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13-17 September 2021, Sapienza University of Roma- Engineering Faculty, Via Eudossiana, 18, 00184, Roma RM, Italy

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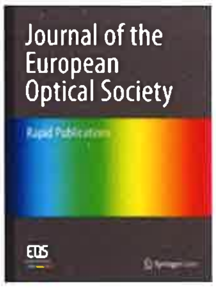

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DGaO Deutsche Gesellschaft für angewandte Optik

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ICO CIO International Commission for Optics
Commission Internationale d'Optique

Conference Agenda

Session

TOM13 S05: Ultrafast: Ultrafast MIR systems

Time: **Tuesday, 14/Sept/2021: 10:15 - 11:45**
Session Chair: **Oliver H. Heckl**, University of Vienna, Austria

Location: **Aula 1**
1st floor

Presentations

10:15 - 10:30
ID: 295 / **TOM13 S05: 1**
TOM 13 Ultrafast Optical Technologies and Applications

Efficient carrier-envelope phase tunable mid-infrared frequency combs based on CW-seeded optical parametric generation

Mikhail Roiz[1], Jui-Yu Lai[2], Juho Karhu[3], Markku Vainio[1,4]
[1]Department of Chemistry, University of Helsinki, FI-00560, Helsinki, Finland; [2]HC Photonics Corp. Hsinchu Science Park, Hsinchu 30078, Taiwan; [3]Metrology Research Institute, Aalto University, Espoo, FI-00076, Finland; [4]Photonics Laboratory, Physics Unit, Tampere University, Tampere, FI-33101, Finland

We present an efficient method for generating frequency combs in the mid-infrared (MIR) spectral range in bulk lithium niobate crystals as well as in waveguides. Our approach is simple and robust, since it is based on single-pass configuration of femtosecond Optical Parametric Generation (OPG) seeded by a telecom continuous-wave laser. Precise and fast tuning of the seed laser allows to rapidly change the offset frequency of the generated MIR comb independent of its repetition rate. The MIR comb's offset frequency is inherently known, so its direct detection is not required.

10:30 - 10:45
ID: 238 / **TOM13 S05: 2**
TOM 13 Ultrafast Optical Technologies and Applications

Mid-IR OPCPA operating in the atmospheric transparency window around 8.6 µm

Ignas Astrauskas[1], Claudia Gollner[1], Tobias Flöry[1], Andrius Baltuška[1,2], Audrius Pugžlys[1,2]
[1]Photonics Institute, TU Wien, Gusshausstrasse 27-387, A-1040 Vienna, Austria; [2]Center for Physical Sciences and Technology, Savanoriu Ave. 231, LT-02300, Vilnius, Lithuania

Generation of a pair of sub-mJ femtosecond pulses with arbitrary delay control in a single cw-pumped Yb regenerative amplifier is demonstrated. The two pulses drive separate optical parametric amplifiers producing seed for Ho:YAG chirped pulse amplifier and mid-IR optical parametric chirped pulse amplifier. As a result, broadband 40 µJ pulses are generated around 8.6 µm wavelength, which lies in the atmospheric transparency window.

10:45 - 11:15
Invited
ID: 454 / **TOM13 S05: 3**
TOM 13 Ultrafast Optical Technologies and Applications

Frequency divide-and-conquer approach to producing ultra-broadband mid-IR frequency combs and single-cycle pulses

Konstantin Vodopyanov
Univ. Cent. Florida, United States of America

A subharmonic (frequency-divide-by-2) optical parametric oscillator (OPO) is reported as an efficient frequency divider that rigorously both down converts and dramatically augments the spectrum of the pump laser, while maintaining its coherence. Our recent result is a demonstration of a subharmonic system with an unprecedented continuous wavelength span of 3–12 µm that covers most of the molecular ro-vibrational "signature" region. The OPO with a minimally dispersive cavity was pumped by a 2.35-µm Kerr-lens mode-locked oscillator and delivered 245 mW of the average power with the conversion efficiency exceeding 20%.

11:15 - 11:30
ID: 400 / **TOM13 S05: 4**
TOM 13 Ultrafast Optical Technologies and Applications

A µJ-level parametric source tunable from 3 to 10 µm by direct difference-frequency generation in LGS at 250 kHz

Vincent Femy, Maxim Neradovskiy, Thomas Pinoteau, José Villanueva, Olivier Albert, Nicolas Forget
FASTLITE, France

We demonstrate the direct generation, at a repetition of 250 kHz, of µJ-level, sub-160 fs pulses from 3 to 10 µm in a LiGaS2 (LGS) crystal pumped at 1030 nm.

11:30 - 11:45
ID: 283 / **TOM13 S05: 5**
TOM 13 Ultrafast Optical Technologies and Applications

Mid-infrared parametric wavelength conversion seeded with fiber optical parametric sources

Ronan A. Battle[1], Anita M. Chandran[1], Timothy H. Runcorn[1], Arnaud Mussot[2], Alexandre Kudlinski[2], Robert T. Murray[1], J. Roy Taylor[1]
[1]Femtosecond Optics Group, Department of Physics, Imperial College London, Prince Consort Road, London SW7 2BW, UK; [2]Université de Lille, CNRS, UMR 8523-PhLAM—Physique des Lasers Atomes et Molécules, F-59000 Lille, France

A new method of seeding $\chi 2$ optical parametric converters with $\chi 3$ fiber optical parametric sources is introduced. We demonstrate a tuneable mid-infrared (MIR) source around 3 µm with the technique and discuss the potential of this architecture.

Mid-IR OPCPA operating in the atmospheric transparency window around 8.6 µm

Ignas Astrauskas[1], *Claudia* Gollner[1], *Tobias* Flöry[1], *Andrius* Baltuška[1,2], and *Audrius* Pugžlys[1,2,*]

[1]Photonics Institute, TU Wien, Gusshausstrasse 27-387, A-1040 Vienna, Austria
[2]Center for Physical Sciences and Technology, Savanoriu Ave. 231, LT-02300, Vilnius, Lithuania

Abstract. Generation of a pair of sub-mJ femtosecond pulses with arbitrary delay control in a single cw-pumped Yb regenerative amplifier is demonstrated. The two pulses drive separate optical parametric amplifiers producing seed for Ho:YAG chirped pulse amplifier and mid-IR optical parametric chirped pulse amplifier. As a result, broadband 40 µJ pulses are generated around 8.6 µm wavelength, which lies in the atmospheric transparency window.

1 Introduction

Some applications, such as 2D spectroscopy [1] and pump-probe laser-flash shadowgraphy [2], require an availability of a pair of energetic pulses separated in time by hundreds of nanoseconds or even microseconds [3]. A production of such a pair of pulses is challenging since conventional opto-mechanical delay between two pulses cannot be realized because of non-realistic distances (100 ns time delay corresponds to an optical path length of 30 m). A common approach to realize such large delays is to use either Herriot cells [4] or two synchronized independent laser amplifiers [3] which increases system complexity and cost. In this paper we report on the generation of a pair of arbitrary delayed with respect to each other pulses, generated in a single regenerative amplifier (RA) operating in a dual-cycle cavity dumping mode. We achieve the same level of flexibility as in the case of two synchronized conventional RAs operating in the single cavity dumping-cycle mode.

2 Experimental setup and results

In our work we employ a pair of near-IR pulses as a frontend for mid-IR optical parametric chirped pulse amplifier (OPCPA) based on ZGP nonlinear optical crystal, which due to high conversion efficiency is a material of choice for many OP(CP)A systems operating in the mid-IR spectral range [5, 6]. Limited transparency of ZGP in the near-IR imposes a requirement for the pump laser to operate at wavelengths longer than 2 µm. The most developed ultrafast laser systems, which are operating above 2 µm, are based on Holmium-doped laser materials. However, common Holmium lasers generate longer than a few picosecond pulses, which are too long for supercontinuum generation and therefore white-light seeded mid-IR parametric amplification is challenging.

Here we propose a scheme where the seed for both mid-IR OPCPA and Ho:YAG CPA, which is acting as a pump for the mid-IR OPCPA, is generated in two optical parametric amplifiers (OPAs), pumped by 1.03 µm, 300 fs pulses originating from a commercial Yb:KGW laser system (Pharos, Light Conversion) (Figure 1a) However, simultaneous seeding of Ho:YAG CPA and the ZGP OPCPA is not straightforward since a 110 ns delay corresponding to the amplification time window in the Ho:YAG RA needs to be compensated. For solving the problem we developed an Yb:KGW CPA system with a double dumping of RA cavity, which generates a pair of delayed with respect to each other pulses.

A straightforward way to realize double pulse amplification in a RA is to switch the Pockels cell (PC) ON for the second amplification cycle immediately after the first amplified pulse is ejected, allowing amplification of another pulse. By varying the second opening time of the PC, one can control a delay between the two pulses. However since a single pass gain in the Ho:YAG RA is substantially higher than in the Yb:KGW RA, considerably fewer roundtrips in the Ho:YAG RA cavity are needed to complete amplification. This leads to a much shorter amplification time of 110 ns in the case of Ho:YAG as compared to Yb:KGW (∼350 ns), which makes the second amplification cycle in the Yb:KGW RA rather inefficient. Therefore, instead of injection of a fresh second oscillator pulse we perform only partial ejection of the already amplified pulse from the RA cavity. This leaves a controllable fraction of energy in

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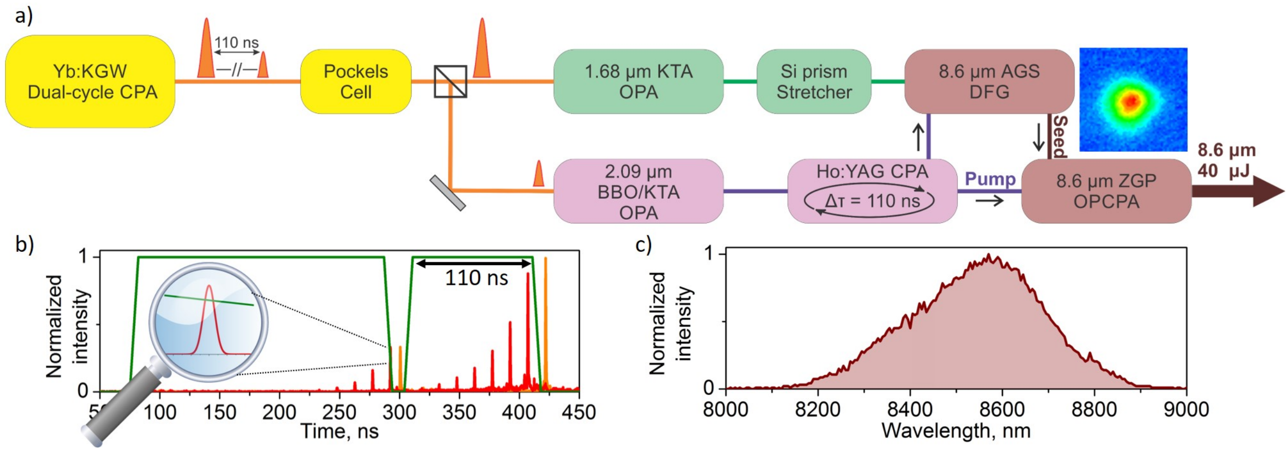

Figure 1. Generation of 8.6 µm pulses. a) Experimental setup. b) Operation of the PC (green) and resulting amplification trains (red) and output pulses (orange), when second pulse is produced and amplified by leaving small portion of the first pulse. c) Spectrum of mid-IR (8.6 µm) pulse generated during amplification in the mid IR ZGP OPCPA pumped by 2.09 µm pulses.

the RA cavity for further amplification (Figure 1b), which is completed in 110 ns. The partial ejection is performed by controlling the timing of PC switching. It has to be noted that pulses in the RA cavity are chirped, so slicing of the pulses could lead to a spectral modification. However, since the opening time of the PC is much longer (∼7 ns) than the chirped pulse duration (∼150 ps), only a marginal spectral transformation takes place.

5 kHz Yb:KGW CPA in a double pulse amplification regime produces a pair of pulses with energies of 20 µJ and 330 µJ, which are spatially separated by a PC operating at λ/2 voltage (Figure 1a) and drive two white-light (WL) seeded OPAs based on BBO and KTA nonlinear optical crystals. The first OPA operates at 2.09 µm corresponding to the maximum gain of Ho:YAG. The OPA delivers 2 µJ pulses, which after stretching in a chirped volume Bragg grating (CVBG) are amplified to 3 mJ energy in Ho:YAG RA. After the amplification, pulses are compressed in the same CVBG to ∼3.5 ps duration and further employed as a pump for mid-IR OPCPA [7].

Seed pulses for the mid-IR OPCPA are produced in a WL seeded KTA OPA pumped by the second (stronger) pulse from the pulse pair. Signal pulses of the OPA are tunable in the spectral range 1.45-1.8 µm, which on the short and long wavelength sides is limited by the phase-matching of KTA crystal and the edge of the WL spectrum generated in YAG crystal, respectively. In order to match the duration of 2.09-µm pulses, the generated 1.68 µm signal pulses were slightly stretched in a pair of silicon prisms.

To provide synchronous arrival of the pump and seed pulses into the mid-IR OPCPA, the second cavity dumping time of the Yb:KGW RA is adjusted to the cavity dumping of the Ho:YAG RA. A fine synchronization of the pump and seed pulses in the OPCPA is realized with an opto-mechanical delay line. 8.6-µm seed for the mid-IR OPCPA, operating in the atmospheric transparency window, was produced by generating difference frequency between the signal pulses (1.68 µm) and Ho:YAG laser output (2.09 µm) in a Type II, 5mm long AGS crystal. In order to prevent the appearance of an angular chirp in the generated 8.6 µm beam, the seed and pump pulses are directed to the AGS crystal strictly collinearly. 8.6-µm pulses are further amplified to the level of 40 µJ (200 mW of average power) in two parametric amplification stages based on a Type I, 2 mm long ZGP crystals non-collinearly pumped by Ho:YAG CPA output. Generated spectrum spans from 8.2 µm to 8.9 µm (Figure 1c) and supports 310 fs pulse duration, what corresponds to 11 optical cycles at this wavelength.

References

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