UNIVERSITI PUTRA MALAYSIA

MULTIWAVELENGTH BRILLOUIN-RAMAN FIBER LASER ASSISTED BY RAYLEIGH SCATTERING

RAHELEH SONEE SHARGH

FK 2013 1

MULTIWAVELENGTH BRILLOUIN-RAMAN FIBER LASER ASSISTED BY RAYLEIGH SCATTERING

By

RAHELEH SONEE SHARGH

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

March 2013

To My Beloved Husband

and

Son

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

MULTIWAVELENGTH BRILLOUIN-RAMAN FIBER LASER ASSISTED BY RAYLEIGH SCATTERING

By

RAHELEH SONEE SHARGH

March 2013

Chair: Mohd Adzir bin Mahdi, PhD

Faculty Engineering

Multiwavelength fiber lasers based on hybrid Brillouin-Raman gain configuration supported by Rayleigh scattering effect have attracted significant research interest due to the large numbers of channel generation from a single light source. When narrow bandwidth Brillouin gain combines with broad bandwidth Raman gain, hundreds of channels would be generated. In multiwavelength Brillouin–Raman fiber laser (MBRFL) architectures, dispersion compensated fiber is utilized as the nonlinear gain media. When a single laser launches into a distributed Raman gain area, it grows very fast through stimulated Raman scattering, and when it acquires threshold condition, it is back-scattered through nonlinear Brillouin and Rayleigh effects, inelastically and elastically inside the gain media respectively. After scattered lights experience amplification through stimulated Raman and Brillouin amplification, they saturate and consequently back-scatter once more. This phenomenon is dubbed as self-feedback-

seeding-effect which is the main principle of MBRFL generation. Normally, the other nonlinear effects such as four waves mixing is assisted by distributed Raman amplifier which generates self-lasing cavity modes that lead to the formation of turbulent waves. The interaction between laser cavity lines and the turbulent waves causes spectral broadening of laser lines that has a direct impact on the quality of Brillouin Stokes lines in terms of Stokes-optical signal to noise ratio (S-OSNR). In this work, it is proven that utilizing large effective area fiber (LEAF) in MBRFL enhances the S-OSNR of Brillouin Stokes lines effectively. Consequently, LEAF is used in the aim of suppressing the noise. In all the experiments which have done in this work, Brillouin pump power is fixed on higher level (8 dBm) due to producing the higher stimulated Brillouin scattering. However Raman pump power and Raman pump direction are two critical features which are studied in this thesis, since they play significant role in the MBRFL characteristics performances. Generation of flat amplitude MBRFL comprises higher number of channels with acceptable S-OSNR utilizing a single frequency Raman pump is the main objective of this research. Investigation and improvement of the characteristics of MBRFL utilizing LEAF is another aim of this work. In this work the optical characteristic performances of generated MBRFL output spectrum at three different configuration; conventional-MBRFL (CON-MBRFL), double-pass MBRFL (DP-MBRFL) and new forward-backward scattering combination-MBRFL (FBSC-MBRFL) are investigated at different Raman pump powers and directions. It is obtained that the forward pumping scheme of CON-MBRFL configuration capable to produce flat amplitude MBRFL with 20 GHz channels spacing. Maximum 322 channels with

acceptable average S-OSNR about 16 dB has been created with this structure, when 1525 nm Brillouin pump wavelength is launched into the linear cavity. In addition, 258 channels with 26 dB SOSNR, excellent uniformity, identical Stokes peak power and linewidth are generated via utilizing backward-Raman pumping scheme of DP-MBRFL configuration. Moreover, it is found that the new configuration FBSC-MBRFL is capable to enhance the Stokes lines count to 700 channels while a single forward-Raman pumping scheme is applied with 1 W power.

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

GENTIAN LASER BRILLOUIN-RAMAN PELBAGAI JARAK GELOMBANG DIBANTU OLEH RAYLEIGH

Oleh

RAHELEH SONEE SHARGH

March 2013

Pengerusi: Mohd Adzir bin Mahdi, PhD

Fakulti Kejuruteraan

Laser gentian pelbagai jarak gelombang berdasarkan konfigurasi gandaan hibrid Brillouin-Raman yang disokong oleh serakan Rayleigh telah menarik perhatian signifikan disebabkan oleh penjanaan bilangan besar saluran dari satu sumber laser. Apabila gandaan lebar jalur Brillouin yang sempit bergabung dengan gandaan lebar jalur Raman yang luas, ratusan saluran dapat dijanakan. Dalam laser gentian pelbagai jarak gelombang Brillouin-Raman (MBRFL), gentian pampasan penyebaran digunakan sebagai media bukan linear. Apabila satu laser dilancarkan ke kawasan gandaan Raman, ia akan membesar melalui proses rangsangan penyelerakan Raman, dan mencapai keadaan ambang Brillouin di mana ia akan diselerakkan ke arah bertentangan melalui kesan bukan linear Brillouin dan Rayleigh, secara tidak elastik dan elastik masing-masing. Pancaran tersebut akan diselerakkan lagi sekiranya tahap ketepuan dicapai melalui gandaan Raman dan Brillouin. Fenomena ini dikenali sebagai *self-feedback-*

seeding-effect yang menjadi prinsip asas penjanaan MBRFL. Biasanya, percampuran empat gelombang (FWM) dibantu oleh gandaan edaran Raman yang menjanakan *self-lasing cavity mode* dan ini akan menyebabkan gelombang bergelora terbentuk. Interaksi antara *self-lasing cavity mode* dan gelombang bergelora menyebabkan pelebaran jalur laser dan menjejaskan kualiti Brillouin *Stokes* dari segi nisbah isyarat-hingar (S-OSNR). Kerja penyelidikan ini membuktikan penggunaan gentian keluasan efektif besar (LEAF) dalam MBRFL meningkatkan prestasi S-OSNR bagi Brillouin Stokes. Seterusnya LEAF digunakan sebagai media menindas hingar. Dalam semua eksperimen, kuasa pam Brillouin (BPP) ditetapkan pada tahap yang tinggi 8 dBm untuk memastikan berlakunya rangsangan penyelerakan Brillouin. Manakala kuasa pam Raman dan arah pam Raman diketahui sebagai dua ciri kritikal yang dikaji dalam tesis ini, memandangkan ciri-ciri memain peranan besar terhadap prestasi MBRFL. Penjanaan MBRFL beramplitud rata, jumlah jarak gelombang yang besar dan S-OSNR yang baik dengan laser frekuensi tunggal Raman adalah objektif dalam penyelidikan ini. Penyiasatan dan penambahbaikan ciri MBRFL dengan LEAF adalah merupakan objektif yang lain dalam kerja penyelidikan ini. Tiga konfigurasi berbeza iaitu MBRFL tradisional (CON-MBRFL), *double-pass* MBRFL (DP-MBRLF) dan konfigurasi baharu *forward-backward scattering combination*-MBRFL (FBSC-MBRFL) telah dikaji dengan pelbagai kuasa dan arah pam Raman. Hasil kajian mendapati konfigurasi CON-MBRFL berupaya menghasilkan MBRFL beramplitud rata dengan jarak saluran 20 GHz. Sebanyak 322 laser dengan 16 dB nilai purata diterima S-OSNR telah dijanakan dengan konfigurasi ini apabila 1525 nm panjang gelombang pam Brillouin di lancarkan dalam

rongga linear. Di samping itu, 258 saluran dengan 26 dB S-OSNR, keseragaman cemerlang, kuasa puncak dan jalur lebar *Stokes* yang serupa telah dicapai dengan skim pam bertentangan arah DP-MBRFL. Kajian ini juga menemui konfigurasi FBSC-MBRFL berjaya menambah bilangan garis *Stokes* sehingga 700 saluran dengan hanya kuasa 1 W digunakan dari pam berfrekuensi tunggal Raman dalam arah mara.

AKNOWLEDGEMENTS

First and foremost, I wish to acknowledge the Creator of the entire world, who all the knowledge is with Him. The infinite thanks to him that from his mercy and kindness forgave me the knowledge.

I would like to express my appreciation for the mentoring and support of my advisor Prof. Dr. Mohd Adzir Mahdi.

I want to tank Dr. M. H. Al-mansoori, Dr. Muhammad Hafiz, Yeo Kwok Shien and Nelidya for the support and cooperation I received.

Not forgotten all my colleagues in Photonics and Fiber Optics Systems Laboratory, UPM, for their trust and encouragement that lead to the continuation and completion of this study.

I owe a special thank to my husband's parents and my own parents. Since I study in a place thousands miles away and I have little opportunities staying with them. They have offered me infinite love, support, and understanding.

Last but not least, I would like to deliver my special thanks to my husband Dr. Amir Saleh, and my son Arad, for their tremendous patience, effort, understanding and encouragement during my research and critical times. This section is too short to acknowledge their perpetual love and sustained support during past three years. I dedicate this work to my husband and my son with whom all of my plans are made and all of my dreams are fulfilled.

I certify that a Thesis Examination Committee has met on 08 March 2013 to conduct the final examination of Raheleh Sonee Shargh on her thesis entitled "Multiwavelength Brillouin-Raman Fiber Laser Assisted by Rayleigh Scattering" in accordance with the 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 Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Abdul Rahman Ramli, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Salasiah Hitam, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Hairul Azhar Abdul Rashid, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

M. Saif Islam, PhD
Professor
Electrical and Computer Engineering Department
University of California
(External Examiner)

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

Date: 30 April 2013

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 the Supervisory Committee were as follows:

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

Ratna Kalos Zakiah Sahbudin, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Siti Barirah Ahmad Anas, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mohammed Hayder Al-Mansoori, PhD
Associate Professor
Faculty of Engineering
Sohar University
(External 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.

RAHELEH SONEE SHARGH

Date: 8 March 2013

TABLE OF CONTENTS