Single polarization, dual wavelength fiber laser based on a 3-stage all fiber Lyot filter

Zhijun Yan, Chengbo Mou, Zuxing Zhang, Xiangchuan Wang, Kaimin Zhou and Lin Zhang

***Abstract*—We have demonstrated a switchable dual-wavelength fiber ring laser with high degree of polarization output by using an intra-cavity 3-stage all fiber Lyot filter. The filter is formed by concatenating four 45° tilted fiber gratings (45°-TFGs) separated by polarization maintaining (PM) fibers with a length ratio of 1:2:4 (20, 40 and 80cm), giving a compact integrated configuration with reduced bandwidth. Switchable dual-wavelength or single wavelength output at 1533.5nm and 1563.3nm has been achieved. The output lasing is considerably stable owing to the in-phase mode-selecting function of the multi-stage Lyot filter, and has a very high degree of polarization higher than 99.9%.**

***Index Terms*—Lyot-filter, tilted fiber grating, fiber ring laser.**

I. INTRODUCTION

All fiber stable multi-wavelength and dual-wavelength laser systems have been attracting more interests, because of their wide prospective applications in optical sensing and communications, two-wavelength interferometry, laser spectroscopy, differential absorption lidar, optical data processing and optical instrument testing[1-4]. The erbium-doped fiber amplifiers (EDFAs) have been intensively studied and developed for commercial applications owing to their low cost, high saturation power, low polarization-dependent gain (PDG) and low signal noise ratio in the telecom C-L band region. However, because of relatively broad homogeneous linewidth (~10nm) at room temperature[5], the EDFA based multi-wavelength laser is always associated with very strong mode competition. So far, the most of the multi-wavelength lasers were achieved by combining an intra-cavity filter with several different techniques include using hybrid gain medium (by adding a semiconductor optical amplifier or Raman amplifier into an EDFA based laser system)[6, 7], using of highly nonlinear configurations[8], inserting a frequency shifter or a phase modulator into the laser cavity [9, 10] and using nonlinear polarization rotation (NPR)[11, 12]. To achieve multi-wavelength operation, an intra-cavity multi-wavelength transmission filter is necessary to be employed, such as in-fiber Mach–Zehnder interferometer[13, 14], Sagnac loop mirror[15-17], birefringent filter[18, 19], sampled and superimposed chirped fiber Bragg grating[20, 21] and large angle tilted fiber grating[22]. The Lyot filter is a type of polarization interference filter based on a combination of polarizers and waveplates in alternating sequence, from which a comb-like transmission spectrum could be generated[23, 24]. In our previous work, an all-fiber Lyot filter (AFLF) by sandwiching a segment of PM fiber between two 45° TFGs UV-inscribed in PM fiber has been reported[25]. The bandwidth and free spectra range (FSR) of a single-stage Lyot filter cannot be separately adjusted by changing the cavity length, because both of the bandwidth and FSR are inversely proportion to the length of the PM fiber, and the bandwidth of Lyot filter is half of the FSR[26]. Fortunately, a multi-stage Lyot filter has the capability of controlling both the bandwidth and FSR separately[27]. For such a multi-stage filter, only the wavelengths which are in phase for each individual stages could have the maximum transmission and the other out-of-phase wavelengths will be suppressed. The bandwidth and FSR of a multi-stage filter is determined by the length of the longest and the shortest cavity, respectively. In this letter, we have proposed and demonstrated a switchable dual-wavelength fiber ring laser by using a 3-stage AFLF based on concatenation of four 45°-TFGs separated by the PM fibers with 1:2:4 length ratio. Comparing with hybrid bulk and fiber birefringence, the multi-stage AFLF features a more compact and integrated structure. Furthermore, the output of the laser is also at high degree of single polarization state.

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II. EXPERIMENT AND RESULTS

The 3-stage AFLF used in the work was constituted by concatenating four 45°-TFGs with PM fiber cavity length ratio of 1:2:4 (20cm, 40 cm and 80cm). The schematic description of the filter is shown in Fig. 1.

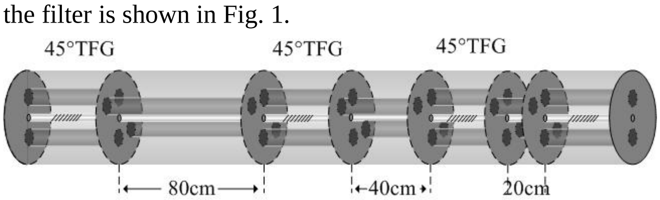


Fig. 1: Schematic structure of a 3-stage AFLF using four 45°-TFGs as in-fiber polarizers.

The transmittance of a multi-stage Lyot filter is given by[27]:

$$T = \prod_{i=1}^{m} cos_i^2\left(\frac{\pi L_i \Delta n}{\lambda}\right) \qquad m = 1,2,3\ldots \qquad (1)$$

Where, L_i is the length of i^{th} PM fiber cavity; Δn is the birefringence of PM fiber; λ is the operation wavelength. The

FSR and bandwidth of a multi-stage Lyot filter can be expressed as:

$$FSR \cong \frac{\lambda^2}{L_{shortest}\,\Delta n} \qquad (2)$$

$$\Delta\lambda \cong \frac{\lambda^2}{2L_{longest}\,\Delta n} \qquad (3)$$

Where, $L_{shortest}$ and $L_{Longest}$ are the lengths of the shortest and longest PM fiber cavities of the filter.

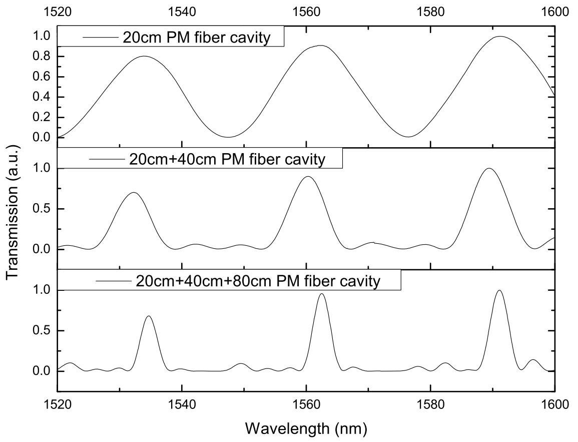


Fig. 2 Measured transmission spectra of three AFLFs with 1-stage (20cm PM fiber cavity); 2-stage (20cm+ 40cm PM fiber cavity) and 3-stage (20cm +40cm +80cm PM fiber cavity), respectively.

Fig.2 **Error! Reference source not found.** shows the transmission spectra of 1-stage, 2-stage and 3-stage AFLFs. It can be seen clearly from the figure that the transmission bands of the AFLFs are generated from coupled cavities, i.e. the transmission maxima are only occur at those wavelengths in phase for each individual cavities and the other non-phase matched wavelengths are suppressed. Meanwhile, we can also see clearly the passband width becomes significantly narrow for multi-stage AFLF. The PM fiber used in our 45°-TFG based AFLFs has a nominal birefringence around 3.27×10^{-4}. From Equation 2 and 3, the FSR and bandwidth of 3-stage filter we designed are around 26.6nm and 6.5nm, respectively. The 3-stage filter has two transmission bands at around 1534nm and 1564 in the erbium fiber gain range.

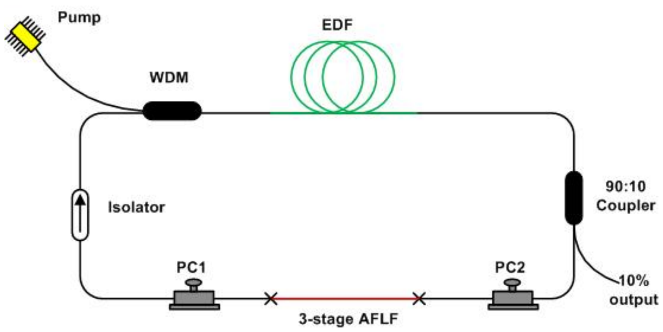
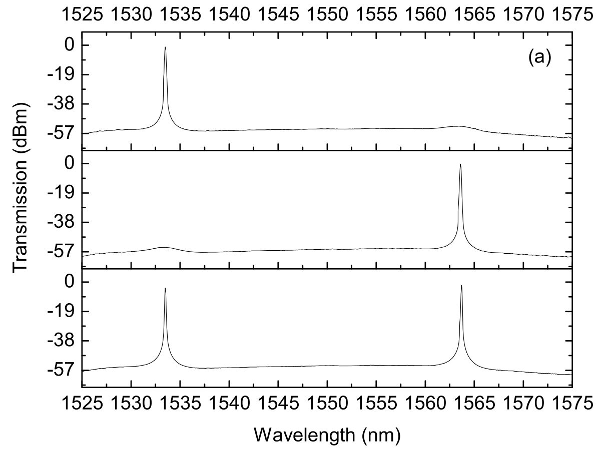


Fig. 3: The schematic of the Dual-wavelength fiber ring laser with an intra-cavity 3-stage AFLF.

The schematic of the proposed switchable dual-wavelength fiber ring laser is shown in Fig.3. A 3m long erbium doped fiber (EDF) with 18dB/m nominal absorption at 1530 nm is used as the gain material. The 975 nm laser diode pump source that could provide up to 300mW pump power is employed through a 980/1550 wavelength division multiplexer (WDM). A 3-stage AFLF sandwiched between two polarization controllers (PCs) is used as wavelength selector. A 90:10 coupler is employed to couple 10% of the laser light out of the cavity. The unidirectional operation is achieved by applying a polarization independent isolator in the laser cavity.



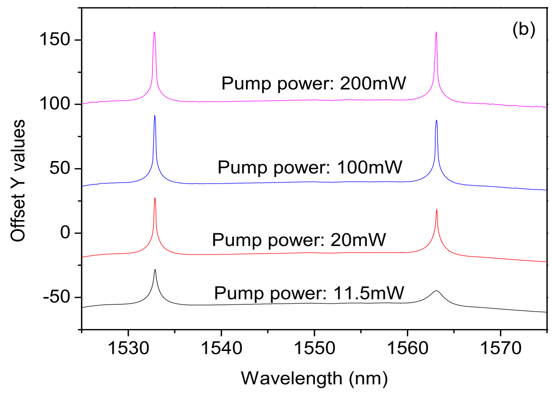


Fig. 4: Laser output spectra (a) at dual-wavelength and single wavelength operation and (b) dual-wavelength operation at different pump power.

In the experiment, the single or dual wavelength operation was obtained by adjusting the PCs. The output power level of each wavelength in dual-wavelength operation could also be adjusted by adjusting the PCs (see in Fig.4 a). The pump power threshold of laser was around 11.5mW for single wavelength operation and around 20mW for dual-wavelength operation. The dual-wavelength operation could be only achieved at the suitable position of the PCs, however, once it was established, which could still self-started at next time. Fig. 4 b shows the output spectra of the ring laser with dual-wavelength operation, at different pump power. In the experiment, the laser was only excited at 1533.5nm and 1563.3nm, and no other lasing modes were observed over the entire erbium gain band. The wavelength spacing of the dual wavelength laser is determined by the FSR of the 3-stage filter.

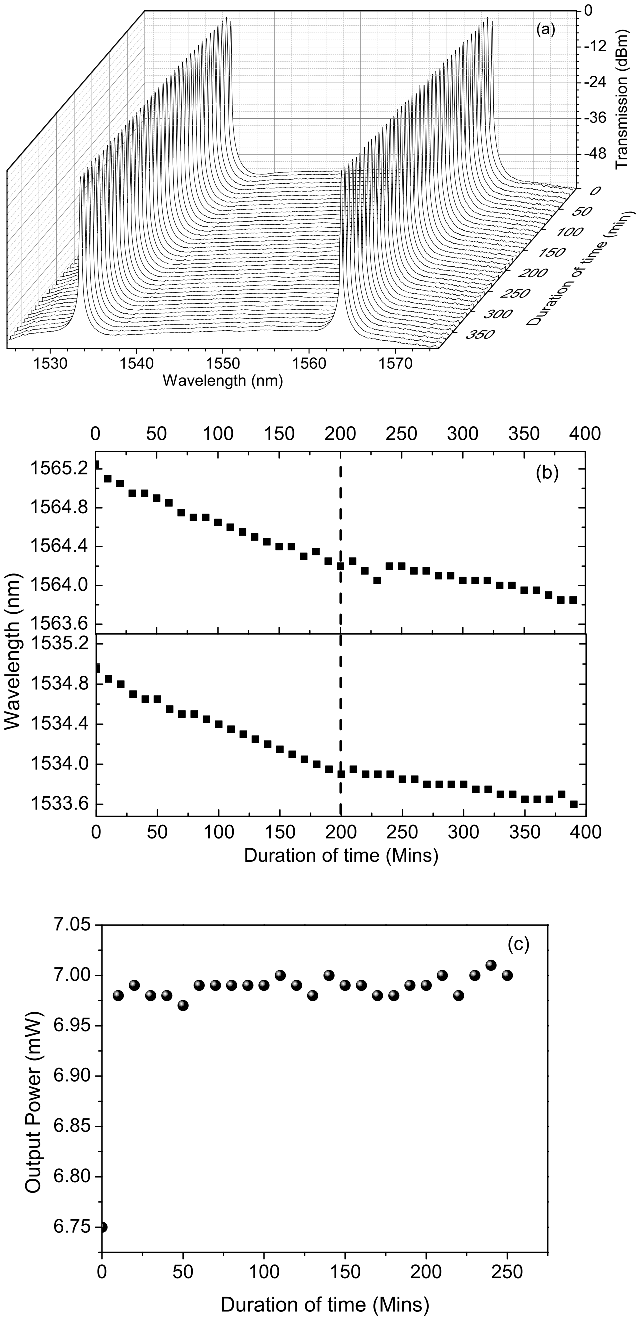


Fig. 5. Repeatedly scanned output spectra of the multi-wavelength laser: (a) dual-wavelength laser output and (b) wavelength drift with 10mins interval time, (c) the fluctuation of output power.

Fig. 5 (a) show laser output spectra captured with 10-min time intervals. The results show the 3-stage AFLF based switchable dual-wavelength laser is stable in terms of both lasing wavelength, which is attributed to the role of the 3-stage AFLF for its in-phase mode selecting function. As shown in Fig. 5 (b), the output wavelengths of laser were shifting to the shorter wavelength, which is because the temperature is increasing during experiment time, and the transmission band of Lyot filter is shifting to the short wavelength with increasing of temperature[28]. In Fig.5 b, it also shows there are two different slope regions for both wavelengths: at the first 200mins, the wavelength drifts were faster due to the cavity temperature was increased quickly. After 200mins, the temperature exchanging between fiber cavity and optical bench was getting equilibrium, and wavelength blue shift was because the temperature of environment was increasing. We monitored the output power at 200mW pump power which the results was plotted in Fig 5c. As it shown, during 250mins with 10min time interval, the average power is around 6.99mW with 0.02mW fluctuation. The PERs of the output of the fiber laser at 1533.5nm and 1563.3nm are shown in Fig. 6 (a) and (b), which are at 34.6dB and 34.5dB, respectively. Thus, the degree of polarization (DOP) of output laser at both wavelengths is higher than 99.9%.

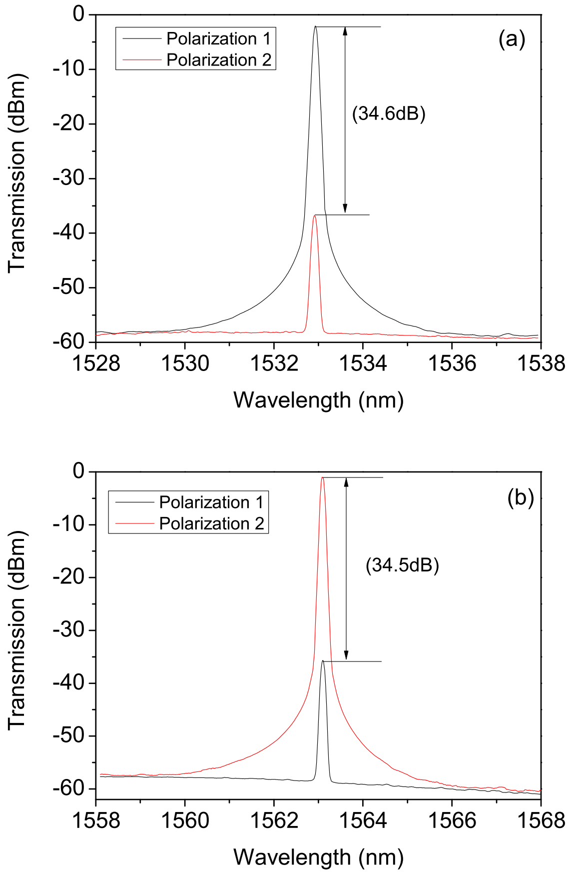


Fig. 6.The PER results of output laser at (a) 1533.5nm and (b) 1563.3nm.

III. Conclusion

In this letter, we have reported a demonstration of a single polarization and switchable dual-wavelength EDFA based fiber ring laser system incorporating an intra-cavity 3-stage AFLF concatenating four 45°-TFGs separated by three PM fiber cavities of lengths at 20cm, 40cm and 80cm. The compact and integrated laser system shows a low pump threshold around 30mW and stable output with low fluctuation on peak intensity and lasing wavelength due to the in-phase mode-selecting function of the multi-stage AFLF. The fluctuation of peak intensity and wavelength were only 0.02mW. Although the wavelength was shifting to shorter wavelength during experiment, we can stable the wavelength by applying temperature controller on the laser cavity. The output laser also shows very high PER of around 34dB, which indicates the laser output is at a high degree of single polarization.

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