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Switchable single-polarization dual-wavelength TDFL using PM Fabry–Perot filter

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ABSTRACT

A switchable single-polarization (SP), dual-wavelength thulium-doped fiber laser using polarization maintaining (PM) Fabry–Perot (F–P) filter is proposed. A combination of the PM F–P filter, a polarization controller (PC) and a polarizer is used to ensure the SP lasing operation. A stable dual-wavelength lasing operation is obtained at 1941.82 nm and 1942.21 nm. By adjusting the PCs, the proposed laser can achieve SP single-wavelength lasing operation; the polarization extinction ratios are higher than 33 dB. When the pump power is higher than 2.98 W, the optical signal-to-noise ratios of the SP single-wavelength operation can reach 60 dB, and the output power variations are less than 0.32 dB (*X*-polarization) and 0.30 dB (*Y*-polarization). The slope efficiencies of SP lasing operation are 6.26% (*X*-polarization) and 8.79% (*Y*-polarization), respectively.

1. Introduction

Dual-wavelength fiber laser has attracted considerable attention in recent years, which has been successfully applied in optical fiber sensing, the terahertz radiation and the wavelength division multiplexing system, et al. The dual-wavelength lasing operation can be realized by using twin core fiber-based filter [1,2], a polarization maintaining fiber (PMF) filter [3], a Wave-Shaper [4], or an arrayed waveguide grating [5]. Different kinds of dual-wavelength thulium-doped fiber lasers (TDFLs) have been proposed by using different techniques in the recent years. We had reported a switchable and spacing-tunable dual-wavelength TDFL, which used two fiber Bragg gratings (FBGs) as the filters [6]; Wang et al. demonstrated a 2 μm switchable dual-wavelength TDFL, which used the filter based on dual-channel Mach–Zehnder interferometer (MZI) and spatial mode beating effect [7]; Soltanian et al. proposed a stable dual-wavelength TDFL operating at 1.9 μm using a 10 cm length of photonic crystal fiber acted as a MZI [8]; A switchable, tunable and power-controllable dual-wavelength TDFL was realized by parallel cavities. The two individual cavities of fiber laser are based on the parallel connection of FBGs using 3 × 3 coupler [9]; Jia et al. designed a widely tunable, dual-wavelength TDFL operating at 1.9 μm, which used a comb filter based on a Sagnac loop incorporating a length of PMF [10]; Ismail et al. showed a tunable dual-wavelength TDFL operating at 1.8 μm, which used a 70 mm non-adiabatic taper fiber filter [11].

These various filters based on the FBGs written into the PMF have also been investigated for dual-wavelength lasing operation. Using the polarization maintaining fiber Bragg gratings (PM-FBGs) filters in the laser cavity, the two linear orthogonal polarization modes are separated in different wavelengths. The polarization characteristic of PM-FBGs is beneficial to enhance polarization hole burning (PHB) in the laser cavity [12,13]. The enhanced PHB effect cannot completely overcome the mode competition in the gain medium. However, assisted by enhanced PHB effect, the stable dual-wavelength lasing operation can be easily achieved. Liu et al. proposed a stable dual-wavelength EDFL with tunable wavelength spacing using an all-PM linear cavity, the laser cavity made use of two reflection peaks from the PM-FBGs [14]; Álvarez-Tamayo et al. demonstrated a linear cavity dual-wavelength fiber laser using a PM-FBG as an end mirror [15]; El-Damak et al. reported a dual-wavelength linearly polarized fiber laser, which consisted of two pairs of PM-FBGs to form a cavity and an Er/Yb co-doped fiber as a gain medium [16]; We had reported the stable dual-wavelength TDFLs using PM-FBG and PM chirped Moiré FBG, respectively [17,18]. Compared with other filters, using the PM-FBGs filter is a simple and effective method in dual-wavelength lasing operation.

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The single-polarization (SP) lasing output is usually archived by using PMF or FBGs written into PMF. Manyam et al. demonstrated a single mode, SP lasing output in large mode area fiber laser, which used a multimode PMF as the mode filter and polarization filter [19]; Guan et al. showed a SP ytterbium-doped fiber laser, which used a PM-FBG as the polarization dependent reflector to generate the SP lasing output [20]; Wang et al. reported an all-fiber linearly-polarized fiber laser at 1120 nm, the laser consisted of a ytterbium-doped PMF and a pair of FBGs written in matched passive fiber [21]; Feng et al. designed a EDFL configuration to achieve SP switchable dual-wavelength of orthogonal polarizations oscillations at room temperature. In the laser cavity, two PM-FBGs and a PM erbium-doped fiber were used to ensure the SP lasing output [22]; Yin et al. proposed a switchable SP dual-wavelength EDFL, which used the taper PM chirped FBG to achieve SP lasing output [23]. However, the dual-wavelength TDFL using a PM-FBG to achieve SP lasing output has seldom been investigated.

In order to achieve simultaneous lasing at two closely-spaced wavelengths, the mode competition in the homogeneously broadened gain medium should be tackled. Various techniques had been proposed to realize multi-wavelength operation, for instance, reducing the homogeneous broadening of the gain medium by cryogenic cooling [24], using the multiple or multicore doped fibers [25,26], accurately adjusting the cavity loss equalization at different wavelengths [27], inserting a frequency shifter in the laser cavity [28], using spatial or polarization hole burning [29], and combining the nonlinear effect [30–33]. In this paper, a nonlinear amplifying loop mirror (NALM) is used to overcome the mode competition.

In this paper, a switchable SP dual-wavelength TDFL using PM Fabry–Perot (F–P) filter is first proposed in 2 μm band. The PM F–P filter is used as the wavelength selection component. A combination of the PM F–P filter, a polarization controller (PC) and a polarizer is used to ensure the SP lasing operation. At room temperature, the proposed scheme allows stable dual-wavelength lasing operation and stable SP single-wavelength lasing operation. The stability of the SP single-wavelength fiber laser versus the pump powers is measured. Furthermore, the slope efficiency of the SP single-wavelength fiber laser has also been investigated.

2. Experimental setup

The experimental schematic of the proposed switchable SP dual-wavelength TDFL using PM F–P filter is shown in Fig. 1. The gain medium is a 5 m commercial double-cladding TDF (CorActive). The double-cladding fiber has the core diameter of 6.3 μm and the inter-cladding diameter of 125 μm, respectively. The gain fiber is pumped by a 793 nm laser diode (LD) with the maximum output power of 12 W through a 793/2000 nm fiber combiner (FC). The optical circulator (OC) is applied to ensure the unidirectional oscillation. The broadband PM-FBG is used as a back reflector. The PM F–P filter is used as a polarization dependent wavelength selection component. The PM F–P filter, the PC2 and the polarizer are used to ensure the SP lasing operation. The left loop of the NALM in Fig. 1, 8 m in length, consists of the 5 m TDF and the 3 m single-mode fiber (SMF). The SMF is composed of pigtailed fiber of the FC, the PC1 and the 50% fiber coupler. The right loop includes a 7 m SMF which is the pigtailed fiber of the OC, the PC2, the polarizer, the 10% fiber coupler and the FBGs. So the length of total laser cavity is about 15 m. The NALM is used to overcome the mode competition. A optical spectrum analyzer (YOKOGAWA AQ6375, OSA) is adopted to receive 10% output power from the laser cavity. The resolution of the OSA is 0.05 nm.

The PM F–P filter and the broadband PM-FBG are fabricated in hydrogen-loaded PMF by using same phase mask (the period

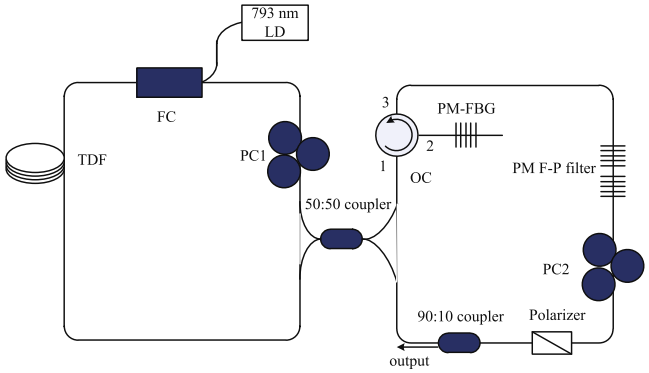

Fig. 1. Experimental setup of the proposed switchable SP dual-wavelength TDFL using PM F–P filter.

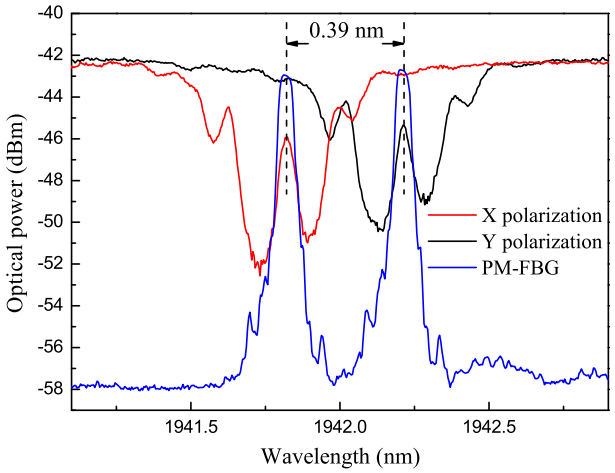

Fig. 2. Transmission spectrum of the PM F–P filter and the reflection spectrum of the broadband PM-FBG.

$\Lambda = 1347.3$ nm) and a 248 nm KrF excimer laser. The PM F–P filter is composed of a pair of uniform FBGs which are written in the same hydrogen-loaded PMF. Fig. 2 shows the transmission spectrum of the PM F–P filter and the reflection spectrum of the broadband PM-FBG. In the measurement, a supercontinuum laser (Koheras Co., SuperK) was used as a polarized white light source. The PMF has different effective refractive indices in *X*- and *Y*-polarization modes respectively. Thus the PM F–P filter exhibits two frequency notches, which are corresponding to *X*- and *Y*-polarization reflection peaks generated by broadband PM-FBG. By adjusting the PC in front of the PM F–P filter, the transmission spectra of the two orthogonal polarization states were observed. It can be seen in the Fig. 2 that the wavelengths of the PM F–P filter transmission peaks which are 1941.82 nm and 1942.21 nm, which corresponding to *X*- and *Y*-polarization states. In order to realize switchable SP lasing, the broadband PM-FBG is used to select two adjacent transmission peaks.

3. Experimental results and discussion

In the experiment, the pump power was fixed at 2.75 W. The PM F–P filter separates two wavelengths into two orthogonal polarizations and the mode competition is suppressed by the NALM technique. By adjusting the PCs, the cavity loss for each wavelength lasing of the fiber laser varied. When the cavity losses