13C4-4

Pulse dropout and subharmonic locking in an active mode-locked birefringent fiber laser

Huy Quoc Lam [1], P. Shum [1], Le Nguyen Binh [2], Y.D. Gong [3], Ming Tang [1], Songnian Fu [1]

[1] Network Technology Research Centre, Nanyang Technological University, Singapore 637553; Tel: 65-67904682; e-mail: huylq@pmail.ntu.edu.sg
[2] Electrical and Electronic Engineering Department, Monash University, Clayton, Melbourne, Australia VIC3800
[3] Institute for InfoComm Research, 21 Heng Mui Keng Terrace, Singapore 119613

Abstract

We report the phenomenon of subharmonic locking of an active mode-locked birefringence fiber laser. The beating between two sets of modes in the birefringent cavity causes pulse dropping and forms the pulse pattern of 0101 or 00010001, which results in the reduction of pulse repetition rate to a half or a quarter of the modulation frequency. This phenomenon demonstrates the dynamic evolutionary property of the active mode-locked fiber laser.

1. Introduction

Active mode locking has attracted widespread attention in recent years due to its potential of producing short and high repetition rate pulse sequence, low timing jitter and ease of synchronization to a stable electronic clock signal [1, 2]. Although tremendous investigations have been performed to explore mode locking mechanisms and applications for various mode-locked fiber lasers [3, 4], the dynamic behavior of active mode-locked fiber laser is still not fully understood.

Recently, we reported the generation of dual amplitude pulses in an active mode-locked fiber laser within a birefringent cavity[5]. Different to normal mode-locked pulses with identical amplitude and polarization state, pulses polarized on both the X and Y axes simultaneously exist in the output pulse train. In this paper, we further investigate the dynamic property of the active mode-locked fiber laser in which the pulse dropout leading to subharmonic locking is presented. The demonstrated phenomenon is useful for understanding the polarization dynamic of active mode-locked fiber laser and for developing highly stable light source for future optical networks or sensor applications.

2. Experimental setup

Fig 1 shows the experimental setup of an active mode-locked fiber laser with a birefringence cavity. The laser has a ring configuration with *15 m* of polarization maintaining Erbium-doped fiber (PM-EDF) serving as a gain medium. The birefringence of the cavity is mainly caused by this PM-EDF. The PM-EDF is pumped by a *980 nm* laser diode through a WDM coupler. An isolator integrated in the WDM ensures unidirectional lasing. A thin-film *1.2 nm* tunable optical bandpass filter is used for tuning the lasing wavelength. A $LiNbO_3$ Mach-Zehnder intensity modulator (MZIM) is used to provide a periodical loss in the ring and hence force the laser to be mode locked. The modulator is driven by a microwave signal extracted from a signal generator. The polarization controller (PC) is used to adjust the polarization state of the lightwave signal traveling in the ring. The optical signal in the ring is coupled to the output port through a 70:30 coupler.

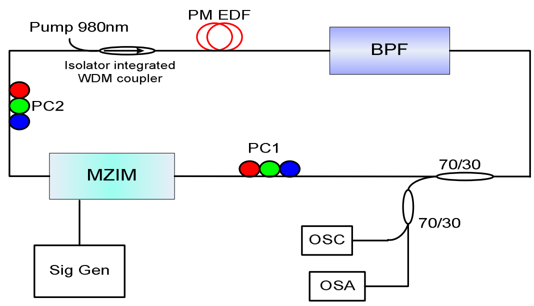

Fig 1 – Active mode-locked fiber laser with birefringence cavity; PM EDF: Polarization maintaining Erbium doped fiber; BPF: bandpass filter; PC: polarization controller; MZIM: Mach-Zehnder intensity modulator; PD: photodiode; OSC: oscilloscope; OSA: optical spectrum analyzer; Sig Gen: signal generator

3. Results and discussion

The total length of the cavity is about *29.5 m* which corresponds to a fundamental frequency f_R of *6.923 MHz*. The modulator is biased at the quadrature point. The central wavelength of the filter is *1550 nm*. The modulation frequency is *2.997668 GHz* which corresponds to the resonance of the 433^{th} harmonic. When the polarization controller is adjusted at an appropriate position, we observed on the oscilloscope a well defined mode-locked pulse train as shown in Fig

2a. Starting from this setting, we recorded the evolution of the pulse train while rotating the middle plate of the polarization controller.

Remarkable frames extracted from the video file are presented in figs 2a – 2d. It can be seen from fig 2b that underfoot appear at every alternative pulse position as the polarization controller is rotated. Pulses in the pulse train is no longer unified but divided into two groups, denoted group A and B respectively. Pulses in group B are gradually dropped out when the PC is rotated. And finally, all pulses of group B are dropped and the pulse train consists of pulses from group A only (see fig 2c). The repetition rate of the pulse train is half of the modulation frequency, subharmonic locking occurs. It is noted that the amplitude of the pulse in this case is nearly double that of the normal locking case since the energy of the dropped pulses are transferred to the remained pulses. Further rotating of the PC results in dropping of pulses in group A as shown in fig 2d.

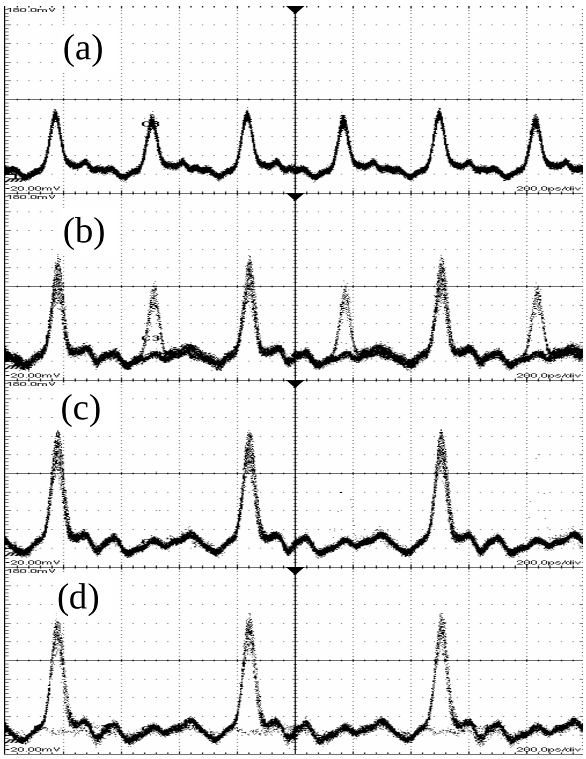

Fig 2 - Oscilloscope trace of the output pulses (a) full rate pulse train with clear pedestral, (b) pulses of group B are droped in some slots, (c) All group-B pulses are droped leaving a subharmonic mode-locked pulse with repetition rate at half of modulation frequency, (d) pulses of group A are droped as further rotating of the polarization controler.

Pulse dropout and subharmonic locking were also observed when the modulation frequency increased to 6.009125 GHz. However, the pulse pattern in this case is ABCDABCD. The pulses are also gradually dropped as the PC is rotated. The evolution of the pulse train is as follow: ABCDABCD, _BCD_BCD, _ _CD_ _CD, _ _ _ D_ _ _D. This results in subharmonic locking of the laser to a quarter of the modulation frequency.

The phenomenon can be explained due to the beating between different modes simultaneously oscillating in the laser cavity. In a birefringence cavity, there are two cavities, one with a fundamental frequency of f_{RX}, the other with f_{RY}. Thus there are two sets of modes oscillating inside the laser cavity. With proper setting of the PC, those two sets may oscillate independently or mutually couple energy from one to another and beat with each other inside the cavity. The independent oscillating of the two sets causes the dual polarization states locking, which has been reported in [5]. In contrast, the beating of the two sets may change the pattern of the pulse train through pulse dropping and causes the laser operate at repetition rate lower than the modulation frequency, i.e. subharmonic locking.

4. Conclusions

By employing a birefringent ring cavity and proper controlling the polarization state of the light insides the laser, we have generated a pulse train with a repetition rate at half or a quarter of the modulation frequency. This subharmonic locking comes from the pulses dropout due to beating between modes simultaneously oscillating in the cavity.

Acknowledgement

This work is partially supported by the Agency for Science, Technology and Research (A*STAR), Singapore, and Open Fund of Key Laboratory of Optical Communication and Lightwave Technologies, Beijing University of Posts and Telecommunications, Ministry of Education, P. R. China.

References

[1] M. Nakazawa, "Ultrafast optical pulses and solitons for advanced communications," presented at Lasers and Electro-Optics, 2003. CLEO/Pacific Rim 2003. The 5th Pacific Rim Conference on, Taipei, Taiwan, 2003.

[2] K. K. Gupta, N. Onodera, K. S. Abedin, and M. Hyodo, "AM mode-locked fibre ring laser generating highly stable, higher-order optical pulse trains with a wavelength tuning range of 1535 nm -1560 nm," presented at Microwave Photonics, 2001. MWP '01. 2001 International Topical Meeting on, Long Beach, CA, 2002.

[3] H. A. Haus, "Mode-locking of lasers," *Selected Topics in Quantum Electronics, IEEE Journal of*, vol. 6, pp. 1173-1185, 2000.

[4] M. Horowitz, C. R. Menyuk, T. F. Carruthers, and I. N. Duling, III, "Theoretical and experimental study of harmonically modelocked fiber lasers for optical communication systems," *J. Lightwave Technol.*, vol. 18, pp. 1565-1574, 2000.

[5] H. Q. Lam, P. Shum, L. N. Binh, and Y. D. Gong, M. Tang " Dual orthogonal polarization states in an active mode-locked birefringent fiber ring laser," *IEEE Photonics Technology Letters*, 2007 (to be published).