UNIVERSITI PUTRA MALAYSIA

SINGLE-WAVELENGTH RING-CAVITY FIBER LASER WITH IMPROVED TUNABILITY BASED ON NONLINEAR STIMULATED BRILLOUIN SCATTERING

NOR AZURA MALINI BT AHMAD HAMBALI

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By

NOR AZURA MALINI BT AHMAD HAMBALI

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

November 2010

Dedicated to;

Abah,

Mak,

Abang,

Yang,

Adik Hafizul

My sweet Azri

Lecturers,

Friends.

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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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Chairman: **Professor Mohd. Adzir Mahdi, Phd**

Faculty: **Engineering**

Stimulated Brillouin scattering (SBS) is a nonlinear phenomenon that occurs in an optical fiber as a result of interaction between an injected coherent pump signal and an acoustic wave, resulting in backward propagating signal named Stokes wave. Practically for single-mode silica fiber (SMF), the Stokes wave was found to be downshifted by 0.08 nm (10 GHz) from the injected signal wavelength, through the Doppler effect. SBS generation has been considered generated a lot of interest for its deployment in a number of applications, such as microwave generation, frequency shifting, narrow-bandwidth amplification and fiber laser.

This thesis focuses on the utilization of the nonlinear effects in dispersion compensating fiber (DCF), particularly the SBS to generate a single-wavelength laser in ring-cavity configurations. In this thesis, three types of fiber laser in ring-cavity configurations were investigated namely; Brillouin fiber laser (BFL), Brillouin Erbium fiber laser (BEFL), and Brillouin Raman fiber laser (BRFL). All the results presented in this thesis have been published.

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For ring cavity BFL, the lowest Brillouin threshold power of 0.9 mW, Brillouin signal (BS) peak power of 7.28 mW and the flatness of the BS power were obtained. The lasing wavelength of BFL structure can be tuned freely in the cavity because the laser structure does not produce any self-lasing cavity modes. The lasing wavelength is strictly dependent on the BP wavelength and subject to the availability of amplification bandwidth.

The impact of Erbium-doped fiber amplifier (EDFA) location in the BEFL structure was investigated. A single-wavelength BEFL-1 structure in which the Brillouin pump (BP) is pre-amplified before entering the DCF produced 25.1 mW of BS signal power and tuning range of 50 nm. In contrast the BS signal power of 15.5 mW and 1.4 mW was obtained from BEFL-2 and BEFL-3, which can only be tuned over 28 nm and 3 nm respectively. In conclusion, the BEFL-1 generated higher gain efficiency to suppress the self-lasing-cavity modes in the cavity and provided higher BS signal power. Next, the characteristics of this BEFL structure in which the BP is pre-amplified before entering the DCF was demonstrated with variation of output coupling ratios from 10% to 99%. The highest BS signal power of 28.7 mW and wider tuning range over 60 nm without any self-lasing cavity modes were obtained.

For the final experiment, the BRFL characteristics in terms of BS signal power, threshold power and tuning range were reported. The BS signal power of 2.71 mW, threshold power of 27 mW and BS signal power flatness of 26 nm were obtained. It is evidently shown that the BRFL can be operated freely without any appearance of the self-lasing cavity modes for all cases of the injected RPU power.

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

ISYARAT PANJANG GELOMBANG TUNGGAL RONGGA CINCIN GENTIAN LASER DENGAN PENAMBAHBAIKAN JULAT PENALAAN BERASASKAN PADA PENYERAKAN BRILLOUIN TERANGSANG

Oleh

NOR AZURA MALINI BT AHMAD HAMBALI

November 2010

Pengerusi: Profesor Mohd. Adzir Mahdi, Phd

Fakulti: Kejuruteraan

Penyerakan Brillouin terangsang (SBS) merupakan fenomena tidak linar yang terjadi disebabkan oleh interaksi antara penyuntikkan isyarat pam optik koheren dan gelombang akustik di dalam gentian optik, ini menyebabkan penghasilan isyarat yang merambat ke belakang yang dinamakan sebagai gelombang Stokes. Untuk mod gentian mod tunggal (SMF), gelombang Stokes telah dipisahkan pada jarak 0.08 nm (10 Ghz) daripada penyuntikkan isyarat pam, ini kenali sebagai kesan Doppler. Generasi SBS telah dipertimbangkan oleh pelbagai lapisan penyelidik sejak bertahun-tahun lagi dan ini menghasilkan minat yang mendalam untuk membangunkan pelbagai aplikasi seperti generasi gelombang mikro, penganjakkan frekuensi, penguatan lebar jalur sempit, dan laser gentian.

Tesis ini menumpukan kepada penggunaan kesan-kesan tidak linar di dalam penyerakan menggantikan gentian (DCF), dimana pada dasarnya SBS digunakan untuk menjana isyarat panjang gelombang tunggal di dalam struktur rongga cincin. Dalam tesis ini, tiga jenis struktur rongga cincin telah dikaji, dinamakan sebagai laser

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gentian Brillouin (BFL), laser gentian Brillouin Erbium (BEFL) dan laser gentian Brillouin Raman (BRFL). Semua keputusan yang dihasilkan di dalam tesis ini telah diterbitkan.

Bagi BFL, takat permulaan Brillouin yang terendah telah diperolehi sebanyak 0.9 mW, puncak kuasa BS sebanyak 7.28 mW dan kerataan bagi kekuatan isyarat BS telah diperolehi. Panjang gelombang bagi struktur BFL boleh menalakan secara bebas dalam rongga, kerana mod berbolak-balik tidak dihasilkan. Ditegaskan, panjang gelombang bergantung kepada panjang gelombang BP dan juga tertakluk kepada ketersediaan penguatan lebar jalur.

Kesan lokasi bagi penguat gentian terdop Erbium (EDFA) di dalam struktur BEFL telah diselidik. Untuk jarak gelombang tunggal bagi struktur BEFL-1 di mana pam Brillouin (BP) adalah pra-diperkuatkan sebelum memasuki DCF telah menghasilkan kekuatan isyarat BS sebanyak 25.1 mW dan juga julat penalaan pada jarak 50 nm. Sebaliknya, kekuatan isyarat BS sebanyak 15.5 mW dan 1.4 mW telah diperolehi daripada BEFL-2 dan BEFL-3, yang juga menghasilkan julat penalaan pada jarak 28 nm dan 3 nm. Kesimpulannya, BEFL-1 telah menghasilkan kecekapan yang tinggi untuk menekan mod berbolak-balik dan ia juga dapat menghasilkan kekuatan isyarat BS yang lebih tinggi. Seterusnya, ciri-ciri struktur BEFL di mana pam Brillouin (BP) yang pra-diperkuatan sebelum memasuki DCF telah ditunjukkan dengan menggunakan pelbagai nilai nisbah gandingan keluaran dari 10% hingga 99%. Kekuatan isyarat BS yang tinggi pada 28.7 mW, dan julat penalaan yang lebih luas pada jarak 60 nm tanpa kemunculan mod berbolak-balik telah dihasilkan**.**

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Untuk kajian yang terakhir, ciri-ciri BRFL dalam perkara yang berkenaan dengan kuasa BS, kuasa takat permulaan dan julat penalaan telah disiasat. Kekuatan isyarat BS sebanyak 2.71 mW, kuasa takat permulaan sekitar 27 mW dan. kerataan bagi kekuatan isyarat BS pada jarak 26 nm telah diperolehi. Dengan ini, terbukti bahawa BRFL boleh dikendalikan secara bebas tanpa sebarang kemunculan mod berbolak-balik pada semua kes penyuntikan kuasa RPU.

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Approval Sheet 1

I certify that an Examination Committee met on date 9 November 2010 to conduct the final examination of Nor Azura Malini Bt Ahmad Hambali on her Doctor of Philosophy thesis entitled "**Single-wavelength Ring Cavity Fiber Laser based with Improved Tunability on Nonlinear Stimulated Brillouin Scattering**" 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 Doctor of Philosophy. Members of the Examination Committee are as follows:

Mohd. Fadlee bin A. Rasid
PhD
Faculty of Engineering,
University Putra Malaysia
(Chairman)

Alyani binti Ismail
PhD
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Salasiah binti Hitam
PhD
Faculty of Engineering
Universiti Putra Malaysia
(Member)

PhD
Internal examiner

BUJANG KIM HUAT, PhD
Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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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 the Supervisory Committee were as follows:

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

Ahmad Fauzi bin Abas @ Ismail, PhD
Lecturer
Faculty of Engineering
University Putra Malaysia
(Member)

M. Iqbal bin Saripan, PhD
Lecturer
Faculty of Engineering
University Putra Malaysia
(Member)

Mohammed Hayder Al-Mansoori, PhD
Associate Professor
Faculty of Engineering
University Tenaga Nasional
(Member)

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

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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 other institutions.

_____

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