Analytical Modeling of Vector Solitons in Fiber Lasers

Wen-Hsuan Kuan[1], Jin-Hao Liu, and Kuei-Huei Lin[2]

Department of Applied Physics and Chemistry, University of Taipei, 1, Ai-Guo West Road, Taipei, Taiwan
E-mails: [1]wenhsuan.kuan@gmail.com; [2]khlin@utaipei.edu.tw

1. Introduction

In birefringent fiber lasers, a new type of optical solitons involving two orthogonal polarization components were found, which are termed as vector solitons [1]. Due to the potential applications in pulse shaping and microwave photonics, many optical methods were proposed to synthesize Gaussian monocycle pulses (GMPs) and Gaussian doublet pulses (GDPs), which have the shapes of the first and second derivatives of Gaussian functions respectively [2]. In this paper, we demonstrate that GMPs and GDPs can be generated in a ring-cavity erbium-doped fiber laser (EDFL) with polarization-locked vector solitons. We further employ qualitative analysis for the interactions of system parameters and their combined effects on the pulse shaping, by solving the coupled complex Ginzburg-Landau equations (CGLEs) with sech- and tanh-based functions.

2. Experimental Method and Theoretical Modeling

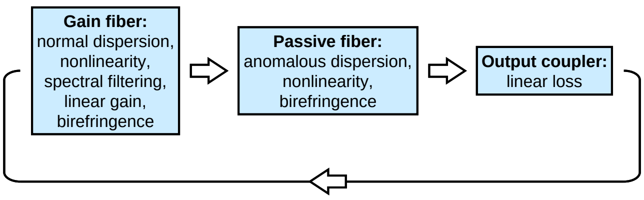

Fig. 1. Schematic setup of the vector-soliton fiber laser.

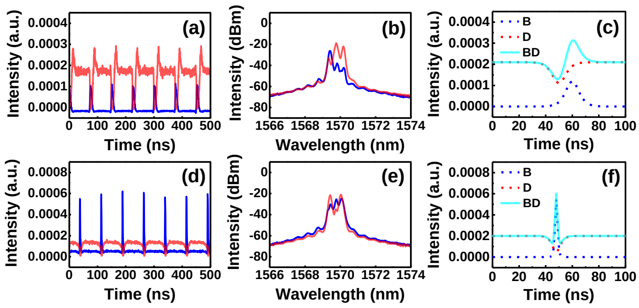

Fig. 2. The pulse trains, optical spectra, and theoretical calculations of the polarization components in the monocycle pulses [(a)-(c)] and doublet pulses [(d)-(f)].

A ring-cavity EDFL is consists of a 980/1550 WDM coupler, a 90-cm erbium-doped fiber (LIEKKI Er80-4/125), a fiber polarization controller (PC), a 10% output coupler, a polarization insensitive optical isolator, and a second PC. The cavity length is about 15.2 m. To simplify the calculation, the EDFL can be modeled as consists of a gain fiber, a passive fiber (SMF-28), and an output coupler (Fig. 1). Monocycle and doublet pulses have been observed by tuning the PCs. As shown in Fig. 2, the monocycle pulses are synthesized by bright (blue curve) and dark solitons (red curve) with orthogonal polarizations, which are also observed for the doublet pulses. The formation of GMPs and GDPs are attributed to the generation of polarization-locked vector solitons [cyan curves in Figs. 2(c) and (f)], which are the superposition of bright and dark solitons.

The propagation of vector solitons is described by the coupled CGLEs:

$$\frac{\partial u}{\partial z} = i\beta u - \delta\frac{\partial u}{\partial t} - \frac{ik''}{2}\frac{\partial^2 u}{\partial t^2} + \frac{ik'''}{6}\frac{\partial^3 u}{\partial t^3} + i\gamma(|u|^2 + \varepsilon_1 |v|^2)u + i\gamma\varepsilon_2 v^2 u^* e^{-2i\rho z} + \frac{g}{2}u + \frac{g}{2\Omega_g^2}\frac{\partial^2 u}{\partial t^2}$$

$$\frac{\partial v}{\partial z} = -i\beta v + \delta\frac{\partial v}{\partial t} - \frac{ik''}{2}\frac{\partial^2 v}{\partial t^2} + \frac{ik'''}{6}\frac{\partial^3 v}{\partial t^3} + i\gamma(|v|^2 + \varepsilon_1 |u|^2)v + i\gamma\varepsilon_2 u^2 v^* e^{2i\rho z} + \frac{g}{2}v + \frac{g}{2\Omega_g^2}\frac{\partial^2 v}{\partial t^2}$$

where u and v represent the envelopes of the two polarization modes, 2β is the wave number difference between the polarization modes. We have analytically solved the coupled CGLEs by assuming sech- and tanh-based functions for the bright and dark solitons to obtain the pulsewidths, chirping parameters, and soliton amplitudes. With the cavity parameters and the criteria of energy conservation at the interfaces, the widths of the bright and dark solitons are calculated as 0.502 ns and 1.496 ns, respectively, which are comparable to the measured widths of 3.65 ns and 3.95 ns. The wave number difference between the orthogonal modes is -1.2×10^{-4} m^{-1}, which is consistent with the assumption of weak birefringent laser cavity.

3. Conclusions

Gaussian monocycle and doublet pulses are generated in a ring-cavity EDFL using passive optical technology. Both GMPs and GDPs are composed of bright and dark solitons having orthogonal polarizations. The propagation of vector solitons in the EDFL can be described by the coupled CGLEs, which are solved analytically by assuming sech- and tanh-based solutions to obtain the pulsewidths, chirping parameters, soliton amplitudes and birefringence. Since the intracavity birefringence can be calculated from the measured pulse parameters, our work provides a method for the in-situ estimation of intracavity laser parameters.

References

[1] X. Yuan, T. Yang, J. Chen, X. He, H. Huang, S. Xu, and Z. Yang, Opt. Express **21** (2013) 23866.
[2] J. Yao, IEEE Microw. Mag. **10** (2009) 82.