Multi-Wavelength Erbium-Doped Fiber Ring Laser Cavity Setup with a Nonlinear Optical Loop Mirror

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ABSTRACT:
Fiber Ring Lasers employed for generation of the multi-wavelength laser with so narrow bandwidth. In this research, the setup of multi-wavelength fiber ring laser source is demonstrated as well as eight figure cavity that by using a piece of Polarization Maintaining Fiber (PMF) in Sagnac filter achieved four stable and constant amplitude wavelengths with same spacing at room temperature. Also, we observed more than 250 narrow line width modes by using the 23 km length of Single Mode Fiber (SMF-28) at C and L communication windows which the stability of modes because of increasing the length was more less in compare to PMF Sagnac.

KEYWORDS: Polarization Maintaining Fiber, Sagnac Filter, Multi-Wavelength Fiber Ring Laser.

1. INTRODUCTION

Fiber lasers were made possible in the 1960s by the incorporation of trivalent rare-earth ions such as neodymium, erbium, and thulium into glass hosts [1].Starting in 1989, the focus tuned to the development of erbium doped fiber lasers since were useful for optical communications, ultrafast phenomena and fiber sensors [2]. Another attractive fiber laser sources is multi-wavelength lasers that can replace Fabry-Perot lasers in Wavelength Division Multiplexing (WDM) systems [3]. Ring Fiber Lasers are suitable replacement for producing the multi-wavelength laser with narrow bandwidth and mode locked laser by employing the nonlinear ring mirror filters. Erbium doped Fiber Ring lasers (EDFRLs) are highly regarded for optical communication applications because of performance at spectral range of 1550 nm and simultaneous operation in the range of low-loss silicon fibers. EDFRLs pumped at 980 or 1480nm wavelengths because of absence of excited state absorption in the wavelengths. The selecting two pump wavelengths are always in terms of conditions, because each one has its advantages [5]. The characteristics of these lasers include: very efficient operation, producing the stable wavelength, very narrow linewidth, high output power and tuning over a range up to 40 nm [4]. In an ideal case, a multi-wavelength source should exhibit the following properties [5]:

1- Stable power and wavelength operation
2- Tunable over a broad wavelength range
3- Large or small tunable wavelength spacing
4- High output power
5- Single mode operation

Not all of the above features need to be satisfied simultaneously and rather it depends on the applications. Multi-Wavelength laser sources vastly due to the cheapness and ease of construction are taken into consideration. These types of lasers have high potential and can be replaced by diode lasers due to their diverse applications in optical fiber sensors, spectroscopy and WDM systems [6].
There are several ways to get the performance of multi-wavelength operation. One common way is to divide the broadband source spectrum for selecting the optimal wavelengths [5]. In this case, various configurations like Eight figure is the most common solution that add fiber Sagnac to laser ring cavity [7]. If Sagnac loop with birefringence properties added to fiber laser, coupling light between the slow and fast axes of birefringence fiber provide spectral filter [8]. In Sagnac, input signal is split into two beams counter-propagation along the loop arm that after propagation in loop recombined at coupler. This interference is depending on birefringence properties of cavity and

reflectivity on this mirror filter is also depending on wavelength.

In particular cavity for generation multi-wavelength laser modes employed Sagnac loop including the Polarization Maintaining Fiber as a comb filter due to its intrinsic advantages such as easy fabrication, stability and flexibility. In this case, the important points are change the length of PMF and operation temperature of comb filter .The conventional PMF loop mirror including one Polarization Controller (PC) can act as a comb filter which the input light at coupler 50:50 is split into two beams counter-propagating in loop and the polarization states of the two beams are altered by PC. Two beams that traverse the cascaded PMF and PC in opposite directions experience different phase delays and the phase difference is proportional to the product of the PMF length and the effective birefringence interference when they are recombined at coupler [9]. By adjusting the state of the polarization controller (PC) can be changed the state of polarization and number of lasing wavelengths [10].

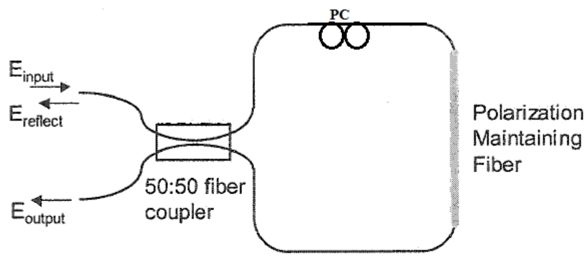


Fig. 1. The schematic diagram of Sagnac filter

As shown in figure 1, the incident wave at the coupler is split into a clockwise direction wave and an anti-clockwise one. These two counter-propagating waves undergo the same length of PMF and mode spacing of PMF follows:

$$\Delta\lambda = \frac{\lambda^2}{2|n_s\text{-}n_f|L_{HiBi}} \quad (1)$$

Where is the oscillating wavelength, $n_{s,f}$ the refractive index of the slow and fast birefringence axes of the PM fiber, respectively and L_{HiBi} is the PM fiber length.

As can be seen from the above equation, with increasing the length of PM fiber, the space of wavelengths decreased and result at constant time interval increase by the number of wavelengths. For example, two times of PMF's length with the same birefringence index in loop achieved half the mode spacing [11].

In 2008, liu and et all demonstrate a multi-wavelength erbium-doped fiber ring laser using a fiber Sagnac loop filter. The fiber Sagnac loop filter served as the wavelength selection component within the ring laser cavity. By tuning the setting of the polarization controller (PC) to effectively change the state of polarization of the light, three, four and five lasing wavelengths were obtained from the output port of the ring laser [12].

2. EXPERIMENTAL RESULTS

The experimental setup of the proposed multi-wavelength fiber ring laser is shown in figure 2 that is consist of 5.6 meter of Erbium fiber as a gain medium, a 10:90 coupler, a 980/1550 WDM coupler as coupling Pump power into the cavity, Isolator and Sagnac filter. Gain medium is placed after WDM coupler and before output coupler. Output coupler was employed to tap the10 percent of lasing output for monitoring with an optical spectrum analyzer (OSA) and coupled the 90 percent of lasing into the cavity. Isolator can guided the light only one direction and block feedback from the WDM coupler. The Sagnac loop is formed by 3.8 meter of PMF (Panda) with birefringence index around 0.00036 that connect to the ring with 50:50 coupler. Linear polarization coupler was also used to tuning the state of polarization.

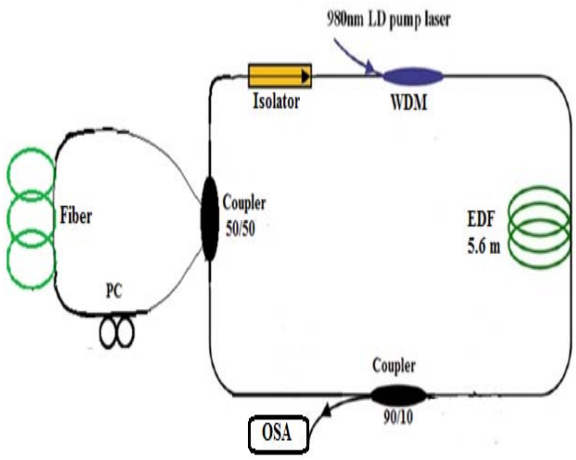


Fig. 2. Schematic diagram of proposed multi-wavelength fiber ring laser

As shown in figure 3 at low power pump (about 30 mW), the filtering effect is dominant and with proper adjustment of the tension and angle of polarization controller at range 1555-1580 nm(C & L bands) appeared about 10 continuous mode with same mode spacing 1.6 nm, that with increase the power to 300 nm gain medium effect is dominant and energy observed at 4 excited main mode with 42 dB Signal to Noise Ratio(SNR) less than 3 dB fluctuation at 1563.6, 1565.2, 1566.8 and 1568.5 nm wavelengths(figure 4).

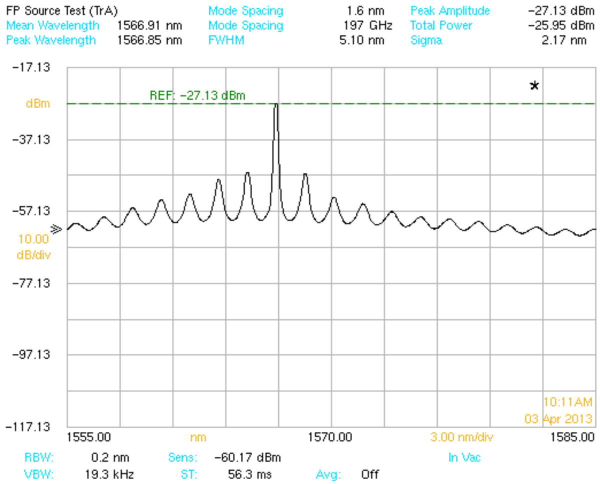


Fig. 3. The output spectra of multi-wavelength fiber ring laser at pump power of 30 mW

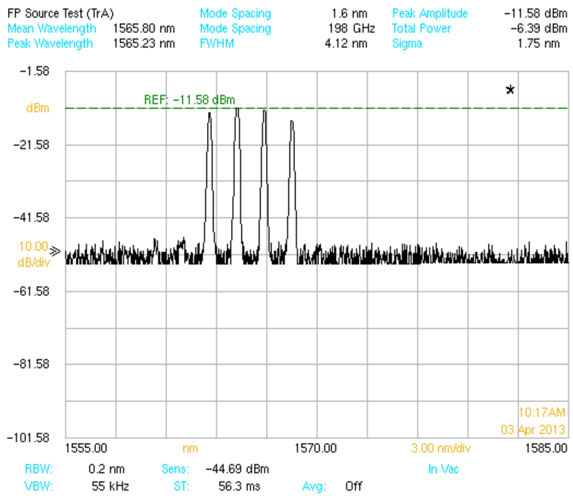
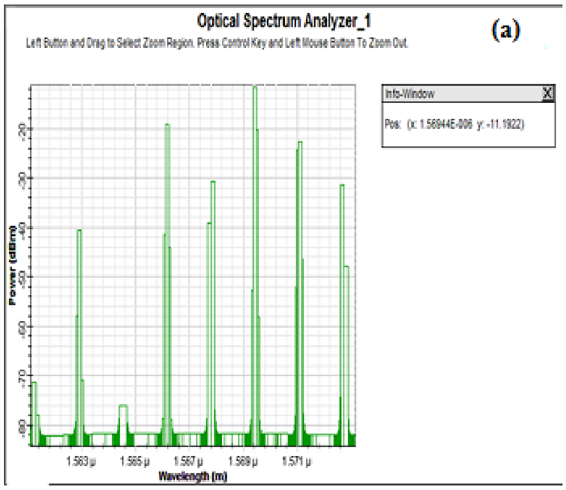
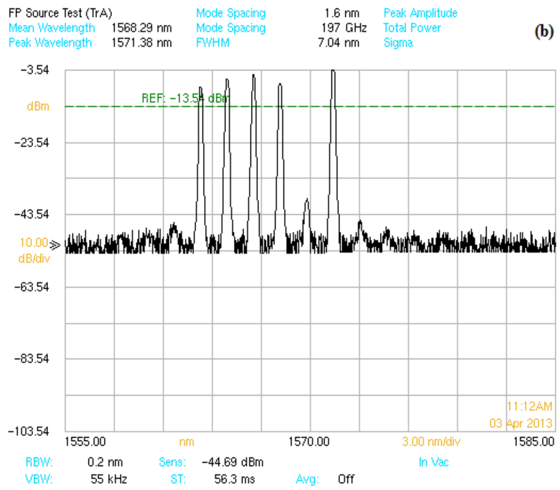


Fig. 4. The output power of multi-wavelength fiber ring laser at pump power of 300 mW

By inserting another polarization controller (PC) to Sagnac loop mirror, the more modes appeared at output that figures (5 a and b) shown results of simulation and experimental efforts, respectively.



(a)



(b)

Fig. 5. The spectral output power of OSA for PMF optical filter with 3.8 meter length **a)** Simulation **b)** experimental results

Before the advent of special fibers with nonlinear, birefringence characteristic and unusual structures, using the simple single mode fibers used instead of certain short fibers to improve the performance of loss and compression of lasers. In this research, the 23 km of single mode fiber also employed in Sagnac loop mirror instead of PMF and the behavior of the two kinds of fibers compared.

Figure 6 is shown the output spectra of 23 km single mode fiber(SMF-28.In this setup, the number of peaks increased and reached to 70 modes at wavelength interval of 12 nm with 0.16 nm mode spacing that covered C and L bands. As can be seen in figure 6, the first stimulated Stocks appeared at 63 Mw peak power with satisfying SMSR more than 35 dB.

In the long Single mode fibers polarization states not maintained, hence, these cases with short birefringence fibers as PMF is compensable. So, Polarization maintaining fibers as type panda are well candidate to achieve mode birefringence with very low losses and low crosstalk effect that have been developed.

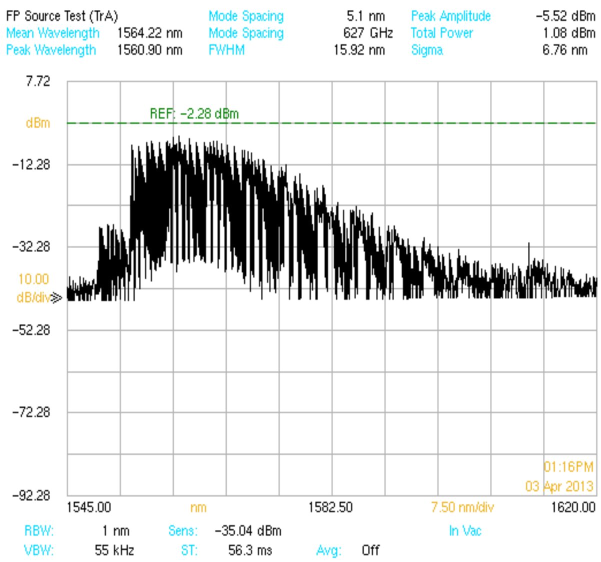


Fig. 6. The output spectra of fiber ring laser and Sagnac loop consist of 23 km of SMF

Figure 7 shows lower range of the spectrum based on figure (6) to prove smoothing the output spectrum which the constant separation mode and low fluctuations (less than 3dB) is presented. The significance of this setup is to create a large number of modes and communication applications, but the problem is instability and high sensitivity that it should be employed fundamental solutions like using the filters, environmental and temperature controllers.

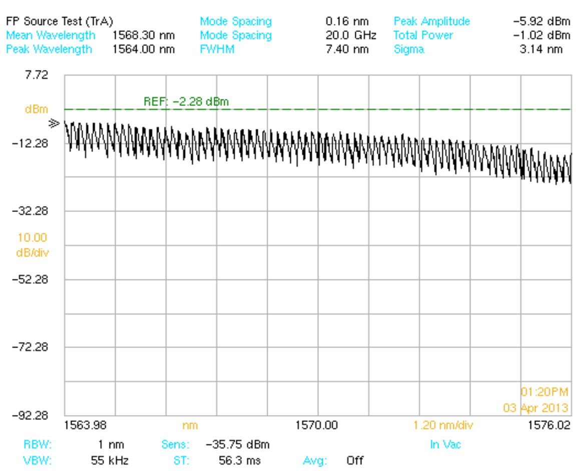


Fig. 7. The expand spectrum of limited range (13 nm) of figure 6

3. RESULTS

In this research, the performance of continuous multi-wavelength erbium doped fiber ring laser demonstrated at C and L bands of telecommunication windows. The four stable and same amplitude wave with fluctuation less than 3 dB , 42 dB Signal to Noise Ratio (SNR) and 1.6 nm mode spacing achieved by employing of 3.8 meter of polarization maintaining fiber in Sagnac filter. Hence, by using the PMF as a part of nonlinear loop mirror simple multi-wavelength filter obtained that by change tension and angle of polarization controller the number of lasing wavelength and mode spacing controlled.

The reason of using Sagnac loop as a multi-wavelength filter is that operate independent of polarization and is equivalent to active modulators at mode locked lasers. Here, the ring array similar to eight figure is simple method and low cost to operating multi wavelength fiber laser.

With replacing 23km of Single mode fiber(SMF-28) in Sagnac loop instead of PMF can covered C and L bands that increase the number of modes, but unstable output spectrum. Furthermore, the very long length of SMF makes problems, that is better to use of special nonlinear fibers with low length and better stability.

Design of multi-wavelength fiber ring laser has unique benefits, like simple topology, adjustable wavelength spacing, tenability lasing, small bulk and low cost.

Table 1. Comparison of performance two kind of fibers with different lengths (PMF and SMF)

Type of Fiber in Sagnac loop	Length	Mode Spacing (nm)	Number of modes	Fluctuation of Modes (dB)	OSNR (dB)	Bandwidth (nm)	Line Width (nm)	telecommunication Window
PMF	3.8 m	1.6	13	3	42	45	0.46	L
SMF	23 Km	0.16	~70 in 12 nm	2	40	65	0.14	C+L

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