UNIVERSITI PUTRA MALAYSIA

ALL-OPTICAL MULTIWAVELENGTH FIBER LASERS BASED ON STIMULATED BRILLOUIN SCATTERING

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By

ZUBAIDAH BINTI ABD. RAHMAN

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

September 2011

DEDICATION

This work was accomplished driven by the feeling of love and faithful dedicated to a loving husband, Nurul Azam Bin Ahmad Ishak and also a father to a sweet little baby of Damia Arissa Bt Nurul Azam. May Allah SWT award us a more blessed life, Amin.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

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ZUBAIDAH BINTI ABD. RAHMAN

September 2011

Chairman: Salasiah Bt. Hitam, PhD

Faculty: Engineering

This thesis focuses on Multiwavelength comb generation in Fiber Lasers based on nonlinear effect in fiber optics named Stimulated Brillouin Scattering (SBS). The study had been carried out both in the linear cavity fiber laser and ring cavity fiber laser. A 5 km single mode fiber (SMF-28) was used as a Brillouin gain medium in the linear cavity of Brillouin/Erbium Fiber Laser (BEFL) incorporating a Tunable Bandpass Filter (TBF). A filter is recently used as a solution for having wider tunability of multiwavelength BEFL (MWBEFL) by suppressing the unwanted cavity mode and allowing the oscillation mode to be occurred at selected band. The exact location of Brillouin Pump (BP) wavelength to take place in order to have the optimum number of channel had been thoroughly studied. However, this technique has the limitation in the

number of channel generated which depends on the filter bandwidth as well as the multiwavelength BEFL tunability that depends on the tunability of the filter.

Two structures of ring cavity Fiber Lasers utilizing 11 km Dispersion Compensation Fiber (DCF) as the Brillouin gain medium which had been successfully demonstrated recently were improved by the development and improvement of the amplifier block as intended in this research work. Three different types of amplifier structures were demonstrated and the performance of each structure was studied. The conventional amplifier structure which consists of 8 m Erbium Doped Fiber (EDF) but pumped with 975 nm at maximum power of 616 mW, came out as the ideal pumping scheme to be used in this research work. The issue of low number of channel in a MWBEFL with a concept of virtual mirror which had been successfully demonstrated with an achievement of wide tunability of the entire Conventional-band (C-band) that only limited by the amplification area was successful resolved. Up to 9 laser lines were observed by utilizing the newly proposed pumping scheme.

Another technique of having wide tuning range is the enhanced reverse-S-shaped BEFL. By using a pre-amplification technique, 10 laser lines was reported with the maximum output power of 20 mW. The issue of narrow tuning range which is only 14.8 nm tunability achieved from this structure was also successfully resolved with a new structure design. The ratio of the output signal that coupled to the Optical Spectrum Analyzer (OSA) was investigated beforehand. A series of experiment were carried out to find out the optimum output coupling ratio by varying the ratio of the variable

coupler from 5% to 80%. The output power, number of channels and tuning range of each coupling ratio were recorded. The optimum output coupling ratio was found to be 10% which was measured based on the number of output channel and its tunability. As a result, 44 nm wide of tuning range was achieved in the reverse-S-shaped Multiwavelength Brillouin Fiber Laser (MWBFL) at 10% of output coupling ratio by utilizing the newly proposed pumping scheme.

A 2 km of Highly Non-linear Fiber (HNLF) was also considered to replace the 11 km DCF as the Brillouin gain medium in the reverse-S-shaped structure. The performance of these two different fibers which act as the Brillouin gain medium was compared. HNLF was found to be a better Brillouin gain medium that managed to give 11 laser lines which can be tuned from 1520 nm to 1560 nm (40 nm) as compared to 11 km DCF.

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

LASER GENTIAN PELBAGAI JARAK GELOMBANG OPTIK-SEPENUHNYA BERDASARKAN PENYERAKAN BRILLOUIN TERANGSANG

Oleh

ZUBAIDAH BINTI ABD. RAHMAN

September 2011

Pengerusi: Salasiah Bt. Hitam, PhD

Fakulti: Kejuruteraan

Tesis ini tertumpu kepada pembentukan sesikat pelbagai jarak gelombang di dalam laser gentian yang berdasarkan kesan tidak lelurus di dalam gentian optik yang dinamakan sebagai penyerakan Brillouin terangsang (SBS). Kajian ini telah dijalankan ke atas kedua-dua laser gentian rongga lelurus dan laser gentian rongga cincin. Satu gentian mod tunggal (SMF-28) sepanjang 5 km telah digunakan sebagai medium gandaan Brillouin di dalam laser gentian Brillouin/Erbium (BEFL) rongga lelurus yang digabungkan dengan sebuah penapis jalur lepas boleh tala (TBF). Baru-baru ini, penapis telah digunakan sebagai satu penyelesaian untuk mempunyai kebolehtalaan yang lebih luas di dalam BEFL pelbagai jarak gelombang (MWBEFL) dengan menekan mod rongga yang tidak dikehendaki dan membenarkan mod ayunan terjadi pada jalur terpilih sahaja. Lokasi sebenar jarak gelombang pam Brillouin untuk berlangsung supaya bilangan optimum saluran diperolehi telah dikaji dengan teliti. Bagaimanapun, teknik ini menghasilkan jumlah bilangan saluran yang terhad di mana ianya bergantung kepada

lebar jalur penapis serta kebolehtalaan BEFL pelbagai jarak gelombangnya bergantung kepada kebolehtalaan penapis.

Dua struktur laser gentian berongga cincin yang menggunakan gentian penggantian penyerakan (DCF) dengan panjang 11 km sebagai medium gandaan Brillouin yang mana telah berjaya ditunjukkan baru-baru ini telah diperbaiki dengan pembangunan dan peningkatan blok penguat seperti yang disarankan di dalam kerja penyelidikan ini. Tiga jenis struktur penguat yang berbeza telah ditunjukkan dan prestasi setiap struktur telah dikaji. Struktur penguat konvensional yang terdiri daripada gentian Erbium terdop (EDF) dengan panjang 8 m tetapi dipamkan dengan pam 975 nm pada kuasa maksimumnya 616 mW, muncul sebagai skim pengepaman ideal untuk diguna pakai di dalam kerja penyelidikan ini. Isu jumlah saluran yang rendah di dalam MWBEFL yang menggunakan konsep cermin maya yang mana telah ditunjukkan dengan jayanya dengan satu pencapaian kebolehtalaan seluas seluruh jalur konvensional (C-band) yang hanya dihadkan oleh kawasan penguatan, telah berjaya diselesaikan. Sebanyak 9 garis laser telah diperhatikan dengan menggunakan skim pengepaman baru yang dicadangkan.

Satu lagi kaedah berbeza untuk memperolehi satu julat penalaan yang luas ialah dengan peningkatan BEFL pembalikan berbentuk S. Dengan menggunakan teknik pra penguatan, 10 garis laser telah dilaporkan dengan kuasa keluaran maksimum 20 mW. Isu julat penalaan sempit yang hanya mencapai kebolehtalaan sebanyak 14.8 nm dari struktur ini juga telah berjaya diselesaikan dengan susunan struktur yang baru. Nisbah

isyarat keluaran yang digandingkan kepada penganalisa spektrum optik (OSA) telah disiasat terlebih dahulu. Satu siri eksperimen telah dijalankan untuk mengetahui nisbah gandingan keluaran optimum dengan mengubah nisbah pengganding bolehubah dari 5% kepada 80 %. Kuasa keluaran, jumlah bilangan saluran dan julat penalaan setiap nisbah gandingan telah direkodkan. Nisbah gandingan keluaran optimum telah didapati pada nisbah 10% di mana ianya diukur berdasarkan jumlah bilangan saluran dan kebolehtalaannya. Hasilnya, julat penalaan seluas 44 nm telah dicapai di dalam BFL pelbagai jarak gelombang (MWBFL) pembalikkan berbentuk S pada nisbah gandingan keluaran 10% dengan menggunakan skim pengepaman baru yang dicadangkan.

Satu gentian tidak lelurus yang tinggi (HNLF) dengan panjang 2 km juga telah dipertimbangkan untuk menggantikan DCF dengan panjang 11 km sebagai medium gandaan Brillouin di dalam struktur pembalikan berbentuk S. Prestasi kedua-dua gentian yang berbeza ini yang bertindak sebagai medium gandaan Brillouin telah dibandingkan. HNLF dengan panjang 2 km telah didapati menjadi medium gandaan Brillouin yang lebih baik yang berjaya memberi 11 garis laser yang mana boleh ditala dari 1520 nm sehingga 1560 nm (40 nm) jika dibandingkan dengan DCF yang panjangnya 11 km.

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Last but not least, love and gratitude to my husband and beloved family; Mak, Abah, Along, Uda, Farid and Adik for their understanding and endless love through the duration of my study.

I certify that a Thesis Examination Committee has met on **19 September 2011** to conduct the final examination of **Zubaidah Bt Abd. Rahman** on her thesis entitled **"All-optical Multiwavelength Fiber Lasers Based On Stimulated Brillouin Scattering"** in accordance with Universities and University College Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Sceince.

Members of the Examination Committee were as follows:

Raja Syamsul Azmir bin Raja Abdullah, PhD
Professor Madya
Faculti of Engineering
Universiti Putra Malaysia
(Chairman)

Ratna Kalos Zakiah bt. Sahbudin, PhD
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Siti Barirah bt. Ahmad Anas, PhD
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Kaharudin bin Dimyati, PhD
Professor
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(External Examiner)

SEOW HENG FONG, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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

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

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

Ahmad Fauzi bin Abas, PhD
Faculty of Engineering
Universiti Putra Malaysia
(Member)

BUJANG BIN KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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.

ZUBAIDAH BINTI ABD. RAHMAN

Date: 19 September 2011

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