PERFORMANCE OF ND:YVO_4 DIODE PUMPED SOLID STATE LASER IN SECOND HARMONIC GENERATION AND Q-SWITCHING

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A thesis submitted in fulfillment of the requirement for the award of the degree of Master of Science (Physics)

Faculty of Science
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JULY 2012

For my ever-supportive parents Khamsan bin Omar and Salmah binti Abdullah,
The loved ones,
My family and friends…
Thank You for your unforgettable support

ACKNOWLEDGEMENT

Bismillahirrahmanmirrahim. In the name of Allah, the Cherishner and Sustainer of the world. First and foremost I thanks to Almighty ALLAH, the most Gracious, the Most Merciful and the source of this success for giving me the strength and time to complete this research.

I would like to express my appreciation to my respected supervisor, Prof. Dr. Noriah Bidin for her encouragement, guidance, enjoyable discussion and friendship throughout this study. Without her continued support and interest, this thesis would not have been the same as presented here.

I would like to acknowledge the help and kind assistance of the following person, Dr. Abd Rahman Tamuri for his ideas and comments, Mr Faizani and Mr Ganesan Krishnan for their assistance, guidance and ideas as my colleague. I am also indebt to the Government of Malaysia through MyBrain MSc for the financial support.

Last but not least, I am grateful to my beloved family and friends Ms Siti Noraiza and Mr Muhammad Safwan Abd Aziz for their continuing support, patience, valuable advices and love throughout the duration of my postgraduate study.

ABSTRACT

Diode pumped solid state laser (DPSS) is one of the most popular types of laser due to its small size and low cost. However, the performance of such DPSS laser remains unstable. This instability depends on many factors including the doping level, crystal lengths and the cooling system. In order to achieve high efficiency and good quality laser, a fundamental diode pumped solid laser was designed, constructed and optimized. In this study, vanadate crystals at different doping levels comprised of 0.5, 1.0 and 1.5 at. % and thickness of 1, 3, and 10 mm were employed as a gain medium. Diode laser centered at 808 nm was used with end pumped technique. The threshold power was optimized using various kind of output coupler including 40, 45, 50, 60, 70 and 75 %. The laser was further modulated by inserting a number of nonlinear materials including KTP to produce second harmonic generation signals. Cr^{4+}:YAG saturable absorber has been used for passive Q-switching technique. Analysis shows that the gain medium with 1.5 at. % is identified as the best doping level with low threshold power and high slope efficiency of 30 %. The best thickness of the crystal bar is identified to be at 3 mm having performance of 55 % slope efficiency with threshold power of 0.6890 W. The output coupler of 75 % reflectivity having slope-efficiency of 54 % with lower threshold power of 0.3974 W, whereas half wave plate is capable to convert almost 95 % to second harmonic generation SHG with threshold power of 0.0063 W. Pulse duration of Q-switched laser is found to be inversely proportional to the input current.

ABSTRAK

Diod pam laser pepejal (DPSS) merupakan salah satu jenis laser yang paling popular kerana saiznya yang kecil dan kosnya yang rendah. Walau bagaimanapun, prestasi laser DPSS itu masih tidak stabil. Ketidakstabilan ini bergantung kepada banyak faktor termasuk tahap endapan, panjang kristal dan sistem penyejukan. Bagi mencapai kecekapan yang tinggi dan laser dengan kualiti yang baik, diod pam laser pepejal telah direka, dibina dan dioptimumkan. Dalam kajian ini, kristal vanadat dengan endapan yang berbeza yang terdiri daripada 0.5, 1.0 dan 1.5 at. % serta ketebalan 1, 3, dan 10 mm telah digunakan sebagai medium penggandaan. Diod laser dengan panjang gelombang 808 nm digunakan dengan teknik pengepaman hujung. Kuasa ambang dioptimumkan dengan menggunakan pelbagai jenis pengganding keluaran termasuk 40, 45, 50, 60, 70 dan 75%. Laser diubahsuai dengan memasukkan beberapa bahan tak linear termasuk KTP untuk menghasilkan isyarat harmoni generasi kedua. Cr^{4+}: YAG penyerap boleh tepu telah digunakan untuk teknik pasif Q-suis. Analisis menunjukkan bahawa medium gandaan dengan 1.5 at. % dikenal pasti sebagai tahap endapan yang terbaik dengan kuasa ambang yang rendah dan kecekapan cerun yang tinggi sebanyak 30%. Ketebalan terbaik bar kristal telah dikenalpasti sebagai 3 mm yang mempunyai prestasi kecekapan cerun 55% dengan kuasa ambang 0.6890 W. Pengganding keluaran dengan pembalikan 75% mempunyai kecekapan cerun sebanyak 54% dengan kuasa ambang yang lebih rendah 0.3974 W. Plat 1/2 gelombang berupaya untuk menukar hampir 95% harmonik generasi kedua dengan kuasa ambang 0.0063 W. Tempoh denyut laser Q-suis didapati berkadar songsang dengan msukan semasa.

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CHAPTER 1

INTRODUCTION

1.1 Overview

High-power diode-pumped compact visible lasers have attracted much attention (Chen *et al.,* 1998). Huge number of lasing materials and variety of laser designs has been developed in the first decade to optimize the laser performance. However, solid state lasers have reached saturation in its development in recent years. Nowadays, the focus is more on improving and maintaining the solid laser system due to its importance in industrial, medical and military fields.

A diode-pumped solid-state (DPSS) laser with high efficiency, high output power, a good spatial beam profile, and good stability is highly desired for use in a lot of applications such as material processing holography, range finding, target illumination and designation, satellite and lunar ranging, thermonuclear fusion, plasma experiments, and in general for scientific work requiring high power densities such as pumping other laser crystals (Koechner, 1976). In addition, such lasers could also become critical components of an all-solid-state compact UV or femtosecond UV laser sources and optical parametric oscillators. They have eventually become commercially available for replacing low-efficiency, cumbersome Ar^+ lasers and flashlamp-pumped solid-state lasers in a variety of practical applications (Bai and Chen, 2002).

Diode laser with 808 nm wavelengths is the key component in the development of DPSS laser. Diode laser can efficiently pump solid state laser, which in turn support the development of even better and more versatile lasers (Koechner, 2006). Stimulated emission in semiconductor laser is more intense compared to other types of laser. This will contribute to high rates of energy generation but also leads to high amount of heat dissipation (Fan and Byer, 1988). The effects of temperature on diode laser output should be paid much attention as the variation of temperature results in change the of spectrum intensity.

Much higher pumping intensity can be achieved using diode lasers instead of flashlamps as pump sources for solid-state lasers because of diode laser high spatial and spectral brightness (Byer, 1988; Fan and Sanchez, 1990). The end coupling pump geometry facilitated a good overlap between the pump and laser modes. This ensured low pump threshold and high gain. This higher brightness has allowed demonstration of solid state laser efficient room-temperature operation on laser transitions with significant population in the lower laser level at thermal equilibrium.

The main advantages of diode lasers over flashlamps as pump sources are overall laser efficiency and extended pump-source lifetime. The increase in efficiency is due to improved use of the optical pump radiation. Solid state laser like Yttrium orthovanadate ($Nd{:}YVO_4$) has optical absorption only in relatively narrow wavelength bands; thus only small portion of the broadband flashlamp energy passes can be absorbed and the rest just passing through the material without being absorbed. On the other hand, diode laser output is narrowband; thus most of it is absorbed and utilized. Flashlamp-pumped Nd lasers are typically only 1 % efficient while diode-pumped lasers are 10 %, efficient (Fan and Byer, 1988). This increase in efficiency has other favorable consequences.

1.2 Problem Statement

Currently diode pumped solid state laser become much more popular because it is portable and much cheaper compare to the other high power laser system. DPSS laser has multipurpose application including for medical, industrial and scientific research. Nd:YVO_4 crystal has been chosen as the gain medium in this research because of the outstanding features which makes Nd:YVO_4 an excellent crystal. However, Nd:YVO_4 crystal is easily crack due to its low thermal conductivity. This affects the laser performance and lifetime of DPSS laser. Therefore it is important to optimize the DPSS laser, so that a appropriate parameters can be selected for better performance and last long operation.

1.3 Research Objectives

The main objective of this study is to optimize the DPSS laser performance. In order to achieve this goal, the following works are performed:

1. To optimize the performance of Nd:YVO_4 laser at various doping level and crystal lengths.
2. To optimize the laser output based on different reflectivity of output couplers

3. To modulate the beam through frequency doubler and saturable absorber.

1.4 Research Scope

In this project, a collimated diode laser will be used as an optical pumping source. Thermoelectric cooler will be developed to stabilize the diode laser. Nd:YVO_4 crystal is used as the active medium. Potassium Titanyl Phosphate (KTP) crystal will be used as the frequency doubler while the Cr^{4+}:YAG as saturable absorber. The characterization of laser beam will be measured using powermeter and digital oscilloscope.

1.5 Thesis Outline

This thesis consists of five chapters. The first chapter describes the introduction and overview of the thesis, problem statement, research objectives and the scope of the study.

Chapter 2 discussed some theories, to explain the physical concept involved in this project. This includes the working principle of solid state laser and basic principle of second harmonic generation and passive q-switching.

Chapter 3 describes the methodology of the research. The specification of diode laser, the properties of crystals employed in this project and others optical parts are discussed in detailed. This also covers the instruments employed, measurement techniques and experimental set-up.

Chapter 4 contains the results obtained from this research. Initially the optimization of $Nd:YVO_4$ crystal as the active medium in the laser resonator are discussed. This followed by the enhancement of second harmonic generation using KTP crystal that acted as frequency doubler. These include the phase matching angle technique and application of polarizer in the cavity. The saturable absorber, Cr^{4+}:YAG was employed as passively Q-switched.

Finally, the conclusion of this research is described in chapter 5. These provides with summarization of the whole project and also problems facing during the period of study. Finally, some suggestions are recommended for future study.

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