UNIVERSITI PUTRA MALAYSIA

MULTIPLE WAVELENGTH LASER UTILIZING HYBRID ERBUIM AND BRILLOUIN GAINS IN DISPERSION COMPENSATING FIBER

MOHAMMED AJIYA

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By

MOHAMMED AJIYA

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

January 2010

DEDICATION

This work is dedicated to the loving memory of my late parents. May Allah (SWA) grant them Al-Jannat Firdaus, Amen.

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

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Chair: Mohd Adzir Bin Mahdi, PhD

Faculty: Engineering

This dissertation presents experimental design and development of multiwavelength fiber laser sources utilizing hybrid erbium and Brillouin gains in dispersion compensating fiber. Four laser designs have been successfully demonstrated. Also presented is a simple method of stimulated Brillouin scattering threshold (SBS) reduction.

Highly stable multiwavelength Brillouin/erbium fiber laser (MWBEFL) in which the cavity is formed by a virtual mirror, where the oscillating modes are reflected back into the laser cavity by SBS effect rather than by a physical reflector is demonstrated. The issue of low tuning range associated with such laser configurations was successfully resolved. Tuning range of 39 nm from 1527 to 1566 nm, which is only limited by the

amplification bandwidth of the erbium gain was successfully achieved. At maximum pumping powers, four channels that are rigidly separated by 0.08 nm (10 GHz) and where each has power above 0 dBm has been demonstrated.

Simple method of SBS threshold reduction was demonstrated. The BP signal was recycled back into the fiber thereby increasing the total gain in the fiber and thus SBS threshold was reduced. In a 5 km long fiber, the proposed method reduced SBS threshold by over 48%, from 16.5 mW to 8.5 mW of the input signal. The Brillouin Stokes generated in the 5 km fiber has a peak power of 9.2 dBm against 4.3 dBm measured using the conventional technique. Similarly, the results obtained from the various lengths of tested fibers, proved that the proposed technique significantly reduced the SBS threshold value and improved the level of the Brillouin Stokes signal power.

Two structures of MWBEFL incorporating the SBS threshold reduction technique were also proposed. In one structure, unidirectional propagation of both the Brillouin Stokes and the Brillouin pump signals was allowed through the erbium amplifier while in the other, bidirectional propagation of the two signals are forced through the erbium gain. The unidirectional amplifier configuration provides greater tuning range of 46.8 nm, against 23 nm provided by the bidirectional configuration at the same pumping powers. On the other hand, the bidirectional amplifier configuration provides 13 output channels against only 6 output channels obtained from the unidirectional amplifier configuration under maximum pumping powers. The channels output power however remained lower than 0 dBm in both cases.

An enhanced structure of MWBEFL that provided flawless tuning range and high channels power was also demonstrated. At maximum pumping powers, up to seven output channels that can broadly be tuned over 35 nm, are demonstrated. Wavelength tunability is also limited by the amplification bandwidth of the erbium amplifier employed. Each of the initial four channels has peak power above 1.6 dBm with the first and seventh channels having a peak power of 8.19 dBm and -8.30 dBm respectively. After an observation period of one hour, the average power fluctuations by all the seven channels is only 1.47 dB with average wavelength shifts of 0.007 nm.

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

LASER PELBAGAI JARAK GELOMBANG MENGGUNAKAN GANDAAN – GANDAAN HIBRID ERBIUM DAN BRILLOUIN DI DALAM GENTIAN OPTIK PAMPASAN PENYEBARAN

Oleh

MOHAMMED AJIYA

Januari 2010

Pengerusi: Mohd Adzir Bin Mahdi, PhD

Fakulti: Kejuruteraan

Disertasi ini membentangkan reka bentuk eksperimen dan perkembangan punca laser gentian pelbagai jarak gelombang menggunakan gabungan perolehan erbium dan Brillouin dalam gentian pemampas penyebaran. empat reka bentuk laser telah berjaya didemonstrasikan. Juga dibentangkan adalah kaedah mudah pengurangan ambang penyerakan Brillouin terangsang.

Laser gentian pelbagai jarak gelombang Brillouin/Erbium (MWBEFL) yang sangat stabil ditunjukkan di mana rongganya dibentuk oleh cermin maya, yang mana mod-mod berayun adalah dipantulkan kembali ke dalam rongga laser oleh kesan SBS dan bukannya oleh pemantul fizikal telah ditunjukkan. Julat penalaan rendah yang dikaitkan dengan konfigurasi laser telah dapat diselesaikan dengan jayanya. Julat penalaan sebesar

39 nm bermula dari 1527 nm ke 1566 nm, yang hanya dihadkan oleh lebar jalur pembesaran dari gandaan erbium telah berjaya dicapai. Pengepaman maksimum, empat saluran yang terpisah secara tegar pada 0.08 nm (10 GHz) dan diaman setiapnya berkuasa melebihi 0 dBm telah didemonstrasikan.

Kaedah mudah untuk mengurangkan ambang SBS telah dipamerkan. Isyarat BP dikitar semula ke dalam gentian lalu meninggikan jumlah perolehan di dalam gentian dan mengurangkan ambang SBS. Pada fiber kepanjangan 5 km, kaedah tercadang mengurangkan ambang SBS sebanyak 48% daripada 16.5 mW ke 5 mW dari signal input. Kuasa Brillouin Stokes tertinggi yang diukur adalah sebanyak 9.2 dBm berbanding 4.3 dBm yang diperolehi melalui teknik konvensional. Kelebihan ini turut didapati pada kepanjangan fiber yang berlainan lalu membuktikan teknik yang diusulkan ini jelas mengurangkan nilai ambang SBS dan turut memperbaiki kuasa isyarat Brillouin Stokes.

Dua struktur MWBEFL yang meggunakan kaedah pengurangan ambang SBS turut diusulkan. Dalam satu struktur propagasi searah membenarkan Brillouin Stokes dan isyarat pam Brillouin bergerak sehala di dalam pengganda erbium manakala satu struktur lagi membenarkan kedua-dua isyarat itu untuk bergerak dua hala di dalam pengganda erbium. Konfigurasi pengganda sehala memberikan julat penalaan yang lebih besar iaitu sebanyak 46.8 nm manakala pada kuasa pam yang sama, julat penalaan bagi konfigurasi pengganda dua hala hanyalah sebesar 23 nm. Namun begitu, pada kuasa pam maksimum, 13 saluran dapat diperolehi melalui konfigurasi pengganda dua hala

berbanding 6 saluran sahaja yang didapati dari konfigurasi penaik sehala. Kuasa saluran adalah lebih rendah dari 0 dBm dalam kedua-dua konfigurasi.

Satu strukur MWBEFL yang telah diperbaiki bagi memberikan julat penalaan yang sempurna berserta kuasa saluran yang tinggi turut dibentangkan. Tujuh saluran yang mampu ditala pada julat sebesar 35 nm diperolehi pada kuasa pam maksimum. Julat penalaan ini dihadkan oleh lebar jalur perolehan pengganda erbium yang digunakan. 4 saluran awal diukur mempunyai kuasa tertinggi melebihi 1.6 dBm dengan saluran pertama dan ketujuh masing-masing berkuasa 8.19 dBm dan -8.30 dBm. Berdasarkan pemerhatian selama satu jam, purata ketidakstabilan kuasa ketujuh-tujuh saluran hanyalah 1.47 dB manakala purata pergerakan jarak gelombang didapati sebanyak 0.007 nm.

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

Mohd Adzir bin Mahdi, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Salasiah bt. Hitam, PhD
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Makhfudzah bt. Mokhtar, PhD
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mohammed H. Al-Mansoori, PhD
Associate Professor,
Faculty of Engineering
Universiti Tenaga Nasional
(External Member)

HASSANAH MOHD GHAZALI, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 17th March 2010

DECLARATION

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

MOHAMMED AJIYA

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