Dual pulse bound states in a dispersion-managed mode-locked all-fiber laser with 101.75MHz repetition rate using 45° tilted fiber grating

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ABSTRACT

We demonstrate a dispersion managed Erbium doped all-fiber laser with 101.75MHz repetition rate using 45°TFG to realize mode locking based on nonlinear polarization rotation technique. In our experiment, stable dual-pulse tightly bound states were observed under the pump power of 505mW.

Keywords: *fiber laser, soliton, Fiber Bragg grating*

1. INTRODUCTION

During past several years, passively mode-locked fiber laser operating in bound state had been paid high attentions in virtue of the extensive application prospects in optical communication system such as information coding and transmission as well as augmenting system capacity [1-3]. And studies of high repetition rate fiber laser were motivated much interest for the applications of high speed optical sampling, optical frequency metrology, and frequency comb generation [4-5]. However, the bound state soliton was mostly revealed in mode-locked fiber laser whose cavity length is relative long [6-7]. And high repetition rate fiber laser always concentrates on single pulse generation [8]. Thus it is interesting to explore the characteristics of bound state obtained in short-cavity mode-locked fiber laser.

At present, a variety of mode-locking methods have been used including semi-conductor saturable absorber mirrors (SESAMs) [9], carbon nanotubes [10] and nonlinear polarization rotation (NPR)[11]. Particularly, NPR functioned as an artificial mode locker which exhibits great advantages such as large modulation depth and fast response time of femtosecond scale. The 45° tilted fiber grating (TFG) couples out *s*-light to radiation modes while *p*-light travels through the grating according to Brewster's law so that it can behave as an ideal polarizer device. Compared with bulk polarizers, 45°TFG gets lots of benefits from low insertion loss and all-fiber concept so as to be integrated into optical system easily [12-13]. In this work, dual-pulse tight bound states were observed with 101.75MHz repetition rate which is the highest one generated from dispersion-managed all-fiber Er-doped laser mode locked by NPR technique.

2. FIBER LASER EXPERIMENT

The specific manufacture process of 45°TFG can be found in reference [14]. The broadband polarization dependent loss (PDL) response from 1530nm to 1610nm of 45°TFG was measured as illustrated in Fig 1. The PDL value at 1550nm is almost near 40dB that is practically high compared to the commercial fiber based polarizing components.

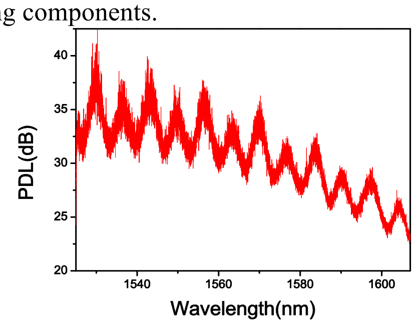


Fig.1. Measured PDL response of 45°TFG from 1550 nm to 1610 nm.

The cavity configuration of proposed fiber laser is depicted in Fig. 2. The 45°TFG and two polarization controllers (PC) are adopted as the NPR mode locking mechanism. 42.3cm EDF whose nominal absorption coefficient of ~80 dB/m at 1530 nm and normal dispersion β_2 = +66.1 ps^2/km is employed as the gain medium. A 980nm benchtop laser (OV LINK) with maximum pump power of 1100mA is utilized to pump the EDFL. There is an optical integrated module (OMI) whose actual length is 3.8cm which is the hybrid of polarization-insensitive isolator, wavelength-division multiplexer (WDM) and output coupler. The pigtail of OMI is 16.6cm HI 1060 with a GVD coefficient of -7ps^2/km. 10% of laser power is tapped out of cavity through a port of the hybrid device. The length of SMF with a GVD coefficient of ~-22.8 ps^2/km is 136.7cm and the total length is 200.05cm corresponding to a fundamental repetition rate 101.75MHz. The net cavity dispersion is calculated to be about -0.0038ps^2 which leads to dispersion-managed solitons generation.

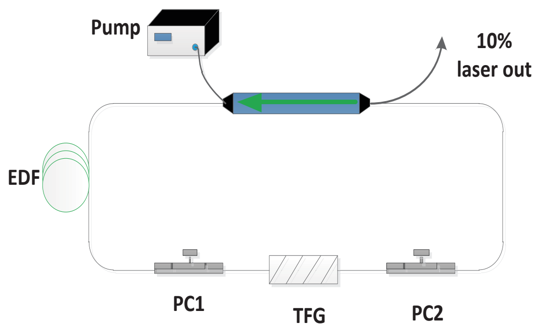
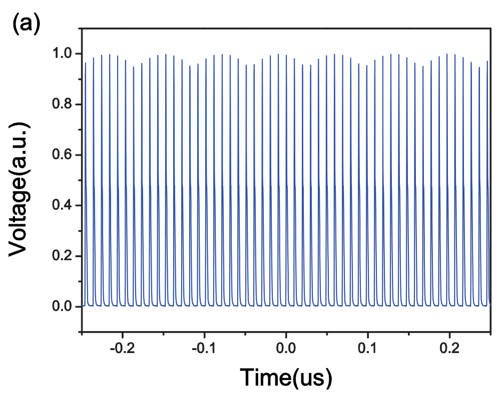


Fig.2. Experimental sketch of passively mode-locked fiber laser based on 45°TFG

3. EXPERIMENTAL RESULTS

By controlling the intra-cavity polarization state and increasing pump power above mode-locking threshold, single pulse dispersion managed soliton can be easily obtained. Figure 3 shows the typical dispersion managed soliton characteristics under the pump power of 505mW. Figure 3(a) illustrates the pulse train emitted from the laser with the fundamental repetition rate of 101.75MHz. Figure 3(b) shows the optical spectrum without Kelly sidebands which is different from conventional soliton. The 3dB bandwidth of the optical spectrum is 32.57 nm centered at 1556.43nm. The corresponding RF spectrum indicates a high signal-to-noise ratio (SNR) of 56.9dB. Furthermore, measured 4.48ps pulse width with Gaussian shape profile is depicted in Figure 3(d). The calculated time bandwidth product is 18.07 indicating strong pulse chirp. By slightly adjusting the PCs, the typical tightly dual-pulse bound state is observed as shown in Figure 4. Strong spectral modulations with a period of 1.94nm which is the unique feature of bound state solitons are shown in Figure 4(a). From the Figure 4(b), we can see that the pulse separation is 4.3ps which is consistent with the spectral modulation period. In addition, the pulse separation is almost 0.98 times of pulse width and the peak-to-peak ratio is 1:2:1 suggesting that each pulse in the bound state has identical intensity.



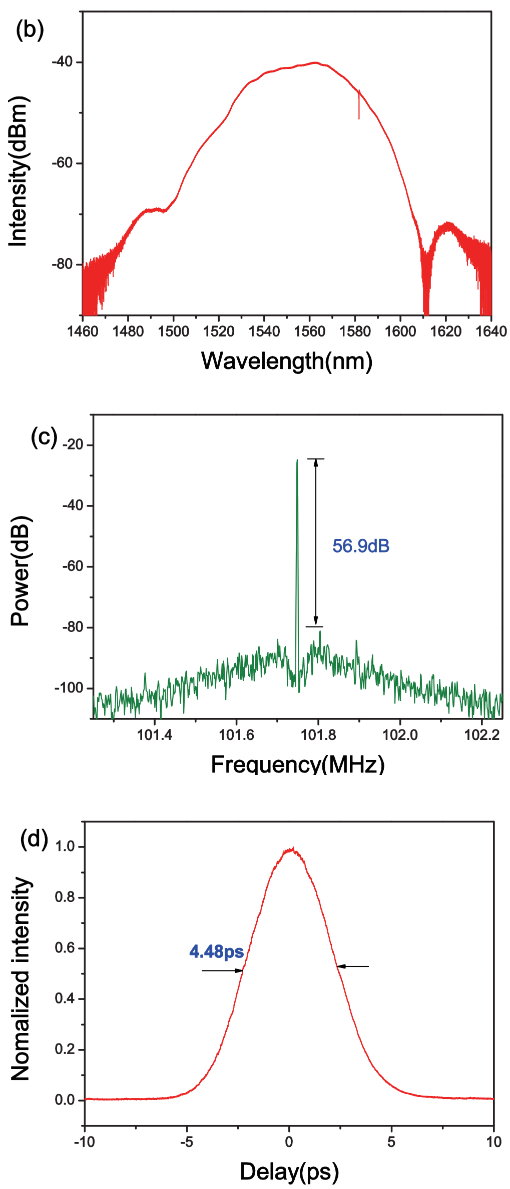
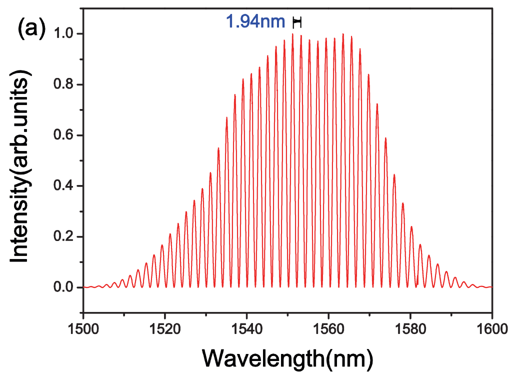


Fig.3.Measured output characteristic of dispersion managed soliton fiber lsaer (a) Oscilloscope trace, (b) optical spectrum, (c) RF spectra, (d) Autocorrelation trace



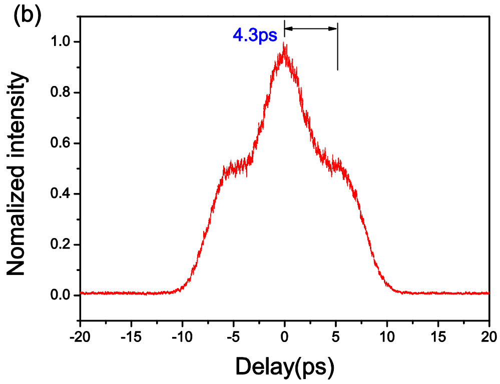


Fig.4. Dual-pulse bound state. (a)Linear optical spectrum, (b) Autocorrelation trace

4. CONCLUSIONS

As a summary, we have experimentally investigated the dual-pulse tightly bound state with 101.75MHz repetition rate in a dispersion-managed fiber laser based on the NPR effect using the 45°TFG.The bound states are verified by the strong modulation in optical spectrum and each pulse in the bound state has identical intensity which are similar with those in relative long-cavity mode-locked fiber laser. Furthermore, we have shown that 45° tilted fiber grating based mode locked fiber laser can be an effective platform to study ultrafast optics, soliton dynamics and nonlinear optics.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] Luo Y, Cheng J, Liu B, et al. Group-velocity-locked vector soliton molecules in a birefringence-enhanced fiber laser[J]. arXiv preprint arXiv:1704.00957, 2017.

[2] Gui L, Xiao X, Yang C. Observation of various bound solitons in a carbon-nanotube-based erbium fiber laser[J]. JOSA B, 2013, 30(1): 158-164.

[3] Liu X, Wang H, Wang Y, et al. Bound dissipative-pulse evolution in the all-normal dispersion fiber laser using a 45 tilted fiber grating[J]. Laser Physics Letters, 2013, 10(9): 095103.

[4] Schlager J B, Hale P D, Franzen D L. High□sensitivity optical sampling using an erbium□doped fiber laser strobe[J]. Microwave and Optical Technology Letters, 1993, 6(15): 835-837.

[5] Rauschenberger J, Fortier T M, Jones D J, et al. Control of the frequency comb from a mode-locked Erbium-doped fiber laser[J]. Optics Express, 2002, 10(24): 1404-1410.

[6] Roy V, Olivier M, Piché M. Pulse interactions in the stretched-pulse fiber laser[J]. Optics express, 2005, 13(23): 9217-9223.

[7] Olivier M, Roy V, Piché M, et al. Pulse collisions in the stretched-pulse fiber laser[J]. Optics letters, 2004, 29(13): 1461-1463.

[8] Qi H, Zhang J, Zhou G, et al. 325 MHz and near transform-limited pulse output directly from an Er: fiber ring laser[J]. Chinese Optics Letters, 2013, 11(6): 061402.

[9] Zhang H, Tang D Y, Wu X, et al. Multi-wavelength dissipative soliton operation of an erbium-doped fiber laser[J]. Optics express, 2009, 17(15): 12692-12697.

[10] Shohda F, Shirato T, Nakazawa M, et al. A passively mode-locked femtosecond soliton fiber laser at 1.5 μm with a CNT-doped polycarbonate saturable absorber[J]. Optics express, 2008, 16(26): 21191-21198.

[11] Feng X, Tam H, Wai P K A. Stable and uniform multiwavelength erbium-doped fiber laser using nonlinear polarization rotation[J]. Optics express, 2006, 14(18): 8205-8210.

[12] Mou C, Bennion I, Zhou K, et al. Characterization of 45°-tilted fiber grating and its polarization function in fiber ring laser[J]. Journal of the Optical Society of America B, 2009, 26(10):1905-1911.

[13] Mou C, Wang H, Bale B G, et al. All-fiber passively mode-locked femtosecond laser using a 45º-tilted fiber grating polarization element.[J]. Optics Express, 2010, 18(18):18906-11.

[14] Zhou K, Chen X F, Simpson A G, et al. High extinction ratio in-fibre polarizer based on a 45º titled fibre Bragg grating[J]. 2005.