1-1-2011

# Stabilisation of Linear-cavity Fibre Laser Using a Saturable Absorber

David Michel
*Edith Cowan University*

Feng Xiao
*Edith Cowan University*

Kamal Alameh
*Edith Cowan University*



10.1109/HONET.2011.6149783
This is an Author's Accepted Manuscript of: Michel, D. D., Xiao, F. , & Alameh, K. (2011). Stabilisation of Linear-cavity Fibre Laser Using a Saturable Absorber. Paper presented at the 8th International Conference on High-Capacity Optical Networks and Emerging Technologies, HONET . King Saud University, Riyadh. Available here

# Stabilisation of Linear-cavity Fibre Laser Using a Saturable Absorber

David Michel*[1], Feng Xiao[1], and Kamal Alameh[1,2]

[1]*WA Centre of Excellence for Micro-Photonic Systems, Electron Science Research Institute, Edith Cowan University, Joondalup, WA, 6027, Australia*
[2]*Department of Nanobio Materials and Electronics, World-Class University (WCU), Gwangju Institute of Science & Technology (GIST), Gwangju 500-712, South Korea*

***Abstract*— We investigate the optimisation of the length of an un-pumped erbium doped fibre (EDF) in order to suppress amplifier noise in a linear-cavity fibre laser structure. The experimental results demonstrate the existence of an optimum length of the un-pumped EDF which eliminates noise due to high optical pumping powers, thus leading to a stable laser output.**

***Index Terms*— Fibre laser, saturable absorber, erbium doped fibre, linear cavity, amplifier noise.**

## I. INTRODUCTION

The unique capabilities of fibre lasers, such as narrow linewidth, easy implementation into a fibre system, high output power and high Side Mode Suppression Ratio (SMSR), make them attractive for applications such as Wavelength Division Multiplexed (WDM) systems, spectroscopy, bio-technology and fibre sensor networks. For example, fibre lasers are used by fibre sensors to monitor temperature and strain in different environments [1]. To increase the output optical power of fibre lasers, several pump sources are usually used to excite the erbium doped fibre (optical gain medium). However, using high pump power leads to the generation of high-gain regions within the optical gain spectrum, leading to noise produced by the amplifier and therefore instability in the output laser power [2].

A number of different techniques have been reported which endeavour to minimise laser mode competition in fibre lasers, including Fibre Bragg Gratings (FGB), etalon based filters like Fabry-Perot cavity and acousto-optic based tunable filters. However, such techniques often employ a combination of components or the requirement to modify their characteristics, thus adding complexity to their operation and control. For example, as reported in [3], stable wavelength output was achieved by the use of an apodised FBG with the addition of an intra-cavity high finesse FBG Fabry-Perot etalon. The modification of the FBG as well as the fact that the fibre system used relatively low pumping power decreased the likelihood of spontaneous noise fluctuations within the gain media. Another example where a device

was modified to change its characteristics can be found in [4]. A number of different patterns were etched onto a Fabry-Perot by using focused ion beam (FIB) milling. This allowed the sculpturing of certain number of laser modes and thus modifying the output spectra produced by the Fabry-Perot device. A final example reported in [5] demonstrates that the output wavelength stability was erratic, highly fluctuating and random when the acousto-optical filter was not utilised in conjunction with a Fabry-Perot etalon.

This paper proposes and demonstrates a simple and cost-effective solution based on the use of a linear cavity (acting as a resonant cavity) in conjunction with a saturable absorber, for suppressing noise fluctuations in the gain media which create mode competition in fibre lasers, thus leading to a stable output.

Experimental results show that by optimising the length of an un-pumped erbium doped fibre (which acts like a saturable absorber) inserted within the lasing cavity, mode competition can significantly be suppressed, thus resulting in a single lasing wavelength being amplified by the gain medium.

*dmichel@our.ecu.edu.au

## II. SYSTEM DESCRIPTION AND EXPERIMENTAL SETUP

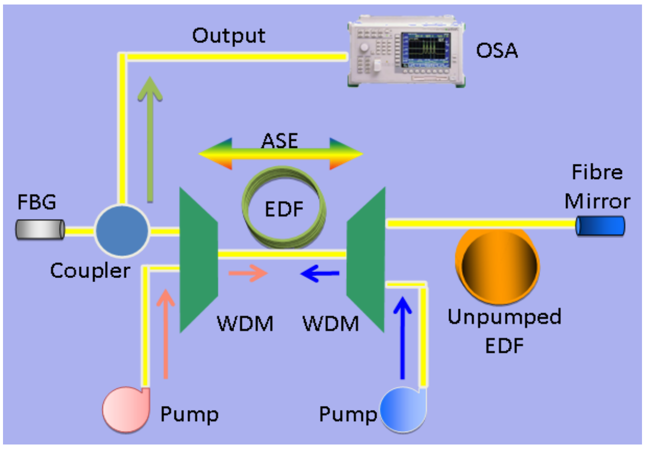


Figure 1. Architecture of the fibre laser employing a saturable absorber. The fibre mirror and fibre Bragg grating set the resonant cavity while the EDFA is the gain medium of the laser. The laser output is tapped using an optical coupler and monitored by an optical spectrum analyser.

Figure 1 illustrates the layout of the proposed fibre laser structure, which is illustrated through a laboratory experiment that was set up. Two optical pump sources were used, namely, a 980 nm laser diode and a 1480 nm laser diode, each had a maximum output optical power of 160 mW. The optical pump signal power levels were 150 mW for the 980 nm pump and 90 mW for the 1480 nm. The light from both pump diodes was launched via a 1550/980 nm and a 1550/1480 nm WDM couplers to ensure that both pump signals were coupled into the EDFA, which had a length of 15 m, and the 1550 nm ports of the WDM multiplexers were connected to a 1538.1 nm fibre Bragg grating (FBG) and a fibre mirror, respectively, thus creating a laser system whose lasing wavelength equals to the Bragg wavelength of the FGB. A saturable absorber was connected between the 1550/1480 nm WDM coupler and the fibre mirror to induce constructive interference between two light waves travelling in opposite directions along the fibre mirror port, thus creating a standing wave within the saturable absorber, and inducing a periodic refractive change, which acted as a narrow band Bragg filter whose centre wavelength coincides with that of the FBG [6], as illustrated in Fig. 2.

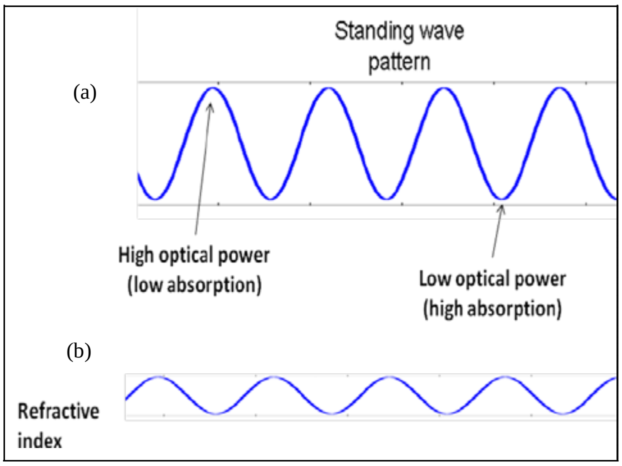


Figure 2 (a) Illustration of the standing wave pattern induced inside a saturable absorber, creating a narrow band optical filter through periodic refractive index perturbations. (b) Standing wave pattern and corresponding super-imposed grating due to the presence of a dominant mode.

Controlling the bandwidth of the saturable absorber is achieved by the doping concentration of erbium atoms present in the fibre, as well as the length of the un-pumped fibre. To create a small bandwidth filter, a high doped fibre is necessary resulting in substantial changes in the refractive index. According to the technical datasheet, the measured absorption for the saturable absorber was 6.75 dB/m at 1532 nm.

A 5:95 fibre coupler was used to couple 95% of the lasing signal power to the FBG, which reflected that power back into the lasing cavity, while the remaining 5%, which is the laser output, was routed to an Optical Spectrum Analyser (OSA) for laser performance monitoring.

## III. EXPERIMENTAL RESULTS

The experiments were intended to demonstrate the simple yet efficient capabilities of the fibre laser to produce a stable laser output by the incorporation of a saturable absorber. By optimising the length of the EDF saturable absorber, mode competition was completely eliminated and stable laser output was achieved, as discussed later.

In a first experiment, we removed the saturable absorber and drove the pump sources until lasing took place. Figure 3 shows a snap shot of the output laser spectrum. It is noticed that while an output signal at 1538.1 nm was generated, different competing modes were also present (two of these modes are seen in the snap shot captured), resulting in an unstable output power at 1538.1 nm. These side modes result from the high pump power launched into the EDFA as seen in Fig. 4, which shows the measured output spectrum of the EDFA used in our experiments.

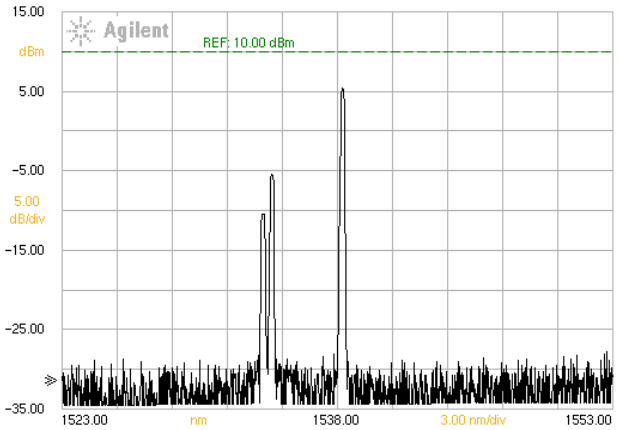


Figure 3. Measured output spectrum of the fibre laser when no saturable absorber was used. The snap shot demonstrates the presence of competing lasing modes within the optical cavity making the output power of the fibre laser unstable.

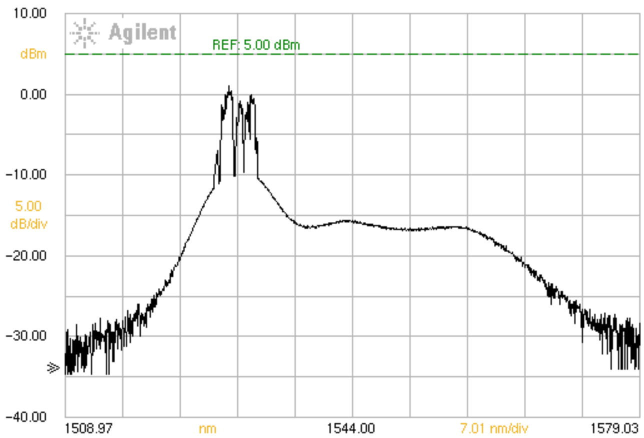


Figure 4 shows the amplified spontaneous emission with the sharp noise spikes caused by the high optical pumping power. The high pumping power is necessary in order to create an output with high beam quality shape and power.

In a second experiment, a 2 m long saturable absorber was used as illustrated in Fig. 1. Figure 5 shows the output spectrum of the laser system when a saturable absorber of length 2 m was used. This length was less than the optimum length, producing substantial mode competition that significantly affected the stability of the laser output. This instability in output laser power is attributed to the fact that by using the EDF saturable absorber with a length less than the optimum value, more optical loss was introduced into the lasing cavity, thus reducing the optical power being generated at 1538.1 nm and allowing more modes to compete within the cavity. Also, several standing waves corresponding to the competing mode wavelengths are generated, thus creating a super-imposed grating that filters the various present modes. However, the short length of the saturable absorber results in a small refractive index contrast, and hence, weak optical filtering effects that are not large enough to fully suppress the competing modes. The overall refractive index change along the saturable absorber length, *L*, is illustrated in Fig. 6, where *Δn* is the difference between the maximum and minimum changes for the refractive index. Since there is no periodic change in the refractive index, the resulting grating pattern allows side modes to compete within the optical cavity.

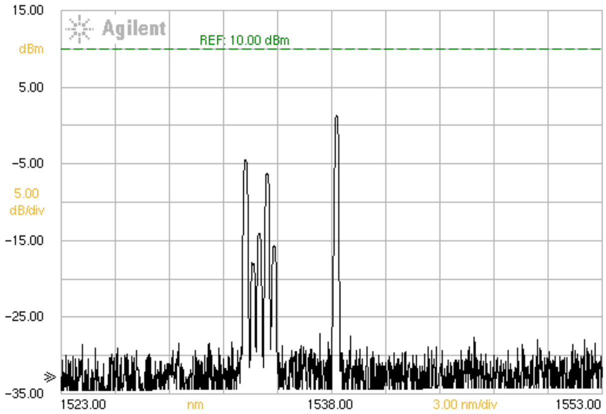


Figure 5. Measured output spectrum of the fibre laser when a 2 m long saturable absorber was used. The snap shot confirms the presence of more competing lasing modes within the optical cavity making the output power of laser unstable for this length of the saturable absorber.

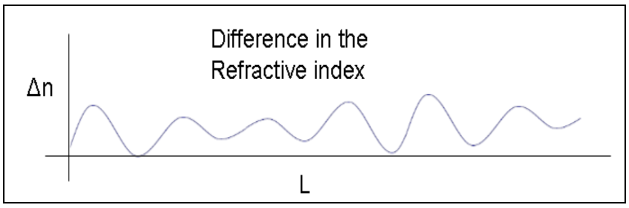


Figure 6. Refractive index differences inside the saturable absorber when no dominant mode is present, which creates a wide Bragg grating. The lack of periodicity in the refractive index, results in a grating pattern which allows side modes to compete within the optical cavity.

Figure 7 shows the output spectrum of the laser when the length of the saturable absorber was increased to 4 m. This length was the optimum length for the saturable absorber, resulting in the superposition of several gratings with the dominant one being the grating that corresponds to the dominant mode at 1538.1 nm. All other gratings have weaker rejection effects that they do not enable other modes to reach the lasing point within the resonant cavity. The measured FWHM linewidth of the dominant mode was less than 0.1 nm (which is the resolution limit of the OSA), the SMSR was higher than 30 dB, and the maximum output power was around 5 dBm.

In a fourth experiment, the length of the saturable absorber was increased to 8 m. Figure 8 shows the corresponding output spectrum of the laser. As it can be seen, this long length of the saturable absorber not only introduced mode competition but also lowered the optimum output power by more than 3 dB. This is due to the fact that for a longer saturable absorber length the cavity loss increases thus reducing the dominant mode power as well as allowing lasing modes to appear inside of the resonant cavity. This results in a standing wave pattern that corresponds to a single Bragg grating at 1538.1 nm but with a weaker rejection (or broader bandwidth), thus enabling modes closer to 1538.1 nm to lase, as evident from Fig. 8.

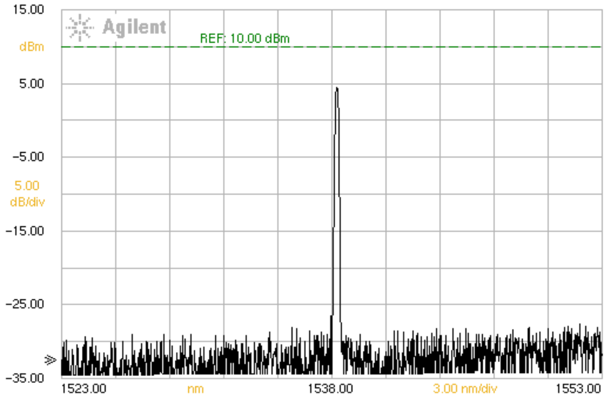


Figure 7. Laser output when the saturable absorber length is 4 m, which corresponds to the optimised length, hence minimising mode competition.

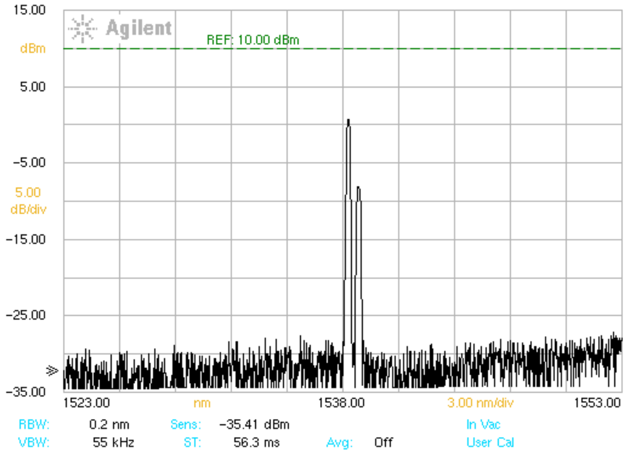


Figure 8. The output of the laser system when the length of the saturable absorber is 8 m corresponding to a length more than the optimum length.

The examples shown above for the effect of using a saturable absorber were taken from experimental results. These results were obtained by starting with a saturable length of 1 m and incrementing this value by 1 m until reaching the final length of 8 m. All of the tested saturable absorber lengths exhibited longitudinal mode generation and promoted mode competition, except for the 4 m long saturable absorber. All of the tests were performed at a room temperature of 23º C.

## V. CONCLUSION

This paper has demonstrated experimentally that the use of un-pumped EDF in a linear laser cavity can produce stable laser output by suppressing the mode competition that are usually present when high pump power levels are used to generate high output laser power levels. We have shown that with an optimum length of the saturable absorber, the laser system produces around 5 mW of output power with a SMSR of more than 30 dB, and that all other lengths for the saturable absorber result in a poor quality laser output due to the competition of various laser modes.

The reported fibre laser system can be integrated to the previously reported Opto-VLSI based fibre laser linear cavity structure [7] to produce a tunable fibre laser system with excellent stability.

## ACKNOWLEDGEMENT

This research is supported by the Faculty of Computing, Health and Science, Edith Cowan University, and the World-Class University Program funded by the Ministry of Education, Science, and Technology through the National Research Foundation of Korea (R31-10026).

## REFERENCES

1. Sanders, S. T. (2002). Wavelength-agile fiber laser using group-velocity dispersion of pulsed super-continua and application to broadband absorption spectroscopy. *Appl. Phys. B: Lasers and Optics, 75*(6-7). doi: 10.1007/s00340-002-1044-z
2. Liu, D., Ngo, N. Q., Chan, H. N., Teu, C. K. and Tjin, S. C. (2006), A switchable triple-wavelength erbium-doped fiber laser with a linear laser cavity. Microwave and Optical Technology Letters, 48: 632–635. doi: 10.1002/mop.21429
3. X. P. Cheng, P. Shum, C. H. Tse, J. L. Zhou, M. Tang, W. C. Tan, R. F. Wu, and J. Zhang, "Single-Longitudinal-Mode Erbium-Doped Fiber Ring Laser Based on High Finesse Fiber Bragg Grating Fabry-Perot Etalon," *IEEE Photon. Technol. Lett.*, 20, 976-978 (2008).
4. Kozlowski, D. A., Young, J. S. E., J.M.C., & Plumb, R. G. S. (1996). Longitudinal mode control in 1.3 μm Fabry-Perot lasers by mode suppression. *Optoelectronics, IEE Proceedings, 143*(1). doi: 10.1049/ip-opt:19960143
5. Stryjak, M., Budnicki, A., Kaczmarek, P., & Abramski, K. M. (2007). Discretely tunable and multiwavelength erbium doped fibre lasers with Fabry-Perot etalon. Photonics and Microsystems. doi: doi: 10.1109/STYSW.2007.4559129.
6. Horowitz, M., Daisy, R., Fischer, B., & Zyskind, J. (1994). Narrow-linewidth, singlemode erbium-doped fibre laser with intracavity wave mixing in saturable absorber. *Electronics Letters, 30*(8), 648-649.
7. Michel, D., Feng, X., & Alameh, K. (2010, 19-21 Dec. 2010). *Opto-VLSI-based tunable linear-cavity fibre laser.* Paper presented at the High-Capacity Optical Networks and Enabling Technologies (HONET), 2010.