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Tunable single wavelength erbium-doped fiber ring laser based on in-line Mach-Zehnder strain

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ABSTRACT

A tunable single-wavelength of an erbium-doped fiber ring laser is proposed and demonstrated. The laser integrates a tapered in-line Mach-Zehnder interferometer (IMZI) in its ring loop as an intracavity filter. The light spectrum is adjusted by changing an axial strain of the interferometer in a 60 μm range. As a result, a total tuning range of 6.19 nm that covers the wavelength from 1552.94 nm to 1559.13 nm is observed, and the sensitivity of 103.5 pm/μm is recorded. This high sensitivity lasing behavior is useful for high selectivity and fine tuning for narrow wavelength applications.

1. Introduction

Fiber optic sensors have enticed a considerable research attention and have been extensively used to detect the refractive index [1], temperature [2], magnetic field [3], gases [4], current [5], strain [6], and other parameters due to their special properties of smaller size, electromagnetic immunity, low attenuation, high response to surrounding environmental, and low cost. Many kinds of optical fiber techniques have been used as strain sensors like Fiber Bragg Grating [7], Fabry–Perot interferometer [8], displacement sensor using multimode interference technique by splicing a section of multimode fiber to single mode fiber [9] and IMZI with an inner air cavity along the fiber length or photonic crystal fiber [10,11]. The principle of Mach-Zehnder interferometer depends on the interference induced by the phase deference between the core and cladding modes. This is due to the difference in the effective refractive index (RI_{eff}) as an effect of change in the surrounding medium or the geometrical dimensions of MZ interferometer [12,13]. Varity tunable filters have been proposed and demonstrated for achieve a tuning fiber laser such as fiber Bragg grating [14], three band pass filters [15], Fabry-Perot filter [16], multimode interference effect [17], and tunable birefringence comb filter using a semiconductor optical amplifier with a Sagnac loop interferometer. [18]. Although there have been reports from the same group concerning fiber lasers covering the optical network bands [19–21] there is a need to explore tunable single wavelength fiber laser.

In this paper, we demonstrated the IMZI as a tuning device implemented in an erbium-doped fiber laser based on differential axial strain adjustment. The sensitivity of the sensor is 103.5 pm/$\mu\varepsilon$ and the value is obtained by adjusting the axial

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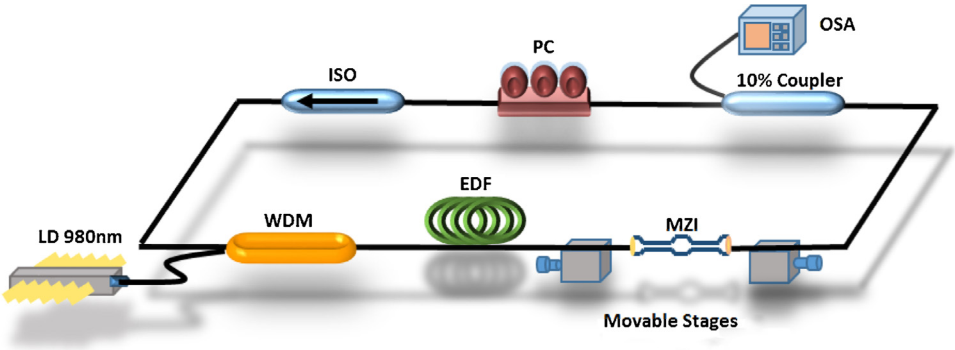

Fig. 1. Experimental setup of the tunable single wavelength EDF laser by strain.

strain to vary the RI_{eff} of the optical fiber core and cladding modes. Consequently, this will induce different resonance of wavelength shifts. The fabricated IMZI waist diameter is 10 μm and the total length is 38 mm [2].

The light that propagated through an IMZI device is split into two output components; guided modes that continue to travel in the core and unguided modes that extend through the cladding-air interface. The unguided modes allow the evanescent field to react with the ambient medium that caused propagation delay and hence, shifting in the wavelength when the modes recombined at the end of the IMZI devices. Since IMZI devices allow for splitting and recombining of modes at the interferometer region, an interference signal can be realized. The phase difference $\boldsymbol{\Phi}$, between core and cladding modes can be given as:

$$\Phi = \frac{2\pi \Delta n_{eff} L}{\lambda} \tag{1}$$

where Δn_{eff} is the difference of the RI_{eff} between the core and the cladding modes, L is interference length of IMZI sensor, and λ is the operating wavelength [22]. The attenuation maxima wavelengths λ_m are characterized by

$$\Phi = (2m+1)\pi \tag{2}$$

where m is an integer. The separation of attenuation maximum wavelengths $\Delta\lambda_m$ is given by

$$\Delta\lambda_m = \lambda_m - \lambda_{m-1} \approx \frac{\lambda^2}{\Delta n_{eff} L} \tag{3}$$

Thus, the interference pattern changes correspond to the changes of the sensing length, and this is an effect of an external axial strain applied to the sensor. Therefore, the shift of the interference peak or dip can monitored to measure the strain [23].

When L increases, the RI_{eff} of cladding modes will increase. However the RI_{eff} of the core modes stays almost constant and Δn_{eff} reduces by δn_{eff}. By (1) and (2), λ_m will be shifted to the shorter wavelength by $\delta\lambda_m$ [24].

$$\delta\lambda_m \approx 2\pi L \delta n_{eff} \tag{4}$$

2. Experimental arrangement

A schematic diagram to measure the strain is shown in Fig. 1. It consists of a laser pump (LD980 nm), a wavelength division multiplexer (WDM), a 3 m long EDF as a gain medium, an IMZI that is sandwiched between two adjustable stages with 13 cm separation distance, a 90/10 coupler, a polarization controller (PC), and an isolator (ISO). The output of the laser was measured simultaneously using an optical spectrum analyzer (OSA, Yokogawa AQ6370B) through the 10 percent port of the coupler.

To fabricate an IMZI we used a standard single mode fiber (SMF) with core and cladding diameters of 8 μm and 125 μm, respectively. Once stripped and cleansed, the fiber was placed on to the motorized fiber holding blocks of a fiber glass processing system Vytran GPX-3400 to taper according to different parameters setting. It is noted that the transition length, the length and the diameter of the waist of the tapered fiber can be precisely controlled during this process so that the adiabaticity and uniformity can be ensured. The tapering system Vytran GPX-3400 uses filament-based heater to soften the fiber while the fiber holders are used to pull the fiber to create the tapered dimensions. The pulling speed and power were set at constant values of 1 mm/s and 42 W, respectively, to ensure the uniformity and the reproducibility of the fabricated tapered fibers. The heating element of the Vytran is fixed. In order to fabricate two tapered regions, firstly the first region is tapered until the desired waist diameter was achieved. Then, the fiber holders were shifted to approximately 1 cm from the first tapered region, and the machine started tapering the second region. The schematic diagram of the IMZI sensor is