All normal dispersion erbium-doped fiber oscillator with tunable intracavity phase modulation

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Abstract：Tunable intracavity phase modulation is applied to an all normal dispersion fiber oscillator to suppress wave-breaking and increase the pulse energy. Spectral broadening beyond 1200-2000 nm is achieved by 15-m-long high nonlinear fiber.

1. Introduction

All normal dispersion (ANDi) fiber oscillators can support higher pulse energy without wave-breaking for the greatly stretched pulse duration will incur smaller nonlinear phase per round trip [1]. In the presence of large linear chirp due to the strong group delay dispersion (GDD), the temporal pulse shape will mimic the power spectrum. As a result, an intracavity spectral filter will suppress the pulse wings in the time domain, behaving like an effective saturable absorber. We previously demonstrated a wavelength- and bandwidth-tunable ANDi fiber oscillator with 3.8 nJ output pulse energy, where an intracavity Fourier transform (FT) pulse shaper with a pair of blades placed on the focal plane was used for tunable spectral amplitude modulation [2]. In this contribution, a liquid crystal modulator (LCM) array is added to increase the intracavity GDD without incurring extra nonlinear phase. The even stretched pulse duration allows for higher pulse energy up to 8.9 nJ (limited by our pump current). Spectral broadening beyond 1200-2000 nm, supporting a transform-limited (TL) pulse width (FWHM) of 12.9 fs, is achieved by coupling the output pulse into a 15-m-long high nonlinear fiber (HNLF). Nano-joule pulses delivered by a compact and economic fiber oscillator will be attractive in pumping optical parametric oscillator (OPO) to get mid-infrared femtosecond pulses [3-4].

2. Experiments

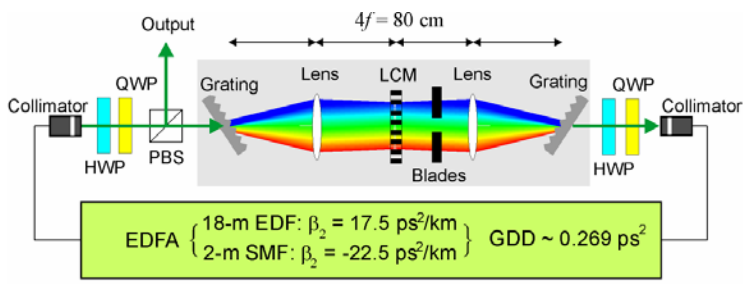

Fig. 1. Experimental setup of the ANDi Er-fiber laser: QWP: quarter waveplate; HWP: half waveplate; PBS: polarization beam splitter. SMF: Single-mode fiber.

The setup of our ANDi fiber oscillator is shown in Fig. 1. An erbium-doped fiber amplifier (EDFA, GIP Tech) consists of 18-m-long EDF and 2-m-long SMF (for connection only) with β_2=17.47 ps^2/km and -22.5 ps^2/km, respectively; contributing to a net cavity GDD of ~0.269 ps^2. An LCM array and two blades are placed on and after the focal plane of a transmission-type FT pulse shaper to modulate the spectral phase and amplitude, respectively. The filled circle in Fig. 2

represents the marginal mode-locking condition (near wave-breaking) in the absence of phase modulation. By adding a GDD of 0.0243 ps^2, the rms bandwidth drops from 22 nm to 19.3 nm (away from wave-breaking). In this case, the pump current (output pulse energy) can increase up to 550 mA (8.9 nJ) without wave-breaking (open circles). At 585-mA pump current and 0.0243-ps^2 extra GDD, the rms bandwidth can be lowered from 23.5 nm back to 19.3 nm by increasing the extra GDD to 0.069 ps^2. This will enable even higher pulse energy if more pump budget is available.

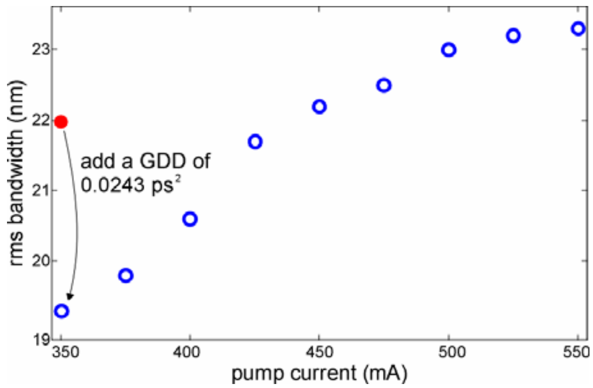

Fig. 2. The root-mean-square (rms) bandwidth of the mode-locked spectrum versus the pump current before (filled circle) and after (open circles) adding a fixed GDD of 0.0243 ps^2 by LCM array.

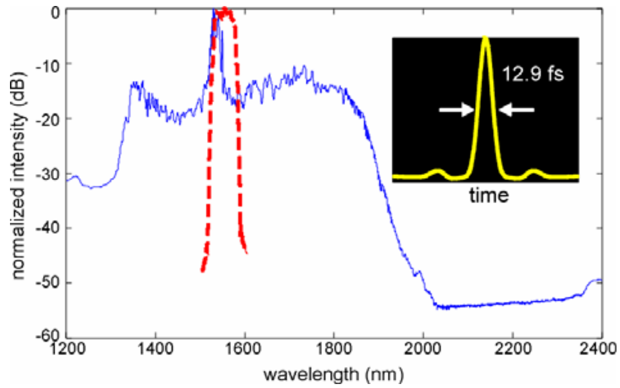

Fig. 3. The power spectra before (dashed) and after (solid) passing through a 15-m-long HNLF. Inset: The temporal intensity profile of a TL pulse with broadened power spectrum.

The output pulses from the ANDi fiber oscillator are roughly dechirped by using a 8-m-long SMF, then passing through a 15-m-long HNLF for spectral broadening. Fig. 3 shows the power spectra before (dashed) and after (solid) the HNLF measured by an optical spectrum analyzer (OSA, Yogogawa, AQ6375). The -30 dB bandwidth increases from 67 nm to 600 nm, supporting a TL pulse (inset) of 12.9 fs duration (FWHM). The blue side of the broadened spectrum is artificially truncated at 1200 nm by the OSA. Wavelengths longer than 1.8 μm could be strongly attenuated by the infrared absorption of the fiber. The abnormal spectral pedestal around 2010-2400 nm could arise from the fake signal of the OSA.

3. Conclusions

We have experimentally demonstrated that the output pulse energy of an ANDi fiber oscillator can be enhanced by introducing intracavity phase modulation. Ultrabroad spectrum extending beyond 1200-2000 nm is obtained by passing the oscillator pulse through a HNLF. We are working on compression and measurement of the ultra-broadband pulses [5,6]. This work was supported by the National Science Council in Taiwan under grants NSC 100-2221-E-007-093-MY3, 99-2120-M-007-010, and by the National Tsing Hua University under grant 101N2081E1.

4. References

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