Optics Communications 335 (2015) 262–265

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Switchable linear-cavity nanotube-mode-locking fiber laser emitting picosecond or femtosecond pulses

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ARTICLE INFO

Article history:
Received 4 July 2014
Received in revised form
29 August 2014
Accepted 12 September 2014
Available online 26 September 2014

Keywords:
Mode-locked lasers
Switchable lasers
Ultrafast lasers
Carbon nanotube

ABSTRACT

A switchable linear-cavity nanotube-mode-locking fiber laser is proposed by exploiting fiber Bragg grating for the first time to the author's best knowledge. The proposed all-fiber laser can deliver either picosecond or femtosecond pulses by controlling the polarization controllers. The durations of picosecond and femtosecond pulses are 16.4 ps and 838 fs with the central wavelengths of 1529.5 and 1560 nm, respectively. The femtosecond pulse has symmetrical spectrum sidebands, but the picosecond pulse almost has no spectral sidebands. Our work provides a simple, low-cost, dual-scale pulse source for practical applications.

1. Introduction

Passively mode-locking fiber lasers have been extensively investigated, since they offer a perfect platform to generate ultrashort/ultrafast pulses [1–6] and study nonlinear phenomenon [7–12]. In past decades, various mode-locking techniques have been proposed in fiber laser, such as nonlinear optical loop mirrors [13], nonlinear polarization rotation [14–16], semiconductor saturable absorber mirrors (SESAMs) [7], graphite [17], carbon nanotubes [18,19], charcoal [20], graphene [21–24], graphene-nanotube mixtures [25], and topological insulator [21,26]. Among them, single-wall carbon nanotubes (SWNTs) have attracted considerable interest for their intrinsic advantages of the ultrashort recovery time, broad operation bandwidth, and polarization insensitivity [27–30]. By using SWNTs, pulses from tens of femtosecond to picosecond have been realized in fiber laser [18,19,29]. The multi-wavelength mode-locking fiber lasers with various configurations have been investigated based on nanotubes [30,31]. In addition, the harmonically passive mode-locking of fiber lasers with a SWNT were demonstrated recently [32].

With the dispersion design of laser cavity, fiber lasers can emit conventional soliton [3,33,34], dispersion-managed soliton [35], self-similar pulse [1], dissipative soliton [36,37], and soliton molecule [38,39]. Generally, mode-locking fiber lasers are realized by the ring [7,27,28,40,41] or figure-eight [13,42] configuration. However, fiber lasers with linear cavity are often employed for its simple design by employing chirped fiber Bragg grating (CFBG) or SESAM without circulator [43,44]. What's more, with incorporating CFBG into a linear cavity, the spatial hole burning can be reduced due to the lack of a fixed cavity length [45]. As a reliable, compact component, FBG is usually utilized for wavelength selectivity in fiber laser or communication system [46–50]. By utilizing FBGs, switchable fiber laser has been proposed by various means [51–54]. For example, a switchable mode-locking operation has been reported by changing the intracavity loss with a tunable attenuator [54]. However, the previous works mainly concentrated on separately emitting picosecond or femtosecond pulses [51–54]. So far, the generation of picosecond or femtosecond pulses in a linear-cavity fiber laser based on SWNTs has not been reported.

In this paper, we report a switchable linear-cavity nanotube-mode-locked fiber laser, which can deliver picosecond or femtosecond pulses by adjusting the polarization controllers. A FBG with central wavelength of 1529.5 nm is inserted in the cavity. By appropriately setting the polarization controllers (PCs), the switchable mode-locking operation with pulse duration of 838 fs or 16.4 ps is observed in the fiber laser. The femtosecond operation spectrum, with a central wavelength of 1560 nm, has clearly symmetrical sidebands at both sides of the spectrum. However, the picosecond operation centered at 1529.5 nm almost has no spectral sideband, which can be attributed to the spectral filtering effect caused by FBG. Compared with constructing independent picosecond laser and femtosecond laser, the proposed scheme significantly reduces the cost and is attractive for ultrafast optics.

2. Experimental setup

The configuration of the proposed fiber laser is schematically shown in Fig. 1(a). The linear cavity is constructed with a fiber-based

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http://dx.doi.org/10.1016/j.optcom.2014.09.036

mirror and a circulator, whose port1 and port3 are connected to form the other cavity mirror. The circulator in contrast to coupler takes minimal cavity loss, which is desirable to act as a cavity mirror. In the

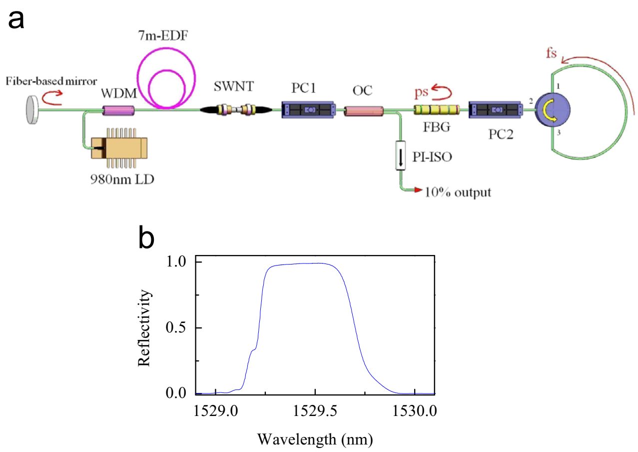

Fig. 1. (a) Laser setup. LD—laser diode; WDM—wavelength-division multiplexer; EDF—erbium-doped fiber; OC—optical coupler; PC—polarization controller; PI-ISO—polarization-insensitive isolator; SWNTs—single-wall carbon nanotubes; FBG—fiber Bragg grating; CR—circulator; fs—femtosecond;ps—picosecond. (b) The reflection spectrum of the FBG.

linear cavity, a 7 m EDF with absorption of 6 dB/m at 980 nm is employed as the gain medium. A 980 nm laser diode (LD) provides pump with a 980/1550 nm wavelength-division-multiplexer (WDM). The 10% port of optical coupler (OC) provides the laser output. The polarization-insensitive isolator (PI-ISO) external to the cavity can prohibit the reflected light from disturbing the signals in fiber laser. The packaged SWNT-polyvinyl alcohol polymer is incorporated into the cavity to generate ultrashort pulses, which is fabricated as shown in Ref. [30]. A FBG centered at ~1529.5 nm is inserted into the cavity adjacent to the circulator, and its reflected spectrum is shown in Fig. 1(b). The reflectivity and the 3 dB bandwidth of the FBG are ~99.1% and ~0.5 nm, respectively. The bandwidth of the FBG is a crucial parameter in the experiment which determines the spectral bandwidth of the picosecond pulse. The PC1 is used to optimize the mode-locking conditions, and PC2 can be utilized to control the loss between FBG and circulator. When we tighten the PC2 paddle and change its orientation, the SMF in PC2 is twisted and squeezed, which leads to increasing the fiber loss. The other fibers in the linear cavity are the standard single mode fiber (SMF) with the length of 14.1 m. The dispersion parameter of EDF and SMF are -9 ps/(nm km) and 17 ps/(nm km), respectively. An optical spectrum analyzer, a commercial autocorrelator, a radio-frequency (RF) analyzer, a 6 GHz oscilloscope, and a 10 GHz photodetector are employed to monitor the laser output.

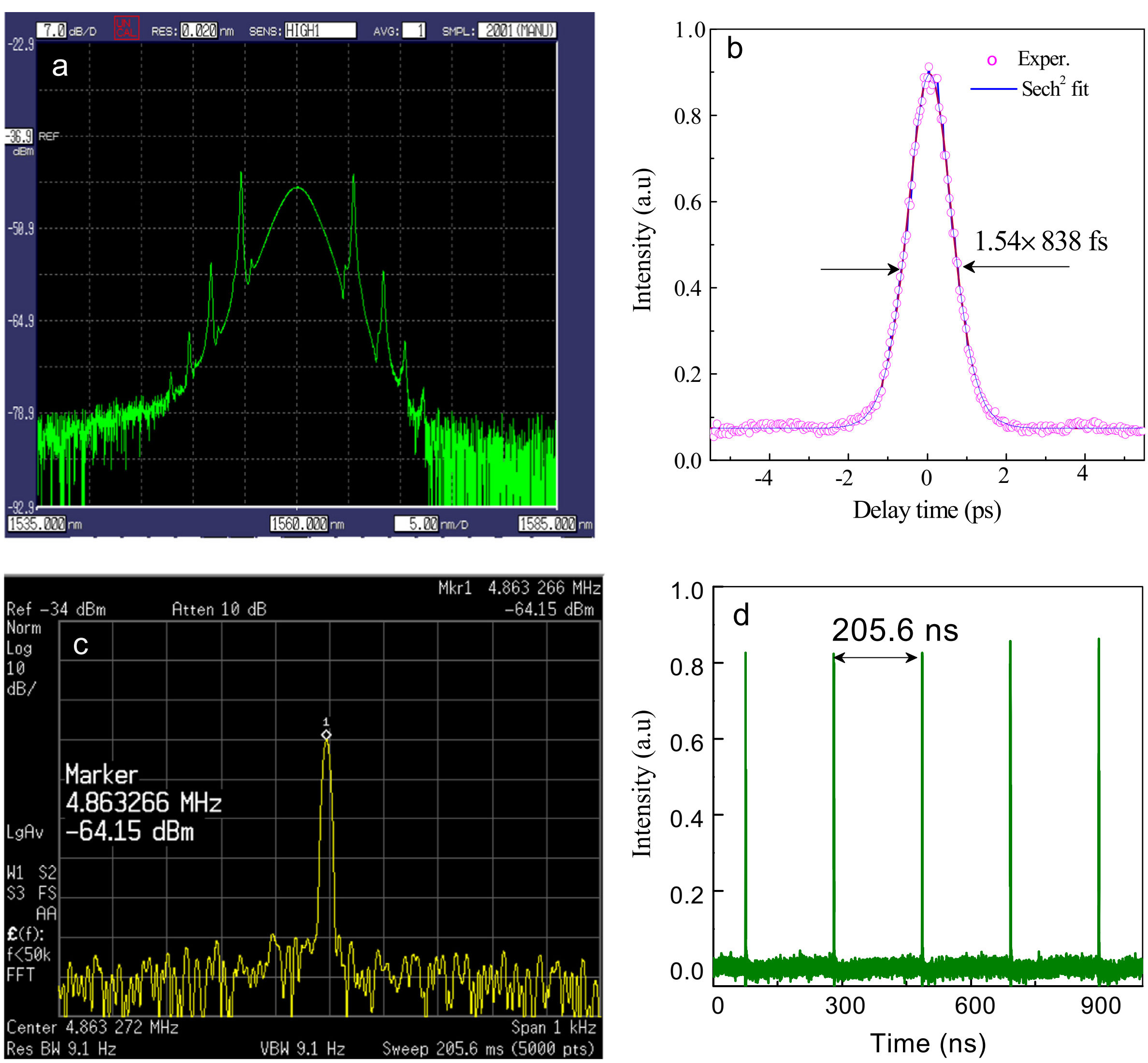

Fig. 2. The femtosecond operation at 1560 nm. (a) Optical spectrum; (b) AC traces; (c) fundamental RF spectrum; and (d) oscilloscope trace.