygen by photosynthesis. The appearance of the frustule is very species dependent with huge variety in size, shape, and micro-structure. We have experimentally investigated optical properties of frustules of several species of diatoms to further understand light harvesting properties together with common traits, effects and differences between the different frustules. We have observed, when incident light interacts with the micro-structured frustule it is multiple diffracted giving rise to wavelength dependent multiple focal points and other optical effects. Experimental results have been simulated and well confirmed by free space FFT propagation routine analysis software. The software uses parameters which are extracted from experimental images as basis for simulation and allows us to extract the influence of the different elements of the frustule. The information could be used both for predicting optical properties of diatoms and by changing frustule parameters, maybe by altering growth conditions of the diatoms tailor their optical properties.
Fiber-Optical Parametric Amplification of Sub-Picosecond Pulses for High-Speed Optical Communications

This article reviews recent results of amplification of short optical pulses using fiber-optical parametric amplifiers. This includes chirped-pulse amplification of 400 fs pulses, error-free amplification of a 640-Gbit/s optical time-division multiplexed signal with less than a 1-dB power penalty, and all-optical phase-preserving amplitude regeneration of a 640-Gbit/s return-to-zero differential phase-shift keying optical time-division multiplexed signal.

General information
State: Published
Organisations: Department of Photonics Engineering, High-Speed Optical Communication, Fiber Optics, Devices and Non-linear Effects, FOTON
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Pages: 23-37
Publication date: 2015
Main Research Area: Technical/natural sciences

Publication information
Journal: Fiber and Integrated Optics
Volume: 34
Issue number: 1-2
ISSN (Print): 0146-8030
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.2 SNIP 0.205 CiteScore 0.38
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.245 SNIP 0.415 CiteScore 0.57
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.273 SNIP 0.566 CiteScore 0.61
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.214 SNIP 0.504 CiteScore 0.39
ISI indexed (2013): ISI indexed yes
Interference patterns and extinction ratio of the diatom Coscinodiscus granii

We report experimental and theoretical verification of the nature and position of multiple interference points of visible light transmitted through the valve of the centric diatom species Coscinodiscus granii. Furthermore, by coupling the transmitted light into an optical fiber and moving the diatom valve between constructive and destructive interference points, an extinction ratio of 20 dB is shown.
Interferometric characterization of few-mode fibers (FMF) for mode-division multiplexing (MDM)

The rapid growth of global data traffic demands the continuous search for new technologies and systems that could increase transmission capacity in optical links and recent experiments show that to do so, it is advantageous to explore new degrees of freedom such as polarization, wavelength or optical modes. Mode division multiplexing (MDM) appears in this context as a promising and viable solution for such capacity increase, since it utilizes multiple spatial modes of an optical fiber as individual communication channels for data transmission. In order to evaluate its performance, a MDM system requires advanced characterization methods with regard to the modal content of its photonics components and in particular of the fibers involved for data transmission. In this contribution we present a time-domain interferometric technique for a full modal characterization of few mode fibers (FMF), commonly used in a MDM scenario. This experimental technique requires the use of a Mach-Zehnder interferometer, where the reference's path length is controlled by an optical delay line. The interference between the output beams of reference and fiber under test (FUT) is recorded on a CCD camera and a careful evaluation of the resulting interferograms allows us to have full access to key parameters such as number of modes, modal weight, differential time delay between propagating modes and intensity profiles. In this work, we apply this simple and complete characterization method to the case of a short link with two optical modes propagating in a FMF, which illustrates its potential as a diagnostic tool for MDM systems.

General information
State: Published
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Publication date: 2015

Host publication information
Title of host publication: Proceedings of SPIE
Volume: 9369
Publisher: SPIE - International Society for Optical Engineering
Editors: Soskind, Y. G., Olson, C.
Article number: 936909
ISBN (Print): 9781628414592

Series: Proceedings of SPIE, the International Society for Optical Engineering
Volume: 9369
ISSN: 0277-786X
Main Research Area: Technical/natural sciences
Mode division multiplexing, Few mode fiber, Low coherence interferometry.
Electronic versions:
936909.pdf
DOIs:
10.1117/12.2079413

Bibliographical note
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Source: FindIt
Source-ID: 274809765
Publication: Research - peer-review › Article in proceedings – Annual report year: 2015

Mode resolved bend-loss analysis in few-mode fibers using spatially and spectrally resolved imaging

The increasing use of few-mode fibers for high-speed optical communication systems in space division multiplexing has created a need for mode resolved characterization of few-mode fibers. In this Letter, we present a new method to characterize the bend loss of the individual modes in a few-mode fiber. This procedure uses a simple setup for spatially and spectrally resolved imaging and allows the measurement of the bend loss of each and every guided mode at once. It does not require the use of mode converters in contrast to other methods. Results for graded-index two-and four-mode fibers are presented, together with comparisons against direct bend-loss measurements for the four-mode and standard single-mode fibers. (C) 2015 Optical Society of America

General information
State: Published
Organisations: Department of Photonics Engineering, Nanophotonics Theory and Signal Processing, Fiber Optics, Devices and Non-linear Effects, OFS Optics
Nonlinear frequency conversion in fiber lasers

The concept of nonlinear frequency conversion entails generating light at new frequencies other than those of the source light. The emission wavelength of typical fiber laser systems, relying on rare-earth dopants, are constrained within specific bands of the infrared region. By exploiting nonlinear processes, light from these specific wavelength bands can be used to generate light at new frequencies otherwise not obtainable by rare-earth elements. This thesis describes work covering Raman fiber lasers (RFLs) and amplifiers for nonlinear frequency down-conversion, and also the method of fiberoptic Cherenkov radiation (FCR) using ultrafast pulses as a means for generating tunable visible (VIS) light at higher frequencies. Two different polarization maintaining (PM) RFL cavities are studied with an emphasis on stability and spectral broadening. The cavities are formed by inscription of fiber Bragg gratings (FBGs) in a PM Raman fiber. Active temperature control feedback of the cavity resonators is investigated as a means for obtaining a high degree of power and spectral stability. The impact of accurate cavity resonator alignment upon the RFL stability and emission characteristics is investigated and a highly stable PM RFL emitting at 1679 nm with a narrow spectral emission bandwidth is demonstrated. A driftless output was obtained for an output power of 680 mW at a 29 pm line width while having high output power and spectral stability; with a sub-pm standard deviation in the emission wavelength and line width. Subsequently, the RFL is used for the demonstration of a Raman amplifier, for which both the gain and noise characteristics in the vicinity of 1800 nm wavelength are examined. The VIS FCR source can be considered for a broad range of applications in the field of biophotonics. FCR emission is characterized by a high temporal and spatial coherence, short temporal pulse duration, a tunable emission wavelength in the tens of nanometer range, along with a potential for having very low noise properties. The pursuit of a compact, portable, and robust VIS FCR source, suitable for applications outside of the optical lab, defined the work on an all fiber based system. Experimentally, the generation of VIS light using the FCR process is demonstrated in both uniform and tapered nonlinear fibers. VIS emission from the blue to the red parts of the VIS spectrum is demonstrated; extending across a 430 to 610 nm wavelength range for output powers up to 2 mW. Utilization of tapered nonlinear fibers resulted in a substantial increase in the obtainable wavelength tunability, with an increase from 20 to 118 nm, when compared to the results obtained for uniform nonlinear fibers.
modelocked oscillator, that employs a free space scheme for coupling onto the saturable absorber mirror and output
coupling, was investigated for different settings of the intracavity dispersion. When the cavity is operated with close to zero
net dispersion, highly stable 0.5-nJ pulses externally compressed to sub-100-fs are generated. These are to our
knowledge the shortest pulses generated from an all-polarization-maintaining Yb-fiber oscillator. The spectral phase of the
output pulses is well behaved and can be compensated such that wing-free Fourier transform limited pulses can be
obtained. Further reduction of the net intracavity third order dispersion will allow generating broader output spectra and
consequently shorter pulses, without sacrificing pulse fidelity.

General information
State: Published
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Number of pages: 2
Publication date: 2015

Host publication information
Title of host publication: The European Conference on Lasers and Electro-Optics 2015
Publisher: Optical Society of America
ISBN (Print): 978-1-4673-7475-0
Main Research Area: Technical/natural sciences
Conference: CLEO/Europe - EQEC 2015, Munich, Germany, 21/06/2015 - 21/06/2015
Atomic and Molecular Physics, and Optics, Dispersion compensation, Electromagnetic dispersion, Fibers, Mirrors,
Polarization, Saturable absorbers, Ytterbium, Intra-cavity dispersion, Mode-locked oscillators, Negative third-order
dispersion, Polarization maintaining, Saturable absorber mirrors, Second-order dispersion, Third order dispersion,
Transform-limited pulse, Polarization-maintaining fiber

Bibliographical note
From the session: Mode-locked Fibre Oscillators (CJ_2)
Publication: Research - peer-review › Article in proceedings – Annual report year: 2015

Sub-100 fs pulses from an all-polarization maintaining Yb-fiber oscillator with an anomalous dispersion higher-order-mode
fiber
We present an Yb-fiber oscillator with an all-polarization-maintaining cavity with a higher-order-mode fiber for dispersion
compensation. The polarization maintaining higher order mode fiber introduces not only negative second order dispersion
but also negative third order dispersion in the cavity, in contrast to dispersion compensation schemes used in previous
demonstrations of all-polarization maintaining Yb-fiber oscillators. The performance of the saturable absorber mirror
modelocked oscillator, that employs a free space scheme for coupling onto the saturable absorber mirror and output
coupling, was investigated for different settings of the intracavity dispersion. When the cavity is operated with close to zero
net dispersion, highly stable 0.5-nJ pulses externally compressed to sub-100-fs are generated. These are to our
knowledge the shortest pulses generated from an all-polarization-maintaining Yb-fiber oscillator. The spectral phase of the
output pulses is well behaved and can be compensated such that wing-free Fourier transform limited pulses can be
obtained. Further reduction of the net intracavity third order dispersion will allow generating broader output spectra and
consequently shorter pulses, without sacrificing pulse fidelity.

General information
State: Published
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Pages: 26139-26145
Publication date: 2015
Main Research Area: Technical/natural sciences

Publication information
Journal: Optics Express
Volume: 23
Issue number: 20
ISSN (Print): 1094-4087
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
Temporal mode sorting using dual-stage quantum frequency conversion by asymmetric Bragg scattering

The temporal shape of single photons provides a high-dimensional basis of temporal modes, and can therefore support quantum computing schemes that go beyond the qubit. However, the lack of linear optical components to act as quantum gates has made it challenging to efficiently address specific temporal-mode components from an arbitrary superposition. Recent progress towards realizing such a "quantum pulse gate," has been proposed using nonlinear optical signal processing to add coherently the effect of multiple stages of quantum frequency conversion. This scheme, called temporal-mode interferometry [D. V. Reddy, Phys. Rev. A 91, 012323 (2015)], has been shown in the case of three-wave mixing to promise near-unity mode-sorting efficiency. Here we demonstrate that it is also possible to achieve high mode-sorting efficiency using four-wave mixing, if one pump pulse is long and the other short - a configuration we call asymmetrically-pumped Bragg scattering. (C) 2015 Optical Society of America
In this work, we present an analytic model for analyzing the range and frequency dependency of a monostatic coherent lidar measuring velocities of a diffuse target. The model of the signal power spectrum includes both the contribution from the optical system as well as the contribution from the time dependencies of the optical field. A specific coherent Doppler wind lidar system measuring wind velocity in the atmosphere is considered, in which a Gaussian field is transmitted through a simple telescope consisting of a lens and an aperture. The effects of the aperture size, the beam waist position, and pulse duration are analyzed. © 2014 Optical Society of America
Asymmetrically pumped Bragg scattering with the effects of nonlinear phase modulation
We derive exact solutions to asymmetrically pumped Bragg scattering with nonlinear phase-modulation (NPM) and show that this setup allows for the frequency conversion of many temporal modes, while reducing the effects due to NPM.

General information
State: Published
Break up of the azimuthal symmetry of higher order fiber modes

We investigate Bessel-like modes guided in a double cladding fiber where the outer cladding is an aircladding. For very high order LP0X-modes, the azimuthal symmetry is broken and the mode is no longer linearly polarized. This is observed experimentally and confirmed numerically. The effect is investigated numerically using a full vectorial modesolver and is observed to be dependent on the fiber design. The effect on the diffraction free propagation distance of the modes is investigated using a fast Fourier transform propagation routine and compared to the properties of an ideal circularly symmetric mode. The free space properties of modes suffering from break up of azimuthal symmetry are also investigated experimentally by measuring the free space propagation of a LP016-mode excited in the double cladding fiber. © 2014 Optical Society of America.
Divergence Angle as a Quality Parameter for Fiber Modes

We suggest using divergence angle as a quality parameter for pure fiber modes. We demonstrate a measurement of the divergence angle of an LP11-mode and obtain agreement with numerical predictions with 2-digit precision.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects
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Number of pages: 2
Publication date: 2014

Host publication information
Title of host publication: Proceedings of 2014 Conference on Lasers and Electro-Optics (CLEO)
Publisher: IEEE
Main Research Area: Technical/natural sciences
Conference: Conference on Lasers and Electro-Optics 2014, San Jose, CA, United States, 08/06/2014 - 08/06/2014
Source: PublicationPreSubmission
Source-ID: 93558910
**Effects of Raman scattering in quantum state-preserving frequency conversion**

We analyse frequency conversion by Bragg scattering numerically including Raman scattering. The frequency configuration that performs the best under influence of Raman noise results in 95% conversion over a 3.25 THz bandwidth with a 2.5-dB noise figure.

**General information**

State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Metro-Access and Short Range Systems, Department of Wind Energy, Test and Measurements, Bell Laboratories
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Number of pages: 2
Publication date: 2014

**Host publication information**

Title of host publication: Proceedings of 2014 Conference on Lasers and Electro-Optics (CLEO)
Publisher: IEEE
Main Research Area: Technical/natural sciences
Conference: Conference on Lasers and Electro-Optics 2014, San Jose, CA, United States, 08/06/2014 - 08/06/2014
Electronic versions:
CLEO_SI_2014_STu2I.2.pdf
Source: PublicationPreSubmission
Source-ID: 93487915
Publication: Research - peer-review › Article in proceedings – Annual report year: 2014

**Fiber Laser for Wind Speed Measurements**

This PhD thesis evaluates the practical construction and use of a Frequency Stepped Pulse Train modulated coherent Doppler wind lidar (FSPT lidar) for wind speed measurement.

The concept of Doppler lidar is introduced as a means to measure line of sight wind speed by the Doppler shift of reflected light from aerosols. Central concepts are introduced and developed, i.a. heterodyne detection, carrier-to-noise ratio, probe length, measuring distance, and velocity precision. On this basis the concepts of a FSPT lidar are introduced and its general setup explained.

The Lightwave Synthesized Frequency Sweeper (LSFS) is introduced and analyzed as a light source for the FSPT lidar. The setup of the LSFS is discussed, and the necessary concepts for modeling and analyzing LSFS noise are developed. The model and measurements are then used to discuss the growth of optical noise in the LSFS and the impact on its use in the FSPT lidar.

A complex ABCD model is developed and described as a method for calculating spatial and frequency dependency of a lidar’s signal strength. The model includes both spatial and temporal components of the lidar system, enabling a model capable of describing both CW, pulsed and FSPT lidars.

Measurements of the range dependency of a FSPT lidar are shown, along with the mapping of range gates into frequency slots. The measured range dependencies are shown to correlate with the dependencies predicted by the complex ABCD model, thus corroborating the model.

Finally, proofs of concept wind speed measurements obtained with the FSPT lidar are shown. This is followed by a discussion of the advantages and disadvantages of a FSPT lidar compared to a CW and a pulsed lidar system, and further avenues for evolving the concepts.

**General information**

State: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology, Department of Wind Energy, Test and Measurements, Fiber Optics, Devices and Non-linear Effects
Authors: Olesen, A. S. (Intern), Mikkelsen, T. K. (Intern), Rottwitt, K. (Intern)
Number of pages: 137
Publication date: 2014

**Publication information**

Place of publication: Kgs. Lyngby
Publisher: Technical University of Denmark (DTU)
Original language: English
Main Research Area: Technical/natural sciences
Electronic versions:
Thesis..PDF

**Relations**
**Nonlinear Optics: Principles and Applications**

As nonlinear optics further develops as a field of research in electromagnetic wave propagation, its state-of-the-art technologies will continue to strongly impact real-world applications in a variety of fields useful to the practicing scientist and engineer. From basic principles to examples of applications, Nonlinear Optics: Principles and Applications effectively bridges physics and mathematics with relevant applied material for real-world use. The book progresses naturally from fundamental aspects to illustrative examples, and presents a strong theoretical foundation that equips the reader with enough knowledge to recognize, understand, and evaluate nonlinear optical phenomena. Structured so that the first five chapters are dedicated to the description of the fundamental formalism of nonlinear optics, and the last five chapters are devoted to a description of practical devices based on nonlinear phenomena, it describes nonlinear wave propagation in bulk and in waveguiding structures, and includes specific examples of applied nonlinear wave propagation through crystals, optical waveguides, and optical fibers. Providing a theoretical description of nonlinear interaction between light and matter, this text focuses on the physical understanding of nonlinear optics, and explores optical material response functions in the time and frequency domain.

**General information**

State: Published

Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Optical Sensor Technology

Authors: Rottwitt, K. (Intern), Tidemand-Lichtenberg, P. (Intern)

Number of pages: 349

Publication date: 2014

**Publication information**

Publisher: C R C Press LLC

ISBN (Print): 978-1-4665-6582-1

ISBN (Electronic): 978-1-4665-6583-8

Original language: English

Main Research Area: Technical/natural sciences

Publication: Research - peer-review › Book – Annual report year: 2015

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**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.

**General information**

State: Published

Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects

Authors: Rishøj, L. S. (Intern), Svane, A. S. (Intern), Lund-Hansen, T. (Intern), Rottwitt, K. (Intern)

Pages: 199-200

Publication date: 2014

Main Research Area: Technical/natural sciences

**Publication information**

Journal: Electronics Letters

Volume: 50

Issue number: 3

ISSN (Print): 0013-5194

Ratings:

BFI (2017): BFI-level 1

Web of Science (2017): Indexed Yes

BFI (2016): BFI-level 1

Scopus rating (2016): SJR 0.442 SNIP 0.882 CiteScore 1.35

Web of Science (2016): Indexed yes

BFI (2015): BFI-level 1

Scopus rating (2015): SJR 0.497 SNIP 1.011 CiteScore 1.31
Quantum Information Processing using Nonlinear Optical Effects

This PhD thesis treats applications of nonlinear optical effects for quantum information processing. The two main applications are four-wave mixing in the form of Bragg scattering (BS) for quantum-state-preserving frequency conversion, and sum-frequency generation (SFG) in second-order nonlinear materials for heralded entanglement.

BS is shown to be separable in the input and output modes in the low-conversion regime, the regime of small pump powers or short interaction times. The selective frequency conversion of a signal is found to only depend on one of the pumps, while the temporal output of the converted idler depends on the other pump. This allows for temporal-mode-
multiplexing. When the effects of nonlinear phase modulation (NPM) are included, the phases of the natural input and output modes are changed, reducing the separability. These effects are to some degree mediated by pre-chirping the pumps.

In the high-conversion regime without the effects of NPM, exact Green functions for BS are derived. In this limit, separability is possible for conversion efficiencies up to 60%. However, the system still allows for selective frequency conversion as well as re-shaping of the output. One way to obtain a 100% conversion efficiency is to use multiple stages of frequency conversion, but this setup suffers from the combined effects of NPM. This problem is circumvented by using asymmetrically pumped BS, where one pump is continuous wave. For this setup, NPM is found to only lead to linear phase shifts of the input and output modes, corresponding to shifts of the central frequencies of the fields. The trade-off is that one is only able to select which signals are converted, or change the shape of the output idler.

Finally, entanglement swapping using SFG was investigated. Considering two pairs of entangled photons, the process of up-converting one photon from each pair leads to heralded entangled pairs by successful detection of the up-converted photon. It was seen that this was indeed possible in the case of anti-correlated phasematching in the up-conversion crystal. Possible ways of increasing the probability of an up-conversion event were investigated briefly.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects
Authors: Andersen, L. M. (Intern), Rottwitt, K. (Intern)
Number of pages: 258
Publication date: 2014

Reducing Raman noise in parametric frequency conversion by varying the input pump power
The phase-matching condition of parametric frequency conversion and the impact of Raman scattering depend on the power of two separate pumps. We show that Raman noise is reduced by asymmetrically varying the pump powers.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects
Authors: Friis, S. M. M. (Intern), Andersen, L. M. (Intern), Rottwitt, K. (Intern)
Number of pages: 2
Publication date: 2014

Selfhealing of asymmetric Bessel-like modes
We numerically investigate asymmetric Bessel-like modes in an aircladding fiber. The selfhealing ability of asymmetric Bessel-like modes is demonstrated and quantified including the angular dependency of this ability.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects
Authors: Israelsen, S. M. (Intern), Rishøj, L. S. (Intern), Rottwitt, K. (Intern)
Number of pages: 1
Publication date: 2014
Non-Linear Fibres for Widely Tunable Femtosecond Fibre Lasers

This Ph.D. thesis investigates how intramodal and intermodal nonlinear processes in few-moded fibres can be used to generate light sources at wavelengths outside the spectral gain-bands of rare-earth-doped optical fibres. The design of two specialty few-moded fibres for use in a widely tunable femtosecond fibre laser is presented. The two fibres are used to facilitate the shifting of a soliton in a cascade configuration from the ytterbium gain-band and to a wavelength of 1280 nm. The temporal pulse duration is on a femtosecond scale with a pulse energy of 5 nJ. The experimentally observed soliton self-frequency shift and thereby the outcome of the experimental demonstration of the widely tunable femtosecond fibre laser is shown to depend highly on the chirped of the input pulse into the first few-moded fibre in the cascade setup. Furthermore, an alternative splicing process, with a combination of a fusion splicer and a gas-line burner, is applied to the few-moded fibres. An intermodal four-wave mixing process and a novel intermodal Cerenkov generation process are demonstrated experimentally in one of the two specialty few-moded fibres. The two intermodal processes are described theoretically and numerically. For the intermodal four-wave mixing experiment an alternative version of the Generalised Non-Linear Schrödinger Equation is derived, which includes the correct dispersion of the transverse field. It is observed that the alternative version of the Generalised Non-Linear Schrödinger Equation, as opposed to the commonly used version, is able to reproduce the intermodal four-wave mixing experiment. The relation between the intramodal self-phase modulation and the intramodal Raman effect is determined from experimental measurements on a number of step-index fibres. The Raman fraction is found to vary with the germanium concentration. For the considered step-index fibres the Raman fraction varies from 0.16 to 0.15 with increasing germanium concentration, which is lower than the often cited value of 0.18. Furthermore, an extensive work regarding modelling of mode-locked lasers was performed. The result of this is reported for an all-normal dispersive polarisation-maintaining laser.

All-fiber Raman Probe using Higher Order Modes

We demonstrate the first all-fiber Raman probe utilizing higher order modes for the excitation. The spectrum of cyclohexane is measured using both the fundamental mode as well as in-fiber-generated Bessel-like modes.
All-optical phase-preserving amplitude regeneration of a 640 Gbit/s RZ-DPSK signal

Phase-preserving amplitude regeneration based on optical parametric amplification has been experimentally demonstrated for a 640 Gbit/s RZ-DPSK signal. Improvement of 2.2 dB in receiver sensitivity at a BER of 10^-9 together with 13.3 dB net gain have been successfully achieved.

Combined temporal and spectral measurement of infrared supercontinuum performed by up-conversion in a non-linear crystal

Up-converting infrared supercontinuum allows a direct measurement of its temporal and spectral properties. The resulting spectrogram reveals that higher order spatial modes play an important role in supercontinuum generation in step index fibres.

Design of an 1800nm Raman amplifier

We present the experimental results for a Raman amplifier that operates at 1810 nm and is pumped by a Raman fiber laser at 1680 nm. Both the pump laser and the Raman amplifier is polarization maintaining. A challenge when scaling Raman amplifiers to longer wavelengths is the increase in transmission loss, but also the reduction in the Raman gain coefficient as the amplifier wavelength is increased. Both polarization components of the Raman gain is characterized, initially for linearly co-polarized signal and pump, subsequently linearly polarized orthogonal signal and pump. The noise performance of the amplifier is also investigated for both configurations. Our results show an on/off gain exceeding 20 dB at 1810 nm for which the obtained effective noise figure is below 3 dB.
Design of an 1800 nm Raman Amplifier

Different approaches are being explored to increase the capacity of communication systems [1,2], both long and short range systems. One approach is by exploiting new optical wavelength bands, outside the conventional communication window from 1530 nm to 1625 nm. Hollow core fibers have been suggested as potential transmission fibers for extended wavelength operation, as low losses at long wavelengths have been predicted [3]. Fig. 1 illustrates the predicted low loss limit for a hollow core fiber and for comparison the measured loss of a OFS True Wave fiber. Besides low loss
transmission fibers, also extended band amplifiers are required. As a solution to the latter challenge, Raman amplifiers are suggested as promising candidates. The main hurdle when designing a long wavelength Raman amplifier is the increased intrinsic fiber attenuation which as a consequence leads to an increase in the pump power requirement and deteriorated noise properties. Here we demonstrate a Raman amplifier designed for signal wavelengths around 1800 nm. The amplification fiber is an OFS PM Raman fiber, and is pumped by a Raman fiber laser emitting at 1680 nm [4]. The amplifier was pumped co-polarized and backward, with respect to the singal. In Fig. 2 a measured Raman on/off gain exceeding 9 dB for 285 mW of injected pump power is obtained in a 4.35 km long fiber. A broadband supercontinuum source was used as a signal from 1700 nm to 1900 nm.

Dynamic characterization and amplification of sub-picosecond pulses in fiber optical parametric chirped pulse amplifiers

We show a first-time demonstration of amplification of 400 fs pulses in a fiber optical parametric amplifier. The 400 fs signal is stretched in time, amplified by 26 dB and compressed back to 500 fs. A significant broadening of the pulses is experimentally shown due to dispersion and limited gain bandwidth both in saturated and unsaturated gain regimes.
Dynamic Characterization of Fiber Optical Chirped Pulse Amplification for Sub-ps Pulses

We investigate experimentally the propagation of sub-picosecond pulses in fiber optical parametric chirped pulse amplifiers, showing a significant broadening of the pulses from 450 fs up to 720 fs due to dispersion and self-phase modulation.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, High-Speed Optical Communication
Authors: Cristofori, V. (Intern), Lali-Dastjerdi, Z. (Intern), Rishøj, L. S. (Intern), Galili, M. (Intern), Peucheret, C. (Intern), Rottwitt, K. (Intern)
Effect of Aircladding on Bessel-Like Modes
The effect of an aircladding in a double cladding fiber designed to guide higher order modes is examined. For very high order symmetrical modes we find that the circular symmetry of the modes is broken.
**Experimental demonstration of intermodal nonlinear effects between full vectorial modes in a few moded fiber**

We experimentally investigate intermodal nonlinear interactions, such as Raman scattering and four wave mixing. The fiber used is a specially designed few moded fiber, which splits the degeneracy of the first mode group, leading to stable propagation of the two full vectorial modes, TM01 and TE01. For the Raman experiments pumping occur in either the fundamental mode or the two full vectorial modes, whereas the signal is in the fundamental mode. In all three experiments approximately 40 dB of gain is achieved using 307 W of pump peak power. When pumping in either of the full vectorial modes four wave mixing is observed.

**General information**

State: Published
Experimental Demonstration of Phase Sensitive Parametric Processes in a Nano-Engineered Silicon Waveguide

We demonstrate experimentally phase-sensitive processes in nano-engineered silicon waveguides for the first time. Furthermore, we highlight paths towards the optimization of the phase-sensitive extinction ratio under the impact of two-photon and free-carrier absorption.

General information
State: Published
Organisations: Department of Photonics Engineering, Diode Lasers and LED Systems, Nanophotonic Devices, High-Speed Optical Communication, Fiber Optics, Devices and Non-linear Effects
Number of pages: 2
Pages: CM4D.7
Publication date: 2013

Host publication information
Title of host publication: Proceedings of 2013 Conference on Lasers and Electro-Optics (CLEO)
Publisher: IEEE
Main Research Area: Technical/natural sciences
Conference: Conference on Lasers and Electro-Optics (CLEO 2013), San Jose, California, United States, 09/06/2013 - 09/06/2013
Electronic versions:
CM4D.007.pdf
DOIs: 10.1364/CLEO_SI.2013.CM4D.7

Bibliographical note
This paper was published in CLEO:2013 Technical Digest and is made available as an electronic reprint with the permission of OSA. The paper can be found at the following URL on the OSA website: http://www.opticsinfobase.org/abstract.cfm?URI=CLEO_SI-2013-CM4D.7. Systematic or multiple reproduction or distribution to multiple locations via electronic or other means is prohibited and is subject to penalties under law.

Relations
Projects:
Experimental Demonstration of Phase Sensitive Parametric Processes in a Nano-Engineered Silicon Waveguide
Source: dtu
Source-ID: u::8130
Publication: Research - peer-review › Article in proceedings – Annual report year: 2014

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.
Fiber Optical Parametric Chirped Pulse Amplification of Sub-Picosecond Pulses

We demonstrate experimentally, for the first time to our knowledge, fiber optical parametric chirped pulse amplification of 400-fs pulses. The 400-fs signal is stretched, amplified by 26 dB and compressed back to 500 fs.

Frequency noise in frequency swept fiber laser

This Letter presents a measurement of the spectral content of frequency shifted pulses generated by a lightwave synthesized frequency sweeper. We found that each pulse is shifted in frequency with very high accuracy. We also discovered that noise originating from light leaking through the acousto-optical modulators and forward propagating Brillouin scattering appear in the spectrum. © 2013 Optical Society of America.
Generation of infrared supercontinuum radiation: spatial mode dispersion and higher-order mode propagation in ZBLAN step-index fibers

Using femtosecond upconversion we investigate the time and wavelength structure of infrared supercontinuum generation. It is shown that radiation is scattered into higher order spatial modes (HOMs) when generating a supercontinuum using fibers that are not single-moded, such as a step-index ZBLAN fiber. As a consequence of intermodal scattering and the difference in group velocity for the modes, the supercontinuum splits up spatially and temporally. Experimental results indicate that a significant part of the radiation propagates in HOMs. Conventional simulations of super-continuum generation do not include scattering into HOMs, and including this provides an extra degree of freedom for tailoring supercontinuum sources.
The nonlinear phenomenon of four-wave mixing (FWM) is investigated using a method, where, without the need of calculus, both phase and amplitudes of the mixing fields are visualized simultaneously, giving a complete overview of the FWM dynamics. This is done by introducing a set of Stokes-like coordinates of the electric fields, which reduce the FWM dynamics to a closed two-dimensional surface, similar to the Bloch sphere of quantum electrodynamics or the Pointcare’ sphere in polarization dynamics. The coordinates are chosen so as to use the gauge invariance symmetries of the FWM equations which also give the conservation of action flux known as the Manley-Rowe relations. This reduces the dynamics of FWM to the one-dimensional intersection between the closed two-dimensional surface and the phase-plane given by the conserved Hamiltonian. The analysis is advantageous for visualizing phase-dependent FWM phenomena which are found in a large variety of nonlinear systems and even in various optical communication schemes.
Highly Stable PM Raman Fiber Laser at 1680 nm
We demonstrate thermal stabilization of a Raman fiber laser. At 1680 nm the laser emission exceeds 500 mW with a power variation below 0.5%, both linewidth and wavelength variations are under 1 pm.

Intermodal Nonlinear Effects between Full Vectorial Modes in Few Modeed Fiber
We experimentally investigate intermodal nonlinear mixing, such as Raman and four wave mixing. This is obtained by pumping in the fundamental mode, or either of the two full vectorial modes, TM01 and TE01 in a specialty designed few modeed fiber.
Intermodal Raman Scattering between Full Vectorial Modes in Few Mode Fiber

We experimentally investigate intermodal Raman interaction. The pump is in the fundamental mode, HE11, and the signal is in either of two full vectorial modes, TM01 or TE01. The on-off gain is approximately 3 dB for both modes, using 4 km of few-moded fiber and 400 mW of pump power.

Mode Selectivity with Quantum-state-preserving Frequency Conversion Using Four-wave Mixing

We consider quantum frequency conversion using four-wave mixing Bragg scattering and the prospects for multiplexing using the temporal modes. We find that there is an optimal strength parameter, but that the fiber length is less critical.
Monolithic PM Raman fiber laser at 1679 nm for Raman amplification at 1810 nm

Stimulated Raman scattering (SRS) has been subject to much attention within the field of fiber lasers and amplifiers as it provides an extended wavelength coverage in comparison to rare-earth based devices. Motivated by the projected capacity crunch [1], different approaches are being explored to increase the capacity of communication systems [2]. One approach is by exploiting new optical wavelength bands, outside the conventional amplification windows. In the development of lasers and amplifiers in the short wave IR above the Erbium band, SRS seems to be a promising candidate. In this paper we demonstrate a monolithic RM Raman fiber laser (RFL), which acts as a pump for a Raman amplifier (RA) at 1810 nm. The lasing wavelength of a RFL, thus also for a RA, can in principle be designed arbitrarily within the entire wavelength range from the Erbium band up to the Thulium/Holmium band by the utilization of cascaded SRS [3].

The Experimental setup is shown in Fig. 1a, and consists of a RFL pumped at 1564 nm lasing at the first stokes shift at 1679 nm [4] along with a RA with a gain maximum at the second stokes shift at 1810 nm. The monolithic RLF cavity contains two signal fiber Bragg gratings (FBGs) 1 and 2 which define the laser cavity, along with a pump grating, FBG3, that enable two pass amplification. The gratings are written directly in the fiber, with a 50 mm phase mask, to avoid additional splice losses in the cavity. To address the issue of intensity noise transfer from the RFL to the RA, the cavity FBGs were temperature stabilized to reduce the RFL output intensity fluctuations. The RA is based on 4.3 km PM fiber where the pump is launched through a circulator in reverse with respect to the launched signal stemming from a NKT SuperK source. Both devices are based on a segment of OFS PM Raman fiber, with an estimated propagation loss of 0.42/0.46/1.3 dB/km at 1564/1679/1810 nm. The Raman gain coefficient was measured to be $g_R=2.66/2.35$ W$^{-1}$km$^{-1}$ at 1679/1810 nm.

The laser curve of the RFL is depicted in Fig. 1b, with a slope efficiency of 67 %. The high slope efficiency was obtained by optimizing the Q-factor of the cavity compared to the fiber length, through the reflectivity of the inscribed FBGs. A linewidth (LW) of 27 pm (2.9 GHz) is obtained at an output power of 275 mW. The LW was sufficiently wide to avoid stimulated Brillouin scattering in the RA. The measured Raman gain is plotted in Fig. 1c, which peaks at 1810 nm with an on/off gain of 9 dB for an input power of $P_{in}=285$ mW at 1679 nm. Based on the fiber parameters, signal transparency for up to 15 km should be attainable at current power levels, whereas discrete gain of 18 dB should be achieved for 500 mW. In comparison for a typical SMF no net gain would be possible for pump powers below 1 W, assuming similar losses and $g_R=0.3$ W$^{-1}$km$^{-1}$.

In conclusion, we have demonstrated a Monolithic PM RFL operating above the Erbium band at 1679 nm, which was shown to be a viable pump laser for a RA centred at 1810 nm. Based on our findings, we show that in spite of high transmission losses at 1810 nm, a high Raman gain coefficient provided by the OFS PM Raman fiber in conjunction with our developed RFL, has the potential to provide a high discrete gain but also distributed amplification across tens of kilometers at reasonable pump powers levels.
Nonlinear Pulse-reshaping of Sub-picosecond Pulses by Non-degenerate Four-wave Mixing

Four-wave mixing does according to various models allow for arbitrary pulse-reshaping of the generated idler. Using sub-picosecond pulses, we investigate numerically whether nonlinear effects and dispersion broadening begin to prevent this ability.

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.

Optical Amplification for Terabit-per-Second Ultra-High Speed Communication Systems

The present thesis is concerned with fiber optical parametric amplification and regeneration for high-speed optical communication systems. Fiber optical parametric amplifiers (FOPAs) have multi-functional applications depending on their implementation in optical systems. Based on a few femtosecond amplification response time and flexible operation spectral range, FOPAs are able to simultaneously operate as amplifiers and all-optical signal processors in high-speed Tbaud networks. In this thesis, we study the performance of FOPAs in detail in the linear and nonlinear (saturated) regimes where they can be utilized as all-optical regenerators. The optical gain and amplitude regeneration properties of FOPAs are investigated for monochromatic waves, short optical pulses and data modulated signals up to 640 Gbit/s.
In the fundamental study part of the thesis, an original physical explanation behind an observed asymmetry in gain saturated single-pump FOPAs is presented. The proposed theory is able to explain the origin of gain asymmetries in single-pump FOPAs based on the interplay between third-order dispersion and radiation of dispersive waves in the saturation regime. Furthermore, it predicts the strength of the asymmetric gain in saturated single-pump FOPAs. Pump-to-signal intensity noise transfer has been recognized as one of the major noise sources in FOPAs as it leads to modulation of the signal gain. The conversion of intensity noise from pump to signal is quantified in detail in terms of modulation frequency and saturation effect in order to assess the degradation of the amplified signal. In a very good agreement with the performed experiments, it is shown that the noise transferred to the signal can be effectively suppressed by operating in the saturation regime.

The amplification of short few picosecond and subpicosecond optical pulses is explored using the chirped-pulse amplification scheme in FOPAs. The dynamics of the chirped-pulse amplification and pulse distortion are studied for differently chirped few-picosecond pulses in transition between the linear and the nonlinear regime. Amplification of short pulses compatible with Tbaud systems is experimentally carried out for the first time where 400 fs pulses are amplified in a single-pump FOPA.

Finally, the first experimental demonstrations of the performance of FOPAs both in long transmission links as well as in high-capacity systems are presented in the last part of this thesis. FOPAs are cascaded as in-line amplifiers using a recirculating loop transmission and error-free transmission of 40 Gbit/s is successfully achieved. On the other hand, error-free parametric amplification for high serial data rates on a single-wavelength channel is demonstrated for an optical time division multiplexed signal at 640 Gbit/s with no power penalty. At last, all-optical phase-preserving amplitude regeneration based on a saturated-FOPA at 640 Gbit/s is demonstrated for phase modulated signals.

**General information**
State: Published
Organisations: Department of Photonics Engineering, High-Speed Optical Communication, Fiber Optics, Devices and Non-linear Effects
Authors: Lali-Dastjerdi, Z. (Intern), Peucheret, C. (Intern), Rottwitt, K. (Intern), Galili, M. (Intern)
Number of pages: 126
Publication date: 2013

**Publication information**
Place of publication: Kgs. Lyngby
Publisher: Technical University of Denmark (DTU)
Original language: English
Main Research Area: Technical/natural sciences
Electronic versions:
Thesis_Zohreh_LaiDastjerdi.pdf
Publication: Research › Ph.D. thesis – Annual report year: 2013

**Optimization of Quantum-state-preserving Frequency Conversion by Changing the Input Signal**
We optimize frequency conversion based on four-wave mixing by using the input modes of the system. We find a 10-25 % higher conversion efficiency relative to a pump-shaped input signal.

**General information**
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, University of Oregon, Bell Laboratories
Authors: Andersen, L. M. (Intern), Reddy, D. V. (Ekstern), McKinstrie, C. J. (Ekstern), Rottwitt, K. (Intern), Raymer, M. G. (Ekstern)
Publication date: 2013
Event: Abstract from Australia and New Zealand Conference on Optics and Photonics (ANZCOP 2013), Perth, Australia.
Main Research Area: Technical/natural sciences
Nonlinear optics, Four-wave mixing, Quantum information processing
Source: dtu
Source-ID: u::10042
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013

**Parametric amplification and phase preserving amplitude regeneration of a 640 Gbit/s RZ-DPSK signal**
We report the first experimental demonstration of parametric amplification and all-optical phase-preserving amplitude regeneration for a 640 Gbit/s return-to-zero (RZ) differential phase-shift keying (DPSK) optical time division multiplexed (OTDM) signal. In the designed gain-flattened single-pump fiber optical parametric amplifier (FOPA), 620 fs short optical pulses are successfully amplified with 15 dB gain with error-free performance and less than 1 dB power penalty. Phase-preserving amplitude regeneration based on gain saturation in the FOPA is carried out for optical signals with degraded optical signal-to-noise ratio. An improvement of 2.2 dB in receiver sensitivity at a bit-error-ratio of 10−9 has been
successfully achieved after regeneration, together with 13.3 dB net gain.
Parametric Amplification of a 640 Gbit/s RZ-DPSK Signal

We report the first demonstration and characterization of parametric amplification of a 640 Gbit/s RZ-DPSK OTDM signal. With proper design of the fiber parametric amplifier, error-free amplification with less than 1 dB penalty has been achieved.

General information
State: Published
Organisations: Department of Photonics Engineering, High-Speed Optical Communication, Fiber Optics, Devices and Non-linear Effects
Number of pages: 3
Pages: JW2A.21
Publication date: 2013

Bibliographical note
This paper was published in Optics Express and is made available as an electronic reprint with the permission of OSA. The paper can be found at the following URL on the OSA website: http://www.opticsinfobase.org/oe/abstract.cfm?uri=oe-21-22-25944. Systematic or multiple reproduction or distribution to multiple locations via electronic or other means is prohibited and is subject to penalties under law.

Periodically-poled Fibers for Quantum Frequency Conversion with the effects of Third-order Nonlinearities

The ability to obtain quantum-state-preserving frequency conversion is an integral part of any quantum communication system [1,2]. Several solutions have been proposed including sum-frequency generation in second-order nonlinear materials and four-wave mixing (FWM) in third-order materials. It has been proposed to impose an effective second-order nonlinearity in optical fibers by periodical thermal poling of the fiber [3, 4]. This gives the advantage from FWM of mode-matching the generated states to those of the transmission fiber. In addition one gets the benefit of large frequency shifts
Quantum and Raman Noise in a Depleted Fiber Optical Parametric Amplifier

The noise properties of both phase-sensitive and phase-insensitive saturated parametric amplifiers are studied using a semi-classical approach. Vacuum fluctuations as well as spontaneous Raman scattering are included in the analysis.

Quantum Frequency Conversion of Single-Photon States by Three and Four-Wave Mixing

Three- or four-wave mixing can convert a single-photon wave packet to a new frequency. By tailoring the shapes of the pump(s), one can achieve add/drop functionality for different temporally orthogonal wave packets.
Quantum-state-preserving Frequency Conversion Using Four-wave Mixing
We investigate the applicability of temporal multiplexing using four-wave mixing Bragg scattering for quantum frequency conversion. Various pump shapes are considered and we find that a large selectivity is possible for all the pump shapes.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, University of Oregon, Bell Laboratories
Authors: Andersen, L. M. (Intern), Reddy, D. V. (Ekstern), McKinstrie, C. J. (Ekstern), Raymer, M. G. (Ekstern), Rottwitt, K. (Intern)
Number of pages: 2
Pages: NTu1A.2
Publication date: 2013

Host publication information
Title of host publication: Nonlinear Optics Technical Digest
Publisher: Optical Society of America
Main Research Area: Technical/natural sciences
Conference: Nonlinear Optics (NLO 2013), Kohala Coast, Hawaii, United States, 21/07/2013 - 21/07/2013
Nonlinear optics, four-wave mixing, Quantum information and processing
Electronic versions:
NLO_2013_NTu1A.2.pdf

Bibliographical note
This paper was published in Nonlinear Optics Technical Digest and is made available as an electronic reprint with the permission of OSA. The paper can be found at the following URL on the OSA website:
http://www.opticsinfobase.org/abstract.cfm?URI=NLO-2013-NTu1A.2. Systematic or multiple reproduction or distribution to multiple locations via electronic or other means is prohibited and is subject to penalties under law.
Source: Bibtex
Source-ID: um:c11735c7f5b97900683e90e479
Publication: Research - peer-review › Article in proceedings – Annual report year: 2013

Raman and loss induced quantum noise in a depleted phase-sensitive parametric amplifier
We study the quantum noise properties of phase-sensitive fiber optical parametric amplifiers in deep pump depletion using a semiclassical approach. Amplified spontaneous emission and spontaneous Raman scattering are included in the analysis.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects
Authors: Friis, S. M. M. (Intern), Rottwitt, K. (Intern)
Number of pages: 1
Publication date: 2013
Event: Abstract from Australia and New Zealand Conference on Optics and Photonics (ANZCOP 2013), Perth, Australia.
Main Research Area: Technical/natural sciences
Optical parametric amplifier, Quantum noise, Pump depletion
Electronic versions:
Friis_ANZCOP2013.pdf
Source: dtu
Source-ID: u::10292
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013

Raman and loss induced quantum noise in depleted fiber optical parametric amplifiers
We present a semi-classical approach for predicting the quantum noise properties of fiber optical parametric amplifiers. The unavoidable contributors of noise, vacuum fluctuations, loss-induced noise, and spontaneous Raman scattering, are included in the analysis of both phase-insensitive and phase-sensitive amplifiers. We show that the model agrees with earlier fully quantum approaches in the linear gain regime, whereas in the saturated gain regime, in which the classical equations are valid, we predict that the amplifier increases the signal-to-noise ratio by generating an amplitude-squeezed
state of light. Also, in the same process, we analyze the quantum noise properties of the pump, which is difficult using standard quantum approaches, and we discover that the pump displays complicated dynamics in both the linear and the nonlinear gain regimes.

**General information**
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Bell Laboratories
Authors: Friis, S. M. M. (Intern), Rottwitt, K. (Intern), McKinstrie, C. J. (Ekstern)
Pages: 29320-29331
Publication date: 2013
Main Research Area: Technical/natural sciences

**Publication information**
Journal: Optics Express
Volume: 21
Issue number: 24
ISSN (Print): 1094-4087
Ratings:
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
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.587 SNIP 2.145 CiteScore 3.85
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.579 SNIP 2.606 CiteScore 4.04
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.943 SNIP 2.466
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 3.092 SNIP 2.669
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 3.195 SNIP 2.393
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 3.27 SNIP 2.032
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 3.233 SNIP 2.326
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 3.334 SNIP 2.379
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 2.833 SNIP 2.499
Short-pulse propagation in fiber optical parametric amplifiers

Fiber optical parametric amplifiers (FOPAs) are attractive because they can provide large gain over a broad range of central wavelengths, depending only on the availability of a suitable pump laser. In addition, FOPAs are suitable for the realization of all-optical signal processing functionalities and can operate with a potentially low noise figure with respect to erbium-doped fiber amplifiers and Raman amplifiers, when working in phase-sensitive configurations. A characterization of the signal distortion mechanisms introduced by FOPAs is relevant for investigating the applicability of FOPAs for the amplification of high speed signals with bit rates in excess of 1 Tbit/s per wavelength channel.

The work presented in this thesis focuses on the distortion mechanisms affecting signals amplified by single-pump phase-insensitive FOPAs. The noise due to the cross coupling between the signal and the pump is also investigated. The pump-to-signal noise transfer has been recognized as one of the major noise source in FOPAs. This is due to the fast response of FOPAs (few fs), because of which intensity fluctuations of the pump cause an instantaneous gain modulation. The intensity modulation transfer from the pump to the signal is experimentally investigated for pump modulation frequencies up to 27 GHz and also in the saturation regime. A good agreement is found both with the theoretical model in the case of an undepleted pump and with the numerical results in the saturation regime, showing that the intensity modulation transfer can be reduced in saturated FOPAs.

In order to characterize propagation impairments such as dispersion and Kerr effect, affecting signals reaching multi-terabit per second per channel, short pulses on the order of 500 fs need to be considered. Therefore, a short pulses fiber laser source is implemented to obtain an all-fiber system. The advantages of all-fiber-systems are related to their reliability, long-term stability and compactness. Fiber optical parametric chirped pulse amplification is promising for the amplification of such signals thanks to the inherent compatibility of FOPAs with fiber optical systems and high gain over broad bandwidths. In particular, the amplification of 400 fs pulses is investigated in a single-pump fiber optical chirped pulse amplification scheme. First, a dynamic characterization is carried out both in unsaturated and saturated regimes and, then, amplification of short pulses compatible with Tbaud systems is experimentally demonstrated for the first time. This opens the way to the demonstration of a first broadband amplification scheme for highspeed signals reaching multi-terabit per second per channel.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, High-Speed Optical Communication
Authors: Cristofori, V. (Intern), Rottwitt, K. (Intern), Peucheret, C. (Intern)
Number of pages: 125
Publication date: 2013

Publication information
Place of publication: Kgs. Lyngby
Temporal mode selectivity by frequency conversion in second-order nonlinear optical waveguides

We explore theoretically the feasibility of using frequency conversion by sum- or difference-frequency generation, enabled by three-wave-mixing, for selectively multiplexing orthogonal input waveforms that overlap in time and frequency. Such a process would enable a drop device for use in a transparent optical network using temporally orthogonal waveforms to encode different channels. We model the process using coupled-mode equations appropriate for wave mixing in a uniform second-order nonlinear optical medium pumped by a strong laser pulse. We find Green functions describing the process, and employ Schmidt (singular-value) decompositions thereof to quantify its viability in functioning as a coherent waveform discriminator. We define a selectivity figure of merit in terms of the Schmidt coefficients, and use it to compare and contrast various parameter regimes via extensive numerical computations. We identify the most favorable regime (at least in the case of no pump chirp) and derive the complete analytical solution for the same. We bound the maximum achievable selectivity in this parameter space. We show that including a frequency chirp in the pump does not improve selectivity in this optimal regime. We also find an operating regime in which high-efficiency frequency conversion without temporal-shape selectivity can be achieved while preserving the shapes of a wide class of input pulses. The results are applicable to both classical and quantum frequency conversion.
Transverse Field Dispersion in the Generalized Nonlinear Schrödinger Equation: Four Wave Mixing in a Higher Order Mode Fiber

An improved version of the generalized nonlinear Schrödinger equation is derived, which takes into account the correct dispersion of the transverse field distribution. The new improved version of the generalized nonlinear Schrödinger equation is verified to give the same results as the standard implementation for a simple single mode soliton propagation example. As opposed to the standard implementation, the new implementation is able to reproduce pulsed four wave mixing observed experimentally in a higher order mode fiber.
Phase Sensitive Amplification using Parametric Processes in Optical Fibers

Phase sensitive amplification using the parametric processes in fiber has the potential of delivering high gain and broadband operation with ultralow noise. It is able to regenerate both amplitude and phase modulated signals, simultaneously, with the appropriate design. This thesis concerns, in specific, the design and optimization of such phase sensitive amplifiers (PSAs). For phase sensitive amplification in highly nonlinear fibers, optima points of operation have been identified for both the standard and the novel high stimulated Brillouin scattering (SBS) threshold highly nonlinear fiber types. The regeneration capability of PSAs on phase encoded signal in an optical link has been optimized. Flat-top phase sensitive profile has been synthesized. It is able to provide simultaneous amplitude and phase noise squeezing, with enhanced phase noise margin compared to conventional designs. Further, phase sensitive parametric processes in a nano-engineered silicon waveguide have been measured experimentally for the first time. Numerical optimizations show that with reduced waveguide propagation loss and reduced carrier life time, larger signal phase sensitive extinction ratio is achievable. Finally, preliminary simulations were carried out to investigate the inline amplification properties of such PSAs, and their pulse shaping capabilities.

General information
State: Published
Organisations: Department of Photonics Engineering, High-Speed Optical Communication, Fiber Optics, Devices and Non-linear Effects
Authors: Kang, N. (Intern), Peucheret, C. (Intern), Rottwitt, K. (Intern), Seoane, J. (Intern)
Number of pages: 96
Publication date: Nov 2012

Publication information
Place of publication: Kgs. Lyngby
Publisher: Technical University of Denmark (DTU)
Original language: English
Main Research Area: Technical/natural sciences
Electronic versions:
20130117_1838_NKAN_PhD_Thesis.pdf
Publication: Research - Ph.D. thesis – Annual report year: 2013

All-Fiber Raman Probe
The design and development of an all-in-fiber probe for Raman spectroscopy are presented in this Thesis. Raman spectroscopy is an optical technique able to probe a sample based on the inelastic scattering of monochromatic light. Due to its high specificity and reliability and to the possibility to perform real-time measurements with little or no sample preparation, Raman spectroscopy is now considered an invaluable analytical tool, finding application in several
fields including medicine, defense and process control. When combined with fiber optics technology, Raman spectroscopy allows for the realization of flexible and minimally-invasive devices, able to reach remote or hardly accessible samples, and to perform in-situ analyses in hazardous environments.

The work behind this Thesis focuses on the proof-of-principle demonstration of a truly in-fiber Raman probe, where all parts are realized by means of fiber components. Assuming the possibility to use a fiber laser with a fundamental radiation at 1064nm, in-fiber efficient second harmonic generation is achieved by optically poling the core of the waveguide delivering the excitation light to the sample. In this way, Raman spectroscopy in the visible range can be performed. The simultaneous delivery of the excitation light and collection of the Raman signal from the sample are achieved by means of a doubleclad fiber, whose core and inner cladding act as independent transmission channels. A double-clad fiber coupler allows for the recovery of the collected Raman scattering from the inner-cladding region of the double-clad fiber, thus replacing the bulk dichroic component normally used to demultiplex the pump and Raman signal. A tunable Rayleigh-rejection filter based on a liquid filled-photonic bandgap fiber is also demonstrated in this work. The integration of the devices described in this Thesis allows for the realization of a complete fiber Raman probe, where also the generation of the excitation radiation is done in-fiber.

**General information**

State: Published  
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Department of Environmental Engineering, Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology  
Authors: Brunetti, A. C. (Intern), Rottwitt, K. (Intern), Gernaey, K. (Intern)  
Number of pages: 122  
Publication date: 2012

**Publication information**

Place of publication: Kgs. Lyngby  
Publisher: Technical University of Denmark (DTU)  
Original language: English  
Main Research Area: Technical/natural sciences  
Electronic versions:

Brunetti_PhDThesis_282_29..PDF  
Publication: Research › Ph.D. thesis – Annual report year: 2012

**All-in-fibre Rayleigh-rejection filter for raman spectroscopy**

An in-line Rayleigh-rejection filter for Raman spectroscopy is demonstrated. The device is based on a solid-core photonic crystal fibre infiltrated with a high-index liquid. At room temperature, the filter exhibits a full width at half maximum bandwidth of 143 nm and an insertion loss of 0.3 dB. A shift of 32 nm of the central wavelength is demonstrated by increasing the temperature from 22 to 70°C. FEM simulations of the spectra at different temperatures showed good agreement with experimental results. The device was successfully employed to perform Raman spectroscopy of a sample of cyclohexane and allowed for a fourfold attenuation of the Rayleigh scattered light.

**General information**

State: Published  
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, NKT Photonics A/S, FOSS, Danish Fundamental Metrology  
Authors: Brunetti, A. C. (Intern), Scolari, L. (Ekstern), Lund-Hansen, T. (Ekstern), Weirich, J. (Ekstern), Rottwitt, K. (Intern)  
Pages: 275-276  
Publication date: 2012  
Main Research Area: Technical/natural sciences

**Publication information**

Journal: Electronics Letters  
Volume: 48  
Issue number: 5  
ISSN (Print): 0013-5194  
Ratings:  
BFI (2017): BFI-level 1  
Web of Science (2017): Indexed Yes  
BFI (2016): BFI-level 1  
Scopus rating (2016): SJR 0.442 SNIP 0.882 CiteScore 1.35  
Web of Science (2016): Indexed yes  
BFI (2015): BFI-level 1  
Scopus rating (2015): SJR 0.497 SNIP 1.011 CiteScore 1.31
We demonstrate experimentally and numerically an unexpected spectral asymmetry in the saturated-gain spectrum of single-pump fiber optical parametric amplifiers. The interaction between higher-order four-wave mixing products and dispersive waves radiated as an effect of third-order dispersion influences the energy transfer to the signal, depending on its detuning with respect to the pump, and breaks the symmetry of the gain expected from phase-matching considerations in unsaturated amplifiers. The asymmetry feature of the saturated spectrum is shown to particularly depend on the dispersion characteristics of the amplifier and shows local maxima for specific dispersion values.
General information
State: Published
Organisations: Department of Photonics Engineering, High-Speed Optical Communication, Fiber Optics, Devices and Non-linear Effects
Authors: Lali-Dastjerdi, Z. (Intern), Rottwitt, K. (Intern), Galili, M. (Intern), Peucheret, C. (Intern)
Pages: 15530-15539
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
Journal: Optics Express
Volume: 20
Issue number: 14
ISSN (Print): 1094-4087
Ratings:
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
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.587 SNIP 2.145 CiteScore 3.85
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.579 SNIP 2.606 CiteScore 4.04
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.943 SNIP 2.466
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 3.092 SNIP 2.669
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 3.195 SNIP 2.393
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 3.27 SNIP 2.032
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 3.233 SNIP 2.326
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 3.334 SNIP 2.379
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 2.833 SNIP 2.499
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 2.688 SNIP 2.193
Demonstration of Cascaded In-Line Single-Pump Fiber Optical Parametric Amplifiers in Recirculating Loop Transmission

The performance of cascaded single-pump fiber optical parametric amplifiers (FOPAs) is experimentally studied for the first time using recirculating loop transmission with 80-km dispersion managed spans. Error-free performance has been achieved over 320 km for 40-Gbit/s CSRZ-OOK and CSRZ-DPSK modulated signals.

Effects of nonlinear phase modulation on Bragg scattering in the low-conversion regime.

In this paper, we consider the effects of nonlinear phase modulation on frequency conversion by four-wave mixing (Bragg scattering) in the low-conversion regime. We derive the Green functions for this process using the time-domain collision method, for partial collisions, in which the four fields interact at the beginning or the end of the fiber, and complete collisions, in which the four fields interact at the midpoint of the fiber. If the Green function is separable, there is only one output Schmidt mode, which is free from temporal entanglement. We find that nonlinear phase modulation always chirps the input and output Schmidt modes and renders the Green function formally nonseparable. However, by pre-chirping the
pumps, one can reduce the chirps of the Schmidt modes and enable approximate separability. Thus, even in the presence of nonlinear phase modulation, frequency conversion with arbitrary pulse reshaping is possible, as predicted previously.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, New Jersey Institute of Technology, Bell Laboratories
Authors: Andersen, L. M. (Intern), Cargill, D. S. (Ekstern), McKinstrie, C. J. (Ekstern), Rottwitt, K. (Intern), Moore, R. O. (Forskerdatabase)
Pages: 27454-27475
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
Journal: Optics Express
Volume: 20
Issue number: 24
ISSN (Print): 1094-4087
Ratings:
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
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.587 SNIP 2.145 CiteScore 3.85
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.579 SNIP 2.606 CiteScore 4.04
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.943 SNIP 2.466
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 3.092 SNIP 2.669
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 3.195 SNIP 2.393
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 3.27 SNIP 2.032
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 3.233 SNIP 2.326
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 3.334 SNIP 2.379
Web of Science (2005): Indexed yes
We consider the effects of nonlinear phase modulation (NPM) on frequency conversion by Bragg scattering. Previously we found that arbitrary mode reshaping without temporal entanglement (separability) was possible. When NPM is included, the modes are chirped and the separability is no longer complete. However, the mode phase shifts are reduced by pump pre-chirping.

Effects of nonlinear phase modulation on low-conversion four-wave mixing Bragg scattering

We consider the effects of nonlinear phase modulation (NPM) on frequency conversion by Bragg scattering. Previously we found that arbitrary mode reshaping without temporal entanglement (separability) was possible. When NPM is included, the modes are chirped and the separability is no longer complete. However, the mode phase shifts are reduced by pump pre-chirping.

Four Wave Mixing using Intermodal Nonlinearities

The nonlinear process of four-wave mixing (FWM) enables coupling of energy between wavelengths. This is useful for both optical amplification and wavelength conversion. A crucial prerequisite for the process is phase matching. This PhD project investigates how higher order modes (HOMs) in fibers can be used as an additional degree of freedom to fulfill this phase matching requirement.

The design of a specialty few mode fiber is discussed. This fiber allows for FWM between a pump in the Ytterbium gain region with a signal at telecommunication wavelengths, hereby generating a new wavelength around 800 nm. Using pulse propagation simulations this process is investigated in details, which includes examining the impact of the overlap integrals and outer diameter (OD) variations along the fiber.

Experimentally, it is demonstrated that using a long period grating (LPG), it is possible to convert 99.8 % of the power from the fundamental mode to a specific HOM in the custom designed fiber. Furthermore, it is demonstrated that stable
propagation in the considered fiber is possible, without deterioration from mode coupling.

Finally, modulation instability and multiple FWM signal and idler lines are demonstrated in the 1 μm wavelength range in the developed large mode area fiber. This is enabled by operating in the LP07 mode, which has anomalous dispersion despite having a mode area of 618 μm² at 1064 nm. In the experiments the maximum employed pump pulse energy was 105 μJ. This was restricted by the available laser since the fiber is capable of pulse energies of 540 μJ before the onset of dielectric breakdown. This represents a factor of 12 increase compared to photonic crystal fibers (PCFs) with similar anomalous dispersion characteristics. Also a peripheral result was obtained as a continuum from 680 to 1600 nm entirely in the LP07 mode was demonstrated.
Gain optimization in fiber optical parametric amplifiers by combining standard and high-SBS threshold highly nonlinear fibers

Combining Al-doped and Ge-doped HNLFs as gain media in FOPAs is proposed and optimized, resulting in efficient SBS mitigation while circumventing the additional loss of the high SBS threshold Al-doped fiber.

High-energy fiber lasers at non-traditional colours, via intermodal nonlinearities

We propose exploiting intermodal four-wave mixing for energy-scalable tuneable fiber lasers, hitherto restricted to low powers, constrained by dispersion-tailoring limitations in PCFs. Conversion over an octave, at mJ-energy-levels, appears feasible.

High-Energy Four-Wave Mixing, with Large-Mode-Area Higher-Order Modes in Optical Fibres

We demonstrate, for the first time, four-wave mixing, in the 1-μm spectral regime, in an LMA silica fiber. Pumping a 618-μm2 LP07 mode (λ₀ = 1038.4 nm) with a 1064.6-nm Nd:YAG laser results in the generation of modulation instability, and multiple Stokes/anti-Stokes lines, opening up the prospect of high-energy parametric processes with fibers.
Nonlinear Properties of Soft Glass Waveguides

This thesis builds around the investigation into using soft glass materials for mid-infrared and THz applications. Soft glasses is a term that covers a wide range of chemical compositions where many are yet to be fully investigated. The work in this thesis is separated in two parts, the mid-infrared applications and the THz applications.

In the mid-infrared, it is investigated whether soft glasses are a suitable candidate for supercontinuum generation (SCG). A few commercially available fluoride fibers are tested for their zero dispersion wavelength (ZDW), a key property when determining the possibility of SCG in a fiber. A group of soft glasses, namely the chalcogenides, are known to display two photon absorption (TPA) which could potentially limit the SCG when this is initiated within the frequency range where this nonlinear process occur. An analytic model is presented to estimate the soliton self frequency shift (SSFS), another key element in SCG, when TPA is present. To show the validity of this model, it is used with chalcogenide fiber parameters from the literature to show that a frequency shift is limited due to the TPA effect.

It is only resent, that soft glass materials have come into focus for THz applications, thus these materials remain relatively unknown. A selection of GeAsSe chalcogenides is investigated to determine whether they have potential as transparent glasses for THz applications. In order to do so, these glasses are tested experimentally in both transmission and reflection measurements to determine the complex refractive index. Knowledge of the index and loss is key in determining if these glasses will be interesting candidates for future applications.

PM Raman fiber laser at 1679 nm

We demonstrate a PM Raman fiber laser emitting light at 1679 nm. The laser has an slope efficiency of 67 % and an output power of more than 275mWwith a 27 pm linewidth.
Polarization-maintaining higher-order mode fiber module with anomalous dispersion at 1 μm

This Letter demonstrates a polarization-maintaining higher-order mode fiber module that has anomalous dispersion at 1 μm. The group velocity dispersion of the module is measured, showing a split of the two polarization axes. The excellent polarization-maintaining properties of the relevant fiber modes for the higher-order mode fiber are likewise demonstrated employing a new simple method for the measurement of the beat length of higher-order modes at a single wavelength. The higher-order fiber module is intended for group velocity dispersion compensation.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, OFS Fitel Denmark ApS, OFS Laboratories
Authors: Larsen, S. H. M. (Intern), Pedersen, M. E. V. (Intern), Grüner-Nielsen, L. (Ekstern), Yan, M. F. (Ekstern), Monberg, E. M. (Ekstern), Wisk, P. W. (Ekstern), Rottwitt, K. (Intern)
Pages: 4170-4172
Publication date: 2012
Main Research Area: Technical/natural sciences
Publication information
Journal: Optics Letters
Volume: 37
Issue number: 20
ISSN (Print): 0146-9592
Ratings:
  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
Pulse Distortion in Saturated Fiber Optical Parametric Chirped Pulse Amplification
Fiber optical parametric chirped pulse amplification is experimentally compared for different chirped pulses in the picosecond regime. The amplified chirped pulses show distortion appearing as pedestals after recompression when the amplifier is operated in saturation.
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.
Quantum Frequency Conversion by Four-wave Mixing Using Bragg Scattering

Two theoretical models for frequency conversion (FC) using nondegenerate four-wave mixing are compared, and their range of validity are discussed. Quantum-statepreserving FC allows for arbitrary reshaping of states for an appropriate pump selection.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Bell Laboratories, University of Oregon
Authors: Andersen, L. M. (Intern), Rottwitt, K. (Intern), McKinstrie, C. J. (Ekstern), Raymer, M. G. (Ekstern)
Number of pages: 2
Pages: JTu5A.18
Publication date: 2012
Quantum frequency translation by four-wave mixing in a fiber: low-conversion regime.
In this paper we consider frequency translation enabled by Bragg scattering, a four-wave mixing process. First we introduce the theoretical background of the Green function formalism and the Schmidt decomposition. Next the Green functions for the low-conversion regime are derived perturbatively in the frequency domain, using the methods developed for three-wave mixing, then transformed to the time domain. These results are also derived and verified using an alternative time-domain method, the results of which are more general. For the first time we include the effects of convecting pumps, a more realistic assumption, and show that separability and arbitrary reshaping is possible. This is confirmed numerically for Gaussian pumps as well as higher-order Hermite-Gaussian pumps.
Quantum-state-preserving optical frequency conversion and pulse reshaping by four-wave mixing
Nondegenerate four-wave mixing driven by two pulsed pumps transfers the quantum state of an input signal pulse to an output idler pulse, which is a frequency-converted and reshaped version of the signal. By varying the pump shapes appropriately, one can connect signal and idler pulses with arbitrary durations and shapes. This process enables a variety of functions required by quantum information networks.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Bell Laboratories, University of Oregon
Authors: McKinstrie, C. J. (Ekstern), Andersen, L. M. (Intern), Raymer, M. G. (Ekstern), Rottwitt, K. (Intern)
Pages: 053829
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
Journal: Physical Review A (Atomic, Molecular and Optical Physics)
Quantum-state-preserving optical pulse reshaping and multiplexing by four-wave mixing in a fiber
Nondegenerate four-wave mixing driven by two pulsed pumps transfers the quantum state of an input signal pulse to an output idler pulse, which is a frequency-translated and reshaped version of the signal. By varying the pump shapes appropriately, one can connect signal and idler pulses with arbitrary durations and shapes. This process enables a variety of functions required by quantum information networks.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Bell Laboratories, University of Oregon
Authors: McKinstrie, C. J. (Ekstern), Andersen, L. M. (Intern), Rottwitt, K. (Intern), Raymer, M. G. (Ekstern)
Number of pages: 2
Pages: JW4A.117
Publication date: 2012

Host publication information
Title of host publication: CLEO Technical Digest
Publisher: Optical Society of America
Main Research Area: Technical/natural sciences
Conference: Conference on Lasers and Electro-Optics (CLEO 2012), San Jose, CA, United States, 06/05/2012 - 06/05/2012
Electronic versions: 0EC74d01.pdf

Bibliographical note
This paper was published in CLEO Technical Digest and is made available as an electronic reprint with the permission of OSA. The paper can be found at the following URL on the OSA website. Systematic or multiple reproduction or distribution to multiple locations via electronic or other means is prohibited and is subject to penalties under law.

Raman Probe Based on Optically-Poled Double-Core Fiber
A Raman probe based on an optically-poled double-core fiber. In-fiber SHG allows for Raman spectroscopy of DMSO at 532nm when illuminating the fiber with 1064nm light. The fiber structure provides independent excitation and collection paths.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, RISE ICT
Authors: Brunetti, A. C. (Intern), Margulis, W. (Ekstern), Rottwitt, K. (Intern)
Number of pages: 3
Pages: STu1F.6
Publication date: 2012

Host publication information
Title of host publication: Imaging and Applied Optics Technical Digest
Publisher: Optical Society of America
Main Research Area: Technical/natural sciences
Conference: Optical Sensors (2012 SENSORS), Monterey, CA, United States, 24/06/2012 - 24/06/2012

Bibliographical note
This paper was published in Imaging and Applied Optics Technical Digest and is made available as an electronic reprint with the permission of OSA. The paper can be found at the following URL on the OSA website:
Raman probes based on optically-poled double-clad fiber and coupler

Two fiber Raman probes are presented, one based on an optically-poled double-clad fiber and the second based on an optically-poled double-clad fiber coupler respectively. Optical poling of the core of the fiber allows for the generation of enough 532nm light to perform Raman spectroscopy of a sample of dimethyl sulfoxide (DMSO), when illuminating the waveguide with 1064nm laser light. The Raman signal is collected in the inner cladding, from which it is retrieved with either a bulk dichroic mirror or a double-clad fiber coupler. The coupler allows for a substantial reduction of the fiber spectral background signal conveyed to the spectrometer.
Synthesis of flat-top gain response in fiber phase sensitive amplifiers with improved phase noise regeneration tolerance

Flat-top gain responses can be obtained together with two-level flat phase responses in fiber phase sensitive amplifiers by introducing moderate saturation together with dispersion engineering, resulting in an improved phase regeneration performance.

Bibliographical note
This paper was published in Optics Express and is made available as an electronic reprint with the permission of OSA. The paper can be found at the following URL on the OSA website: http://www.opticsinfobase.org/oe/abstract.cfm?uri=oe-20-27-28563. Systematic or multiple reproduction or distribution to multiple locations via electronic or other means is prohibited and is subject to penalties under law.

Source: Bibtex
Source-ID: urn:6c5d64d4d51c6eae52b7343d18233cec
Publication: Research - peer-review › Journal article – Annual report year: 2012

Synthesis of flat-top gain response in fiber phase sensitive amplifiers with improved phase noise regeneration tolerance
Flat-top gain responses can be obtained together with two-level flat phase responses in fiber phase sensitive amplifiers by introducing moderate saturation together with dispersion engineering, resulting in an improved phase regeneration performance.

General information
State: Published
Organisations: Department of Photonics Engineering, High-Speed Optical Communication, Fiber Optics, Devices and Non-linear Effects
Authors: Kang, N. (Intern), Seoane, J. (Intern), Rottwitt, K. (Intern), Peucheret, C. (Intern)
Number of pages: 2
Pages: CM4N.8
Publication date: 2012

Host publication information
Title of host publication: CLEO Technical Digest
Publisher: Optical Society of America
Main Research Area: Technical/natural sciences
Conference: Conference on Lasers and Electro-Optics (CLEO 2012), San Jose, CA, United States, 06/05/2012 - 06/05/2012
Electronic versions:
CM4N.8.pdf

Bibliographical note
This paper was published in Technical Digest and is made available as an electronic reprint with the permission of OSA. The paper can be found at the following URL on the OSA website:
Accurate simulation of Raman amplified lightwave synthesized frequency sweeper

A lightwave synthesized frequency sweeper using a Raman amplifier for loss compensation is presented together with a numerical model capable of predicting the shape of individual pulses as well as the overall envelope of more than 100 pulses. The generated pulse envelope consists of 116 pulses with constant peak power and no significant growth of noise. The numerical simulation is based on careful measurements of the physical properties of the individual components and a well established Raman amplifier model. Very good agreement between the measured and the simulated data is found.

(C) 2011 Optical Society of America

General information
State: Published
Organisations: Fiber Optics, Devices and Non-linear Effects, Department of Photonics Engineering
Authors: Pedersen, A. T. (Intern), Olesen, A. S. (Intern), Rottwitt, K. (Intern)
Pages: 1493-1497
Publication date: 2011
Main Research Area: Technical/natural sciences

Publication information
Journal: Optical Society of America. Journal B: Optical Physics
Volume: 28
Issue number: 6
ISSN (Print): 0740-3224
Ratings:
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
Asymmetric Gain-Saturated Spectrum in One-pump Fiber Optical Parametric Amplifiers

The effect of third-order dispersion on the saturated-gain in fiber optical parametric amplifiers is experimentally demonstrated. A possible interpretation in terms of dispersive waves, which change the power transfer to the signal, is presented.

General information
State: Published
Organisations: High-Speed Optical Communication, Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects
Authors: Lali-Dastjerdi, Z. (Intern), Rottwitt, K. (Intern), Galili, M. (Intern), Peucheret, C. (Intern)
Pages: 316-317
Publication date: 2011

Host publication information
Title of host publication: 2011 IEEE Photonics Conference
Publisher: IEEE
ISBN (Print): 978-1-4244-8940-4
Main Research Area: Technical/natural sciences
Dispersive wave, Fiber optical parametric amplifier (FOPA), Gain saturation, Third-order dispersion (TOD)
DOIs: 10.1109/PHO.2011.6110554
Links: http://www.photonicsconferences.org/PHOTONICS2011/

Bibliographical note
This paper was published in Optical Society of America. Journal B: Optical Physics and is made available as an electronic reprint with the permission of OSA. The paper can be found at the following URL on the OSA website: http://www.opticsinfobase.org/abstract.cfm?URI=josab-28-6-1493. Systematic or multiple reproduction or distribution to multiple locations via electronic or other means is prohibited and is subject to penalties under law.
Source: orbit
Source-ID: 277625
Publication: Research - peer-review › Journal article – Annual report year: 2011
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.

Relative intensity noise, Intensity modulation transfer, Noise figure, Fibre optic parametric amplifiers, RIN magnification coefficient

DOIs: 10.1109/ICTON.2011.5970950

Links: http://www.ict.kth.se/MAP/FMI/Negonet/icton2011/

Experimental methods and modeling techniques for description of cell population heterogeneity

With the continuous development, in the last decades, of analytical techniques providing complex information at single cell level, the study of cell heterogeneity has been the focus of several research projects within analytical biotechnology. Nonetheless, the complex interplay between environmental changes and cellular responses is yet not fully understood, and the integration of this new knowledge into the strategies for design, operation and control of bioprocesses is far from being an established reality. Indeed, the impact of cell heterogeneity on productivity of large scale cultivations is acknowledged but seldom accounted for. In order to include population heterogeneity mechanisms in the development of novel bioprocess control strategies, a reliable mathematical description of such phenomena has to be developed. With this review, we search to summarize the potential of currently available methods for monitoring cell population heterogeneity as well as model frameworks suitable for describing dynamic heterogeneous cell populations. We will furthermore underline the highly important coordination between experimental and modeling efforts necessary to attain a reliable quantitative description of cell heterogeneity, which is a necessity if such models are to contribute to the development of improved control of bioprocesses.

General information

State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Systems Microbiology, Department of Systems Biology, Center for Microbial Biotechnology, Fiber Optics, Devices and Non-linear Effects, Department of Photonics Engineering, CHEC Research Centre, Aalborg University, University of Groningen, Ghent University, University of Copenhagen
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.

General information
State: Published
Organisations: High-Speed Optical Communication, Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects
Authors: Kang, N. (Intern), Lund-Hansen, T. (Intern), Seoane, J. (Intern), Rottwitt, K. (Intern), Peucheret, C. (Intern)
Pages: 103-104
Publication date: 2011

Host publication information
Title of host publication: 2011 IEEE Photonics Conference
Publisher: IEEE
ISBN (Print): 978-1-4244-8940-4
Main Research Area: Technical/natural sciences
Fiber-optical parametric amplifier (FOPA), Phase sensitive amplifier (PSA)
DOIs: 10.1109/PHO.2011.6110446

Bibliographical note
Oral presentation.
Source: orbit
Source-ID: 312292
Publication: Research - peer-review › Article in proceedings – Annual report year: 2011

Formation and characterization of varied size germanium nanocrystals by electron microscopy, Raman spectroscopy, and photoluminescence

Germanium nanocrystals are being extensively examined. Their unique optical properties (brought about by the quantum confinement effect) could potentially be applied in wide areas of nonlinear optics, light emission and solid state memory etc. In this paper, Ge nanocrystals embedded in a SiO2 matrix were formed by complementary metal-oxide-semiconductor compatible technology, e.g. plasma enhanced chemical vapour deposition and annealing. Different sizes of the Ge nanocrystals were prepared and analyzed by transmission electron microscopy with respect to their size, distribution and crystallization. The samples of different size Ge nanocrystals embedded in the SiO2 matrix were characterized by Raman spectroscopy and photoluminescence. Interplayed size and strain effect of Ge nanocrystals was demonstrated by Raman spectroscopy after excluding the thermal effect with proper excitation laser power. It was clarified that two strong emission peaks at 3.19 eV and 4.40 eV are from the interface between Ge nanocrystals and SiO2 matrix.

General information
State: Published
Organisations: Nanophotonic Devices, Department of Photonics Engineering, Energy and Materials, Department of Chemistry, Fiber Optics, Devices and Non-linear Effects
Authors: Ou, H. (Intern), Ou, Y. (Intern), Liu, C. (Intern), Berg, R. W. (Intern), Rottwitt, K. (Intern)
Pages: 643-651
Publication date: 2011
Main Research Area: Technical/natural sciences

Publication information
Journal: Optical Materials Express
Volume: 1
Issue number: 4
ISSN (Print): 2159-3930
Ratings:
Web of Science (2017): Indexed yes
Scopus rating (2016): SJR 1.082 SNIP 1.287 CiteScore 2.74
Web of Science (2016): Indexed yes
Scopus rating (2015): SJR 1.406 SNIP 1.411 CiteScore 3.07
Web of Science (2015): Indexed yes
Scopus rating (2014): SJR 1.546 SNIP 1.653 CiteScore 3.17
Frequency Stepped Pulse Train Modulated Wind Sensing Lidar

In this paper a wind sensing lidar utilizing a Frequency Stepped Pulse Train (FSPT) is demonstrated. One of the advantages in the FSTP lidar is that it enables direct measurement of wind speed as a function of distance from the lidar. Theoretically the FSPT lidar continuously produces measurements as is the case with a CW lidar, but at the same time with a spatial resolution, and without the range ambiguity originating from e.g. clouds. The FSPT lidar utilizes a frequency sweeping source for generation of the FSPT. The source generates a pulse train where each pulse has an optical carrier frequency shifted a set quantity relative to the carrier frequency of the previous pulse. In the scheme presented here, the measured frequency depends on the distance from which the signal originates. The measured frequency is related to the Doppler frequency shift induced by the wind and an integer number of frequency shifts corresponding to a specific distance. The spatial resolution depends on the repetition rate of the pulses in the pulse train. Directional wind measurements are shown and compared to a CW lidar measurement. The carrier to noise ratio of the FSPT lidar compared to a CW lidar is discussed as well as the fundamental differences between the two systems. In the discussion we describe the most dominant noise sources in our system and what influences these have on the FSPT lidar’s ability to measure under different scattering conditions.
Full and semi-analytic analyses of two-pump parametric amplification with pump depletion

This paper solves the four coupled equations describing non-degenerate four-wave mixing, with the focus on amplifying a signal in a fiber optical parametric amplifier (FOPA). Based on the full analytic solution, a simple approximate solution describing the gain is developed. The advantage of this new approximation is that it includes the depletion of the pumps, which is lacking in the usual quasi-linearized approximation. With the proposed model it is thus simple to predict the gain of a FOPA, which we demonstrate with a highly nonlinear fiber to show that an undepleted FOPA can produce a flat gain spectrum with a bandwidth in the 100-nm range, centered on the zero-dispersion wavelength. When running the FOPA in depletion, this range can be slightly increased. © 2011 Optical Society of America.

Bibliographical note

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Source: orbit
Source-ID: 285501
Publication: Research - peer-review › Conference article – Annual report year: 2011
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, regeneration, 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) (}

Impact of the Scalar Approximation on the Prediction of the Group Velocity Dispersion

A detailed study of the impact of using a scalar approximation to the wave equation on the prediction of the group velocity dispersion is shown by comparing predictions against results obtained by using a full-vectorial wave equation and measurements of commercially available optical fibers. The effect is significant for fibers with large waveguide dispersion, such as highly nonlinear and dispersion compensating fibers.
Influence of Two Photon Absorption on Soliton Self-Frequency Shift
The creation of mid-infrared supercontinua necessitates the use of soft-glass fibers. However, some materials, like chalcogenide, have a substantial two photon absorption. We introduce a model for soliton self-frequency shift that successfully includes this effect.

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.
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.

General information
State: Published
Organisations: High-Speed Optical Communication, Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects
Pages: 1145-1147
Publication date: 2011

Host publication information
Title of host publication: 2011 Quantum Electronics Conference & Lasers and Electro-Optics (CLEO/IQEC/PACIFIC RIM)
Publisher: The Australian Optical Society
ISBN (Print): 978-0-9775657-7-1
Main Research Area: Technical/natural sciences
DOIs:
10.1109/IQEC-CLEO.2011.6194076
Links:
Source: orbit
Source-ID: 283018

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 phase insensitive fibre optic parametric amplifiers is presented.

General information
State: Published
Organisations: Fiber Optics, Devices and Non-linear Effects, Department of Photonics Engineering, High-Speed Optical Communication
Pages: 314-315
Publication date: 2011

Host publication information
Title of host publication: 2011 IEEE Photonics Conference
Publisher: IEEE
ISBN (Print): 978-1-4244-8940-4
Main Research Area: Technical/natural sciences
DOIs:
10.1109/PHO.2011.6110552
Links:
http://www.photonicsconferences.org/PHOTONICS2011/

Bibliographical note
Oral presentation.
Source: orbit
Source-ID: 286888
Publication: Research - peer-review › Article in proceedings – Annual report year: 2011
Simultaneous measurements of wind speed at multiple distances without range ambiguity

General information
State: Published
Organisations: Fiber Optics, Devices and Non-linear Effects, Department of Photonics Engineering
Authors: Olesen, A. S. (Intern), Pedersen, A. T. (Intern), Rottwitt, K. (Intern)
Publication date: 2011

Host publication information
Title of host publication: Proceedings from the 16th Coherent Laser Radar Conference (CLRC)
Main Research Area: Technical/natural sciences
Electronic versions:
Paper Olesen.pdf
Links:
http://space.hsv.usra.edu/clrc2011/introduction.html
Source: orbit
Source-ID: 312449
Publication: Research - peer-review › Article in proceedings – Annual report year: 2011

Size-effect of germanium nanocrystals
Different sizes of Ge nanocrystals embedded in a SiO2 matrix were formed by PECVD, and analyzed by TEM. Size effect of Ge nanocrystals was demonstrated by Raman spectroscopy after excluding the thermal effect.

General information
State: Published
Organisations: Nanophotonic Devices, Department of Photonics Engineering, Energy and Materials, Department of Chemistry, Fiber Optics, Devices and Non-linear Effects
Authors: Ou, H. (Intern), Ou, Y. (Intern), Liu, C. (Intern), Berg, R. W. (Intern), Rottwitt, K. (Intern)
Publication date: 2011

Host publication information
Title of host publication: Proceedings of CLEO:2011
Publisher: Optical Society of America
Main Research Area: Technical/natural sciences
Conference: Conference on Lasers and Electro-Optics 2011, Baltimore, MD, United States, 01/05/2011 - 01/05/2011
Semiconductor material, Nanomaterial
Electronic versions:
JWA60.pdf
Links:
http://www.cleoconference.org/
Source: orbit
Source-ID: 276681
Publication: Research - peer-review › Article in proceedings – Annual report year: 2011

The Raman Contribution to the Intensity Dependent Refractive Index in Optical Fibers
We report on the Raman contribution to the intensity dependent refractive index in step-index fibers with germanium doped silica core. The IR value is found to be 0.157 ± 0.07 for a field weighted germanium concentration between 5 and 25 mol %.

General information
State: Published
Organisations: Fiber Optics, Devices and Non-linear Effects, Department of Photonics Engineering, OFS Fitel Denmark ApS
Authors: Pedersen, M. E. V. (Intern), Pálsson, T. (Ekstern), Jespersen, K. G. (Ekstern), Jakobsen, D. (Ekstern), Pálsdóttir, B. (Ekstern), Rottwitt, K. (Intern)
Pages: 571-572
Publication date: 2011

Host publication information
Title of host publication: 2011 IEEE Photonics Conference (PHO)
Publisher: IEEE
Uniform and reproducible stirring in a microbioreactor

At present, research in bioprocess science and engineering increasingly requires fast and accurate analytical data (rapid testing) that can be used for investigation of the interaction between bioprocess operation conditions and the performance of the bioprocess. Miniaturization is certainly an attractive option that potentially allows for obtaining vast amounts of experimental data. Microbioreactors indeed have clear advantages, like small volume (and thus small footprint), little or no need for cleaning (one time usage), high throughput (multiple microbioreactors in parallel), high information content and control capabilities. Even though microbioreactors have many advantages, it is important to bear in mind that they also have issues related to their size and handling. Evaporation, proper and reliable stirring, interconnections between micro and macro world are just some of the burning problems that need to be addressed. In addition, signal collection of different process variables in microbioreactors is not straightforward. It relies on analytical methods which are not sufficiently developed at the moment. Moreover signal collection is not cheap and straightforward. Another important question is which microbioreactor volume is optimal while keeping in mind the final objective – application. Do we need a sample or not? Do we talk about cells in suspension or adhered on some substrate? Final microbioreactor design should thus strongly depend on the final goal of a specific microbioreactor application. In order to address some of these questions, we are currently investigating and developing a microbioreactor platform with a reactor volume up to 1ml, as we believe that this volume is of interest to many industrial applications. It is widely known that stirring plays a very important role in achieving successful cultivations by promoting uniform process conditions and – for aerobic cultivations – a high oxygen transfer rate. In this contribution, the development of a suitable, reliable and reproducible stirrer in a microbioreactor for batch and continuous cultivation of S.cerevisiae will be demonstrated.

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Microbial Biotechnology, Department of Systems Biology, Fiber Optics, Devices and Non-linear Effects, Department of Photonics Engineering
Authors: Bolic, A. (Intern), Eliasson Lantz, A. (Intern), Rottwitt, K. (Intern), Gernaey, K. (Intern)
Publication date: 2011
Event: Abstract from 8th European Congress of Chemical Engineering, Berlin, Germany.
Main Research Area: Technical/natural sciences
Electronic versions:
prod21320318728586.ANB_ECCE8_abstract[1].pdf
Source: orbit
Source-ID: 312231
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2011

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.

General information
State: Published
Organisations: Fiber Optics, Devices and Non-linear Effects, Department of Photonics Engineering
Authors: Svane, A. S. (Intern), Lund-Hansen, T. (Intern), Rishøj, L. S. (Intern), Rottwitt, K. (Intern)
Pages: JThA14
Publication date: 2011
Influence of variations of the GVD on wavelength conversion at second gain region of a parametric process
Impact on the second gain region in a parametric process, caused by random variations of the group velocity dispersion along the fiber is demonstrated. The model includes both pump depletion and fiber loss.

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.

Raman assisted lightwave synthesized frequency sweeper
We present a Lightwave Synthesized Frequency Sweeper comprising a Raman amplifier for loss compensation. The generated pulse train contains 123 pulses and has a flat signal level as well as a low noise level.
Raman Scattering in a Dimethyl Sulfoxide-Filled Hollow-Core Photonic Crystal Fiber

General information
State: Published
Organisations: Fiber Optics, Devices and Non-linear Effects, Department of Photonics Engineering
Authors: Brunetti, A. C. (Intern), Rottwitt, K. (Intern)
Publication date: 2010

Host publication information
Title of host publication: Xxii International Conference on Raman Spectroscopy
Place of publication: Melville
Publisher: American Institute of Physics

Series: Aip Conference Proceedings
Number: 1267
ISSN: 0094-243X
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 269700
Publication: Research - peer-review › Book chapter – Annual report year: 2010

Signal-to-background ratio enhancement in the raman spectrum of a DMSO-filled hollow-core Photonic Crystal Fiber

General information
State: Published
Organisations: Fiber Optics, Devices and Non-linear Effects, Department of Photonics Engineering
Authors: Brunetti, A. C. (Intern), Rottwitt, K. (Intern)
Publication date: 2010
Event: Poster session presented at 22nd International Conference On Raman Spectroscopy, Boston, United States.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 268330
Publication: Research - peer-review › Poster – Annual report year: 2010

Stimulated Raman scattering in microstructured polymer optical fibers

General information
State: Published
Organisations: Fiber Sensors and Supercontinuum Generation, Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects
Authors: Nielsen, K. (Intern), Brunetti, A. C. (Intern), Pakarzadeh, H. (Ekstern), Rottwitt, K. (Intern)
Pages: 11
Publication date: 2010
Conference: Photonics Europe 2010, Brussels, Belgium, 12/04/2010 - 12/04/2010
Main Research Area: Technical/natural sciences

Publication information
Journal: Proceedings of SPIE, the International Society for Optical Engineering
Volume: 7714
ISSN (Print): 0277-786X
Ratings:
BFI (2017): BFI-level 1
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 0.42 SNIP 0.245
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Amplitude regeneration of RZ-DPSK signals in single-pump fiber-optic parametric amplifiers

The input power tolerance of a single-pump fiber-optic parametric amplifier (FOPA) is experimentally shown to be enhanced for return-to-zero differential phase-shift keying (RZ-DPSK) modulation compared to RZ ON-OFF keying modulation at 40 Gb/s. The improved nonlinear tolerance is exploited to demonstrate amplitude regeneration of a distorted RZ-DPSK signal in a gain-saturated FOPA. An optical signal-to-noise ratio penalty of 3.5 dB after amplitude distortion is shown to be reduced to 0.2 dB after the FOPA, thus clearly demonstrating the regenerative nature of saturated FOPAs for RZ-DPSK modulation.

General information
State: Published
Organisations: High-Speed Optical Communication, Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects
Pages: 872-874
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: IEEE Photonics Technology Letters
Volume: 21
Issue number: 13
ISSN (Print): 1041-1135
Ratings:
BFI (2017): BFI-level 2
Enhancing the capacity of light: biowatch: it's time for a healthcheck

General information
State: Published
Organisations: Fiber Optics, Devices and Non-linear Effects, Department of Photonics Engineering
Authors: Rottwitt, K. (Intern), Brunetti, A. C. (Intern), Laeegsaaard, J. (Intern), Weirich, J. (Intern), Rishøj, L. S. (Intern), Liu, X. (Intern), Scolari, L. (Intern), Pedersen, M. E. V. (Intern), Pedersen, A. T. (Intern), Steffensen, H. (Intern), Wei, L. (Intern)
Number of pages: 267
Pages: 75-87
Publication date: 2009

Fabrication of Ge nanocrystals doped silica-on-silicon waveguides and observation of their strong quantum confinement effect

Germanium (Ge) nanocrystals embedded in silica matrix is an interesting material for new optoelectronic devices. In this paper, standard silica-on-silicon waveguides with a core doped by Ge nanocrystals were fabricated using plasma enhanced chemical vapour deposition and reactive ion etching. The cross-sectional waveguide structures were investigated by scanning electron microscopy. Transmission of the waveguide was measured using a broadband light source covering the wavelength range from 500 nm to 1700 nm, and the results were compared against transmission through a standard waveguide. Strong absorption peaks at 1056.8 nm, 1263.2 nm and 1406 nm were observed. These are assigned to the quantum confinement effect in Ge nanocrystals in the core. Putting Ge nanocrystals in a waveguide enables easy material characterisation and potential application in an integrated lightwave circuit device. PACS 42.82.-m · 42.50.-p · 1.07.Ta

General information
State: Published
Organisations: Diode Lasers and LED Systems, Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects
Authors: Ou, H. (Intern), Rottwitt, K. (Intern)
Pages: 57-60
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: Applied Physics B
Volume: 96
Issue number: 1
ISSN (Print): 0946-2171
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.801 SNIP 1.058 CiteScore 1.91
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.931 SNIP 1.112 CiteScore 1.74
Frequency dependence of the pump-to-signal RIN transfer in fiber optical parametric amplifiers

Using a numerical model, the frequency dependence of the pump-to-signal RIN transfer in FOPAs has been investigated. The model includes fiber loss, pump depletion as well as difference in group velocity among interacting beams.

General information

State: Published

Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects
High-speed signal processing using highly nonlinear optical fibres: [invited]

We review recent progress in all-optical signal processing techniques making use of conventional silica-based highly nonlinear fibres. In particular, we focus on recent demonstrations of ultra-fast processing at 640 Gbit/s and above, as well as on signal processing of novel modulation formats relying on the phase of the optical field. Topics covered include all-optical switching of 640 Gbit/s and 1.28 Tbit/s serial data, wavelength conversion at 640 Gbit/s, optical amplitude regeneration of differential phase shift keying (DPSK) signals, as well as midspan spectral inversion for differential 8-state phase shift keying (D8PSK) signals.

Measurement and modeling of low-wavelength losses in silica fibers and their impact at communication Wavelengths

Using the cutback technique, the attenuation of four different silica step-index fibers is measured in the very wide wavelength range of 190-1700 nm. The measured spectra are deconvolved into components describing Rayleigh scattering, infrared losses, Urbach edge, anomalous loss, and different localized absorptions using a least squares fit. The evaluated Urbach edge is compared against results based on measurements on bulk glass samples and good agreement between the two is found. Furthermore, the Urbach edge is found to contribute significantly to the overall attenuation at communication wavelengths for two of the four fibers investigated.
Self-pulsation in Raman fiber amplifiers
Dynamic behavior caused by Brillouin scattering in Raman fiber amplifiers is studied. Modes of self-pulsation steady state oscillations are found. Their dependence on amplification scheme is demonstrated.

General information
State: Published
Organisations: Fiber Optics, Devices and Non-linear Effects, Department of Photonics Engineering, Structured Electromagnetic Materials
Authors: Pedersen, M. E. V. (Intern), Ott, J. R. (Intern), Rottwitt, K. (Intern)
Number of pages: 2
Pages: 1-2
Publication date: 2009

Host publication information
Title of host publication: Proceedings of the 11th International Conference on Transparent Optical Networks. Azores, Portugal, 2009
Publisher: IEEE
Main Research Area: Technical/natural sciences
Conference: 11th International Conference on Transparent Optical Networks, Azores, Portugal, 28/06/2009 - 28/06/2009
Electronic versions:
Pedersen.pdf
DOI: 10.1109/ICTON.2009.5185179

Bibliographical note
IEEE catalog number: CFP09485-CDR
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Source: orbit
Source-ID: 249605
Publication: Research - peer-review › Article in proceedings – Annual report year: 2009

Self-pulsation threshold of Raman amplified Brillouin fiber cavities
An implicit equation for the oscillation threshold of stimulated Brillouin scattering from Raman amplified signals in fibers with external feedback is derived under the assumption of no depletion. This is compared to numerical investigations of Raman amplification schemes showing good agreement for high reflectivities. For low reflectivities and high attenuation or long fibers, the assumption of no depletion is shown not to be valid. In these cases the effects of the depletion on the self-pulsation is examined.

General information
State: Published
Organisations: Structured Electromagnetic Materials, Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects
Authors: Ott, J. R. (Intern), Pedersen, M. E. V. (Intern), Rottwitt, K. (Intern)
Pages: 16166-16176
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: Optics Express
Volume: 17
Issue number: 8
ISSN (Print): 1094-4087
Ratings:
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
Spontaneous emission from saturated parametric amplifiers

Noise performance of parametric amplifiers is typically calculated assuming un-depleted operation. However, in many applications especially when applied as regenerative amplifiers in systems based on phase shift keyed modulation schemes, this assumption is not valid. Here we show the impact on accumulated spontaneous emission for a parametric amplifier operated in saturation.

General information
State: Published
Organisations: Fiber Optics, Devices and Non-linear Effects, Department of Photonics Engineering, Structured Electromagnetic Materials
Authors: Rottwitt, K. (Intern), Ott, J. R. (Intern), Steffensen, H. (Intern), Ramachandran, S. (Intern)
Pages: 1-2
Publication date: 2009

Suppression of Brillouin scattering in fibre-optical parametric amplifier by applying temperature control and phase modulation

An increased gain in a fibre-optical parametric amplifier through suppression of stimulated Brillouin scattering is demonstrated by applying a temperature distribution along the fibre for a fixed phase modulation of the pump. The temperature distribution slightly impacts the gain spectrum.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Department of Micro- and Nanotechnology
Authors: Lorenzen, M. R. (Intern), Noordegraaf, D. (Intern), Nielsen, C. V. (Intern), Odgaard, O. (Ekstern), Grüner-Nielsen, L. (Ekstern), Rottwitt, K. (Intern)
Pages: 125-127
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: Electronics Letters
Volume: 45
Issue number: 2
ISSN (Print): 0013-5194
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
730-nm optical parametric conversion from near- to short-wave infrared band

A record 730 nm parametric conversion in silica fiber from the near-infrared to the short-wave infrared band is reported and analyzed. A parametric gain in excess of 30 dB was measured for a signal at 1300 nm (with corresponding idler at 2030 nm). This conversion was performed in a travelling single-pass one-pump parametric architecture and high efficiency is achieved by a combination of high peak power and a nonlinear fiber with a reduced fourth-order dispersion coefficient.

General information
State: Published
Organisations: Fiber Optics, Devices and Non-linear Effects, Department of Photonics Engineering
Authors: Boggio, J. (Ekstern), Windmiller, J. (Ekstern), Knutzen, M. (Ekstern), Jiang, R. (Ekstern), Bres, C. (Ekstern), Alic, N. (Ekstern), Stossel, B. (Ekstern), Rottwitt, K. (Intern), Radic, S. (Ekstern)
Pages: 5435-5443
Publication date: 2008
Main Research Area: Technical/natural sciences

Publication information
Journal: Optics Express
Volume: 16
Issue number: 8
ISSN (Print): 1094-4087
Ratings:
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
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.587 SNIP 2.145 CiteScore 3.85
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.579 SNIP 2.606 CiteScore 4.04
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.943 SNIP 2.466
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 3.092 SNIP 2.669
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 3.195 SNIP 2.393
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 3.27 SNIP 2.032
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 3.23 SNIP 2.326
Web of Science (2006): Indexed yes
Brillouin suppression in a fiber optical parametric amplifier by combining temperature distribution and phase modulation

We demonstrate an increased gain in optical parametric amplifier through suppression of stimulated Brillouin scattering by applying a temperature distribution along the fiber resulting in a reduction of the required phase modulation.

Dynamic range enhancement and amplitude regeneration in single pump fibre optic parametric amplifiers using DPSK modulation

Input power dynamic range enhancement and amplitude regeneration of highly distorted signals are demonstrated experimentally for 40 Gbit/s RZ-DPSK in a single-pump fibre parametric amplifier with 22 dB small signal gain.
Fabrication of Ge Nanocrystals Doped Silica-on-Silicon Waveguides and Observation of Their Strong Quantum Confinement Effect

Standard silica-on-silicon waveguides with a core doped by Ge nanocrystals were fabricated using PECVD and RIE. Transmission of the waveguide was measured, and strong absorption peaks at 1056.8 nm, 1406 nm and 1263.2 nm were observed.

General information
State: Published
Organisations: Diode Lasers and LED Systems, Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects
Authors: Ou, H. (Intern), Rottwitt, K. (Intern)
Pages: 119-120
Publication date: 2008

Fiber Optical Trap Deposition of Carbon Nanotubes on fiber End-faces in a Modelocked Laster

General information
State: Published
Organisations: High-Speed Optical Communication, Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Optical Transmission and Network Elements
Authors: Ji, H. (Intern), Oxenløwe, L. K. (Intern), Gallili, M. (Intern), Rottwitt, K. (Intern), Jeppesen, P. (Intern), Grünernielsen, L. (Ekstern)
Pages: 1702-1703
Publication date: 2008
Gain characteristics of a saturated fiber optic parametric amplifier

In this work we discuss saturation performance of a fiber optic parametric amplifier. A simple numerical model is described and applied to specific cases. A system experiment using a saturated amplifier illustrates a 4 dB improvement in required signal to noise ratio for a fixed bit error ratio.

General information
State: Published
Organisations: Fiber Optics, Devices and Non-linear Effects, Department of Photonics Engineering, Optical Transmission and Network Elements
Authors: Rottwitt, K. (Intern), Lorenzen, M. R. (Intern), Noordegraaf, D. (Intern), Peucheret, C. (Intern)
Pages: 62-64
Publication date: 2008

Host publication information
Title of host publication: Anniversary International Conference on Transparent Optical Networks
Publisher: IEEE
ISBN (Print): 978-1-4244-2625-6
Main Research Area: Technical/natural sciences
Conference: 10th Anniversary International Conference on Transparent Optical Networks, Athens, Greece, 22/06/2008 - 22/06/2008
Electronic versions:
Rottwitt.pdf
DOIs:
10.1109/ICTON.2008.4598371

Bibliographical note
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Source: orbit
Source-ID: 222195
Publication: Research - peer-review › Article in proceedings – Annual report year: 2008

Ge nanoclusters in PECVD-deposited glass caused only by heat treatment

This paper reports the formation of Ge nanoclusters in a multi-layer structure consisting of alternating thin films of Ge-doped silica glass and SiGe, deposited by plasma-enhanced chemical vapor deposition (PECVD) and post annealed at 1100 °C in N2 atmosphere. We studied the annealed samples by transmission electron microscopy (TEM) and Raman spectroscopy. As-deposited and annealed samples were analyzed by secondary ion mass spectroscopy (SIMS). TEM investigation shows that Ge nanoclusters were formed in the as-deposited SiGe layer and the SiGe layer was transformed into a silicon dioxide layer embedded with Ge nanoclusters after annealing. These nanoclusters are crystalline and varied in size. There were no clusters in the Ge-doped glass layer. Raman spectra verified the existence of crystalline Ge clusters. The positional shift of the Ge vibrational peak with the change of the focus depth indicates that the distribution of the stress applied to the Ge clusters varies with depth. SIMS measurements show clearly the dramatic O increase in the as-deposited SiGe layer after annealing. The creation of Ge nanoclusters by the combination of PECVD and annealing makes possible the application in complicated waveguide components.

General information
State: Published
Organisations: Diode Lasers and LED Systems, Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Materials and Surface Engineering, Department of Mechanical Engineering, Department of Management Engineering, Energy and Materials, Department of Chemistry, DTU Danchip
Authors: Ou, H. (Intern), Rørdam, T. P. (Intern), Rottwitt, K. (Intern), Grumsen, F. B. (Intern), Horsewell, A. (Intern), Berg, R. W. (Intern), Shi, P. (Intern)
Pages: 177-181
Low Wavelength Loss of Germanium Doped Silica Fibers

Attenuation of four step-index fibers are measured with high accuracy from 190 nm to 1700 nm. The spectra are deconvolved into different contributions and the influence of the Urbach edge at transmission wavelengths is investigated.

Mode profiling of optical fibers at high laser powers

This paper describes the development of a measuring equipment capable of analysing the beam profile at high optical powers emitted by delivery fibers used in manufacturing processes. Together with the optical delivery system, the output beam quality from the delivery fiber and the shape of the focused spot can be determined. The analyser is based on the principle of a rotating wire being swept though the laser beam, while the reflected signal is recorded [1]. By changing the incident angle of the rotating rod from 0° to 360° in relation to the fiber, the full profile of the laser beam is obtained. Choosing a highly reflective rod material and a sufficiently high rotation speed, these measurements can be done with high laser powers, without any additional optical elements between the fiber and analyzer. The performance of the analyzer was evaluated by coupling laser light into different fibers, and measuring the output beam profiles. Fibers with different core diameters and different surface qualities were tested.
Raman Amplifiers in Optical Fibers: Principles and Applications

General information
State: Published
Organisations: Fiber Optics, Devices and Non-linear Effects, Department of Photonics Engineering
Authors: Rottwitt, K. (Intern)
Publication date: 2008

Structure, stability properties, and nonlinear dynamics of lateral modes of a broad area semiconductor laser

General information
State: Published
Organisations: Nanophotonics Theory and Signal Processing, Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Diode Lasers and LED Systems, Center for Nanoteknologi
Authors: Blaaberg, S. (Intern), Rottwitt, K. (Intern), Petersen, P. M. (Intern), Tromborg, B. (Intern)
Publication date: Jan 2007

All-Fiber parametric Conversion From Near-to Short-Wave Infrared Band

General information
State: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Authors: Boggio, J. C. (Ekstern), Knutzen, M. (Ekstern), Bres, C. (Ekstern), Alic, N. (Ekstern), Windmiller, J. (Ekstern), Stossel, B. (Ekstern), Rottwitt, K. (Intern), Radic, S. (Ekstern)
Publication date: 2007

Host publication information
Title of host publication: European Conference on Optical Communication
Main Research Area: Technical/natural sciences
Brillouin scattering in fiber optical parametric amplifiers

Ge nanoclusters in PECVD-deposited glass after heat treating and electron irradiation

This paper reports the formation of Ge nanoclusters in silica glass thin films deposited by plasma-enhanced chemical vapor deposition (PECVD). We studied the samples by transmission electron microscopy (TEM) and Raman spectroscopy after annealing. TEM investigation shows that the Ge nanoclusters at two areas were formed by different mechanisms. The Ge nanoclusters formed in a single row along the interface of a silicon substrate and the silica glass film by annealing during high-temperature heat treatment. Ge nanoclusters did not initially form in the bulk of the film but could be subsequently formed by the electron-beam irradiation. The interface between the silicon substrate and the silica glass film was investigated by Raman spectroscopy. The shift of the Raman peaks around 286.8 cm⁻¹ and 495 cm⁻¹ suggests that the interface is a Si₁₋ₓGeₓ alloy film and that the composition x varies along the film growth direction.
Ge-nanostructures doped silica-on-silicon waveguides

General information
State: Published
Organisations: Department of Photonics Engineering, Fibers & Nonlinear Optics
Authors: Ou, H. (Intern), Rørdam, T. P. (Intern), Rottwitt, K. (Intern), Grumsen, F. (Ekstern), Horsewell, A. (Ekstern), Berg, R. W. (Ekstern)
Publication date: 2007

Host publication information
Title of host publication: Proceedings of SPIE : APOC
Volume: 6782
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 211767
Publication: Research - peer-review » Article in proceedings – Annual report year: 2007

Recent advances in optical fiber Raman and parametric amplifiers
Ultra-compact silica-on-silicon microresonators by etching deep trenches

General information
State: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Authors: Ou, H. (Intern), Rottwitt, K. (Intern), Philipp, H. T. (Intern)
Number of pages: 1
Pages: WB3
Publication date: 2007

Host publication information
Title of host publication: ECIO proceedings
Place of publication: Kgs. Lyngby
Publisher: COM.DTU
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 199198
Publication: Research - peer-review › Article in proceedings – Annual report year: 2007

Thulium distributed-feedback fiber lasers

Rare-earth doped silica bers have already shown their huge potential in the telecom and sensing industry. The most successful of all rare-earths today is erbium, well known for its ideal characteristics for optical amplification in the telecommunications frequency window. Yet, interest is growing in the utilization of other rare-earth doped bers to reach wavelengths outside the standard telecom range of 1525 nm - 1565 nm. Other rare-earths include ytterbium, neodymium and thulium. Thulium has potential applications in optical amplification, remote sensing, optical radar (aka. lidar), spectroscopy and frequency conversion. Thulium has a primary emission band from 1700-2100 nm, depending the chemical compounds of the silica ber. The primary absorption bands are centered around 790 nm and 1560-1600 nm which oers the opportunity of high-power pumps. This ph.d. project is devoted to characterization of thulium in silica and the fabri- cation, design and characterization of coherent Distributed Feed-Back (DFB) ber lasers incorporating thulium as the active laser medium. Our recent results have proved that single-frequency, single-polarization, narrow-linewidth (tens of kHz) operation of thulium doped DFB ber lasers is possible. Demonstrations of single-frequency lasers have, until now, been achieved at 1740 nm, 1984 nm and at a record-breaking 2090 nm. The 1740 nm laser has been boosted to 60 mW
of output power with a linewidth of only 3 kHz and implemented in a plug-and-play turnkey system with SMF28-APC output in collaboration with Koheras A/S (www.koheras.dk).

**General information**
State: Published
Organisations: Department of Photonics Engineering, Fibers & Nonlinear Optics
Authors: Agger, S. D. (Intern), Povlsen, J. H. (Intern), Rottwitt, K. (Intern)
Number of pages: 164
Publication date: May 2006

**Publication information**
ISBN (Print): 87-90974-88-3
Original language: English
Main Research Area: Technical/natural sciences
Electronic versions:
Soeren_AggerPHDthesis.pdf
Source: orbit
Source-ID: 197548
Publication: Research › Ph.D. thesis – Annual report year: 2006

**Attenuation in silica-based optical fibers**
In this thesis on attenuation in silica based optical fibers results within three main topics are reported. Spectral attenuation measurements on transmission fibers are performed in the wide wavelength range 290 nm – 1700 nm. The measured spectral attenuation is analyzed with special emphasis on absorption peaks in order to investigate the cause of an unusual high attenuation in a series of transmission fibers. Strong indications point to Ni2+ in octahedral coordination as being the cause of the high attenuation. The attenuation of fibers having a high core refractive index is analyzed and the cause of the high attenuation measured in such fibers is described as being due to scattering of light on fluctuations of the core diameter. A novel semi-empirical model for predicting the attenuation of high index fibers is presented. The model is shown to be able to predict the attenuation of high index fibers having viscosity profiles similar to those for which the model was calibrated but not of fibers having dissimilar viscosity profiles. The model is improved by including the viscosity profiles of the fibers. A set of fibers is produced demonstrating that by carefully designing the index profile as well as the viscosity profile a lower attenuation of high index fibers can be obtained. The design of dispersion compensating fibers using the super mode approach is described, the object being to design dispersion compensating fibers for dispersion compensating fiber modules having a low attenuation, described by a high figure of merit. The major trade offs encountered when designing dispersion compensating fibers with high figure of merit are to obtain a very negative dispersion, low attenuation and low micro bend loss at the same time. The model for predicting the attenuation of high index fibers is used for the optimization process and results are reported of a dispersion compensating fiber having a record high figure of merit of 470 ps/(nm dB).

**General information**
State: Published
Organisations: Department of Photonics Engineering, Fibers & Nonlinear Optics
Authors: Wandel, M. E. (Intern), Rottwitt, K. (Intern), Povlsen, J. H. (Intern)
Number of pages: 91
Publication date: Mar 2006

**Publication information**
ISBN (Print): 978-87-90974-91-6
Original language: English
Main Research Area: Technical/natural sciences
Electronic versions:
Marie_Wandel_PhD_fina051204l.pdf
Source: orbit
Source-ID: 205783
Publication: Research › Ph.D. thesis – Annual report year: 2006

**A Generic Lightwave Integrated Chip (GLIC) for fast high-resolution wavelength monitoring**

**General information**
State: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Authors: Ging, J. (Ekstern), Larkin, A. (Ekstern), O’Dowd, R. (Ekstern), Haiyan, O. (Intern), Rottwitt, K. (Intern)
Pages: 6183-02
Publication date: 2006
Deep glass etched microring resonators based on silica-on-silicon technology

Microring resonators fabricated on silica-on-silicon technology using deep glass etching are demonstrated. The fabrication procedures are introduced and the transmission spectrum of a resonator is presented.

General information
State: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Authors: Ou, H. (Intern), Rottwitt, K. (Intern), Philipp, H. T. (Intern)
Pages: 581-583
Publication date: 2006
Main Research Area: Technical/natural sciences

Publications information
Journal: Electronics Letters
Volume: 42
Issue number: 10
ISSN (Print): 0013-5194
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.442 SNIP 0.882 CiteScore 1.35
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.497 SNIP 1.011 CiteScore 1.31
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.522 SNIP 1.061 CiteScore 1.31
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.59 SNIP 1.155 CiteScore 1.45
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.631 SNIP 1.161 CiteScore 1.45
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.634 SNIP 1.098 CiteScore 1.44
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.637 SNIP 1.011
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.728 SNIP 1.072
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.843 SNIP 0.957
Ge-nanoclusters were formed by electron-beam irradiation in Ge-doped silica-on-silicon thin films. The size and density of the clusters can be controlled by the irradiation intensity and time.

General information
State: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering, Department of Management Engineering, Center for Nanotechnology
Authors: Ou, H. (Intern), Rørdam, T. P. (Intern), Rottwitt, K. (Intern), Grumsen, F. B. (Intern), Horsewell, A. (Intern)
Pages: 532-534
Publication date: 2006
Main Research Area: Technical/natural sciences

Publication information
Journal: ELECTRONICS LETTERS
Volume: 42
Issue number: 9
ISSN (Print): 0013-5194
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.442 SNIP 0.882 CiteScore 1.35
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.497 SNIP 1.011 CiteScore 1.31
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.522 SNIP 1.061 CiteScore 1.31
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Novel deep glass etched microring resonators based on silica-on-silicon technology

General information
State: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Authors: Ou, H. (Intern), Rottwitt, K. (Intern), Philipp, H. T. (Intern)
Publication date: 2006
Event: Abstract from Integrated Photonics Research and Applications, Topical meeting or the Nanophotonics Topical Meeting, Uncasville, Connecticut, USA
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 189561
Raman amplification in optical fibers

General information
State: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Authors: Rottwitt, K. (Intern), Povlsen, J. H. (Intern)
Pages: 3597
Publication date: 2006
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Lightwave Technology
Volume: 23
Issue number: 11
ISSN (Print): 0733-8724
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.87 SJR 1.233 SNIP 1.881
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.689 SNIP 1.955 CiteScore 4.15
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.801 SNIP 2.423 CiteScore 4.23
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.533 SNIP 2.341 CiteScore 4.03
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.711 SNIP 2.335 CiteScore 3.21
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.605 SNIP 2.758 CiteScore 3.2
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.802 SNIP 2.411
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 2.312 SNIP 2.761
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 2.371 SNIP 2.423
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 2.467 SNIP 2.114
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 2.149 SNIP 2.603
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 2.939 SNIP 3.016
Web of Science (2005): Indexed yes
Supercontinuum generation in fibers infiltrated with liquid crystals

Supercontinuum generation in a capillary tube infiltrated with a nematic liquid crystal is investigated theoretically in the near infrared region. A liquid crystal with a high electronic nonlinearity is chosen, which makes it possible to generate 100 nm wide supercontinua using 100 ps pulses with peak power 1.5 kW in a 10 cm long waveguide. The possibility of tuning the spectrum of the generated Supercontinuum by changing the dispersion of the waveguide is also considered. It is found that the broadening of the spectrum in both the normal and anomalous regime is mainly due to self phase modulation, and therefore the dispersion of the waveguide is only of minor importance. The tuning of the dispersion is achieved by varying the temperature of the liquid crystal inside the capillary.
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<th>Web of Science</th>
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<td>2006</td>
<td>BFI-level 1</td>
<td>SJR 2.112 SNIP 1.884</td>
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<td>2002</td>
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<td>SJR 3.519 SNIP 1.678</td>
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<td>BFI-level 1</td>
<td>SJR 2.345 SNIP 1.202</td>
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Analyses of spectral efficiency and nonlinear tolerance of DPSK formats in 160-Gb/s Raman amplified systems
Five-channel 160-Gb/s wavelength-division-multiplexing (WDM) systems using ABA dispersion map and Raman amplification are investigated numerically. Transmission distance and system margin are evaluated for return-to-zero differential phase-shift keying (RZ-DPSK) and carrier-suppressed return-to-zero (CSRZ)-DPSK formats. The results show that RZ-DPSK can offer 2300-km system reach at large WDM channel spacing, while CSRZ-DPSK is more robust against nonlinear effects in the fibers and offers a reach of 1900 km at a spectral efficiency of 0.53 b/s/Hz. CSRZ-DPSK can also provide twice the dispersion tolerance of RZ-DPSK and larger spectral efficiency.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects
Authors: Xu, Z. (Intern), Rottwitt, K. (Intern), Jeppesen, P. (Intern)
Pages: 1552 - 1554
Publication date: 2005
Main Research Area: Technical/natural sciences

Publication information
Journal: I E E E Photonics Technology Letters
Volume: 17
Issue number: 7
ISSN (Print): 1041-1135
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.52 SJR 1.018 SNIP 1.279
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.263 SNIP 1.327 CiteScore 2.62
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.461 SNIP 1.614 CiteScore 2.78
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.487 SNIP 1.547 CiteScore 2.95
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.623 SNIP 1.706 CiteScore 2.46
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.51 SNIP 2.012 CiteScore 2.48
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.474 SNIP 1.623
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.775 SNIP 1.804
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Analyzing the fundamental properties of Raman amplification in optical fibers

The Raman response of germanosilicate fibers is presented. This includes not only the material dependence but also the relation between the spatial-mode profile of the light and the Raman response in the time and frequency domain. From the Raman-gain spectrum, information is derived related to the nonlinear refractive index due to nuclear motions and the Raman response function in the time domain. It is demonstrated that the Raman-gain coefficient may be reduced up to 60% if the signal propagates in the fundamental mode while the pump alternates between the fundamental mode and a higher order mode. A simple model shows that the time response related to the decay of phonons is significantly larger in germanate glass relative to silica glass. From the Raman gain, it is found that the contribution to the nonlinear refractive index from nuclear motions is reduced by a factor of 2 in germanate relative to silica glass.
Application of stimulated Raman scattering in optical fibers

General information
State: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Authors: Rottwitt, K. (Intern)
Publication date: 2005

Host publication information
Title of host publication: Proceedings ICOL 2005
Main Research Area: Technical/natural sciences
Conference: International conference on optics and optoelectronics, Dehradun, India, 01/01/2005
Source: orbit
Source-ID: 185499
Publication: Research - peer-review › Article in proceedings – Annual report year: 2005

Deep silica and silicon etching in silica-on-silicon waveguide technology

General information
State: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Authors: Ou, H. (Intern), Rottwitt, K. (Intern)
Pages: 518-521
Publication date: 2005

Host publication information
Title of host publication: European Conference on Integrated Optics: Proceedings
Volume: Paper ThPo 36
Main Research Area: Technical/natural sciences
Conference: 12th European Conference on Integrated Optics, Grenoble, France, 06/04/2005 - 06/04/2005
Source: orbit
Source-ID: 183163
Publication: Research - peer-review › Article in proceedings – Annual report year: 2005

Ge-Nanoclusters embedded in Ge-doped silica-on-silicon waveguides

General information
State: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Authors: Ou, H. (Intern), Rørdam, T. P. (Intern), Rottwitt, K. (Intern), Grumsen, F. (Ekstern), Horsewell, A. (Ekstern)
Publication date: 2005
Event: Abstract from Integrated Photonics Research and Applications Topical Meeting, San Diego, California, USA.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 183164
Publication: Research › Conference abstract for conference – Annual report year: 2005

Nonlinear germanium nanocluster doped planar waveguides

General information
State: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Authors: Rottwitt, K. (Intern), Ou, H. (Intern), Wandel, M. E. (Intern)
Publication date: 2005

Host publication information
Title of host publication: Proceedings Photonics North 2005
Main Research Area: Technical/natural sciences
Tunable photonic bandgap fiber based devices for optical networks

In future all optical networks one of the enabling technologies is tunable elements including reconfigurable routers, switches etc. Thus, the development of a technology platform that allows construction of tuning components is critical. Lately, microstructured optical fibers, filled with liquid crystals, have proven to be a candidate for such a platform. Microstructured optical fibers offer unique wave-guiding properties that are strongly related to the design of the air holes in the cladding of the fiber. These wave-guiding properties may be altered by filling the air holes with a material, for example a liquid crystal that changes optical properties when subjected to, for example, an optical or an electrical field. The
utilization of these two basic properties allows design of tunable optical devices for optical networks. In this work, we focus on applications of such devices and discuss recent results.

**High-Index Contrast Silicon Rich Silicon Nitride Optical Waveguides and Devices**

This research focused on the realization of high-density integrated optical devices made with high-index contrast waveguides. The material platform used for to develop these devices was modeled after standard silicon on silicon technology. The high-index waveguide core material was silicon rich silicon nitride. This provided a sharp contrast with silica and made low-loss waveguide bending radii less than 25mm possible. An immediate consequence of such small bending radii is the ability to make practical ring resonator based devices with a large free spectral range. Several ring resonator based devices have been demonstrated. Directly UV-written waveguides have also been used with high-index contrast ring resonators to make hybrid devices. These hybrid devices are interesting because of the possibility of making practical low insertion-loss devices that utilize the benefits of a high-index platform.

**Chapter 3**

**General information**

State: Published
Organisations: Department of Photonics Engineering
Authors: Rottwitt, K. (Intern)
Publication date: 2004
Dispersion and nonlinearity tolerance of modulation formats for 160 Gb/s systems
We compare the RZ-DQPSK modulation format in 160 Gb/s single channel systems with RZ, CSRZ, RZ-DPSK and CSRZ-DPSK for the first time. We find that RZ-DQPSK offers nearly three time better dispersion tolerance than CSRZ-DPSK.

Evaluation of modulation formats for 160 Gb/s transmission systems using Raman amplification
We evaluate 160 Gb/s systems with different modulation formats. RZ-DPSK gives best performance for a single channel system with 40% reach improvement compared to RZ, CSRZ-DPSK is more robust in a WDM system.
GE NANOCLUSTERS IN PLANAR GLASS WAVEGUIDES DEPOSITED BY PECVD

Germanium (Ge) has been widely used as the dopant in the core layer of planar glass waveguides to increase the refractive index because it gives a small propagation loss. Plasma enhanced chemical vapour deposition (PECVD) and flame hydrolysis deposition (FHD) are two main material deposition methods for waveguide components. For the first time to our best knowledge, this paper reports the formation of Ge nanoclusters in glass thin films deposited by using PECVD. Ge nanoclusters in glass have been demonstrated to have great potential for application to the nonlinear waveguide components. In this work we study the size and distribution of the nanoclusters by transmission electron microscopy (TEM) and Raman spectroscopy. The formation of the clusters is investigated by varying the Ge concentration in the glass and changing the annealing conditions such as temperature, atmosphere and time. The combined effect of a strong nonlinear glass material and a material platform that is well known from standard planar lightwave components makes this Ge nanoclusters material very promising for optical nonlinear waveguide components that are readily fabricated by using the same processing as standard waveguide components.

General information
State: Published
Organisations: Department of Photonics Engineering, Department of Chemistry
Authors: Haiyan, O. (Intern), Olsen, J. H. (Ekstern), Rottwitt, K. (Intern), Berg, R. W. (Intern)
Number of pages: 7
Publication date: 2004

Host publication information
Title of host publication: XX International Congress on Glass : September 26-October 1, 2004
Volume: Published on DVD by the organizers, The Ceramic Society of Japan, Glass Division
Place of publication: Kyoto, Japan
Publisher: Ceramic Society of Japan, Glass Division
Edition: XX

Series: International Congress on Glass
Number: XX
Main Research Area: Technical/natural sciences

Links:
http://www.kemi.dtu.dk/%7Eajo/rolf/kyoto.pdf

Bibliographical note
Extended abstract Paper
Source: orbit
Source-ID: 154278
Publication: Research - peer-review › Article in proceedings – Annual report year: 2004

Ge nanoclusters in planar glass waveguides deposited by PECVD tentative presentation

General information
State: Published
Organisations: Department of Photonics Engineering
Authors: Haiyan, O. (Intern), Olsen, J. H. (Ekstern), Rottwitt, K. (Intern), Berg, R. (Ekstern)
Pages: 1-6
Publication date: 2004

Host publication information
Title of host publication: 20th international congress on glass
Main Research Area: Technical/natural sciences
Conference: 20th international congress on glass, Kyoto, Japan, 01/01/2004
Source: orbit
Source-ID: 155775
Publication: Research - peer-review › Article in proceedings – Annual report year: 2004

Optimization of pumping schemes for 160-Gb/s single channel Raman amplified systems

Three different distributed Raman amplification schemes—backward pumping, bidirectional pumping, and second-order pumping—are evaluated numerically for 160-Gb/s single-channel transmission. The same longest transmission distance of 2500 km is achieved for all three pumping methods with a 105-km span composed of superlarge effective area fiber and
inverse dispersion fiber. For longest system reach, second-order pumping and backward pumping have larger pump power tolerance than bidirectional pumping, while the optimal span input signal power margin of second-order pumping is the largest and gets 5-dB improvement compared to backward pumping. Span loss tolerance increased to 140 km with more than 2000-km reach. Optimal signal power variation at both ends of the span can provide about 6-dB positive net gain.
Trenches for building blocks of advanced planar components

General information
State: Published
Organisations: Department of Photonics Engineering
Authors: Haiyan, O. (Intern), Rottwitt, K. (Intern)
Publication date: 2004
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 155774
Publication: Research - peer-review › Poster – Annual report year: 2004

Advances in silica-based integrated optics

General information
State: Published
Organisations: Department of Photonics Engineering
Pages: 2821-2834
Publication date: 2003
Main Research Area: Technical/natural sciences
Publication information
Journal: Optical Engineering
Volume: 42
Issue number: 10
ISSN (Print): 0091-3286
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.11 SJR 0.406 SNIP 0.812
Advances within silica-on-silicon planar waveguides

General information
State: Published
Organisations: Department of Photonics Engineering
Authors: Poulsen, M. R. (Intern), Kristensen, M. (Intern), Rottwitt, K. (Intern), Svalgaard, M. (Intern)
Pages: 126-139
Publication date: 2003

Host publication information
Title of host publication: Photonics West
Main Research Area: Technical/natural sciences
An investigation of different Raman amplification configuration in a photonic crystal fibre using picosecond pulses at 1550 nm

General information
State: Published
Organisations: Systems, Department of Photonics Engineering, Glass Components and Materials
Authors: Zhenbo, X. (Intern), Rottwitt, K. (Intern), Jeppesen, P. (Intern)
Publication date: 2003

Host publication information
Title of host publication: Technical Digest >Conference on Lasers and Electro-Optics 2003
Volume: Paper CL6-3-FRI
Main Research Area: Technical/natural sciences
Conference: CLEO 2003, Munich, Germany, 01/01/2003
Source: orbit
Source-ID: 43180
Publication: Research - peer-review › Article in proceedings – Annual report year: 2003

An investigation of different Raman amplification configurations in 160 Gbit/s transmission
In this paper, different Raman pumping schemes are numerically simulated with newly developed super large core area fiber (SLA) at 160 Gbit/s single channel. We find that the optimal scheme is inverse dispersion fiber pump scheme. Transmission distance of 1700 km is predicted and shorter pulse is preferred.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects
Authors: Xu, Z. (Intern), Rottwitt, K. (Intern), Jeppesen, P. (Intern)
Number of pages: 631
Publication date: 2003

Host publication information
Publisher: IEEE
ISBN (Print): 0-7803-7734-6
Main Research Area: Technical/natural sciences
Electronic versions:
Xu.pdf
DOIs:
10.1109/CLEOE.2003.1313693

Bibliographical note
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Source: orbit
Source-ID: 258690
Publication: Research - peer-review › Article in proceedings – Annual report year: 2003

Experimental characterisation of distributed Raman amplification in a standard single mode fibre based 160 Gbit/s transmission system

General information
State: Published
Organisations: Systems, Department of Photonics Engineering, Glass Components and Materials
Authors: Zhenbo, X. (Intern), Oxenløwe, L. K. (Intern), Siahlo, A. (Intern), Berg, K. S. (Intern), Clausen, A. (Intern), Le, N. T. Q. (Intern), Poucheret, C. (Intern), Rottwitt, K. (Intern), Jeppesen, P. (Intern)
Pages: 344-354
Publication date: 2003
Scaling of Raman gain coefficient

General information
State: Published
Organisations: Department of Photonics Engineering
Authors: Rottwitt, K. (Intern)
Publication date: 2003
Event: Paper presented at Workshop on advances in raman-based, high-speed photonics, Los Alamos, New Mexico, .
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 61590
Publication: Research › Paper – Annual report year: 2003

This paper presents a comprehensive analysis of the temperature dependence of a Raman amplifier and the scaling of the Raman gain coefficient with wavelength, modal overlap, and material composition. The temperature dependence is derived by applying a quantum theoretical description, whereas the scaling of the Raman gain coefficient is derived using a classical electromagnetic model. We also present experimental verification of our theoretical findings.

Scaling the Raman gain coefficient: Applications to Germanosilicate fibers

General information
State: Published
Organisations: Department of Photonics Engineering
Authors: Rottwitt, K. (Intern), Bromage, J. (Ekstern), Stentz, A. (Ekstern), Leng, L. (Ekstern), Lines, M. (Ekstern), Smith, H. (Ekstern)
Pages: 1652-1663
Publication date: 2003
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Lightwave Technology
Volume: 21
Issue number: 7
ISSN (Print): 0733-8724
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.87 SJR 1.233 SNIP 1.881
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.689 SNIP 1.955 CiteScore 4.15
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.801 SNIP 2.423 CiteScore 4.23
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.533 SNIP 2.341 CiteScore 4.03
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.711 SNIP 2.335 CiteScore 3.21
Sub-micrometer waveguide for nano-optics

With the recent progress within the field of processing nano structures, there is an increasing interest in coupling light into such structures both for characterization of optical properties and new optical components. In this work we propose the use of a sub-micrometer planar waveguide for probing the reflection of light against a nano structure. The planar waveguide is based on a silicon nitride core layer, surrounded by a silica cladding region. In our design we utilize this waveguide to couple light into a nano-structure.

General information
State: Published
Organisations: Department of Photonics Engineering
Authors: Rottwitt, K. (Intern), Dyndgaard, M. G. (Intern), Andersen, K. N. (Intern), Hansen, T. (Ekstern)
Design of optical waveguide probe for nanooptics

General information
State: Published
Organisations: Department of Photonics Engineering
Authors: Dyndgaard, M. G. (Intern), Rottwitt, K. (Intern), Mølhave, K. (Ekstern)
Publication date: 2002
Event: Poster session presented at Annual meeting of the Danish Optical Society 2002, Risø, Denmark.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 61851
Publication: Research › Poster – Annual report year: 2002

Scaling the Raman Gain Coefficient of Optical Fibers
Scaling rules for the Raman gain coefficient are provided with emphasis on the effective area and wavelength dependence. Translation from measurements made at one pump wavelength to other pump wavelengths is demonstrated.

General information
State: Published
Organisations: Fiber Optics, Devices and Non-linear Effects, Department of Photonics Engineering
Authors: Rottwitt, K. (Intern), Bromage, J. (Ekstern), Leng, L. (Ekstern)
Pages: 1-2
Publication date: 2002

Host publication information
Volume: 3
Publisher: IEEE
ISBN (Print): 87-90974-63-8
Main Research Area: Technical/natural sciences
Conference: 28th European Conference on Optical Communication, Copenhagen, Denmark, 08/09/2002 - 08/09/2002
Electronic versions:
Rottwitt.pdf

Bibliographical note
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Source: orbit
Source-ID: 259089
Publication: Research - peer-review › Article in proceedings – Annual report year: 2002
Transparent dispersion compensator with built-in gain equalizer
In this work we describe a method to obtain a transparent or even an amplifying dispersion compensating module with built-in gain equalization functionality. The principle of operation and experimental results are illustrated.

General information
State: Published
Organisations: Department of Photonics Engineering
Authors: Rottwitt, K. (Intern), Doerr, C. (Ekstern)
Pages: 1-2
Publication date: 2002

Host publication information
Volume: 2
Publisher: IEEE
ISBN (Print): 87-90974-63-8
Main Research Area: Technical/natural sciences
Conference: 28th European Conference on Optical Communication, Copenhagen, Denmark, 08/09/2002 - 08/09/2002
Electronic versions:
Rottwitt.pdf
DOIs:
10.1109/ECOC.2002.204477

Bibliographical note
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Source: orbit
Source-ID: 62133
Publication: Research - peer-review › Article in proceedings – Annual report year: 2002

Polarization sensitivity of the nonlinear amplifying loop mirror. [CBC1]

General information
State: Published
Organisations: Department of Informatics and Mathematical Modeling, Department of Electromagnetic Systems, Department of Photonics Engineering
Authors: Clausen, C. A. B. (Intern), Povlsen, J. H. (Intern), Rottwitt, K. (Intern)
Pages: 1535-1537
Publication date: 1996
Main Research Area: Technical/natural sciences

Publication information
Journal: Optics Letters
Volume: 21
ISSN (Print): 0146-9592
Ratings:
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
Detailed comparison of two approximate methods for the solution of the scalar wave equation for a rectangular optical waveguide

Two approximate methods for the determination of the fundamental mode of an optical waveguide with rectangular core cross section and step refractive-index profiles are presented and analyzed thoroughly. Both methods are based on Galerkin’s method. The first method uses Hermite-Gauss basis functions and the second uses the guided and nonguided slab waveguide solutions as basis functions. The results are compared with results from an accurate circular harmonic analysis. Both methods provide values of the normalized propagation constant with errors less than 0.1% for practical rectangular single-mode waveguides. The slab waveguide method is the fastest, and even when only one slab waveguide mode is used the propagation constant for the fundamental mode can be calculated with an error of less than 1%. The slab waveguide method also gives very accurate results for the propagation constant for higher order modes.
Long distance transmission through distributed erbium-doped fibers
High bit rate, all-optical long-distance transmission could be created through the combined use of loss-compensating gain in erbium-doped fibers and solitons. A detailed analysis of the distributed erbium-doped fiber, including the spectral-gain dependency, is combined with an optimum design of the transmission fiber and general bit-error-rate calculations. Changes in wavenumber, group velocity, and fiber dispersion due to erbium doping in a single-mode fiber are evaluated, and a reduction in bit-error rates due to the erbium spectral-gain profile is shown. Transmission through distributed erbium-doped fiber with 100-km separation between each pump-power station is shown, with a total bit-rate distance product of 55 Gb/s · Mm
Noise in distributed erbium-doped fibers

The theoretical limits in noise figure for a long-haul transmission line based on lumped amplification are contrasted with distributed amplification. The latter results in a reduction of approximately 60% of the required number of pump power stations. The distributed optical amplification is provided by an erbium-doped fiber and comparisons of aluminum and germanium as codopant materials are shown. The pump power consumption and noise figure are analyzed with respect to the background loss.

General information
State: Published
Organisations: Fiber Optics, Devices and Non-linear Effects, Department of Photonics Engineering, Technical University of Denmark
Authors: Rottwitt, K. (Intern), Povlsen, J. H. (Intern), Bjarklev, A. O. (Intern), Lumholt, O. (Ekstern), Pedersen, B. (Ekstern), Rasmussen, T. (Ekstern)
Quantum limited noise figure operation of high gain erbium doped fiber amplifiers

Performance improvements obtained by using an isolator as an amplified-spontaneous-emission-suppressing component within erbium-doped fibers are evaluated. Simultaneous high-gain and near-quantum-limited noise figures can be obtained by such a scheme. The noise figure improves for input signal powers below -5 dBm, and an improvement of 2.0 dB with a simultaneous gain increase of 4.1 dB is measured relative to a gain-optimized fiber. The optimum isolator location is evaluated for different pump and signal wavelengths in both an Al/Er-doped and a Ge/Er-doped fiber, for pump and signal power variations and different pump configurations. In all cases the optimum isolator position lies within 10-37% of the total fiber length for small signal operation.

General information

State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Technical University of Denmark
Authors: Lumholt, O. (Ekstern), Povlsen, J. H. (Intern), Schüsler, K. (Ekstern), Bjarklev, A. O. (Intern), Dahl-Petersen, S. (Ekstern), Rasmussen, T. (Ekstern), Rottwitt, K. (Intern)
Pages: 1344-1352
Publication date: 1993
Main Research Area: Technical/natural sciences

Publication information

Journal: Journal of Lightwave Technology
Volume: 11
Issue number: 8
ISSN (Print): 0733-8724
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.87 SJR 1.233 SNIP 1.881
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.689 SNIP 1.955 CiteScore 4.15
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.801 SNIP 2.423 CiteScore 4.23
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.533 SNIP 2.341 CiteScore 4.03
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.711 SNIP 2.335 CiteScore 3.21
Fundamental design of a distributed erbium-doped fiber amplifier for long-distance transmission

Comprehensive theoretical analysis on the design of a distributed erbium-doped fiber amplifier for long-distance transmission has been carried out, using a highly accurate model. The dispersion of the optical fiber as a function of the numerical aperture and the cutoff wavelength is included. Designs based on a bidirectional pumping scheme are evaluated, taking nonlinearities into account. The optimum value of the numerical aperture will be evaluated for cutoff wavelengths where the propagating pump power is single moded. For distances between each pumping station in the region between 10 and 100 km, the optimum ratio of copropagating and counterpropagating pump power will also be evaluated.

General information
State: Published
Optimum design of Nd-doped fiber optical amplifiers

The waveguide parameters for a Nd-doped fluoride (Nd:ZBLANP) fiber amplifier have been optimized for small-signal and booster operation using an accurate numerical model. The optimum cutoff wavelength is shown to be 800 nm and the numerical aperture should be made as large as possible. Around 80% booster quantum conversion efficiency can be reached for an input power of 10 dBm and a pump power of 100 mW by the use of one filter.
Optimum position of isolators within erbium-doped fibers

An isolator is used as an amplified spontaneous emission suppressing component within an erbium-doped fiber. The optimum isolator placement is both experimentally and theoretically determined and found to be slightly dependent upon pump power. Improvements of 4 dB in gain and 2 dB in noise figure are measured for the optimum isolator location at 25% of the fiber length when the fiber is pumped with 60 mW of pump power at 1.48 μm.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Technical University of Denmark
Optimum signal wavelength for a distributed erbium-doped fiber amplifier

Theoretical analysis of a 100-km-long transparent germanosilicate distributed erbium-doped optical fiber has been carried out. It is shown that the optimum signal wavelength is 1.554 μm both considering the noise performance and the necessary pump power for achieving unity gain when the distributed erbium-doped fibers are pumped at 1.48 μm.
Stability of a 500 km erbium-doped fiber amplifier cascade
The stability of a cascade system of erbium-doped fiber amplifiers, due to pump and signal power variations, has been examined by use of a very accurate model. Even with an automatic gain control loop included, a fallout of a pump laser in the first inline amplifier is shown to produce a more than seven times as high increase of the bit error rate than for the fallout of other amplifier pumps, showing that the fallout of the forward pump is by far the most critical. The stability to simultaneous changes in pump and signal power is examined and can be increased remarkably insertion of an additional amplifier.

General information
State: Published
Organisations: Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Technical University of Denmark
Projects:

**Long distance quantum communication**
Department of Photonics Engineering  
Period: 15/08/2017 → 14/08/2020  
Number of participants: 4  
PhD Student:  
da Lio, Beatrice (Ekstern)  
Supervisor:  
Bacco, Davide (Intern)  
Ding, Yunhong (Intern)  
Main Supervisor:  
Rottwitt, Karsten (Intern)

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

**High Dimensional Quantum Key Distribution Based on Space Division Multiplexing**
Department of Photonics Engineering  
Period: 01/03/2017 → 29/02/2020  
Number of participants: 4  
PhD Student:  
Cozzolino, Daniele (Intern)  
Supervisor:  
Bacco, Davide (Intern)  
Rottwitt, Karsten (Intern)  
Main Supervisor:  
Oxenløwe, Leif Katsuo (Intern)

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

**Processing and Generation of Photon Pairs using Nonlinear Effects in Optical Fibers**
Department of Photonics Engineering
Period: 01/09/2016 → 31/08/2019
Number of participants: 3
Phd Student:
Koefoed, Jacob Gade (Intern)
Supervisor:
Usuga Castaneda, Mario A. (Intern)
Main Supervisor:
Rottwitt, Karsten (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Samfinansieret - Andet
Project: PhD

Four-wave Mixing in Higher Order Mode Optical Fibers

Department of Photonics Engineering
Period: 01/05/2016 → 30/04/2019
Number of participants: 3
Phd Student:
Christensen, Erik Nicolai (Intern)
Supervisor:
Usuga Castaneda, Mario A. (Intern)
Main Supervisor:
Rottwitt, Karsten (Intern)

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

Highly efficient on-chip frequency comb generation

Department of Photonics Engineering
Period: 01/04/2016 → 31/03/2019
Number of participants: 4
Phd Student:
Kamel, Ayman Nassar (Intern)
Supervisor:
Pu, Minhao (Intern)
Thomsen, Jan Westenkær (Ekstern)
Main Supervisor:
Rottwitt, Karsten (Intern)

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

Advanced modulation formats for W-band and Low-Terahertz RoF Systems

Department of Photonics Engineering
Period: 01/12/2015 → 30/11/2018
Number of participants: 3
Phd Student:
Astorino, Antonio (Intern)
Supervisor:
Berger, Michael Stübert (Intern)
Main Supervisor:
Rottwitt, Karsten (Intern)
Financing sources
Source: Internal funding (public)
Name of research programme: Marie Curie (EU-stipendium)
Project: PhD

Fibre Design for Advanced Space-division Multiplexing
Department of Photonics Engineering
Period: 15/11/2015 → 14/11/2018
Number of participants: 3
Phd Student:
Ingerslev, Kasper (Intern)
Supervisor:
Rottwitt, Karsten (Intern)
Main Supervisor:
Morioka, Toshio (Intern)

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

Nonlinear Signal Processing in Optical Quantum Information Systems
Department of Photonics Engineering
Period: 15/10/2015 → 14/10/2018
Number of participants: 3
Phd Student:
Christensen, Jesper Bjerge (Intern)
Supervisor:
Oxenløwe, Leif Katsuo (Intern)
Main Supervisor:
Rottwitt, Karsten (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Samfinansierede - Virksomhed
Project: PhD

Optical Time Lens Signal Processing using Highly Nonlinear Fibres
Department of Photonics Engineering
Period: 01/09/2014 → 31/08/2017
Number of participants: 7
Phd Student:
Lillieholm, Mads (Intern)
Supervisor:
Galili, Michael (Intern)
Grüner-Nielsen, Lars Erik (Intern)
Main Supervisor:
Oxenløwe, Leif Katsuo (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Kolner, Brian H. (Ekstern)
Stephens, Marc (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD
Higher Order Modes on a Nano-Biophotonics Workstation
Department of Photonics Engineering
Period: 01/06/2013 → 07/12/2016
Number of participants: 7
Phd Student:
Friis, Søren Michael Mørk (Intern)
Main Supervisor:
Rottwitt, Karsten (Intern)
Examiner:
Morioka, Toshio (Intern)
Glückstad, Jesper (Intern)
Morioka, Toshio (Intern)
Antonelli, Cristian (Ekstern)
Karlsson, Magnus (Ekstern)

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

Relations
Publications:
Project: PhD

Advanced optical design for multicolored LED systems for lighting applications
Department of Photonics Engineering
Period: 01/01/2013 → 15/06/2016
Number of participants: 6
Phd Student:
Chakrabarti, Maumita (Intern)
Supervisor:
Petersen, Paul Michael (Intern)
Main Supervisor:
Dam-Hansen, Carsten (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Martinsons, Christophe (Ekstern)
Pedersen, Kjeld (Ekstern)

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

Relations
Activities:
Danish national CIE committee (External organisation)
Project: PhD

IR Sensing and Imaging
Department of Photonics Engineering
Period: 01/11/2012 → 16/03/2016
Number of participants: 6
Phd Student:
Høgstedt, Lasse (Intern)
Supervisor:
Pedersen, Christian (Intern)
Main Supervisor:
Tidemand-Lichtenberg, Peter (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Arie, Ady (Ekstern)
Ebrahim-Zadeh, Majid (Ekstern)

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

Relations
Publications:
Parametric Processes for Generation and Low Noise Detection of Infrared Light
Project: PhD

Ultrahigh-capacity photonic transport beyond Pbit/s
Department of Photonics Engineering
Period: 01/10/2012 → 20/04/2016
Number of participants: 6
Phd Student:
Ye, Feihong (Intern)
Supervisor:
Peucheret, Christophe (Intern)
Main Supervisor:
Morioka, Toshio (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Limberger, Hans Georg (Ekstern)
Schaeffer, Christian G. (Ekstern)

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

Relations
Publications:
High-Capacity Multi-Core Fibers for Space-Division Multiplexing
Project: PhD

Higher order mode fibers
Department of Photonics Engineering
Period: 01/09/2012 → 02/11/2016
Number of participants: 5
Phd Student:
Israelsen, Stine Møller (Intern)
Main Supervisor:
Rottwitt, Karsten (Intern)
Examiner:
Galili, Michael (Intern)
Poletti, Francesco (Ekstern)
Sillard, Pierre (Ekstern)

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

Relations
Publications:
Higher Order Mode Fibers
Project: PhD

Inter modal nonlinear effects
Fiber optics, nonlinear optics, laser optics
Department of Photonics Engineering
Fiber Optics, Devices and Non-linear Effects
Period: 01/02/2012 → 31/12/2012
Number of participants: 2
Project ID: 70716
Project participant:
Ramachandran, Siddharth (Ekstern)
Project Manager, academic:
Rottwitt, Karsten (Intern)

Financing sources
Source: Forskningsrådene - Andre
Name of research programme: Styrelsen for Forskning og Innovation
Amount: 259,920.00 Danish Kroner
Year of approval: 2012

Photonic crystal fiber amplifiers and lasers with distributed gain shaping
Department of Photonics Engineering
Period: 01/01/2012 → 22/04/2015
Number of participants: 7
Phd Student:
Petersen, Sidsel Rübner (Intern)
Supervisor:
Alkeskjold, Thomas Tanggaard (Intern)
Olausson, Christina Bjarnal Thulin (Intern)
Main Supervisor:
Lægsgaard, Jesper (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Hernandez, Yves (Ekstern)
Sharping, Jay Edward (Ekstern)

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

Applications of Nanophotonic Devices for Terabit Optical Communications
Department of Photonics Engineering
Period: 01/10/2011 → 18/03/2015
Number of participants: 8
Phd Student:
Vukovic, Dragana (Intern)
Supervisor:
Mørk, Jesper (Intern)
Peucheret, Christophe (Intern)
Xu, Jing (Intern)
Main Supervisor:
Oxenløwe, Leif Katsuo (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Financing sources
Source: Internal funding (public)
Name of research programme: Institut, samfinansiering
Project: PhD

Optical Signal Processing using Four Wave Mixing
Department of Photonics Engineering
Period: 01/10/2011 → 26/01/2015
Number of participants: 5
Phd Student:
Andersen, Lasse Mejling (Intern)
Main Supervisor:
Rottwitt, Karsten (Intern)
Examiner:
Willatzen, Morten (Intern)
Karlsson, Magnus (Ekstern)
Qian, Li (Ekstern)

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

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

Infrared fiberlaser utilising novel semiconductor optical fibers
Department of Photonics Engineering
Period: 01/01/2011 → 09/12/2015
Number of participants: 7
Phd Student:
Svane, Ask Sebastian (Intern)
Supervisor:
Liu, Xiaomin (Intern)
Lægsgaard, Jesper (Intern)
Main Supervisor:
Fiber laser for wind speed measurements

Department of Photonics Engineering  
Period: 15/10/2010 → 18/03/2015  
Number of participants: 6  
Phd Student: Olesen, Anders Sig (Intern)  
Supervisor: Mikkelsen, Torben Krogh (Intern)  
Main Supervisor: Rottwitt, Karsten (Intern)  
Examiner: Rodrigo, Peter John (Intern)  
Skov Hansen, René (Intern)  
Harris, Michael (Ekstern)

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

Relations  
Publications:  
Fiber Laser for Wind Speed Measurements  
Project: PhD

Optical Amplification for Terabit-per-Second Ultra-High Speed Communication Systems

Department of Photonics Engineering  
Period: 15/04/2010 → 26/09/2013  
Number of participants: 7  
Phd Student: Lali-Dastjerdi, Zohreh (Intern)  
Supervisor: Galili, Michael (Intern)  
Rottwitt, Karsten (Intern)  
Main Supervisor: Peucheret, Christophe (Intern)  
Examiner: Lægsgaard, Jesper (Intern)  
Andreksen, Peter A. (Ekstern)  
Mussot, Arnaud (Ekstern)

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

Relations  
Publications:  
Optical Amplification for Terabit-per-Second Ultra-High Speed Communication Systems  
Project: PhD
Optical Amplification for Terabit-per-Second Ultra-High Speed Communication Systems

Department of Photonics Engineering
Period: 15/04/2010 → 26/09/2013
Number of participants: 6
Phd Student: Cristofori, Valentina (Intern)
Supervisor: Peucheret, Christophe (Intern)
Main Supervisor: Rottwitt, Karsten (Intern)
Examiner: Tafur Monroy, Idelfonso (Intern)
Slavik, Radan (Ekstern)
Wong, Kenneth Kin-Yip (Ekstern)

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

High-power green-yellow diode lasers for medical applications

Department of Photonics Engineering
Period: 01/03/2010 → 15/08/2013
Number of participants: 7
Phd Student: Müller, André (Intern)
Supervisor: Andersen, Peter E. (Intern)
Jensen, Ole Bjarlin (Intern)
Main Supervisor: Petersen, Paul Michael (Intern)
Examiner: Rottwitt, Karsten (Intern)
Drewsen, Michael (Ekstern)
Rafailov, Edik (Ekstern)

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

Monitoring Continuous formentation processes in microbioreactors

Department of Chemical and Biochemical Engineering
Period: 01/03/2010 → 30/09/2016
Number of participants: 8
Phd Student: Bolic, Andrijana (Intern)
Supervisor: Eliasson Lantz, Anna (Intern)
Rottwitt, Karsten (Intern)
Main Supervisor: Gernaey, Krist V. (Intern)
Examiner: Dufva, Martin (Intern)
Dufva, Martin (Intern)
Roca, Christophe Francois Aime (Intern)
Financing sources
Source: Internal funding (public)
Name of research programme: Offentlig finansiering
Project: PhD

Photonic crystal rod amplifiers: Understanding a new class of active optical waveguides
Department of Photonics Engineering
Period: 01/01/2010 → 21/02/2013
Number of participants: 7
Phd Student:
Laurila, Marko (Intern)
Supervisor:
Alkeskjold, Thomas Tanggaard (Intern)
Broeng, Jes (Intern)
Main Supervisor:
Lægsgaard, Jesper (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Balling, Peter (Ekstern)
Hönninger, Clemens (Ekstern)

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

Phase Sensitive Amplification using Parametric Processes in Optical Fibres
Department of Photonics Engineering
Period: 01/12/2009 → 27/05/2013
Number of participants: 7
Phd Student:
Kang, Ning (Intern)
Supervisor:
Rottwitt, Karsten (Intern)
Seoane, Jorge (Intern)
Main Supervisor:
Peucheret, Christophe (Intern)
Examiner:
Oxenløwe, Leif Katsuo (Intern)
Eskildsen, Lars (Intern)
Rasmussen, Christian (Intern)

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

Non-Linear Fibres for Widely Tunable Femtosecond Lasers
Department of Photonics Engineering
Period: 01/11/2009 → 30/09/2013
Number of participants: 7
Phd Student:
Pedersen, Martin Erland Vestergaard (Intern)
Supervisor:
Grüner-Nielsen, Lars Erik (Intern)
Phase Sensitive Amplification for Advanced Fibre Optic Communication Systems

Optical amplifiers – devices where light signals are periodically amplified along their transmission paths in a network- have revolutionized communications using optical fibres and have had a major impact on the information revolution and the building of the Internet. Even though optical fibres can be used to carry massive amounts of information, it is expected that the growth of data usage will result in capacity exhaustion in the coming decades if no breakthrough technology is introduced. One such disruptive technology could well be a new type of optical amplifier that selectively amplifies the signal depending on its phase. Such a “phase sensitive amplifier” (PSA) has been theoretically shown to be able to provide amplification while adding minimum noise to the signal. It will also be a useful tool to periodically “clean” signal distortion and noise accumulated over a link. Currently, those impairments limit the range and capacity of optical fibre
links. PSAs are eminently attractive since one major trend in optical communication is the introduction of advanced modulation formats that mimic those that have made the breakthrough of digital wireless communication a reality. In this context, being able to process both the amplitude and phase of the signal all-optically will open the way to new functionalities, including the periodic regeneration of the phase of high bit rate (>40 Gbit/s) signals, which has not been demonstrated so far. However, the implementation of such amplifiers is known to be difficult. Nevertheless, a few sound approaches which overcome some of their practical limitations have been suggested over the past few years. It is therefore now time to revisit the concepts and applications of PSAs and to experimentally demonstrate some of their functionalities for the first time, which are the goals of this project.

High-Speed Optical Communication
Department of Photonics Engineering
Fiber Optics, Devices and Non-linear Effects
OFS Laboratories
OFS Fitel Denmark ApS
Photonics Laboratory
Period: 01/09/2009 → 31/08/2012
Number of participants: 5
Optical communication systems, optical amplifiers, optical modulation, optical signal processing
Project ID: 70478
Contact person:
Peucheret, Christophe (Intern)
Ramachandran, Siddharth (Ekstern)
Palsdottir, Bera (Ekstern)
Andreksen, Peter (Ekstern)
Project participant:
Rottwitt, Karsten (Intern)

Financing sources
Source: Forskningsrådene - Andre
Name of research programme: Forskningsrådene - Andre
Amount: 5,055,600.00 Danish Kroner
Project

All-fiber Raman Probe
Department of Photonics Engineering
Period: 01/05/2009 → 22/11/2012
Number of participants: 6
Phd Student:
Brunetti, Anna Chiara (Intern)
Supervisor:
Gernaey, Krist V. (Intern)
Main Supervisor:
Rottwitt, Karsten (Intern)
Examiner:
Tidemand-Lichtenberg, Peter (Intern)
Brambilla, Gilberto (Ekstern)
De Matos, Christiano José Santiago (Ekstern)

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

Generation of Optical Shrōdinger Cat-States
Department of Physics
Period: 01/01/2009 → 21/06/2012
Number of participants: 6
Phd Student:
Polymer fiber-optical microphones

Department of Photonics Engineering
Period: 01/01/2009 → 22/03/2012
Number of participants: 6
PhD Student:
Stefani, Alessio (Intern)
Supervisor:
Yuan, Scott Wu (Intern)
Main Supervisor:
Bang, Ole (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Keiding, Søren Rud (Ekstern)
Schuster, Kay (Ekstern)

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

Ikke-lineære fænomener i gas- og væskefyldte optiske fibre

Department of Photonics Engineering
Period: 01/11/2008 → 29/05/2013
Number of participants: 2
PhD Student:
Falk, Charlotte Ijeoma (Intern)
Main Supervisor:
Rottwitt, Karsten (Intern)

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

Frequency swept fiber laser for wind speed measurements

Department of Photonics Engineering
Period: 01/10/2008 → 19/04/2012
Number of participants: 6
PhD Student:
Pedersen, Anders Tegtmeier (Intern)
Supervisor:
Lindelow, Per Jonas Petter (Intern)
Main Supervisor:
Rottwitt, Karsten (Intern)
Examiner:
Pedersen, Christian (Ekstern)
Hill, Chris (Ekstern)
Poulsen, Christian (Intern)

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

**Defence and security-related application of THz radiation**

Department of Photonics Engineering
Period: 15/09/2008 → 14/12/2011
Number of participants: 6
Phd Student:
Iwaszczuk, Krzysztof (Intern)
Supervisor:
Heiselberg, Henning (Intern)
Main Supervisor:
Jepsen, Peter Uhd (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Keiding, Søren Rud (Ekstern)
M. Mittleman, Daniel (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: 1/3 FUU, 1/3 inst 1/3 Andet
Project: PhD

**Pulsed Blue and Ultraviolet Laser System for Fluorescence Diagnostics based on Nonlinear Frequency Conversion**

Department of Photonics Engineering
Period: 15/01/2008 → 22/06/2011
Number of participants: 8
Phd Student:
Cheng, Haynes Pak Hay (Intern)
Supervisor:
Andersen, Peter E. (Intern)
Jensen, Ole Bjarlin (Intern)
Petersen, Paul Michael (Intern)
Main Supervisor:
Pedersen, Christian (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Laurell, Fredrik (Ekstern)
Thomsen, Jan Westenkær (Ekstern)

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

**Nano-Technology for ultra high-speed optical communications (Nano-Com) - Pulsed fibre lasers**

Department of Photonics Engineering
Period: 01/08/2007 → 21/12/2010
Number of participants: 9
Phd Student:
Ji, Hua (Intern)
Supervisor:
Galili, Michael (Intern)
Grüner-Nielsen, Lars Erik (Intern)
Oxenløwe, Leif Katsuo (Intern)
Rottwitt, Karsten (Intern)
Veng, Torben Erik (Intern)
Main Supervisor:
Jeppesen, Palle (Intern)
Examiner:
Tafur Monroy, Idelfonso (Intern)
Petropoulos, Periklis (Ekstern)

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

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**Long-pulse Super-continuum Light Sources**

Department of Photonics Engineering
Number of participants: 6
Phd Student:
Moselund, Peter M. (Intern)
Supervisor:
Thomsen, Carsten L. (Ekstern)
Main Supervisor:
Bang, Ole (Intern)
Examiner:
Dudley, John Michael (Ekstern)
Keiding, Søren Rud (Ekstern)
Rottwitt, Karsten (Intern)

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

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**Mikrostrukturede Fibre til Raman-baserede Biosensor**

Department of Photonics Engineering
Period: 01/11/2005 → 31/12/2006
Number of participants: 3
Phd Student:
Lang, Morten Markussen (Intern)
Supervisor:
Jensen, Jesper Bo (Intern)
Main Supervisor:
Rottwitt, Karsten (Intern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: ErhvervsPhD-ordningen VTU
Project: PhD
Liquid Crystal Filled Microstructured Polymer Optical Fibres
Department of Photonics Engineering
Period: 01/08/2005 → 25/09/2008
Number of participants: 6
PhD Student:
Rasmussen, Per Dalgaard (Intern)
Supervisor:
Lægsgaard, Jesper (Intern)
Main Supervisor:
Bang, Ole (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Broeng, Jes (Intern)
Skryabin, Dmitry Vladimirovich (Ekstern)

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

Raman Forstærkning i Optiske Kommunikationssystemer
Department of Photonics Engineering
Period: 01/06/2005 → 25/09/2008
Number of participants: 7
PhD Student:
Kjær, Rasmus (Intern)
Supervisor:
Oxenløwe, Leif Katsuo (Intern)
Pálslóttir, Bera (Ekstern)
Main Supervisor:
Jeppesen, Palle (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Bayvel, Polina (Ekstern)
Rasmussen, Christian (Intern)

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

Side-Emitting Fibres for Lighting Applications
Department of Photonics Engineering
Period: 01/09/2004 → 25/02/2008
Number of participants: 5
PhD Student:
Shyroki, Dzmitry (Intern)
Main Supervisor:
Rottwitt, Karsten (Intern)
Examiner:
Mortensen, N. Asger (Intern)
Bozhevolnyi, Sergey I. (Intern)
Busch, Kurt (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: DTU-lønnet stipendie
Project: PhD
Passive and Adaptive Planar Lightwave Circuit Filters for Telecommunication Networks

Department of Photonics Engineering
Period: 01/08/2004 → 15/10/2004
Number of participants: 4
Phd Student:
Visona, Simone (Intern)
Supervisor:
Larsen, Britt Hvolbæk (Intern)
Leick, Lasse (Intern)
Main Supervisor:
Rottwitt, Karsten (Intern)

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

Ultra High-Speed Data Rates mfor Future Generation Internet

Department of Photonics Engineering
Period: 01/05/2004 → 29/10/2007
Number of participants: 7
Phd Student:
Galili, Michael (Intern)
Supervisor:
Clausen, Anders (Intern)
Oxenløwe, Leif Katsu (Intern)
Main Supervisor:
Jeppesen, Palle (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Mikkelsen, Benny (Intern)
Nakazawa, Masataka (Ekstern)

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

Spectroscopic Studies of Cytochrome P450 Enzymes by Application of Optical Spectroscopic Techniques Combined with QM/MM Calculations

Department of Physics
Period: 01/02/2004 → 01/08/2007
Number of participants: 6
Phd Student:
Johannessen, Christian (Intern)
Supervisor:
Abdali, Salim (Intern)
Main Supervisor:
Bohr, Henrik (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Blanch, Ewan William (Ekstern)
Ramanujam, P.S. (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: DTU-lønnet stipendie
Biomedical Applications of Photonic Crystal Fibres

Department of Photonics Engineering
Period: 01/09/2003 → 05/02/2007
Number of participants: 8
Phd Student:
Frosz, Michael Henoch (Intern)
Supervisor:
Andersen, Peter E. (Intern)
Bang, Ole (Intern)
Broeng, Jes (Intern)
Main Supervisor:
Bjarklev, Anders Overgaard (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Dudley, John Michael (Ekstern)
Keiding, Søren Rud (Ekstern)

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

Non-linear waveguides

Fibers & Nonlinear Optics
Department of Photonics Engineering
Period: 01/09/2003 → 30/08/2006
Number of participants: 1
Project ID: 70236
Contact person:
Rottwitt, Karsten (Intern)

Financing sources
Source: Forskningsrådene - STVF
Name of research programme: Forskningsrådene - STVF
Amount: 2,000,000.00 Danish Kroner
Project

Lyskilder til ikke-invasive to-foton processer i øjet

Department of Physics
Period: 01/01/2003 → 31/05/2007
Number of participants: 7
Phd Student:
Thorhauge, Morten (Intern)
Supervisor:
Buchhave, Preben (Intern)
Larsen, Michael (Ekstern)
Main Supervisor:
Tidemand-Lichtenberg, Peter (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Laurell, Fredrik (Ekstern)
Sander, Birgit Agnes (Ekstern)

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

Photonic Crystal Fibres as the Transmission Medium for Future Optical Communication Systems

Department of Photonics Engineering
Number of participants: 7
Phd Student:
Zsigri, Beata (Intern)
Supervisor:
Maack, Martin Dybendal (Ekstern)
Peucheret, Christophe (Intern)
Main Supervisor:
Jeppesen, Palle (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Hanik, Norbert (Intern)
Watanabe, Shigeki (Intern)

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

Ulineær Dynamik i Halvlederlasere

Department of Photonics Engineering
Period: 01/11/2002 → 30/01/2007
Number of participants: 7
Phd Student:
Blaaberg, Søren (Intern)
Supervisor:
Petersen, Paul Michael (Intern)
Tromborg, Bjarne (Intern)
Main Supervisor:
Rottwitt, Karsten (Intern)
Examiner:
Merk, Jesper (Intern)
Buus, Jens (Ekstern)
Willatzen, Morten (Intern)

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

Integreede Optiske Bølgeledere

Department of Photonics Engineering
Period: 01/10/2002 → 27/06/2005
Number of participants: 6
Phd Student:
Dyvelkov, Karin Nordstrøm (Intern)
Supervisor:
Poulsen, Mogens Rysholt (Intern)
Main Supervisor:
Rottwitt, Karsten (Intern)
Examiner:
Jensen, Flemming (Ekstern)
Novel Fibre-ring Laser System Based on Frequency Chirping for Optical Coherence Tomography (OCT)

Department of Photonics Engineering
Period: 01/10/2002 → 31/05/2006
Number of participants: 6
PhD Student: Agger, Søren Dyøe (Intern)
Supervisor: Rottwitt, Karsten (Intern)
Main Supervisor: Povlsen, Jørn Hedegaard (Intern)
Examiner: Mark, Jesper (Intern)
Pedersen, Bo (Ekstern)
Taylor, James Roy (Ekstern)

OFS Fitel
Fibers & Nonlinear Optics
Department of Photonics Engineering
Period: 01/09/2002 → 30/06/2003
Number of participants: 1
Project ID: 70207
Contact person: Rottwitt, Karsten (Intern)

Loss in Optical Fibres
Department of Photonics Engineering
Period: 01/08/2002 → ...
Number of participants: 7
PhD Student: Wandel, Marie (Intern)
Supervisor: Grüner-Nielsen, Lars Erik (Intern)
Povlsen, Jørn Hedegaard (Intern)
Main Supervisor: Rottwitt, Karsten (Intern)
Examiner: Jeppesen, Palle (Intern)
Pedersen, Jens Engholm (Intern)
Stolen, Rogers Hall (Ekstern)

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

**Novel Fibre-ring Laser System Based on Frequency Chirping for Optical Coherence Tomography (OCT)**
Department of Photonics Engineering
Period: 01/08/2002 → 28/04/2006
Number of participants: 7
Phd Student: Nielsen, Frederik Donbæk (Intern)
Supervisor: Andersen, Peter E. (Intern)
Thrane, Lars (Intern)
Main Supervisor: Bjarklev, Anders Overgaard (Intern)
 Examiner: Rottwitt, Karsten (Intern)
Zellmer, Holger (Ekstern)
Østergaard, John Erland (Intern)

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

**Investigation of 160gb/s Optical Communication Systems**
Department of Photonics Engineering
Period: 01/07/2002 → 06/06/2006
Number of participants: 7
Phd Student: Xu, Zhenbo (Intern)
Supervisor: Peucheret, Christophe (Intern)
Rottwitt, Karsten (Intern)
Main Supervisor: Jeppesen, Palle (Intern)
 Examiner: Tromborg, Bjarne (Intern)
Grüner-Nielsen, Lars Erik (Intern)
Mikkelsen, Benny (Intern)

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

**Kontrol af neurale atomer med laserlys til anvendelse**
Fibers & Nonlinear Optics
Department of Photonics Engineering
Period: 01/04/2002 → 31/08/2003
Number of participants: 1
Project ID: 70195
Contact person: Rottwitt, Karsten (Intern)
Financing sources
Source: Forskningsrådene - STVF
Name of research programme: Forskningsrådene - STVF
Amount: 424,114.00 Danish Kroner
Project

Optical Signal Processing in OTDM Systems using Photonic Crystal Fibers

Department of Photonics Engineering
Period: 01/02/2002 → 26/09/2005
Number of participants: 7
Phd Student:
Andersen, Peter Andreas (Intern)
Supervisor:
Clausen, Anders (Intern)
Pedersen, Claus Friis (Ekstern)
Peucheret, Christophe (Intern)
Main Supervisor:
Jeppesen, Palle (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Ludvigsen, Hanne (Ekstern)

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

High-capacity optical communication systems employing optical signal processing

Department of Photonics Engineering
Period: 01/11/2001 → 17/12/2004
Number of participants: 7
Phd Student:
Xu, Lin (Intern)
Supervisor:
Mørk, Jesper (Intern)
Oxenløwe, Leif Katsuo (Intern)
Main Supervisor:
Jeppesen, Palle (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Koonen, Ton (Ekstern)
Poustie, Alistair James (Ekstern)

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

Nonlinear Photonic Crystals

Department of Informatics and Mathematical Modeling
Period: 01/02/2001 → 18/08/2004
Number of participants: 8
Phd Student:
Nikolov, Nikola Ivanov (Intern)
Supervisor:
Bang, Ole (Intern)
Bjarklev, Anders Overgaard (Intern)
Technology Platform for digital optical filter structures

Department of Photonics Engineering
Period: 01/02/2001 → 26/10/2004
Number of participants: 6
Phd Student:
Philipp, Hugh Taylor (Intern)
Supervisor:
Povlsen, Jørn Hedegaard (Intern)
Main Supervisor:
Rottwitt, Karsten (Intern)
Examiner:
Mark, Jesper (Intern)
Johansen, Per Michael (Intern)
Margalit, Moti (Ekstern)

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

Semiconductor Photonic Crystals for Genuine Integrated Optics and Ultracompact Optical Components

Department of Photonics Engineering
Number of participants: 7
Phd Student:
Boltasseva, Alexandra (Intern)
Supervisor:
Bozhevolnyi, Sergey I. (Intern)
Østergaard, John Erland (Intern)
Main Supervisor:
Hvam, Jørn Marcher (Intern)
Examiner:
Rottwitt, Karsten (Intern)
Hanson, Steen Grüner (Intern)
Krenn, Joachim (Ekstern)

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

Programmable phase optics for optical tweezers

Department of Physics
Modeling of optoelectronic components for ultra high-speed optical signal processing

Department of Photonics Engineering
Period: 01/08/1998 → 14/11/2002
Number of participants: 6
Phd Student: 
Hejfeldt, Sune (Intern)
Supervisor: 
Bischoff, Svend (Intern)
Main Supervisor: 
Merk, Jesper (Intern)
Examiner: 
Rottwitt, Karsten (Intern)
Olin, Ulf (Ekstern)
Tessler, Nir (Ekstern)

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

Optically Pumped Waveguide Lasers and Amplifiers

Department of Photonics Engineering
Period: 01/02/1996 → 09/04/2001
Number of participants: 3
Phd Student: 
Yujun, Qian (Intern)
Main Supervisor: 
Nicolaisen, Ejner (Intern)
Examiner: 
Rottwitt, Karsten (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Kandidatstipendium ansat på DT
Project: PhD

Nonlinear optics
Soliton propagation and quasi phase matching in stochastic nonlinear media (of chi(3) and chi(2) type) is investigated.

Publications (PLC, CBC, and MPS) refer to publication lists of P.L. Christiansen, C.B. Clausen, and M. P. Soerensen):

Department of Informatics and Mathematical Modeling
Department of Electromagnetic Systems
Department of Mathematics

Tele Danmark Research
Period: 01/01/1996 → …
Number of participants: 10
Project participant:
Sørensen, Mads Peter (Intern)
Clausen, Carl A. Balslev (Intern)
Povlsen, Jørn Hedegaard (Intern)
Rottwitt, Karsten (Intern)
Flytzanis, N. (Ekstern)
Teixeiro, Manolo-Quirogo (Ekstern)
Caputo, Jean Guy (Intern)
Torner, L. (Ekstern)
Eilbeck, J.C. (Ekstern)

Project Manager, organisational:
Christiansen, Peter Leth (Intern)

Financing sources
Source: Unknown
Name of research programme: Ukendt
Amount: 50,000.00 Danish Kroner
Source: Unknown
Name of research programme: Ukendt
Amount: 25,000.00 Danish Kroner

Activities:

Hvad er lys
Period: 15 Nov 2015
Karsten Rottwitt (Lecturer)
Department of Photonics Engineering
Fiber Optics, Devices and Non-linear Effects
Centre of Excellence for Silicon Photonics for Optical Communications

Description
Foredrag på Folkeuniversitetet

foredrag på Folkeuniversitetet

Related external organisation

Unknown external organisation
Activity: Talks and presentations › Conference presentations

Syddansk Universitet, Odense: Bachelorprojekt 'Analyse og modellering af elektromagnetiske felter i og omkring metalliske nanostrukturen'
Period: 29 Jun 2010
Karsten Rottwitt (Other)
Department of Photonics Engineering
Fiber Optics, Devices and Non-linear Effects
Related external organisation

Odense, Denmark
Activity: Talks and presentations › Guest lectures, external teaching and course activities at other universities

Syddansk Universitet, Odense: Kandidatspeciale 'Konstruktion og karakterisering af lasersystem, indeholdende laserdioder og ulineært krystal, opsat som optisk parametrisk oscillator'
Period: 29 Jun 2010
Karsten Rottwitt (External examiner)
Department of Photonics Engineering
Fiber Optics, Devices and Non-linear Effects
Activity: Examinations and supervision › External examination

Press clippings:

interview til Videnskab.dk
Karsten Rottwitt
01/02/2015

Subject
Fysik, hvad er lys.
Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Centre of Excellence for Silicon Photonics for Optical Communications

Media contribution (1)

interview til Videnskab.dk
01/02/2015
Videnskab.dk, Print
Karsten Rottwitt
Department of Photonics Engineering, Fiber Optics, Devices and Non-linear Effects, Centre of Excellence for Silicon Photonics for Optical Communications
Press / Media