FIBER LASER TUNING USING NON-THERMAL PLASMA AS TEMPERATURE REGULATOR

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Gracias, my beloved Family and Friend

On your support and guidance

Overflowing kindness

Give me strength

Love and

Encouragement

I dedicated this work for all of you

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ABSTRACT

Wavelength tuning of laser with conventional thermal based technique is a very slow process. The tuning speed is limited by the rate of heat transfer via thermal conduction of the temperature controller to the wavelength tuning element. Recent studies show that non-thermal plasma (NTP) can achieve fast gas heating due to the existence of additional heating channels. Utilizing the advantage of these heating channels, the temperature of the gas within the plasma reactor can be varied rapidly. This study presents the development of a thermal based wavelength tuning technique for fiber laser with NTP as the solution to improve the tuning speed. The NTP is generated by means of dielectric barrier discharge (DBD). Fiber Bragg grating (FBG) has been applied as temperature sensor owing to its immunity to the influence of electromagnetic interference in the plasma environment. The wavelength tuning process has been carried out by using the DBD plasma reactor as a temperature regulator that provides temperature conditioning for the laser resonator. The emission spectrum of the fiber laser has been monitored from time to time with an optical spectrum analyzer (OSA). The results show that the emission wavelength of laser shifts when there is a temperature change in the laser resonator. Besides, the tuning range and the temperature tuning resolution achieved depend on the given discharge condition to generate the plasma. Using Helium plasma generated at 5 kV, a tuning range of 3.027 nm and tuning resolution of 11.57 pm $°C^{-1}$ can be achieved. During the tuning process, temperature varied from 25 °C to around 300 °C. It takes only about 10 minutes to complete the process. The laser emission is also thermally stable as it shows a very low shifting when the temperature is kept constant. In conclusion, the emission wavelength of fiber laser is successfully tuned by the NTP based temperature regulator.

ABSTRAK

Penalaan panjang gelombang laser gentian berdasarkan teknik terma yang biasa merupakan satu proses yang sangat perlahan. Kelajuan penalaan adalah dihadkan oleh kadar permindahan haba secara konduksi terma daripada pengatur suhu kepada elemen panala panjang gelombang. Kajian terkini menunjukkan bahawa kebolehan plasma bukan terma (NTP) memanaskan gas dengan cepat disebabkan oleh kewujudan saluran pemanasan tambahan. Dengan menggunakan kelebihan saluran pemanasan ini, suhu gas di dalam reaktor plasma dapat diubah dengan cepat. Kajian ini berkaitan dengan pembangunan teknik penalaan panjang gelombang bagi laser gentian yang berdasarkan terma dengan menggunakan NTP sebagai solusi untuk mempercepatkan kelajuan penalaan. NTP telah dijana secara pelepasan halangan dielektrik (DBD). Parutan Bragg gentian (FBG) digunakan sebagai penderia suhu oleh kerana kekebalannya daripada pengaruh ganguan elektromagnet di persekitaran plasma. Proses penalaan panjang gelombang dilakukan dengan menggunakan reaktor plasma DBD sebagai pengatur suhu yang membekalkan suhu yang ditetapkan kepada resonator laser. Spektrum pancaran laser gentian telah dipantau dari masa ke masa dengan menggunakan penganalisis spektrum optik (OSA). Hasil kajian menunjukkan peralihan panjang gelombang pancaran apabila suhu resonator laser berubah. Selain daripada itu, julat penalaan dan resolusi suhu penalaan yang dapat dicapai bergantung kepada keadaan pelepasan untuk menghasilkan plasma. Dengan menggunakan plasma Helium yang dihasilkan pada 5 kV, julat penalaan sebanyak 3.027 nm dan juga resolusi penalaan sebanyak 11.57 pm $°C^{-1}$ boleh dicapai. Semasa proses penalaan, perubahan suhu adalah daripada 25 °C kepada sekitar 300 °C. Ia mengambil masa lebih kurang 10 minit untuk melengkapkan proses tersebut. Pancaran laser adalah stabil secara terma oleh kerana peralihan panjang gelombang adalah sangat sedikit apabila suhu dikekalkan. Kesimpulannya, panjang gelombang pancaran laser gentian telah berjaya ditalakan dengan menggunakan pengatur suhu yang berasaskan NTP.

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LIST OF ABBREVIATIONS

CTE	-	Complete thermodynamic equilibrium
DBD	-	Dielectric barrier discharge
DBF	-	Distributed feed back
DBR	-	Distributed Bragg reflector
ECL	-	External cavity lasers
EDF	-	Erbium doped fiber
EDFL	-	Erbium doped fiber laser
FBG	-	Fiber Bragg grating
LTE	-	Local thermodynamic equilibrium
NTP	-	Non-thermal plasma
OSA	-	Optical spectrum analyzer
PLTE	-	Partial Local thermodynamic equilibrium
sccm	-	standard cubic centimeter per minute
SMF	-	Single mode fiber
TP	-	Thermal plasma
WDM	-	Wavelength division multiplexer

LIST OF SYMBOLS

λ_B	-	Bragg's Wavelength
n_{eff}	-	Effective reflective index
Λ	-	Grating period
α_Λ	-	Thermal expansion coefficient
α_n	-	Thermo-optic coefficient
V_B	-	Breakdown voltage

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The rise of fiber laser has been a trend in laser technology. This class of laser has been dominating the market share of laser industry for many years. The rapid growth is often associated to its reliability, efficiency and flexibility. Fiber laser technology plays an important role in our daily life. Many applications of fiber laser have been developed for supporting new manufacturing processes, sensing purposes, health care management as well as telecommunications [1]. The attention given to fiber laser has not been cease ever since its first demonstration by Snitzer in 1961 [2]. Over the years, this class of laser has received extensive on-going research and development in order to improve its performance. Advancing in fiber laser technology continues to deliver cutting edge products to mankind. High power fiber laser has been applied for material processing, especially in cutting, drilling, brazing, welding, annealing and engraving purposes. It even changes the material cutting market which is previously dominated by CO_2 lasers. Recently, a fiber laser that can attain power as high as 10 kW has been reported [3].

While most laser emission occurs a particular wavelength, in some applications, it is desirable to have adjustable output spanning a certain range of wavelength. This refers to the case of applying fiber laser in optical fiber sensing, wavelength division multiplexing, compact photonic device design and optical signal processing [4–6]. The tunability of laser is further divided into a few types based on the wavelength accessibility. It can be customized to fulfill the requirement of a certain functions. Currently available tuning mechanisms allow lasers to be single line or multi-line tuned as well as having narrow or broad tuning range. Tunable lasers can provide a broad selection of accessible wavelengths which is essential for telecommunication purposes. Besides that, tunable laser is also a cost effective product that realize different laser emission with the same configuration of laser, instead of having multiple laser systems.

The laser tunability can be achieved via modification of the gain medium or the resonator. For the distributed feed back laser and distributed Bragg reflection laser, their wavelength emission can be tuned using thermal approach. This is because the wavelength selectivity of this type of laser depends on the spacing and refractive index of the grating. It allows the emission wavelength of a laser to be o be thermally controlled [7] thorough the thermal expansion and thermal-optic effect. Both factors are sensitive to temperature change of the surrounding. The tunable performance provided by thermal tuning mechanism is less sensitive to the mechanism disturbance that potentially damage the laser structure. The cost of ownership is therefore reduce since it does not require frequent maintenance.

Based on the study conducted by Liu *et. al.* [8], the neutral gas temperature of plasma can be manipulated by generating the plasma using electrical power at different frequency. The rise and fall of the neutral gas temperature are exponential with the power supplied. This suggests rapid temperature manipulation can be realized with the application of plasma. The plasma generator itself can be considered as a temperature regulator. For laboratory scale, the plasma can be generated using dielectric barrier discharge arrangement. It is a common method to obtain non-thermal plasma [9]. Utilizing the heating effect of plasma, it is possible to increase the performance of thermal based laser tuning mechanism by reducing the time consumption for the heating and cooling process. Jidenko *et. al.* [10] has successfully demonstrated thermal conditioning using filamentary dielectric barrier discharge.

Temperature measurement in high voltage and high electromagnetic interference condition has always been a challenge for conventional electronic based thermometers. In such harsh environment, the electronic sensors are susceptible to high level of noise which will jeopardize the credibility of the data acquired due to malfunction [11]. This makes the electrical sensors not suitable for the thermometry in plasma. As an answer to the challenge, optical based sensing technique is developed. The optical components are connected together by optical fiber to achieve sensing performance. Since their working principle is based on optical signal, they are immune to electrical noises. There has been some studies implementing FBG based optical sensors for thermometry in plasma system [8, 12–14].

1.2 Problem Statement

Thermal tuning is one of the commonly used technique in adjusting the emission wavelength of laser. It can provide large tuning coefficient [15] and tuning range of a few nanometer wide [16]. However, most thermal tuning mechanisms bare the weakness of having very slow tuning speed [17]. This is because the traditional thermal tuning method for fiber laser mainly rely on the heat transfer via thermal conduction. Since it is a very slow process, the wavelength tuning is time consuming. In order to improve the efficiency of thermal tuning in term of time consumption, one of the approaches is to perform the temperature conditioning rapidly. This would require a device that can modify the surrounding temperature swiftly. There has been literature reporting the application of non-thermal plasma in rapid heating of gases. The non-thermal heating mechanisms in the plasma can provide fast heating channels to manipulate the gas temperature rapidly [18, 19]. This makes the dielectric barrier discharge plasma reactor a potential candidate to be applied as temperature regulator in thermal tuning process since it is a frequent method to generate non-thermal plasma. In order to examine the wavelength tuning performance of the plasma reactor, comprehensive studies need to be conducted.

1.3 Objective of Study

(a) To design a temperature regulator based on dielectric barrier discharge arrangement.

(b) To develop a wavelength tuning mechanism for fiber laser using the dielectric barrier discharge temperature regulator.

(c) To determine the wavelength tuning performance of the dielectric barrier discharge temperature regulator.

1.4 Scope of Study

A plasma reactor was fabricated using dielectric barrier discharge configuration. The plasma was discharged with AC voltage ranged between 3 kV and 8 kV. Helium and Nitrogen was applied as the plasma carrier gas. The pressure of the carriers gases was maintained at a constant flow rate of 50 sccm using a mass flow controller. The plasma gas temperature was measured using fiber Bragg grating

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