Real-time high-resolution mid-infrared optical coherence tomography

The potential for improving the penetration depth of optical coherence tomography systems by using light sources with longer wavelengths has been known since the inception of the technique in the early 1990s. Nevertheless, the development of mid-infrared optical coherence tomography has long been challenged by the maturity and fidelity of optical components in this spectral region, resulting in slow acquisition, low sensitivity, and poor axial resolution. In this work, a mid-infrared spectral-domain optical coherence tomography system operating at a central wavelength of 4 µm and an axial resolution of 8.6 µm is demonstrated. The system produces two-dimensional cross-sectional images in real time enabled by a high-brightness 0.9- to 4.7-µm mid-infrared supercontinuum source with a pulse repetition rate of 1 MHz for illumination and broadband upconversion of more than 1-µm bandwidth from 3.58–4.63 µm to 820–865 nm, where a standard 800-nm spectrometer can be used for fast detection. The images produced by the mid-infrared system are compared with those delivered by a state-of-the-art ultra-high-resolution near-infrared optical coherence tomography system operating at 1.3 µm, and the potential applications and samples suited for this technology are discussed. In doing so, the first practical mid-infrared optical coherence tomography system is demonstrated, with immediate applications in real-time non-destructive testing for the inspection of defects and thickness measurements in samples that exhibit strong scattering at shorter wavelengths.
Lad vand og data strømme

General information
Publication status: Published
Organisations: Urban Water Systems, Department of Environmental Engineering, Environmental Fate & Effect of Chemicals, Air, Land & Water Resources, Water Technologies, Research group for Food Microbiology and Hygiene, National Food Institute, Systems Analysis, Department of Technology, Management and Economics, Molecular Windows, Nanocharacterization, National Centre for Nano Fabrication and Characterization, PROSYS - Process and Systems Engineering Centre, Department of Chemical and Biochemical Engineering, Section for Oceans and Arctic, National Institute of Aquatic Resources, Department of Energy Conversion and Storage, Design and Processes, Department of Civil Engineering, Dynamical Systems, Department of Applied Mathematics and Computer Science, Fluid Mechanics, Coastal and Maritime Engineering, Department of Mechanical Engineering, Ultrafast Infrared and Terahertz Science, Center for Nanostructured Graphene, Department of Photonics Engineering, Networks Technology and Service Platforms, Optical Sensor Technology, Office for Research and Relations, Office for Innovation & Sector Services
Number of pages: 71
Publication date: 2019

Pulsered upconversion imaging of mid-infrared supercontinuum light using an electronically synchronized pump laser
In this paper, a versatile method for synchronized imaging upconversion in the mid-IR wavelength range is presented. A 1064 nm master oscillator power amplifier source pump laser is electronically adjusted in pulse duration and repetition rate to match the output from a 40 kHz, 1.6 ns pulse mid-IR supercontinuum light source followed by upconversion to the near-infrared captured by a sensitive CCD camera. The systems noise is characterized, and we present a simple algorithm for correcting for the image distortion caused by the use of off-axis parabolic mirrors.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology, NKT Photonics A/S
Contributors: Huot, L., Moselund, P. M., Tidemand-Lichtenberg, P., Pedersen, C.
Pages: 244-249
Publication date: 2019
Peer-reviewed: Yes

Pulsered upconversion imaging of mid-infrared supercontinuum light using an electronically synchronized pump laser
In this paper, a versatile method for synchronized imaging upconversion in the mid-IR wavelength range is presented. A 1064 nm master oscillator power amplifier source pump laser is electronically adjusted in pulse duration and repetition rate to match the output from a 40 kHz, 1.6 ns pulse mid-IR supercontinuum light source followed by upconversion to the near-infrared captured by a sensitive CCD camera. The systems noise is characterized, and we present a simple algorithm for correcting for the image distortion caused by the use of off-axis parabolic mirrors.
SHG (532 nm)-induced spontaneous parametric downconversion noise in 1064-nm-pumped IR upconversion detectors

As a novel technique for infrared detection, frequency upconversion has been successfully deployed in many applications. However, investigations into the noise properties of upconversion detectors (UCDs) have also received considerable attention. In this Letter, to the best of our knowledge, we present a new noise source-second-harmonic generation (SHG)-induced spontaneous parametric downconversion experimentally and theoretically shown to exist in short-wavelength-pumped UCDs. We investigate the noise properties of two UCDs based on single-pass 1064-nm-pumped periodically poled LiNbO3 bulk crystals. One UCD is designed to detect signals in the telecom band and the other in the mid-infrared regime. Our experimental demonstration and theoretical analysis reveal the basic properties of this newly discovered UCD noise source, including its dependence on crystal temperature and pump power. Furthermore, the principle behind the generation of this noise source can also be applied to other UCDs, which utilize nonlinear crystals either in waveguide form or with different bulk materials. This study may also aid in developing methods to suppress the newly identified noise in future UCD designs.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Diode Lasers and LED Systems, Optical Sensor Technology, Barcelona Institute of Science and Technology
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Pages: 1670-1673
Publication date: 2019
Peer-reviewed: Yes

Publication information
Journal: Optics Letters
Volume: 44
Issue number: 7
ISSN (Print): 0146-9592
BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
Original language: English
Electronic versions:
1903.00260.pdf
DOIs:
10.1364/OL.44.001670
Source: FindIt
Source-ID: 2444887863
Research output: Contribution to journal › Journal article – Annual report year: 2019 › Research › peer-review

Upconversion detector for range-resolved DIAL measurement of atmospheric CH4

We demonstrate a robust, compact, portable and efficient upconversion detector (UCD) for a differential absorption lidar (DIAL) system designed for range-resolved methane (CH4) atmospheric sensing. The UCD is built on an intracavity pump system that mixes a 1064 nm pump laser with the lidar backscatter signal at 1646 nm in a 25-mm long periodically poled lithium niobate crystal. The upconverted signal at 646 nm is detected by a photomultiplier tube (PMT). The UCD with a noise equivalent power around 127 fW/Hz^1/2 outperforms a conventional InGaAs based avalanche photodetector when both are used for DIAL measurements. Using the UCD, CH4 DIAL measurements have been performed yielding differential absorption optical depths with relative errors of less than 11% at ranges between 3 km and 9 km.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology, German Aerospace Center (DLR), NLIR ApS
Corresponding author: Meng, L.
Contributors: Meng, L., Fix, A., Wirth, M., Høgstedt, L., Tidemand-Lichtenberg, P., Pedersen, C., Rodrigo, P. J.
Pages: 3850-3860
Publication date: 19 Feb 2018
Peer-reviewed: Yes

Publication information
Journal: Optics Express
Volume: 26
Issue number: 4
ISSN (Print): 1094-4087
Mid-IR hyperspectral imaging for label-free histopathology and cytology

Mid-infrared (MIR) imaging has emerged as a valuable tool to investigate biological samples, such as tissue histological sections and cell cultures, by providing non-destructive chemical specificity without recourse to labels. While feasibility studies have shown the capabilities of MIR imaging approaches to address key biological and clinical questions, these techniques are still far from being deployable by non-expert users. In this review, we discuss the current state of the art of MIR technologies and give an overview on technical innovations and developments with the potential to make MIR imaging systems more readily available to a larger community. The most promising developments over the last few years are discussed here. They include improvements in MIR light sources with the availability of quantum cascade lasers and supercontinuum IR sources as well as the recently developed upconversion scheme to improve the detection of MIR radiation. These technical advances can substantially speed up data acquisition of multispectral or hyperspectral datasets thus providing the end user with vast amounts of data when imaging whole tissue areas of many mm². Therefore, effective data analysis is of tremendous importance, and progress in method development is discussed with respect to the specific biomedical context.

Diode laser systems based on nonlinear frequency conversion

In this chapter, we will give a short introduction to nonlinear frequency conversion with second-order nonlinear optics to provide the basic background to the topic and highlight the important parameters to consider when designing a light source based on frequency conversion. In the following section, the different commonly used implementations of nonlinear frequency conversion will be introduced and some examples of demonstrated laser sources will be given. Finally, we will provide an outlook for the development of frequency converted diode laser light sources and briefly discuss some of the applications.
In this Letter, a novel method for the characterization of mid-infrared pulses is presented. A cross-correlator system, with no moving parts, combining ultra-broadband pulsed upconversion detection with fast active electronic delay tuning was built to perform time-resolved spectral characterization of 1.6 ns mid-infrared supercontinuum pulses. Full wavelength/time spectrograms were acquired in steps of 20 ps over a range that can, in theory, extend to microseconds in a matter of seconds, with 48 ps temporal resolution and 22 cm\(^{-1}\) spectral resolution in the 2700-4300 nm range. This work proves the potential for the use of electronic delay tuning instead of mechanical delay tuning for applications such as cross-correlators and laser spectroscopy, where their fast precise tunability and long delay ranges are a strong asset. (C) 2018 Optical Society of America
and (2) applying a spatial filter (instead of an ultra-narrow bandpass filter) at the output. This simple spatial filtering technique resulted in a 14 dB dark-count rate reduction. Due to a corresponding decrease in the interaction length of the signal with the pump, the upconversion efficiency also decreased, but only with a 2.2 dB penalty. (C) 2018 Optical Society of America under the terms of the OSA Open Access Publishing Agreement

Infrared upconversion spectrometer for the mid-IR range
The invention provides an infrared upconversion spectrometer for determining a mid-IR spectrum of received infrared light with a high resolution. The spectrometer applies upconversion to transform light in the mid-IR to the near-IR range where efficient detectors are available. The upconversion causes divergence of the light, and in addition, the invention applies an extra dispersive element to record a spectrum.

Investigation of optical signatures for discriminating salmon lice from other species of zooplankton
We present a study of optical signatures of salmon lice and the ability to distinguish them from a reference zooplankton species. This forms the basis for developing an instrument for detecting salmon lice in situ
Long wavelength identification of microcalcifications in breast cancer tissue using a quantum cascade laser and upconversion detection

Spectral imaging in the long-wave infrared regime has great potential for medical diagnostics. Breast cancer is the most common cancer amongst females in the US. The pathological features and the occurrence of the microcalcifications are still poorly understood. However, two types of microcalcifications have been identified as unique biomarkers: type I consisting of calcium oxalate (benign lesions) and type II composed of hydroxyapatite (benign or invasive lesions). In this study, we propose a new approach based on vibrational spectroscopy that is non-destructive, label-free and chemically specific for breast cancer detection. Long-wave infrared spectroscopy combining quantum cascade lasers (QCL) and upconversion detection, offer to improve signal-to-noise ratios compared to standard long-wave infrared spectroscopy. We demonstrated long-wave identification of synthetic samples of carbonated hydroxyapatite and of microcalcification in breast cancer tissue using upconversion detection. Absorbance spectra and upconverted images of in situ breast cancer biopsy are compared with that of Fourier-transform infrared (FTIR) spectroscopy.

Low repetition rate 343 nm passively Q-switched solid-state laser for time-resolved fluorescence spectroscopy

We demonstrate a low-cost 343 nm solid-state laser delivering up to 20 µJ per pulse, with a pulse width of 2.3 ns at a repetition rate of 100 Hz. The 343 nm is obtained through a third harmonic generation of a passively Q-switched 1030 nm Yb:YAG laser with pulse energy of 190 µJ at 100 Hz and a pulse width of 5.4 ns. The IR-UV conversion efficiency is 10.4%, comparable to that achieved with mode-locked IR lasers. The light source is electronically controlled for easy synchronization with a detection circuit. The low repetition rate specifically targets applications exploiting the millisecond scale lifetime of lanthanides employed in fluoroimmunoassay measurements for time-resolved fluorescence spectroscopy. Low repetition rate and even pulse-on-demand operation is demonstrated.
Mid-Infrared (6 - 10 μm) upconversion in LiInS2 using 1064 nm CW pump

For the first time wide-band mid-infrared (6-10 μm) frequency upconversion in a LiInS2 crystal is obtained using a 1064 nm pump. The absorption spectrum of polystyrene is characterized using a near-infrared grating and a Si-CCD.

Mid-infrared coincidence measurements based on intracavity frequency conversion

In the last years, the Mid Infrared (MIR) spectral region has attracted the attention of many areas of science and technology, opening the way to important applications, such as molecular imaging, remote sensing, free-space communication and environmental monitoring. However, the development of new sources of light, such as quantum cascade laser, was not followed by an adequate improvement in the MIR detection system, able to exceed the current challenges. Here we demonstrate the single-photon counting capability of a new detection system, based on efficient up-converter modules, by proving the correlated nature of twin photons pairs at about 3.1μm, opening the way to the extension of quantum optics experiments in the MIR.
Mid-infrared imaging using upconversion - Principles and applications

Different schemes for mid-infrared hyperspectral imaging using upconversion detection are implemented and compared in terms of spectral coverage, field-of-view, resolution, and speed. Both broadband and narrowband, continuous wave and pulsed imaging systems are considered.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology
Contributors: Tidemand-Lichtenberg, P., Rodrigo, P. J., Pedersen, C.
Publication date: 2018

Host publication information
Title of host publication: Mid-Infrared Coherent Sources 2018
Volume: 2018
Publisher: Optical Society of America OSA
Article number: Paper MM4C.1
ISBN (Print): 978-1-943580-40-8
(Optics Infobase Conference Papers).
DOIs:
10.1364/MICS.2018.MM4C.1

Bibliographical note
From the session: Remote Sensing and Imaging (MM4C)
Source: FindIt
Source-ID: 2434893662
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 2018 – Research – peer-review

Mid-infrared upconversion based hyperspectral imaging

Mid-infrared hyperspectral imaging has in the past decade emerged as a promising tool for medical diagnostics. In this work, nonlinear frequency upconversion based hyperspectral imaging in the 6 to 8 μm spectral range is presented for the first time, using both broadband globar and narrowband quantum cascade laser illumination. AgGaS2 is used as the nonlinear medium for sum frequency generation using a 1064 nm mixing laser. Angular scanning of the nonlinear crystal provides broad spectral coverage at every spatial position in the image. This study demonstrates the retrieval of series of monochromatic images acquired by a silicon based CCD camera, using both broadband and narrowband illumination and a comparison is made between the two illumination sources for hyperspectral imaging. (C) 2018 Optical Society of America under the terms of the OSA Open Access Publishing Agreement

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology, Humboldt State University, Technical University of Denmark
Contributors: Junaid, S., Tomko, J., Semtsiv, M. P., Kischkat, J., Masselink, W. T., Pedersen, C., Tidemand-Lichtenberg, P.
Pages: 2203-2211
Publication date: 2018
Peer-reviewed: Yes

Publication information
Journal: Optics Express
Volume: 26
Issue number: 3
ISSN (Print): 1094-4087
Ratings:
Point-Spread Function Engineering in Upconversion Imaging

We demonstrate an upconversion based 4-fimaging system and investigate how its point-spread function can be altered by spatially manipulating the amplitude and/or phase profiles of the otherwise Gaussian mixing field. This is accomplished by imaging different amplitude and phase masks illuminated by the mixing field into the Fourier plane of the imaging system where nonlinear sum frequency mixing occurs. A bulk lithium niobate crystal is used as the nonlinear medium and an Er-Tm fiber laser is used to generate the mixing and the signal fields at 1550 nm and 1877 nm, respectively. Object information is probed by the 1877 nm signal beam and upconverted to form an image at 849 nm, which allows for image acquisition using an inexpensive room-temperature Si camera.

S/N ratio of an upconversion detector dominated by upconverted spontaneous parametric down-conversion noise

We designed an upconversion detector (UCD) for 1575 nm operation. The signal-to-noise ratio of the UCD is investigated by considering the dependence of upconversion efficiency and upconverted spontaneous parametric down-conversion noise on pump power.
Thermal noise in mid-infrared broadband upconversion detectors

Low noise detection with state-of-the-art mid-infrared (MIR) detectors (e.g., PbS, PbSe, InSb, HgCdTe) is a primary challenge owing to the intrinsic thermal background radiation of the low bandgap detector material itself. However, researchers have employed frequency upconversion based detectors (UCD), operable at room temperature, as a promising alternative to traditional direct detection schemes. UCD allows for the use of a low noise silicon-CCD/camera to improve the SNR. Using UCD, the noise contributions from the nonlinear material itself should be evaluated in order to estimate the limits of the noise-equivalent power of an UCD system. In this article, we rigorously analyze the optical power generated by frequency upconversion of the intrinsic black-body radiation in the nonlinear material itself due to the crystals residual emissivity, i.e. absorption. The thermal radiation is particularly prominent at the optical absorption edge of the nonlinear material even at room temperature. We consider a conventional periodically poled lithium niobate (PPLN) based MIR-UCD for the investigation. The UCD is designed to cover a broad spectral range, overlapping with the entire absorption edge of the PPLN (3.5 - 5 \(\mu\)m). Finally, an upconverted thermal radiation power of similar to 30 pW at room temperature (similar to 30 degrees C) and a maximum of similar to 70 pW at 120 degrees C of the PPLN crystal are measured for a CW mixing beam of power similar to 60 W, supporting a good quantitative agreement with the theory. The analysis can easily be extended to other popular nonlinear conversion processes including OPO, DFG, and SHG. (C) 2018 Optical Society of America under the terms of the OSA Open Access Publishing Agreement.
Upconversion detection of long-wave infrared radiation from a quantum cascade laser

Broadly tunable upconversion is demonstrated for long-wave infrared (LWIR) detection. The upconversion system is evaluated by the detection of 50 ns pulses from a narrow linewidth tunable quantum cascade laser (QCL) in the 9.4 to 12 μm range. The LWIR signal is mixed with a 1064 nm laser beam in a silver gallium sulfide (AgGaS2) crystal, resulting in an upconverted signal in the 956 to 977 nm range, using angle tuning for optimal phase-matching. This allows for efficient, high speed detection using a standard silicon detector. A theoretical model including absorption and diffraction shows qualitative agreement with experimental data. (C) 2018 Optical Society of America under the terms of the OSA Open Access Publishing Agreement

Upconversion raster scanning microscope for long-wavelength infrared imaging of breast cancer microcalcifications

Long-wavelength identification of microcalcifications in breast cancer tissue is demonstrated using a novel upconversion raster scanning microscope. The system consists of quantum cascade lasers (QCL) for illumination and an upconversion system for efficient, high-speed detection using a silicon detector. Absorbance spectra and images of regions of ductal carcinoma in situ (DCIS) from the breast have been acquired using both upconversion and Fourier-transform infrared (FTIR) systems. The spectral images are compared and good agreement is found between the upconversion and the FTIR systems. (C) 2018 Optical Society of America under the terms of the OSA Open Access Publishing Agreement
340nm UV LED excitation in time-resolved fluorescence system for europium-based immunoassays detection

In immunoassay analyzers for in-vitro diagnostics, Xenon flash lamps have been widely used as excitation light sources. Recent advancements in UV LED technology and its advantages over the flash lamps such as smaller footprint, better wall-plug efficiency, narrow emission spectrum, and no significant afterglow, have made them attractive light sources for gated detection systems. In this paper, we report on the implementation of a 340 nm UV LED based time-resolved fluorescence system based on europium chelate as a fluorescent marker. The system performance was tested with the immunoassay based on the cardiac marker, TnI. The same signal-to-noise ratio as for the flash lamp based system was obtained, operating the LED below specified maximum current. The background counts of the system and its main contributors were measured and analyzed. The background of the system of the LED based unit was improved by 39% compared to that of the Xenon flash lamp based unit, due to the LEDs narrower emission spectrum and longer pulse width. Key parameters of the LED system are discussed to further optimize the signal-to-noise ratio and signal-to-background, and hence the sensitivity of the instrument.
Broadband upconversion imaging around 4 µm using an all-fiber supercontinuum source

We present a novel mid-infrared imaging system born from the combination of an all-fiber mid-IR supercontinuum source developed at NKT with ultra-sensitive upconversion detection technology from DTU Fotonik. The source delivers 100 mW of average power and its spectrum extends up to 4.5 µm. The infrared signal is passed through a sample and then focused into a bulk AgGaS2 crystal and subsequently mixed with a synchronous mixing signal at 1550 nm extracted from the pump laser of the supercontinuum. Through sum frequency generation, an upconverted signal ranging from 1030 nm to 1155 nm is generated and acquired using an InGaAs camera.

Concave Grating Enabled Compact Mid-IR Upconversion Spectrometer

The paper demonstrates a wide-band (3.6 - 4.8 µm) compact mid-infrared grating spectrometer combining a nonlinear frequency upconversion process and a flat-field aberration corrected concave grating with overall system dimension of 25cm×50cm.

GHz-bandwidth upconversion detector using a unidirectional ring cavity to reduce multilongitudinal mode pump effects

We demonstrate efficient upconversion of modulated infrared (IR) signals over a wide bandwidth (up to frequencies in excess of 1 GHz) via cavity-enhanced sum-frequency generation (SFG) in a periodically poled LiNbO3. Intensity modulated IR signal is produced by combining beams from two 1547 nm narrow-linewidth lasers in a fiber coupler while tuning their wavelength difference down to 10 pm or less. The SFG crystal is placed inside an Nd:YVO4 ring cavity that provides 1064 nm circulating pump powers of up to 150 W in unidirectional operation. Measured Fabry-Perot spectrum at 1064 nm confirms the enhanced spectral stability from multiple to single longitudinal mode pumping condition. We describe analytically and demonstrate experimentally the deleterious effects of using a multimode pump to the high-bandwidth RF spectrum of the 630 nm SFG output. Offering enhanced sensitivity without the need for cooling, the GHz-bandwidth upconverter can readily be extended to the mid-IR (2 - 5 µm) as an alternative to cooled low-bandgap semiconductor detectors for applications such as high-speed free-space optical communications. (C) 2017 Optical Society
High-sensitivity detection of cardiac troponin I with UV LED excitation for use in point-of-care immunoassay

High-sensitivity cardiac troponin assay development enables determination of biological variation in healthy populations, more accurate interpretation of clinical results and points towards earlier diagnosis and rule-out of acute myocardial infarction. In this paper, we report on preliminary tests of an immunoassay analyzer employing an optimized LED excitation to measure on a standard troponin I and a novel research high-sensitivity troponin I assay. The limit of detection is improved by factor of 5 for standard troponin I and by factor of 3 for a research high-sensitivity troponin I assay, compared to the flash lamp excitation. The obtained limit of detection was 0.22 ng/L measured on plasma with the research highsensitivity troponin I assay and 1.9 ng/L measured on tris-saline-azide buffer containing bovine serum albumin with the standard troponin I assay. We discuss the optimization of time-resolved detection of lanthanide fluorescence based on the time constants of the system and analyze the background and noise sources in a heterogeneous fluoroimmunoassay. We determine the limiting factors and their impact on the measurement performance. The suggested model can be generally applied to fluoroimmunoassays employing the dry-cup concept.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology, Radiometer Turku, Radiometer Medical ApS
Contributors: Rodenko, O., Eriksson, S., Tidemand-Lichtenberg, P., Trolldborg, C. P., Fodgaard, H., van Os, S., Pedersen, C.
Pages: 3749-3762
Publication date: 2017
Peer-reviewed: Yes

Publication information
Journal: Biomedical Optics Express
Volume: 8
Issue number: 8
ISSN (Print): 2156-7085
Ratings:
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 3.9 SJR 1.486 SNIP 1.591
Web of Science (2017): Impact factor 3.482
Web of Science (2017): Indexed yes
Original language: English
Inherent Limitations in Mid-Wave and Long-Wave-IR Upconversion Detector

Inherent limitations in terms of optical losses, selection of nonlinear crystal(s), detection efficiency and pumping conditions in mid-wave (3-5 µm) and long-wave (8-12 µm) infrared frequency upconversion modules are investigated in this paper.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology
Contributors: Barh, A., Tseng, Y., Pedersen, C., Tidemand-Lichtenberg, P.
Number of pages: 2
Publication date: 2017

Host publication information
Title of host publication: Proceedings of Frontiers in Optics 2017
Publisher: OSA - The Optical Society
Article number: JTu3A.38
(OSA, Technical Digest).
DOI: 10.1364/FIO.2017.JTu3A.38
Source: PublicationPreSubmission
Source-ID: 140592645
Research output: Chapter in Book/Report/Conference proceeding – Annual report year: 2017 › Research › peer-review

intracavity upconversion for IR absorption lidar: Comparison of linear and ring cavity designs

Upconversion detection is a promising technology for measurement of IR signals in the 1.5 µm–2 µm region used for lidar remote sensing [1-2]. In comparison to conventional InGaAs detector, the upconversion detector can achieve IR detection with better signal-to-noise ratio (SNR), not only due to lower dark noise directly, but also because of its limited field-of-view and acceptance bandwidth that results in a much lower background noise.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology, IRSee ApS
Contributors: Meng, L., Høgstedt, L., Tidemand-Lichtenberg, P., Pedersen, C., Rodrigo, P. J.
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
Keywords: Cavity resonators, Detectors, Laser radar, Atmospheric measurements, Crystals, Absorption, Signal to noise ratio
DOI: 10.1109/CLEOE-EQEC.2017.8086562
Source: FindIt
Source-ID: 2392694306
Research output: Chapter in Book/Report/Conference proceeding › Conference abstract in proceedings – Annual report year: 2017 › Research › peer-review

Investigation of mid-IR picosecond image upconversion

Imaging and spectroscopy in the mid-infrared (Mid-IR) wavelength region have received considerable attention in recent years. The reason is the high Mid-IR spectral specificity of many gases and complex molecules. In this pilot study we focus on picosecond upconversion imaging exploiting the $\chi(2)$ nonlinearity of a bulk lithium niobate crystal as a means to convert the optical Mid-IR signal into the visible wavelength region, thus allowing the use of fast and sensitive silicon
based CCD cameras. The picosecond upconversion system is synchronously pumped in order to increase the quantum efficiency, hence allowing for upconversion of faint pulsed Mid-IR light.

**General information**
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology
Contributors: Mathez, M. D., Pedersen, C., Rodrigo, P. J., Tidemand-Lichtenberg, P.
Number of pages: 7
Publication date: 2017

**Host publication information**
Title of host publication: Proceedings of SPIE
Volume: 10088
Publisher: SPIE - International Society for Optical Engineering
Article number: 100880L
Keywords: Nonlinear wave mixing, Infrared imaging, Upconversion, Pulsed laser
Electronic versions:
100880L_1_.pdf
DOIs:
10.1117/12.2251107

**Bibliographical note**
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Source: FindIt
Source-ID: 2371627747
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2017 › Research › peer-review

Mid-infrared coincidence measurements on twin photons at room temperature
Quantum measurements using single-photon detectors are opening interesting new perspectives in diverse fields such as remote sensing, quantum cryptography and quantum computing. A particularly demanding class of applications relies on the simultaneous detection of correlated single photons. In the visible and near infrared wavelength ranges suitable single-photon detectors do exist. However, low detector quantum efficiency or excessive noise has hampered their mid-infrared (MIR) counterpart. Fast and highly efficient single-photon detectors are thus highly sought after for MIR applications. Here we pave the way to quantum measurements in the MIR by the demonstration of a room temperature coincidence measurement with non-degenerate twin photons at about 3.1 μm. The experiment is based on the spectral translation of MIR radiation into the visible region, by means of efficient up-converter modules. The up-converted pairs are then detected with low-noise silicon avalanche photodiodes without the need for cryogenic cooling.

**General information**
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology
Number of pages: 8
Publication date: 2017
Peer-reviewed: Yes

**Publication information**
Journal: Nature Communications
Volume: 8
Article number: 15184
ISSN (Print): 2041-1723
Ratings:
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 12.41 SJR 6.582 SNIP 2.912
Web of Science (2017): Impact factor 12.353
Web of Science (2017): Indexed yes
Original language: English
Electronic versions:
ncomms15184.pdf
Towards rapid high-resolution mid-IR imaging for molecular spectral histopathological diagnosis of oesophageal cancers

Modern western societies suffer from diseases of civilization which are mainly associated with smoking, fatty diets and obesity. One of those is the Gastroesophageal reflux disease (GERD) often also loosely called heartburn. GERD can in some cases lead to an abnormal change of cells (metaplasia) in the lining of the oesophagus. This syndrome is defined as Barrett's oesophagus (BO). If the oesophagus suffers from reflux of acid (heartburn) it can protect itself by replacing the normal stratified squamous epithelium by acid resistant columnar epithelium with goblet cells usually found lower in the gastrointestinal tract. These cells growing in an area where they usually do not belong, have a significantly higher risk to degenerate into cancers. These conditions are evaluated by performing endoscopy with harvest of biopsies. Biopsies are then cut and stained with haematoxylin and eosin and assessed by a pathologist. Patients diagnosed with BO undergo a regular surveillance in order to monitor if the metaplasia progresses into dysplasia or adenocarcinoma.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology, University of Exeter, Humboldt State University
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
Keywords: Quantum cascade lasers, Cancer, Biomedical imaging, Physics, Light sources
DOIs: 10.1109/CLEOE-EQEC.2017.8087789
Source: FindIt
Source-ID: 2392693488
Research output: Chapter in Book/Report/Conference proceeding » Conference abstract in proceedings – Annual report year: 2017 » Research » peer-review

Upconversion based MIR hyperspectral imaging
Midinfrared (MIR) hyperspectral imaging has a great potential to be used as a tool for medical diagnostics featuring a combination of imaging and spectroscopy. In hyperspectral imaging, the images of the (biomedical) samples contains both spectral and spatial information.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology
Contributors: Junaid, S., Tidemand-Lichtenberg, P., Pedersen, C.
Number of pages: 1
Publication date: 2017

Host publication information
Title of host publication: Proceedings of 2017 Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference (CLEO/Europe-EQEC)
Publisher: IEEE
DOIs: 10.1109/CLEOE-EQEC.2017.8086475
Source: FindIt
Source-ID: 2392695027
Research output: Chapter in Book/Report/Conference proceeding » Conference abstract in proceedings – Annual report year: 2017 » Research » peer-review
Upconversion based spectral imaging in 6 to 8 μm spectral regime
Spectral imaging in the 6 to 8μm range has great potential for medical diagnostics. Here a novel technique based on frequency upconversion of the infrared images to the near visible for subsequent acquisition using a Si-CCD camera is investigated. The upconversion unit consists of an AgGaS2 crystal and a 1064nm diode pumped solid state laser. A globar is used as mid-infrared illumination source. Acquired images contain both spectral and spatial information. Angle tuning of the nonlinear crystal is exploited to scan the phase match condition, which allows to cover the full spectral range of interest for the full field of view. Simulated images are created and compared with the measured images.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology, Department of Physics
Contributors: Junaid, S., Tidemand-Lichtenberg, P., Pedersen, C.
Number of pages: 7
Publication date: 2017

Host publication information
Title of host publication: Proceedings of SPIE
Volume: 10088
Publisher: SPIE - International Society for Optical Engineering
Article number: 100880I
(Proceedings of SPIE - International Society for Optical Engineering).
Keywords: Sum frequency generation (SFG), Birefringence, Non-collinear phase matching, Spectral imaging
Electronic versions: 100880I_1_.pdf
DOIs: 10.1117/12.2250538

Bibliographical note
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Source: FindIt
Source-ID: 2371785719
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 2017 – Research – peer-review

Upconversion detector for methane atmospheric sensor
We demonstrate an efficient upconversion detector (UCD) for a methane (CH4) atmospheric sensor. The UCD shows comparable performance with a conventional detector when measuring the backscattered signal from the hard target located 2.3 km away.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology, German Aerospace Center (DLR), NLIR ApS
Corresponding author: Meng, L.
Contributors: Meng, L., Fix, A., Høgstedt, L., Tidemand-Lichtenberg, P., Pedersen, C., Rodrigo, P. J.
Number of pages: 2
Publication date: 2017

Host publication information
Title of host publication: Optics and Photonics for Energy and the Environment, EE 2017
Volume: Part F65-EE 2017
Publisher: OSA - The Optical Society
Article number: EW4B.2
ISBN (Electronic): 9781557528209
DOIs: 10.1364/EE.2017.EW4B.2
Source: Scopus
Source-ID: 85035128874
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 2017 – Research – peer-review
Upconversion imaging using short-wave infrared picosecond pulses
To the best of our knowledge, we present the first demonstration of short-wavelength infrared image upconversion that employs intense picosecond signal and pump beams. We use a fiber laser that emits a signal beam at 1877 nm and a pump beam at 1550 nm—both with a pulse width of 1 ps and a pulse repetition rate of 21.7 MHz. Due to synchronization of high peak-power pulses, efficient upconversion is achieved in a single-pass setup that employs a bulk lithium niobate crystal. Optimizing the temporal overlap of the pulses for high upconversion efficiency enables us to exploit a relatively large pump beam diameter to upconvert a wider range of signal spatial frequencies in the crystal. The 1877 nm signal is converted into 849 nm—enabling an image to be acquired by a silicon CCD camera. The measured size of the smallest resolvable element of this imaging system is consistent with the value predicted by an improved model that considers the combined image blurring effect due to finite pump beam size, thick nonlinear crystal, and polychromatic infrared illumination.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology
Contributors: Mathez, M. D., Rodrigo, P. J., Tidemand-Lichtenberg, P., Pedersen, C.
Pages: 579-582
Publication date: 2017
Peer-reviewed: Yes

Publication information
Journal: Optics Letters
Volume: 42
Issue number: 3
ISSN (Print): 0146-9592
Ratings:
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 3.89 SJR 1.79 SNIP 1.597
Web of Science (2017): Impact factor 3.589
Web of Science (2017): Indexed yes
Original language: English
DOIs: 10.1364/OL.42.000579
Source: PublicationPreSubmission
Source-ID: 130575263
Research output: Contribution to journal › Journal article – Annual report year: 2017 › Research › peer-review

340 nm pulsed UV LED system for europium-based time-resolved fluorescence detection of immunoassays
We report on the design, development and investigation of an optical system based on UV light emitting diode (LED) excitation at 340 nm for time-resolved fluorescence detection of immunoassays. The system was tested to measure cardiac marker Troponin I with a concentration of 200 ng/L in immunoassay. The signal-to-noise ratio was comparable to state-of-the-art Xenon flash lamp based unit with equal excitation energy and without overdriving the LED. We performed a comparative study of the flash lamp and the LED based system and discussed temporal, spatial, and spectral features of the LED excitation for time-resolved fluorimetry. Optimization of the suggested key parameters of the LED promises significant increase of the signal-to-noise ratio and hence of the sensitivity of immunoassay systems.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology, Diode Lasers and LED Systems, Radiometer Medical ApS
Contributors: Rodenko, O., Fodgaard, H., Tidemand-Lichtenberg, P., Petersen, P. M., Pedersen, C.
Pages: 22135-22143
Publication date: 2016
Peer-reviewed: Yes

Publication information
Journal: Optics Express
Volume: 24
Issue number: 19
ISSN (Print): 1094-4087
Ratings:
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.48 SJR 1.532 SNIP 1.544
Web of Science (2016): Impact factor 3.307
Eye-safe diode laser Doppler lidar with a MEMS beam-scanner
We present a novel Doppler lidar that employs a cw diode laser operating at 1.5 μm and a micro-electro-mechanical-system scanning mirror (MEMS-SM). In this work, two functionalities of the lidar system are demonstrated. Firstly, we describe the capability to effectively steer the lidar probe beam to multiple optical transceivers along separate lines-of-sight. The beam steering functionality is demonstrated using four lines-of-sight – each at an angle of 18° with respect to their symmetry axis. Secondly, we demonstrate the ability to spatially dither the beam focus to reduce the mean irradiance at the probing distance (R = 60 m) of each line-of-sight – relevant for meeting eye-safety requirements. The switching time of the MEMS-SM is measured to be in the order of a few milliseconds. Time-shared (0.25 s per line-of-sight) radial wind speed measurements at 50 Hz data rate are experimentally demonstrated. Spatial dithering of the beam focus is also implemented using a spiral scan trajectory resulting in a 16 dB reduction of beam focus mean irradiance.
Mid-infrared nonlinear upconversion imaging and sensing

The mid-IR wavelength range is highly relevant for a number of applications related to gas spectroscopy and spectral analysis of complex molecules such as those including CH bounds. The main obstacles for exploitation of mid-IR applications include suitable and affordable mid-IR light sources for excitation of the sample and sensitive mid-IR detectors. With the advent of mid-IR Quantum cascaded lasers and super continuum light sources new possibilities has emerged. However, low-noise, mid-IR (2-15 μm) detection is still challenging requiring cryogenic cooling to gain sensitivities needed for measurements of fluorescence or absorptions signals. Mid-IR upconversion imaging and detection using nonlinear crystals offers good promise as an alternative, sensitive mid-IR imaging and detection technology. In this paper the fundamental properties of upconversion is discussed.

Mid-infrared upconversion spectroscopy

Mid-infrared (MIR) spectroscopy is emerging as an attractive alternative to near-infrared or visible spectroscopy. MIR spectroscopy offers a unique possibility to probe the fundamental absorption bands of a large number of gases as well as the vibrational spectra of complex molecules. In this paper we discuss non-collinear upconversion as a means for obtaining MIR spectra in the 5-10 μm range with a resolution better than 20 cm⁻¹ over the full interval using four discrete phase-match settings. A theoretical treatment of non-collinear upconversion is given and two different experimental implementations are tested.
Room temperature Up-conversion detection of a broadband Mid-IR source

The paper presents efficient up-conversion based room temperature detection of a broadband mid-infrared light source, ranging from 3.6 ~ 4.9 μm, exploiting nonlinear sum frequency generation in a periodically poled lithium-niobate crystal.

General information
Publication status: Published
Host publication information
Title of host publication: International Conference on Fibre Optics and Photonics 2016
Publisher: Optical Society of America OSA
Article number: Tu2G.3
ISBN (Print): 978-1-943580-22-4
(Optics Infobase Conference Papers).
Keywords: Electronic, Optical and Magnetic Materials, Mechanics of Materials
DOI:
10.1364/PHOTONICS.2016.Tu2G.3
Bibliographical note
From the session: Optical Fiber Devices/Sensors I (Tu2G)
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 2017

Upconversion-based lidar measurements of atmospheric CO2

For the first time an upconversion based detection scheme is demonstrated for lidar measurements of atmospheric CO2-concentrations, with a hard target at a range of 3 km and atmospheric backscatter from a range of similar to 450 m. The pulsed signals at 1572 nm are upconverted to 635 nm, and detected by a photomultiplier tube, to test how the upconversion technology performs in a long range detection system. The upconversion approach is compared to an existing direct detection scheme using a near-IR detector with respect to signal-to-noise ratio and quantum efficiency. It is
for the first time analyzed how the field-of-view of a receiver system, for long range detection, depends critically on the parameters for the nonlinear upconversion process, and how to optimize these parameters in future systems. (C) 2016 Optical Society of America

**General information**
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology, Department of Physics, Risø National Laboratory for Sustainable Energy, DLR
Contributors: Høgstedt, L., Fix, A., Wirth, M., Pedersen, C., Tidemand-Lichtenberg, P.
Pages: 5152-5161
Publication date: 2016
Peer-reviewed: Yes

**Publication information**
Journal: Optics Express
Volume: 24
Issue number: 5
ISSN (Print): 1094-4087
Ratings:
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.48 SJR 1.532 SNIP 1.544
Web of Science (2016): Impact factor 3.307

**Keywords:** OPTICS, DIFFERENTIAL ABSORPTION LIDAR, DETECTOR, GENERATION

Upconversion imaging using an all-fiber supercontinuum source
In this Letter, the first demonstration, to the best of our knowledge, of pulsed upconversion imaging using supercontinuum light is presented. A mid-infrared (IR) imaging system was built by combining a mid-IR supercontinuum source emitting between 1.8 and 2.6 μm with upconversion detection. The infrared signal is used to probe a sample and mixed with a synchronized 1550 nm laser pulse inside a lithium niobate (LiNbO3) crystal. The signal is thus upconverted to the 860-970 nm range and acquired on a standard silicon CCD array at a rate of 22 frames per second. In our implementation, spatial features in the sample plane as small as 55 μm could be resolved. (C) 2016 Optical Society of America

**General information**
Publication status: Published
Organisations: Department of Photonics Engineering, Department of Physics, Optical Sensor Technology, Risø National Laboratory for Sustainable Energy, NKT Group
Contributors: Huot, L., Moselund, P. M., Tidemand-Lichtenberg, P., Leick, L., Pedersen, C.
Pages: 2466-2469
Publication date: 2016
Peer-reviewed: Yes

**Publication information**
Journal: Optics Letters
Volume: 41
Issue number: 11
ISSN (Print): 0146-9592
Ratings:
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.54 SJR 1.769 SNIP 1.549
Web of Science (2016): Impact factor 3.416

**Keywords:** Indexed yes
Original language: English
Electronic versions:
260901.pdf
Design of a solid state laser for low noise upconversion detection of near infrared light
To maximize signal-to-noise ratio for upconversion of near-infrared light we show that the mixing intensity should be 3 GW/m². With emphasis on the noise contribution from random duty-cycle errors the optimum design parameters is discussed.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology, Department of Physics
Contributors: Høgstedt, L., Tidemand-Lichtenberg, P., Pedersen, C.
Publication date: 2015

Host publication information
Title of host publication: Proceedings of Advanced Solid State Lasers 2015
Publisher: Optical Society of America (OSA)
Article number: AM5A.6
ISBN (Print): 9781943580026
Keywords: Electrical and Electronic Engineering, Electronic, Optical and Magnetic Materials

Development of semiconductor laser based Doppler lidars for wind-sensing applications
We summarize the progress we have made in the development of semiconductor laser (SL) based Doppler lidar systems for remote wind speed and direction measurements. The SL emitter used in our wind-sensing lidar is an integrated diode laser with a tapered (semiconductor) amplifier. The laser source is low-cost and compact - enhancing the potential of lidar wind sensors for mass production. This paper describes two embodiments of the patented wind lidar technology and presents experimental results that evaluate the wind sensors' performance. Due to compactness, portability and cost-efficiency, SL based wind sensors have a strong potential in a number of applications such as wind turbine control, wind resource assessment, and micrometeorology (e.g. as alternative to the construction of meteorological towers with anemometers and wind vanes).

General information
Publication status: Published
Organisations: Risø National Laboratory for Sustainable Energy, Department of Photonics Engineering, Optical Sensor Technology
Contributors: Rodrigo, P. J., Hu, Q., Pedersen, C.
Number of pages: 4
Pages: 1-4
Publication date: 2015

Host publication information
Title of host publication: Proceedings of 2015 IEEE Region 10 Humanitarian Technology Conference
Publisher: IEEE
ISBN (Print): 9781467377287
Keywords: Computing and Processing, Engineering Profession, Power, Energy and Industry Applications, Robotics and Control Systems, Transportation, Doppler effect, Laser beams, Laser radar, lidar, Optical fiber sensors, semiconductor laser, sensors, Wind speed, Wind turbines

DOIs:
10.1364/OL.41.002466
Source: FindIt
Source-ID: 2304462635
Research output: Contribution to journal › Journal article – Annual report year: 2016 › Research › peer-review

DOIs:
10.1364/ASSL.2015.AM5A.6
Source: FindIt
Source-ID: 2289510721
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2016 › Research › peer-review

DOIs:
10.1109/R10-HTC.2015.7391864
Source: FindIt
Source-ID: 277206692
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2016 › Research › peer-review
Direct Detection Doppler Lidar using a Scanning Fabry-Perot Interferometer and a Single-Photon Counting Module

**General information**
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology
Contributors: Rodrigo, P. J., Pedersen, C.
Number of pages: 1
Publication date: 2015
Peer-reviewed: Yes
Event: Poster session presented at CLEO/Europe - EQEC 2015, Munich, Germany.
Source: PublicationPreSubmission
Source-ID: 117832948
Research output: Contribution to conference › Poster – Annual report year: 2015 › Research › peer-review

Effects of 1/f frequency noise in self-heterodyne linewidth measurement system with various delay lengths

**General information**
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology
Contributors: Hu, Q., Rodrigo, P. J., Pedersen, C.
Number of pages: 1
Publication date: 2015
Peer-reviewed: Yes
Event: Poster session presented at CLEO/Europe - EQEC 2015, Munich, Germany.

**Bibliographical note**
From the session: CH Poster Session (CH_P)
Source: PublicationPreSubmission
Source-ID: 117832810
Research output: Contribution to conference › Poster – Annual report year: 2015 › Research › peer-review

Infrared hyperspectral upconversion imaging using spatial object translation

In this paper hyperspectral imaging in the mid-infrared wavelength region is realised using nonlinear frequency upconversion. The infrared light is converted to the near-infrared region for detection with a Si-based CCD camera. The object is translated in a predefined grid by motorized actuators and an image is recorded for each position. A sequence of such images is post-processed into a series of monochromatic images in a wavelength range defined by the phasematch condition and numerical aperture of the upconversion system. A standard USAF resolution target and a polystyrene film are used to impart spatial and spectral information unto the source.

**General information**
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology, Center for Nuclear Technologies, Radiation Physics
Contributors: Kehlet, L. M., Sanders, N. H., Tidemand-Lichtenberg, P., Dam, J. S., Pedersen, C.
Number of pages: 6
Publication date: 2015
Peer-reviewed: Yes

**Publication information**
Journal: Optics Express
Volume: 23
Issue number: 26
Article number: 252894
ISSN (Print): 1094-4087
Ratings:
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.78 SJR 2.186 SNIP 1.664
Web of Science (2015): Indexed yes
Original language: English
Keywords: Multispectral and hyperspectral imaging, Infrared imaging, Upconversion
Electronic versions:
Infrared upconversion hyperspectral imaging

In this Letter, hyperspectral imaging in the mid-IR spectral region is demonstrated based on nonlinear frequency upconversion and subsequent imaging using a standard Si-based CCD camera. A series of upconverted images are acquired with different phase match conditions for the nonlinear frequency conversion process. From this, a sequence of monochromatic images in the 3.2-3.4 μm range is generated. The imaged object consists of a standard United States Air Force resolution target combined with a polystyrene film, resulting in the presence of both spatial and spectral information in the infrared image. (C) 2015 Optical Society of America

Multi-channel up-conversion infrared spectrometer and method of detecting a spectral distribution of light

A multi-channel infrared spectrometer for detecting an infrared spectrum of light received from an object. The spectrometer comprises a wavelength converter system comprising a nonlinear material and having an input side and an output side. The wavelength converter system comprises at least a first up-conversion channel and a second up-conversion channel, and is arranged such that light traversing the wavelength converter system at different angles in the nonlinear material is imaged into different positions in an image plane. The first up-conversion channel is configurable for phase-matching infrared light in a first input wavelength range incident on the first side and light in a first output wavelength range output on the second side. The spectrometer further comprises a demultiplexer configured for demultiplexing light in the first up-conversion channel and light in the second up-conversion channel. The demultiplexer is located on the first side or the second side of the wavelength converter system. Finally, the spectrometer comprises a spatially resolved detector arranged in the image plane to detect light in the first output wavelength range and second output wavelength range output of the wavelength converter system.
Upconversion applied for mid-IR hyperspectral image acquisition
Different schemes for upconversion mid-IR hyperspectral imaging is implemented and compared in terms of spectral coverage, spectral resolution, speed and noise. Phasematch scanning and scanning of the object within the field of view is considered.

Coaxial direct-detection lidar-system
The invention relates to a coaxial direct-detection LIDAR system for measuring velocity, temperature and/or particulate density. The system comprises a laser source for emitting a laser light beam having a lasing center frequency along an emission path. The system further comprises an optical delivery system arranged in the emission path of the laser source, the optical delivery system being arranged for delivering the laser light beam in a measuring direction, the optical delivery system further being configured for collecting a return signal backscattered along the measuring direction. Finally, the system comprises a detector system arranged to receive the return signal from the optical delivery system, the detector system comprising a narrowband optical filter and a detector, the narrowband optical filter having a filter center frequency of a pass-band, wherein the center lasing frequency and/or the center filter frequency may be scanned. The invention further relates to an aircraft airspeed measurement device, and a wind turbine airspeed measurement device comprising the LIDAR system.
Diode laser lidar wind velocity sensor using a liquid-crystal retarder for non-mechanical beam-steering

We extend the functionality of a low-cost CW diode lasercoherent lidar from radial wind speed (scalar) sensing to wind velocity(vector) measurements. Both speed and horizontal direction of the wind at~80 m remote distance are derived from two successive radial speedestimates by alternately steering the lidar probe beam in two different lines-of-sight (LOS) with a 60° angular separation. Dual-LOS beam-steering isimplemented optically with no moving parts by means of a controllabléliquid-crystal retarder (LCR). The LCR switches the polarization between two orthogonal linear states of the lidar beam so it either transmits throught or reflects off a polarization splitter. The room-temperature switching timebetween the two LOS is measured to be in the order of 100μs in one switchdirection but 16 ms in the opposite transition. Radial wind speedmeasurement (at 33 Hz rate) while the lidar beam is repeatedly steered from one LOS to the other every half a second is experimentally demonstrated –resulting in 1 Hz rate estimates of wind velocity magnitude and direction atbetter than 0.1 m/s and 1° resolution, respectively

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology, Windar Photonics A/S
Contributors: Rodrigo, P. J., Iversen, T. F. Q., Hu, Q., Pedersen, C.
Pages: 26674-26679
Publication date: 2014
Peer-reviewed: Yes

Publication information
Journal: Optics Express
Volume: 22
Issue number: 22
ISSN (Print): 1094-4087
Ratings:
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 4.18 SJR 2.584 SNIP 2.228
Web of Science (2014): Impact factor 3.488
Web of Science (2014): Indexed yes
Original language: English
Electronic versions:
oe_22_22_26674.pdf
DOIs:
10.1364/OE.22.026674

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-22-22-26674. Systematic or multiple reproduction or distribution to multiple locations via electronic or other means is prohibited and is subject to penalties under law.
Source: PublicationPreSubmission
Source-ID: 101567525
Research output: Contribution to journal › Journal article – Annual report year: 2014 › Research › peer-review

Field test of an all-semiconductor laser-based coherent continuous-wave Doppler lidar for wind energy applications

The wind energy industry is gaining interest in prevision of the rotor inflow for turbine control. The potential benefits are increased power production due to better alignment of the rotor to the mean wind direction as well as prolonged lifetime of the turbine due to load reductions. Several lidar-based instruments for wind turbine mounting are now commercially available. However, they suffer from high price and bulkiness. Therefore, the Technical University of Denmark has, in collaboration with the Danish company Windar Photonics A/S, developed a compact and low-cost lidar called WindEye based on a mass-produced all-semiconductor laser. The instrument is a coherent continuous-wave lidar with two fixed-focus telescopes for launching laser beams in two different directions. The alternation between the telescopes is achieved by a novel switching technique without any moving parts. Here, we report results from comparison campaigns with ultrasonic anemometer (METEK USA-1, Germany) measurements at a distance of about 80 meters from the lidar instrument. The influence of the finite spatial sampling volume at this range on the measured wind spectra is demonstrated. The sampling volume in the latest version of the instrument has been narrowed due to an improved telescope design and the signal quality has improved. Good reliability is essential for the anticipated applications for wind turbines. Thus, the lidar has been tested over extended periods in various meteorological conditions and the influence on the lidar signal strength from external atmospheric parameters such as relative humidity and concentrations of atmospheric particles is discussed. This novel lidar instrument design seems to offer a promising low-cost alternative for prevision remote sensing of wind turbine inflow.

General information
Impact of primary aberrations on coherent lidar performance

In this work we investigate the performance of a monostatic coherent lidar system in which the transmit beam is under the influence of primary phase aberrations: spherical aberration (SA) and astigmatism. The experimental investigation is realized by probing the spatial weighting function of the lidar system using different optical transceiver configurations. A rotating belt is used as a hard target. Our study shows that the lidar weighting function suffers from both spatial broadening and shift in peak position in the presence of aberration. It is to our knowledge the first experimental demonstration of these tendencies. Furthermore, our numerical and experimental results show good agreement. We also demonstrate how the truncation of the transmit beam affects the system performance. It is both experimentally and numerically proven that aberration effects have profound impact on the antenna efficiency, the optimum truncation of the transmit beam and the spatial sensitivity of a CW coherent lidar system. Under strong degree of aberration, the spatial confinement is significantly degraded. However for SA, the degradation of the spatial confinement can be reduced by tuning the truncation of the transmit beam, which results from the novel finding in this work, namely, that the optimum truncation ratio depends on the degree of SA.

Influence of laser frequency noise on scanning Fabry-Perot interferometer based laser Doppler velocimetry

In this work, we study the performance of a scanning Fabry-Perot interferometer based laser Doppler velocimeter (sFPI-LDV) and compare two candidate 1.5 um single-frequency laser sources for the system – a fiber laser (FL) and a semiconductor laser (SL). We describe a straightforward calibration procedure for the sFPI-LDV and investigate the effect of different degrees of laser frequency noise between the FL and the SL on the velocimeter’s performance.
**Infrared up-conversion microscope**

There is presented an up-conversion infrared microscope (110) arranged for imaging an associated object (130), wherein the up-conversion infrared microscope (110) comprises a non-linear crystal (120) arranged for up-conversion of infrared electromagnetic radiation, and wherein an objective optical component (100) has an entrance pupil with a first diameter D1, and an optical component system which is arranged for forming an external image (136) of the back-focal plane (132) of the objective optical component (100), which has a diameter (given by the diameter of a circle enclosing all optical paths at the plane of the 10 external image) which is denominated D2 and wherein D1 is larger than a second diameter D2.

**Infrared up-conversion telescope**

There is presented an up-conversion infrared telescope (110) arranged for imaging an associated scene (130), wherein the up-conversion infrared telescope (110) comprises a non-linear crystal (120) arranged for up-conversion of infrared electromagnetic radiation, and wherein a first optical component (101) has an entrance pupil with a first diameter D1, and an optical component system which is arranged for forming an first image (136) of the back-focal plane (132) of the objective optical component (100), which has a diameter (given by the diameter of a circle enclosing all optical paths at the plane of the external image) which is denominated D2 and wherein D1 is larger than a second diameter D2 and wherein the telescope further comprises a third optical component (103) and a fourth optical component (104); arranged for re-imaging the first image into a second image of the back-focal plane (132) of the first optical component (101).
Low-noise mid-IR upconversion detector for improved IR-degenerate four-wave mixing gas sensing

We compare a nonlinear upconversion detector with a conventional cryogenic InSb detector for the detection of coherent infrared light showing near-shot-noise-limited performance in the upconversion system. The InSb detector is limited by dark noise, which results in a 500 times lower signal-to-noise ratio. The two detectors are compared for the detection of a coherent degenerate four-wave mixing (DFWM) signal in the mid-infrared, and applied to measure trace-level acetylene in a gas flow at atmospheric pressure, probing its fundamental rovibrational transitions. In addition to lower noise, the upconversion system provides image information of the signal, thus adding new functionality compared to standard point detection methods. We further show that the upconversion detector system can be implemented as a simple replacement of the cryogenic detector.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology, Lund University
Contributors: Høgstedt, L., Dam, J. S., Sahlberg, A., Li, Z., Alden, M., Pedersen, C., Tidemand-Lichtenberg, P.
Pages: 5321-5324
Publication date: 2014
Peer-reviewed: Yes

Publication Information
Journal: Optics Letters
Volume: 39
Issue number: 18
ISSN (Print): 0146-9592
Ratings:
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.86 SJR 2.736 SNIP 2.11
Web of Science (2014): Impact factor 3.292
Web of Science (2014): Indexed yes
Original language: English
Electronic versions:
ol_39_18_5321.pdf
DOIs:
10.1364/OL.39.005321

Bibliographical note
This paper was published in Optics Letters 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/ol/abstract.cfm?uri=ol-39-18-5321. Systematic or multiple reproduction or distribution to multiple locations via electronic or other means is prohibited and is subject to penalties under law.
Source: PublicationPreSubmission
Source-ID: 101501406
Research output: Contribution to journal › Journal article – Annual report year: 2014 › Research › peer-review

Mid infrared upconversion spectroscopy using diffuse reflectance

We present a novel approach for mid infrared (mid-IR) spectral analysis using upconversion technology applied in a diffuse reflectance setup. We demonstrate experimentally that mid-IR spectral features in the 2.6-4 μm range using different test samples (e.g. zeolites) can be obtained. The results are in good agreement with published data. We believe that the benefit of low noise upconversion methods combined with spectral analysis will provide an alternative approach to e.g. mid-IR Fourier Transform microsopy. We discuss in detail the experimental aspects of the proposed method. The upconversion unit consists of a PP:LN crystal situated as an intracavity component in a Nd:YVO 4 laser. Mixing incoming spectrally and spatially incoherent light from the test sample with the high power intracavity beam of the Nd:YVO 4 laser results in enhanced conversion efficiency. The upconverted light is spectrally located in the near infrared (NIR) wavelength region easily accessible for low noise Silicon CCD camera technology. Thus the room temperature upconversion unit and the Silicon CCD camera replaces noisy mid infrared detectors used in existing Fourier Transform Infrared Spectroscopy. We demonstrate specifically that upconversion methods can be deployed using a diffuse reflectance setup where the test sample is irradiated by a thermal light source, i.e. a globar. The diffuse reflectance geometry is particularly well suited when a transmission setup cannot be used. This situation may happen for highly scattering or absorbing samples.

General information
Publication status: Published
Organisations: Department of Chemical and Biochemical Engineering, CHEC Research Centre, Department of Photonics Engineering, Optical Sensor Technology, Technical University of Denmark, Haldor Topsoe AS
Near diffraction limited mid-IR spectromicroscopy using frequency upconversion

Mid-infrared microscopy and spectroscopy is interesting due to its medical, biological and chemical applications. Spectromicroscopy can be used for histopathology, sample analysis and diagnosis. The ability to do spectromicroscopy in the 2.5 to 4.5 μm wavelength range where many organic molecules have their fundamental vibrations, with the addition of sufficient spectroscopic resolution to resolve these bands, can potentially allow for diagnostics without the need for staining of the sample. On a longer timeframe, mid-IR spectromicroscopy has the potential for in-vivo diagnostics, combining morphological and spectral imaging. Recent developments in nonlinear frequency upconversion, have demonstrated the potential to perform both imaging and spectroscopy in the mid-IR range at unparalleled low levels of illumination, the low upconversion detector noise being orders of magnitude below competing technologies. With these applications in mind, we have incorporated microscopy optics into an image upconversion system, achieving near diffraction limited spatial resolution in the 3 μm range. Spectroscopic information is further acquired by appropriate control of the phase match condition of the upconversion process. Multispectral images for a region of interest can be obtained by XY-scanning this region of interest within the field of view of the mid-IR upconversion system. Thus, the whole region of interest can be imaged with all available converter wavelengths, and the spectral representation becomes equal for all points in the image. In addition, the range of converted/imaged wavelengths can be tuned continuously by changing the temperature of the crystal, or discretely by using a different poling channel in the PPLN crystal.

Non-collinear upconversion of incoherent light: designing infrared spectrometers and imaging systems

Upconversion of incoherent mid-infrared radiation to near visible wavelengths, offers very attractive sensitivity compared to conventional means of infrared detection. Incoherent light, focused into a nonlinear crystal, results in noncollinear phase matching of a narrow range of wavelengths for each angle of propagation. Non-collinear phase matching has been an area of limited attention for many years due to inherent incompatibility with tightly focused laser beams typically used for most second order processes in order to achieve acceptable conversion efficiency. The development of periodically poled crystals have allowed for non-critical phase matching of most wavelengths, virtually eliminating the need for non-collinear phase matching. When considering upconversion of thermal light, spectral radiance is limited due to the finite temperature of the Planck radiation source. It is, however, straightforward to increase the incoherent power by increasing the receiving aperture of the upconversion unit i.e. the diameter of the upconversion laser beam. Hence, the optimal conversion efficiency for incoherent light is not achieved by tightly focused beams. In this paper we show that filling the
Nonlinear crystal with as large a pump beam as possible yields the best conversion as this allows for upconversion of large angles of incoming incoherent light. We present results of non-collinear mixing and how it affects spectral and spatial resolution in the image and compare against experiments. We finally discuss how it can be used to design and predict system performance and how incoherent upconversion can be used for mid-IR spectroscopy and imaging.

Non-collinear upconversion of infrared light

Two dimensional mid-infrared upconversion imaging provides unique spectral and spatial information showing good potential for mid-infrared spectroscopy and hyperspectral imaging. However, to extract spectral or spatial information from the upconverted images an elaborate model is needed, which includes non-collinear interaction. We derive here a general theory providing the far field of the upconverted light when two arbitrary fields interact inside a non linear crystal. Theoretical predictions are experimentally verified for incoherent radiation and subsequently applied to previously published data with good agreement.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology
Contributors: Dam, J. S., Hu, Q., Pedersen, C., Tidemand-Lichtenberg, P.
Number of pages: 7
Publication date: 2014
Peer-reviewed: Yes

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology
Number of pages: 10
Publication date: 2014
Peer-reviewed: Yes

Research output: Contribution to journal › Conference article – Annual report year: 2014 › Research › peer-review

Bibliographical note
This paper was published in Optics Letters 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/search2.cfm?reissue=&journalList=&fullrecord=Non-collinear+upconversion+of+infrared+light&basicsearch=Go. Systematic or multiple reproduction or distribution to multiple
Room-temperature mid-infrared single-photon imaging using upconversion

The mid-wave infrared (MWIR) region is a fast developing research area due to many possible applications. Indeed a lot of research has been put into the development of novel light sources in the MWIR. This has led to very powerful sources such as quantum cascade lasers (QCL) and optical parametric oscillators (OPO). Even super-continuum MWIR sources have been developed and are readily becoming commercial availability. However, on the detector side fundamental issues are limiting the sensitivity of particularly uncooled devices. Specifically, very large dark noise is hampering even most cooled MWIR detectors, when compared to silicon based detectors available for the visible and near visible spectral range. In fact, camera sensitivities down to the single photon level have been developed for sub-μm wavelengths. This discrepancy in sensitivity makes it attractive to perform wavelength upconversion in order to shift the information from MWIR to sub-μm wavelengths. However, historically this dream has been riddled by low conversion efficiency and large dark noise. We present a virtually dark noise free, high quantum conversion efficiency device, which when combined with a sensitive visible light camera paves the path to single-photon sensitive imaging device for the MWIR. The device is based on sum-frequency mixing of the MWIR signal with a 1064 nm laser. Thus a signal at 3 μm is upconverted to 0.785 μm which is easily detectable with low noise detectors. In order to obtain low power consumption and a portable device, while having high conversion efficiency, the wavelength conversion is based on an intra-cavity design. In this way a few Watts of pump power results in a circulating field of about 100 W in the nonlinear material. Using a 20 mm long MgO:PPLN nonlinear crystal intra-cavity enables upconversion efficiencies of 20 % for polarized collinear MWIR light. To make the module truly portable the laser cavity is assembled in a closed mechanical unit which ensures that visible light cannot enter from the outside, and provides a very stable mount for the optical components. Figure 1 depicts the actual conversion device and a drawing of the conversion module.

Semiconductor Laser Lidar Wind Velocity Sensor for Turbine Control

A dual line-of-sight CW lidar that measures both wind speed and direction is presented. The wind lidar employs a semiconductor laser, which allows for inexpensive remote sensors geared towards enhanced control of wind turbines.
Upconversion enhanced degenerate four-wave mixing in the mid-infrared for sensitive detection of acetylene in gas flows

We present a new background free method for in situ gas detection that combines degenerate four-wave mixing with an infra-red light detector based on parametric frequency upconversion of infra-red light. The system is demonstrated at mid infrared wavelengths for low concentration measurements of acetylene diluted in a N2 gas flow at ambient conditions. It is demonstrated that the system is able to cover more than 100 nm in scanning range and detect concentrations as low as 3 ppm based on the R9e line. A major issue in small signal measurements is scattered light and it is showed how a spatial analysis can be used to reduce this level.

Continuous-wave near-photon counting spectral imaging detector in the mid-infrared by upconversion

Low noise upconversion of IR images by three-wave mixing, can be performed with high efficiency when mixing the object radiation with a powerful laser field inside a highly non-linear crystal such as periodically poled Lithium Niobate. Since IR cameras are expensive and have high levels of intrinsic noise, we suggest to convert the wavelength from the mid infrared to the visible/NIR wavelength for simple detection using CCD cameras. The intrinsic noise in cameras has two main contributions. First, read noise originating from the charge to signal read-out electronics. This noise source is usually measured in number of electrons. The second noise source is usually referred to as dark noise, which is the background signal generated over time. Dark noise is usually measured in electrons per pixel per second. For silicon cameras certain models like EM-CCD have close to zero read noise, whereas high-end IR cameras have read noise of hundreds of electrons. The dark noise for infrared cameras based on semiconductor materials is also substantially higher than for silicon cameras, typical values being millions of electrons per pixel per second for cryogenically cooled cameras whereas peltier cooled CCD cameras have dark noise measured in fractions of electrons per pixel per second. An ideal solution thus suggest the combination of an efficient low noise image wavelength conversion system combined with low noise silicon based cameras for low noise imaging in the IR region. We discuss image upconversion as a means to do low noise conversion of IR light to visible light. We demonstrate system noise performance orders of magnitude lower than existing cryogenic cooled IR cameras.
Direct Seeded Single Frequency mid-IR OPA all Passive Light Source
We present a two stage pulsed mid-infrared light source based on nonlinear downconversion of light. The light source is single frequency, tunable, all passive, single moded and build with standard optical components.

Highly Stable, All-fiber, High Power ZBLAN Supercontinuum Source Reaching 4.75 µm used for Nanosecond mid-IR Spectroscopy
We demonstrate compact all-fiber mid-IR supercontinuum generation up to 4.75 µm with 1.2 W output power during hundreds of hours. This source is applied to upconversion spectroscopy using the energy corresponding to a single pulse.
High resolution mid-infrared spectroscopy based on frequency upconversion

We present high resolution upconversion of incoherent infrared radiation by means of sum-frequency mixing with a laser followed by simple CCD Si-camera detection. Noise associated with upconversion is, in strong contrast to room temperature direct mid-IR detection, extremely small, thus very faint signals can be analyzed. The obtainable frequency resolution is usually in the nm range where sub nm resolution is preferred in many applications, like gas spectroscopy. In this work we demonstrate how to obtain sub nm resolution when using upconversion. In the presented realization one object point is imaged through the upconverter. Assuming homogeneous spherical emission from the object point, the upconverted radiation will carry the spectral information as con-centric rings. From the optical path length and dispersion properties of the nonlinear material, the acceptance bandwidth of the upconversion process is calculated. It is then straightforward to deduce the spectral information of the light emitted from the object point by a simple analysis of the upconverted radiation. In order to increase resolution, a scanning Fabry-Perot etalon is inserted in a collimated geometry of the upconverted light generated by the crystal. The etalon is designed with a free-spectral range larger than the bandwidth of the upconversion process. Hence, the spectral resolution is now set by the finesse of the etalon. Based on this approach a spectral resolution of 0.2 nm has been reached around 2.9 μm. We demonstrate high resolution spectral performance by observing emission from hot water vapor in a butane gas burner.
Monostatic coaxial 1.5 μm laser Doppler velocimeter using a scanning Fabry-Perot interferometer

We present a laser Doppler velocimeter (LDV) in monostatic coaxial arrangement consisting of off-the-shelf telecom-grade components: a single frequency laser (wavelength λ = 1.5 μm) and a high-finesse scanning Fabry-Perot interferometer (sFPI). In contrast to previous 1.5 μm LDV systems based on heterodyne detection, our sFPI-LDV has the advantages of having large remote sensing range not limited by laser coherence, high velocity dynamic range not limited by detector bandwidth and inherent sign discrimination of Doppler shift. The more optically efficient coaxial arrangement where transmitter and receiver optics share a common axis reduces the number of components and greatly simplifies the optical alignment. However, the sensitivity to unwanted backreflections is increased. To circumvent this problem, we employ a custom optical circulator design which compared to commercial fiber-optic circulator achieves ~40 dB reduction in strength of unwanted reflections (i.e. leakage) while maintaining high optical efficiency. Experiments with a solid target demonstrate the performance of the sFPI-LDV system with high sensitivity down to pW level at present update rates up to 10 Hz.
Multispectral mid-infrared imaging using frequency upconversion

It has recently been shown that it is possible to upconvert infrared images to the near infrared region with high quantum efficiency and low noise by three-wave mixing with a laser field [1]. If the mixing laser is single-frequency, the upconverted image is simply a band-pass filtered version of the infrared object field, with a bandwidth corresponding given by the acceptance parameter of the conversion process, and a center frequency given by the phase-match condition. Tuning of the phase-matched wavelengths has previously been demonstrated by changing the temperature [2] or angle [3].

Unfortunately, temperature tuning is slow, and angle tuning typically results in alignment issues. Here we present a novel approach where the wavelength of the mixing field is used as a tuning parameter, allowing for fast tuning and hence potentially fast image acquisition, paving the way for upconversion based real time multispectral imaging. In the present realization the upconversion module consists of an external cavity tapered diode laser in a Littrow configuration with a computer controlled feedback grating. The output from a tunable laser is used as seed for a fiber amplifier system, boosting the power to approx. 3 W over the tuning range from 1025 to 1085 nm. Using a periodically poled lithium niobate crystal, the infrared wavelength that can be phase-matched is tunable over more than 200 nm. Using a crystal with multiple poling periods allows for upconversion within the entire transparency range of the nonlinear material.
Upconversion based continuous-wave mid-infrared detection
We present theoretical and experimental work on upconversion based mid-wavelength infrared detection using silicon detectors without the need for cryogenic cooling. We consider both multi-spectral imaging and point spectroscopy targeting several specific applications.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology
Contributors: Tidemand-Lichtenberg, P., Dam, J. S., Pedersen, C.
Number of pages: 2
Pages: NM3B.3
Publication date: 2013

Host publication information
Title of host publication: Nonlinear Optics Technical Digest
Publisher: Optical Society of America
Keywords: Image analysis, Upconversion, Spectroscopy, infrared
Electronic versions:
NLO_2013_NM3B.3.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-NM3B.3. Systematic or multiple reproduction or distribution to multiple locations via electronic or other means is prohibited and is subject to penalties under law.
Source: Bibtext
Source-ID: urn:5debddf80346740ae648e06c71a02edf
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2013 › Research › peer-review

Upconversion imager measures single mid-IR photons
The most sensitive IR detectors today are based on exotic semiconductor technology such as indium antimonide or mercury cadmium telluride. High quality detectors of these sorts are expensive and suffer from high dark currents. Dark current can be somewhat alleviated by extreme cooling. Comparing the performance of today's state of the art IR detectors for the visible/near-IR region shows a striking contrast, as the latter can have dark currents in the range of 0.001 electrons per second. Demonstrated performance of waveguide upconversion techniques still show considerable dark noise, even when working in the near-IR. Conventional detection schemes for IR radiation include microbolometers, which rely on minute temperature changes induced in a 2D nanophotonic sensor device when IR radiation is adsorbed. Microbolometers exist both as cryogenically cooled and uncooled devices. The wavelength upconversion is performed with only extremely small added dark noise, even when operating at room temperature.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology
Contributors: Dam, J. S., Tidemand-Lichtenberg, P., Pedersen, C.
Pages: 82-85
Publication date: 2013
Peer-reviewed: Yes

Publication information
Journal: Laser Focus World
Volume: 49
Issue number: 1
ISSN (Print): 1043-8092
Ratings:
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 0.16 SJR 0.145 SNIP 0.185
Web of Science (2013): Impact factor 0.26
ISI indexed (2013): ISI indexed yes
500 nm Continuous Wave Tunable SingleFrequency MidIR Light Source for C–H Spectroscopy

A computer controlled tunable mid-IR light source, based on single resonant difference frequency generation (DFG), is experimentally investigated. The DFG process is pumped by an external cavity tapered diode laser, tunable over a spectral range of 30 nm. Grating feedback to the single mode channel of the tapered diode narrows the spectrum and allows for tuning of the emitted spectrum in the range from 780 to 810 nm. The DFG process takes place intra-cavity in a high finesse diode pumped 1064 nm solid state Nd:YVO4 laser cavity, using periodically poled LiNbO3 as the nonlinear material. Based on this new approach, a tunable single-frequency output power exceeding 3 mW was obtained in the mid-IR tuning range from 2.9 to 3.4 μm.

Broadband Fourier domain mode-locked laser for optical coherence tomography at 1060 nm

Optical coherence tomography (OCT) in the 1060nm range is interesting for in vivo imaging of the human posterior eye segment (retina, choroid, sclera) due to low absorption in water and deep penetration into the tissue. Rapidly tunable light sources, such as Fourier domain mode-locked (FDML) lasers, enable acquisition of densely sampled three-dimensional datasets covering a wide field of view. However, semiconductor optical amplifiers (SOAs)-the typical laser gain media for swept sources-for the 1060nm band could until recently only provide relatively low output power and bandwidth. We have implemented an FDML laser using a new SOA featuring broad gain bandwidth and high output power. The output spectrum coincides with the wavelength range of minimal water absorption, making the light source ideal for OCT imaging of the posterior eye segment. With a moderate SOA current (270 mA) we achieve up to 100nm total sweep range and 12 μm depth resolution in air. By modulating the current, we can optimize the output spectrum and thereby improve the resolution to 9 μm in air (~6.5 μm in tissue). The average output power is higher than 20mW. Both sweep directions show similar performance; hence, both can be used for OCT imaging. This enables an A-scan rate of 350 kHz without buffering the light source output.
Broadband frequency conversion

We demonstrate a method for frequency conversion of broadly tunable or broad bandwidth light in a static, passive setup. Using simple optical components like lenses, mirrors and gratings and a BiBO crystal as the nonlinear material, we are able to frequency double a single-frequency, tunable, external cavity diode laser in the 1020-1090 nm range into the 510-545 nm range with almost equal efficiency for all wavelengths. Phase matching is obtained as follows; a diffraction grating is used to disperse light at different wavelengths into different angles, followed by an appropriately selected lens that ensures phase matching over a broad spectral range in the BBO crystal. Since the tuning mechanism relies on all-passive components with extremely short response times the proposed method is well suited for short pulse, broad bandwidth laser sources like mode-locked lasers or super-continuum sources. The method is generic and can be extended to cover other wavelength ranges with a suitable choices of lenses, gratings and nonlinear material.

General information

Publication status: Published
Organisations: Department of Photonics Engineering, Diode Lasers and LED Systems, Optical Sensor Technology, Technical University of Denmark
Contributors: Sanders, N. H., Jensen, O. B., Dam, J. S., Tidemand-Lichtenberg, P., Pedersen, C.
Number of pages: 1
Publication date: 2012
Peer-reviewed: Yes
Event: Abstract from Northern Optics 2012, Snekkersten, Denmark.
Electronic versions:
Broadband frequency conversion Northern Optics 2012.pdf
Source: dtu
Source-ID: u::5590
Research output: Contribution to conference › Conference abstract for conference – Annual report year: 2012 › Research › peer-review
Comparative study of the performance of semiconductor laser based coherent Doppler lidars

Coherent Doppler Lidars (CDLs), operating at an eye-safe 1.5-micron wavelength, have found promising applications in the optimization of wind-power production. To meet the wind-energy sector's impending demand for more cost-efficient industrial sensors, we have focused on the development of continuous-wave CDL systems using compact, inexpensive semiconductor laser (SL) sources. In this work, we compare the performance of two candidate emitters for an all-semiconductor CDL system: (1) a monolithic master-oscillator-power-amplifier (MOPA) SL and (2) an external-cavity tapered diode laser (ECTDL).

Field performance of an all-semiconductor laser coherent Doppler lidar

We implement and test what, to our knowledge, is the first deployable coherent Doppler lidar (CDL) system based on a compact, inexpensive all-semiconductor laser (SL). To demonstrate the field performance of our SL-CDL remote sensor, we compare a 36 h time series of averaged radial wind speeds measured by our instrument at an 80 m distance to those simultaneously obtained from an industry-standard sonic anemometer (SA). An excellent degree of correlation (R²=0.994 and slope=0.996) is achieved from a linear regression analysis of the CDL versus SA wind speed data. The lidar system is capable of providing high data availability, ranging from 85% to 100% even under varying outdoor (temperature and humidity) conditions during the test period. We also show the use of our SL-CDL for monitoring the dependence of aerosol backscatter on relative humidity. This work points to the feasibility of a more general class of low-cost, portable remote sensors based on all-SL emitters for applications that require demanding laser stability and coherence.
Frequency up-conversion based single photon, mid-IR spectral imaging with 20% quantum efficiency

Spectral imaging of mid-infrared (mid-IR) light is emerging as a promising technology since important chemical compounds display unique and strong mid-IR spectral fingerprints. We demonstrate for detection a novel method including a field deployable imaging system with single photon sensitivity and 20% quantum efficiency in the 2.9-4.5 μm range.

High-resolution mid-IR spectrometer based on frequency upconversion

We demonstrate a novel approach for high-resolution spectroscopy based on frequency upconversion and postfiltering by means of a scanning Fabry-Perot interferometer. The system is based on sum-frequency mixing, shifting the spectral content from the mid-infrared to the near-visible region allowing for direct detection with a silicon-based CCD camera. This approach allows for low noise detection even without cooling of the detector. A setup is realized for the 3xA0; x3BC;m regime with a spectral resolution of 0.2xA0; nm using lithium niobate as the nonlinear material and mixing with a single-frequency 1064xA0; nm laser. We investigate water vapor emission lines from a butane burner and compare the measured results to model data. The presented method we suggest to be used for real-time monitoring of specific gas lines and reference signals.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology
Contributors: Hu, Q., Dam, J. S., Pedersen, C., Tidemand-Lichtenberg, P.
Pages: 5232-5234
Publication date: 2012
Peer-reviewed: Yes

Bibliographical note
This paper was published in Optics Letters 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/ol/abstract.cfm?URI=ol-37-12-2277. Systematic or multiple reproduction or distribution to multiple locations via electronic or other means is prohibited and is subject to penalties under law.

Research output: Contribution to journal › Journal article – Annual report year: 2012 › Research › peer-review
High-speed polarization-sensitive OCT at 1060 nm using a Fourier domain mode-locked swept source

Optical coherence tomography (OCT) in the 1060nm range is interesting for in vivo imaging of the human posterior eye segment (retina, choroid, sclera), as it permits a long penetration depth. Complementary to structural images, polarization-sensitive OCT (PS-OCT) images visualize birefringent, polarization-maintaining or depolarizing areas within the sample. This information can be used to distinguish retinal layers and structures with different polarization properties. High imaging speed is crucial for imaging ocular structures in vivo in order to minimize motion artifacts while acquiring sufficiently large datasets. Here, we demonstrate PS-OCT imaging at 350 kHz A-scan rate using a two-channel PS-OCT system in conjunction with a Fourier domain mode-locked laser. The light source spectrum spans up to 100nm around the water absorption minimum at 1060 nm. By modulating the laser pump current, we can optimize the spectrum and achieve a depth resolution of 9 μm in air (6.5 μm in tissue). We acquired retinal images in vivo with high resolution and deep penetration into choroid and sclera, and features like the depolarizing RPE or an increasing phase retardation at the chorio-scleral interface are clearly visualized.
**Image upconversion - a low noise infrared sensor?**

Low noise upconversion of IR images by three-wave mixing, can be performed with high efficiency when mixing the object with a powerful laser field inside a highly non-linear crystal such as periodically poled Lithium Niobate. This feature effectively allows the use of silicon based cameras for detection of infrared images. Silicon cameras have much smaller intrinsic noise than their IR counter part- some models even offer near single photon detection capability. We demonstrate that an ordinary CCD camera combined with a low noise upconversion has superior noise characteristics when compared to even state-of-the-art IR cameras.

**General information**
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology
Contributors: Dam, J. S., Tidemand-Lichtenberg, P., Pedersen, C.
Number of pages: 1
Publication date: 2012
Peer-reviewed: Yes
Electronic versions:
Image_upconversion_as_low_noise_infrared_sensor_v3.pdf

**Bibliographical note**
Oral presentation number 8240-15.
Source: dtu
Source-ID: u::5602

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**Image upconversion, a low noise infrared sensor?**

Low noise upconversion of IR images by three-wave mixing, can be performed with high efficiency when mixing the object with a powerful laser field inside a highly non-linear crystal such as periodically poled Lithium Niobate. This feature effectively allows the use of silicon based cameras for detection of infrared images. Silicon cameras have much smaller intrinsic noise than their IR counter part- some models even offer near single photon detection capability. We demonstrate that an ordinary CCD camera combined with a low noise upconversion has superior noise characteristics when compared to even state-of-the-art IR cameras.

**General information**
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology
Contributors: Dam, J. S., Pedersen, C., Tidemand-Lichtenberg, P.
Publication date: 2012
Media of output: Power Point Presentation

**Event information**
Location: San Francisco, CA, United States
Electronic versions:
pw2012_jdam_8240_15.pdf

**Bibliographical note**
Oral presentation number 8240-15.
Number of pages: 14

**Improved space bandwidth product in image upconversion**

We present a technique increasing the space bandwidth product of a nonlinear image upconversion process used for spectral imaging. The technique exploits the strong dependency of the phase-matching condition in sum frequency generation (SFG) on the angle of propagation of the interacting fields with respect to the optical axis. Appropriate scanning of the phase-match condition (Δk=0) while acquiring images, allow us to perform monochromatic image reconstruction with a significantly increased space bandwidth product. We derive the theory for the image reconstruction process and demonstrate acquisition of images with >10 fold increase in space bandwidth product, i.e. the number of pixel elements, when compared to upconversion of images using fixed phase-match conditions.
Investigation of the impact of water absorption on retinal OCT imaging in the 1060 nm range

Recently, the wavelength range around 1060 nm has become attractive for retinal imaging with optical coherence tomography (OCT), promising deep penetration into the retina and the choroid. The adjacent water absorption bands limit the useful bandwidth of broadband light sources, but until now, the actual limitation has not been quantified in detail. We have numerically investigated the impact of water absorption on the axial resolution and signal amplitude for a wide range of light source bandwidths and center wavelengths. Furthermore, we have calculated the sensitivity penalty for maintaining the optimal resolution by spectral shaping. As our results show, with currently available semiconductor-based light sources with up to 100–120 nm bandwidth centered close to 1060 nm, the resolution degradation caused by the water absorption spectrum is smaller than 10%, and it can be compensated by spectral shaping with negligible sensitivity penalty. With increasing bandwidth, the resolution degradation and signal attenuation become stronger, and the optimal operating point shifts towards shorter wavelengths. These relationships are important to take into account for the development of new broadband light sources for OCT.
Room temperature mid-IR single photon spectral imaging

Spectral imaging and detection of mid-infrared (mid-IR) wavelengths are emerging as an enabling technology of great technical and scientific interest; primarily because important chemical compounds display unique and strong mid-IR spectral fingerprints revealing valuable chemical information. While modern Quantum cascade lasers have evolved as ideal coherent mid-IR excitation sources, simple, low noise, room temperature detectors and imaging systems still lag behind. We address this need presenting a novel, field-deployable, upconversion system for sensitive, 2-D, mid-IR spectral imaging. Measured room temperature dark noise is 0.2 photons/spatial element/second, which is a billion times below the dark noise level of cryogenically cooled InSb cameras. Single photon imaging and up to 200 x 100 spatial elements resolution is obtained reaching record high continuous wave quantum efficiency of about 20 % for polarized incoherent light at 3 μm. The proposed method is relevant for existing and new mid-IR applications like gas analysis and medical diagnostics.

Theory for upconversion of incoherent images

Upconversion of images is a generic method for shifting the spectral content of entire images. A comprehensive theory for upconversion of incoherent light images is presented and compared against experiments. In particular we consider the important case for upconversion of infinity corrected light. We show that the spatial resolution for upconversion of incoherent light images is better than for the corresponding coherent image upconversion case. The fundamental differences between upconversion of coherent and incoherent images are investigated theoretically and experimentally. The theory includes the general case of upconversion using TEMnm modes.
Tunable mW Narrow Bandwidth Mid-Infrared Light Source

A Tunable Mid-IR light source base on single resonant Difference Frequency Generation (DFG) is experimentally investigated. The DFG process is pumped by an 800 nm tunable tapered diode laser. Grating feedback to the single mode channel of the tapered diode narrows the spectrum and allows for tuning of the diode laser wavelength by rotating the grating. The system tunes 500 nm using a single diode, ranging from 2.9 μm to 3.4 μm with mW's of output power over the entire range. The maximum measured output is 2.5 mW at 3.2 μm.

Bibliographical note
This paper was published in Lasers, Sources, and Related Photonic Devices 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=lasers-2012-AW4A.2. Systematic or multiple reproduction or distribution to multiple locations via electronic or other means is prohibited and is subject to penalties under law.

Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2012 › Research › peer-review
**Vector velocimeter**

The present invention relates to a compact, reliable and low-cost vector velocimeter for example for determining velocities of particles suspended in a gas or fluid flow, or for determining velocity, displacement, rotation, or vibration of a solid surface, the vector velocimeter comprising a laser assembly for emission of a measurement beam for illumination of an object in a measurement volume with coherent light whereby a signal beam emanating from the object in the measurement volume is formed in response to illumination of the object by the measurement beam, a reference beam generator for generation of a reference beam, a detector system comprising a first detector arrangement arranged in such a way that the signal beam and the reference beam are incident upon the first detector arrangement with the reference beam propagating at an angle relative to a signal beam, and wherein the first detector array comprises a first detector array of first detector elements, each of the first detector elements converting the intensity of the interfering signal beam and reference beam incident thereupon into a corresponding electronic detector element signal thereby generating an oscillating electronic detector element signal when the fringe pattern formed by the interfering signal beam and reference beam moves across the first detector array; and a signal processor that is adapted for generation of a velocity signal corresponding to a first velocity component of movement of the object in the measurement volume in the longitudinal direction of the measurement volume based on the electronic detector element signals from each of the first detector elements.

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**General information**

Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology
Contributors: Hanson, S. G., Jakobsen, M. L., Iversen, T. F. Q., Rodrigo, P. J., Pedersen, C.
Publication date: 2012

**Publication information**

IPC: G01B9/02; G01B9/025; G01S17/58; G01S7/481
Patent number: WO2012019871
Filing date: 16/02/2012
Priority date: 09/08/2010
Priority number: EP20100172261
Original language: English
Electronic versions: WO2012019871A11.pdf

**Bibliographical note**

Also published as: EP2603811 (A1) EP2603811 (B1) US2013222786 (A1) US9285385 (B2)
Research output: Patent › Patent – Annual report year: 2012 › Research

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**A simple model for 2D image upconversion of incoherent light**

We present a simple theoretical model for 2-dimensional (2-D) image up-conversion of incoherent light. While image upconversion has been known for more than 40 years, the technology has been hindered by very low conversion quantum efficiency (~10⁻⁷). We show that our implementation compared to previous work can result in a feasible system: Using intracavity upconversion and Quasi Phase Matching (QPM) nonlinear materials provide increased conversion efficiency. Using a QPM crystal and choosing the wavelengths so the first order term in the phasematch wavelength acceptance vanishes, results in very large wavelength acceptance. This work describes how the bandwidth acceptance can be predicted and designed. This gives promise of a new way to make infrared imaging devices with tunable spectral sensitivity.

**General information**

Publication status: Published
Organisations: Optical Sensor Technology, Department of Photonics Engineering
Contributors: Dam, J. S., Pedersen, C., Tidemand-Lichtenberg, P.
Pages: 791714
Publication date: 2011
Peer-reviewed: Yes

**Publication information**

Journal: Proceedings of the SPIE - The International Society for Optical Engineering
Volume: 7917
ISSN (Print): 0277-786X
Ratings: BFI (2011): BFI-level 1
Bringing the infrared to light
Infrared imaging is usually done by use of infrared cameras. We present an effective alternative approach where infrared light is converted to near visible light in a non-linear process, and then detected by low cost, high performance camera. The approach is generic and can be applied towards many different applications.

General information
Publication status: Published
Organisations: Optical Sensor Technology, Department of Photonics Engineering
Contributors: Dam, J. S., Tidemand-Lichtenberg, P., Pedersen, C.
Publication date: 2011
Peer-reviewed: Yes
Event: Abstract from Danish Optical Society Annual Meeting, Aarhus, Denmark,
Source: orbit
Source-ID: 313934
Research output: Contribution to conference › Conference abstract for conference – Annual report year: 2011 › Research › peer-review

Broadband Fourier domain mode-locked laser for optical coherence tomography at 1060 nm

General information
Publication status: Published
Organisations: Teraherts Technologies and Biophotonics, Department of Photonics Engineering, Optical Sensor Technology, Ludwig-Maximilians-Universität München
Contributors: Marschall, S., Klein, T., Wieser, W., Biedermann, B., Pedersen, C., Huber, R., Andersen, P. E.
Publication date: 2011

Host publication information
Title of host publication: Proceedings of Optical Sensors and Biophotonics III
Electronic versions:
acp11_summary.pdf
URLs:
http://www.acp-ce.org/index.html

Bibliographical note
Oral presentation.
Source: orbit
Source-ID: 316135
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2011 › Research

Efficient near diffraction limited blue light source by sum-frequency mixing of a BAL and a solid-state laser
Sum-frequency mixing of an 808 nm broad area laser (BAL) with a build-in grating structure for spectral control and a 1064 nm solid-state laser is experimentally investigated. The spectrally improved 20 nm wide BAL can deliver up to 700 mW of output power with an M-2 of 1.4 and 5.3 in the fast and slow axis of the diode, respectively. The BAL output beam is
single-passed through a periodically poled KTiOPO4 (PPKTP) crystal placed in an intra-cavity beam waist of a 1064 nm Nd:YVO4 laser, resulting in 100 mW of sum-frequency generated blue output power. This corresponds to a power conversion efficiency of 15%. The near diffraction limited blue output beam is measured to have an M-2 of 1.2 and 1.7 in the directions corresponding to the fast and slow axis of the BAL diode, respectively.

Experimental investigation of relative timing jitter in passively synchronized Q-switched lasers
Relative timing jitter between synchronized Q-switched lasers, or lack thereof, is important for stable sum-frequency generation. Experimental investigation of two passively synchronized lasers shows that the jitter is minimized when the free-running repetition rates of the two lasers are close to, but not exactly, matching. When the free-running repetition rates are matched, the jitter is significantly large. At the best operating point, the pulse-to-pulse period was 200 μs, while the relative jitter between the two lasers was 9 ns. If the effect of the master laser's pulse-to-pulse jitter is removed, the residual timing jitter between the two lasers was 6 ns, which corresponds to the lower limit set by pump power fluctuations and noise from spontaneous emission. © 2011 Optical Society of America.
High power swept source for Optical Coherence Tomography

General information
Publication status: Published
Organisations: Teraherts Technologies and Biophotonics, Department of Photonics Engineering, Diode Lasers and LED Systems, Optical Sensor Technology, Ludwig-Maximilians-Universität München
Contributors: Marschall, S., Klein, T., Wieser, W., Biedermann, B., Jensen, O. B., Pedersen, C., Huber, R., Andersen, P. E.
Publication date: 2011
Peer-reviewed: No
Event: Poster session presented at OPTO Meeting for Young Researchers, Torum (PL), 11-14 May.
Electronic versions:
High power swept source.pdf
Source: orbit
Source-ID: 314669
Research output: Contribution to conference › Poster – Annual report year: 2011 › Research

High resolution 2D image upconversion of incoherent light
An optimized method for continuous wave 2-dimensional (2-D) upconversion of incoherent or thermal light is demonstrated and quantified. Using standard resolution targets a resolution of 200×1000 pixels is obtained. The suggested method is viewed in scope of modern CCD cameras operating in the near infrared (NIR) portion of the electromagnetic spectrum. The key is optimization of the upconversion process. This include Quasi-Phase-Matching leading to higher effective nonlinearities and elimination of walk-off, an intra-cavity design enhancing the upconversion process, and finally the use of modern NIR CCD detectors. Furthermore, we discuss the exceptionally good depth of field possible for imaging systems based on the proposed method.

General information
Publication status: Published
Organisations: Optical Sensor Technology, Department of Photonics Engineering
Contributors: Dam, J. S., Pedersen, C., Tidemand-Lichtenberg, P.
Pages: 791713
Publication date: 2011
Peer-reviewed: Yes

Publication information
Journal: Proceedings of the SPIE - The International Society for Optical Engineering
Volume: 7917
ISSN (Print): 0277-786X
Ratings:
BFI (2011): BFI-level 1
Scopus rating (2011): CiteScore 0.31 SJR 0.197 SNIP 0.234
ISI indexed (2011): ISI indexed no
Original language: English
Keywords: Sum frequency generation, Upconversion, Infrared imaging, Thermal imaging
Electronic versions:
NIR Capturing images with spectral information in the mid-infrared

General information
Publication status: Published
Organisations: Optical Sensor Technology, Department of Photonics Engineering
Contributors: Dam, J. S., Tidemand-Lichtenberg, P., Pedersen, C.
Publication date: 2011
Peer-reviewed: Yes
Event: Abstract from Danish Optical Society, Roskilde, Denmark.
URLs:
http://www.dops.dk/?id=585
Source: orbit
Source-ID: 283908
Research output: Contribution to conference › Conference abstract for conference – Annual report year: 2011 › Research › peer-review

Passive synchronized Q-switching between a quasi-three-level and a four-level laser
Synchronized Q-switching between quasi-three-level and four-level lasers is interesting for sum-frequency generation into the blue and ultraviolet. We report, for the first time, stable synchronized Q-switching between a quasi-three-level laser at 946 nm and a four-level laser at 1064 nm in an all passive approach. While timing jitter of the individual free-running lasers were on the order of 10 μs, the relative timing jitter, defined as one standard-deviation of the experimental data, was only 9 ns between the two synchronized pulses. The minimum delay between the two pulses was 64 ns during stable operation, which gave a 79% temporal overlap when normalized against the zero-delay scenario. Preliminary results show promise for non-linear frequency conversion, which could lead to high power pulsed blue and ultraviolet lasers.

General information
Publication status: Published
Organisations: Diode Lasers and LED Systems, Department of Photonics Engineering, Optical Sensor Technology, Terahertz Technologies and Biophotonics
Contributors: Cheng, H. P. H., Tidemand-Lichtenberg, P., Jensen, O. B., Andersen, P. E., Petersen, P. M., Pedersen, C.
Pages: 79120W
Publication date: 2011
Peer-reviewed: Yes

Publication information
Journal: Proceedings of the SPIE - The International Society for Optical Engineering
Volume: 7912
ISSN (Print): 0277-786X
Ratings:
BFI (2011): BFI-level 1
Scopus rating (2011): CiteScore 0.31 SJR 0.197 SNIP 0.234
ISI indexed (2011): ISI indexed no
Original language: English
Keywords: Nd:YAG, Lasers, Diode-pumped, Solid-state, Q-switched
Electronic versions:
3272AD42d01.pdf
DOIs:
10.1117/12.873382
Spectral Imaging by Upconversion

We present a method to obtain spectrally resolved images using upconversion. By this method an image is spectrally shifted from one spectral region to another wavelength. Since the process is spectrally sensitive it allows for a tailored spectral response. We believe this will allow standard silicon based cameras designed for visible/near infrared radiation to be used for spectral images in the mid infrared. This can lead to much lower costs for such imaging devices, and a better performance.

All passive synchronized Q-switching of a quasi-three-level and a four-level Nd:YAG laser

Using an all passive approach, synchronized Q-switching of two Nd:YAG lasers, at 946 nm and 1064 nm, is reported. Two laser crystals are used to avoid gain competition, and stable operation is reported for the first time. The pulse trains are synchronized over a wide range of pump powers and a relative timing jitter of 36 ns is achieved. A minimum delay of 64 ns is observed between the two laser pulses, and by making the 946 nm pulse relatively long, a 79% temporal overlap is obtained when compared to the zero-delay scenario.
Autofluorescence of pigmented skin lesions using a pulsed UV laser with synchronized detection: clinical results

We report preliminary clinical results of autofluorescence imaging of malignant and benign skin lesions, using pulsed 355 nm laser excitation with synchronized detection. The novel synchronized detection system allows high signal-to-noise ratio to be achieved in the resulting autofluorescence signal, which may in turn produce high contrast images that improve diagnosis, even in the presence of ambient room light. The synchronized set-up utilizes a compact, diode pumped, pulsed UV laser at 355 nm which is coupled to a CCD camera and a liquid crystal tunable filter. The excitation and image capture is sampled at 5 kHz and the resulting autofluorescence is captured with the liquid crystal filter cycling through seven wavelengths between 420 nm and 580 nm. The clinical study targets pigmented skin lesions and evaluates the prospects of using autofluorescence as a possible means in differentiating malignant and benign skin tumors. Up to now, sixteen patients have participated in the clinical study. The autofluorescence images, averaged over the exposure time of one second, will be presented along with histopathological results. Initial survey of the images show good contrast and diagnostic results show promising agreement based on the histopathological results.

Efficient frequency up-conversion of Broad Area Laser diode

General information
Publication status: Published
Organisations: Diode Lasers and LED Systems, Department of Photonics Engineering, Optical Sensor Technology
Contributors: Sørensen, K. P., Tidemand-Lichtenberg, P., Pedersen, C.
Publication date: 2010
Peer-reviewed: Yes
Event: Poster session presented at OSA Optics & Photonics Congress: Nonlinear Photonics, Karlsruhe, Germany.
Source: orbit

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Diode Lasers and LED Systems, Optical Sensor Technology, Terahertz Technologies and Biophotonics, Lund University
Pages: 77151K
Publication date: 2010
Peer-reviewed: Yes
Publication information
Journal: Proceedings of SPIE, the International Society for Optical Engineering
Volume: 7715
ISSN (Print): 0277-786X
Ratings:
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.208 SNIP 0.225
Web of Science (2010): Indexed yes
Original language: English
DOIs:
10.1117/12.855837
Source: orbit
Source-ID: 263199
Research output: Contribution to journal › Conference article – Annual report year: 2010 › Research › peer-review
**Efficient quasi-three-level Nd:YAG laser at 946 nm pumped by a tunable external cavity tapered diode laser**

Using a tunable external cavity tapered diode laser (ECDL) pumped quasi-three-level Nd:YAG laser, a fivefold reduction in threshold and twofold increase in slope efficiency is demonstrated when compared to a traditional broad area diode laser pump source. A TEM00 power of 800 mW with 65% slope efficiency is obtained, the highest reported TEM00 power from any 946 nm Nd:YAG laser pumped by a single emitter diode laser pump source. A quantum efficiency of 0.85 has been estimated from experimental data using a simple quasi-three-level model. The reported value is in good agreement with published values, suggesting that the model is adequate. Improvement of the 946 nm laser due to the ECDL's narrow spectrum proves to be less significant when compared to its spatial quality, inferring a broad spectrum tapered diode laser pump source may be most practical. Experimental confirmation of such setup is given.

**FDML swept source at 1060 nm using a tapered amplifier**

We present a novel frequency-swept light source working at 1060nm that utilizes a tapered amplifier as gain medium. These devices feature significantly higher saturation power than conventional semiconductor optical amplifiers and can thus improve the limited output power of swept sources in this wavelength range. We demonstrate that a tapered amplifier can be integrated into a fiber-based swept source and allows for high-speed FDML operation. The developed light source operates at a sweep rate of 116kHz with an effective average output power in excess of 30mW. With a total sweep range of 70 nm an axial resolution of 15 µm in air (~11µm in tissue) for OCT applications can be achieved.
Fourier domain mode-locked swept source at 1050 nm based on a tapered amplifier

While swept source optical coherence tomography (OCT) in the 1050 nm range is promising for retinal imaging, there are certain challenges. Conventional semiconductor gain media have limited output power, and the performance of high-speed Fourier domain mode-locked (FDML) lasers suffers from chromatic dispersion in standard optical fiber. We developed a novel light source with a tapered amplifier as gain medium, and investigated the FDML performance comparing two fiber delay lines with different dispersion properties. We introduced an additional gain element into the resonator, and thereby achieved stable FDML operation, exploiting the full bandwidth of the tapered amplifier despite high dispersion. The light source operates at a repetition rate of 116 kHz with an effective average output power in excess of 30 mW. With a total sweep range of 70 nm, we achieved an axial resolution of 15 μm in air (~11 μm in tissue) in OCT measurements. As our work shows, tapered amplifiers are suitable gain media for swept sources at 1050 nm with increased output power, while high gain counteracts dispersion effects in an FDML laser.
High-power FDML laser for swept source-OCT at 1060 nm

We present a novel frequency-swept light source working at 1060nm that utilizes a tapered amplifier as gain medium. These devices feature significantly higher saturation power than conventional semiconductor optical amplifiers and can thus improve the limited output power of swept sources in this wavelength range. We demonstrate that a tapered amplifier can be integrated into a fiber-based swept source and allows for high-speed FDML operation. The developed light source operates at a sweep rate of 116kHz with an effective average output power in excess of 30mW. With a total sweep range of 70 nm an axial resolution of 15 μm in air (~11μm in tissue) for OCT applications can be achieved.

General information
Publication status: Published
Organisations: Teraherts Technologies and Biophotonics, Department of Photonics Engineering, Diode Lasers and LED Systems, Optical Sensor Technology
Contributors: Marschall, S., Klein, T., Wieser, W., Biedermann, B., Hsu, K., Sumpf, B., Hasler, K., Erbert, G., Jensen, O. B., Pedersen, C., Huber, R., Andersen, P. E.
Publication date: 2010
Peer-reviewed: Yes

Publication information
Journal: Proceedings of SPIE, the International Society for Optical Engineering
Volume: 7715
ISSN (Print): 0277-786X
Ratings:
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.208 SNIP 0.225
Web of Science (2010): Indexed yes
Original language: English
DOI:
10.1117/12.854238
URLs:
http://spie.org/x648.html?product_id=854238
Source: orbit
Source-ID: 268086
Research output: Contribution to journal › Conference article – Annual report year: 2010 › Research › peer-review

High power swept source for optical coherence tomography

General information
Publication status: Published
Organisations: Teraherts Technologies and Biophotonics, Department of Photonics Engineering, Diode Lasers and LED Systems, Optical Sensor Technology
Contributors: Marschall, S., Jensen, O. B., Pedersen, C., Andersen, P. E.
Publication date: 2010
Peer-reviewed: No
Event: Poster session presented at PhD Summer School Nanooptics 2010, Ebeltoft, Denmark.
Source: orbit
Source-ID: 267047
Research output: Contribution to conference › Poster – Annual report year: 2010 › Research

High-resolution two-dimensional image upconversion of incoherent light

We consider a technique for high-resolution image upconversion of thermal light. Experimentally, we demonstrate cw upconversion with a resolution of more than 200 × 1000 pixels of thermally illuminated objects. This is the first demonstration (to our knowledge) of high-resolution cw image upconversion. The upconversion method promises an alternative route to high-quantum-efficiency all-optical imaging in the mid-IR wavelength region and beyond using standard CCD cameras. A particular advantage of CCD cameras compared to state-of-the-art thermal cameras is the possibility to tailor and tune the spectral response leading to functional spectral imaging.

General information
Publication status: Published
Organisations: Optical Sensor Technology, Department of Photonics Engineering
Contributors: Dam, J. S., Pedersen, C., Tidemand-Lichtenberg, P.
Pages: 3796-3798
Publication date: 2010
Mid-IR image acquisition using a standard CCD camera
Direct image acquisition in the 3-5 µm range is realized using a standard CCD camera and a wavelength up-converter unit. The converter unit transfers the image information to the NIR range where state-of-the-art cameras exist.

General information
Publication status: Published
Organisations: Optical Sensor Technology, Department of Photonics Engineering, Diode Lasers and LED Systems
Contributors: Dam, J. S., Sørensen, K. P., Pedersen, C., Tidemand-Lichtenberg, P.
Publication date: 2010

Optical Arrangement and Method
Processing of electromagnetic radiation is described, said incoming electromagnetic radiation comprising radiation in a first wavelength interval and a plurality of spatial frequencies. An arrangement comprises a focusing arrangement for focusing the incoming electromagnetic radiation, a first cavity configured to comprise an intra-cavity laser beam, a nonlinear crystal arranged in the first cavity such that it is capable of receiving the focused electromagnetic radiation and, in dependence on the spatial overlap between the focused electromagnetic radiation and the intra-cavity laser beam, by interaction with the intra-cavity laser beam provide processed electromagnetic radiation, said processed electromagnetic radiation comprising radiation in a second wavelength interval and at least a subset of said plurality of spatial frequencies. In other words, such an arrangement is capable of enabling imaging, e.g., by utilizing a detector that is sensitive in the second wavelength interval, a source of radiation that emits in a first wavelength interval and comprising several spatial frequencies. Furthermore, such arrangement is capable of improving the spatial quality of the incoming radiation.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology
Contributors: Karamehmedovic, E., Tidemand-Lichtenberg, P., Pedersen, C.
Publication date: 2010

Optical Arrangement and Method
Processing of electromagnetic radiation is described, said incoming electromagnetic radiation comprising radiation in a first wavelength interval and a plurality of spatial frequencies. An arrangement comprises a focusing arrangement for focusing the incoming electromagnetic radiation, a first cavity configured to comprise an intra-cavity laser beam, a nonlinear crystal arranged in the first cavity such that it is capable of receiving the focused electromagnetic radiation and, in dependence on the spatial overlap between the focused electromagnetic radiation and the intra-cavity laser beam, by interaction with the intra-cavity laser beam provide processed electromagnetic radiation, said processed electromagnetic radiation comprising radiation in a second wavelength interval and at least a subset of said plurality of spatial frequencies. In other words, such an arrangement is capable of enabling imaging, e.g., by utilizing a detector that is sensitive in the second wavelength interval, a source of radiation that emits in a first wavelength interval and comprising several spatial frequencies. Furthermore, such arrangement is capable of improving the spatial quality of the incoming radiation.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology
Contributors: Karamehmedovic, E., Tidemand-Lichtenberg, P., Pedersen, C.
Publication date: 2010

Optical Arrangement and Method
Processing of electromagnetic radiation is described, said incoming electromagnetic radiation comprising radiation in a first wavelength interval and a plurality of spatial frequencies. An arrangement comprises a focusing arrangement for focusing the incoming electromagnetic radiation, a first cavity configured to comprise an intra-cavity laser beam, a nonlinear crystal arranged in the first cavity such that it is capable of receiving the focused electromagnetic radiation and, in dependence on the spatial overlap between the focused electromagnetic radiation and the intra-cavity laser beam, by interaction with the intra-cavity laser beam provide processed electromagnetic radiation, said processed electromagnetic radiation comprising radiation in a second wavelength interval and at least a subset of said plurality of spatial frequencies. In other words, such an arrangement is capable of enabling imaging, e.g., by utilizing a detector that is sensitive in the second wavelength interval, a source of radiation that emits in a first wavelength interval and comprising several spatial frequencies. Furthermore, such arrangement is capable of improving the spatial quality of the incoming radiation.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology
Contributors: Karamehmedovic, E., Tidemand-Lichtenberg, P., Pedersen, C.
Publication date: 2010

Optical Arrangement and Method
Processing of electromagnetic radiation is described, said incoming electromagnetic radiation comprising radiation in a first wavelength interval and a plurality of spatial frequencies. An arrangement comprises a focusing arrangement for focusing the incoming electromagnetic radiation, a first cavity configured to comprise an intra-cavity laser beam, a nonlinear crystal arranged in the first cavity such that it is capable of receiving the focused electromagnetic radiation and, in dependence on the spatial overlap between the focused electromagnetic radiation and the intra-cavity laser beam, by interaction with the intra-cavity laser beam provide processed electromagnetic radiation, said processed electromagnetic radiation comprising radiation in a second wavelength interval and at least a subset of said plurality of spatial frequencies. In other words, such an arrangement is capable of enabling imaging, e.g., by utilizing a detector that is sensitive in the second wavelength interval, a source of radiation that emits in a first wavelength interval and comprising several spatial frequencies. Furthermore, such arrangement is capable of improving the spatial quality of the incoming radiation.
Reduction of phase-induced intensity noise in a fiber-based coherent Doppler lidar using polarization control

Optimization of signal-to-noise ratio is an important aspect in the design of optical heterodyne detection systems such as a coherent Doppler lidar (CDL). In a CDL, optimal performance is achieved when the noise in the detector signal is dominated by local oscillator shot-noise. Most modern CDL systems are built using rugged and cost-efficient fiber optic components. Unfortunately, leakage signals such as residual reflections inherent within fiber components (e.g. circulator)
can introduce phase-induced intensity noise (PIIN) to the Doppler spectrum in a CDL. Such excess noise may be a few orders of magnitude above the shot-noise level within the relevant CDL frequency bandwidth – corrupting the measurement of typically weak backscattered signals. In this study, observation of PIIN in a fiber-based CDL with a master-oscillator poweramplifier tapered semiconductor laser source is reported. Furthermore, we experimentally demonstrate what we believe is a newly proposed method using a simple polarization scheme to reduce PIIN by more than an order of magnitude.

**General information**
Publication status: Published
Organisations: Optical Sensor Technology, Department of Photonics Engineering
Contributors: Rodrigo, P. J., Pedersen, C.
Pages: 5320-5327
Publication date: 2010
Peer-reviewed: Yes

**Publication information**
Journal: Optics Express
Volume: 18
Issue number: 5
ISSN (Print): 1094-4087
Ratings:
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 3.209 SNIP 2.516
Web of Science (2010): Impact factor 3.753
Web of Science (2010): Indexed yes
Original language: English
Electronic versions:
6F883d01.pdf
DOIs:
10.1364/OE.18.005320

**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-18-5-5320. 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: 259399
Research output: Contribution to journal › Journal article – Annual report year: 2010 › Research › peer-review

**Unidirectional ring-laser operation using sum-frequency mixing**
A technique enforcing unidirectional operation of ring lasers is proposed and demonstrated. The approach relies on sum-frequency mixing between a single-pass laser and one of the two counterpropagating intracavity fields of the ring laser. Sum-frequency mixing introduces a parametric loss for the intracavity field copropagating with the single-pass field, effectively generating a loss difference between the copropagating and counterpropagating intracavity fields. This loss mechanism ensures stable unidirectional lasing. The approach is generic and can be implemented at any desired lasing wavelength where lossless second-order nonlinear materials are available. Numerical modeling and experimental demonstration of parametric-induced unidirectional operation of a diode-pumped solid-state 1342 nm cw ring laser are presented.

**General information**
Publication status: Published
Organisations: Optical Sensor Technology, Department of Photonics Engineering, Diode Lasers and LED Systems
Contributors: Tidemand-Lichtenberg, P., Cheng, H. P. H., Pedersen, C.
Pages: 2567-2569
Publication date: 2010
Peer-reviewed: Yes

**Publication information**
Journal: Optics Letters
Volume: 35
Issue number: 15
ISSN (Print): 0146-9592
Ratings:
χ(2) Induced Non-Reciprocal Loss and/or Phase Shift for Unidirectional Operation of Ring Lasers

Numerical modelling and experimental validation of sum-frequency mixing enforcing stable unidirectional operation of a diode pumped solid-state 1342 nm ring laser with improved stability toward feedback.

General information
Publication status: Published
Organisations: Optical Sensor Technology, Department of Photonics Engineering, Diode Lasers and LED Systems
Contributors: Tidemand-Lichtenberg, P., Cheng, H. P. H., Pedersen, C.
Pages: ATuA19
Publication date: 2010

Host publication information
Title of host publication: OSA Technical Digest : Advanced Solid-State Photonics (ASSP) 2010
Publisher: Optical Society of America
URLs:
http://www.opticsinfobase.org/abstract.cfm?URI=ASSP-2010-ATuA19
Source: orbit
Source-ID: 269243

2D Nonlinear Image Up-conversion and Filtering Using Enhanced Sum Frequency Generation

General information
Publication status: Published
Organisations: Optical Sensor Technology, Department of Photonics Engineering, Teraherts Technologies and Biophotonics, Department of Physics
Contributors: Pedersen, C., Karamajmedovic, E., Dam, J. S., Buchhave, P., Tidemand-Lichtenberg, P.
Pages: Oral FThR6
Publication date: 2009

Host publication information
Title of host publication: Proceeding of The Frontiers in Optics 2009/Laser Science XXV
Publisher: Optical Society of America
Source: orbit
Source-ID: 256115

COHERENT LIDAR SYSTEM BASED ON A SEMICONDUCTOR LASER AND AMPLIFIER

The present invention relates to a compact, reliable and low-cost coherent LIDAR (Light Detection And Ranging) system for remote wind-speed determination, determination of particle concentration, and/or temperature based on an all semiconductor light source and related methods. The present invention provides a coherent LIDAR system comprising a semiconductor laser for emission of a measurement beam of electromagnetic radiation directed towards a measurement volume for illumination of particles in the measurement volume, a reference beam generator for generation of a reference beam, a detector for generation of a detector signal by mixing of the reference beam with light emitted from the particles in the measurement volume illuminated by the measurement beam, and a signal processor for generating a velocity signal corresponding to the velocity of the particles based on the detector signal.
Enhanced 2D-image upconversion using solid-state lasers

Based on enhanced upconversion, we demonstrate a highly efficient method for converting a full image from one part of the electromagnetic spectrum into a new desired wavelength region. By illuminating a metal transmission mask with a 765 nm Gaussian beam to create an image and subsequently focusing the image inside a nonlinear PPKTP crystal located in the high intra-cavity field of a 1342 nm solid-state Nd:YVO4 laser, an upconverted image at 488 nm is generated. We have experimentally achieved an upconversion efficiency of 40% under CW conditions. The proposed technique can be further adapted for high efficiency mid-infrared image upconversion where direct and fast detection is difficult or impossible to perform with existing detector technologies.
Heavy cavity tapered diode pumped laser to generate pulsed UV light for autofluorescence diagnostics

General information
Publication status: Published
Organisations: Diode Lasers and LED Systems, Department of Photonics Engineering, Quantum Physics and Information Technology, Department of Physics, Terahertz Technologies and Biophotonics, Optical Sensor Technology
Contributors: Cheng, H. P. H., Tidemand-Lichtenberg, P., Jensen, O. B., Andersen, P. E., Petersen, P. M., Pedersen, C.
Publication date: 2009
Peer-reviewed: No
Event: Poster session presented at Biophotonics 09, Hven, Sweden.
Source: orbit
Source-ID: 250646
Research output: Contribution to conference › Poster – Annual report year: 2009 › Research

Frequency-swept laser light source at 1050 nm with higher bandwidth due to multiple semiconductor optical amplifiers in series

We report on the development of an all-fiber frequency-swept laser light source in the 1050 nm range based on semiconductor optical amplifiers (SOA) with improved bandwidth due to multiple gain media. It is demonstrated that even two SOAs with nearly equal gain spectra can improve the performance of the light source when installed in series. This serial SOA configuration (SSOA) is compared with the common MasterOscillator/Power Amplifier architecture (MOPA) where a single SOA is used as laser gain medium in the resonator and a second one outside as booster. We show that for high sweep rates (20 kHz) the SSOA configuration can maintain a significantly higher bandwidth (~50% higher) compared to the MOPA architecture. Correspondingly narrower point spread functions can be generated in a Michelson interferometer.

General information
Publication status: Published
Organisations: Terahertz Technologies and Biophotonics, Department of Photonics Engineering, Optical Sensor Technology, Micron Optics, Inc.
Contributors: Marschall, S., Thrane, L., Andersen, P. E., Pedersen, C., Hsu, K.
Publication date: 2009
High power swept source for Optical Coherence Tomography

General information
Publication status: Published
Organisations: Terahertz Technologies and Biophotonics, Department of Photonics Engineering, Diode Lasers and LED Systems, Optical Sensor Technology
Contributors: Marschall, S., Jensen, O. B., Pedersen, C., Andersen, P. E.
Publication date: 2009
Peer-reviewed: No
Source: orbit
Source-ID: 271496
Research output: Contribution to conference › Poster – Annual report year: 2009 › Research

Modeling image conversion in sum-frequency generation

General information
Publication status: Published
Organisations: Department of Physics, Quantum Physics and Information Technology, Optical Sensor Technology, Department of Photonics Engineering
Contributors: Buchhave, P., Tidemand-Lichtenberg, P., Pedersen, C.
Publication date: 2009
Peer-reviewed: Yes
Event: Poster session presented at NonLinear Optics, Honolulu, HI, United States.
Source: orbit
Source-ID: 255582
Research output: Contribution to conference › Poster – Annual report year: 2009 › Research › peer-review

Nonlinear beam clean-up using resonantly enhanced sum-frequency mixing
We investigate the possibility of improving the beam quality and obtaining high conversion efficiency in nonlinear sum-frequency generation. A 765 nm beam from an external cavity tapered diode laser is single-passed through a nonlinear crystal situated in the high intracavity field of a 1342 nm Nd:YVO4 laser, generating a SFG beam at 488 nm. The ECDL have MH^2=1.9 and MV^2=2.4 and the solid-state laser has M^2

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology, Diode Lasers and LED Systems, Quantum Physics and Information Technology, Department of Physics
Contributors: Karamehmedovic, E., Pedersen, C., Jensen, O. B., Tidemand-Lichtenberg, P.
Pages: 409-413
Publication date: 2009
Peer-reviewed: Yes

Publication information
Journal: Applied Physics B
Volume: 96
Issue number: 2-3
ISSN (Print): 0946-2171
Nonlinear optics using tapered diode lasers: [invited]

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology
Contributors: Pedersen, C.
Publication date: 2009
Peer-reviewed: Yes
Event: Paper presented at Meeting on Optical Engineering and Science in Israel, Tel Aviv, Israel.
Source: orbit
Source-ID: 247842
Research output: Contribution to journal › Journal article – Annual report year: 2009 › Research › peer-review

Novel concepts to improve Swept Sources for Optical Coherence Tomography

General information
Publication status: Published
Organisations: Terahertz Technologies and Biophotonics, Department of Photonics Engineering, Optical Sensor Technology
Contributors: Marschall, S., Pedersen, C., Andersen, P. E.
Publication date: 2009
Peer-reviewed: Yes
Event: Poster session presented at 4th International Graduate summer school - Biophotonics '09, Ven, Sweden.
Source: orbit
Source-ID: 271497
Research output: Contribution to conference › Paper – Annual report year: 2009 › Research › peer-review

Singly-resonant sum frequency generation of visible light in a semiconductor disk laser

In this paper a generic approach for visible light generation is presented. It is based on sum frequency generation between a semiconductor disk laser and a solid-state laser, where the frequency mixing is achieved within the cavity of the semiconductor disk laser using a singlepass of the solid-state laser light. This exploits the good beam quality and high intra-cavity power present in the semiconductor disk laser to achieve high conversion efficiency. Combining sum frequency mixing and semiconductor disk lasers in this manner allows in principle for generation of any wavelength within the visible spectrum, by appropriate choice of semiconductor material and single-pass laser wavelength.

General information
Publication status: Published
Organisations: Quantum Physics and Information Technology, Department of Physics
Contributors: Andersen, M. T., Schlosser, P., Hastie, J., Tidemand-Lichtenberg, P., Dawson, M., Pedersen, C.
Pages: 6010-6017
Publication date: 2009
Peer-reviewed: Yes

Publication information
Journal: Optics Express
Volume: 17
Issue number: 8
ISSN (Print): 1094-4087
Ratings:
BFI (2009): BFI-level 2
Tapered diode laser pumped 946 nm Nd:YAG laser

We successfully implemented a 946 nm Nd:YAG laser based on a 808 nm tapered diode pump laser. The tapered diode is developed at the Ferdinand-Braun-Institute für Höchstfrequenztechnik in Germany. Figure 2 shows the experimental setup and results of each pump source coupled into a 1.5 mm crystal and a 3 mm crystal in a cavity with 3% output coupling. We failed to achieve lasing in the 3 mm crystal with the BAL pump, but this was expected and agreed with numerical results. Absorption of the tapered pump is 84% and 63% for the 3 mm and 1.5 mm crystal respectively. In comparison with a BAL pumped laser, we show that tapered diode laser pumping potentially increase the power of 946 nm lasers by a factor of two and reduce the threshold by a factor of three.
Visible and ultraviolet light sources based nonlinear interaction of lasers

Different light sources can be used for optically stimulated luminescence measurements and usually a halogen lamp in combination with filters or light emitting diodes (LED’s) are used to provide the desired stimulation wavelength. However lasers can provide a much more well-defined beam, very narrow spectrum, high intensities and fast pulsing characteristics. Apart from potential significant reduction in filtration requirements as compared to the LED’s, these characteristics help in accurate examination of different trap parameters. In this poster recent work on a general approach for synthesizing any wavelength in the visible and ultraviolet light based sum frequency generation between two lasers is presented.

General information
Publication status: Published
Organisations: Radiation Physics, Radiation Research Division, Rise National Laboratory for Sustainable Energy, Quantum Physics and Information Technology, Department of Physics, Optical Sensor Technology, Department of Photonics Engineering
Contributors: Andersen, M. T., Tidemand-Lichtenberg, P., Jain, M., Pedersen, C.
Publication date: 2009
Peer-reviewed: No
Keywords: Radiation physics, Nuclear technologies
Electronic versions:
Visible and UV light sources Final.pdf
Source: orbit
Source-ID: 256371
Research output: Contribution to conference › Poster – Annual report year: 2009 › Research

300 mW of coherent light at 488 nm using a generic approach
We present a generic approach for efficient generation of CW light with a predetermined wavelength within the visible or UV spectrum. Based on sum-frequency generation (SFG), the circulating intra-cavity field of a high-finesse diode pumped CW solid-state laser (DPSSL) and the output from a tapered, single-frequency external cavity diode laser (ECDL) are mixed inside a 10 mm periodically poled KTP crystal (pp-KTP). The pp-KTP is situated inside the DPSSL cavity to enhance conversion efficiency of the nonlinear mixing process. This approach combines different solid state technologies; the tuneability of ECDLs, the high intra-cavity field of DPSSLs and flexible quasi phase matching in pp-KTP. We demonstrate the potential of the proposed method by synthesizing a beam at 488 nm using a single-frequency tapered ECDL with a center wavelength of 766 nm in combination with a high finesse Nd:YVO4 laser at 1342 nm. Up to 308 mW of light at 488nm was measured in our experiments. The conversion of the ECDL beam was up to 47% after it was transmitted through a PM fiber, and up to 32% without fiber coupling. Replacing the seed laser and the nonlinear crystal makes it possible to generate light at virtually any desired wavelength within the visible spectrum.

General information
Publication status: Published
Organisations: Rise National Laboratory for Sustainable Energy, Optical Sensor Technology, Quantum Physics and Information Technology, Department of Physics
Contributors: Karamehmedovic, E., Pedersen, C., Andersen, M. T., Tidemand-Lichtenberg, P.
Number of pages: 422
Pages: 87512-87512
Publication date: 2008

Host publication information
Title of host publication: Nonlinear frequency generation and conversion: materials, devices, applications VII
Volume: 6875
Publisher: SPIE - International Society for Optical Engineering
ISBN (Print): 978-1-60845-762-0
DOIs: 10.1117/12.762876
All semiconductor laser Doppler anemometer at 1.55 μm

We report to our best knowledge the first all semiconductor Laser Doppler Anemometer (LIDAR) for wind speed determination. We will present the design and first experimental results on a focusing coherent cw laser Doppler anemometer for measuring atmospheric wind velocities in the 10 meters to 300 meters distance range. Especially, we will demonstrate that both the output power as well as the demanding coherence properties required from the laser source can be accomplished by an all semiconductor laser. Preliminary tests at a distance of 40 meters indicate a typical signal to noise ratio of 9 dB. This result is obtained at a clear day with an up-date rate of 12 Hz.

A new pulsed 404 nm laser source for biomedical applications

Comparison of a Ti:S Laser and a Tapered External Cavity Diode Laser for Sum Frequency Generation in a High-Finesse 1342 nm Nd:YVO4 Laser
**Frequency-swept laser light source at 1050 nm with higher bandwidth due to multiple SOAs in series**

**General information**
Publication status: Published
Organisations: Terahertz Technologies and Biophotonics, Department of Photonics Engineering, Optical Sensor Technology, Micron Optics, Inc.
Contributors: Marschall, S., Thrane, L., Pedersen, C., Hsu, K., Andersen, P. E.
Number of pages: 50
Pages: 24-24
Publication date: 2008

**Host publication information**
Title of host publication: [Book of Abstracts]
Publisher: University of Kent, School of Physical Sciences
Source: orbit
Source-ID: 224123

Research output: Chapter in Book/Report/Conference proceeding – Conference abstract in proceedings – Annual report year: 2008 – Research

**Pulsed UV Laser for Fluorescence Diagnostics based on Non-Linear Frequency Conversion**

**General information**
Publication status: Published
Organisations: Diode Lasers and LED Systems, Department of Photonics Engineering, Terahertz Technologies and Biophotonics, Optical Sensor Technology
Contributors: Cheng, H. P. H., Jensen, O. B., Andersen, P. E., Petersen, P. M., Pedersen, C.
Publication date: 2008
Peer-reviewed: No
Event: Poster session presented at Pulsed UV Laser for Fluorescence Diagnostics based on Non-Linear Frequency Conversion, Quantum and Nonlinear Optics PhD Summer School, Hven (SE), 2008
Source: orbit
Source-ID: 250644

Research output: Contribution to conference – Poster – Annual report year: 2008 – Research

**Pulsed UV-light source for auto-fluorescence diagnostics**

**General information**
Publication status: Published
Organisations: Quantum Physics and Information Technology, Department of Physics, Optical Sensor Technology, Department of Photonics Engineering, Diode Lasers and LED Systems
Contributors: Tidemand-Lichtenberg, P., Pedersen, C., Cheng, H. P. H., Petersen, P. M., Buchhave, P.
Publication date: 2008
Peer-reviewed: Yes
Source: orbit
Source-ID: 232312

Research output: Contribution to conference – Poster – Annual report year: 2008 – Research – peer-review

**Pulsed UV-light source for auto-fluorescence diagnostics**

**General information**
Publication status: Published
Organisations: Optical Sensor Technology, Department of Photonics Engineering, Risø National Laboratory for Sustainable Energy, Diode Lasers and LED Systems, Quantum Physics and Information Technology, Department of Physics
Theoretical comparison of SHG and SFG efficiencies for visible light generation

General information
Publication status: Published
Organisations: Quantum Physics and Information Technology, Department of Physics, Optical Sensor Technology, Department of Photonics Engineering
Contributors: Sørensen, K., Tidemand-Lichtenberg, P., Andersen, M. T., Buchhave, P., Pedersen, C.
Publication date: 2008
Peer-reviewed: Yes
Event: Poster session presented at DFS/DOPS Annual Meeting, Nyborg Strand, .
Source: orbit
Source-ID: 232322
Research output: Contribution to conference » Poster – Annual report year: 2008 » Research

Theoretical comparison of SHG and SFG efficiency and stability

General information
Publication status: Published
Organisations: Quantum Physics and Information Technology, Department of Physics, Optical Sensor Technology, Department of Photonics Engineering
Contributors: Tidemand-Lichtenberg, P., Sørensen, K., Andersen, M. T., Buchhave, P., Pedersen, C.
Publication date: 2008
Peer-reviewed: Yes
Source: orbit
Source-ID: 232317
Research output: Contribution to conference » Poster – Annual report year: 2008 » Research » peer-review

Efficient visible light generation by mixing of a solid-state laser and a tapered diode laser

General information
Publication status: Published
Enhance non-linear frequency conversion using diode pumped VECSELs

General information
Publication status: Published
Organisations: Rise National Laboratory for Sustainable Energy, Department of Physics
Contributors: Pedersen, C., Tidemand-Lichtenberg, P.
Publication date: 2007

Publication information
Original language: English
Source: orbit
Source-ID: 209892
Research output: Contribution to journal › Journal article – Annual report year: 2007 › Research

Nonlinear cavity dumping of a high finesse frequency mixing module

General information
Publication status: Published
Organisations: Department of Physics, Optical Diagnostics and Information Processing, Optics and Plasma Research Department, Rise National Laboratory for Sustainable Energy
Pages: 9799-9803
Publication date: 2007
Peer-reviewed: Yes

Publication information
Journal: Optics Express
Volume: 15
ISSN (Print): 1094-4087
Ratings:
Scopus rating (2007): SJR 3.299 SNIP 2.08
Web of Science (2007): Indexed yes
Original language: English
DOIs:
10.1364/OE.15.009799
URLs:
Source: orbit
Source-ID: 209897
Research output: Contribution to journal › Journal article – Annual report year: 2007 › Research
**Fasekonjugeret tapered diodelaser**

**General information**
Publication status: Published
Organisations: Risø National Laboratory for Sustainable Energy
Contributors: Pedersen, C.
Publication date: 2006
Peer-reviewed: No
Event: Abstract from Møde i Dansk Optisk Selskab, Risø, Denmark.
Source: orbit
Source-ID: 309788
Research output: Contribution to conference › Conference abstract for conference – Annual report year: 2006 › Research

**Single frequency, high power, tapered diode laser using phase-conjugated feedback**

**General information**
Publication status: Published
Organisations: Risø National Laboratory for Sustainable Energy
Contributors: Pedersen, C., Hansen, R.
Pages: 3961 - 3968
Publication date: 2005
Peer-reviewed: Yes

**Publication information**
Journal: Opt. Express
Volume: 13
Ratings:
Scopus rating (2005): SJR 3.412 SNIP 2.459
Web of Science (2005): Indexed yes
Original language: English
DOIs:
10.1364/OE.13.003961
Source: orbit
Source-ID: 308043
Research output: Contribution to journal › Journal article – Annual report year: 2005 › Research › peer-review

**Tunable high-power narrow-linewidth semiconductor laser based on an external-cavity tapered amplifier**

**General information**
Publication status: Published
Organisations: Risø National Laboratory for Sustainable Energy
Contributors: Chi, M., Jensen, O., Holm, J., Pedersen, C., Andersen, P. E., Ebert, G., Sumpf, B., Petersen, P.
Pages: 10589-10596
Publication date: 2005
Peer-reviewed: Yes

**Publication information**
Journal: Opt. Express
Volume: 13
Ratings:
Scopus rating (2005): SJR 3.412 SNIP 2.459
Web of Science (2005): Indexed yes
Original language: English
DOIs:
10.1364/OE.13.010589
Source: orbit
Source-ID: 308717
Research output: Contribution to journal › Journal article – Annual report year: 2005 › Research › peer-review

**Off-axis beam combining**
Variable stripe mirror

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Optical Sensor Technology
Contributors: Pedersen, C., Tidemand-Lichtenberg, P., Sheng, W.
Publication date: 2002

Publication information
Patent number: WO02082593
Filing date: 17/10/2002
Original language: English
Electronic versions:
WO02082593A21.pdf

Triangular laser resonators with astigmatic compensation

General information
Publication status: Published
Organisations: Department of Physics
Contributors: Skettrup, T., Meelby, T., Færch, K., Frederiksen, S. L., Pedersen, C.
Pages: 4306-4312
Publication date: 2000
Peer-reviewed: Yes

Publication information
Journal: Applied Optics
Volume: 39
Issue number: 24
ISSN (Print): 1559-128X
Ratings: Scopus rating (2000): SJR 1.12 SNIP 1.102
Original language: English
Source: orbit
Source-ID: 177006
Research output: Contribution to journal › Journal article – Annual report year: 2000 › Research › peer-review

Frequency doubling in LiNbO3 using temperature dependent QPM
We report the application of temperature-dependent quasi-phase matching (QPM) for second harmonic generation of green light using periodically field poled LiNbO3. In contrast to the usual QPM devices, here the fundamental and second harmonic waves are polarized orthogonally so that the second harmonic signal corresponds to the extraordinary wave. This requires the utilization of the d31 component of the nonlinear tensor (i.e. the same component as used for ordinary birefringent phase matching). d31 is smaller than the d33 component usually used in QPM devices and therefore yields a lower efficiency. However, the use of QPM in our geometry with orthogonally polarized waves results in a greatly enhanced temperature tunability, which increases the versatility of the devices. Moreover, the domain inversion grating period required in this geometry for first-order QPM at the Nd laser wavelength 1064 nm and room temperature is relatively large (350 ...m), and therefore easier to fabricate. Compared with birefringent phase matching, the QPM
technique allows for phase matching at any wavelength and eliminates the walk-off effect since the fields propagates along one of the dielectric principal axes. The interaction path can therefore, in principle, be extended over arbitrarily long distances.

**General information**
Publication status: Published
Organisations: Department of Physics
Contributors: Belmonte, M., Skettrup, T., Pedersen, C.
Pages: 60-63
Publication date: 1999
Peer-reviewed: Yes

**Publication information**
Volume: 1
Issue number: 1
ISSN (Print): 2040-8978
Original language: English
DOI: 10.1088/1464-4258/1/1/008
Source: orbit
Source-ID: 171328
Research output: Contribution to journal → Journal article – Annual report year: 1999 → Research → peer-review

**New prism ring laser design incorporating frustrated total internal reflection output coupling**
A novel prism ring laser design incorporating total internal reflection resonator mirrors and frustrated total internal reflection output coupling is analyzed and tested experimentally.

**General information**
Publication status: Published
Organisations: Department of Physics
Contributors: Heyde, C., Hansen, P., Buchhave, P., Pedersen, C.
Pages: 201-203
Publication date: 1997

**Host publication information**
Title of host publication: Technical Digest TuC12

**Bibliographical note**
Poster presentation.
Source: orbit
Source-ID: 167985
Research output: Chapter in Book/Report/Conference proceeding → Article in proceedings – Annual report year: 1997 → Research → peer-review

**Signal-flow graphs in coupled laser resonator analysis**
Signal-flow graph analysis of coupled linear systems is introduced in order to find a simple method to treat systems of coupled optical resonators. The proposed method turns out to be well suited for this purpose, and the reflectance and transmittance of coupled resonator systems are easily found. The expressions for amplitude reflectivity and transmittivity are derived for the simplest systems of coupled resonators for systems coupled both in series and in parallel. Some specific examples for the two- and three-mirror cases with beam splitters are given.

**General information**
Publication status: Published
Organisations: Department of Physics
Contributors: Pedersen, C., Skettrup, T.
Pages: 1791-1798
Publication date: 1997
Peer-reviewed: Yes

**Publication information**
Volume: 14
Issue number: 8
ISSN (Print): 1084-7529
Single-frequency diode-pumped Nd:YAG prism laser with use of a composite laser crystal
A compact, stable, diode-pumped Nd:YAG laser suitable for high-power single-frequency operation is investigated theoretically as well as experimentally. Residual spatial hole burning has been eliminated with a unidirectional ring-laser design with a specially designed intracavity prism and a composite YAG laser crystal. A detailed Jones matrix analysis is performed, leading to design criteria for high loss difference and high-frequency stability.

Frequency tuning and stability of Nd:YVO4 in a dual coupled cavity
Frequency tuning and stability properties of single- and multi-cavity designs have been investigated theoretically and experimentally. Special attention is paid to a dual coupled cavity single-frequency diode-pumped solid-state Nd:YVO4 laser crystal. 350 mW single frequency output power has previously been demonstrated using dual coupled linear cavity. Frequency tuning versus temperature and cavity length of a coupled cavity Nd:YVO4 have been investigated and compared to those of a non-planar monolithic, unidirectional Nd:YAG ring laser. A way to extend the tuning range by design of the air to crystal length ratio is proposed. Finally the long term frequency stability of both lasers has been measured. The stability of the lasers are presented through the Allan variance of the frequency fluctuations.

Investigation of frequency stability and design criteria of ring lasers
We present a comprehensive Jones matrix analysis of two commonly used ring laser resonators. Different aspects on how to obtain low loss eigenmodes and/or high loss difference between the two directions of the cavity, and thus high frequency stability, are investigated. Also different approximations are evaluated. Since the theory has been kept general,
the derived results can be applied to a large class of ring laser designs. Finally the influence of backscattered light on the stability is considered. Experimental results on two ring lasers are discussed.

**General information**
Publication status: Published
Organisations: Department of Physics
Contributors: Pedersen, C., Lichtenberg Hansen, P., Buchhave, P., Skettrup, T.
Pages: 400-402
Publication date: 1996

**Host publication information**
Title of host publication: Advanced Solid-State Lasers, Technical Digest
Place of publication: Washington DC
Publisher: Optical Society of America

**Bibliographical note**
Poster presentation.
Source: orbit
Source-ID: 167218
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 1996 › Research › peer-review

**Laser modes and threshold condition in N-mirror resonator.**
Two formal methods for finding laser modes and threshold conditions in laser resonators containing as many as N mirrors are presented. The first method is based on an analysis determining the reflectivity and the transmittivity of an N-mirror system with gain. This is an extension of the classical 2 × 2 matrix method. The second method is based on self-consistency equations for the system and directly yields the circulating fields of the individual resonators. A set of rules has been proved to allow these fields to be calculated directly by means of inspection. The laser oscillation condition for an N-mirror system is found. Examples are given for systems with as many as five mirrors.

**General information**
Publication status: Published
Organisations: Department of Physics
Contributors: Pedersen, C., Skettrup, T.
Pages: 926-937
Publication date: 1996
Peer-reviewed: Yes

**Publication information**
Journal: Optical Society of America. Journal B: Optical Physics
Volume: 13
Issue number: 5
ISSN (Print): 0740-3224
Original language: English
DOIs: 10.1364/JOSAB.13.000926
Source: orbit
Source-ID: 167651
Research output: Contribution to journal › Journal article – Annual report year: 1996 › Research › peer-review

**Reduction of spatial holeburning in a diode pumped Nd:YAG laser by the use of a composite laser crystal**

**General information**
Publication status: Published
Organisations: Department of Physics
Contributors: Pedersen, C., Lichtenberg Hansen, P., Buchhave, P.
Publication date: 1996

**Host publication information**
Title of host publication: XX International Quantum Electronics Conference, Technical Digest
Place of publication: Washington DC
Publisher: Optical Society of America

**Bibliographical note**
Oral presentation.
Tuning and stability properties of a single frequency diode-pumped coupled-cavity Nd:YVO4 laser

Frequency tuning of a coupled cavity solid-state Nd:YVO4 laser has been investigated both theoretically and experimentally. The frequency tuning curve was calculated from equations describing the normalized circulating field (enhancement) of a coupled cavity introducing a Lorentzian gain profile into one of the cavities. The equations describing the coupled cavity have been derived by substituting the passive cavity by a mirror, with a frequency dependent reflection coefficient and phase shift.

Diode-pumped single-frequency Nd:YVO4 laser with a set of coupled resonators

350 mW of single-frequency power from a diode-pumped solid-state Nd:YVO4 laser has been obtained from a coupled resonator design without any intracavity elements. Single-frequency operation was obtained by use of a very short laser rod and a coupled resonator design. The two coupled resonators were formed by the two faces of a very short Nd:YVO4 laser crystal and an output coupling mirror. The interaction of the two coupled cavities caused a modification of the eigenmodes supporting laser action in a single longitudinal mode. This design, which is extremely simple, represents a cost-effective way of obtaining single-frequency output.
Samfinansieret - Andet
01/06/2018 → 31/01/2021
Award relations: Mid-Infrared Upconversion Imaging and Spectroscopy using Short Pulse Light Sources
Project: PhD

Optical Monitoring of Zooplankton
Nielsen, J. H., PhD Student, Department of Photonics Engineering
Rodrigo, P. J., Main Supervisor
Pedersen, C., Supervisor
Rasmussen, F. B., Supervisor
Industrial PhD
01/01/2017 → 31/12/2019
Award relations: Optical Monitoring of Zooplankton
Project: PhD

Undersøgelser af optiske parametriske oscillatorer (OPOsystemer) specielt mhb anvendelser som infrarøde lyskilder
Pedersen, C., PhD Student, Department of Physics
Skettrup, T., Main Supervisor
Lading, L., Examiner
Akademiet for de Tekniske Videnskaber
01/07/1991 → 16/10/1995
Award relations: Undersøgelser af optiske parametriske oscillatorer (OPOsystemer) specielt mhb anvendelser som infrarøde lyskilder
Project: PhD

Upconversion based hyperspectral imaging
Junaid, S., PhD Student, Department of Photonics Engineering
Tidemand-Lichtenberg, P., Main Supervisor
Stone, N., Supervisor
Rottwitt, K., Examiner
Francoy, J. C., Examiner
Harren, F. J. M., Examiner
Pedersen, C., Supervisor
Marie Curie (EU-stipendium)
01/12/2015 → 06/03/2019
Award relations: Upconversion based hyperspectral imaging
Project: PhD

Power scaling of frequency converted visible lasers
Christensen, M., PhD Student, Department of Photonics Engineering
Jensen, O. B., Main Supervisor
Noordegraaf, D., Supervisor
Pedersen, C., Examiner
Jungbluth, B., Examiner
Lucas-Leclin, G., Examiner
Industrial PhD
01/11/2015 → 03/04/2019
Award relations: Power scaling of frequency converted visible lasers
Project: PhD

Upconversion DIAL for Remote Gas Sensing
Meng, L., PhD Student, Department of Photonics Engineering
Rodrigo, P. J., Main Supervisor
Høgstedt, L., Supervisor
Pedersen, C., Supervisor
Jensen, O. B., Examiner
Fejer, M. M., Examiner
Kühnemann, F., Examiner
Marie Curie (EU-stipendium)
15/11/2015 → 06/02/2019
Award relations: Upconversion DIAL for Remote Gas Sensing
Project: PhD
Long-wavelength Infrared (LWIR) Upconversion Spectroscopy and Imaging
Tseng, Y., PhD Student, Department of Photonics Engineering
Tidemand-Lichtenberg, P., Main Supervisor
Pedersen, C., Supervisor
Lindvold, L. R., Examiner
Francoy, J. C., Examiner
Suchowski, H., Examiner
Marie Curie (EU-stipendium)
01/10/2015 → 15/12/2018
Award relations: Long-wavelength Infrared (LWIR) Upconversion Spectroscopy and Imaging
Project: PhD

UV light source for next generation immunoassay analyzer
Rodenko, O., PhD Student, Department of Photonics Engineering
Pedersen, C., Main Supervisor
Fodgaard, H., Supervisor
Pedersen, P. M., Supervisor
Tidemand-Lichtenberg, P., Supervisor
Willy Lindegaard, A., Supervisor
Lindvold, L. R., Examiner
Laurell, F., Examiner
Toivonen, J. I., Examiner
Industrial PhD
01/06/2015 → 30/09/2018
Award relations: UV light source for next generation immunoassay analyzer
Project: PhD

Super continuum laser for broadband spectroscopy using upconversion
Huot, L., PhD Student, Department of Photonics Engineering
Pedersen, C., Main Supervisor
Moselund, P. M., Supervisor
Tidemand-Lichtenberg, P., Supervisor
Julsgaard, B., Examiner
Arie, A., Examiner
Genty, G., Examiner
Eksternt EU-finansieret
15/03/2015 → 23/01/2019
Award relations: Super continuum laser for broadband spectroscopy using upconversion
Project: PhD

Novel concepts for improving swept sources for Optical Coherence Tomography
Marschall, S., PhD Student, Department of Photonics Engineering
Andersen, P. E., Main Supervisor
Pedersen, C., Supervisor
Petersen, P. M., Examiner
Wojtkowski, M., Examiner
Andersson-Engels, S., Examiner
Anden EU-finansiering
01/11/2008 → 23/05/2012
Award relations: Novel concepts for improving swept sources for Optical Coherence Tomography
Project: PhD

Pulsed Blue and Ultraviolet Laser System for Fluorescence Diagnostics based on Nonlinear Frequency Conversion
Cheng, H. P. H., PhD Student, Department of Photonics Engineering
Pedersen, C., Main Supervisor
Andersen, P. E., Supervisor
Jensen, O. B., Supervisor
Petersen, P. M., Supervisor
Rottwitt, K., Examiner
Laurell, F., Examiner
Thomsen, J. W., Examiner
**Institut, samfinansiering**
15/01/2008 → 22/06/2011
Award relations: Pulsed Blue and Ultraviolet Laser System for Fluorescence Diagnostics based on Nonlinear Frequency Conversion
Project: PhD

**Novel diode laser LiDAR systems**
Hu, Q., PhD Student, Department of Photonics Engineering
Pedersen, C., Main Supervisor
Korsgaard Jensen, J., Supervisor
Rodrigo, P. J., Supervisor
Mikkelsen, T. K., Examiner
Fix, A., Examiner
Sørensen, M. B., Examiner
ErhvervPhD-ordningen VTU
15/03/2013 → 15/06/2016
Award relations: Novel diode laser LiDAR systems
Project: PhD

**Composite Fibre and Solid-State Visible Light Source**
Andersen, M. T., PhD Student, Department of Physics
Tidemand-Lichtenberg, P., Main Supervisor
Pedersen, C., Supervisor
Petersen, P. M., Examiner
Arie, A., Examiner
Dunn, M., Examiner
DTU, Samfinansiering
01/03/2006 → 23/09/2009
Award relations: Composite Fibre and Solid-State Visible Light Source
Project: PhD

**New light Sources for Biomedical Applications**
Argyraki, A., PhD Student, Department of Photonics Engineering
Petersen, P. M., Main Supervisor
Dam-Hansen, C., Supervisor
Pedersen, C., Examiner
Spigulis, J., Examiner
Martiny, K. P. J., Examiner
Samfinansieret - Andet
15/12/2013 → 11/01/2018
Award relations: New light Sources for Biomedical Applications
Project: PhD

**IR Sensing and Imaging**
Högstedt, L., PhD Student, Department of Photonics Engineering
Tidemand-Lichtenberg, P., Main Supervisor
Pedersen, C., Supervisor
Rottwitt, K., Examiner
Arie, A., Examiner
Ebrahim-Zadeh, M., Examiner
Arie, A., Examiner
Technical University of Denmark
01/11/2012 → 16/03/2016
Award relations: IR Sensing and Imaging
Project: PhD

**Cost-efficient lidar for pitch control**
EUDP project
Rodrigo, P. J., Project Participant, Department of Photonics Engineering, Optical Sensor Technology
Pedersen, C., Project Participant, Department of Photonics Engineering, Optical Sensor Technology
01/07/2014 → 30/06/2016
Project: Research
Low-cost semiconductor laser wind sensors

Our objective is to develop, demonstrate and validate prototype laser wind sensors that measure wind speed and direction based on low-cost, compact semiconductor lasers and new optical methods we have recently devised and patented. These wind sensor prototypes will represent the next-generation of compact, rugged and inexpensive laser-based wind sensors for wind energy research and turbine industry.

Rodrigo, P. J., Project Manager, Department of Photonics Engineering, Optical Sensor Technology
Pedersen, C., Project Participant, Department of Photonics Engineering, Optical Sensor Technology
Dellwik, E., Project Participant, Meteorology, Department of Wind Energy
Mann, J., Project Participant, Meteorology, Department of Wind Energy
Sjöholm, M., Project Participant, Department of Wind Energy, Test and Measurements

Project ID: 70720
Energiteknologisk Udviklings- og Demonstrationprogram: DKK7,391,990.00
01/03/2012 → 28/02/2014
Collaborators: Windar Photonics A/S
Award relations: Low-cost semiconductor laser wind sensors
Project: Research

BiL: Bringing the infrared to light

Dam, J. S., Project Manager, Department of Photonics Engineering
Tidemand-Lichtenberg, P., Project Participant, Department of Photonics Engineering
Pedersen, C., Project Participant, Department of Photonics Engineering

Project ID: 70579
Forskningsrådene - Andre: DKK750,000.00
01/01/2012 → 31/12/2012
Award relations: Bringing the infrared to light
Project: Research

Synlig lyskilde 1700167: General approach to high power, coherent, visible and ultraviolet

Pedersen, C., Project Manager, Department of Photonics Engineering

Forsk. Andre offentlige og private - Nordiske
11/03/2008 → 22/01/2010
Collaborators: Ministry of Higher Education and Science
Award relations: Synlig lyskilde 1700167: General approach to high power, coherent, visible and ultraviolet
Project: Research

SMIRI: Spectral Mid-IR imaging

Dam, J. S., Project Participant, Department of Photonics Engineering
Pedersen, C., Project Participant, Department of Photonics Engineering
Tidemand-Lichtenberg, P., Project Participant, Department of Photonics Engineering

Project ID: 70669
Forskningsprojekter - Andre ministerier og styrelser: DKK540,000.00
01/03/2011 → 01/09/2011
Award relations: Spectral Mid-IR Imaging
Project: Research

Activities:

Workshop on "Laser Sources for LIDAR Applications"

Period: 24 Nov 2014
Christian Pedersen (Invited speaker)
Department of Photonics Engineering
Optical Sensor Technology

Description
Diode based coherent LIDARs for wind sensing
Links:
http://www.britespace.eu/workshop/
Room temperature nonlinear imaging and detection with single photon sensitivity at mid-IR wavelengths
Period: 19 Nov 2014
Christian Pedersen (Invited speaker)
Department of Photonics Engineering
Optical Sensor Technology
Links:

Mid-IR Single Photon Imaging and Spectroscopy using Upconversion: SPECIALISTS’ MEETING SET-210
Period: Jul 2014
Christian Pedersen (Invited speaker)
Department of Photonics Engineering
Optical Sensor Technology
Description
Abstract:
Low noise, spectral mid-infrared (mid-IR) imaging and detection based on upconversion are emerging as a promising technology of great technical and scientific interest. The reason is that many important chemical compounds display unique and strong mid-IR spectral fingerprints revealing valuable chemical information. We report on a portable mid-IR upconversion system that is compatible with standard NIR/VIS cameras. Examples will be given illustrating the potential of upconversion for single photon imaging at 3 µm, mid-IR hyper-spectral imaging and spectroscopy.
Links:
https://www.cso.nato.int/page.asp?ID=2462

Meeting on Optical Engineering and Science in Israel; 12
Period: 16 Mar 2009 → 17 Mar 2009
Christian Pedersen (Speaker)
Department of Photonics Engineering
Optical Sensor Technology

Description
Place: Tel Aviv, Israel

Related external organisation