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Comb multi-wavelength, rectangular pulse, passively mode-locked fiber laser enhanced by un-pumped Erbium-doped fiber

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A R T I C L E I N F O

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A B S T R A C T

We propose and demonstrate a comb multi-wavelength, nanosecond rectangular pulse, passively mode-locked Erbium-doped fiber (EDF) laser. A section of un-pumped EDF had been employed to optimize the multi-wavelength pulses for the first time to the best of our knowledge. The un-pumped EDF absorbs the unwanted the short-wavelength lasing and optimizes the gain, therefore allowing for the enhancement of the long-wavelength lasing. Because of the gain competition effect in the un-pumped EDF, the output wavelength line number of the fiber laser can be significantly increased from three wavelengths to twenty lasing wavelengths. The mode-locked pulse has a rectangular temporal profile with pump power dependent pulse duration. Experimental results illustrate that the fiber laser has a good stability at room temperature. This work provides a new configuration for the design of multi-wavelength, rectangular nanosecond pulse that may fit for specific applications.

1. Introduction

Rectangular pulse lasers have attracted significant interest for their wide and important applications in many fields, such as all-optical rectangular-wave clocks, fiber grating, and laser micromachining [1–3]. Recently, dissipative soliton resonance (DSR) was theoretically proposed to achieve wave-breaking-free rectangular pulse by properly choosing parameters in the frame of complex Ginzburg–Landau equation [4–7]. By using the nonlinear polarization rotation (NPR) mode-locked technique, the rectangular pulses have been experimentally investigated in fiber ring lasers [8,9]. The rectangular pulse has also been reported in figure-of-eight fiber lasers with net normal dispersion [10] and anomalous dispersion [11]. According to the previous work [8–12], all of the rectangular pulse mode-locked fiber lasers operate in a certain wavelength range. In contrast, little work about multi-wavelength rectangular pulse fiber laser had been reported.

On the other hand, multi-wavelength pulsed fiber lasers have received considerable attention for their versatile applications, including wavelength division multiplexer (WDM) fiber communication systems, photonic component characterization and optical signal processing [13–16]. Recently, Zhang et al. reported a triple-wavelength passively mode-locked fiber laser in an all-normal dispersion cavity with a semiconductor saturable absorber mirror (SESAM) [17]. Luo et al. demonstrated a multi-wavelength fiber laser by using a SESAM and an inline birefringence fiber filter [18]. Up to seventh lasing wavelengths mode-locked pulse in 3 dB bandwidth with 3.65 nm channel spacing are obtained. The number of the lasing wavelength is an important performance parameter for the multi-wavelength fiber laser. And a desirable multi-wavelength source needs large channel count when the channel spacing is given. However, most of the previous research about multi-wavelength mode-locked fiber laser focuses only on the generation of multi-wavelength lasing. And no experimental work has undertaken until now to investigate the improvement on the number of lasing wavelength in a multi-wavelength mode-locked fiber laser.

In this paper, we have experimentally demonstrated a comb multi-wavelength, nanosecond rectangular pulse, passively mode-locked EDF laser by using the nonlinear amplifying loop mirror (NALM) technique and a fiber Sagnac loop comb filter. A section of un-pumped EDF has been inserted in the cavity to operate as a booster which transfers the energy from the higher-energy resonance modes to the lower-energy resonance modes. It is the first time to use the un-pumped EDF for the enhancement of multi-wavelength output in a mode-locked fiber laser. Up to 20 lasing wavelengths are obtained, which represents about six

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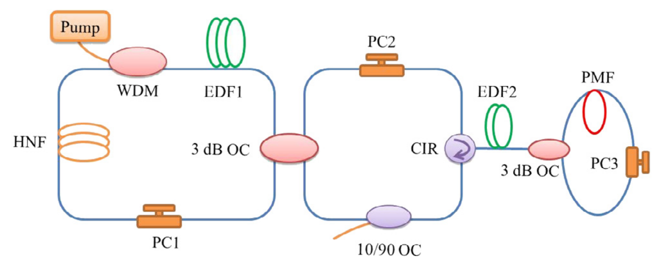

Fig. 1. Experimental setup of the multi-wavelength mode-locked fiber laser. EDF: erbium-doped fiber; WDM: wavelength division multiplexer; HNF: high nonlinearity fiber; PMF: polarization maintaining fiber; PC: polarization controller; OC: optical coupler; CIR: circulator.

times increase in the number of the generated wavelengths compared with that from the fiber laser without the un-pumped EDF.

2. Experimental setup

The experimental setup of the proposed multi-wavelength mode-locked EDF laser is schematically shown in Fig. 1. It is a figure-of-eight configuration which consists of a NALM and a unidirectional ring (UR). A piece of 7 m EDF (EDF1) with an absorption coefficient of 23.9 dB/m @979 nm is used as the gain medium. It is pumped by a 976 nm single-mode laser diode (LD) with the maximum output power of 620 mW through a 980/1550 nm WDM. A segment of 118 m high-nonlinearity fiber (HNF) with a nonlinear coefficient of 10 /W/km is introduced into the NALM cavity to increase the intra-cavity nonlinearity. Two polarization controllers (PC1 and PC2) are used to adjust the polarization state of the circulating light. A section of 1.7 m EDF (EDF2) with the same parameters of EDF1 is inserted in the UR cavity. The fiber optical circulator (CIR) plays the role of an isolator which enforces the unidirectional operation. A fiber Sagnac loop which is made up of a 3 dB optical coupler (OC), PC3 and 4 m polarization maintaining fiber (PMF), is used as a comb filter to select the lasing channels. The output power is extracted from the cavity through a 10/90 OC. A 1 GHz digital phosphor oscilloscope (Tektronix DPO7014C) together with a 45 GHz high-speed photoelectric detector (New Focus 1014) is employed to monitor the traces of the mode-locked pulses. An optical spectrum analyzer (OSA, YOKOGAWA AQ6370B) is used to measure the optical spectrum.

3. Result and discussion

The NALM technique is employed to realize the passively mode-locked state in our fiber laser. By performing the comparison experiment on multi-wavelength fiber laser with or without using EDF2, we are able to understand the contribution of the un-pumped EDF. Firstly, we conduct the experiment without using EDF2. By properly adjusting the orientation of the PCs, the self-started multi-wavelength rectangular pulses mode-locked state can be achieved when the pump power exceeds the threshold. Fig. 2 shows a typical mode-locked state of the multi-wavelength fiber laser at the pump power of 560 mW. Fig. 2(a) is the oscilloscope trace of the output pulse with the repetition rate of

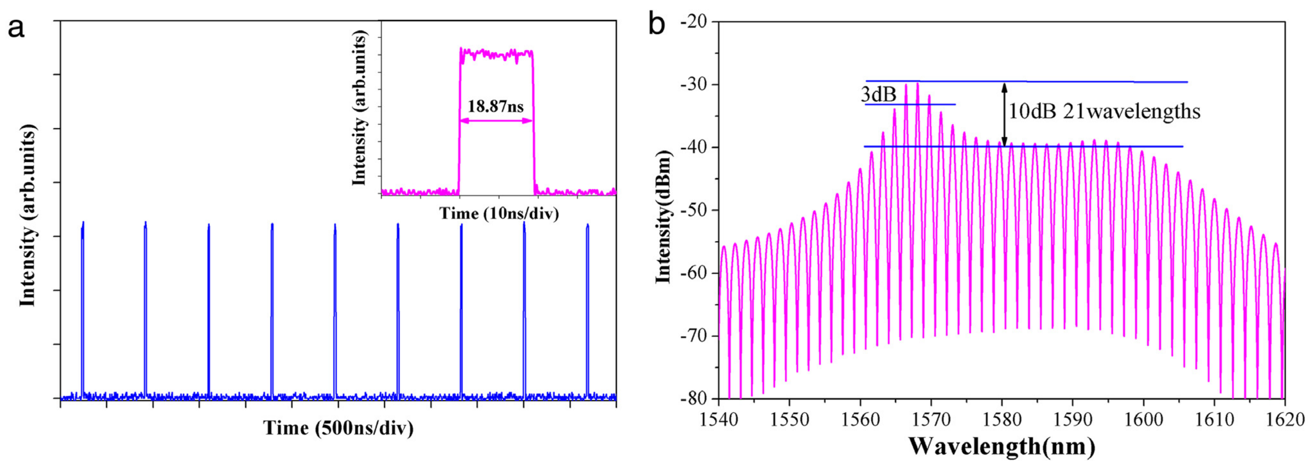

Fig. 2. Typical mode-locked state without EDF2. (a) Oscilloscope trace of the rectangular pulse. Inset: a single pulse. (b) Corresponding optical spectrum.

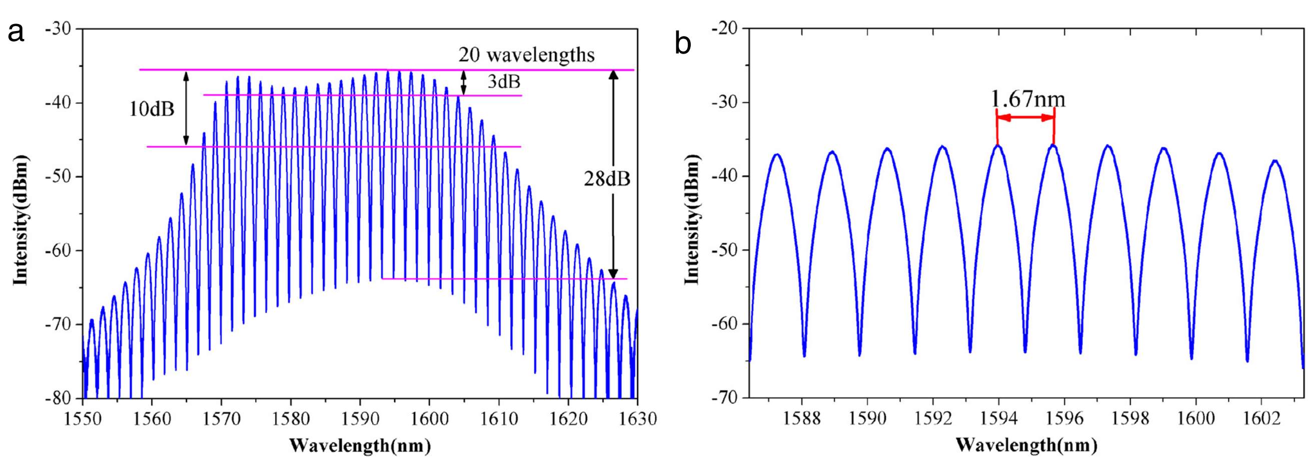

Fig. 3. (a) The output spectrum optimized by EDF2; (b) The enlarged output spectrum.

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