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1.3 W, super-octave-spanning Pulses at 2.3 µm from a Cr:ZnS Amplifier

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Abstract: We investigate spectral broadening in TiO_2 seeded by > 2 W, $\tau_{0.5}$ = 26 fs, 23 MHz pulses from a Cr:ZnS amplifier. We generate pulses covering spectrum from 1.1 to 3.2 µm at the -20-dB level at 1.3 W.

1. Introduction

Kerr-lens mode-locked Cr:ZnS oscillators and amplifiers have emerged as new sources providing broadband femtosecond pulses in the 2-3 µm range [1]. The direct output of a 23-MHz Cr:ZnS oscillator could recently be efficiently broadened in a single TiO_2 plate and compressed to ~ 7 fs, corresponding to a single cycle of the electric field oscillation at 2.2 µm [2]. The infrared single-cycle pulses can be carrier-envelope-phase stabilized with exceptional stability [2] and converted with > 10 % efficiency into controllable, multi-octave-spanning mid-infrared (MIR) pulses [3]. With their broad bandwidth and single-cycle duration, this new class of infrared laser sources is promising as drivers for field-resolved infrared spectroscopy (FRS) [4] and light-wave driven electronics [5].

Despite their performance, the power of the broadened output, generated directly from the Cr:ZnS oscillators, is limited to the several-hundred milli-Watt regime. On the other hand, the signal/noise and sensitivity in FRS scales favorably with the available MIR and gate-pulse powers, and many strong-field experiments will require higher peak intensities. In this contribution, we therefore explore supercontinuum generation in TiO_2 with the > 2 W output from a single-pass Cr:ZnS amplifier. We demonstrate the generation of super-octave-spanning pulses covering the spectral range 1.1-3.2 µm at 23 MHz repetition rate and 1.3 W of average power. Our experimental results are complemented by nonlinear-optical simulations of pulse propagation in TiO_2.

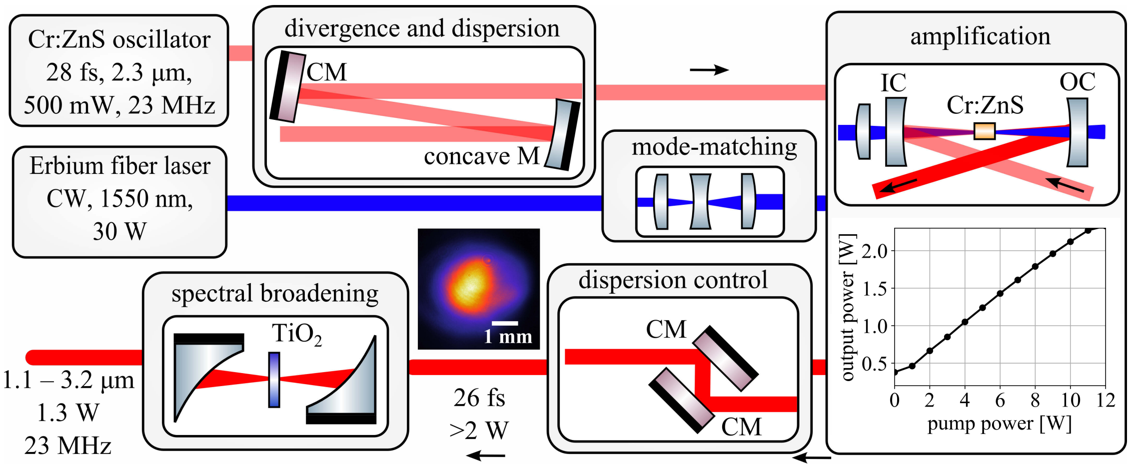

Fig. 1. Schematic of the single-pass amplifier followed by broadening in TiO_2. The amplifier is seeded by a Cr:ZnS oscillator whose divergence is controlled by a concave reflective mirror with f = 2000 mm while the dispersion is controlled using chirped mirrors. The amplifier is based on a 9 mm long thermal diffusion-doped Cr:ZnS crystal and is pumped by an erbium-doped fiber laser. The spatial mode and divergence of the pump laser are tuned to match the seed beam. The amplifier output pulses (P_{av} > 2 W) are recompressed using chirped mirrors to 26 fs and used as an input for broadening in a 0.5 mm thick TiO_2 plate, resulting in the generation of a super-octave spanning spectrum.

2. Fiber-pumped single-pass amplification

The amplifier setup is presented in Fig 1. The amplifier is seeded by 23 MHz, 2.3 µm, 22 nJ, 28 fs output pulses from a Kerr-lens mode locked Cr:ZnS oscillator. An erbium-doped continuous-wave fiber laser emitting up to 30 W of power at 1550 nm serves as a pump source. Both laser beams are focused and collinearly overlapped in a 9-mm-long Cr:ZnS crystal in a single-pass. Mode-matching of both laser beams in the amplifier crystal is achieved by introducing a variable-zoom telescope in the pump beam. The dispersion of the seed pulses is tuned such that spectral narrowing inside the amplifier crystal due to self-phase modulation is avoided and slight spectral broadening is observed. We limited the pump power to ~10 W to avoid thermal lensing and maintain an optimum output beam profile. The typical gain factor for the amplifier at P_{pump} = 10 W is ~5, with an output power of 2.12 W. The output pulses of the amplifier are recompressed to $\tau_{0.5}$ ~ 26 fs (Fig. 2 **a** and **b**) using 3 bounces of chirped mirrors with negative GDD, compensating the ZnS dispersion.

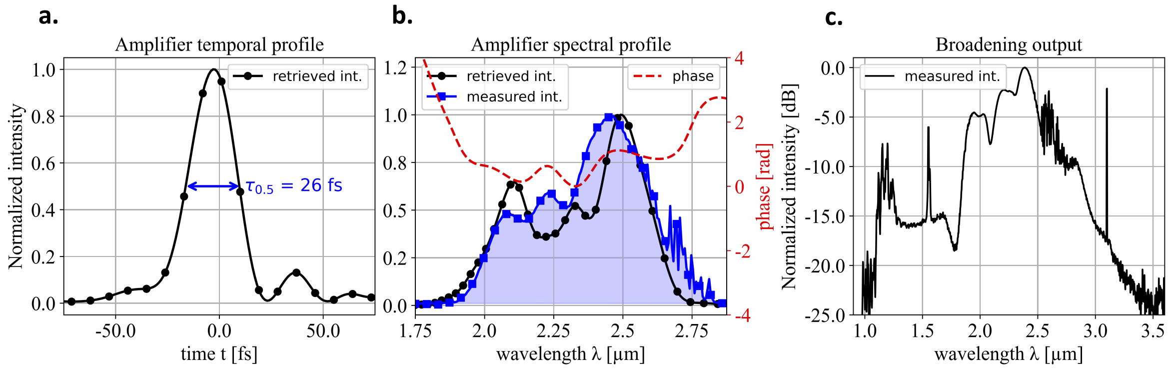

Fig. 2. **a.** Temporal profile of the amplifier output at 8W of pump power. The pulse duration was measured using SHG-FROG using a $LiIO_3$ crystal; **b.** Retrieved and measured spectrum together with the retrieved spectral phase; **c.** Spectrally broadened output in TiO_2, seeded by the amplifier output. Pump leakage leads to the spike at 1.55 µm, replicated as an artefact at 3.1 µm; SHG generation from the amplifier crystal peaks around 1.15 µm and overlaps with the blue edge of the broadened output from TiO_2.

3. Spectral broadening and compression

Using a 90º off-axis parabolic mirror (f = 25 mm), the amplifier output is focused onto a 0.5-mm-thick TiO_2 crystal (001-cut and AR coated). At high intensities, light-matter interaction is governed by an interplay between multiple linear and nonlinear effects. The pulsed beam experiences self-focusing, self-phase modulation, multi-photon absorption induced plasma generation and defocusing, together with material dispersion. As previously demonstrated and numerically simulated [2], a balance of these effects can result in a supercontinuum-like broadening. In our experiment, we generate super-octave-spanning pulses (Fig. 2 **c**) with spectral components ranging from 1.1 to 3.2 µm at the -20-dB level with 1.3 W of average power. The loss in the crystal (up to 1 W) and spectral bandwidth is consistent with numerical simulations (Lightwave explorer [6]). Despite the nonlinear losses, the output is stable without deterioration. Estimated from Fourier-transform limit, the broadened output supports sub < 10 fs pulse duration.

4. Conclusions

We have shown the possibility of generating super-octave bandwidth optical pulses in TiO_2 seeded by the multi-Watt level output from a single-pass Cr:ZnS amplifier. Extreme spectral broadening and stable output despite considerable nonlinear losses makes TiO_2 a promising candidate for future power scaling of sub-10 fs laser pulses. Further results on the broadening efficiency optimization and pulse compression will be presented at the conference.

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