Complex Swift Hohenberg Equation (CSHE) Dissipative Soliton Fiber Laser

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Abstract: We report dissipative solitons of CSHE in a mode-locked fiber laser by employing a unique fiber filter which produces a fourth order spectral response. The laser generates moving, asymmetric pulses with a highly asymmetric spectrum.

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

1. Introduction

Passively mode-locked lasers with fast saturable absorbers can be easily modeled by Cubic Quintic Ginzberg Landau equation (CQGLE) [1]. In this model, the spectral filter transmission equation contains only a second order term which leads to a single maximum spectral response. But in reality, gain spectrum is wide and can exhibit several maxima and therefore, it is desirable to include higher order spectral filter response. The addition of a fourth-order spectral filter term in the CQGLE, converts it into the CSHE. Soto-Crespo *et al.* used such a filter in numerical simulations and found various soliton solutions of CSHE [2]. Latas reported high energy soliton solutions of CSHE in both normal and anomalous dispersion regime numerically [3]. Zhao *et al.* numerically simulated a mode-locked fiber laser with a fourth order spectral filter to obtain dissipative soliton resonance pulses [4]. Despite extensive numerical simulations, very few experiments [5,6] have been performed for observing dissipative solitons of CSHE fiber laser. A spectral filter with a fourth order transmission which is very important to realize solutions of CSHE experimentally, is not readily available. We have reported a birefringent fiber-based bandwidth tunable spectral filter which can produce various transmission profiles [7]. Here, we have used the same spectral filter along with a bandpass filter (BPF) to create a higher order spectral filter response. It is then used in an ytterbium (Yb) laser cavity and a stable mode-locking state is achieved. These pulses are believed to be the moving pulse solutions of the CSHE as they depict asymmetric temporal profile as well as highly asymmetric spectrum [2]. To the best of our knowledge, this is the first demonstration of CSHE dissipative soliton fiber laser thus a first step in studying effects of higher order spectral filtering in mode-locked fiber lasers.

2. Numerical and experimental results

The schematic of the fiber laser is shown in Fig. 1. A 55 cm Yb gain fiber is pumped by a 976 nm pump through a wavelength division multiplexer (WDM). The gain is followed by 1m of single mode fiber (SMF). Polarization controller (PC1), a half waveplate (HWP), a quarter waveplate (QWP), and a polarizing beam splitter (PBS) act as an artificial saturable absorber to initiate mode-locking. An isolator maintains unidirectional operation of the laser. A dual filter in the form of a birefringent fiber-based tunable bandwidth spectral filter and a 10 nm full width half maximum BPF easily produces a fourth order spectral response. An 80/20 fused coupler is used to verify this spectral response by operating the laser below lasing threshold and carefully tuning PC2 and PC3.

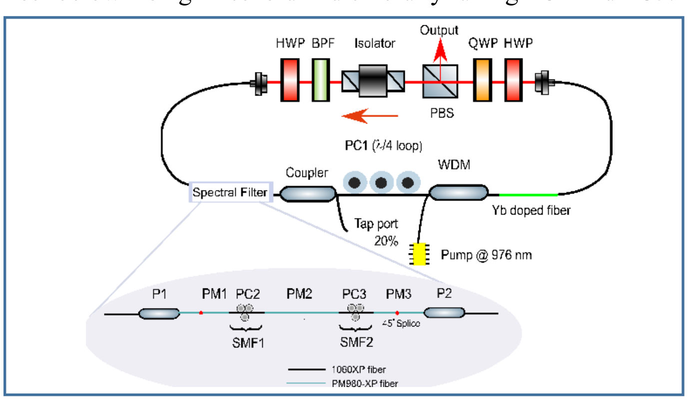

Fig. 1. Experimental set up. PBS: polarizing beam splitter. HWP: half wave plate. QWP: quarter wave plate. WDM: wavelength division multiplexer, SMF: single mode fiber, PM: polarization maintaining fiber, PC: polarization controller, BPF: bandpass filter

To understand the pulse evolution in the laser, we performed numerical simulations using the standard split-step Fourier method. The simulation includes a fourth order spectral filter with transmission $T(\omega) = e^{(\delta-\beta\omega^2+\gamma\omega^4)}$, where δ = -0.7133, β = -0.0809 and γ = 0.0023. The simulation quickly converges to a pulse profile which is asymmetric in shape with unequal shoulders and it has a slight linear chirp (Fig. 2(a)). Interestingly, this is a moving pulse solution, and the pulses are moving slower than the fundamental repetition rate as illustrated in Fig. 2(b). The spectrum of these pulses is also asymmetric (Fig. 2(c)) featuring two unequal maxima.

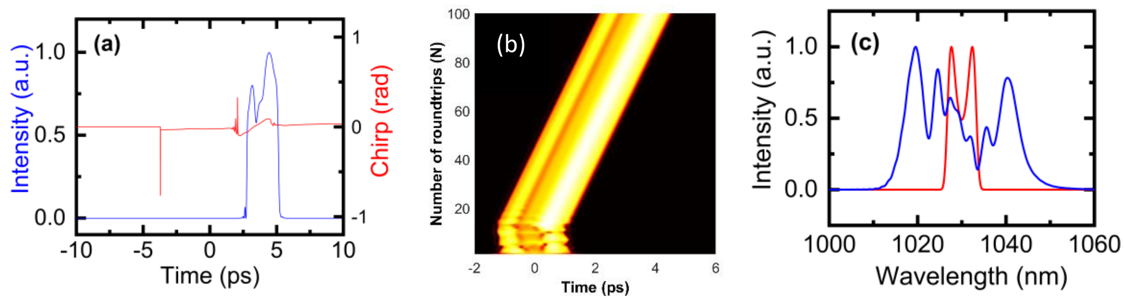

Fig. 2. Simulation results a) asymmetric pulse (blue curve) with chirp (red curve) b) temporal dynamics of the moving pulse. c) simulated spectrum (blue curve) with the spectral filter response (red curve)

Fig. 3(a) shows the output pulse measured by cross-correlation, which has an asymmetric structure as predicted by the simulation. Corresponding asymmetric spectrum at the output and spectral filter response are shown in Fig. 3(b). Fig. 3(c) depicts the spectrum at the coupler output, and it proves that the spectrum circulating the laser cavity always stays asymmetric. The laser can emit ~ 110 fs pulses with pulse energy of ~ 3 nJ with ~37.5 MHz repetition rate. We also notice that solitons pertaining to different mode-locking states travel with different velocities.

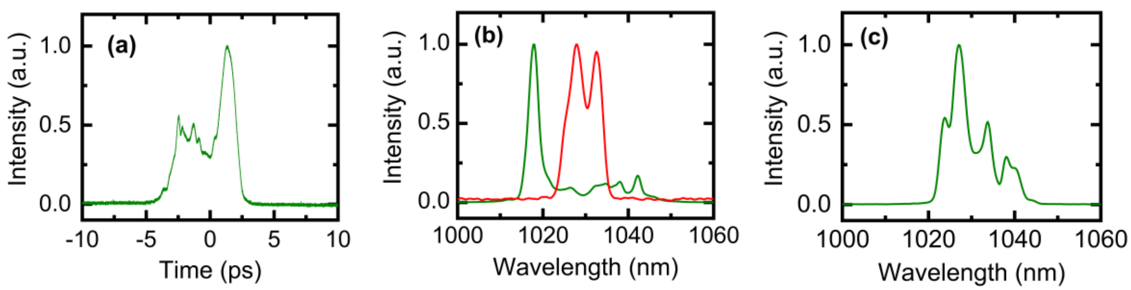

Fig. 3. Experimental a) output pulse and b) output spectrum (green curve) with spectral filter response (red curve) c) spectrum taken at the 20% port of the coupler

4. Conclusion

We have numerically simulated and experimentally implemented a CSHE dissipative soliton fiber laser by employing a double peak spectral filter. The highly asymmetric spectrum along with the asymmetric pulse provides strong evidence of moving solitons in the cavity. It is scientifically interesting to realize dissipative solitons of CSHE and we believe that our studies provide the basis for further investigation of dissipative soliton dynamics in mode-locked fiber lasers.

5. Acknowledgement

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