2022 International Symposium on Nonlinear Theory and Its Applications,
NOLTA2022, Virtual, December 12-15, 2022

Multi-Wavelength Broadband Chaos in Long-Cavity FP Lasers Subject to Optical Feedback

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Abstract–Broadband laser chaos synchronization is very desired for its application in secure communication. Limited by intrinsic relaxation oscillation, the bandwidth of laser chaos is lower than 10 GHz. Many methods have been proposed and demonstrated to obtain broadband chaos by breaking the limitation of relaxation oscillation. However, the chaos synchronization becomes difficult. Here we demonstrate the generation and synchronization of broadband chaos in long-cavity FP lasers. Enhanced by modes beating in 1.5 mm-long-cavity FP lasers, the bandwidth of laser chaos is up to 37 GHz. By filtering multiple wavelength slices, multi-wavelength broadband chaos is obtained with synchronization above 0.98.

1. Introduction

Chaos communication has attracted great interest for its high-level security on physical layer encryption, compatibility with existing fiber networks [1]. Limited by the bandwidth of chaotic carrier, the transmission rate of chaos communication is still far from the requirement for the deployed optical fiber communication system.

To obtain broadband laser chaos, many methods have been proposed. By the methods of optical injection [2-3], optical mutual-injection between two lasers [4], fiber ring resonator with an inbuilt optical filter [5], self-phase-modulated optical feedback or injection [6-7], optical heterodyning or electrical heterodyning [8], the chaos bandwidth of semiconductor laser (SL) can be enhanced to more than 30 GHz. But all these methods greatly add the complexity of system, making chaos synchronization a tough challenge. Therefore, it is of greatly importance to generate broadband laser chaos by simple optical feedback configuration.

Here we proposed and demonstrated the generation of broadband laser chaos by using optical-feedback long-cavity Fabry-Perot (LC-FP) SL. Due to the modes beat frequency in LC-FP SL, the bandwidth of laser chaos was significantly enhanced. Induced by the injection of common chaotic signal, broadband chaos synchronization between two response SLs was achieved, with high synchronization coefficient above 0.98. To our surprise, by filtering the laser chaos from the response SLs, multi-wavelength low-correlation broadband laser chaos are simultaneously obtained, with high synchronization coefficient preserved. This work will promote the wavelength-division-multiplexing chaos communication and pave the way for the practical application.

2. Scheme and Method

In this work, LC FP SL subject to optical feedback, as shown in Fig. 1(a), was firstly investigated for generation of broadband chaos. And then, the broadband chaos was injected into one or two response LC FP SL, to study chaos synchronization, as shown in Fig. 1(b) and Fig. 1(c).

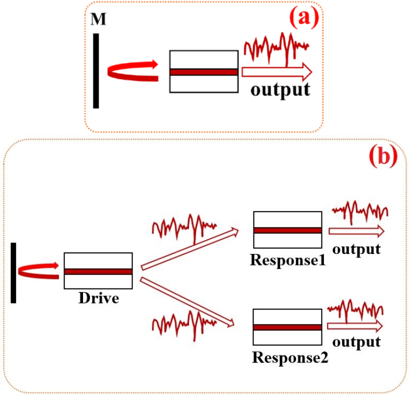

Fig. 1. Schematic diagram of (a) optical-feedback LC-FP SL and (b) common-signal injection into response LC-FP SLs. M: mirror.

All investigations in this work were undertaken by using the VPI component Maker software.

3. Result and Discussion

First of all, we investigated the laser chaos generation by optical-feedback FP SL, with the active cavity length of 200 μm, 800 μm and 1500 μm. As shown in Fig. 2(a1) and (c1), the optical spectrum of chaos from the 200 μm-long

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FP SL included evidently different chaotic modes, and in the power spectrum, only relaxation-oscillation peak was observed. The modes beating above 200 GHz would not enhance the chaos bandwidth. As shown in Fig. 2(a2) and (c2), the optical spectrum of chaos from the 800 μm-long FP SL included different chaotic modes with overlap, and in the power spectrum, both the peaks of relaxation oscillation and modes beating were observed. The modes beating around 50 GHz can enhance the chaos bandwidth. As shown in Fig. 2(a3) and (c3), the different chaotic modes interweaved with each other in the optical spectrum of chaos from the 1500 μm-long FP SL, and in the power spectrum, the peaks of relaxation oscillation and modes beating also interweaved. The chaos bandwidth was enhanced up to 37 GHz, by the modes beating of 28 GHz.

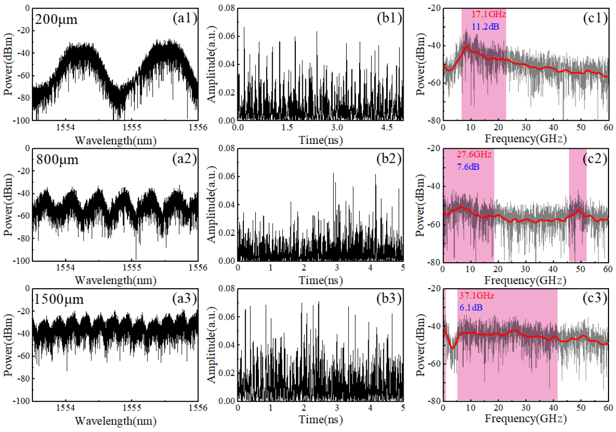

Fig. 2. (a) Optical spectra, (b) time series and (c) power spectra of the laser chaos generated by optical-feedback FP SLs, with the active cavity length of (1) 200 μm, (2) 800 μm and (3) 1500 μm. All lasers were at the same condition: $3I_{\mathrm{th}}$, $K_f = 0.5$.

Then the broadband chaos generated by 1500 μm-long FP SL (drive) with optical feedback was injected into two 1500 μm-long FP SLs (response) without optical feedback. From the time series and the associated point diagrams in Fig. 3, it could be observed that the synchronization coefficient between the two response SLs was high (nearly 0.99), while the synchronization coefficient between the drive SL and response SL was only 0.46.

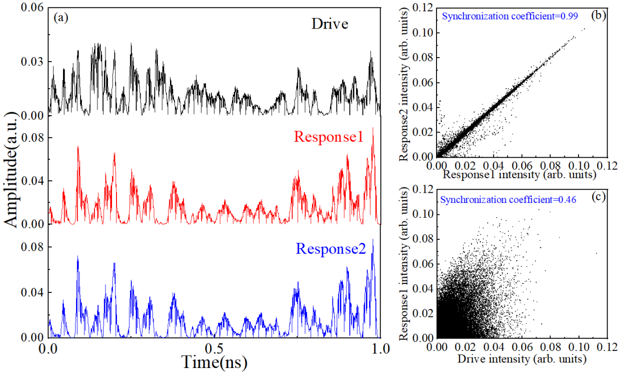

Fig. 3. Time series and associated point diagram of the three outputs under common-signal-induced synchronization. (a) time series of three lasers chaos, (b) associated point diagram of Response1 and Response2, (c) associated point diagram Drive and Response1.

Furthermore, the synchronized chaos from the two response SLs were filtered by different channels. The linewidth of all filtering channels was 50 GHz, and the interval of two adjacent filtering channels was 60 GHz. Fig. 4 shows the results from two channels. As shown in Fig. 4(a) and (b), after filtering, the synchronization coefficient between the two responses was still more than 0.98. To our surprise, the correlation coefficient was very low (0.12), namely, the chaos from two different filtering channels were low-correlation. We also studied the chaos bandwidth after filtering. Both of the chaos bandwidth from two channel were more than 26 GHz.

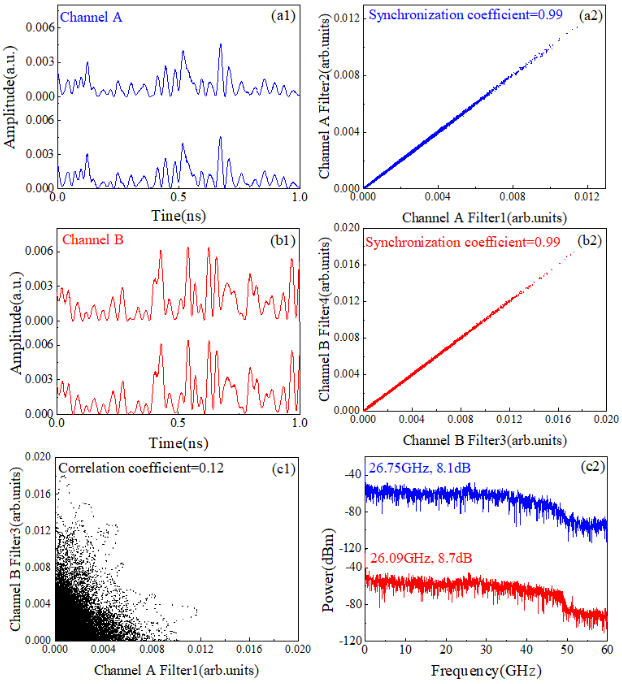

Fig. 4. Multi-wavelength low-correlation broadband laser chaos, with high synchronization coefficient preserved, obtained by filtering the laser chaos generated from the response SLs.

4. Conclusion

Simultaneous generation and synchronization of multi-wavelength low-correlation broadband laser chaos were demonstrated, based on LC-FP SL. Enhanced by the modes beat frequency in 1.5 mm-long-cavity FP SL, the bandwidth of laser chaos from the optical-feedback LC-FP SL is enhanced up to 37 GHz. Under common-signal-induced synchronization, synchronization coefficient between two responses is more than 0.98. By filtering, multi-wavelength low-correlation broadband chaos were produced. The synchronization coefficient is preserved.

Acknowledgments

This work was supported in part by National Key Research and Development Program of China (2019YFB1803500); NSFC (62035009, 61731014); Shanxi “1331 Project” Key Innovative Team; International Cooperation of Key R&D Program of Shanxi Province

(201903D421012); Development Fund in Science and Technology of Shanxi Province (YDZJSX2021A009); Open Fund of Guangdong Provincial Key Laboratory of Information Photonics Technology (GKPT20-01); Open Fund of the State Key Laboratory of Applied Optics (SKLAO2022001A09)

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