Breathers driven by polarization instabilities

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Abstract: Using an Er-doped fiber laser passively mode-locked fiber laser based on nonlinear polarization rotation (NPR) as a testbed, here we, for the first time, experimentally demonstrate the effect of the slow scale (thousands round-trip time) polarization instabilities on the emergence of breather-like spatiotemporal structures.

1. Introduction

At present, mode-locked lasers (MLLs) play the role of the ideal testbeds for studying self-coherent structures - dissipative solitons (DSs) – with stable spatiotemporal profile supported by the balance between dispersion and nonlinearity [1]. However, under some conditions, the profile and energy of DSs can oscillate (breathe) periodically [1-4]. It has been recently found that unlike the breather emergence in anomalous dispersion mode-locked fiber lasers caused by modulation instability (MI) [1], the breathers in the normal dispersion regime can be driven by the Hopf bifurcation [2] and subharmonic entrainment (SHE) [3]. Also, in an NPR mode-locked fiber laser, the vector nature of DSs has often been ignored [1, 2]. Unlike this, it has been recently demonstrated theoretically and experimentally for Er-doped laser mode-locked with carbon nanotubes that the orthogonal states of polarization (SOPs) can be regarded as coupled oscillators controlling the synchronization scenarios taking the form of a variety of spatiotemporal structures including breathers [4, 5]. In this paper, we transfer the paradigm of the coupled oscillators (orthogonal SOPs) synchronization to Er-doped fiber laser mode-locked based on nonlinear polarization rotation. As a result, we, for the first time, reveal experimentally a new mechanism of the breather soliton emergence caused by the transition from the zero-lag synchronization to phase difference entrainment and desynchronization.

2. Experiment Configuration and results

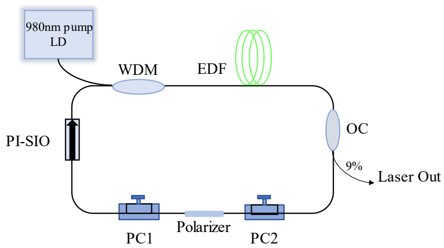

Fig. 1. Schematic setup of the NPR mode-locked fiber laser.

The configuration of NPR mode-locked fiber laser is shown in the Fig.1. A 1.48 m erbium-doped fiber (EDF) with a normal dispersion of +66.1 ps^2/km is used in this cavity. Besides, the cavity also contains 0.9 m of OFS980 fiber with a normal of + 4.5 ps^2/km dispersion and 2.34 m of a single mode fiber (SMF) with an anomalous dispersion of -21.67 ps^2/km. The total length of the cavity is 4.72 m, corresponding to the fundamental frequency of 44.18 MHz and the net dispersion of the cavity is + 0.046 ps^2 and so the laser operates in the normal dispersion. The pump light is coupled to the laser cavity through a 980 / 1550 nm wavelength division multiplexer (WDM). A 91:9 coupler is used to direct out 9% of the pulse energy outside the cavity. The polarization-independent isolator (PI-ISO) in the cavity makes the unidirectional transmission of the pulse train. The polarizer and the two polarization controllers (PCs) are used to support NPR mechanism of the passive mode-locking. By using the fast photodetector and oscilloscope we record the dynamics waveforms. By utilizing commercial polarimeter (THORLABS, IPM5300) with 1μs resolution, we can observe the evolution of the polarization attractors at the Poincare sphere in terms of the normalized Stoke parameters s_1, s_2 and s_3, the power for the orthogonal x- and y-polarization components (I_x, I_y) and the total power S_0, the phase difference $\Delta\phi$ and degree of polarization DOP. The results are shown in Fig.2 (a-l) for different pump powers, i.e. I_p=500 mW (Fig.2, a-d), I_p=460 mW (Fig. 2, e-h) and I_p=450 mW (Fig. 2, i-l) and adjusted in-cavity polarization controllers positions.

As follows from the Fig. 2 (a-d), the polarization locked vector solitons demonstrate stabilized cw mode-locking at the long (1 μs – 1 ms) time scale cause by zero-lag (const phase difference) synchronization of two orthogonal SOPs. The breather dynamics shown in Fig 2 (e and i) demonstrates slow of 100 μs periodic and aperiodic oscillations shown in Fig. 2 (f and j). The first breather-type dynamics (Fig.2, e) is caused by the phase difference entrainment (oscillations) shown in Fig. 2 (g) and results in the SOP periodic evolution (Fig. 2, h). Unlike this, the second type of breather (Fig. 2, i) is caused by the phase difference slips shown in Fig. 2 (k) leading to the partial desynchronization of two SOPs (Fig. 2, l). The DOP in Fig. 2 (c, g, k) is of 90 % that means that the dynamic is slow at the time scale of 1 μs – 1 ms.

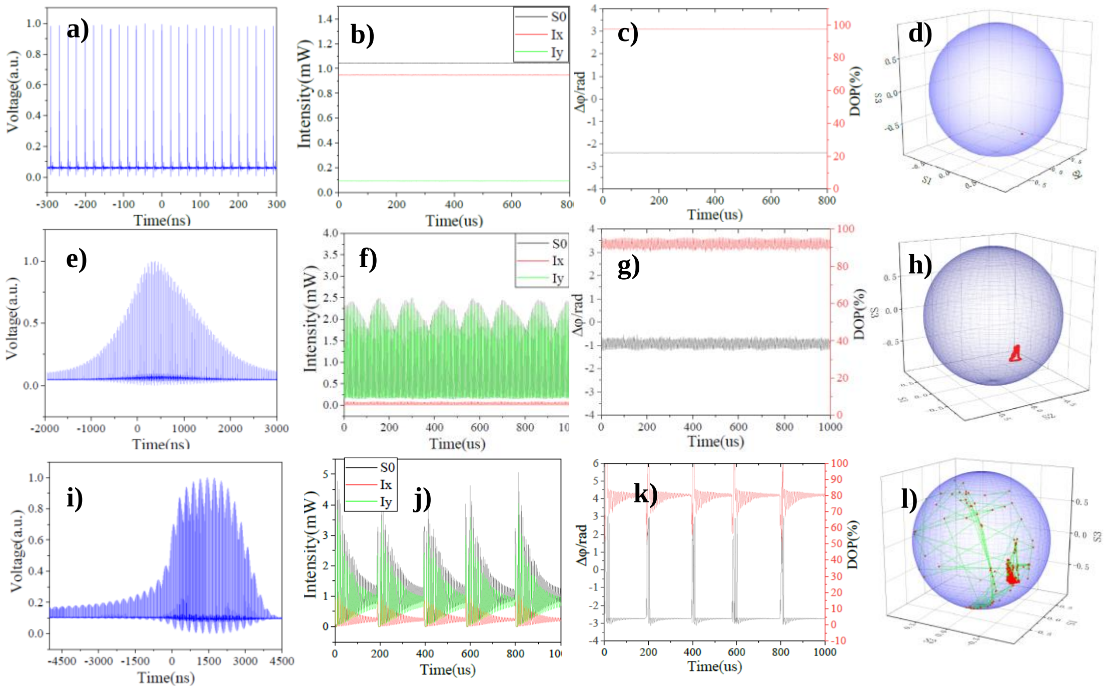

Fig. 2. Dynamics of Er-doped fiber laser mode-locked by NRP. (a, e, i) Fast dynamics, slow dynamics: (b, f, j) Output power of the orthogonal SOPs (I_x, I_y) and the total power (S_0); (c, g, k) the phase difference between the orthogonal SOP and DOP; (d, h, l) trajectories of the SOP evolution in terms of the normalized Stokes parameters at the Poincare sphere.

3. Conclusion

In conclusion, we reveal a new mechanism of the breather's dynamics emergence caused by the phase difference entrainment and desynchronization of two orthogonally polarized SOP in Er-doped fiber laser mode-locked by NPR. The breathers appears when we adjust the coupling strength between the orthogonal SOPs by tuning the pump power and polarization controllers. The developed presentation of the breather's emergence as desynchronization events in the system of coupled oscillators show great potential for mapping conditions for the complex dynamics emergence and so for developing techniques for stabilization of laser dynamics.

4. Acknowledgments

The authors would like to acknowledge funding support from National Natural Science Foundation of the National Natural Science Foundation of China (61975107, 61575120), the "111" project (D20031), the Natural Science Foundation of Shanghai (20ZR1471500), Horizon 2020 ETN MEFISTA (861152).

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