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All-fiber dissipative soliton laser based on single-walled carbon nanotube absorber in normal dispersion regime

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ABSTRACT

We demonstrat a compact Yb-doped fiber (YDF) laser based on the single-walled carbon nanotube (SWCNT) wall-paper absorber. It can operate at dissipative solitons mode-locking state stably for more than 24 h at the room temperature, and there is no significant degradation of the laser spectra, pulse train, and output power. The spectral bandwidth of the mode-locked pulses varies from 0.35 to 0.64 nm depending on the level of the pump power. The amplified pulses possess single pulse energy of 3.87 nJ and pulse duration of 421.9 ps. The repetition rate is ~23.83 MHz. The largest output power reaches 92.3 mW.

1. Introduction

With low cost, simple cavity design, and the capability of generating ultra-short pulses, fiber lasers have been intensively investigated in the past decades [1–3]. Various applications have been realized, such as ultrafast phenomena, optical communications, supercontinuum generation, nonlinear optics, and optical sensors [4–8]. Different mode-locked techniques, such as nonlinear polarization rotation (NPR), nonlinear-optical loop mirrors (NOLM), nonlinear amplification loop mirrors (NALM), optical injection locking (OIL), and saturable absorbers (SAs) have been used to generate ultrashort pulses [8–18]. The NPR technique is sensitive to the environment because of its pulse-generation mechanism, which causes a lot of limitation on the practical applications. The SAs including semiconductor saturable mirrors (SESAM), carbon nanotubes (CNTs), grapheme, grapheme oxde (GO), and topological insulator based nano-particles are independent on the polarization state of light wave when mode locking, so more and more researchers prefer to choose the SAs as the mode-locker [19–26]. Among them, SESAMs have been widely used for generating Q-switched and mode-locked laser pulses in the past few years [27,28]. However, the SESAMs have the drawbacks of high cost, complex fabrication, long recovery time and low damage threshold, which limit their practical usage. On comparison, the single-walled carbon nanotube (SWCNT) absorber possesses the advantages of low-cost material, simple fabrication technique, short recovery time (~1 ps), and high damage threshold. In Ref. [29], a technique of using SWCNT absorber as mode locker for high-energy pulse formation was proposed. It showed that the high optical power induced damage on the nanotube was avoided. Recently, mode-locked fiber lasers based on SWCNT absorber have also been reported, and different kinds of soliton including conventional soliton, dispersion-managed soliton and dissipative soliton (DS) were obtained experimentally [16,30,31]. The DS usually generated in the normal-dispersion

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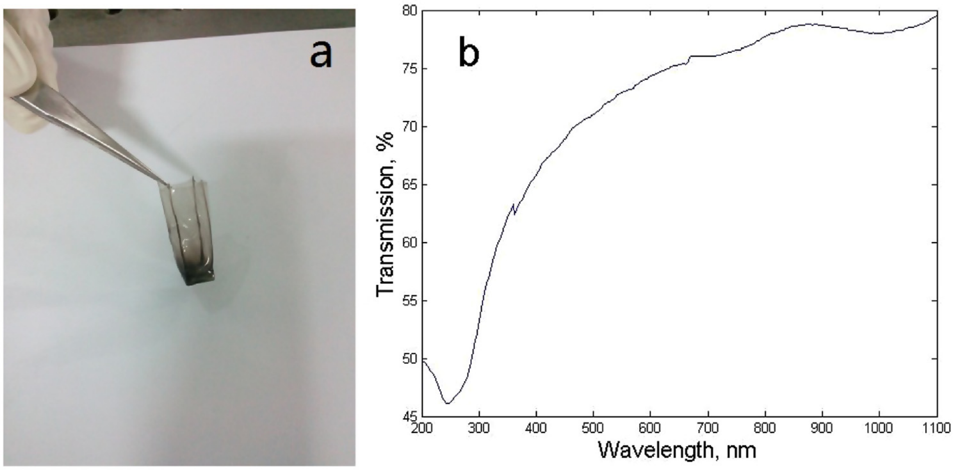

Fig. 1. The SWCNT-PVA wall paper absorber (a) and its linear transmission curve (b).

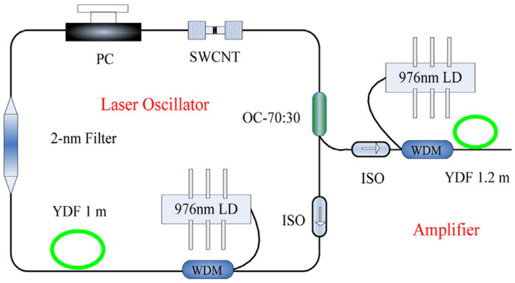

Fig. 2. Schematic of the fiber laser setup.

regime, have attracted great attention due to its promise of realizing much higher pulse energy than that of conventional solitons or stretched pulse [32–35]. Liu et al. have got DS in a Yb-doped fiber (YDF) laser mode-locked by SWCNT with an amplified pulse energy of ~2 nJ [31].

In this letter, we have demonstrated an all-normal-dispersion passively mode-locked YDF laser based on the SWCNT-PVA absorber. The filtering effect is essential in the all normal-dispersion regime. Stable mode-locked DS is obtained in the cavity with different pump power (from 113 to 130 mW). The spectra exhibit typical steep edges, and the spectra width varies from 0.35 to 0.64 nm. The output power can be further amplified to 92.3 mW, which corresponds to the pulse energy of 3.87 nJ and pulse duration of 421.9 ps. The pulse energy is about one time higher than the result in Ref. [31]. The output pulses are monitored for more than 24 h, and there is no significant degradation of the laser spectra, pulse train on oscilloscope, as well as the output power. The SWCNT-PVA absorber used in our experiment is home-made absorber.

2. Experimental setup

The fabrication of SWCNT-PVA absorber is similar to that in Ref [16]. An UV–visible–NIR spectrophotometer made by Chinese PERSEE was employed to measure the linear optical transmission of the SWCNT-PVA absorber, as shown in Fig. 1(b).

The configuration of proposed fiber laser system is schematically shown in Fig. 2. The left part is the oscillator for mode-locked pulses emission. The right part is an amplifier to enhance the pulse energy. Two 976-nm single-mode laser diodes (LD) with the maximum power of 650 mW are used to provide pump through the 980/1053 nm wavelength-division-multiplexer (WDM) in the oscillator and amplifier. A 1-m and a 1.2-m YDF (SM-YSF-HI with core diameter of around 6 μm, cladding diameter of 125 μm, Numerical Aperture of 0.11, and Core Absorption of about 250 dB/m at 976 nm) act as the gain media in the oscillator and amplifier. The group velocity dispersion (GVD) is about −45 ps/nm/km at 1030 nm. The other fibers in the laser system together with the pigtail of the passive components are HI-1060 with dispersion parameter D of −37 ps/nm/km. The total length of the oscillator is ~12.6 m, which corresponds to a fundamental repetition of ~23.8 MHz. Two polarization insensitive isolators (ISO) are respectively used to ensure unidirectional operation in the oscillator and amplifier. One set of polarization controller (PC) with a 2-nm filter at 1053 nm are used in the oscillator for adjusting the linear cavity birefringence and laser wavelength selection. The ~1.5 mm^2 SWCNT-PVA wall pager absorber is sandwiched between two fiber ferrules inside a physical contact ferrule connector (SWCNT-PVA was briefly marked as SWCNT in the diagram). A fused optical coupler (OC) with 30% output is placed after it as the output port. The output prosperities of the laser oscillator and amplifier