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Tunable dual-wavelength single-longitudinal-mode fiber laser based on spectral narrowing effect in a nonlinear semiconductor optical amplifier

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ABSTRACT

A tunable dual-wavelength single-longitudinal-mode (SLM) fiber laser based on a nonlinear semiconductor optical amplifier (NL-SOA) and an optical comb filter is proposed and demonstrated successfully. The SLM operation principle is based on the spectral narrowing effect resulting from the inverse four-wave mixing (FWM) in a NL-SOA. By inserting the NL-SOA inside the fiber laser cavity, SLM lasing can be possibly achieved when stable laser oscillation is established after many roundtrips through the NL-SOA. Further, tunable dual-wavelength SLM output can be obtained by incorporating a tunable optical filter (TOF) and a comb filter inside the laser cavity to perform dual-wavelength selection function. As a result, tunable dual-wavelength SLM oscillation with a wavelength spacing of 0.4 nm and a wavelength tuning range of about 56 nm has been achieved. Each wavelength has a linewidth less than 8 kHz and a side-mode suppression ratio (SMSR) larger than 40 dB.

1. Introduction

Dual-wavelength single-longitudinal-mode lasers have attracted much interest for the potential applications in microwave and THz generation [1–10] and optical fiber sensor system [11–13] due to the advantage of good coherence. Since SLM operation and dual wavelength output have to be implemented by different techniques separately, it is always a challenge to realize dual-wavelength and SLM oscillation from a fiber laser simultaneously. To date, various techniques have been proposed to achieve dual-wavelength SLM oscillation in fiber lasers. Many reported techniques involve the use of short cavity such as distributed feedback (DFB) and distributed Bragg reflector (DBR) fiber lasers combined with special fiber Bragg gratings (FBGs) [1–4,12–17], the insertion of high finesse sub-cavity or ultra-narrow filters in the cavity [3,4,18], the utilization of combined filtering effect of dual-wavelength filter and unpumped erbium-doped fiber as saturable absorber [5,6,19–21], or the use of Tm-Ho co-doped fiber as a saturable absorber [22,23] and FP-LD injection locking [24]. However, these approaches typically either suffer from very low output power or require somewhat complicated operation to optimize the sub-cavity length or the unpumped fiber length to obtain SLM output.

Recently, Sergei K. Turitsyn et al. presented a new nonlinear self-action effect and self-parametric amplification (SPA), which manifests itself as optical spectrum narrowing in normal dispersion fiber [25]. The narrowing effect results from inverse four-wave mixing, resembling an effective parametric amplification of the central part of the spectrum by energy transfer from the spectral tails. It can be concluded that the spectral width of a multi-longitudinal-mode (MLM) signal becomes narrower after propagation in a sufficient length of normal dispersion fiber. Just recently, we proposed to use an NL-SOA to demonstrate this spectrum narrowing and its application in a fiber ring laser to achieve tunable single-frequency lasing [26]. In this paper, we further successfully applied the spectral narrowing effect in a widely tunable dual-wavelength SLM fiber laser. The NL-SOA can effectively narrow the linewidth of the injected MLM light. As a result, SLM operation can be possibly achieved when stable laser oscillation is established after many roundtrips through the NL-SOA in the ring cavity. By adjustment of a TOF and an optical comb filter (OCF) in the laser cavity, dual-wavelength SLM output with a wavelength tuning range of about 56 nm has been demonstrated experimentally. The results show the linewidth of each wavelength is less than 9 kHz and the signal-to-noise ratio (SNR) is large than 40 dB. The proposed dual-wavelength SLM fiber laser has the advantage of simple configuration and wide wavelength tuning range.

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2. Experimental setup and operation principle

The experimental setup of the proposed fiber laser is shown in Fig. 1. It contains a conventional semiconductor optical amplifier (SOA-S), a NL-SOA, a TOF, an OCF, two polarization controllers (PCs), two isolators (ISOs) and an 80:20 optical coupler. The SOA-S used in the experiment offers the optical gain in the cavity and has a maximum gain of about 23 dB and a bandwidth of about 60 nm. The central wavelength band can be adjusted by the TOF, while the OCF divides the whole waveband filtrated by TOF into several channels with wavelength separation to be about 0.4 nm. The insertion losses for the OCF and the OTF are 0.5 dB and 2.0 dB, respectively. The main function of the NL-SOA is to compress the laser linewidth, with a supplementary function of offering a small part of gain in the cavity. An ISO and a PC are inserted before each SOA to ensure unidirectional operation and to optimize gain performance respectively. The output of the fiber laser is existed through the 20% output port of the optical coupler and is measured by a 0.02 nm resolution optical spectrum analyzer (OSA) and a 13.6 GHz bandwidth electrical spectrum analyzer (ESA) after being detected at a photodetector (PD) through the two output ports of a 50:50 optical coupler respectively.

The key component in the proposed fiber laser scheme is the NL-SOA. Similar to the spectral narrowing effect in a normal dispersion fiber which is due to the inverse FWM [25], spectral narrowing effect resulted from inverse FWM can also occur in a NL-SOA with normal dispersion [26]. Therefore, a SLM operation can be achieved when a stable laser oscillation is established [26]. Dual-wavelength SLM output can be obtained when the coarse and fine wavelength tunability is done by tuning the center wavelength of the TOF to filtrate different pair of adjacent channels of the OCF. The wavelength separation of the fiber laser depends on the channel separation of the OCF, which can be tuned by using an OCF with tunable free spectral range (FSR).

3. Results and discussion

In experiment, the drive currents of the NL-SOA and the SOA-S are set to be 100 mA and 125 mA respectively. The center wavelength of the TOF is tuned to be 1530.8 nm and the bandwidth is adjusted to filtrate the adjacent 1530.6 nm and 1531.0 nm channels of the OCF. The filtering spectrum of the OCF before and after the TOF is measured as shown in Fig. 2. It can be seen that only the two channels, which are used to define the laser wavelength, are

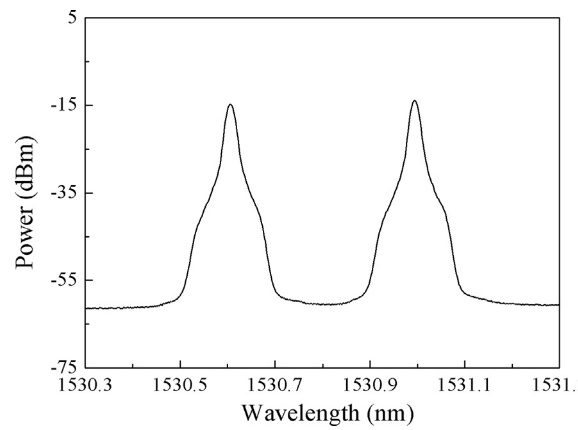

Fig. 3. Output optical spectrum of the proposed dual-wavelength SLM fiber laser.

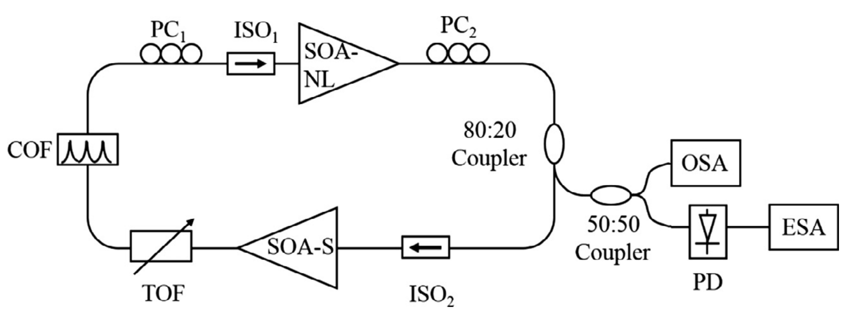

Fig. 1. Experimental setup of the proposed dual-wavelength SLM fiber laser.

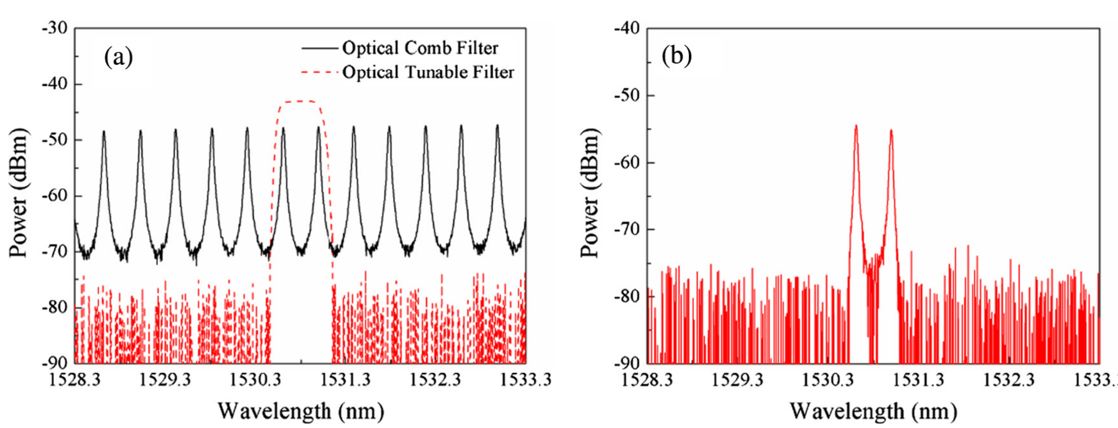

Fig. 2. (a) Individual transmission spectrum of the OCF (black solid line) and the OTF (red dotted line), and (b) overall transmission spectrum of the OCF and OTF. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)