Theoretical and Experimental Investigation of Multi-Wavelength Fiber Laser

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ABSTRACT

In this paper, a method for realizing a stable multi-wavelength EDFL at room temperature is analyzed theoretically and obtained experimentally. We have proposed a multi-wavelength fiber ring cavity laser by using EDF as the gain medium. A F-P and a band-pass filter are inserted into the cavity to achieve the selection of multi-wavelength. Meanwhile, by inserting a nonlinear optical loop mirror (NOLM) in the linear cavity, which can suppresses the mode competition owing to the homogeneous broaden line in EDF and eliminates the unstable single wavelength lasing, stable output can be obtained at room temperature. As a result, power-stable, broad bandwidth and uniform multi-wavelength operations with narrow line-width and high side mode suppression ratio are obtained at room temperature. In addition, we also demonstrate a kind of tunable multi-wavelength EDFL based on multi-channel FBG (M-FBG). Four-wavelength output with the flatness and SNR of almost 1dB and more than 50dB is achieved and the output wavelength can be changed by applying stress on the M-FBG.

Key words: multi-wavelength; fiber laser; EDF; ring cavity

1. INTRODUCTION

Dense-wavelength division multiplexing (DWDM) is one of the key technologies for capacity expansion in optical fiber network systems. The multi-wavelength laser is an important component in DWDM transmission systems. The main gain mediums used in multi-wavelength EDFL include erbium doped fiber amplifiers (EDFA), Raman amplifiers, and semiconductor optical amplifier (SOA). Compared to SOA and Raman amplifiers, EDFA has advantages due to the reason of their low insertion loss and flatter gain spectrum, the Erbium-doped fiber laser (EDFL) has been one of the most promising light sources in DWDM systems [1-3].

Previously, several approaches have been proposed and demonstrated to achieve multi-wavelength output. Multi-wavelength oscillations have mostly achieved by inserting various elements such as feedback device and interferometer filters into the cavities [4]. For example, Sagnac interferometer, F-P filter and FBG are all used to obtain multi-

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wavelength [5]. Other methods like using special fiber or the nonlinear effects of the fiber also have been demonstrated [6]. However, since the homogeneous line broadening of erbium ions leads to great mode competition, it is not easy to obtain the stable multi-wavelength operation at room temperature. Putting the EDF in liquid nitrogen can suppress the mode competition induced by the homogenous line broadening, but this method is impractical in many applications. To obtain multi-wavelength output, several approaches have been proposed recently. Graydon obtained 3 to 8 wavelength at room temperature by a specially designed erbium-doped twin-core fiber used to provide inhomogeneous gain through macroscopic spatial hole-burning [7].

In this letter, we investigate and experimentally demonstrate a multi-wavelength EDFL based on F-P and band-pass filter. With the intensity-wavelength dependent loss induced by the NOLM, the multi-wavelength output can be achieved at room temperature. In addition to this, we also propose a tunable multi-wavelength EDFL based on M-FBG. By increase the stress put on the M-FBG, continuously tunable lasing output has been obtained.

2. MULTI-WAVELENGTH EDFL BASED ON F-P AND BAND-PASS FILTER

2.1 Experimental setup

The experimental configuration of the proposed multi-wavelength EDF laser based on F-P and band-pass filter is shown in Fig. 1. An erbium-doped fiber amplifier (EDFA) is used to provide the gain of the laser. A F-P etalon and a band-pass filter are inserted into the cavity as the wavelength selector. The isolator is used to ensure the unidirection of the laser. The output is extracted from the cavity by a 10:90 fiber coupler, with which 90% power is fed back into the EDFA to get gain and 10% power is used as the laser output. A PC is exploited to adjust the polarization state in the ring cavity. The final output through the 10 % output port of the optical fiber coupler is measured by an optical spectrum analyzer with 0.1 nm resolution. Moreover, in order to suppress the mode competition owing to the homogeneous broaden line in erbium-doped fiber, a NOLM is constructed by splicing two output ports of the optical coupler with a 96:4 power splitting ratio. The NOLM consists of 1km highly nonlinear fiber (HNLF) with nonlinear coefficient 10/(W*km), and a PC for controlling the polarization state of the laser.

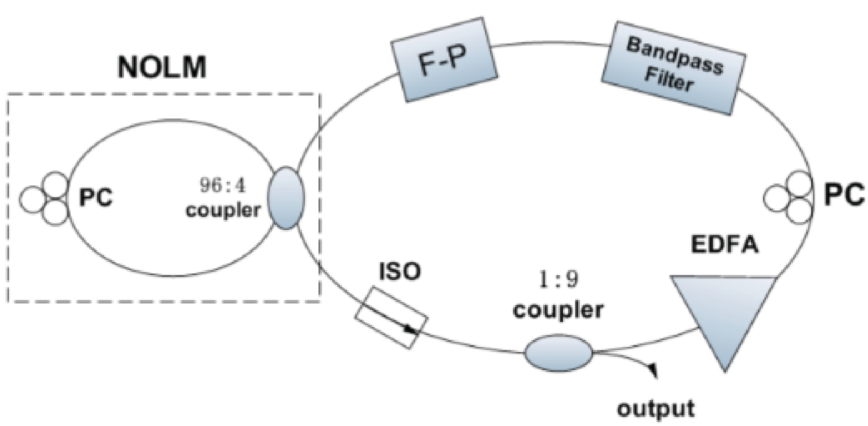

Fig. 1. Setup for the multi-wavelength fiber laser based on F-P and band-pass filter

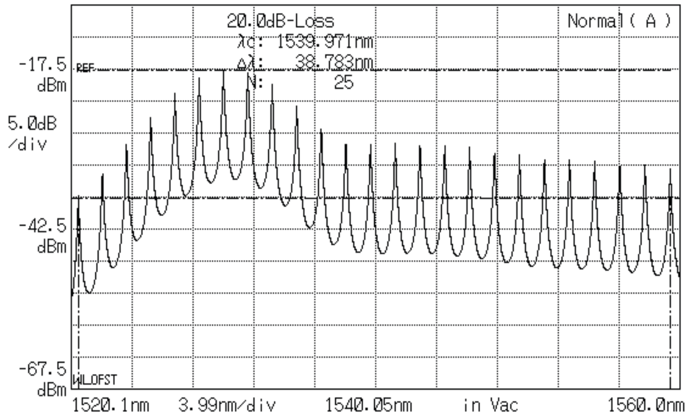

Fig. 2(a) transmission spectrum of F-P filter

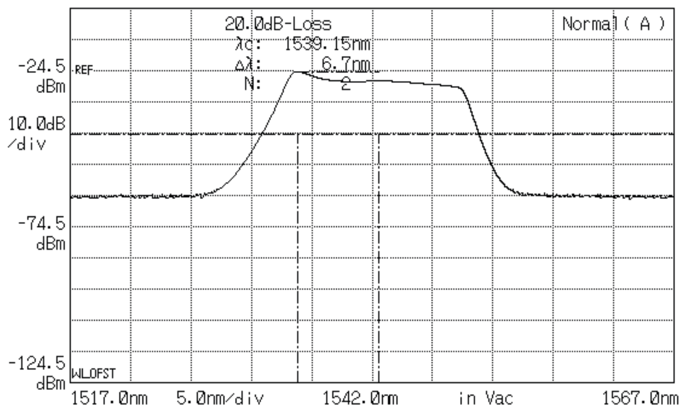

Fig. 2(b) transmission spectrum of band-pass filter

The transmission spectrum of the F-P filter is shown in Fig. 2(a). This figure is obtained by the ASE source from the EDFA and the channels spacing of F-P filter is 1.6 nm with the range of 1520-1560nm. Fig. 2(b) depicts the transmission spectrum of the band-pass filter.

2.2 Results and discussion

At first, 3 wavelength output have been obtained only by carefully adjusting the PC and the loss in the cavity, without inserting NOLM into the cavity. The result is shown in the Fig. 3(a).

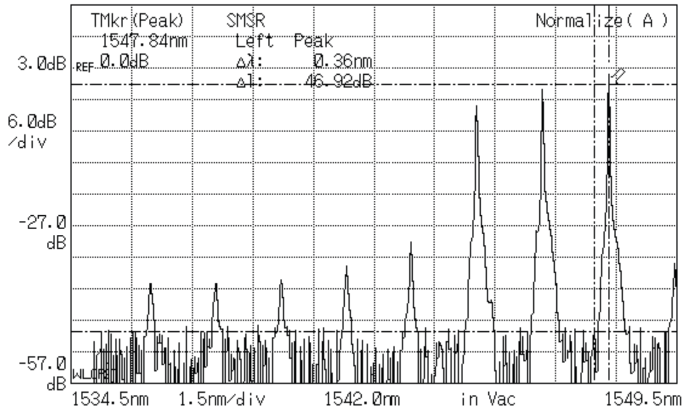

Fig. 3(a) three wavelengths output spectrum of the multi-wavelength EDF laser

The maximum power intensity difference among the peak values of the lasing wavelengths is about 4dB and the side mode suppression ratio is better than 40dB. The peak power variations in each wavelength are measured to be almost 0.5dB. Though multi-wavelength has been achieved, the output peak flatness is not very well because of the mode competition due to the homogeneous broaden line in erbium-doped fiber. Since the intensity-wavelength dependent loss induced by the NOLM can effectively suppress the mode competition of the EDF, the stable output at room temperature can be obtained by adjusting the PC in the NOLM, as shown in Fig. 3(b).

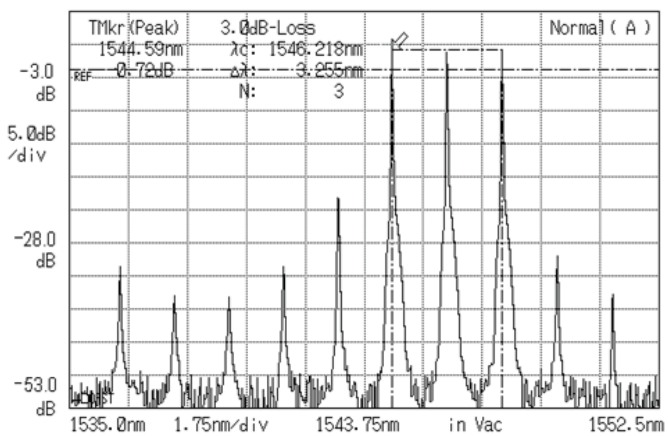

Fig. 3(b) three wavelengths output spectrum of the multi-wavelength EDF laser

By inserting NOLM into the cavity, the output peak flatness is measured to be less than 0.5 dB with high side mode suppression ratio of more than 50dB. The 3dB bandwidth of each wavelength is about 0.09nm.

3. TUNABLE MULTI-WAVELENGTH EDFL BASED ON M-FBG

3.1 Experimental setup

Except researching on the multi-wavelength EDF laser (M-EDFL) based on F-P and band-pass filter, we also experimentally investigate another kind of M-EDFL based on M-FBG. As it is shown in Fig. 4, the laser consists of a

EDFA, a PC, an isolator, a 10/90 optical coupler, a optical circulator and a M-FBG. The transmission spectrum of M-FBG is shown in Fig. 5.

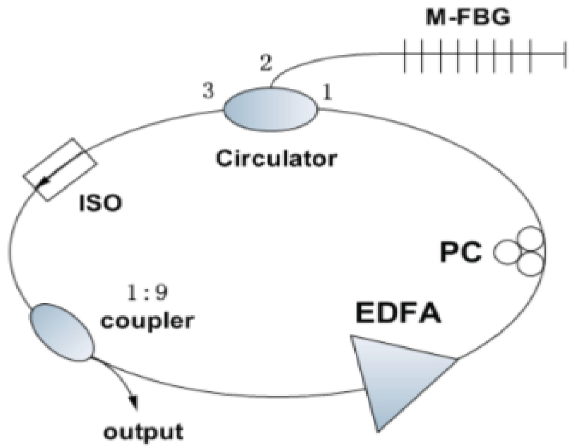

Fig. 4 Setup for the multi-wavelength fiber laser based on M-FBG

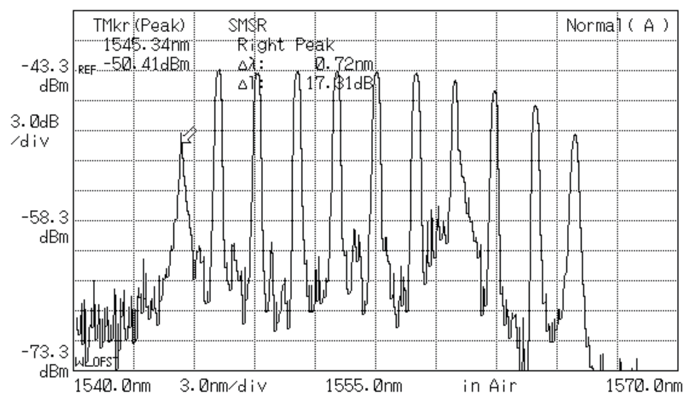

Fig. 5 transmission spectrum of M-FBG

3.2 **Results and discussion**

In the experiment, when the PC and the loss in the cavity is adjusted to an appropriate state, simultaneous four-wavelength lasing can be achieve as depicted in Fig. 6.

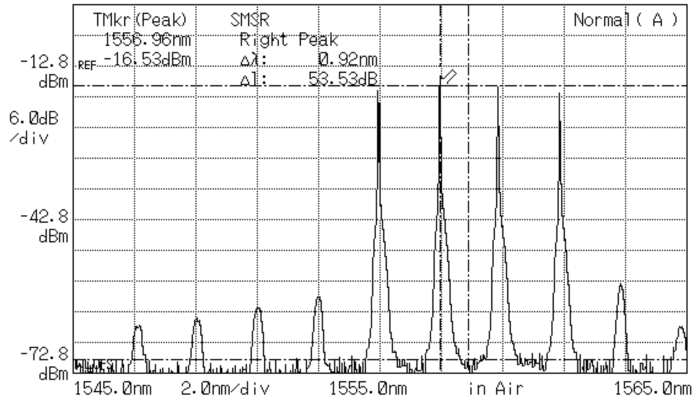

Fig. 6 four-wavelength lasing output

The output wavelengths are 1554.92nm、1556.96nm、1558.84nm and 1560.84nm with side mode suppression ratio 53.53dB.The power of each output lasing are -17.38dBm、-16.53dBm、-16.71dBm、-17.92dBm.

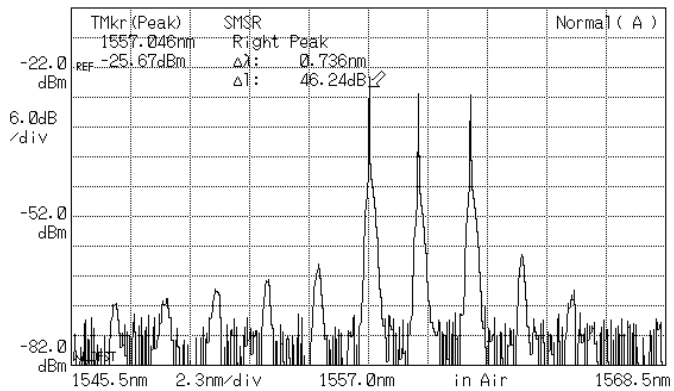

Fig. 7(a) three-wavelength lasing output (without applying stress)

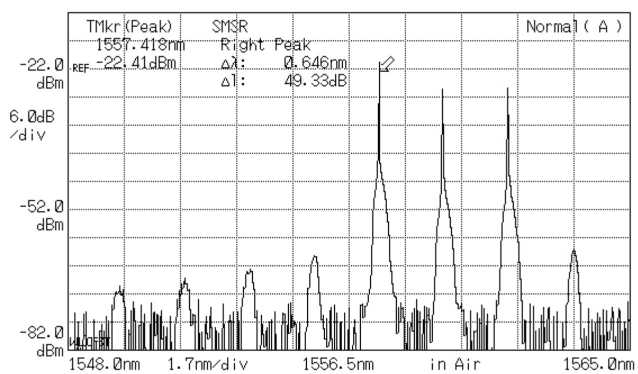

Fig. 7(b) three-wavelength lasing output (applying stress)

As seen in Fig. 7, the output three-wavelength shifts form 1557.046nm, 1558.932nm and 1560.956nm to 1557.276nm, 1559.208nm and 1561.186nm when the stress put on the M-FBG increases. So by this way, continuously tunable multi-wavelength fiber laser can be achieved. Since the output depend upon both the value and the direction of the stress, it is possible to find the relationship between stress and the output wavelength.

4. CONCLUSION

In conclusion, we have experimentally demonstrated a kind of M-EDFL based on F-P and band-pass filter. By inserting NOLM into the ring cavity, the mode competition can be effectively suppress and the flatness of the output spectrum has been greatly improved from 4dB to 0.5dB. What's more, we have proposed and demonstrated another tunable M-EDFL based on M-FBG. The output wavelength shifts toward longer wavelength when increase the stress applied on the M-FBG.

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