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Wavelength tunable L Band polarization-locked vector soliton fiber laser based on SWCNT-SA and CFBG

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A B S T R A C T

Wavelength tunable L-Band polarization-locked vector soliton fiber laser based on single-walled carbon nanotube saturable absorber (SWCNT-SA) and chirped fiber Bragg grating (CFBG) is presented for the first time. By inserting the SWCNT-SA into an all-fiber laser cavity, polarization-locked vector solitons (PLVS) are obtained. The CFBG glued on a plastic cantilever is used for wavelength tuning. By mechanically bending the cantilever, the center wavelength of the PLVS pulses can be continuously tuned from 1606.8 nm to 1614 nm, while the polarization-locked state is kept stable. The properties and dynamics of PLVSs are experimentally investigated and stable PLVS operation including high-order PLVSs is demonstrated. The pulse width and repetition rate are 7.06 ps and 11.9 MHz at a wavelength of 1611 nm, respectively. This work demonstrates the feasibility of using polarization-insensitive CFBG to realize wavelength tuning in PLVS fiber laser.

1. Introduction

The L band telecommunication window, which refers to the wavelength range from 1565 nm to 1625 nm, has attracted much research interest because of the low loss in silica fiber at this spectral region. During the last decade, numerous works related to optical solitons at L band were reported but they were treated as scalar solitons [1–3]. In reality, due to the asymmetry caused by bending or mechanical strain, there is slight birefringence in single mode fibers (SMFs). Consequently, SMFs always support two orthogonal modes. Taking fiber birefringence into consideration, the vector nature of solitons has attracted interest recently [4,5]. Usually the two orthogonal modes have different phase velocities, thus the polarization state of solitons will evolve along the fiber. However, in some fibers with well-controlled birefringence, potential nonlinear birefringence caused by self-phase modulation (SPM), cross phase modulation(CPM), coherent energy exchange and so on can balance the linear birefringence. Regarding this, when solitons periodically propagate in the laser cavity, the phase velocities of two orthogonal modes will be locked. Therefore, polarization-locked vector solitons (PLVSs) can be formed in laser cavity [6–11].

Generally, passive mode-locking techniques by nonlinear polarization rotation (NPR), nonlinear optical loop mirror (NOLM), and saturable absorber (SA) are widely used in the generation of optical solitons. Recently, figure eight fiber lasers based on nonlinear amplifier loop mirror have been proposed to investigate the vector nature of solitons [12,13]. In order to obtain PLVSs in a fiber laser, polarization dependent elements in the laser cavity should be avoided [14]. Therefore, polarization insensitive saturable absorbers such as single-walled Carbon nanotubes (SWCNT), graphene and semiconductor saturable absorber mirror (SESAM) have shown unique advantages [15–17]. Among those SWCNT has attracted lots of attention because of its easy fabrication and long-term stability. By inserting the SWCNT film in a fiber connector connecting two fibers, PLVSs can be generated in a non-polarization maintaining cavity of mode-locked fiber laser.

Nonetheless, for most of PLVS fiber lasers, the wavelength is not tunable [10–17]. The wavelength tunability is one of the most attractive characteristics of mode-locked lasers. To realize the wavelength tuning in PLVS fiber laser, polarization dependent wavelength tuning methods, e.g. NPR, cannot be used. In this paper, we present an L-band wavelength tunable polarization-locked vector soliton fiber laser by using the SWCNT-SA and chirped fiber grating (CFBG). The CFBG is mounted on a Polymethyl Methacrylate Resin (PMMA) cantilever. By bending the cantilever, the center wavelength of the PLVS can be precisely tuned from

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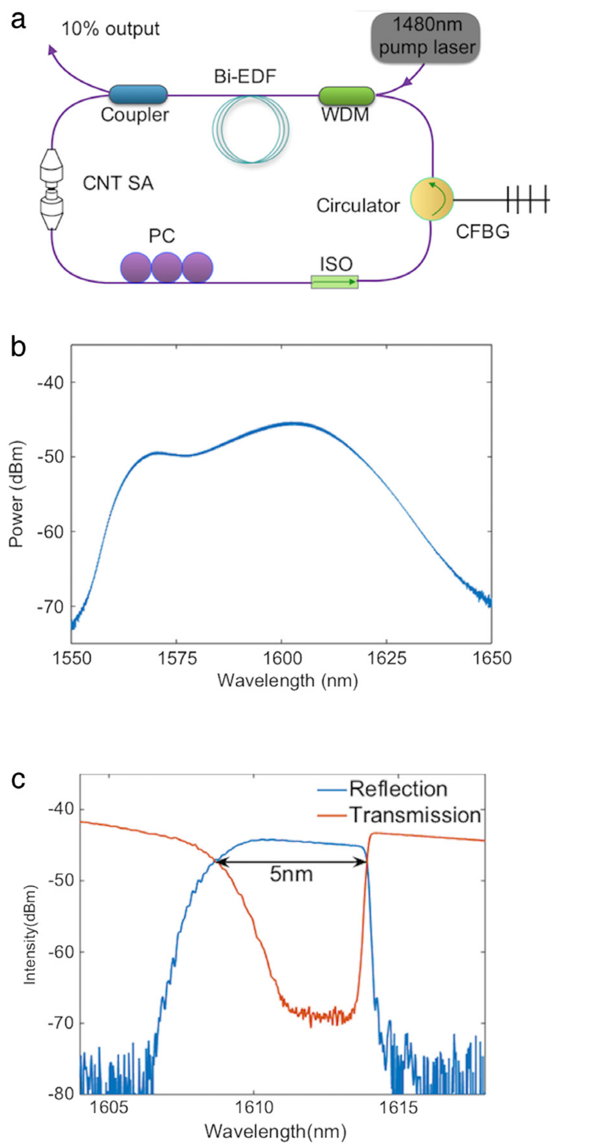

Fig. 1. (a) Schematic diagram of the tunable L-band PLVS fiber laser. (b) Gain spectrum of Bi-EDF when a pump with wavelength of 1475 nm and power of 180 mW is used. (c) The reflection and transmission spectra of the CFBG used in the experiment.

1606.8 nm to 1614 nm, while the polarization-locked state is kept stable. Moreover, high-order PLVSs are also observed in our experiment.

2. Experimental setup

The schematic diagram of the tunable L-band PLVS fiber laser is shown in Fig. 1(a). The PLVS fiber laser has a ring cavity which consists of a gain medium, a 10 dB output coupler, a polarization controller (PC), a polarization insensitive isolator (PI-ISO), a CFBG and a SWCNT-SA. The gain medium is a 101.3 cm-long bismuth-based erbium doped fiber (Bi-EDF) with Er^{3+} doping concentration of 6500 ppm/wt, which is pumped by a Raman laser with a wavelength of 1475 nm. The Bi-EDF can provide larger gain compared with conventional silica based erbium doped fiber, especially at long wavelength of L band region (>1600 nm). The gain profile of the Bi-EDF is obtained when it is pumped at a power of 180 mW, as shown in Fig. 1(b). We can see that the Bi-EDF has broad gain bandwidth covering the region beyond 1600 nm, which makes the Bi-EDF an excellent gain medium for L band fiber lasers. The laser output is measured at one output port (10%) of the fiber coupler. The PC is used to tune the cavity birefringence. The PI-ISO is used to ensure unidirectional operation of the laser. The home-made SWCNT film is inserted in the connector between two single mode fibers and forms the SWCNT-SA. The non-saturable loss, modulation depth, and saturation intensity of SWCNT-SA are 94%, 6% and 10 MW/cm^2, respectively. In order to realize the wavelength tuning, we fabricate a CFBG by using a Talbot interferometer and a 213 nm pulsed solid-state laser. During the laser writing process, a Gaussian apodization profile is applied to the CFBG so that no obvious interference ripples are observed in the CFBG spectrum. Here a highly reflective CFBG is fabricated to minimize the cavity loss. The CFBG is

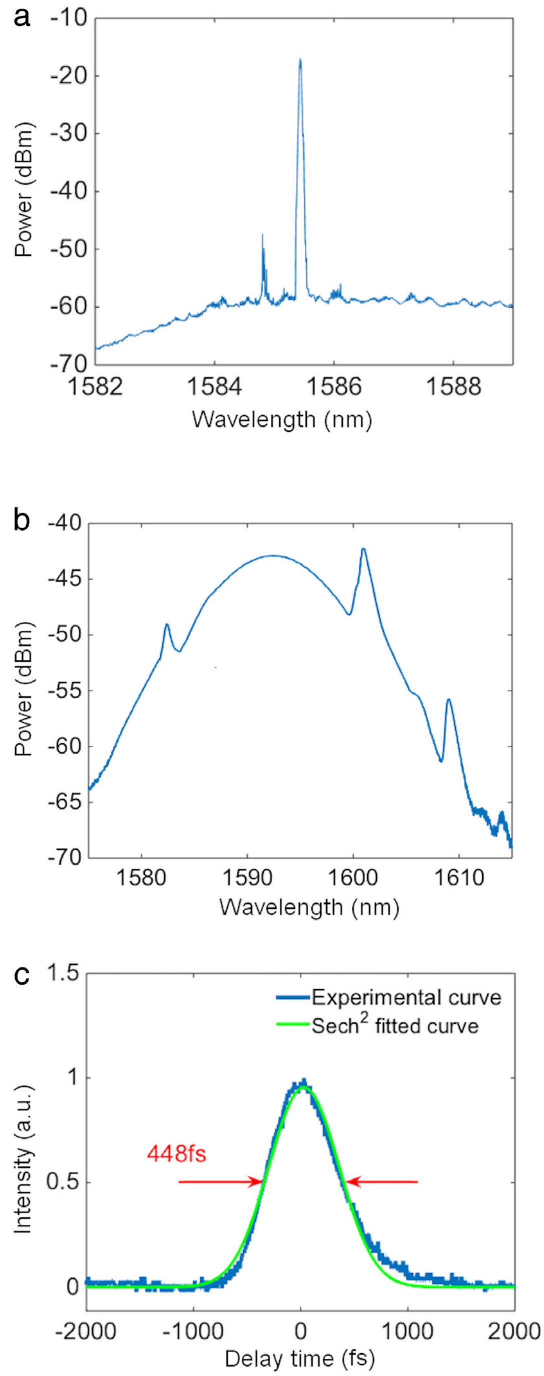

Fig. 2. (a) Optical spectrum of the continuous-wave L-band fiber laser using Bi-EDF. (b) Optical spectrum of the L band mode-locked fiber laser by inserting SWCNT-SA into the cavity. (c) Corresponding autocorrelation trace for the laser in (b).