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Switchable multi-wavelength laser based on a core-offset Mach-Zehnder interferometer with non-zero dispersion-shifted fiber

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ABSTRACT

In this paper, a switchable multi-wavelength erbium-doped fiber ring laser, based on a core-offset Mach-Zehnder interferometer (MZI) with non-zero dispersion shifted fiber (NZ-DSF), is proposed and experimentally demonstrated. Here, the core-offset MZI was implemented by fusion splicing a segment of a NZ-DSF between two single-mode fiber sections. In the proposed ring cavity design, the core-offset MZI is acting as a wavelength selective filter and it is optimized in order to achieve a single-mode suppression ratio (SMSR) of about of 56 dB. In addition, the laser is capable of emitting a single, double, or triple line, which can be switched from 1546 to 1564 nm by controlling its polarization states. Finally, this laser fiber offers a high output power stability at room temperature, compactness, robustness and low implementation cost.

1. Introduction

Multi-wavelength erbium doped fiber lasers (MWEDFLs) have been used as light sources due to their unique properties such as high output power, low threshold, high signal-to-noise radio, high stability at room temperature, and low fabrication cost [1,2]. For theses reasons, the MWEDFLs are widely applied in spectroscopy, optical fiber sensing, fiber device testing, optical signal processing, and wavelength division multiplexing for communication systems [3–7]. However, the main challenge to obtain a MWEDFL is suppressing the unstable mode competition produced by the homogeneous broadening of the erbium doped fiber (EDF) spectrum [8]. In order to overcome this drawback, a wavelength selective filter (WSF) can be inserted in the laser cavity [9]. The WSF can be implemented by using modal interferences such as: acoustic optical filters [10], non-adiabatic microfiber [11], microfiber couplers [12], Fabry-Perot interferometer (FPI) [13–16], Sagnac interferometer [17,18], and Mach-Zehnder interferometer (MZI) [19–26]. Among them, the MZIs possess the advantages of low cost, high sensitivity, flexible structure, and simple configuration for a MWEDFL application. In literature, several multi-wavelength fiber lasers using a MZI as a WSF can be found. For instance, in [19] a MZI was implemented by core-offset fusion splicing one section of a few-mode fiber between two single mode fibers, and it was capable to switch the laser in a single, double, triple, and quadruple line with an average single-mode suppression ratio (SMSR) of 54 dB. Another example of a MWEDFL was reported in [20], where the MZI was formed by an all-fiber single-mode core-offset structure, in which a single laser line was obtained and the SMSR was about of 47 dB. In [21] Zou et al. proposed a wavelength-tunable fiber laser with a SMSR of 45 dB; in this case, the MZI was manufactured by splicing of a piece of twin-core fiber between two standard single mode fibers. Other cases of MWEDFLs based on MZIs were demonstrated in [22,23], where the author reported lasers with triple emission lines and SMSRs from 30 to 45 dB. In those works, the MZIs were manufactured by fusion splicing a segment of photonic crystal fiber (PCF) between two SMFs. Shi et al. [24], reported a MWEDFL where a MZI was based on a pair of long-period grating (LPGs) and the laser emitted a single line with a SMSR of 50 dB. Recently, a dual-wavelength erbium-doped fiber laser was demonstrated using a MZI implemented with a segment of Nd-doped fiber

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spliced between two pieces of SMFs, where a double line emission with a SMSR of 46 dB [25].

In this work, a switchable multi-wavelength erbium-doped fiber laser based on a core-offset MZI is presented. Here, the MZI was manufactured by core-offset fusion splicing a segment of NZ-DSF between two pieces of SMFs forming a SMF/NZ-DSF/SMF structure and, to the best of our knowledge, was used for the first time as a WSF in a laser ring. The laser can be switched in a range from 1546 to 1564 nm with a SMSR of 56 dB. Moreover, this laser can emit a single, double or triple line by controlling polarization states. Finally, the principle operation is discussed and a high stability at room temperature of the MWEDFL is experimentally demonstrated.

2. Fabrication process and operation principle of the MZI based on a NZ-DSF

As it is known, the most important component of a fiber laser is the design of the wavelength selective filter, since it avoids the gain competition produced by the homogeneous broadening of the EDF. For this reason, in our experiment a core-offset MZI was used as WSF. This MZI was implemented by core-offset fusion splicing a 2.5 cm segment of NZ-DSF (Corning Fiber Model SMFLF) between two SMFs using a commercial splicer machine (Fitel S175) following the technique reported in [27]. The NZ-DSF has a core diameter of 5.8 µ m, a ring core with a diameter of 16 µm and a thickness of 3 µm, and a cladding diameter of 125 µm (see Fig. 1a); for further reference, all modal properties of this fiber were reported in [28]. The first core-offset fusion splice was obtained by core aligning the NZ-DSF and the SM fiber first, and then by moving the NZ-DSF downward for a distance of 30 µm, and finally applying 20 discharges to the joint (see Fig. 1b). The other NZ-DSF joint was carried out using the same parameters, and as a result a SMF|NZ-DSF|SMF structure was obtained (see Fig. 2). Here, it is important to point out, that when a MZI is used as a wavelength selective filter, the extinction ratio is a very important parameter in order to obtain a switchable laser [29,30]. Thus, several interferometers were implemented using different lengths of NZ-DSF and different downward distances in order to obtain the highest value of the extinction ratio. In this work, we used a length of 2.5 cm of NZ-DSF and 30 µm of core-offset, since with this displacement, a 20 dB of extinction ratio was achieved [27]. In the other hand, the splicing joints were obtained using the splicer machine in manual mode with the following parameters: (a) 91 of arc power, (b) 240 ms of prefusion time, and (c) 750 ms of arc

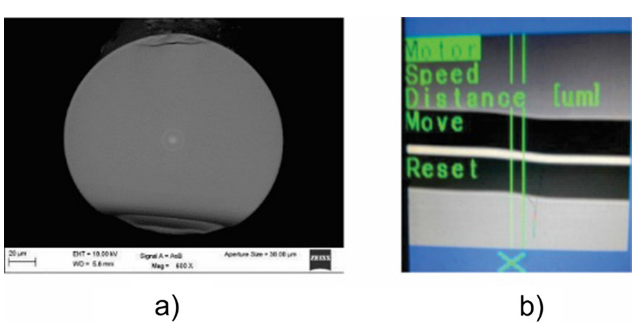

Fig. 1. (a) Image NZ-DSF, (b) core offset splice.

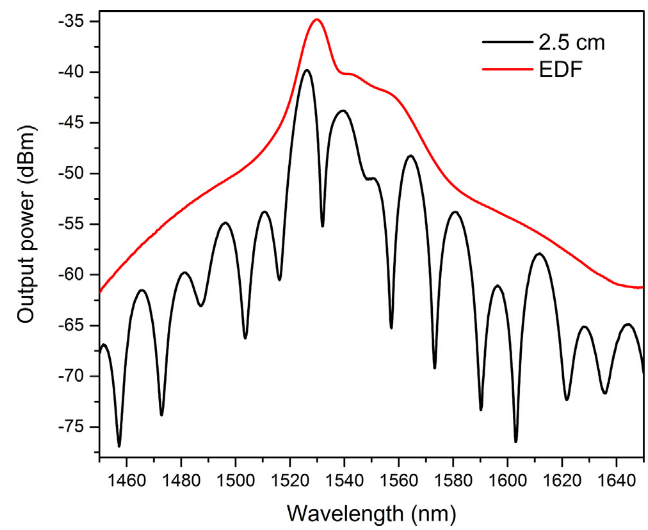

Fig. 3. Output power spectrum of the EDF and of the core-offset MZI.

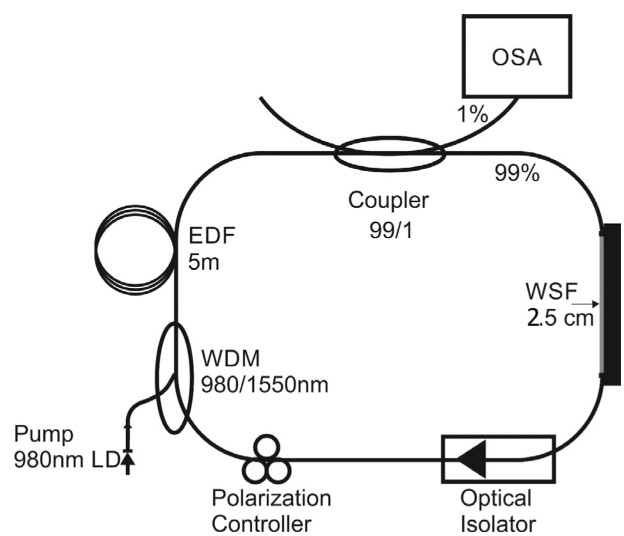

Fig. 4. Experimental setup of the multi-wavelength erbium-doped fiber laser.

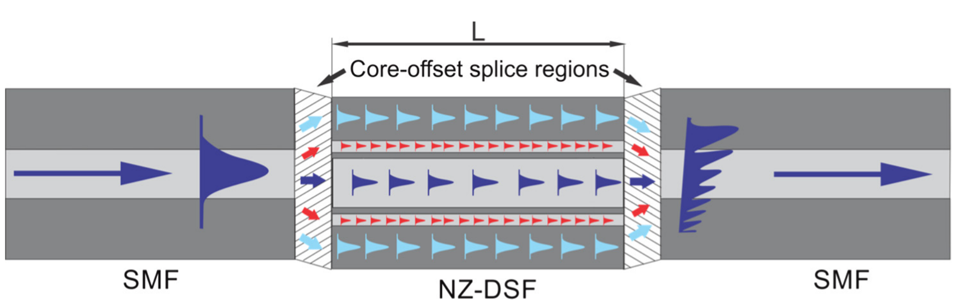

Fig. 2. Core-offset MZI Schematic diagram.