Coherent laser phase retrieval in the presence of measurement imperfections and incoherent light

Phase retrieval is a powerful numerical method that can be used to determine the wavefront of laser beams based only on intensity measurements, without the use of expensive, low-resolution specialized wavefront sensors such as Shack–Hartmann sensors. However, phase retrieval techniques generally suffer from poor convergence and fidelity when the input measurements contain electronic or optical noise and/or an incoherent intensity contribution overlapped with the otherwise spatially coherent laser beam. Here, we present an implementation of a modified version of the standard multiple-plane Gerchberg–Saxton algorithm and demonstrate that it is highly successful at extracting the intensity profile and wavefront of the spatially coherent part of the light from various lasers, including tapered laser diodes, at a very high fidelity despite the presence of incoherent light and noise.
1.9 W yellow, CW, high-brightness light from a high efficiency semiconductor laser-based system

Semiconductor lasers are ideal sources for efficient electrical-to-optical power conversion and for many applications where their small size and potential for low cost are required to meet market demands. Yellow lasers find use in a variety of bio-related applications, such as photocoagulation, imaging, flow cytometry, and cancer treatment. However, direct generation of yellow light from semiconductors with sufficient beam quality and power has so far eluded researchers. Meanwhile, tapered semiconductor lasers at near-infrared wavelengths have recently become able to provide near-diffraction-limited, single frequency operation with output powers up to 8 W near 1120 nm.

We present a 1.9 W single frequency laser system at 562 nm, based on single pass cascaded frequency doubling of such a tapered laser diode. The laser diode is a monolithic device consisting of two sections: a ridge waveguide with a distributed Bragg reflector, and a tapered amplifier. Using single-pass cascaded frequency doubling in two periodically poled lithium niobate crystals, 1.93 W of diffraction-limited light at 562 nm is generated from 5.8 W continuous-wave infrared light. When turned on from cold, the laser system reaches full power in just 60 seconds. An advantage of using a single pass configuration, rather than an external cavity configuration, is increased stability towards external perturbations. For example, stability to fluctuating case temperature over a 30 K temperature span has been demonstrated. The combination of high stability, compactness and watt-level power range means this technology is of great interest for a wide range of biological and biomedical applications. © (2017) COPYRIGHT Society of Photo-Optical Instrumentation Engineers (SPIE
3.5 W of diffraction-limited green light at 515 nm from SHG of a single-frequency tapered diode laser

Multi-Watt efficient compact green laser sources are required for a number of applications e.g. within biophotonics, laser pumping and laser displays. We present generation of 3.5 W of diffraction-limited green light at 515 nm by second harmonic generation (SHG) of a tapered diode laser, itself yielding more than 9 W at 1030 nm. SHG is performed in single pass through a cascade of two nonlinear crystals with re-focusing and dispersion compensating optics between the two nonlinear crystals. The laser is single-frequency and the output power is stabilized to better than ±0.4%.
Deep modulation of second-harmonic light by wavelength detuning of a laser diode

Power modulated visible lasers are interesting for a number of applications within areas such as laser displays and medical laser treatments. In this paper, we present a system for modulating the second-harmonic light generated by single-pass frequency doubling of a distributed feedback (DFB) master oscillator power amplifier (MOPA) laser diode with separate electrical contacts for the MO and the PA. A modulation depth in excess of 97% from 0.1 Hz to 10 kHz is demonstrated. This is done by wavelength tuning of the laser diode using only a 40 mA adjustment of the current through the MO. The bandwidth of the modulation is limited by the electronics. This method has the potential to decrease the size as well as cost of modulated visible lasers. The achievable optical powers will increase as DFB MOPAs are further developed. (C) 2017 Optical Society of America
Efficient generation of 3.5W laser light at 515nm by frequency doubling a single-frequency high power DBR tapered diode laser

More than 3.5 W of green light at 515 nm is generated by frequency doubling a single-frequency high power DBR tapered diode laser. The frequency doubling is performed in a cascade of PPMgLN and PPMgSLT crystals in order to reach high power and avoid thermal effects present in PPMgLN at high power. The green light is diffraction limited (M2 <1.1) and single-frequency operation is demonstrated with a linewidth less than 2 pm.
Epi-detecting label-free multimodal imaging platform using a compact diode-pumped femtosecond solid-state laser

We have developed an epi-detected multimodal nonlinear optical microscopy platform based on a compact and cost-effective laser source featuring simultaneous acquisition of signals arising from hyperspectral coherent anti-Stokes Raman scattering (CARS), two-photon fluorescence, and second harmonic generation. The laser source is based on an approach using a frequency-doubled distributed Bragg reflector-tapered diode laser to pump a femtosecond Ti:sapphire laser. The operational parameters of the laser source are set to the optimum trade-off between the spectral and temporal requirements for these three modalities, achieving sufficient spectral resolution for CARS in the lipid region. The experimental results on a biological tissue reveal that the combination of the epi-detection scheme and the use of a compact diode-pumped femtosecond solid-state laser in the nonlinear optical microscope is promising for biomedical applications in a clinical environment.
Modulation of Frequency Doubled DFB-Tapered Diode Lasers for Medical Treatment

The use of visible lasers for medical treatments is on the rise, and together with this comes higher expectations for the laser systems. For many medical treatments, such as ophthalmology, doctors require pulse on demand operation together with a complete extinction of the light between pulses. We have demonstrated power modulation from 0.1 Hz to 10 kHz at 532 nm with a modulation depth above 97% by wavelength detuning of the laser diode. The laser diode is a 1064 nm monolithic device with a distributed feedback (DFB) laser as the master oscillator (MO), and a tapered power amplifier (PA). The MO and PA have separate electrical contacts and the modulation is achieved with wavelength tuning by adjusting the current through the MO 40 mA.
Comparison of SHG Power Modulation by Wavelength Detuning of DFB- and DBR-Tapered Laser Diodes

Pulsed visible lasers are used for a number of applications such as laser displays and medical treatments. Generating this visible light by direct frequency doubling of high power diode lasers opens new possibilities on how the power modulation can be performed. We present an investigation of the response of the second harmonic light to perturbations of the infrared laser diode and compare how the response differs for DFB- and DBR-Tapered laser diodes. We show that the visible light can be modulated from CW to kHz with modulation depths above 90% by wavelength detuning the laser diode.

Efficient generation of 1.9 W yellow light by cascaded frequency doubling of a distributed Bragg reflector tapered diode

Watt-level yellow emitting lasers are interesting for medical applications, due to their high hemoglobin absorption, and for efficient detection of certain fluorophores. In this paper, we demonstrate a compact and robust diode-based laser system in the yellow spectral range. The system generates 1.9 W of single-frequency light at 562.4 nm by cascaded single-pass frequency doubling of the 1124.8 nm emission from a distributed Bragg reflector (DBR) tapered laser diode. The absence of a free-space cavity makes the system stable over a base-plate temperature range of 30 K. At the same time, the use of a laser diode enables the modulation of the pump wavelength by controlling the drive current. This is utilized to achieve a power modulation depth above 90% for the second harmonic light, with a rise time below 40 μs.
New class of compact diode pumped sub 10 fs lasers for biomedical applications

Diode-pumping Ti:sapphire lasers promises a new approach to low-cost femtosecond light sources. Thus in recent years much effort has been taken just to overcome the quite low power and low beam qualities of available green diodes to obtain output powers of several hundred milliwatts from a fs-laser. In this work we present an alternative method by deploying frequency-doubled IR diodes with good beam qualities to pump fs-lasers. The revolutionary approach allows choosing any pump wavelengths in the green region and avoids complicated relay optics for the diodes. For the first time we show results of a diode-pumped 10 fs-laser and how a single diode setup can be integrated into a 30 x 30 cm$^2$ fs-laser system generating sub 20 fs laser pulses with output power towards half a Watt. This technology paves the way for a new class of very compact and cost-efficient fs-lasers for life science and industrial applications.

Laser Apparatus with Cascade of Nonlinear Frequency Mixers

A laser apparatus comprising: a first laser source operable to generate a first laser beam having a least a beam component having a first frequency
a second laser source operable to generate a second laser beam having a least a beam component having a second frequency
a beam combiner operable to combine the first and second laser beams into a combined initial laser beam comprising at least a frequency component having the first frequency, and a frequency component having the second frequency one or more nonlinear frequency mixers operable to perform a frequency mixing process of a frequency component having the first frequency and a frequency component having the second frequency and resulting in at least a frequency component having a third frequency equal to a sum or difference of the first and second frequencies
wherein the laser apparatus is configured to direct the combined initial laser beam through a first one of the one or more nonlinear frequency mixers resulting in a first frequency-mixed beam, the first frequency-mixed beam comprising a frequency component having the first frequency, a frequency component having the second frequency, and a frequency component having the third frequency
wherein the laser apparatus is further configured to direct the resulting first frequency-mixed beam along an intermediate beam path to a subsequent nonlinear frequency mixer chosen from the first and another one of the one or more nonlinear frequency mixers, resulting in a second frequency-mixed beam comprising at least an output frequency component having at least said third frequency
a dispersive element configured to adjustably change an optical path length of the intermediate beam path of the first frequency-mixed beam so as to compensate for dispersion along at least the intermediate beam path.

**General information**

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5.5 W of Diffraction-Limited Green Light Generated by SFG of Tapered Diode Lasers in a Cascade of Nonlinear Crystals
Diode-based high power visible lasers are perfect pump sources for, e.g., titaniumsapphire lasers. The combination of favorable scaling laws in both SFG and cascading of nonlinear crystals allows access to unprecedented powers in diode-based systems.

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Concept for power scaling second harmonic generation using a cascade of nonlinear crystals

Within the field of high-power second harmonic generation (SHG), power scaling is often hindered by adverse crystal effects such as thermal dephasing arising from the second harmonic (SH) light, which imposes limits on the power that can be generated in many crystals. Here we demonstrate a concept for efficient power scaling of single-pass SHG beyond such limits using a cascade of nonlinear crystals, in which the first crystal is chosen for high nonlinear efficiency and the subsequent crystal(s) are chosen for power handling ability. Using this highly efficient singlepass concept, we generate 3.7 W of continuous-wave diffraction-limited 2 (1.25) M = light at 532 nm from 9.5 W of non-diffraction-limited 2 (7.7) M = light from a tapered laser diode, while avoiding significant thermal effects. Besides constituting the highest SH power yet achieved using a laser diode, this demonstrates that the concept successfully combines the high efficiency of the first stage with the good power handling properties of the subsequent stages. The concept is generally applicable and can be expanded with more stages to obtain even higher efficiency, and extends also to other combinations of nonlinear media suitable for other wavelengths.

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ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
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Efficient generation of 509 nm light by sum-frequency mixing between two tapered diode lasers

We demonstrate a concept for visible laser sources based on sum-frequency generation of beam combined tapered diode lasers. In this specific case, a 1.7 W sum-frequency generated green laser at 509 nm is obtained, by frequency adding of 6.17 W from a 978 nm tapered diode laser with 8.06 W from a 1063 nm tapered diode laser, inside a periodically poled MgO doped lithium niobate crystal. This corresponds to an optical to optical conversion efficiency of 12.1%. As an example of potential applications, the generated nearly diffraction-limited green light is used for pumping a Ti:sapphire laser, thus demonstrating good beam quality and power stability. The maximum output powers achieved when pumping the Ti:sapphire laser are 226 mW (CW) and 185 mW (mode-locked) at 1.7 W green pump power. The optical spectrum emitted by the mode-locked Ti:sapphire laser shows a spectral width of about 54 nm (FWHM), indicating less than 20 fs pulse width.
Diode lasers, Sum frequency generation, Tapered lasers, Visible lasers

Electronic versions:
Post_print_Optics_Communications339_2015_137140.pdf
Highly efficient single-pass sum frequency generation by cascaded nonlinear crystals

The cascading of nonlinear crystals has been established as a simple method to greatly increase the conversion efficiency of single-pass second-harmonic generation compared to a single-crystal scheme. Here, we show for the first time that the technique can be extended to sum frequency generation, despite differences in the phase relations of the involved fields. An unprecedented 5.5 W of continuous-wave diffraction-limited green light is generated from the single-pass sum frequency mixing of two diode lasers in two periodically poled nonlinear crystals (conversion efficiency 50%). The technique is generally applicable and can be applied to any combination of fundamental wavelengths and nonlinear crystals.
High-power non linear frequency converted laser diodes

We present different methods of generating light in the blue-green spectral range by nonlinear frequency conversion of tapered diode lasers achieving state-of-the-art power levels. In the blue spectral range, we show results using single-pass second harmonic generation (SHG) as well as cavity enhanced sum frequency generation (SFG) with watt-level output powers. SHG and SFG are also demonstrated in the green spectral range as a viable method to generate up to 4 W output power with high efficiency using different configurations.

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Organisations: Department of Photonics Engineering, Diode Lasers and LED Systems, Norlase ApS
Authors: Jensen, O. B. (Intern), Andersen, P. E. (Intern), Hansen, A. K. (Intern), Marti, D. (Intern), Skovgaard, P. M. W. (Intern), Petersen, P. M. (Intern)
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Compact green-diode-based lasers for biophotonic bioimaging
Diode lasers simultaneously offer tunability, high-power emission, and compact size at fairly low cost and are increasingly preferred for pumping titanium:sapphire lasers.

A high power directly diode pumped Ti:sapphire laser with synchronized Yb-fiber amplifier for nonlinear optical microscopy and optical coherence tomography
Efficient generation of 509 nm light by sum-frequency mixing between two tapered diode lasers

General information
State: Published
Organisations: Department of Photonics Engineering, Diode Lasers and LED Systems, Technical University of Denmark, Leibniz-Institut für Höchstfrequenztechnik
Authors: Tawfieq, M. (Ekstern), Jensen, O. B. (Intern), Hansen, A. K. (Intern), Sumf, B. (Ekstern), Andersen, P. E. (Intern)
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Generation of 3.5 W of diffraction-limited green light from SHG of a single tapered diode laser in a cascade of nonlinear crystals

Many applications, e.g., within biomedicine stand to benefit greatly from the development of diode laser-based multi-Watt efficient compact green laser sources. The low power of existing diode lasers in the green area (about 100 mW) means that the most promising approach remains nonlinear frequency conversion of infrared tapered diode lasers. Here, we describe the generation of 3.5 W of diffraction-limited green light from SHG of a single tapered diode laser, itself yielding 10 W at 1063 nm. This SHG is performed in single pass through a cascade of two PPMgO:LN crystals with re-focusing and dispersion compensating optics between the two nonlinear crystals. In the low-power limit, such a cascade of two crystals has the theoretical potential for generation of four times as much power as a single crystal without adding significantly to the complexity of the system. The experimentally achieved power of 3.5 W corresponds to a power enhancement greater than 2 compared to SHG in each of the crystals individually and is the highest visible output power generated by frequency conversion of a single diode laser. Such laser sources provide the necessary pump power for biophotonics applications, such as optical coherence tomography or multimodal imaging devices, e.g., FTCARS-OCT, based on a strongly pumped ultrafast Ti:Sapphire laser.

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Power Scaling of Nonlinear Frequency Converted Tapered Diode Lasers for Biophotonics

Diode lasers have proven to be versatile light sources for a wide range of applications. Nonlinear frequency conversion of high brightness diode lasers has recently resulted in visible light power levels in the watts range enabling an increasing number of applications within biophotonics. This review provides an overview of the developments within nonlinear frequency converted high power laser diodes in the visible spectral range. Single-pass nonlinear frequency doubling is presented as a nonsophisticated method to achieve watt-level output powers and possible routes to higher power and efficiency are included. Application examples within pumping of mode-locked Ti:sapphire lasers and implementation of such lasers in optical coherence tomography are presented showing the application potential of these lasers.

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BFI (2014): BFI-level 2
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Green, compact diode laser-based systems for biophotonics application

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Authors: Andersen, P. E. (Intern), Jensen, O. B. (Intern), Müller, A. (Intern), Sumpf, B. (Ekstern), Hansen, A. K. (Intern), Petersen, P. M. (Intern), Unterhuber, A. (Ekstern), Drexler, W. (Ekstern)
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Green, compact diode laser-based systems for biophotonics application

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Publication date: 2013

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

Projects:

High Power Frequency Converted Tapered Diode Lasers
Department of Photonics Engineering
Period: 01/07/2017 → 30/06/2020
Number of participants: 4
Phd Student: Jamal, Muhammad Tahir (Intern)
Supervisor: Andersen, Peter E. (Intern)
Hansen, Anders Kragh (Intern)
Main Supervisor: Jensen, Ole Bjarlin (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Marie Curie (EU-stipendium)
Project: PhD

Multimodal, Functional Bio-Photonic Imaging
Department of Photonics Engineering
Diode Lasers and LED Systems
Technical University of Munich
Medical University of Vienna
Eindhoven University of Technology
Ecole Polytechnique Federale de Lausanne (EPFL)
NKT Photonics A/S
Femtolasers Produktions GmbH
Philips Electronics Nederland B.V.
EKSPLA UAB
iThera Medical GmbH
Period: 01/10/2016 → 01/10/2020
Number of participants: 4
Acronym: FBI
Project ID: 721766
Multi-modal, Endoscopic Biophotonic Imaging of Bladder Cancer for Point-of-Care Diagnosis

Department of Photonics Engineering

Diode Lasers and LED Systems

Period: 01/01/2016 → 31/12/2020

Number of participants: 4

Acronym: MIB

Project participant:
Marti, Dominik (Intern)
Hansen, Anders Kragh (Intern)
Jensen, Ole Bjarlin (Intern)

Project Coordinator:
Andersen, Peter E. (Intern)

Relations

Press / Media items:
Innovative Treatment & Frontline Research: Dept. of Urology, Herlev & Gentofte University Hospital

Activities:

High power diode lasers converted to the visible

Period: 11 Oct 2017

Ole Bjarlin Jensen (Invited speaker)
Anders Kragh Hansen (Invited speaker)
Peter E. Andersen (Guest lecturer)
Mathias Christensen (Guest lecturer)
André Müller (Invited speaker)
Mahmoud Tawfiq (Invited speaker)
Bernd Sumpf (Invited speaker)
Paul Michael Petersen (Invited speaker)

Department of Photonics Engineering

Diode Lasers and LED Systems

Copenhagen Center for Health Technology

Description
Invited talk at the conference including 2 page abstract to be published in IEEE Xplore.
Degree of recognition: International

Related event

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11/10/2017 → 12/10/2017
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Activity: Talks and presentations › Conference presentations