



UNIVERSITI PUTRA MALAYSIA

**ALL-OPTICAL GENERATION OF MULTIWAVELENGTH
BRILLOUINERBIUM FIBER LASER IN LONG-WAVELENGTH BAND**

MOHAMMED HAYDER AL-MANSOORI

FS 2008 45

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**DOCTOR OF PHILOSOPHY
UNIVERSITI PUTRA MALAYSIA**

2008



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By

MOHAMMED HAYDER AL-MANSOORI

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the Requirements for the Degree of Doctor of Philosophy**

May 2008



In the Name of God, Most Gracious, Most Merciful

Dedication

To my parents, for their support and encouragement.

To my beloved sons, my brother and my friends for their
encouragement and love.



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

ALL-OPTICAL GENERATION OF MULTIWAVELENGTH BRILLOUIN-ERBIUM FIBER LASER IN LONG-WAVELENGTH BAND

By

MOHAMMED HAYDER AL-MANSOORI

May 2008

Chairman: Associate Professor Mohd Adzir Mahdi, PhD

Faculty: Engineering

In this dissertation, the design and development of the multiwavelength Brillouin-Erbium fiber laser (BEFL) sources operating in the L-band transmission window is presented and characterized. Four different laser designs have been successfully demonstrated using a combination of stimulated Brillouin scattering effect in optical fiber and Erbium-doped fiber (EDF) amplification. The experimental results obtained from the characterization and optimization of these laser structures are the threshold power, number of the Stokes signals generated, Stokes signals power, self-lasing oscillation and the tuning range. The results are taken from the studies which have been carried out to analyze the effects of 1480 nm pump power, Brillouin pump (BP) power, BP wavelength and single mode fiber (SMF) length.

The first laser structure is an efficient multiwavelength L-band BEFL pumped by a 1480 nm pump laser in a linear cavity configuration with direct BP injection into SMF. The issue of low gain efficiency of the L-band in the EDF lasers is resolved



with the efficient linear cavity structure and the 1480 nm pumping scheme. The proposed laser structure exhibits a low threshold power of 18 mW and a maximum number of 26 stable output channels with 0.089 nm (10.5 GHz) channels spacing.

The second and third laser structures are focused on the enhanced multiwavelength BEFL, in which the BP power is pre-amplified before entering the SMF within the laser cavity. The BP pre-amplification techniques - single pass and double pass represent a new mode of operation of multiwavelength BEFL's. This intra-cavity BP pre-amplification provided by the EDF has created higher intensity of Brillouin Stokes signals generated in the single-mode fiber that leads to the homogenous gain saturation. This effect is able to suppress the built-up of the self-lasing cavity modes in a wider wavelength range and the number of output channels is also enhanced as compared to the conventional BP direct injection. Output of more than 33 laser channels is achieved and the tuning range is almost doubled than that of the conventional BP direct injection technique.

Finally, for the fourth laser configuration, the multiwavelength BEFL incorporates either the amplified fiber loop mirror (AFLM) or non-linear amplified fiber loop mirror filter (AFLMF). Fifty-four stable output channels, with 0.089 nm channels spacing, have been achieved. A non-linear AFLMF which induces wavelength-dependent cavity loss and serves as an amplitude equalizer is employed to shift and flatten the EDF gain spectrum. Two control mechanisms have been demonstrated to shift and flatten the EDF gain profile through the adjustment of the polarization controller in the AFLMF. Therefore, the multiwavelength BEFL could be tuned over



the whole L-band window from 1570 nm to 1610 nm with the average number of 24 output channels. In addition, flattening the EDF laser oscillation overcomes the requirements of the BP wavelength tuning, in conjunction with the adjustment of the polarization controllers in the fiber loop.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor of Falsafah

**PENJANAAN PELBAGAI PANJANG GELOMBANG LASER GENTIAN
OPTIK BRILLOUIN-ERBIUM DALAM JALUR PANJANG GELOMBANG
PANJANG**

Oleh

MOHAMMED HAYDER AL-MANSOORI

Mei 2008

Pengerusi: Profesor Madya Mohd Adzir Mahdi, PhD

Fakulti: Kejuruteraan

Di dalam disertasi ini, rekapipta dan pembangunan laser gentian optik jenis pelbagai panjang-gelombang Brillouin-Erbium (BEFL) yang beroperasi dalam tingkap penghantaran jalur L dipersembahkan dan dicirikan. Empat jenis rekapipta laser telah berjaya dihasilkan dengan menggabungkan kesan perserakan Brillouin teransang di dalam gentian optik dan kesan penguat gentian-optik terdop Erbium (EDF). Keputusan eksperimen yang diperolehi dari pencirian dan pengoptimuman struktur laser ini adalah kuasa ambang, jumlah isyarat Stokes yang dijanakan, kuasa isyarat Stokes, kitaran laser sendiri dan julat talaan. Hasil yang diperolehi daripada kajian ynag dilaksanakan adalah untuk menganalisa kesan kuasa laser pengepam 1480 nm, kuasa laser pengepam Brillouin (BP), panjang gelombang BP dan panjang gentian optik satu mod (SMF).

Struktur laser yang pertama adalah sebuah BEFL pelbagai panjang gelombang jalur L yang efisien dengan menggunakan laser pengepam 1480 nm dalam sebuah kaviti linear dan pengepam Brillouin yang dimasukkan terus ke dalam SMF. Isu kadar penguatan yang rendah dalam jalur L dalam laser EDF dapat diatasi dengan menggunakan kaviti linear yang efisien dan skema pengepaman 1480 nm. Struktur laser yang dicadangkan mempamerkan kuasa ambang yang rendah iaitu 18 mW dan 26 saluran maksima yang stabil dengan jarak antara saluran 0.089 nm (10.5 GHz).

Struktur laser yang kedua dan ketiga adalah berfokuskan kepada struktur termaju BEFL pelbagai panjang gelombang, di mana pengepam Brillouin dikuatkan terlebih dahulu sebelum memasuki SMF dalam kaviti laser. Teknik pra-penguatan BP satu aliran dan dua aliran adalah merupakan satu mod baru dalam operasi BEFL pelbagai panjang gelombang. Pra penguatan BP di dalam kaviti ini dihasilkan oleh EDF, dapat menghasilkan kekuatan Stoke Brillouin yang lebih tinggi. Kesan ini dapat mengurangkan penghasilan laser sendiri mod kaviti dalam julat panjang gelombang yang lebih besar dan jumlah saluran keluar juga dapat ditambah berbanding dengan kaedah biasa pengepaman terus BP. Hasil keluaran yang melebihi 33 saluran dapat dicapai dan julat talaan yang hampir dua kali ganda berbanding dengan kaedah biasa pengepaman terus BP.

Akhirnya, konfigurasi laser yang ke-empat, BEFL pelbagai panjang gelombang menggunakan sama ada penguat gentian optik lingkungan balik (AFLM) atau penguat gentian optik lingkungan balik tidak linear (AFLMF). Sebanyak 54 saluran keluaran dengan jarak antara saluran sebanyak 0.089 nm telah berjaya dicapai. AFLMF yang mengakibatkan kehilangan kaviti berkait dengan panjang gelombang

dan berperanan sebagai penyama-rata amplitud digunakan untuk mengalih panjang gelombang dan meratakan kekuatan spektra EDF. Dua kaedah kawalan telah ditunjukkan untuk mengalih dan meratakan profil kekuatan EDF dengan merubah pengawal polar dalam AFLMF. Oleh itu, BEFL pelbagai panjang gelombang ini dapat ditala secara keseluruhan dalam tingkap jalur L antara 1570 nm dan 1610 nm dengan bilangan purata sebanyak 24 saluran keluaran. Tambahan pula, perataan kitaran laser EDF dapat mengatasi keperluan untuk penalaan panjang gelombang BP, dengan pelarasan pengawal polar dalam gentian optik lingkungan balik.

ACKNOWLEDGEMENTS

First of all, I would like to express my greatest gratitude to Allah the almighty, for his help and support during the course of life and moment of truth. Alhamdulillah.

I would like to express my deepest gratitude to my supervisor, Associate Professor Dr. Mohd Adzir Mahdi. I feel privilege to have him as my advisor. I am profoundly grateful for his tremendous support, prompt decision, encouragement, quick response and mentoring through my research.

My special thanks go to my committee members, Professor Dr. Mohamad Khazani Abdullah and Dr. Syed Javaid Iqbal for their valuable assistance, wise council, guidance, and encouragements during this period.

Appreciation also to the assistance rendered by the respective lecturers, staff, and all friends in the Photonic and Fiber Optics System Laboratory of the Faculty of Engineering who has contributed to the successful completion of this study.

Last, but definitely not least, I would like to thank my father and my mother-the best that anybody could have-for their unconditional love and continual support that made me strong in completing this dissertation. Also, I would like to thank my wife, my family, my friends Talib, Ousama, Hany and Ammar, and my brothers Abas and Ali for their constant support and encouragement throughout my life.



I certify that an Examination Committee has met on 8 May 2008 to conduct the final examination of Mohammed Hayder Al-Mansoori on his Doctor of Philosophy thesis entitled “All-Optical Generation of Multiwavelength Brillouin-Erbium Fiber Laser in Long-Wavelength Band” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the degree of Doctor of Philosophy.

Members of the Examination Committee were as follows:

Borhanuddin Mohd Ali, PhD

Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Sudhansh Shekar Jamuar, PhD

Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Wan Mahmood Mat Yunus, PhD

Professor
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Shabudin Shaari, PhD

Professor
Institute of Nanoelectric and Micro Engineering
Universiti Kebangsaan Malaysia
(External Examiner)

HASANAH MOHD. GHAZALI, PhD

Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:22-07-2008



This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of Supervisory Committee were as follows:

Mohd Adzir Mahdi, PhD

Associates Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Khazani Abdullah, PhD

Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Syed Javaid Iqbal, PhD

Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

AINI IDERIS, PhD

Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 14 August 2008



DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it is not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

MOHAMMED HAYDER AL-MANSOORI

Date:

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