Multiwavelength Fiber Laser based on Bidirectional Lyot Filter in Conjunction with Intensity Dependent Loss Mechanism

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Article Info

ABSTRACT

We experimentally demonstrate a multiwavelength fiber laser (MWFL) based on bidirectional Lyot filter. A semiconductor optical amplifier (SOA) is used as the gain medium, while its combination with polarization controllers (PCs) and polarization beam combiner (PBC) induces intensity dependent loss (IDL) mechanism. The IDL mechanism acts as an intensity equalizer to flatten the multiwavelength spectrum, which can be obtained at a certain polarization state. Using different ratio of optical splitter has affected to multiwavelength flatness degradation. Subsequently, when we removed a polarizer in the setup, the extinction ratio (ER) is decreased. Ultimately, with two segments of polarization maintaining fiber (PMF), two channel spacings can be achieved due to splicing shift of 0° and 90°.

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1. INTRODUCTION

MWFL has become one of the main attractions in photonics research communities. The type of comb filters that have been used for multiwavelength generation are Fabry-perot filter [1], Mach Zehnder interferometer [2], Lyot filter [3, 4] and array waveguide grating [5] and two–stage Sagnac loop filter [6]. Lyot filter-based MWFL is an attractive choice for multiple laser generation due to its qualities such as low optical loss and simple structure. Most of MWFL based on the Lyot filter have used an erbium-doped fiber amplifier (EDFA) as the gain medium [7, 8]. However, the existence of high mode competition in EDFA-based MWFL limits the number of laser lines produced by the system. The high mode competition in EDFA is due to its gain medium characteristic of naturally homogeneous that leads to unstable lasing lines. This condition should be evaded in MWFL system that targets high number of lines, unless an additional device is inserted into the configuration setup to reduce the mode competition. The device to reduce the mode competition is piezo-electric transducer [9], highly nonlinear fiber [8], nonlinear polarization rotation effect [10] or polarization dependent isolator [11, 12], which inadvertently increased the complexity and loss to the laser structure. Raman amplification is a viable alternative due to its inhomogeneous broadening, but a high pump power is required to induce the effect thus leads to inefficient MWFL system. The MWFL based on SOA [5], [13] were proved in having a stable and flat multiwavelength spectrum due to its inhomogenenous gain broadening that can suppress the mode competition.

Additionally, previous researches on Lyot filter-based MWFL operated solely in unidirectional configuration [3], [14], thus raising the opportunity to explore the potential of Lyot filter in bidirectional operation [15, 16]. Even though, we have investigated an advanced mechanism of bidirectional Lyot filter [17], the investigation is only done at several variations of SOA current, comparison of unidirectional and bidirectional configuration, variation of polarization angle and laser stability. In this article, more details on spectrum variation is investigated for MWFL based on bidirectional Lyot filter. The multiwavelength flatness is degraded at different ratio of optical splitter while the ER value is decreased with polarizer removal. Ultimately, with different splicing shift in between the two segments of PMF, the channel spacing is varied due to the change of effective length.

2. EXPERIMENTAL SETUP

Figure 1 illustrates the laser structure in a ring cavity. The gain medium is an SOA, driven by a laser diode controller from ILX Lightwave, model LDC-3900. This Qphotonics SOA (QSOA-1550) has an operating maximum current and a center wavelength of 400 mA and 1530 nm, respectively. In this experiment, two types of PCs are used. PC1 has three plates which is made from a type of anisotropic birefringent material. PC1 has the disadvantage of high loss because the light propagates in free space when passing through the plates. The high loss is also because the plates are exposed to dusk, which can degrade its performance. The entire plates of PC1 can manually adjust any polarization angle in 360° rotation with a minimum setting of 5°. In the meantime, PC2 is a fiber PC with its plate is based on looped fiber. PC1 is better as compared to PC2 in terms of polarization adjustment and wavelength stability. In this work, the quarter wave plates of PCs are used to change the polarization state of light to either circular, linear or elliptical polarization. In the meantime, the half wave plate of the PCs work to adjust the polarization angle, which is the angle between polarization direction of light and the birefringent axis of the PMF. At least two PCs are needed in this SOA-based MWFL to achieve the best multiwavelength operation due to polarization dependence of the SOA (around 0.5 dB) [18].

When the PC is combined with the PMF, a Lyot filter is formed [8], which can 'slice' the ASE of SOA into multiwavelength laser. In this work, two PCs are combined to form a bidirectional Lyot filter. The bidirectional Lyot has the most optimum performance when the optical power at point A and B are equal. From the measurement, the optical power at both points are approximately 1 mW at SOA current of 350 mA. A segment of PMF is used as a birefringent device, with its length fixed at 53.2 m for the entire data gathering. This Panda-type PMF has high birefringence value of 4.5×10^{-4}, which is appropriate in obtaining a narrow channel spacing. A PBC is employed as a light combiner and also as a polarizer. No PC is inserted before the PBC inputs to simplify the setup. The PBC combination with SOA induces the IDL mechanism in producing a flat multiwavelength spectrum with high number of lines as well as high ER. In the meantime, a 50/50 optical splitter is used to evenly distribute the light from the SOA output to the bidirectional Lyot filter. The two circulators, on the other hand are used as a bridge to route the light from SOA to the bidirectional Lyot filter, and reroute the light to PBC. Other function of the circulators is to prevent the light from the SOA input to pass through the bidirectional Lyot filter. Eventually, an output splitter of 10/90 is used to extract the multiwavelength spectrum output to an OSA. For the entire data acquisition stage, the OSA resolution and sensitivity setting is fixed at 0.02 nm and high1, respectively.
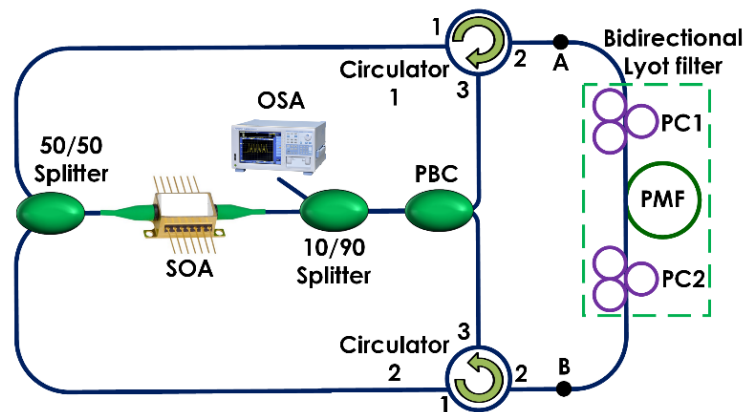

Figure 1. The structural view of multiwavelength laser setup based on bidirectional Lyot filter

3.   PRINCIPLE OF OPERATION

The principle of operation in generating the multiwavelength spectrum based on the bidirectional Lyot filter is described as follows. At first, the light from SOA is equally splitted via 50/50 optical splitter. Subsequently, the splitted lights routed to Circulator 1 and Circulator 2 before making a clockwise and counter-clockwise directions, respectively. In the region of bidirectional Lyot filter, the lights counter propagated to each other. The polarization directions of the light are finely adjusted by the half wave plates of PC1 and PC2 to 45° with respect to the birefringent axis of the PMF. It is worth noting that, the Lyot filter requires 45° of polarization angle in between the polarization direction of light and birefringent axis of PMF so that double refraction of light can occur into two orthogonal lights of ordinary and extraordinary states. In the PMF, the lights are travelled in the fast and slow axes of the PMF at different speed due to their refractive index difference. Then, the combination of two lights creates phase differences. Here, double constructive interferences occur simultaneously and finally generate a sine-like transmission, but with condition that both lights in the axes of the PMF having the same amplitude and polarization state of light. Due to the bidirectional Lyot filter, double constructive interferences are occured to reshape the lights and leads to a flatter multiwavelength spectrum. Both interfered lights from each ends of PMF are then combined and polarized in PBC. When the light is arrived at the 10/90 output splitter, 10% of the light went to OSA, while the other 90% was fed back into the ring cavity to continue the laser oscillation.

4.   RESULTS AND DISCUSSIONS

At first, we investigated the performance of multiwavelength spectrum when the 50/50 of optical splitter is replaced with other splitting ratio. Figure 2 shows the multiwavelength spectra at different optical splitter of 10/90, 30/70 and 50/50. From the figure, it is clearly shown that the wavelength region, the number of lines and the multiwavelength flatness are reduced with larger intensity difference between point A and B. The number of lines is measured at 38, 78 and 96 within 5 dB bandwidth based on the splitting ratio of 10/90, 30/70 and 50/50, respectively. Multiwavelength spectrum based on 10/90 of splitting ratio has the worst flatness between the other two splitters since the light is travelled at the lowest intensity at the 10% of tap port. In Figure 2(b) and (c), the multiwavelength flatness and the number of lines is further degraded because of larger intensity difference in the bidirectional Lyot filter.
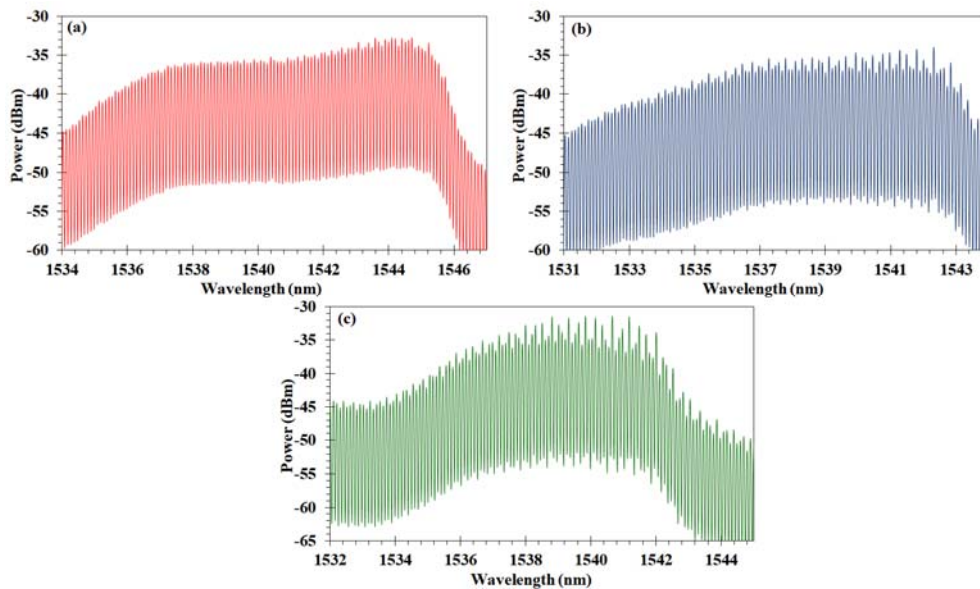
Figure 2. The multiwavelength spectrum at splitting ratio of (a) 50/50, (b) 30/70 and (c) 10/90

Figure 3 shows another evaluation of flatness performance of the MWFL with variation of splitting ratio. The evaluation is observed by plotting the ER value against its center wavelength of each line from 1539 nm to 1540 nm. The values are taken at splitting ratio of 50/50, 30/70 and 10/90. From the lines in the figure, it is clear that splitting ratio of 50/50 produces the flattest lasing lines followed by 30/70 and 10/90 of splitting ratio. The flatness performance is further determined from the difference of the highest to the lowest

ER value. From the calculation, splitting ratio of 50/50, 30/70 and 10/90 has difference of 0.95 dB, 1.88 dB and 4.15 dB, respectively. From these values, 0.95 dB indicates that the multiwavelength spectrum based on 50/50 splitter is the flattest compared with the other splitting ratios.

Next observation is the multiwavelength performance without a polarizer in the setup by removing the polarizer in the laser structure. In this observation, the PBC is replaced with 50/50 optical coupler which has the same splitting ratio as the PBC. In short, with and without polarizer refers to the setup based on the reference setting (multiwavelength spectrum of Figure 2(a)) and the 50/50 coupler replacement, respectively. Figure 4(a) illustrates the multiwavelength spectrum without polarizer in the setup. The multiwavelength spectrum is seen flat, with the number of lines is 94 within 5 dB bandwidth. However, the ER is reduced to 9 dB, which is lower than the multiwavelength spectrum with polarizer, as can be seen in Figure 4(b), which is the zoom in version of Figure 4(a). Without the polarizer, the ER value is low because of lower IDL strength in the cavity, since no polarizer is used. With polarizer removal, the IDL mechanism is only induced from SOA. From the experimental result, it is clearly verified that the polarizer is an important device to induce the optimum IDL strength. Thus, the multiwavelength spectrum without polarizer is not recommended due to lower ER even though the multiwavelength flatness is great.
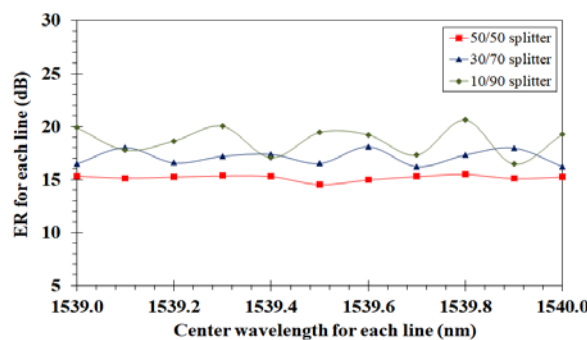

Figure 3. The ER ratio against center wavelength for each line at different splitting ratio of optical splitter
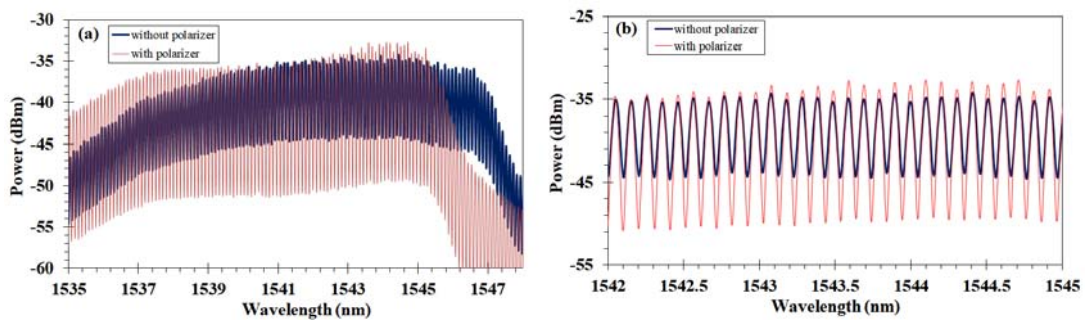

Figure 4. (a) The multiwavelength spectrum when the PBC is replaced with 50/50 coupler, which means no polarizer in the setup. (b) Zoom in version of (a) at 3 nm of wavelength span

This section investigates the multiwavelength spectrum based on two segments of PMF. The experimental setup is exactly as in Figure 1, but with an addition of another segment of PMF. The experimental setup based on the two segments of PMF is as shown in Figure 5. The length of PMF1 (L1) and PMF2 (L2) is 53.2 m and 13.1 m, respectively. In this experiment, the two segments of PMF are spliced at splicing shift (θ) of 0° and 90° using a PMF splicer, model FSM-100P manufactured from Fujikura. With θ of 0° and 90°, the effective length of the PMF becomes L1 + L2 (66.3 m) and L1 – L2 (40.1 m), respectively. Then, the formula of channel spacing is used to measure the channel according to the effective length.

Figure 6(a) depicts the multiwavelength spectrum at θ of 0°. With this condition, the two PMF segments combine into a single segment of PMF. From the figure, the effective length is the sum of L1 and L2 (66.3 m), resulting in narrower channel spacing than the best multiwavelength spectrum as seen in Figure 2(a). The multiwavelength spectrum is flat with 84 number of lines within 5 dB bandwidth. Figure 6(b)

illustrates the multiwavelength spectrum at θ of 90° that resulted in an effective length of L1 - L2 (40.1 m). The channel spacing is broader, leading to lower number of lines, which is 45 lines within 5 dB bandwidth.

Figure 6(c) on the other hand depicts the comparison in a close up view of the multiwavelength spectrum at θ of 0° and 90°. In the figure, the span is magnified to 0.5 nm for a better observation. Theoretically, based on the equation of channel spacing, the channel spacing is calculated at 0.081 nm and 0.133 nm, when the θ is 0° and 90°, respectively. However, when the channel spacings are measured from the experimental result, the channel spacing is 0.087 nm and 0.141 nm at θ of 0° and 90°, respectively. The channel spacing deviation between theoretical and experimental results at θ of 0° and 90° is 0.006 nm and 0.008 nm, respectively. These deviations are due to the θ uncertainty during the PMF splicing at around 1°, which is the limitation of the PMF splicer. However, the inaccuracy of the channel spacing can be neglected since the deviation is very small.

Figure 5. The experimental setup based on the two segments of PMF

Figure 6. The multiwavelength spectrum based on two-segment of PMF at θ of (a) 0° and (b) 90°. (c) The channel spacing comparison of multiwavelength spectrum at θ of 0º and 90º

5.   CONCLUSION

We have experimentally proposed a multiwavelength fiber laser based on bidirectional Lyot filter utilizing a gain medium of SOA. The flatness of multiwavelength spectrum is attributed from the intensity equalizer obtained from the IDL mechanism. Firstly, we investigated the effect of splitting ratio difference towards the flatness performance. The degradation of multiwavelength flatness is increased with larger difference of splitting ratio. Then, without polarizer in the setup, the ER value is lower as compared to with polarizer. We also demonstrated the effect on using two segments of PMF to study the channel spacing

variation with different θ. The channel spacing is measured at 0.087 nm and 0.141 nm when the θ is set to 0° and 90°, respectively.

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Abdul Hadi Sulaiman received his Bachelor of Science degree majoring Industrial Physics under Department of Physics from Universiti Teknologi Malaysia, Johore in 2007. He obtained his MSc degree at Universiti Malaya, Malaysia in 2009, under the field of photonics devices for optical communication. In 2015, he completed his PhD degree at Universiti Putra Malaysia, under research area of photonics and fiber optic system engineering. Both research works of his MSc and PhD were completed at Photonics Research Center and Wireless and Photonics Networks Research Centre, respectively. He also worked as a research assistant from 2012 until 2014 while doing his PhD. After completing his PhD, he served as a senior research officer and postdoctoral fellow at Universiti Teknologi Petronas (2015) and International Islamic University Malaysia (2016), respectively. Currently, he is working at Universiti Tenaga Nasional as a post-doctoral researcher. His research expertise include Brillouin optical time domain analyzer, multiwavelength fiber laser, Lyot filter, nonlinear polarization rotation and semiconductor optical amplifier.

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Mohd Adzir Mahdi (M'99–SM'03) received the Bachelor degree with first class honors in Electrical, Electronics and Systems Engineering from the Universiti Kebangsaan Malaysia, Selangor, Malaysia in 1996. Later, he received the Master and Ph.D. degrees with distinctions in Optical Fiber Communications from the Universiti Malaya, Kuala Lumpur, Malaysia in 1999 and 2002, respectively. In January 2003, he joined the Faculty of Engineering, Universiti Putra Malaysia, Selangor, Malaysia where he was an Associate Professor and is now a full Professor. Prior to the current appointment, Adzir was an optical design engineer at IOA Corporation, Sunnyvale, USA and a research officer at Research and Development Division, Telekom Malaysia Berhad. Since 1996, he has been involved in photonics research specializing in optical amplifiers and lasers. He has authored and coauthored over 330 scientific papers in journals and 210 articles in conference proceedings. His research interest includes optical fiber amplifiers and lasers, optical fiber communications, optical sensors and nonlinear optics. Adzir's awards and honors include the IEEE LEOS Graduate-Student Fellowship, the Australia-Malaysia Institute Research Fellowship, the Leading Scientists and Engineers of OIC Member States (COMSTECH), the COMSTECH Young Scientist, the TWAS Young Affiliate Fellow, and the National Academic Award (Young Academician Award).