UNIVERSITI PUTRA MALAYSIA

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

MOHAMMED HAYDER AL-MANSOORI

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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

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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, rekacipta dan pembangunan laser gentian optik jenis pelbagai panjang-gelombang Brillouin-Erbium (BEFL) yang beroperasi dalam tingkap penghantaran jalur L dipersembahkan dan dicirikan. Empat jenis rekacipta 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 efisyen 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 efisyen dan skima 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 menghasilan 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.

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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.

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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:

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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.

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MOHAMMED HAYDER AL-MANSOORI

Date:

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