MULTI-WAVELENGTH LASER GENERATION BASED ON NONLINEAR EFFECTS IN PCF AND Bi-EDF

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ABSTRAK

Tesis ini memperihalkan proses penjanaan laser pelbagai jarakgelombang berasaskan Brillouin berselerak terangsang (stimulated Brillouin scattering SBS) dan empat-gelombang campuran (four wave mixing) kesan taklinear yang menggunakan gentian kristal fotonik (photonic crystal fibre PCF) atau/dan gentian terdop Erbium berasaskan Bismuth (Bi-EDF) sebagai bahantara gandaan. Pertama sekali, keadaan ambang kuasa SBS untuk sekeping gentian PCF sepanjang 100 meter telah dikaji didalam sebutan parameter-parameter gentian dan kuasa input pam. Gandaan ambang eksponen, G_{th}, dapat dijangka dengan simulasi yang bergantung kuat pada panjang gentian kandungan gandaan Brillouin dan luas berkesan. Nilai ini berubah dari 14 sehingga 18 bergantung pada panjang gentian mengikut definasi Smith. Anjakan frekuensi bagi Brillouin Stokes dalam PCF diukur sebanyak 9.75 GHz melalui kaedah pengukuran heterodin. Untuk mengurangkan panjang gentian taklinear, satu Bi-EDF 49cm panjang digunakan dan telah berjaya menunjukkan satu jarakgelombang gentian laser Brillouin Erbium (BEFL) dengan puncak kuasa lebih kurang -4 dBm dan nisbah sampingan mod penindasan (SMSR) adalah 14 dB didalam rongga lingkaran pada pam Brillouin (BP) 6 dBm dan kuasa pam 144 mW. Satu laser gentian Brillouin (BFL) mudah pelbagai jarakgelombang telah juga ditunjuk menggunakan PCF bersama jeriji gentian Bragg (FBG) untuk menghasilkan sekurangnya 7 garis Stokes dan 4 garis anti-Stokes dengan jarak garis adalah 0.08 nm. Untuk mendapatkan garis jarak dua kali ganda, satu laser gentian Brillouin padat pelbagai-jarakgelombang mengikut konfigurasi angka-lapan telah dicadang. Pada kuasa BP sebanyak 15.3 dBm, sekurangnya 4 garis serentak dengan 20 GHz atau jarak garis 0.16 nm telah tercapai dan garis tertib-ganjil dikeluarkan. Garis anti-Stokes dijana melalui proses FWM didalam

rongga laser. Spektrum output bagi BFL yang dicadang boleh ditala sebanyak 80 nm, bergantung pada ketersediaan sumber BP yang sesui. Untuk menambahkan bilangan garis-garis dan jarak saluran, satu laser gentian terdop Erbium pelbagai–jarakgelombang (MWEDFL) telah ditunjuk dengan menggunakan satu Bi-EDF sepanjang 215 cm melalui proses FWM didalam konfigurasi lingkaran. Laser yang dicadangkan dapat menjana 17 garis bersama jarak saluran tetap 0.41 nm pada kawasan jalur-L dengan menggunakan kuasa pam 1480 nm, 147 mW. MWEDFL yang lain dan stabil berasaskan FWM menggunakan media gandaan hybrid PCF 100m dan Bi-EDF 49cm. Pada kuasa pam maksimum 1480 nm, terdapat 5 garis dan jarak diantara garis adalah 2.15 nm dan nisbah isyarat-hingar adalah lebih dari 20dB. Hasil dari kajian menunjukkan kegunaan gentian sangat taklinear PCF dan Bi-EDF berupaya untuk menjanakan satu laser padat pelbagai jarak-gelombang untuk banyak aplikasi seperti didalam sistem pemultipleks pembahagian gelombang (WDM), sistem optik komunikasi dan sensor.

ABSTRACT

This thesis describes multi-wavelength laser generation process based on stimulated Brillouin scattering (SBS) and four-wave mixing (FWM) nonlinear effects utilizing photonic crystal fibre (PCF) or/and Bismuth based Erbium doped fibre (Bi-EDF) as the gain medium. Firstly, the threshold power condition of SBS for a piece of100 m long PCF has been theoretically studied in terms of fibre parameters and input pump power. The threshold exponential gain, G_{th}, can be anticipated by this simulation which strongly depends on the fibre length Brillouin gain content and effective area. This value varies from 14 to 18 depending on the fibre length according to the Smith's definition. The frequency shift of Brillouin Stokes in the PCF is measured nearly 9.75 GHz via heterodyne measurement method. In order to reduce the nonlinear fibre length, 49 cm long Bi-EDF is used, which successfully demonstrates a single wavelength Brillouin Erbium fibre laser (BEFL) with a peak power of approximately -4 dBm and a side mode suppression ratio (SMSR) of 14 dB in a ring cavity at fixed Brillouin pump (BP) power of 6 dBm and 1480 nm pump power of 144 mW. A simple multi-wavelength Brillouin fibre laser (BFL) is also demonstrated using the PCF in conjunction with a fibre Bragg grating (FBG) to produce at least 7 Stokes and 4 anti-Stokes lines with a line spacing of 0.08 nm. To produce double-spacing Brillouin lines, a compact multi-wavelength Brillouin fibre laser in conjunction with a figure-of-eight configuration is proposed. At a BP power of 15.3 dBm, at least 4 simultaneous lines with 20 GHz or 0.16 nm line spacing is achieved by removing the odd-order Stokes lines. The anti-Stokes lines are also generated via FWM process in the laser cavity. The output spectrum of the proposed BFL can be tuned by 80 nm, dependent on the availability of an appropriate BP source. To increase the number of lines and channel spacing, a multi-wavelength Erbium doped fibre laser (MWEDFL) is demonstrated with

incorporating a piece of 215 cm long Bi-EDF through FWM process in a ring configuration. The proposed laser is able to generate up to 17 lines with a constant channel spacing of 0.41 nm at L-band region using 147 mW of 1480 nm pump power. The other stable MWEDFL based on FWM using a hybrid gain media of 100 m long PCF and 49 cm long Bi-EDF fibre is demonstrated. At a maximum pump power of 1480 nm, 5 lines are observed with nearly 2.15 nm spacing between the lines, and with a signal to noise ratio of more than 20 dB. These results show that the use of a highly nonlinear PCF and Bi-EDF is capable to produce a compact and efficient multi-wavelength laser for many applications such as wavelength division multiplexing system (WDM) optical communication network system and sensors.

Dedication

To the five pillars of my life: God, my supportive parents, my beloved husband, my new born son. Without you, my life would fall apart.

I might not know where the life's road will take me, but walking with you, **God**, through this journey has given me strength.

Mother, you have given me so much, thanks for your faith in me, and for teaching me that I should never surrender.

Father, you always told me to “reach for the stars.” I think I got my first one.

Yousef, my patient beloved husband, without your love and understanding I would not to be able to make it.

My new born son, you truly are a blessing and the greatest gift God could have given me.

We made it...

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Acronyms

Throughout this work, some jargons are used to avoid the repeated unnecessary some group of words. Although, each acronym is usually defined the first time it appears in a chapter, here a list of acronyms are presented to help the readers.

A_{eff}	Effective area
ASE	Amplified Spontaneous Emission
BEFL	Brillouin Erbium Fibre Laser
BFL	Brillouin Fibre Laser
Bi-EDFA	Bismuth-Erbium Doped Fibre Amplifier
BP	Brillouin Pump
BRFL	Brillouin Raman Fibre Laser
BS	Brillouin Stokes
XPM	Cross Phase Modulation
DCF	Dispersion-Compensating Fibre
DWDM	Dense Wavelength Division Multiplexing
EDF	Erbium Doped Fibre
EDFA	Erbium Doped Fibre Amplifier
FBG	Fibre Bragg Grating
FWHM	Full Width Half Maximum
FWM	Four-wave mixing
GVD	Group Velocity Disperssion
L_{eff}	Effective length
MBEFL	Multi-wavelength Brillouin Erbium Fibre Laser

MWFL	Multi-wavelength Erbium Fibre Laser
OSA	Optical Spectrum Analyzer
PD	Photo Diode
P_{th}	Threshold Pump
SBS	Stimulated Brillouin Scattering
SMF	Single Mode Fibre
SMSR	Side Mode Suppression ratio
SNR	Signal to Noise ratio
SOA	Semiconductor Optical Amplifier
SPM	Self Phase Modulation
TDM	Time Division Multiplexing
TLS	Tunable Laser Source
WDM	Wavelength Division Multiplexing