A dual Wavelength Erbium Doped Fibre Ring Laser Employing 3dB Coupler and FBGs in Preparation for Dispersion Measurement

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Abstract – **A simple dual -wavelength c-band laser source with the aid of Fibre Bragg gratings (FBG) with an optical SNR of up to 70dB is demonstrated. The laser includes a 3,2m Erbium doped fibre with 11,38dB/m absorption in a ring resonating cavity with optical couplers. The ring cavity had two FBGs centred at 1555.12nm and 1560.32nm attached by a 3dB coupler. A 1m long sagnac loop with 70:30 coupling was used to stabilise the dual wavelength emission to about 2dB. The multiwavelength and narrow spectral width of 0.183nm and 0.195nm of the laser can be used for dispersion measurement in WDM communication links which consist of more than one wavelength. The laser was characterised for dual output power response and power stability. The paper present a characterisation of an Erbium doped fibre (EDF) ring laser. The laser is cost effective and dynamic in selecting preferred components for optimal performance in terms of power and wavelength stability, wavelength selectivity and narrow spectral width. EDF lasers are commercial available and already showing great promise in terms of the formidability and compatibility with current industrial requirements**.

Keywords – **Dual wavelength, Erbium doped fibre, FBG, 3dB coupler and 1m SMF sagnac loop**

I. INTRODUCTION

Erbium doped fibre laser (EDF) has made great progress in terms of keeping up with the continuous growth of optical communication systems. Its flexibility with regard to ease of design, construction and compatibility with optical fibre together with low threshold and high power conversion has made it a very attractive laser to work with. Many application have over time demonstrated the usefulness of fibre lasers; in sensors, communication and spectroscopy.

A particularly interesting application we looked at is the use of the fibre laser in WDM communication system. The multi-wavelength fibre laser have had a significant impact on WDM system in terms of allowing the providence of high bandwidth and high speed communications. It is part of the reasons that a lot of research has been done on fibre lasers for communication [1]–[5]. It has furthermore been reported on various occasions that most of the challenges are in generating multiwavelength laser source with EDF is that they saturate at room temperature [6]–[11].

Some techniques of overcoming the saturation include hydrogen cooling[12]–[14] of the EDF, hole burning[10], [15], [16] and introducing an intracavity Fabry–Perot etalon as an oscillation wavelength filter. We are demonstrating a dual wavelength ring fibre laser with two FBGs by balancing the wavelength dependent net gain and loss in the cavity. It has been reported that in a resonator only the wavelength with a loss, low enough to match the available gain, will be emitted. Thus, upon introducing wavelength dependent loss and in the process, balance the reflectivity difference of the wavelengths defined by the FBG, a dual multiwavelength laser was achieved.

The wavelength and power stability of a three wavelength EDF laser using a nonlinear optical loop mirror (NOLM, also known as a sagnac loop) is demonstrated in [17]. A 2.5km NOLM is used to stabilise the FBG defined multi-wavelength emission. In [18] the NOLM is used as an intensity dependent loss in the laser cavity to study the mechanism to attain a stable and ultra–flat multi-wavelength oscillation.

An EDF laser that is switchable and generate multi-wavelengths is demonstrated in [9], [10], [18]–[21] which employ either one or both wavelength dependent and intensity dependent loss in the cavity, however no FBG as the wavelength filter were used.

It is also demonstrated in [20] that nonlinear polarization rotation can be employed to achieve a multiwavelength EDF laser by introducing intensity and wavelength dependent loss to alleviate mode competition caused by the homogenous broadening of EDF.

In this paper, two FBG’s were utilised to achieve the dual wavelength EDF source as in [12], [13], [15], [22]–[26]. In the latter, some of the dual wavelength are achieved through cavity configuration, linear or ring. They may incorporate different types of EDF (pumped or unpumped) and or combination of the EDF and semiconductor amplification. The ring cavity may entail a series configuration of circulators or a combination of circulators and couplers to reduce cost and complexity Some employ different types of gratings (Phase shift FBG, Chirped FBG e.tc.) while other introduce intracavity loss – through polarization control, Sagnac loops and tuneable filters.

We employed a 3dB coupler with a 50:50 coupling ratio in series with a 1m long sagnac loop with both uniform FBG attached to one output branch of the coupler as shown in Figure 1. The configuration is set to be cheaper and dynamic in terms design to meet specific operational characteristics. The advantage of using FBGs in the cavity is that the operating wavelengths and bandwidth is defined by the grating. As such, a stable and wavelength controlled laser can be produced for specific purposes such as dispersion control in an optical fibre link.

II. EXPERIMENTAL SETUP

A fibre laser system consists of three main features, the pump source, the gain medium and lastly the feedback system as illustrated in Figure 1. The laser diode pumps power at a specific frequency (υ_p) to excite ions of the gain medium to produce a population inversion through absorption[27], [28].

Erbium doped fibre forms the gain medium and consist of a rare–earth element Erbium ions. Population inversion is produced with this medium through a certain energy level structure with different states (ground state, excited state and ‘metastable state’). It is this level structured system that determines which pump frequency ($980nm/1480nm$) is required to emit the lasing light at a specific frequency ($\sim \pm 1550nm$), this happens spontaneously. The third feature of the fibre laser which stimulates the emission of light, is the feedback system. It directs the emitted light from the gain medium continuously back and forth as demonstrated in Figure 1 with the ring configuration to produce an emission beam [27], [28].

The experimental setup of the experiment is shown in the schematic of Figure 1. The setup makes up the dual wavelength fibre ring cavity laser source by means of two FBGs centred at 1555.12nm and 1560.32nm. Each grating has a bandwidth and reflectivity of 0.183nm, 0.195nm and 96.01%, 96.35% respectively. The 3,2m EDF with an absorption of 11.38dB/m was pumped through a 980/1550nm WDM coupler with a laser diode at 980nm.

Furthermore, with the use of series connected FBGs for emission at the prescribed grating wavelength, a combination of two optical isolators and a 50:50 optical coupler was utilised to guarantee unidirectional transmission. The combination of a 50:50 coupler and a 70:30 coupler with a 30% looping over a 1metre single mode fibre to introduce an intensity and wavelength dependent loss to ensure that only the 1555.12nm and 1560.32nm lasing wavelengths are produced. The oscillating wavelength are filtered from the amplified spontaneous emission generated in the EDF by the external series connection of the FBG’s with 96% reflectivity at 1555.12nm and 1560nm. These wavelengths are the ones at which the loss is low enough to match the available gain. This means that most of the gain attained in the cavity will be distributed evenly at these two wavelengths.

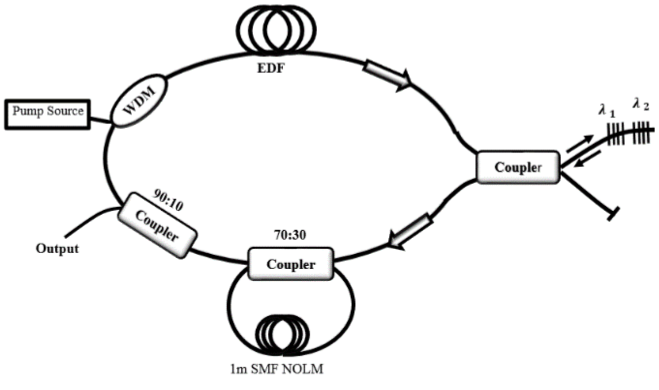

Figure 1: Dual fibre ring laser schematic with two gratings at 1555.12nm and 1560.32nm.

An optical spectrum analyser was used to measure the laser output.

III. EXPERIMENTAL RESULTS AND DISUSSION

A series of experiments were conducted with the configuration in Figure 1. The exchanging of an optical circulator and optical coupler was performed to achieve the dual lasing wavelength. It was found that the coupler easily matched the gain loss requirement in the cavity than when inserting an optical circulator, with the addition of the 1m sagnac loop.

The laser output spectrum at 1555.12nm and 1560.32nm is shown for a pump power of 43.053mW in Figure 2. Figure 3 and Figure 4 demonstrates the effect that an increase in pump power has on the two generated wavelengths. It is shown that as the pump power increase, the output lasing spectra increases simultaneously. Meaning that there is a balance between the two-wavelength’s power increase relative the pump power. Figure 3 gives a visual display of the output power increase over 5mW to 50mW.

In optical telecommunication systems, such as Dense WDM networks, this may be used to modulate more than one wavelength with the guarantee that the lasing wavelength power are equivalent. Also, the laser that the threshold for both wavelength is $15mW$ from Figure 4. This confirms the low pump threshold characteristics of fibre lasers and thus, low cost.

A stability performance test over a 2hour duration was also performed as shown in Figure 5 (power fluctuation curve) and Figure 6 the spectral power stability. The dual laser is stable and maintains a fluctuation of about 5%. Also, the spectral widths of the two wavelengths were maintained at 0.183nm and 0.195nm respectively with the configuration. This is important in optical communication WDM networks where EDF laser are used. It compared with the semiconductor lasers which when employed in WDM network, they need to be used in bulk which is often a challenge in terms cost and compactness. The EDF lasers are cheaper, compact and easily constructed to meet current bandwidth requirements of network. They can also be utilised for dispersion measurement in an optical fibre link since it is possible to achieve multiwavelength. WDM system present high bandwidth however have limitation in terms of transmission length as a result of dispersion.[29]–[31]. As such, setting up experiments to test dispersion over a multiwavelength transmission link can help improve the transmission length with dispersion compensators as demonstrated in[32]. The approach would be to characterise Erbium doped fibre (EDF) ring laser for dispersion measurement and compensation. It is cost effective and dynamic in selecting preferred components for optimal performance in terms of power and wavelength stability, wavelength selectivity (dispersion and loss profile) and control spectral-width of source to minimize dispersion effects of the source. EDF is commercial available and is already showing great promise in terms of the formidability and compatibility with current industrial requirements.

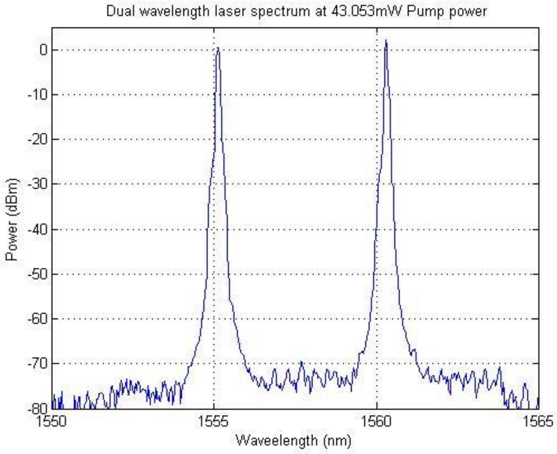

Figure 2: Laser output spectrum

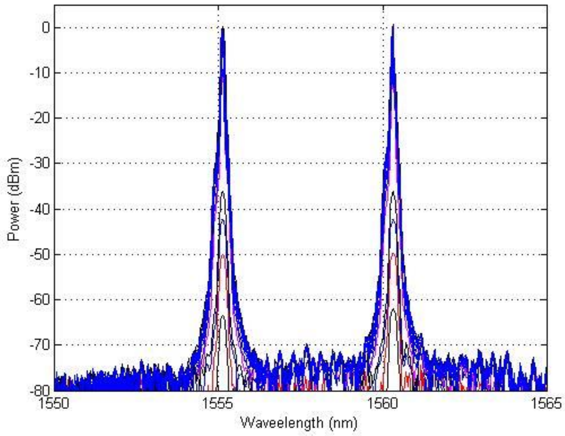

Figure 3: Laser spectrum at 1555.12nm and 1560.32nm for different pump power 100mA – 500m

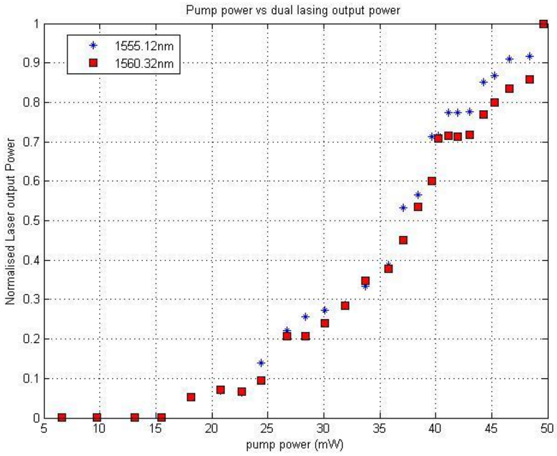

Figure 4: Laser spectrum power response at 1555.12nm and 1560.32nm with increase in pump power.

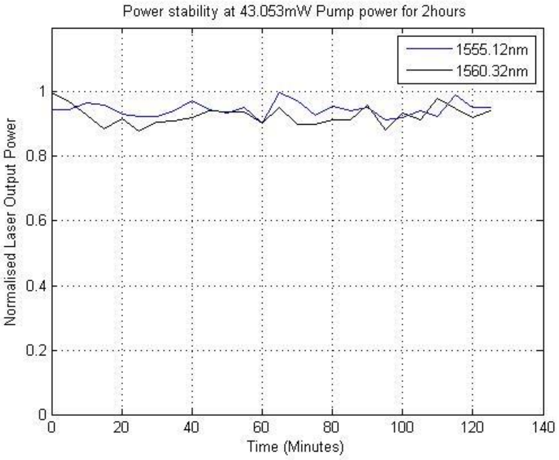

Figure 5: Output power fluctuation of laser at 1555.12nm and 1560.32nm for 2hour duration.

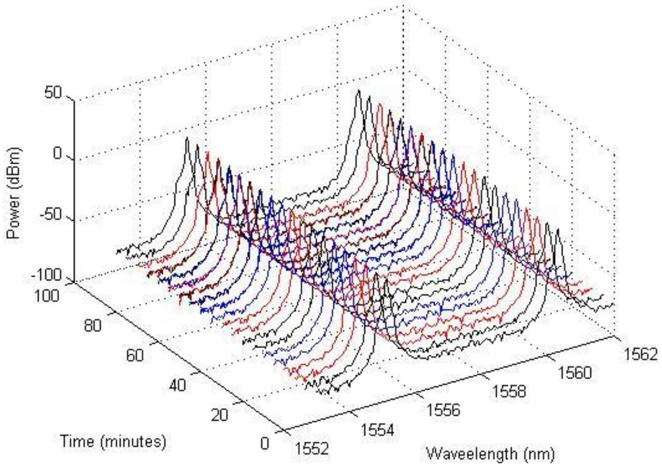

Figure 6: Laser spectrum over the 2hour duration

IV. CONCLUSION

A simple dual wavelength ring laser has been demonstrated. The lasing wavelength was defined by the two series connected fibre Bragg gratings at 1555.12nm and 1560.32nm. The configuration used was able to maintain the linewidth specified by the FBGs. The multiwavelength operation will especially be useful for dispersion measurement in a WDM communication link.

V. FUTURE WORK

To optimize the dual wavelength laser stability performance and increase the lasing wavelength to three or four. Also, the laser will then be further characterised to test its performance in a WDM optical link of length L for dispersion measurement and compensation in a fibre.

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REFERENCES

[1] A. Fujisaki, N. Yoshizawa, Y. Emori, K. Tominaga, K. Tanaka, and J. Nishina, “Linewidth controlled 50-W output polarization maintaining fiber laser,” *Furukawa Rev.*, no. 35, pp. 12–17, 2009.

[2] H. Chi and J. Yao, “Fiber chromatic dispersion measurement based on wavelength-to-time mapping using a femtosecond pulse laser and an optical comb filter,” *Opt. Commun.*, vol. 280, no. 2, pp. 337–342, 2007.

[3] R. Anthony, “Design Optimization of Erbium-Doped Fiber Ring Laser For C and L Band Amplification Incorporating Chirped Fiber Bragg Grating,” vol. 3, no. 1, pp. 1–4.

[4] D. K. Tripathi, P. Singh, N. K. Shukla, and H. K. Dixit, “Performance study in dispersion compensation techniques with Duobinary format at different bit rates,” *ICPCES 2012 - 2012 2nd Int. Conf. Power, Control Embed. Syst.*, pp. 0–4, 2012.

[5] G. Gnanagurunathan and F. A. Rahman, “Comparing FBG and DCF as dispersion in the long haul narrowband WDM systems,” *Wirel. Opt. Commun. Networks, 2006 IFIP Int. Conf.*, p. 4 pp.-pp.4, 2006.

[6] A. Zhang, M. S. Demokan, and H. Y. Tam, “Room temperature multiwavelength erbium-doped fiber ring laser using a highly nonlinear photonic crystal fiber,” *Opt. Commun.*, vol. 260, no. 2, pp. 670–674, 2006.

[7] C. H. Yeh, C. W. Chow, Y. F. Wu, F. Y. Shih, C. H. Wang, and S. Chi, “Optical Fiber Technology Multiwavelength erbium-doped fiber ring laser employing Fabry – Perot etalon inside cavity operating in room temperature,” *Opt. Fiber Technol.*, vol. 15, no. 4, pp. 344–347, 2009.

[8] A. Bellemare, M. Karásek, M. Rochette, S. LaRochelle, and M. Têtu, “Room temperature multifrequency erbium-doped fiber lasers anchored on the ITU frequency grid,” *J. Light. Technol.*, vol. 18, no. 6, pp. 825–831, 2000.

[9] X. Feng, H. yaw Tam, H. Liu, and P. K. A. Wai, “Multiwavelength erbium-doped fiber laser employing a nonlinear optical loop mirror,” *Opt. Commun.*, vol. 267, no. 3, pp. 278–281, 2006.

[10] W. Chen, S. Lou, L. Wang, H. Zou, W. Lu, and S. Jian, “Switchable multi-wavelength fiber ring laser using a side-leakage photonic crystal fiber based filter,” *Opt. Laser Technol.*, vol. 44, no. 3, pp. 611–616, 2012.

[11] H. Zou, S. Lou, and G. Yin, “A wavelength-tunable fiber laser based on a twin-core fiber comb filter,” *Opt. Laser Technol.*, vol. 45, no. 1, pp. 629–633, 2013.

[12] F. Abdullah, A. S. M. Noor, M. A. Mahdi, M. Z. Jamaludin, K. Dimyati, and M. K. Abdullah, “Simultaneous dual-wavelength lasing of an erbium-doped fibre laser over wide spectrum range by intracavity loss optimisation,” *Opt. Laser Technol.*, vol. 37, no. 8, pp. 638–641, 2005.

[13] F. Abdullah, B. Bouzid, M. A. Mahdi, C. L. Cheah, M. Z. Jamaludin, and M. K. Abdullah, “Characterization of a dual wavelength fibre laser based-on dumbbell configuration,” *Opt. Laser Technol.*, vol. 36, no. 3, pp. 187–190, 2004.

[14] Y. G. Han, G. Kim, J. H. Lee, S. H. Kim, and S. B. Lee, “Lasing wavelength and spacing switchable multiwavelength fiber laser from 1510 to 1620 nm,” *IEEE Photonics Technol. Lett.*, vol. 17, no. 5, pp. 989–991, 2005.

[15] Z. M. Liu, J. Li, P. Liu, J. J. Zheng, L. Y. Fan, and S. S. Jian, “Switchable dual-wavelength polarization-maintaining erbium-doped fiber laser using an optical circulator as the all-reflecting mirror,” *Opt. Laser Technol.*, vol. 42, no. 8, pp. 1261–1265, 2010.

[16] Y. Guo, D. Wang, and F. Liu, “A Novel Single-mode , Linearly Polarized , Erbium- doped Fiber Laser with a Stabilized Frequency.”

[17] S. Qhumayo et al., “Wavelength and power stabilization of a three wavelength Erbium doped fiber laser using a nonlinear optical loop mirror,” *Africon*, pp. 1–4, 2006.

[18] X. Feng, C. Lu, H. Y. Tam, P. K. A. Wai, D. Y. Tang, and B. O. 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, 2012.

[19] F. Li, X. Feng, H. Zheng, C. Lu, H. Y. Tam, J. N. Kutz, and P. K. A. Wai, “Multiwavelength lasers with homogeneous gain and intensity-dependent loss,” *Opt. Commun.*, vol. 284, no. 9, pp. 2327–2336, 2011.

[20] X. Feng, H.-Y. Tam, and P. K. a Wai, “Stable and uniform multiwavelength erbium-doped fiber laser using nonlinear polarization rotation.,” *Opt. Express*, vol. 14, no. 18, pp. 8205–8210, 2006.

[21] D. Wang, E. A. Golovchenko, A. N. Pilipetskii, C. R. Menyuk, and M. F. Arend, “Nonlinear optical loop mirror based on standard communication fiber,” *J. Light. Technol.*, vol. 15, no. 4, pp. 642–646, 1997.

[22] X. He, D. N. Wang, and C. R. Liao, “Tunable and Switchable Dual-Wavelength Erbium-Doped Fiber Lasers,” vol. 29, no. 6, pp. 842–849, 2011.

[23] W. Yang, P. Lu, S. Wang, D. Liu, J. Zhang, E. Chen, and J. Liu, “A Novel Switchable and Tunable Dual-Wavelength Single-Longitudinal-Mode Fiber Laser at 2 μ m,” vol. 28, no. 11, pp. 1161–1164, 2016.

[24] H. Ahmad, M. R. K. Soltanian, C. H. Pua, M. Z. Zulkifli, and S. W. Harun, “Narrow spacing dual-wavelength fiber laser based on polarization dependent loss control,” *IEEE Photonics J.*, vol. 5, no. 6, 2013.

[25] S. Rota-Rodrigo, L. Rodriguez-Cobo, M. A. Quintela, J. M. Lopez-Higuera, and M. Lopez-Amo, “Dual-wavelength single-longitudinal mode fiber laser using phase-shift bragg gratings,” *IEEE J. Sel. Top. Quantum Electron.*, vol. 20, no. 5, 2014.

[26] M. A. Quintela, R. A. Perez-herrera, I. Canales, M. Fernández-vallejo, M. Lopez-amo, S. Member, J. M. López-higuera, and S. Member, “Stabilization of Dual-Wavelength Erbium-Doped Fiber Ring Lasers by Single-Mode Operation,” vol. 22, no. 6, pp. 368–370, 2010.

[27] J. M. Senior and M. Y. Jamro, *Optical Fiber Communications: Principles and Practice*. 2009.

[28] J. Monga, “Design and Development of an All-Optical Active Q-switched Erbium-Doped Fibre Ring Laser,” no. November, 2011.

[29] W. Liu, S. Guo, L. Chang, and F. Sun, “The Optimal Design of 2500km-10Gbps Optical Communication Dispersion Compensation Systems Based on FBG without Electric Regenerator,” *2010 Int. Conf. Electr. Control Eng.*, pp. 4439–4442, 2010.

[30] A. Macedo and A. Vieira, “Analysis and Simulation of Dispersion Compensation in Fiber Optic Systems using DCF and CFBG,” pp. 1–9.

[31] Y. T. Aladadi, A. F. Abas, and M. T. Alresheedi, “Optimum apodization profile for chirped fiber Bragg gratings based chromatic dispersion compensator,” *J. Eur. Opt. Soc. Publ.*, vol. 12, no. 1, p. 6, 2016.

[32] A. N. Mohammed, M. N. Okasha, and H. M. Aly, “A wideband apodized FBG dispersion compensator in long haul WDM systems,” vol. 18, no. June, pp. 475–479, 2016.