Generation of 17 fs pulses from a Mamyshev oscillator with intra-cavity photonic crystal fiber

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Abstract: A few cycle pulses (~5 cycles) with broad spectrum (~400 nm) are generated from a Mamyshev oscillator. Such a broad spectrum can be stabilized in the cavity by a self-similar attractor in the gain fiber.

OCIS code: (140.3510) Lasers, fiber; (140.4050) Mode-locked lasers

1. Introduction

Few-cycle pulses have applications such as frequency metrology, high harmonic generation, and attosecond science. However, the pulses from mode-locked fiber lasers are still much longer than those from its solid-state counterparts [1]. So far, dispersion managed soliton fiber lasers have generated sub 30 fs pulses [2]. The main obstacle is the limited gain bandwidth (BW) of the gain fiber which restricts a very broad spectrum in a mode-locked fiber laser. To overcome the limit, a strong intracavity nonlinear attractor becomes useful. A self-similar evolution in the gain fiber followed by a strong spectral broadening can stabilize a very broad spectrum (~200 nm with 21 fs) in the fiber cavity [3]. To enhance the mode-locked spectral BW, high peak power intracavity pulses are desired. Therefore, a Mamyshev oscillator with a noticeable performance (50 nJ, 40 fs) is a good candidate to generate ultrabroad spectra [4]. By inserting a high nonlinear photonic crystal fiber (PCF) in a Mamyshev oscillator, we successfully mode-locked the oscillator to reach ~400 nm wide spectrum with a 17 fs dechirped pulse duration. To our best knowledge, this is the broadest spectrum generated directly from a mode-locked fiber laser with the shortest dechirped pulse duration.

2. Numerical and experiment results

The experimental setup of the oscillator is shown in Fig. 1. The two pump combiners couple 976 nm pump into the 3.1 m Yb-doped double cladding fibers which are followed by 0.7 m of single mode fibers (SMF). Two quarter waveplates (QWP), a half waveplate (HWP) and a polarizing beam splitter (PBS) act as an artificial saturable absorber to start the mode-locking without a seed. Two 600 /mm gratings with collimators compose 4 nm bandwidth Gaussian spectral filters centered at ~1040 nm and ~1050 nm wavelength while center wavelength of the gain lies around 1045 nm. Two HWPs after the isolators adjust the polarization to maximize the efficiency of diffraction gratings. The dispersion delay line of a 1200 /mm grating pair has been set to enhance the peak power before a ~45 cm highly nonlinear photonic crystal fiber (PCF).

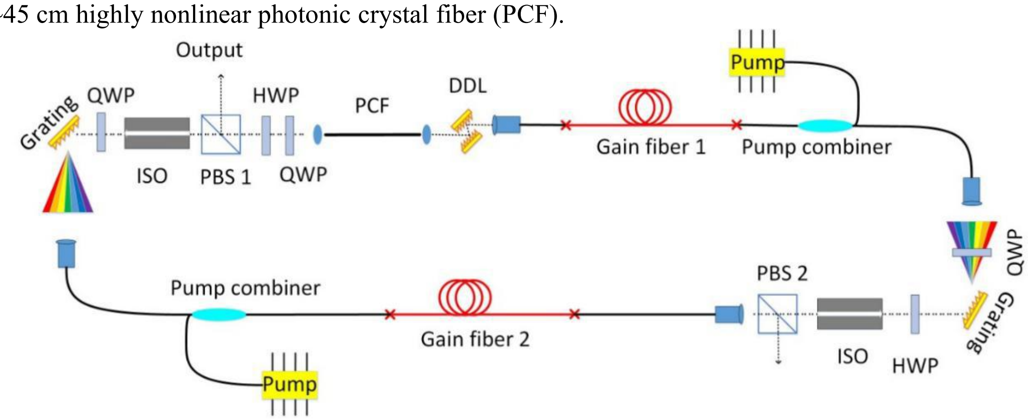

Fig. 1. Experimental set up. PBS: polarizing beam splitter. HWP: half wave plate. QWP: quarter wave plate. DDL: dispersion delay line, PCF: photonic crystal fiber. ISO: isolator.

To understand the pulse evolution in the oscillator, we performed numerical simulations by the standard split-step Fourier method including Kerr nonlinearity, Raman scattering, and second- and third-order dispersion. Fig.2(a) shows the evolution of the pulse duration and the spectral BW in the cavity. The pulse duration continues to grow inside the gain fiber. The spectral BW also grows due to the self-similar evolution in the gain fiber. After the gain fiber, the grating pair quickly cuts down the pulse duration before the pulse enters the PCF. The spectrum broadens significantly in the PCF, but a narrow spectral filter cuts down the BW significantly. However, the narrow spectrum grows again self-similarly in the gain fiber to stabilize such dramatic perturbations in the fiber laser cavity. Fig.2(b) shows the output pulse which is chirped. Fig.2(c) shows the mode-locked spectrum (~400 nm at -20 dB level).

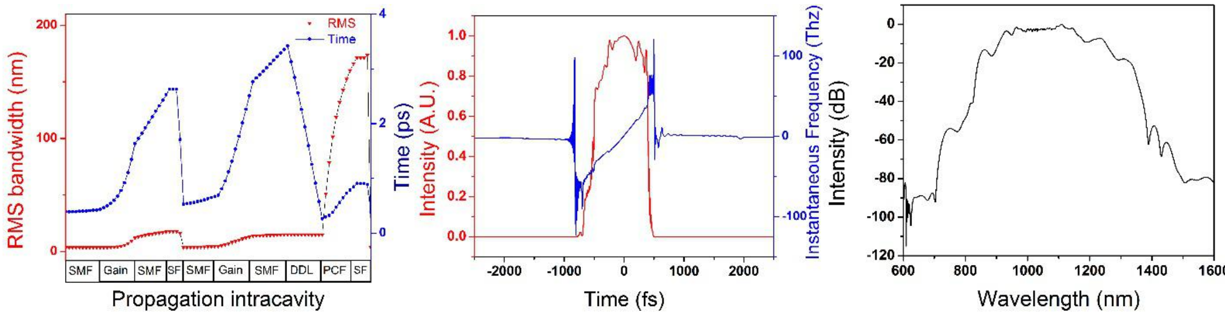

Fig. 2. a) Evolution of pulse duration and spectral BW through the cavity. b) Simulated output pulse. c) Simulated spectrum

Experimental results are shown in Fig.3. Fig.3(a) shows the output spectrum after the PCF. 394 nm BW at -20 dB level matches with the simulation result. The output pulse energy is 3.5 nJ at 17.5 MHz repetition rate. After dechirped by a 300 /mm grating pair, 17 fs (5-cycles) pulses are obtained. It is remarkable that the self-similar evolution in the gain fiber can stabilize such broad intracavity spectrum. Some pedestals are observed in the pulse owing to higher order phase accumulation. The transform limited pulse calculated by the output spectrum indicates even shorter pulses (~9 fs) may be possible with a better dechirping technique such as a multiphoton intrapulse interference phase scans (MIIPS).

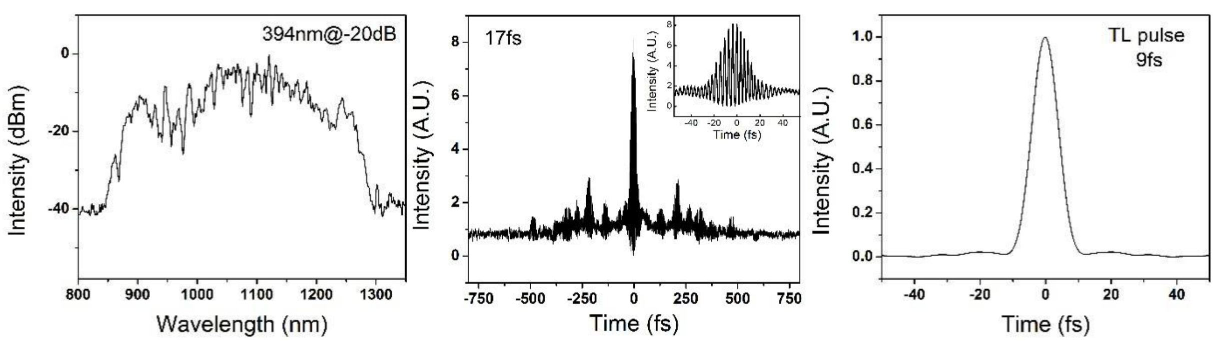

Fig. 3. Experimental observed (a) Spectrum and (b) Dechirped autocorrelation. (c) Calculated transform limited pulse.

4. Conclusion

We have numerically and experimentally investigated a Mamyshev oscillator with an intracavity highly nonlinear PCF. A ~400 nm BW with 17 fs dechirped pulses was generated stably owing to a self-similar evolution in the cavity. To our best knowledge, this is the broadest spectrum generated directly from a mode-locked fiber laser.

5. Acknowledgement

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6. References

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