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High-power ultrafast pulsed 2060 nm laser from a self-phase-locked doubly resonant optical parametric oscillator

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In the domain of spectroscopy, harmonic generation, or medical and eye-safe remote sensing, femtosecond pulses in the 2-µm spectral region are essential [1]. While there are multiple methods to produce ultrashort 2-µm pulses, nonlinear processes offer advantages for achieving shorter pulse durations and higher peak power compared with direct laser-emitting methods. Among these, the synchronously pumped degenerate OPO stands out due to its wide parametric gain bandwidth, enabling broadband output aligned with the pump laser's characteristics. Moreover, the intrinsic phase-locking of the OPO output to the pump source at the cavity locking state facilitates the generation of an ideal two-colour optical waveshape, ideal for generating light at very low (THz) frequencies through photoionization dynamics, such as in semiconductors [2]. In our experiment, we synchronously pump the DROPO by a home-built Yb based Kerr-lens mode-locked thin-disk laser, emitting pulses at a wavelength of 1030 nm with a pulse duration of 270 fs, 20 W output power and 33 MHz repetition rate.

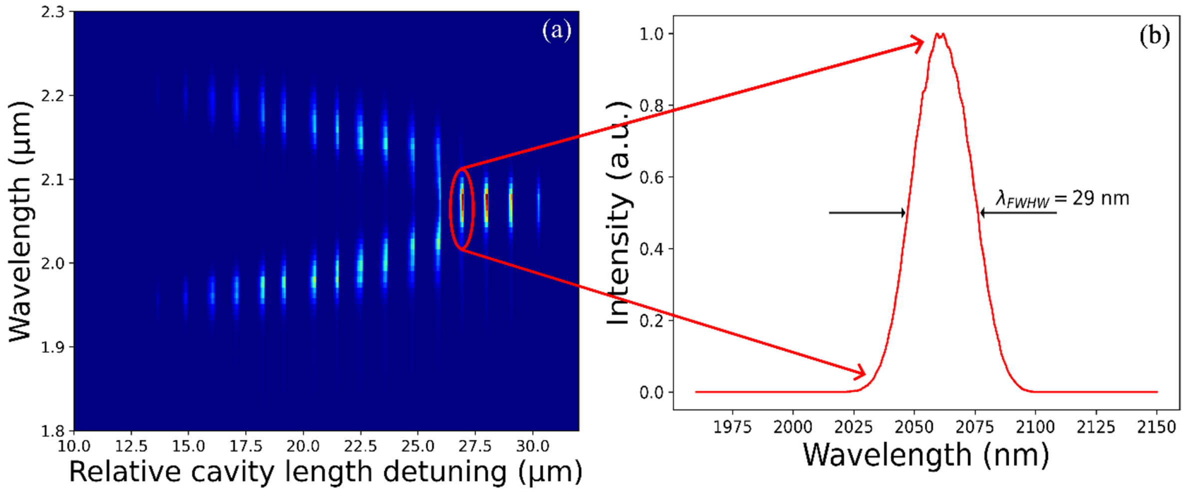

Fig. 1. (a) DROPO spectra in dependence of the cavity length. (b) Spectrum of the degenerate output.

Fig. 1 displays the typical interrupted tuning behaviour of a DROPO. As shown in [3], the spectral tuning characteristics are strongly dependent of the second and third order intracavity dispersion. The spectrum in dependence on the cavity length is shown in Fig. 1(a) with nearly zero group delay dispersion and high third-order intracavity dispersion. Within the spectrum, the degenerate area is clearly distinct from the non-degenerate operation, which is beneficial for the active phase-locking. Fig. 1(b) shows the spectrum at the degeneracy point at 2060 nm with a bandwidth of 29 nm.

By using a side-of-fringe dither free locking scheme [4] which utilizes monitoring of a parasitic sum-frequency mixing of signal and pump in the gain crystal, we stabilized our DROPO on the first degeneracy fringe as shown in Fig. 1. A stable output power of 4.9 W was achieved with a pump power of 18.7 W, which results in a conversion efficiency of 26%.

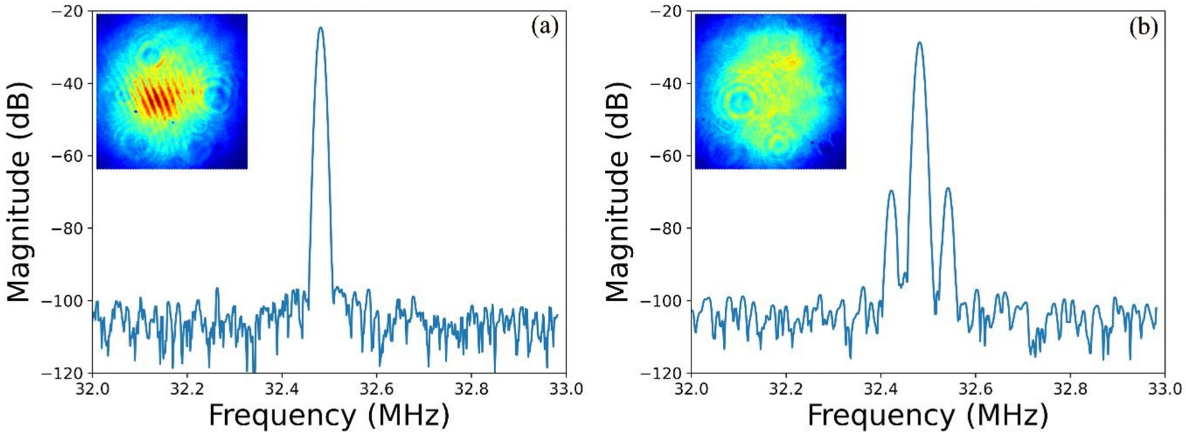

Fig. 2. Radio frequency spectra of DROPO output in (a) degenerate and (b) non-degenerate state. The insets show spatial fringes patterns observed in both cases.

To verify the locking of the phase between the pump and the output, we implemented f-2f interferometry to demonstrate the phase coherence. The stabilized DROPO output was frequency doubled by a BBO crystal with a phase-matching angle of 21.3° and then overlapped with the original 1030 nm pump beam spatially and temporally with a time delay line and a 50:50 beam-splitter. The spatial interference pattern of the two beams is recorded by a CCD camera which is shown in the inset of Fig. 2. In stabilized operation, a stable fringe pattern could be observed on the CCD camera, proving the phase lock between the pump and the OPO. After the cavity was detuned away from degeneracy, the spatial interference pattern disappeared. For further verification of the phase-lock, a radio frequency (RF) measurement of the DROPO output was performed. The RF traces for the non-degenerate and degenerate cases are both shown in the Fig.2. We can observe satellite peaks on two sides, with the fundamental peak of 32.5 MHz during non-degenerate operation. When the DROPO cavity was adjusted and stabilized to degeneracy, the satellite peaks vanished and only a single peak oscillating frequency exists as shown in Fig. 2(a).

In summary, we have demonstrated a high-power stable degenerate DROPO system at 2060 nm. The inherent phase-locking between the DROPO degeneracy output and its pump enables the resulting two-colour laser waveshape to be utilized for strong-fields applications, such as THz generation via the Brunel mechanism.

References

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