Proceedings of TENCON 2018 - 2018 IEEE Region 10 Conference (Jeju, Korea, 28-31 October 2018)

SOA-based Multiwavelength Fiber Laser Assisted by Intensity Dependent Transmission Mechanism

A. H. Sulaiman, F. Abdullah, M. Z. Jamaludin, A. Ismail
Institute of Power Engineering,
Universiti Tenaga Nasional,
Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia
hadisulaiman4@gmail.com

M. A. Mahdi
Wireless and Photonics Networks Research Center,
Faculty of Engineering, Universiti Putra Malaysia,
43400 Serdang, Selangor, Malaysia
mam@upm.edu.my

***Abstract*— We investigate an intensity influence towards the flatness of multiwavelength fiber laser (MWFL) based on intensity dependent transmission (IDT) mechanism. The intensity is varied by changing semiconductor optical amplifier (SOA) current and throughput port ratio. Owing to the IDT mechanism, the multiwavelength flatness is degraded with the increment of SOA current. The change of throughput port ratio of optical splitter from 10% to 90% has also affected a worse multiwavelength flatness. The flattest multiwavelength spectrum is achieved at SOA current and throughput port of 150 mA and 10%, respectively, with the lasing lines are counted up to 300 channels within 3 dB uniformity.**

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

I. INTRODUCTION

MWFL has become one of the main attractions in photonics research areas for the application of optical communication and optical sensor. Optical amplifiers such as erbium doped fiber amplifier (EDFA) [1], [2], SOA [3]–[7] and Raman amplifier [8], [9] have been utilized as the gain medium to generate the multiwavelength laser. Due to the high mode competition in EDFA, a stable and high lasing lines of multiwavelength spectrum is hardly achieved unless a nonlinear characteristic such as nonlinear polarization rotation (NPR) effect is introduced in the laser cavity as realized in [10], [11]. The NPR effect can induce a mechanism of either intensity dependent loss (IDL) or IDT, depends on polarization state. Previous works on MWFL have applied these mechanisms of IDL [10], [12]–[19] and IDT [7], [20]–[23] as intensity equalizer for a flat multiwavelength spectrum.

The IDT mechanism within the ring cavity is also induced from NPR effect derived from SOA and its combination with other polarization components [24]. In the working state of IDT, the laser operates in positive feedback [21] and the transmission is proportional to the input intensity. In the previous work, two operational works can be realized through IDT, which are saturable absorber for passive mode-locked laser [12], [25], and intensity equalizer to alleviate mode competition in multiwavelength generation [23], [26]. For intensity equalizer, the multiwavelength flatness is depends on the cavity loss which can be adjusted by altering the intensity in the cavity [7].

The research work based on IDT mechanism using SOA is hardly reported. In this work, we investigate the importance of IDT mechanism to explain the phenomena related to the variation of multiwavelength flatness at different intensity in the cavity. The increment of SOA current and the use of 10% to 90% of throughput port of optical splitter has increased the intensity in the cavity, hence deteriorated the multiwavelength flatness.

II. EXPERIMENTAL SETUP

Fig. 1 illustrates the experimental setup in generating the multiwavelength laser. The SOA is electrically pumped by a laser diode controller and manufactured by Qphotonics. The SOA used to provide the gain as well as the nonlinear provider for NPR, and will induce the mechanism of IDT when combining with a polarization controller (PC) and a polarizer [23]. The SOA has maximum current and wavelength range of 400 mA and 1500 to 1560 nm, respectively. The multiwavelength laser is generated by constructive interference based on Lyot filter, as it is formed from a combination of polarization maintaining fiber (PMF) and a PC. The Lyot filter is applied in the setup to 'slice' the amplified spontaneous emission from SOA into comb-like output which eventually utilized as seed to generate the multiwavelength laser output.

The next component is polarization dependent isolator (PDI) which provides a linearly polarized light output, which depends on the incoming polarization direction before entering PDI input by adjusting PC2. The PDI can also work as an isolator to ensure a unidirectional operation in the ring cavity. The PDI works as a polarizer when the PDI input is connected to a PC. Note that, the MWFL requires a polarizer as in this experiment, we used the combination of PDI and PC2 to induce the IDT mechanism. The PC is used to change the polarization orientation in the laser cavity. The half wave plate (HWP) and the quarter wave plate (QWP) of PC is rotated to change the polarization angle and the polarization state of light, respectively. Eventually, an optical splitter is used to extract a portion of the multiwavelength laser through its tap port to an optical spectrum analyzer (OSA), while the remaining power is fed back through a throughput port to the ring cavity. In this experimental work, the resolution and sensitivity settings of the OSA were set to a constant setting of 0.02 nm and 'high1', respectively.

978-1-5386-5457-6/18/$31.00 ©2018 IEEE

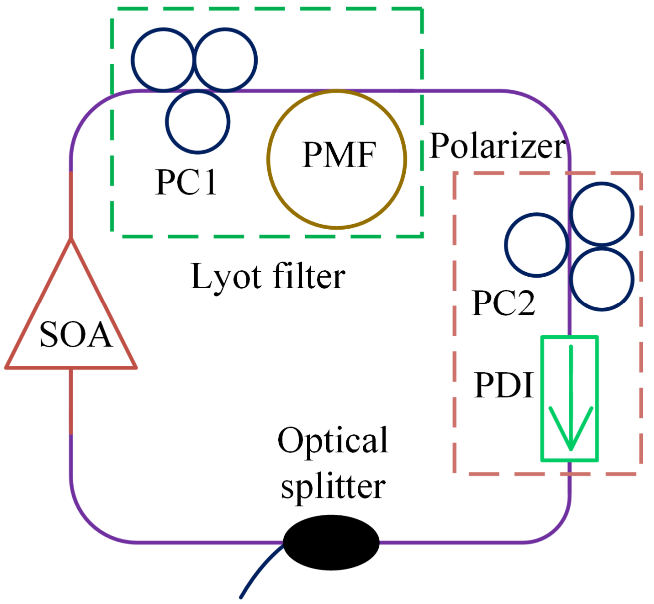

Fig. 1: The experimental setup of MWFL based on IDT mechanism utilizing unidirectional Lyot filter.

III. OPERATION PRINCIPLE

In this work, the multiwavelength generation based on the Lyot filter is based on constructive interference occurs in the PMF. At first, the incoming light from the SOA output is passed through PC1 before the HWP of the PC is rotated to ensure the polarization direction of the light that enters the PMF has 45° angle with respect to the polarization axis of the PMF. In this condition, the light splits into two orthogonal polarization components along two polarization axes within the PMF and travel at different speeds. Both of the traveling lights now have the same amplitude and polarization state, and are combined in-phase along the PMF resulting in two fold of amplitude at the same wavelength. The combined light accumulates phase difference to produce constructive interference which defines the multiwavelength spectrum.

IV. RESULTS AND DISCUSSIONS

Fig. 2 shows the power/SOA current (P/I) curves at different throughput port ratio with 20 mA of current intervals and finer steps of 5 mA at the curved line of the lasing thresholds. From the figure, the lasing threshold at throughput port 10% and 90% is determined at 130 mA and 90 mA, respectively. After the determination of the lasing threshold from the P/I curve, the slope efficiency is also measured. The slope efficiency is attained from the gradient of the plotted data above the lasing threshold. The slope efficiency is defined mathematically as dP/dI, where dP is the change of power output, while dI is the changed of SOA current. The slope efficiency of throughput port 10% and 90% is 8.592 mW/A and 0.906 mW/A, respectively. Meanwhile, the maximum output power of throughput port 10% and 90% is 1.830 mW and 0.235 mW, respectively. From the observations, the slope efficiency is proportional to the maximum output power and the lasing threshold. From the comparison of output powers, the use of throughput port 10% provides the highest maximum output power than throughput port 90%. In summary, the 10 % of throughput port ratio has the best performance in terms of high power, low lasing threshold and flat spectrum.

Fig. 3 depicts the spectra of MWFL at variation of SOA current. The increment of SOA current raises the value of intensity in the cavity. Initially, the SOA current is set to 100 mA, which achieved the flattest but the lowest power multi-wavelength spectrum as compared to the other figures as can be seen in Fig. 2(a). However, since the lasing threshold for throughput port of 10% is 130 mA, the multiwavelength spectrum at 100 mA is merely a filtered output of the ASE coming from the SOA. Afterward, the SOA current is increased to 150 mA and produced the output in Fig. 2 (b), as this is the best multiwavelength spectrum with 300 lasing lines within 3 dB uniformity. At this SOA current setting, due to the IDT mechanism, the cavity loss is high, thus the lasing wavelengths are equalized throughout the wavelength range. Instead of the adjustment of intensity, PCs are also altered in achieving flat multiwavelength spectrum with high extinction ratio value of 12 dB. This is done in order to obtain a working state of IDT, which can only be induced at a certain polarization state. Fig. 2(c) shows the multiwavelength spectra at SOA current of 200 mA. At this SOA current, the multiwavelength flatness is reduced with higher intensity. In other observation, the numbers of fluctuated lines is started to appear at the SOA current of 200 mA. This phenomenon is due to the resonant effect which increases with higher SOA current [27]. This resonant effect influences the number of fluctuated lines at approximately 20 dB, as can be seen in Fig. 2(c).

The variation of SOA current has influenced the light intensity in the cavity. The relationship of intensity in the cavity to the multiwavelength flatness can be related to the IDT mechanism. Owing to the IDT mechanism, the cavity loss is inversely proportional to the intensity in the cavity. In achieving a flat multiwavelength spectrum, the cavity loss must be high [14]. This is why the multiwavelength flatness in the working state of IDT deteriorates with the increment of SOA current to 200 mA as evident from the spectra shown in Fig. 2(c). Hence, the mechanism to flatten the multiple lasing lines ultimately depends on the cavity loss of the experimental setup. Additionally, the IDT strength is lower at higher intensity, thus also becomes the factor that can affect the multiwavelength flatness. Hence, from the experimental work, it was proved that the working state is indeed IDT because the multiwavelength flatness is deteriorated when the cavity loss is decreased through intensity increment.

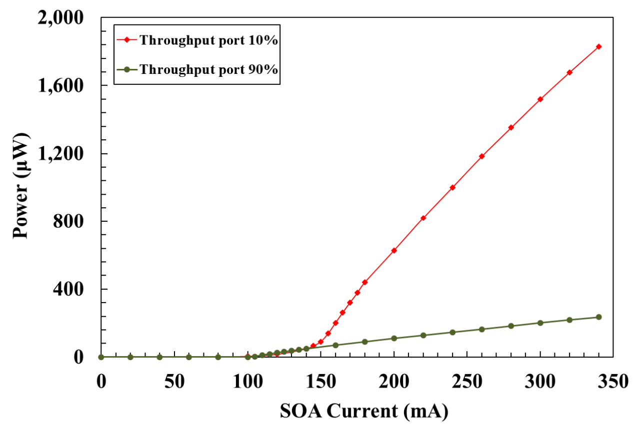

Fig. 2: The lasing threshold comparison of the best performance of MWFL based on different throughput port variation.

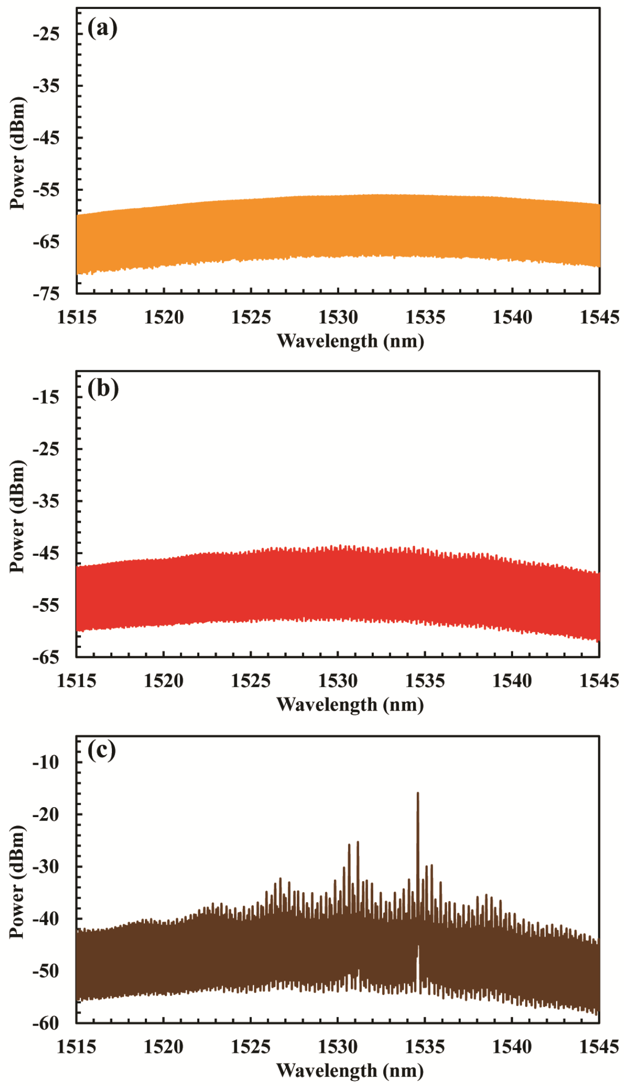

Fig. 3. Multiwavelength spectra based on throughput port of 10% when the SOA current is set to (a) 100 mA, (b) 150 mA and (c) 200 mA.

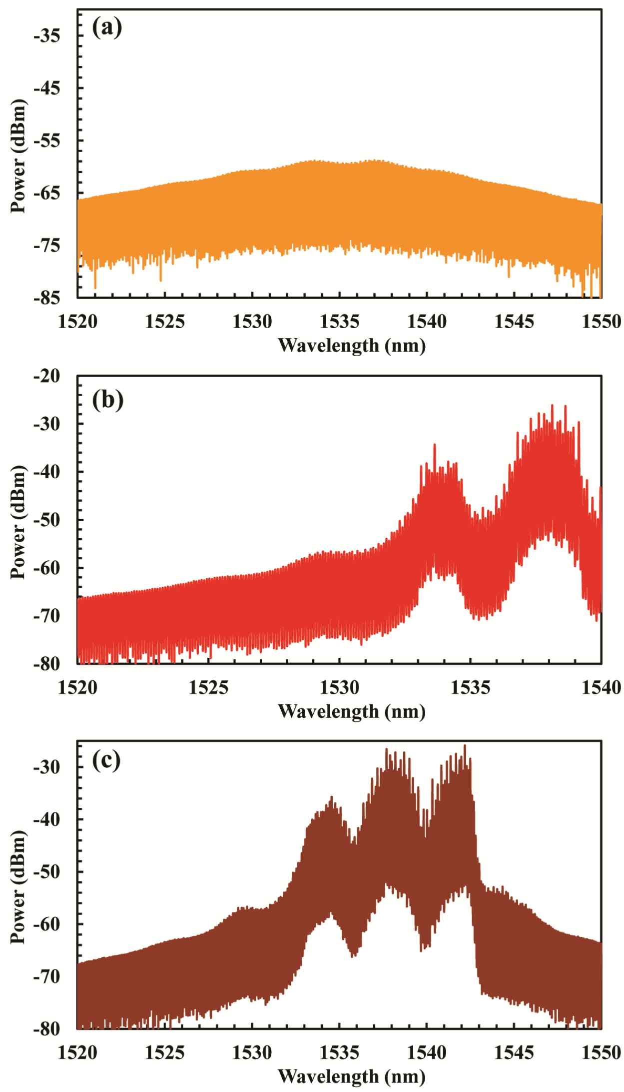

Fig. 4 Multiwavelength spectra based on throughput port of 90% when the SOA current is set to (a) 100 mA, (b) 150 mA and (c) 200 mA.

The investigation on multiwavelength performance is continued with the intensity effect to the multiwavelength flatness by varying the throughput port ratio of 10% to 90%, as the tap port now is 10%. Fig. 4 shows the observation on the multiwavelength spectrum with SOA current variation at a constant throughput port ratio of 90%. The use of throughput port ratio of 90% increases further the intensity in the cavity and produces lower output power due to the use of tap port ratio of 10%. At SOA current of 100 mA, a flat spectrum is achieved and it is beyond the lasing threshold of 90 mA. However, the peak power of multiwavelength laser is a dismal -57 dBm which is considered too low than any other published values and not appropriate for the application of MWFL. In the previous work of MWFL based on SOA [28], the peak power is at approximately -28 dBm.

When SOA is increased to 150 mA, the fluctuations are seen apparent and higher as compared to the throughput port ratio of 10% as in Fig. 3(b). The phenomenon is due to the cavity loss that is lower at throughput port ratio of 90% than the throughput port ratio of 10%. Thus, throughput port ratio of 90% is not suitable to be used for the constant parameter setting required in the investigation of this MWFL based on IDT mechanism. This is due to the increment of cavity loss that has affected the intensity decrement in the cavity in the working state of IDT. At an increased cavity loss, a flat multiwavelength spectrum can be achieved [14]. Hence, since the cavity loss is lower in throughput port of 90%, a worse multiwavelength spectrum is obtained. The spectral profile is extremely unequal at SOA current of 200 mA as can be seen in Fig. 4(c) due to the further increment of intensity in the cavity. With higher intensity in the cavity, the cavity loss and IDT strength is lower, thus deteriorating the multiwavelength flatness, even with PCs adjustment.

Conclusively, the use of low intensity in the cavity that above the lasing threshold value is an enormous advantage for this MWFL structure in generating high and flat multiwavelength spectrum. Additionally, the low intensity is also beneficial because operating in high intensity mode for long period will lead to the generation of more heat which could quicker damage the device in the setup.

Finally, we observed the multiwavelength performance pertains to the wavelength stability within 8 min. The wavelength stability is checked at a wavelength range from 1529.5 until 1530.5 nm. Fig. 5 exhibits the wavelength fluctuation of 0.05 nm that is attributed from the SOA which has high polarization sensitivity. This problem can be rectified by employing all-PMF PC, which should be able to mitigate the wavelength fluctuation.

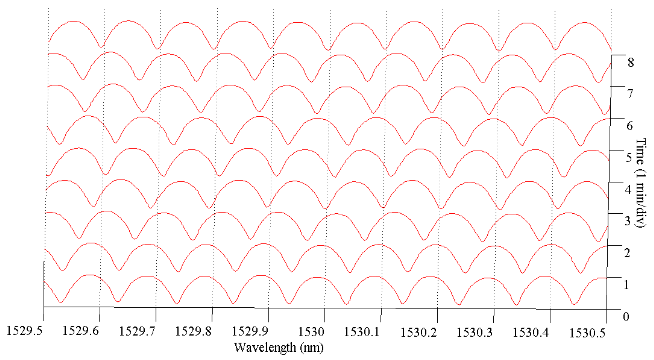

Fig. 5: Wavelength stability of the MWFL spectra within 8 min of interval time.

V. CONCLUSION

We have demonstrated a multiwavelength generation based on IDT mechanism. The multiwavelength spectrum is flat due to the IDT mechanism as the intensity equalizer, which is induced from the NPR effect obtained from the combination of SOA with a PDI and a PC. The intensity in the cavity is increased through the raise of SOA current and throughput port ratio, resulting to a worse multiwavelength flatness. The deterioration of multiwavelength performance is due to the IDT mechanism. In this IDT-based MWFL, high cavity loss is also an important factor to achieve a flat spectrum, as the high cavity loss is obtained at lower intensity in the cavity.

ACKNOWLEDGMENT

In completing this manuscript, the authors extend their appreciation to the facility at Wireless and Photonics Networks Research Center, Faculty of Engineering, Universiti Putra Malaysia.

REFERENCE

[1] S. Saleh, N. A. Cholan, A. H. Sulaiman, and M. A. Mahdi, “Stable multiwavelength erbium-doped random fiber laser,” IEEE J. Sel. Top. Quantum Electron., vol. 24, pp. 1–6, May-June 2018.

[2] S. Saleh, N. A. Cholan, A. H. Sulaiman, and M. A. Mahdi, “Lyot-based multi-wavelength fiber laser,” Int. J. Electr. Comput. Eng., vol. 7, pp. 981–985, April 2017.

[3] A. H. Sulaiman, N. Yusoff, S. Hitam, A. F. Abas, and M. A. Mahdi, “Investigation of continuously adjustable extinction ratio in a multiwavelength SOA fiber laser based on intensity dependent transmission effect,” IEEE 4th International Conference on Photonics, pp. 151–153, December 2013.

[4] A. H. Sulaiman, N. Md. Yusoff, M. H. Abu Bakar, S. Hitam, and M. A. Mahdi, “Multiwavelength SOA fiber ring laser based on bidirectional Lyot filter,” 1st Int. Conf. Telemat. Futur. Gener. Networks, pp. 1–4, October 2015.

[5] A. H. Sulaiman, A. K. Zamzuri, N. M. Yusoff, S. Hitam, A. F. Abas, and M. A. Mahdi, “Wavelength-spacing tunable S-band multi-wavelength fiber laser based on Lyot filter,” IEEE 2nd International Conference on Photonics, pp. 6–8, December 2011.

[6] A. H. Sulaiman, N. M. Yusoff, N. A. Cholan, and M. A. Mahdi, “Multiwavelength fiber laser based on bidirectional Lyot filter in conjunction with intensity dependent loss mechanism,” Indones. J. Electr. Eng. Comput. Sci., vol. 10, pp. 401–408, June 2018.

[7] A. H. Sulaiman, A. K. Zamzuri, S. Hitam, A. F. Abas, and M. A. Mahdi, “Flatness investigation of multiwavelength SOA fiber laser based on intensity-dependent transmission mechanism,” Opt. Commun., vol. 291, pp. 264–268, March 2013.

[8] Y. Han, J. Lee, and S. Kim, “Tunable multi-wavelength Raman fibre laser based on fibre Bragg grating cavity with PMF Lyot-Sagnac filter,” Electron. Lett., vol. 40, pp. 1475 - 1476, November 2004.

[9] W. Gao, M. Liao, D. Deng, T. Cheng, T. Suzuki, and Y. Ohishi, “Raman comb lasing in a ring cavity with high-birefringence fiber loop mirror,” Opt. Commun., vol. 300, pp. 225–229, July 2013.

[10] Z. Zhang, L. Zhan, K. Xu, J. Wu, Y. Xia, and J. Lin, “Multiwavelength fiber laser with fine adjustment, based on nonlinear polarization rotation and birefringence fiber filter,” Opt. Lett., vol. 33, pp. 324–326, February 2008.

[11] T. Liu, D. Jia, T. Yang, Z. Wang, and Y. Liu, “Stable L-band multi-wavelength SOA fiber laser based on polarization rotation,” Appl. Opt., vol. 56, pp. 2787–2791, April 2017.

[12] Z. X. Zhang, K. Xu, J. Wu, X. B. Hong, and J. T. Lin, “Two different operation regimes of fiber laser based on nonlinear polarization rotation : passive mode-locking and multiwavelength emission,” IEEE Photonics Technol. Lett., vol. 20, pp. 979–981, May 2008.

[13] X. S. Liu, L. Zhan, X. Hu, H. G. Li, Q. S. Shen, and Y. X. Xia, “Multiwavelength erbium-doped fiber laser based on nonlinear polarization rotation assisted by four-wave-mixing,” Opt. Commun., vol. 282, no. 14, pp. 2913–2916, July 2009.

[14] X. Feng, C. Lu, H. Y. Tam, P. K. A. Wai, D. Y. Tang, and B. Guan, “Mechanism for stable, ultra-flat multiwavelength operation in erbium-doped fiber lasers employing intensity-dependent loss,” Opt. Laser Technol., vol. 44, no. 1, pp. 74–77, February 2012.

[15] J. Tian, Y. Yao, J. J. Xiao, X. Yu, and D. Chen, “Tunable multiwavelength erbium-doped fiber laser based on intensity-dependent loss and intra-cavity loss modulation,” Opt. Commun., vol. 285, pp. 2426–2429, May 2012.

[16] Z. Luo, A. Luo, and W. Xu, “Tunable and switchable multiwavelength passively mode-locked fiber laser based on SESAM and in-line birefringence comb filter,” IEEE Photonics J., vol. 3, pp. 64–70, February 2011.

[17] Z. Zhang, Q. Kuang, M. Sang, Z. Ye, and Y. Nie, “Multiwavelength fiber laser with ultradense wavelength spacing based on inhomogeneous loss with assistance of nonlinear polarization rotation,” Opt. Commun., vol. 283, pp. 254–257, January 2010.

[18] H. Lin, “Waveband-tunable multiwavelength erbium-doped fiber laser,” Appl. Opt., vol. 49, pp. 2653–2657, May 2010.

[19] H. Lin, Y.-F. Huang, and Y.-S. Huang, “Full L-band coverage of multiwavelength erbium-doped fiber laser,” Opt. Commun., vol. 284, pp. 5357–5360, October 2011.

[20] Z. X. Zhang, K. Xu, J. Wu, X. B. Hong, and J. T. Lin, “Multiwavelength figure-of-eight fiber laser with a nonlinear optical loop mirror,” Laser Phys. Lett., vol. 5, pp. 213–216, March 2008.

[21] Z. X. Zhang, Z. Q. Ye, M. H. Sang, and Y. Y. Nie, “Nonlinear-polarization-rotation based multiwavelength erbium-doped fiber lasers with highly nonlinear fiber,” Laser Phys., vol. 21, pp. 1820–1824, September 2011.

[22] Z. Zhang, P. Liang, M. Sang, and Y. Zhiqing, “Wavelength-spacing switchable multiwavelength fiber lasers based on nonlinear polarization rotation with cascaded birefringence fibers,” J. Mod. Opt., vol. 58, pp. 82–86, January 2011.

[23] Z. Zhang, J. Wu, K. Xu, and X. Hong, “Tunable multiwavelength SOA fiber laser with ultra-narrow wavelength spacing based on nonlinear polarization rotation,” Opt. Express, vol. 17, pp. 17200–17205, September 2009.

[24] X. Feng, H. Tam, and P. K. A. Wai, “Stable and uniform multiwavelength erbium-doped fiber laser using nonlinear polarization rotation,” Opt. Express, vol. 14, pp. 8205–8210, September 2006.

[25] C. Tu, W. Guo, Y. Li, and S. Zhang, “Stable multiwavelength and passively mode-locked Yb-doped fiber laser based on nonlinear polarization rotation,” Opt. Commun., vol. 280, pp. 448–452, December 2007.

[26] X. Liu, L. Zhan, S. Luo, Z. Gu, J. Liu, Y. Wang, and Q. Shen, "Multiwavelength erbium-doped fiber laser based on a nonlinear amplifying loop mirror assisted by un-pumped EDF," Opt. Express, vol. 20, no. 7, pp. 7088–7094, March 2012.

[27] H. Ahmad, K. Thambiratnam, A. H. Sulaiman, N. Tamchek, and S. W. Harun, "SOA-based quad-wavelength ring laser," Laser Phys. Lett., vol. 5, pp. 726–729, October 2008.

[28] A. H. Sulaiman, A. K. Zamzuri, N. Md. Yusoff, N. A. Cholan, F. Abdullah, A. F. Abas, M. T. Alresheedi and M. A. Mahdi, "Broad wavelength region of SOA-based multiwavelength laser incorporating bidirectional Lyot filter", Chinese Opt. Lett., vol. 16, pp. 090603-1-090603-5, September 2018.