DESIGN AND DEVELOPMENT OF A NOVEL MULTIWAVELENGTH BRILLOUIN-ERBIUM FIBER LASER

By

MOHAMMED HAYDER AL-MANSOORI

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

March 2004

In the name of Allah, Most Gracious, Most Merciful

Dedication to

My parents, my son Abd-Rahman,

And all of my family members

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

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Chairman: Professor Borhanuddin Mohd. Ali, Ph.D.

Faculty: Engineering

Multi-wavelength laser sources with constant wavelength spacing are of great interest in dense wavelength division multiplexing (DWDM) communication and sensors systems. As the transmission capacity of optical communication systems is approaching a few Tb/s through WDM method in recent years, multiwavelength generation technology becomes more important, considering that the complexity and the cost of the source will increase as the number of WDM channel increases.

In this thesis, the design and development of a novel architecture of multi-wavelength Brillouin/Erbium fiber laser (BEFL) utilizing a linear cavity fiber loop technique is presented. Simultaneous and stable multiple wavelength lasing in a linear cavity have been achieved. The results are based completely on the experimental work. The requirement of internal feedback that is commonly used for multiple wavelengths Brillouin/Erbium fiber laser using a ring configuration is achieved by the proposed linear

cavity design. This design used only a single 980 nm pump laser for its multiple wavelengths operation. Based on the design parameters namely; 980 nm pump power, Brillouin pump power, Brillouin pump wavelength and single mode fiber (SMF) the performance of a novel BEFL is presented in terms of threshold power, Stokes signal peak power, number of Stokes generated, stability of the Stokes and tuning range. Throughout this work, three lengths of SMF-fiber are used, 1.9 km, 8.8 km and 25 km. The optimization of Brillouin pump wavelength, power and Erbium gain led to a maximum possible number of Stokes. Twenty-two stable output laser lines with 10.88 GHz (0.088 nm) line spacing were obtained at 1558 nm that was the peak of Erbium-doped fiber (EDF) gain. The injected Brillouin pump power into the 8.8 km SMF-fiber was set at 0.9 dBm and the EDF was pumped by 100 mW of 980 nm pump laser.

The most efficient cascaded Brillouin Stokes operation occurred at the peak of Erbium gain centered on 1558 nm. The number of Stokes decreased as the Brillouin pump increased in the highest region of Erbium gain. On the contrary, the number of Stokes was proportional to the intensity of the Brillouin pump power outside this wavelength range. The best performance and conversion efficiency of Brillouin pump to the BEFL signal occurs at the lower levels of injected Brillouin pump power. A low threshold of 4 mW pump power with 2.3 mW launched Brillouin pump into the 8.8 km of SMF-fiber at 1558 nm was obtained. The tuning range of the Stokes signal must be taken into account both the Brillouin and EDF pump powers, at a fixed EDF pump power the Stokes signal can be tuned wider at a higher Brillouin pump power while higher EDF pump power produces smaller tuning range.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

REKACIPTA DAN PEMBANGUNAN LASER FIBER ERBIUM-BRILLOUIN PELBAGAI-PANJANG GELOMBANG BARU

Oleh

MOHAMMED HAYDER AL-MANSOORI

Mac 2004

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Punca laser pelbagai-panjang gelombang dengan jedaan panjang gelombang yang tetap merupakan sesuatu yang diminati dalam sistem komunikasi Pemultipleksan Pembahagi Panjang-gelombang Padat (DWDM) dan sensor. Kapasiti penghantaran sistem komunikasi optik menghampiri Terabit/saat melalui cara WDM dalam beberapa tahun kebelakangan ini dan teknologi penghasilan pelbagai-panjang gelombang menjadi semakin penting, di mana kerumitan dan kos punca cahaya meningkat dengan peningakatan bilangan saluran WDM.

Dalam tesis ini, rekacipta dan pembangunan senibina baru laser fiber Brillouim/Erbium (BEFL) pelbagai-panjang gelombang menggunakan teknik gelung fiber kaviti linar dipersembahkan. Pelaseran pelbagai-panjang gelombang serentak dan stabil dalam kaviti linar telah berjaya dicapai. Keputusan adalah berdasarkan kepada ujikaji sepenuhnya.

Keperluan terhadap suapbalik dalaman yang biasanya digunakan dalam laser fiber Brillouin/Erbium pelbagai-panjang gelombang menggunakan konfigurasi gelang telah dicapai melalui rekacipta kaviti linar yang dicadangkan. Rekacipta ini menggunakan hanya satu laser pam 980 nm untuk operasi pelbagai-panjang gelombangnya. Berdasarkan parameter rekacipta iaitu kuasa pam, panjang gelombang dan kuasa pam Brillouin, dan Fiber Mod Tunggal (SMF), prestasi BEFL dipersembahkan dari segi kuasa ambang, kuasa puncak isyarat Stokes, bilangan Stokes yang terhasil, kestabilan Stokes dan julat pelarasan.

Di sepanjang kajian ini, pelbagai panjang SMF digunakan, iaitu 1.9 km, 8.8 km, dan 25 km. Pengoptimaan panjang gelombang pam Brillouin, kuasa dan gandaan Erbium menghasilkan bilangan Stokes semaksima mungkin. Dua puluh dua garisan laser keluaran yang stabil dengan jedaan panjang-gelombang sebanyak 10.88 GHz (0.088 nm) pada 1558 nm iaitu gandaan puncak fiber terdop-Erbium (EDF) telah didapati. Kuasa pam Brillouin yang dimasukkan ke dalam SMF 8.8 km disetkan pada 0.9 dBm dan EDF itu dipam oleh laser pam 980 nm dengan kuasa sebanyak 100 mW.

Operasi Brillouin Stokes adalah paling berkesan berlaku pada puncak gandaan Erbium pada 1558 nm. Nombor Stokes berkurang apabila pam Brillouin ditingkatkan kepada ruang tertinggi gandaan Erbium. Secara mutlaknya, nombor Stokes adalah seiring dengan ketumpatan kuasa pam Brillouin diluar julat panjang-gelombang. Prestasi yang terbaik dan kebolehan penukaran pam Brillouin kepada isyarat BEFL terjadi di peringkat rendah di mana kuasa pam Brillouin di berikan. Kuasa pam ambang rendah iaitu 4 mW dengan pam Brillouin dilancarkan 2.3 mW, SMF 8.8 km pada 1558 nm telah dihasilkan. Julat pelarasan bagi isyarat Stokes mestilah diambil kira untuk kedua-dua kuasa; Brillouin dan kuasa pam EDF, pada kuasa pam EDF yang telah ditetapkan isyarat Stokes boleh ditala dengan lebih luas pada kuasa pam Brillouin yang lebih tinggi sementara pada kuasa pam EDF yang lebih tinggi menghasilkan julat talaan yang lebih kecil.

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I certify that an Examination Committee met on 1st March 2004 to conduct the final examination of Mohammed Hayder Al-Mansoori on his Master of Science thesis entitled "Design and Development of a Novel Multiwavelength Brillouin-Erbium Fiber Laser" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for the quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or currently submitted for any other degree at UPM or other institutions.

MOHAMMED HAYDER AL-MANSOORI

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