International Journal of Electrical and Computer Engineering (IJECE)
Vol. 7, No. 2, April 2017, pp. 981~985
ISSN: 2088-8708, DOI: 10.11591/ijece.v7i2.pp981-985

Lyot-based Multi-Wavelength Fiber Laser

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Article Info

Article history:

Received Dec 30, 2016
Revised Feb 26, 2017
Accepted Mar 12, 2017

Keyword:

Four-wave mixing
Lyot filter
Multi-wavelength fiber laser

ABSTRACT

A multi-wavelength fiber laser which is based on a Lyot filter is experimentally demonstrated. A combination of four-wave mixing in a highly nonlinear fiber and Lyot filter mechanism in the laser cavity is able to generate multi-wavelength with relatively high extinction ratio (ER). At the input current of 100mA, six laser lines with ER more than 5 dB are successfully generated. The wavelength spacing for the multi-wavelength is 0.15nm, corresponding to the characteristics of the Lyot filter used.

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1. INTRODUCTION

Multi-wavelength fiber lasers (MFLs) can be utilized not only in optical communication systems, but also in optical instrument testing and signal processing [1]. Owing to these applications, many substantial research efforts have been initiated to generate the MFLs. In order to select the wavelengths in the MFLs, researchers have utilized optical nonlinerities [2], [3] and comb filters [4-12] in the laser cavities. Under optical nonlinearities, the nonlinearity of stimulated Brillouin scattering (SBS) in the fiber, for example, can be utilized to generate the multi-wavelength but the wavelength spacing is fixed to 0.08 nm (10 GHz) as a result of the nature of SBS [2]. Another example of optical nonlinearities is four wave mixing [3]. Despite the flexibility it offers, FWM is very much dependent on the phase matching of the generated waves, thus limiting the number of wavelengths generated if the phase matching is not optimized. Under the comb filters on the other hand, many types of comb filters that have been utilized to generate multi-wavelength such as a Sagnac interferometer [4-6], Mach-Zehnder interferometer [7] Fabry-Perot interferometer [8], [9] and Lyot filter [10-16]. In this work, we demonstrate the combination of a Lyot filter and FWM in a highly nonlinear fiber (HNLF) in the laser cavity for the generation of multi-wavelength. For the input current of 100mA, six laser lines with extinction ration (ER) of more than 5 dB are successfully generated.

2. EXPERIMENT AND OPERATING PRINCIPLE

The multi-wavelength generation scheme utilizing a commercial erbium-doped fiber amplifier developed by Universiti Putra Malaysia (UPM) (see Figure 1) and Lyot filter is described in Figure 2. Two polarization controllers (PCs), a 35.6m long polarization maintaining fiber (PMF), an isolator, a 300m long highly nonlinear fiber (HNLF), a 90/10 coupler and the UPM EDFA establishes the ring-structured laser scheme. The Lyot filter is constructed from a combination of a PC (see PC1 in Figure 2) and the PMF that serves as a comb generator [9]. Another PC (see PC2 in Fig. 2) provides adjustment for polarization states of light so as to optimize the four wave mixing (FWM) conversion efficiency in the HNLF. The direction of light propagation is controlled by the isolator which keeps unidirectional path in the ring cavity. There are three operation modes provided by the UPM EDFA which are automatic current control (ACC), automatic power control (APC) and automatic gain control (AGC); however, in this work only ACC mode is used and the maximum current supplied is 450mA. The reason for the use of ACC mode is that it is more convenient to adjust current (ACC), instead of power (APC) and gain (AGC) to operate the EDFA. However, regardless of the mode used, the EDFA will give the same output power provided that the right input setting is utilized. Light amplification over the C-band region is provided by the EDFA and its maximum output power is 20 dBm. Besides amplification, the EDFA can generate amplified spontaneous emission (ASE) as well, which is useful for component characterization and optical sensor's application. The nonlinear medium is provided by the HNLF and it leads to the stabilization process against the gain mode competition in the EDFA. The length of HNLF used is 300 m with the nonlinearity coefficient of 11.5 $(\text{Wkm})^{-1}$ and zero dispersion wavelength of 1556.5 nm. As a consequence of the Lyot filter mechanism, the constructive interference process occurs in the PMF, leading to the generation of multi-wavelength. The wavelength spacing between lines in the multi-wavelength can be determined by $\Delta\lambda = \lambda^2 / BL$, where λ, B and L represents the operating wavelength, PMF birefringence and PMF length respectively. The PMF length used is 35.6m and the birefringence is 4.5×10^{-4}. The losses incurred by multi-wavelength lasers that oscillate in the cavity through PC1, PMF, PC2, isolator, HNLF, 90/10 coupler are compensated by the EDFA gain. The 10% fraction of the signal is tapped out of the cavity for the laser output, while the remaining 90% portion is channeled back into the cavity.

Figure 1. A commercial EDFA developed by UPM

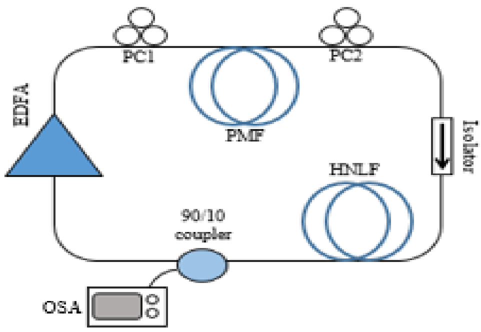

Figure 2. The experimental setup of multi-wavelength generation utilizing a Lyot filter

3. RESULTS AND ANALYSIS

The EDFA is firstly characterized. We would like to observe the behavior of the EDFA output power as the input current increases. The input for the UPM EDFA is provided by a laser source with -20 dBm power and the EDFA output power is recorded by an optical power meter. Figure 3 shows the behavior in which the output power achieves a steep increase for the input current up to 100mA. This is caused by the population inversion of the dopant ions that create significant gain for the input signal. Beyond the 100mA, the output power grows slowly, resulting from the saturation of gain as the signal power increases.

We then run the experiment (see Figure 2) and investigate the laser spectrum as the EDFA input current increases. In this investigation, the laser lines are counted if they are in consecutive order and the extinction ratio (ER) value achieves at least 5dB. According to Figure 4, the number of lines keeps reducing as the EDFA input current increases from 100mA to 300mA. The reduction is attributed to the effect of FWM in the HNLF. As the EDFA current increases, more power is transferred from high power lasers to lower power lasers through FWM processes in the HNLF. Consequently, the laser lines suffer from the reduction of ER, resulting in fewer numbers of generated multi-wavelengths. Despite the setback, the design is favorable in that it is successful in generating multi-wavelength at low EDFA's current. With the input current of just 100mA, six laser lines with ER more than 5 dB are successfully generated (see Figure 5).

We then look into detail the spectrum of multi-wavelength in terms of wavelength spacing (see Figure 6). Owing to the Lyot structure as the comb filter, the wavelength spacing for the generated multi-wavelength follows the equation mentioned in the previous section. Applying the equation with the operating wavelength of 1550nm, PMF birefringence of $4.5\times10^{-4}$and PMF length of 35.6m, the calculated wavelength spacing is 0.15nm. This calculated value agrees with the experimental value that is measured from the spectrum captured on the optical spectrum analyzer. It is important to note that the laser lines obtained in the experimental work does not contain Brillouin component as a result of the unidirectional oscillation in the clockwise direction. As the Brillouin component is backward reflected, such Brillouin part is blocked by the isolator. Therefore, the nonlinearity of FWM is the one that is responsible for the generation of multi-wavelength in the fiber laser.

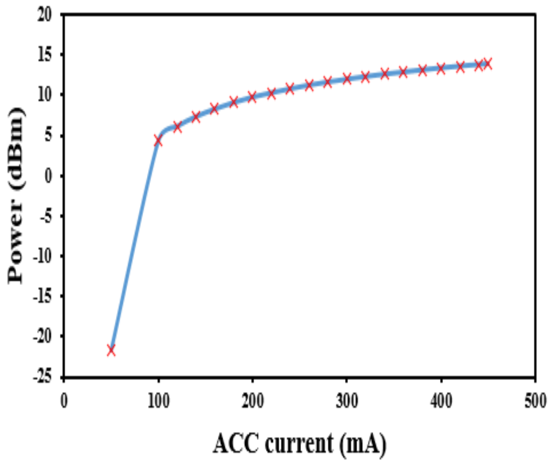

Figure 3. EDFA output power as a function EDFA input current

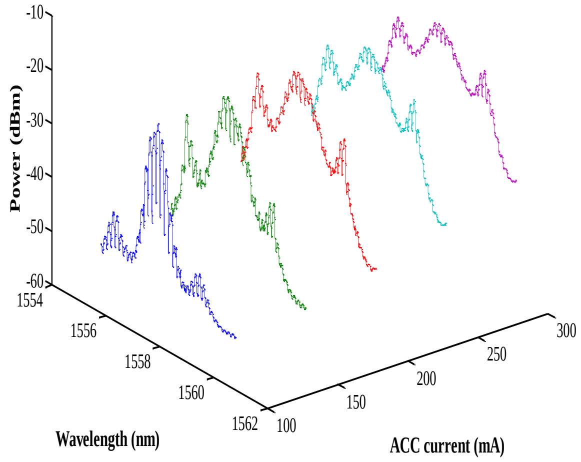

Figure 4. The spectra of multi-wavelength as the EDFA input current varies

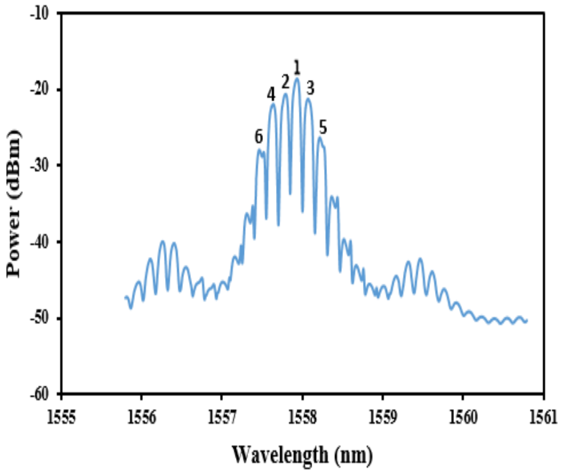

Figure 5. The spectrum of multi-wavelength at the EDFA input current of 100mA

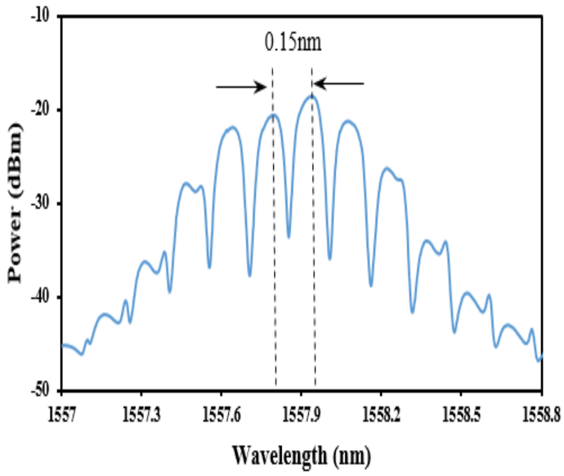

Figure 6. The wavelength spacing of generated multi-wavelength

4. CONCLUSION

Multi-wavelength generation with the incorporation of Lyot filter in the laser cavity is experimentally demonstrated. The Lyot structureserves as the comb filter, while FWM in the HNLF help stabilizes the multi-wavelength against the gain mode competition in the EDFA. At the EDFA input currentof 100mA, six laser lines with ER more than 5 dB are successfully generated. The multi-wavelength could find applications in optical sensors and communication systems.

ACKNOWLEDGEMENTS

This work was supported in part by the Ministry of Higher Education, Malaysia under research grant FRGS/2/2014/TK03/UTHM/03/1 and RACE grant Vot 1509.

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Suhairie bin Saleh was born on 3th January 1992 in Klang, Selangor, Malaysia. After graduated from Kolej Matrikulasi Perak in 2011, he pursued his bachelor degree in Engineering (Electrical-Telecommunication) at Universiti Teknologi Malaysia (UTM), Skudai Johor, Malaysia and finished in 2015. He continued his master level study in Master of Electrical-Telecommunication Engineering at Universiti Tun Hussein Onn (UTHM), Malaysia and has been appointed as graduated research assistant in photonic/optical communication field. He had a collaboration research work at Universiti Putra Malaysia (UPM) under the supervision of Prof. Dr. Mohd Adzir Mahdi started in January 2016 until December 2016. He has been author for 2 conference proceeding papers and as of now, he continued his research work at UTHM's photonic laboratory.

Noran Azizan Cholan was born on 31st August 1979 in Segamat, Johor, Malaysia. He received his bachelor degree in Electronics Engineering from Universiti Tenaga Nasional (UNITEN), Malaysia in 2002. Afterwards in 2004, he obtained his master degree in Electronics-Telecommunications Engineering form Universiti Teknologi Malaysia (UTM), Malaysia. In 2010, he enrolled as a PhD student in Universiti Putra Malaysia under the supervision of Prof. Dr. Mohd Adzir Mahdi. During his PhD study in 2012, he went to Swansea University, UK for a 3 months attachment under the guidance of Prof. Emiritus Michel E. Marhic for a collaborated project of Brillouin amplifiers. Later in the same year, he went to The Hong Kong Polytechnic University, Hong Kong for a month to collaborate with Prof Lu Chao for a project of optical communication systems. Since then, he has served as a senior lecturer in Universiti Tun Hussein Onn Malaysia (UTHM). As of now, he has been authors/co-authors for 6 journal and 14 conference proceeding papers.

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 Master of Science (MSc) degree at Universiti Malaya, Malaysia in 2009, under the field of photonics devices for optical communication. He completed his Doctor of Philosophy (PhD) degree in 2015 at Universiti Putra Malaysia, under research area of photonics and fiber optic system engineering.Both research work of his MSc and PhD were completed at Photonics Research Center and Photonics lab, respectively. He served as a research assistance and senior research officer at Universiti Putra Malaysia (2012-2014) and Universiti Teknologi Petronas (2015), respectively. Currently, he serves as Postdoctoral Fellow at International Islamic University Malaysia. His research interests include multiwavelength fiber laser, Lyot filter, nonlinear polarization rotation and semiconductor optical amplifier.

Mohd Adzir Mahdi received his B.Eng. degree from the Universiti Kebangsaan Malaysia, and M.Sc. and Ph.D. degrees from the Universiti Malaya in 1996, 1999 and 2002 respectively. He joined the Department of Computer and Communication Systems Engineering, Faculty of Engineering, Universiti Putra Malaysia on January 21, 2003. He is now a full professor at the Universiti Putra Malaysia. Prior to the current position, he worked for a start-up company; Pine Photonics Communications Inc. in Fremont, CA, USA during the period of economic boom there. He then opted for another start-up company; IOA Corporation in Sunnyvale, CA to further sharpens his skills and widens experiences. It was during his stint at both companies that he came up with 2 commercial designs, 1 alpha prototype and 4 engineering prototypes that all related to optical amplification technologies. Adzir served as a research officer at the Photonics Laboratory, Research and Development Division, Telekom Malaysia Berhad.