Polarization Dynamics in Ultrafast Thulium Fiber Lasers

Ahmet E. Akosman[1], Michelle Y. Sander[1, 2*]
[1]*Department of Electrical and Computer Engineering and BU Photonics Center, Boston University, Boston, MA 02215*
[2]*Division of Materials Science and Engineering, Boston University, Brookline, MA 02446*
*msander@bu.edu

Abstract: Polarization dynamics in soliton mode-locked femtosecond thulium fiber lasers are presented that can lead to pulse modulation. A dual output pulse train with orthogonally polarized interlaced pulses is discussed.
OCIS codes: (140.3510) Lasers, fiber; (140.4050) Mode-locked lasers; (190.5530) Pulse propagation and temporal solitons.

1. Introduction

Mode-locking mechanisms beyond the conventional single pulsing regime have been studied to generate numerous ultrafast phenomena including harmonic mode-locking [1] and vector solitons [2]. In mode-locked fiber lasers without any polarizing elements in the cavity, vector soliton propagation can be supported, yielding an easy access to rich polarization dependent pulse dynamics. Polarization induced attractors have been studied for harmonically mode-locked states [3] and for dual output orthogonally polarized pulse trains in thin disk lasers [4] have been explored in order to achieve innovative femtosecond pulsing schemes. Dual output lasers are particularly attractive for dual-comb spectroscopy applications, where a single laser cavity can replace the need for two locked frequency comb systems with slightly varying repetition rate.

In the following, we will discuss the polarization dynamics in ultrafast thulium (Tm) fiber lasers that lead to new pulse modulation schemes. A novel dual-output laser configuration with orthogonally polarized interlaced pulses at slightly different repetition rates, ideal for applications in dual-comb spectroscopy, will be presented.

2. Experimental results and discussions

The ultrafast thulium fiber laser design is depicted in Fig. 1(a). Two different laser cavities with 128 cm and 70 cm Tm/Ho co-doped fibers (single-mode single-cladding gain fiber TH512, from Coractive) have been developed to explore ultrafast pulse train modulation [5] and dual output vector soliton pulse trains [6], respectively. Both cavities rely on soliton mode-locking with a saturable Bragg reflector (SBR, from BATOP GmbH). The ultrafast output is obtained by separating the pump light through a dichroic mirror (DM). The net birefringence of the laser cavities is controlled with an inline polarization controller (PC). An external linear polarizer is used to investigate the polarization dynamics of the ultrafast output pulse train.

Fig. 1(b) shows that the mode-locked laser directly transitions into stable harmonically mode-locked states by solely increasing the coupled pump power into the cavity for a given PC setting (presented up to the 6th harmonically mode-locked state (HML) at 464.8 MHz). Based on the soliton area theorem and energy quantization, pulse splitting with equidistant distributions sets in, leading to similar optical spectra, see Fig. 1(c), centered at 1961 nm with a full-width at half maximum of 7.2 nm.

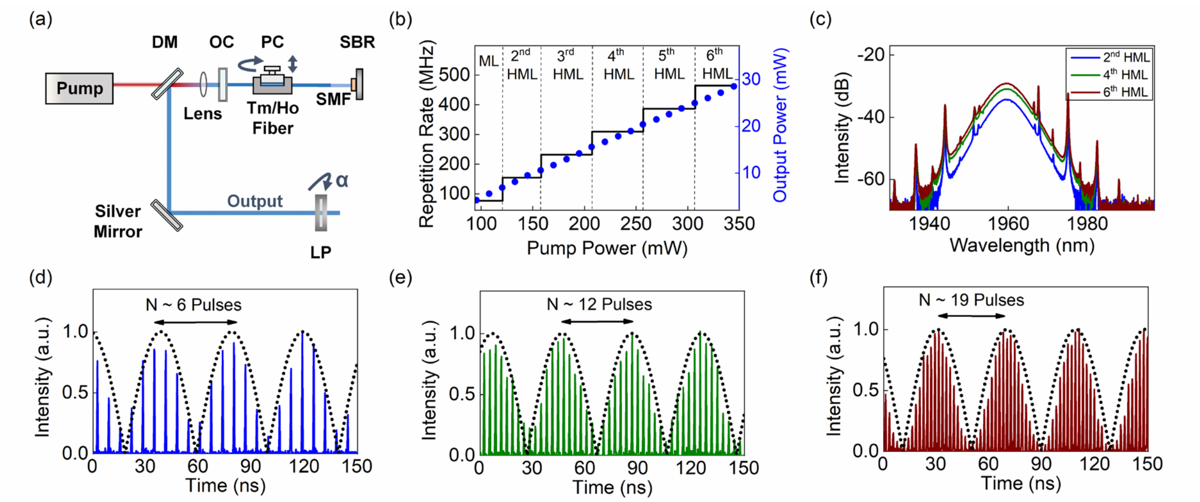

Fig. 1. (a) Schematic of the proposed Tm fiber laser with an inline polarization controller (PC) for changing the cavity birefringence. (b) Mapping of repetition rate from 77.5 MHz to 464.8 MHz and output power for HML states with respect to the coupled pump power. (c) The optical spectrum for different HML states retains its shape and features. (d)-(f) Oscilloscope traces for 2nd HML, 4th and 6th HML states after external linear polarizer and associated pulse bunching periodicity.

This leads to vector soliton behavior and an amplitude pulse modulation where multiple pulses are binned together (e.g. 6 pulses in for Fig. 1(d) for the 2nd HML), as determined by the polarization evolution frequency, that remains constant for all HML states. This offers an inherent and stable modulation scheme, as shown in the oscilloscope traces in Figs. 1(d)-(f) [5].

A novel dual-output laser state with orthogonally polarized interlaced pulses at slightly different repetition rates close to 135.2 MHz [6] is generated for a specific intracavity linear polarizer (LP) setting at angle α. As shown in Figs. 2(a), (b) for the LP at α and α+90°, orthogonal polarization eigenstates at half of the fundamental repetition rate at 67.6 MHz are supported. For a LP setting at α + 45°, a linear superposition of both eigenstates and coherent energy exchange is visible in the sharp dip of the polarization induced sideband in the optical spectrum, Fig. 2(c).

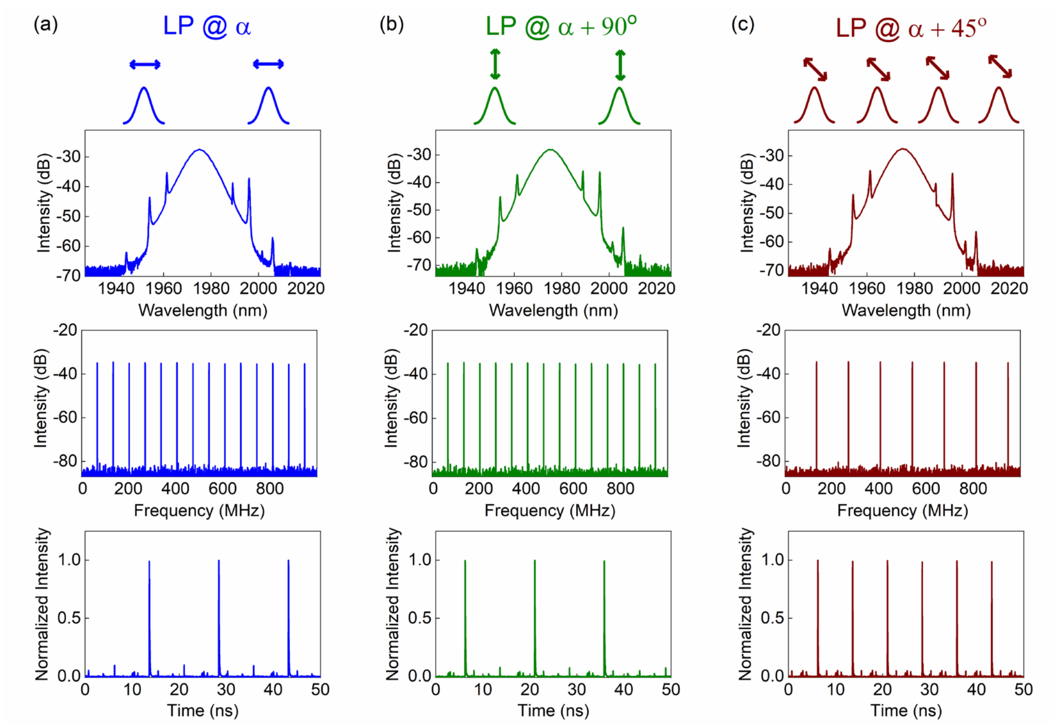

Fig. 2. (a)-(c) Optical spectrum, RF spectrum and oscilloscope traces for specific external linear polarization settings with angle α, α + 90°, and α + 45°, respectively. Here, the angle α and α + 90° represents the two orthogonal polarization eigenstates at half the fundamental repetition rate of 67.6 MHz, while a LP setting at α + 45° corresponds to the linear superposition of both eigenstates, resulting in orthogonally polarized interlaced pulses at a repetition rate of 135.2 MHz.

3. Conclusion

Polarization induced vector solitons are discussed for linear thulium-doped soliton fiber lasers, giving rise to novel pulse dynamics. The dual output pulse train is generated directly from a single, all-fiber based cavity, so that both pulse trains are exposed to the same drift and environmental noise. With an offset between the two pulse train repetition rates of 510 Hz, this system offers an attractive potential for applications in dual comb spectroscopy, optical metrology or polarization entanglement measurements.

4. References

1. A. B. Grudinin and S. Gray, "Passive harmonic mode locking in soliton fiber lasers," JOSA B **14**, 144–154 (1997).
2. B. C. Collings, S. T. Cundiff, N. N. Akhmediev, J. M. Soto-Crespo, K. Bergman, and W. H. Knox, "Polarization-locked temporal vector solitons in a fiber laser: experiment," JOSA B **17**, 354–365 (2000).
3. T. Habruseva, C. Mou, A. Rozhin, and S. V. Sergeyev, "Polarization attractors in harmonic mode-locked fiber laser," Opt. Express **22**, 15211–15217 (2014).
4. S. M. Link, A. Klenner, M. Mangold, C. A. Zaugg, M. Golling, B. W. Tilma, and U. Keller, "Dual-comb modelocked laser," Opt. Express **23**, 5521 (2015).
5. A. E. Akosman, J. Zeng, P. D. Samolis, and M. Y. Sander, "Polarization Rotation Dynamics in Harmonically Mode-Locked Vector Soliton Fiber Lasers," IEEE J. Sel. Top. Quantum Electron. **24**, 1–7 (2018).
6. A. E. Akosman and M. Y. Sander, "Dual comb generation from a mode-locked fiber laser with orthogonally polarized interlaced pulses," Opt. Express **25**, 18592–18602 (2017).