Effect of PMF Length to Channel Spacing Tunability by Temperature in Multiwavelength Fiber Laser

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***Abstract* —A channel spacing tunability of multiwavelength fiber laser (MWFL) based on bidirectional Lyot filter and semiconductor optical amplifier (SOA) is demonstrated. The birefringence value of polarization maintaining fiber (PMF) is temperature dependence, thus by heating the PMF, the channel spacing is narrower. From the experimental data, the temperature coefficient based on PMF length of 53.2 m and 10.6 m is 0.49 ×10^{-3} nm/°C and 1.35 ×10^{-3} nm/°C, respectively, thus shorter PMF is more sensitive to temperature.**

Keywords— multiwavelength fiber laser; Lyot filter; intensity dependent loss; semiconductor optical amplifier

I. Introduction

MWFL is one of the main attractions in the application of laser source for wavelength dense multiplexing, optical sensing and many other application. Several type of comb filters was utilized to generate the multiwavelength laser such as cascaded fiber Bragg gratings [1], Sagnac loop mirror filter [2], Fabry-Perot filter [3], Lyot filter [4]–[6], Mach Zehnder interferometer [7] and array waveguide grating [8]. MWFL based on Lyot filter is an attractive choice for multiple lasing channels due to its advantage of low optical loss and simple design. Some of the MWFL works were based on Lyot filter in conjunction with an erbium-doped fiber amplifier (EDFA) as the gain medium [9], [10]. However, due to high mode competition in EDFA, the multiwavelength generation is only limited to a few number of lasing channels. Moreover, the lasing channels is not stable due to homogeneous characteristic in an erbium-doped fiber, unless an additional device is added into the laser cavity to decrease the mode competition, either piezo-electric transducer [11], highly nonlinear fiber [10] or polarization dependent isolator [12], [13]. Even though one can make use of an inhomogeneous broadening gain in Raman amplifier, the pump power for the Raman amplifier must be high to ensure the laser can be finely operated. The multiwavelength generation based on SOA produced a stable and flat multiwavelength spectrum [4], [8], [14], [15] due to its inhomogeneous gain broadening that can suppress the mode competition, even at low setting of SOA current.

Previously, the multiwavelength generation based on Lyot filter were operated solely in unidirectional configuration [4], [9], [10], [14]. More advanced Lyot filter has been carried out based on bidirectional Lyot filter [6], [15], [16]. However, the investigation of temperature dependence based on a bidirectional Lyot filter is rarely demonstrated. In this article, another aspect of spectrum variation is investigated which is temperature difference that affecting channel spacing in a bidirectional Lyot filter. The channel spacing of MWFL is inversely proportional to the temperature of PMF in the Lyot filter.

II. EXPERIMENTAL SETUP

The experimental setup is illustrated in Fig. 1, with the SOA (Qphotonics–Q1550) is the only active device, while the rest are passive devices. The SOA has maximum current of 400 mA and wavelength range of 1500 to 1560 nm. During the experiment, the SOA current is limited to a maximum of 350 mA to minimize the potential of damaging the SOA facet. The main function of SOA is to provide the gain as well as the medium for nonlinear polarization rotation (NPR) effect. Additionally, the operating temperature of the SOA is fixed to 25°C. Subsequently, a combination of a section of PMF and two polarization controllers (PCs) forms a bidirectional Lyot filter which is applied in the setup to 'slice' the amplified spontaneous emission (ASE) from SOA into comb-like output as seed to generate multiwavelength laser. A 50/50 optical splitter is engaged to split the light before entering circulators. Two circulators are used to ensure the light propagate only in one direction from 50/50 splitter to the bidirectional region on SOA through Port 1 and 3. Meanwhile, Port 2 of the circulators guarantee bidirectional propagation as the two lights make counter propagation in the SOA. A polarization beam combiner (PBC) is used to combine both incoming lights from Port 3 of circulators. A 10/90 splitter is utilized to extract the laser output, with the remaining light propagates to the ring cavity to continue laser oscillation. The laser output is viewed by an optical spectrum analyzer (OSA) with a constant resolution and sampling data point of 0.02 nm and 10001, respectively.

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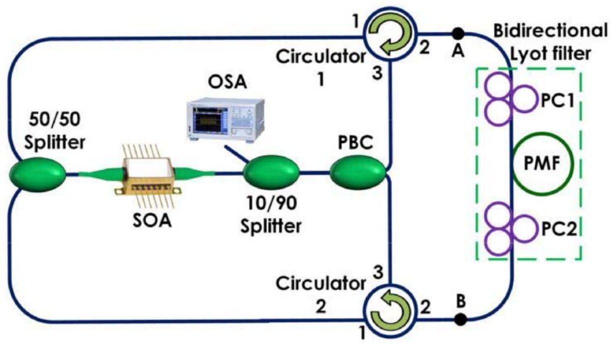

Fig. 1. The multiwavelength laser structure based on bidirectional Lyot filter.

III. OPERATION PRINCIPLE

In our work, an NPR effect is obtained from SOA and its combination with two PCs and PBC. The NPR effect induces an intensity dependent loss (IDL) mechanism, subjected to a certain polarization state. The IDL mechanism is utilized as an amplitude equalizer to achieve a flat multiwavelength spectrum.

The ASE signal from SOA acts as the source of light, and will split into half by 50/50 splitter. Subsequently, both lights will reach to the Lyot filter via Circulator 1 and Circulator 2. The intensity of light at point A and B must be equal in order to achieve the best flatness of multiwavelength spectrum. A constructive interference is occurred in Lyot filter when the two refracted lights combined with same phase and amplitude in the PMF leading to generation of multiwavelength output. The refracted lights were produced inside the birefringence medium of PMF when the polarization direction of the incoming light towards PMF is set to 45° in between the axes of PMF.

The constructive interference has a phase shift of [4]

$$\varphi = \frac{2\pi BL}{\lambda} \qquad (1)$$

where B is the birefringence of PMF, L is PMF length and λ is the operating wavelength. In the meantime, the channel spacing is determined using

$$\lambda = \frac{\lambda^2}{BL} \qquad (2)$$

It is possible to tune the channel spacing by changing the birefringence value. In our experimental work, the birefringence is increased with temperature. As demonstrated in the previous work, the channel spacing was tuned due to temperature variation [18], where the PMF is placed at a temperature-controllable furnace. Other equation in regards to the temperature and channel spacing can be seen in Equation (3). From the equation, the channel spacing is reliant upon the difference of temperature and birefringence.

$$\left(\frac{\partial B}{\partial T} + B\frac{\partial L_{eff}}{\partial T}\right) T \qquad (3)$$

where L_{eff}, T and B is the effective length of PMF, temperature variation and birefringence variation, respectively.

IV. RESULTS AND DISCUSSIONS

For the data gathering, the SOA current and splitting ratios is fixed to 350 mA and 50/50 ratio, respectively. The heating device used is a polarization and temperature controller (PTC) system manufactured by Alnair. The lowest and highest temperature settings of the PTC are 26°C and 55°C, respectively. Since the PTC can be influenced by ambient temperature where the displayed value may not be accurate, the PTC reading is calibrated against thermocouple measurement (Proskit Digital Multimeter, MT-1860). The thermocouple was inserted into the chamber, thus it measures the chamber temperature where it is the intended measurement. Fig. 2 illustrates the temperature reading where it shows that there are about 5°C difference across the range between set temperature and chamber temperature. Therefore, the chamber temperature will be used as independent variable in this study. Meanwhile, the PMF is inserted into the chamber after being wrapped using aluminum foil so that it will be heated evenly. Two PMF with different length, 53.2 m (PMF1) and 10.6 m (PMF2) were used.

Fig. 3 illustrates the laser output spectrum when two different length of PMFs are used. In Fig. 3(a), there is a clear difference of channel spacing when the PMF1 is heated. At room temperature of 23.6°C, the channel spacing is 0.104 nm and decreases to 0.101 nm and 0.092 nm when the temperature changes to 34.0°C and 45.5°C, respectively. Hence, the temperature coefficient is calculated to be 0.55 x 10^{-3} nm/°C. Meanwhile, in Fig. 3(b), the shorter PMF length in PMF2 also produce the same trend. The channel spacing is 0.506 nm, 0.502 nm and 0.474 nm as the temperature was increased in the same manner. However, the temperature coefficient is slightly higher at 1.46 x 10^{-3} nm/°C.

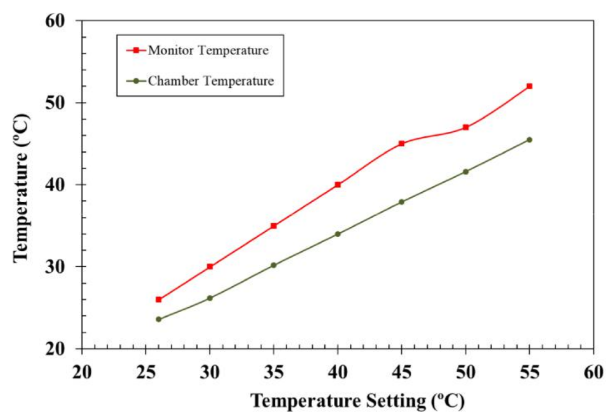

Fig. 2. The characterization of the chamber temperature of the PTC and compared with the monitor temperature.

Fig. 4 shows the variation of channel spacings at increased chamber temperature for PMF1 and PMF2. The figure clearly shows that the channel spacing is narrower with temperature increment. From the slope, the temperature coefficient for PMF1 is 0.49 $\times 10^{-3}$ nm/°C which nearly equal to the previous calculation as in Fig. 3. Meanwhile, using shorter PMF in PMF2, the temperature coefficient from the slope is increased to 1.35 $\times 10^{-3}$ nm/°C. Note that the negative value is negligible since the difference value of channel spacing is always in positive value. Due to higher temperature coefficient, using shorter PMF i.e. PMF2 is more sensitive to temperature change.

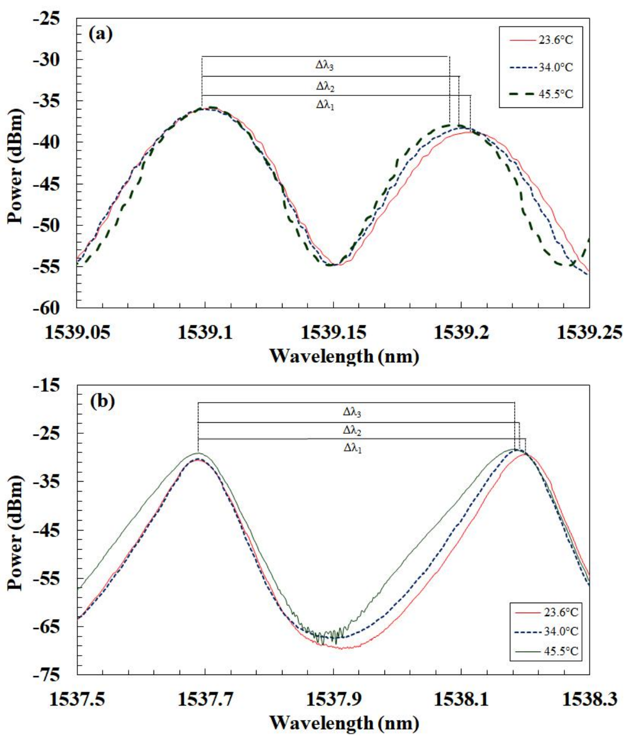

Fig. 3. The multiwavelength spectra at different channel spacing based on (a) 53.2 m and (b) 10.6 m of PMF.

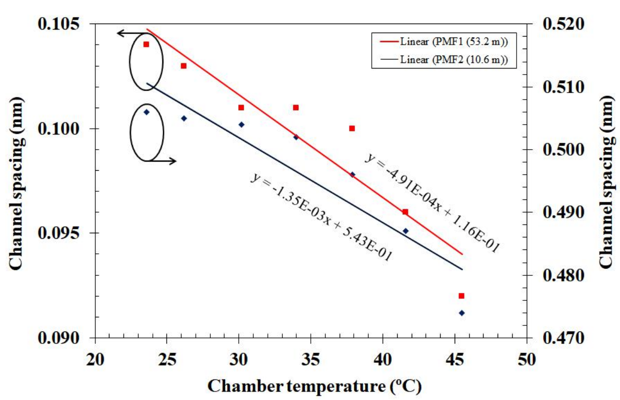

Fig. 4. The determination of temperature coefficient based on two different length of PMFs due to temperature increment nm/°C.

V. CONCLUSION

We have demonstrated several variation of channel spacing with respect to the temperature change in a MWFL based on bidirectional Lyot filter. The channel spacing is narrower with temperature increment due to the increment of birefringence value. The temperature coefficient increases with shorter PMF length, thus it is more sensitive to temperature change as compared to 53.2 m of PMF length.

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