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THE COMPARISON OF DUAL WAVELENGTH FIBER LASER SPECTRUM IN SMF AND HNLF BY UTILIZING LASER DIODE

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ABSTRACT

A dual-wavelength erbium-doped fiber (EDF) fiber ring laser in single mode fiber and highly nonlinear fiber is demonstrated and both optical spectrums are compared at 400 mA of Laser Diode (LD) output. The fiber ring laser cavity incorporated sagnac loop had been applied for the laser to lase two wavelengths simultaneously due to high birefringent in polarizaton-maintaining fiber (PMF). Experimental results show that, owing to the contributions of two degenerate four-wave mixings (FWM) in the HNLF and the dual-wavelength proposed fiber laser is quite stable with small fluctuation power in 1.93 dB within 24 minutes in HNLF.

Keywords: erbium-doped fiber, polarization-maintaing fiber, four wave mixing.

INTRODUCTION

Multiwavelengthfiber lasers or MFLs have become a great interest since their potential as cost effective multiwavelength sources which is practical for wavelength-division multiplexing (WDM) optical sensors, gas detection and optical communication(Mirza and Stewart, 2009), (Wang *et al*., 2013), (Awang *et al*., 2012). Multiwavelength is able to be applied as wavelength converter and for that purpose a commercial Fabry Perot laser had been effectively used as cheap wavelength converter (Tsang *et al.*, 1998). A good performance of multiwavelength laser with proper set up had been recorded recently (Latif *et al.*, 2011). Wavelength tunability in laser hadbeen explored by optimization in laser cavity (Bustamante, 2001).

Erbium doped fiber ring laser had been used to produce tunable dual wavelength (Antonio-Lopez *et al.*, 2012). The gain competition leads to the instability of laser output due to the homogeneous gain broadening of erbium-doped fibers (EDFs). Several methods have been introduced to palliate the gain competition (Mirza and Stewart, 2009), (Wang *et al.*, 2013), (Liu and Lu, 2005), (Han *et al.,* 2006). MFLs experiment which applied four wave mixing (FWM) in dispersion shifted fibers (DFSs) and photonic crystal fibers (PCFs) to stabilize the laser outputs have been reported(Mirza and Stewart, 2009), (Wang *et al*., 2013), (Liu and Lu, 2005), (Han *et al.*, 2006). FWM had been utilized in wavelength conversion with large spacing and wide tunability (Awang, 2010). Various methods had been introduced to stabilize dual wavelength lasing (Durán-Sánchez *et al.*, 1998). One of the applicablemethod is FWM which had been applied to obtain stable dual wavelength lasing (Fok and Shu, 2007).

Instead dual wavelength, triple wavelength also had been reported using Sagnac loop application (Shu *et al.*, 2000). MFLs based on FWM also have been experimentally demonstrated in single mode fiber (SMF) and highly nonlinear fiber (HNLF) in 2013 to investigate the lasing stability (Han *et al.*, 2006). Here we report the use of HNLF as optical nonlinearity platform for MFLs.

There are a lot of possibilities to apply HNLF in optical sensing and one of them had been suggested in 2012 (Wong *et al*., 2012). In this paper, we investigate the two wavelengths in a SMF from a laser diode source based on MFLs and the four-wave mixing in HNLF. The output power and wavelengths were measured over an increment of pumping power of laser diode in SMF and the stability of the peak power HNLF under a constant pumping power at normal room temperature.

EXPERIMENTAL SETUP

A schematic diagram of the experimental setup is shown in Figure-1. The ring cavity of laser consists of a tunable laser diode (LD), a 5.4 m SMF, a 980/1550 wavelength division multiplexing (WDM) coupler, 600 mm EDF, a 90/10 fiber coupler, an isolator, a 50/50 fiber coupler, an optical spectrum analyser (OSA) and a sagnac loop filter with 2 m polarization maintaining fiber (PMF) and a polarization controller (PC). The loop is used to form a comb filter to enhance the peak power of the output laser. The PC is utilized to maximize the output power and minimized the polarization in the ring cavity.

This experiment had been carried out by varying the input current at the LD. The current was varied from 240 mA until 400 mA. The optical spectrum at the output had been recorded by an OSA under a 0.03nm resolution for each 10 mA input current increment. Then, the SMF was replaced with 500 m HNLF to determine the dual wavelength laser.

Observation and evaluation on the peak power produced in HNLF had been carried out when 400 mA current is launched from the LD. The spectrum in the laser cavity had been taken for 12 interval of time at the pumping current of 440 mA. Each interval is separated by two minutes period.

RESULT AND DISCUSSIONS

The comb threshold pump current is 47 mA. The dual wavelength threshold pump current is 52 mA in SMF while 54 mA is the threshold current for dual wavelength lasing in HNLF. As the pump current reached 52 mA, two lasing wavelengths was detected with too low and unstable power.

The peak power of the DWFL in SMF as input current was varied from 240 mA to 400 mA is shown in Figure-2. The highest peak power was selected and had been compared with all of set of data from 240 mA until 400 mA with 10 mA inclination. The lowest peak power was recorded at 240 mA with a value of -16.52 dB. The highest peak power is -9.59 dB. As plotted, the increasing of peak power DWFL in SMF is dependent to the increasing current in LD.

The homogeneous broadening of gain medium in EDF leads to the mode competition in the cavity, as such, the output lines are fluctuated. The sagnac loop which act as a mirror to generate a periodic filter to the cavity and enhanced for the arising of higher peak power. The peak power variation will increase in cavity if the polarization of system was unstable (Peng *et al.*, 2003).

The result for 400 mA injection current spectrum comparison between SMF and HNLF can be observed in the Figure-3. These figure shown the comparison of optical spectrum between the HNLF and SMF when the same 400 mA input current is applied. The less peak power different is observed in HNLF compare to SMF. The channel spacing is 2.5 nm and 2.58 nm in HNLF and SMF respectively. The other way to reduce the channel spacing length is by applying longer Polarization Maintaining Fiber (PMF) as agreed in (Lee *et al.*, 2004). The peak power different in SMF is 7.06 dB while in HNLF is 0.324 dB. HNLF is recommended to produce dual wavelength lasing as it has higher power for both peaks compared to the SMF which struggled with the higher power difference between both peaks and the channel spacing is smaller compare with the SMF. The smaller of a channel spacing will enhance to the formation of DWFL.

As refer to (Liu *et al.*, 2005), FWM effect in the cavity is related to three parameters of optical fiber, the length, the dispersion and the nonlinearity coefficient.

A length of a fiber has relation with the optical power propagation as refer to equation (1)

$$P_T = P_0 \exp(-\alpha L), \tag{1}$$

Where $P_0$the launched power at the input of a fiber is,P_T is the transmitted power, α is the attenuation constant and L is the length of a fiber. The greater the length of a fiber will reduce the intensity of optical power at the output. In the FWM case the equation (2) should be consider as a laser has a coherence length in order to maintain the intensity of optical power.

$$L \leq L_{coh} \equiv \frac{2\pi}{|\Delta\beta|} = \frac{c}{4\pi^2 f_P |D(f_P)|} * \frac{1}{\Delta f^2} \propto \frac{1}{\Delta f^2} \tag{2}$$

Where$L$is the fiber length, L_{coh} is the coherent length , a parameter having a length dimension,$\Delta\beta$ is the phase mismatch of the propagation constant, D is chromatic dispersion,Δf is the channel spacing be the frequency spacing between the pumping light and the signal (or idler) light.$f_P$is the pumping frequency.

$$D(\lambda) = \frac{dt_g(\lambda)}{d(\lambda)} = -\frac{2\pi c}{\lambda^2}\beta_2 \approx \frac{\lambda}{c}\frac{d^2 n}{d\lambda^2}, \left[\frac{ps}{nm \times km}\right] \tag{3}$$

Where the $dt_g(\lambda)$ is the group time delay per km, $d(\lambda)$is the signal change per wavelength, c is the speed of light, λ is the wavelength and n is the refractive index of fiber. In equation (3), the dispersion in fiber has a relation to the refactive index of a fiber which is relate to the fiber-design parameters such as core radius and core cladding index difference.

The nonlinearity coefficient is shown as in equation (4). The pumping frequency has a linear relation to the nonlinearity coefficient.

$$\gamma \equiv \frac{2\pi f_p}{c} * \frac{n_2}{A_{eff}} \tag{4}$$

Where γ is the nonlinearity coefficient, f_p is the frequency of pumping light, n_2 is the nonlinear refractive index, A_{eff} is the effective area of a fiber and c is the speed of light in a vacuum. The higher value of nonlinearity coefficient will enhance the FWM in fiber.

Based on the theory, the HNLF is highly recommended compare to SMF to increase the FWM effect in cavity. Regarding to that, we demonstrated the HNLF with non-degenerate four wave mixing at 440 mA for over 12 sets of 2 minutes interval with 1.93 dB fluctuation side mode suppression ratio (SMSR).The result is shown as in Figure-4. The highest SMSR was recorded at 44.81 dB and the lowest is 42.88 dB. The dual wavelength in HNLF had attained channel spacing about less than 2.68 nm.

The Figure-5 shown the result of fluctuation of channel spacing in HNLF. The fluctuation of channel spacing recorded in HNLF is 0.19 nm. This fluctuation is the different value of maximal channel spacing among all sets experiment is compared with the minimal channel spacing in order to read the stability for HNLF. This fluctuation is reflecting to the consistency of a lasing wavelength. The smaller the figure numbers of this fluctuation the greater the stability of the DWFL in term of wavelength stability. This value is useful to develop a threshold of wavelength lasing at a receiver or sensor. Channel spacing can be adjusted using different length of PMF.

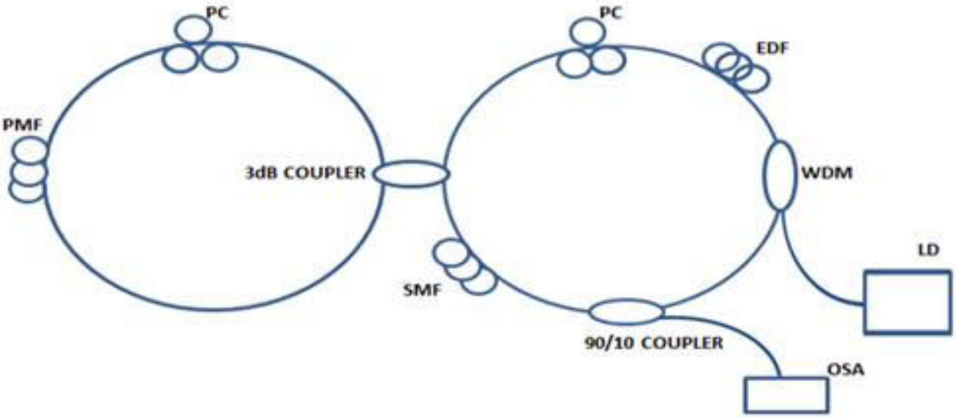

Figure-1. Experimental set up for DWFL.

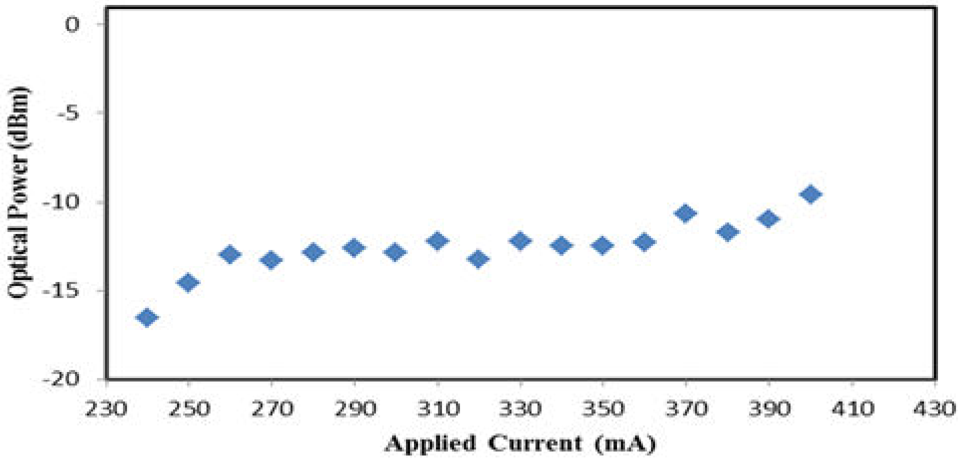

Figure-2. Peak power different in various pump current for SMF.

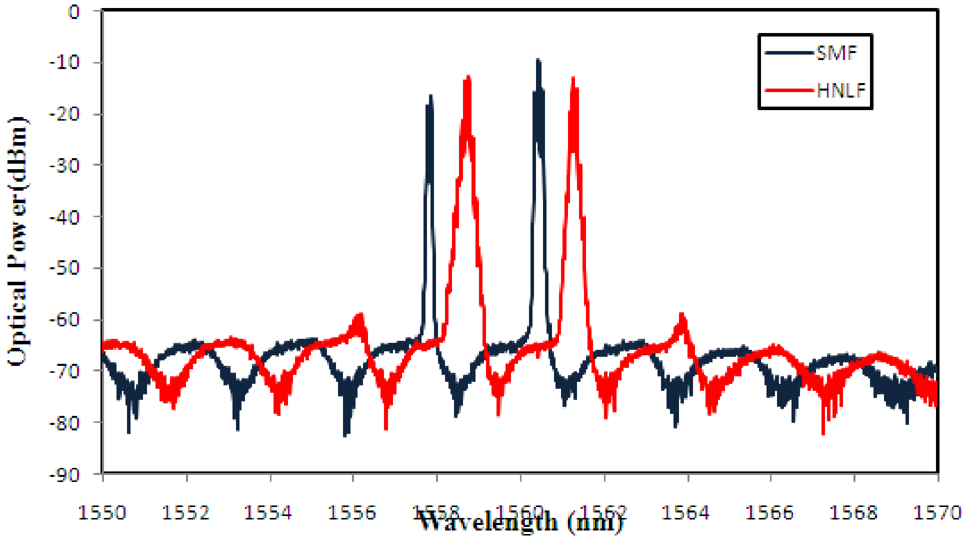

Figure-3. The optical spectrum of dual wavelength in SMF and HNLF.

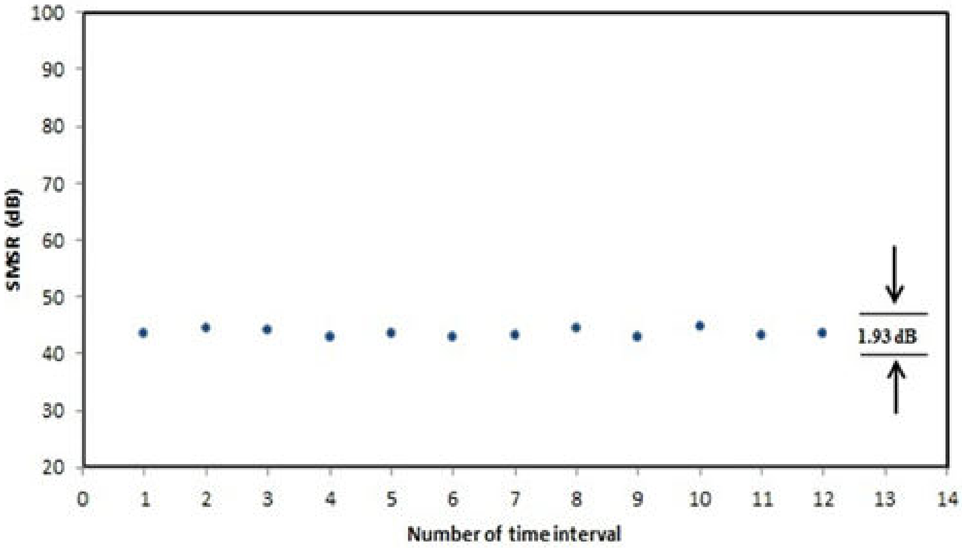

Figure-4. The SMSR foreach two minutes intervalfor HNLF.

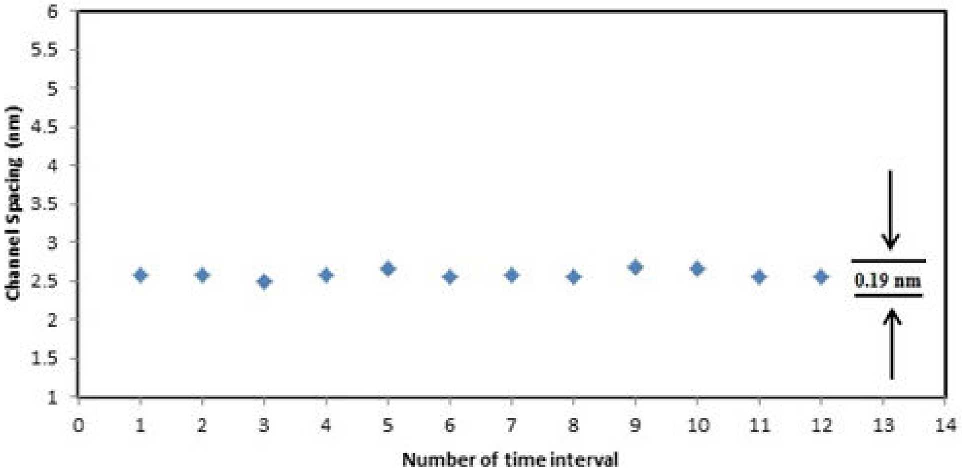

Figure-5. The channel spacing for each two minutes intervalfor HNLF.

CONCLUSIONS

This dual wavelength erbium doped fiber laser which is based on fiber ring configuration combined with a sagnac loop had been investigated. In a short SMF it is difficult to earn a high stability dual wavelength lasing compare with the HNLF employment in the ring cavity. The four-wave mixing occurred when the input current 400 mA was applied to the LD along with HNLF insertion in the cavity. Less channel spacing and less fluctuation of power was obtained by employing HNLF in cavity compared with SMF. The peak power fluctuation in 440 mA LD in HNLF at 1.93 dB with the largest of 0.19 nm peak difference had been measured. This number is able to be reduced by insertion of longer PMF and longer EDF.

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