Instantaneous Spectral Span of 2.85 - 8.40 µm Achieved in a Cr:ZnS Laser Pumped Subharmonic GaAs OPO

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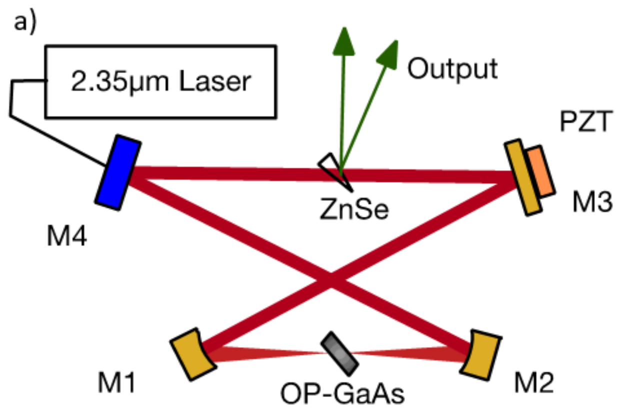
Abstract: We report a broadband mid-IR output reaching >1.5 octaves at -30dB level from a subharmonic orientation-patterned GaAs OPO pumped by an ultrafast (62-fs) Kerr-lens mode-locked Cr:ZnS laser at 2.35 µm with 800-mW average power.

OCIS codes: (190.4975) Parametric processes; (190.4410) Nonlinear optics, parametric processes

1. Introduction

Degenerate (subharmonic) optical parametric oscillators (OPO) show great promise for the generation of broadband mid-infrared (MIR) frequency combs. Their main features are low pump threshold, dramatic extension of the spectrum of the pump laser, and phase locking to the pump frequency comb [1]. Ultrafast Cr:ZnS and Cr:ZnSe lasers operating in the range of 2.3-2.5 µm [2] are well-suited for pumping GaAs-based subharmonic OPOs and potentially allow achieving >2 octave-wide frequency combs, thanks to the low group dispersion of GaAs in this range. In 2015, broad bandwidth spectrum spanning 3.6-5.6 µm (-50dB) was demonstrated in an orientation-patterned GaAs (OP-GaAs) based subharmonic OPO pumped by Cr:ZnS femtosecond laser [3]. But in that experiment, to get suitable wavelength to match the OP-GaAs period, the Cr:ZnS laser was forced to work in a non-preferable regime. In this experiment, we took the full advantage of the 800-mW femtosecond Cr:ZnS and get much broader instantaneous spectrum spanning from 2.85-8.4 µm (-30dB). This broad spectrum having 2320 cm^{-1} -wide instantaneous span, overlaps with a plethora of fundamental molecular IR resonances and can be used for frequency comb spectroscopic detection applied to such fields as remote sensing, fast combustion dynamics analysis and medical diagnostics, to name a few.



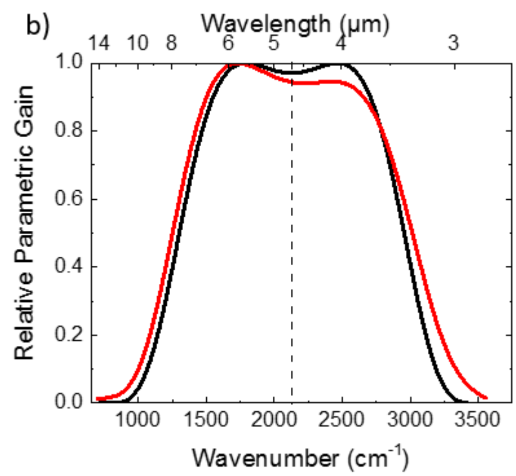


Fig. 1 (a) The experimental setup of the 2.35-µm Cr:ZnS laser pumped OP-GaAs OPO. M1 and M2 are parabolic gold-coated mirrors, M3 is flat gold-coated mirror, and M4 is the dielectric incoupling mirror. The ZnSe wedge was used for dispersion compensation and outcoupling the signal/idler wave. PZT is the piezo attached to the mirror for fine-tuning the cavity length. (b) The relative parametric gain for 0.5-mm thick 88-µm QPM period OP-GaAs. The black curve corresponds to a monochromatic 2.35 µm pump, while the red curve takes into account the real spectrum of the fs pump pulse.

2. Experiment Setup

The ring-cavity OP-GaAs based OPO was synchronously pumped by a free running Kerr lens mode locked 2.35 µm Cr^{2+}:ZnS laser, with 62-fs time-bandwidth limited pulse duration, 800-mW average power, and 79 MHz repetition rate. The OPO cavity (Fig. 1(a)) was composed of two gold-coated parabolic mirrors (M1 and M2) with 30° off axis angle and 30 mm apex radius, five flat gold-coated mirrors (for simplicity only M3 was shown in the setup figure, the other four gold mirrors were just used for folding the cavity), and a dielectric mirror M4 (YAG substitute) with high reflection (>95%) for 3-7 µm (the OPO subharmonic band) and high transmission (>85%) for the 2.35-µm pump. A 0.3-mm-thick ZnSe wedge was used inside the cavity to minimize group velocity dispersion and for outcoupling the signal/idler wave. The 0.5-mm-long GaAs was made at BAE Systems by a combination of molecular-beam and hydride vapor phase epitaxy. The GaAs was placed at Brewster's angle and its quasi-phase-matching (QPM) period of GaAs was 88 µm, designed to get the broadest parametric gain at OPO degeneracy. All polarizations were along the <111> direction of the GaAs crystal to harness the material's maximum nonlinear coefficient. The normalized parametric gain of the 0.5-mm OP-GaAs was calculated for (i) monochromatic 2.35-µm pump and (ii) broadband pump (FWHM 90 nm), corresponding to our experiment, and is shown in Fig. 1b. The calculated FWHM gain bandwidth was from 3.3 to 8 µm.

3. Results

The OPO operates at several discrete cavity lengths when the piezo actuator detunes the cavity. When going from longer to shorter cavity, the output spectrum varies gradually (Fig. 2(a)). The second peak from top yields an extremely broad spectrum extending from 1190 to 3500 cm^{-1} (2.85 - 8.40 µm) at 30 dB, more than 1.5 octaves in the frequency band. The usual (1D) spectrum corresponding to this peak is shown in Fig. 2b. The dashed line here is the extra phase accumulated per cavity round trip (the estimated tolerance is ± 0.5 rad). The reflectivity of the dielectric in-coupling mirror is also shown in Fig. 2(b). The reflectivity decreases beyond 7 µm and has several low reflection dips below 3.3 µm. These features fit well the OPO output spectrum. We believe the reflectivity of the dielectric mirror is the main limitation for obtaining an even broader spectrum.

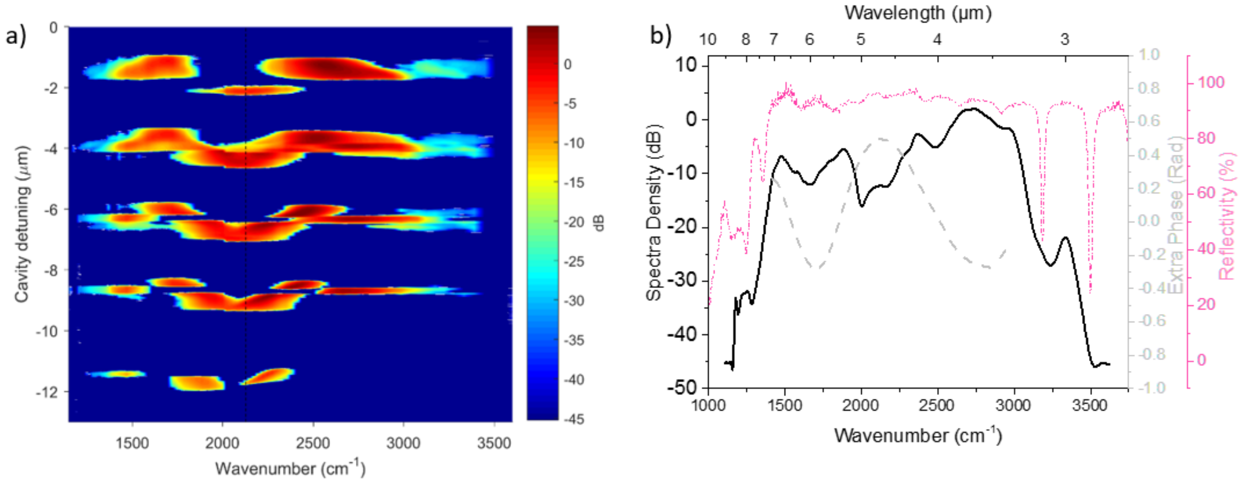


Fig. 2 (a) The 2D spectra measured by detuning the cavity length in steps, corresponding to integer of the pump wavelength (2.35 µm). The dashed line indicates the degenerate frequency 2127 cm^{-1} (4.7 µm). (b) Black curve: 1D spectrum corresponding to the second peak in the 2D spectrum. Dashed gray: the computed cavity extra phase accumulated per round trip. Dotted pink: reflectivity of the dielectric incoupling mirror.

4. Conclusion

We demonstrate a subharmonic OPO with an instantaneous spectral span of 2.85 - 8.40 µm that can serve as the basis for fully stabilized frequency comb in the mid-IR molecular 'fingerprint' region. The 1.56-octave-wide spectrum can be further broadened by fabricating an incoupling dielectric mirror with (i) broader reflectivity range and (ii) with compensation of the residual group velocity dispersion.

References

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