EFFICIENCY AT VARIOUS LENGTH OF 1 at % NEODYMIUM DOPED YTTRIUM ORTHOVANADATE (Nd: YVO_4) CRYSTAL

SHIRLEY ARVILLA ANDREW

UNIVERSITI TEKNOLOGI MALAYSIA

EFFICIENCY AT VARIOUS LENGTH OF 1 at % NEODYMIUM DOPED YTTRIUM ORTHOVANADATE (Nd: YVO_4) CRYSTAL

SHIRLEY ARVILLA ANDREW

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

Faculty of Science
Universiti Teknologi Malaysia

MAY 2011

Dedication to

my beloved father and mother

(Mr. Andrew and Mdm. Saihim),

my siblings, and all my friends..

Thank you for your unforgettable supports

ACKNOWLEDGEMENT

First and foremost, I wish to give all the praise and gratitude to Almighty God for giving me the strength and time to complete this research. With His blessings, may this work be beneficial for the whole of humanity.

I would like to express my sincere gratitude to my supervisor, Prof. Dr. Noriah Bt Bidin for her encouragement, guidance, advice, comment and valuable discussion throughout this work. Without her continued support and interest, this thesis would not have been the same as presented here.

My sincere thanks and appreciations extend to Nur Ezaan Khamsan and Ganesan A/L Krishnan who had helped me in many ways and to all my colleagues and friends while completing this research for their help, co-operation and assistance.

I am also indebted to Universiti Teknologi Mara (UiTM) and Ministry of High Education (MOHE) for giving me the scholarship to support my study. Without this financial support, this project would not be possible.

Last but not least, I would also like to acknowledge the kindly good encouragement, continuing support and valuable advice of my parents and siblings throughout this duration of my study.

ABSTRACT

Orthovanadate crystal is well known as a gain medium. However in scale-up the output power some parameters of the crystals have to be considered. This included the thickness or the length of the bar crystal. Therefore the aim of this project is to investigate best choice of length of 1 at % Nd:YVO_4 crystal for the best laser performance. In attempt to achieve this goal, various lengths of bar crystal were under studied including 1.15, 3.00 and 10.00 mm. The crystals were longitudinally pumped by diode laser. The laser output was measured using powermeter, spectrum analyzer and CCD video camera. The beam spot of the laser outputs were recorded using CCD video camera. The Nd:YVO_4 output beam spectrum centered at 1063.93 nm with linewidth of 0.70 nm. The output power for 1.15 and 3.00 mm crystals showed spontaneous emission in the initial stage. This followed by stimulated emission after exceeding threshold point. In the case for 10.00 mm crystal merely shows the spontaneous emission process. The limited pumping power does not allow lasing to occur from 10.00 mm crystal. The optimized length of 1 at % Nd:YVO_4 crystals was found to be from the 3.00 mm crystal with slope efficiency of 4.51% and threshold power of 1921 mW. Meanwhile for 1.15 mm crystal manage to produce an efficiency of 1.07 % with threshold power of 2400 mW. The exciting beam for 10.00 mm crystal was dissipated and dispersed in the bulk of crystal causing spontaneous without stimulated emission.

ABSTRAK

Kristal Orthovanadate dikenali sebagai medium aktif laser. Walaubagaimanapun beberapa parameter kristal tersebut perlu dipertimbangkan semasa pengukuran kuasa keluar. Ini termasuklah ketebalan atau panjang kristal. Oleh itu, tujuan projek ini dijalankan adalah untuk mengenalpasti panjang terbaik 1 at % Nd:YVO_4 kristal yang menghasilkan prestasi laser terbaik. Bagi mencapai objektif ini, panjang kristal 1.15, 3.00 dan 10.00 mm digunakan. Kristal-kristal ini dipam secara membujur oleh laser diod. Keluaran laser oleh kristal diukur dengan menggunakan meterkuasa, penganalisis spektrum dan kamera video CCD. Bintik keluaran laser kristal dirakamkan dengan menggunakan kamera video CCD. Kristal Nd:YVO_4 menghasilkan laser yang berpusat pada 1063.93 nm dengan lebar jalur 0.70 nm. Pada permulaannya, kuasa keluaran kristal bagi 1.15 dan 3.00 mm adalah pancaran spontan sahaja. Ini diikuti dengan pancaran ransangan yang berlaku selepas kuasa ambang. Bagi kristal 10.00 mm, kuasa keluaran hanya menunjukkan proses pancaran spontan sahaja. Kuasa pengepaman yang terhad tidak dapat menghasilkan laser bagi kristal 10.00 mm. Panjang optimum kristal 1 at % Nd:YVO_4 daripada projek ini adalah kristal 3.00 mm dengan kecekapan tukaran optikal 4.51% dan kuasa ambang 1921 mW. Sementara itu, kristal 1.15 mm menghasilkan kecekapan 1.07% dengan kuasa ambang 2400 mW. Pancaran daripada kristal 10.00 mm tersebar dan hilang di dalam kristal menyebabkan berlakunya pancaran spontan tanpa pancaran ransangan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

η_s	-	Slope efficiency [%]
P_o	-	Output power [W]
P_{in}	-	Input power [W]
λ_P	-	Wavelength of pumping light [nm]
λ	-	Wavelength of output power light [nm]
η_p	-	Quantum efficiency [%]
η_m	-	Mode matching efficiency [%]
l	-	Length of Nd:YVO_4 crystal [mm]
T	-	Transmission efficiency of the output coupler
ρ	-	Nd^{3+} doping concentration [%]
δ_o	-	Diffraction loss due to the thermally induced spherical aberration
C_1	-	Empirical constant [0.015 $W^{-1/2}$]
C_2	-	Empirical constant [0.04 cm^{-1}]

CHAPTER 1

INTRODUCTION

1.1 Overview

The advantage of pumping solid-state lasers with monochromatic pump source has been recognized earlier but the low power output, low packaging density and extremely high cost of diode lasers prevented any serious application for laser pumping until the mid-1980s. The decreasing cost and great development of the laser diode during the last two decades has attracted a great deal of attention. Properties such as output power, compactness, beam quality, lifetime, efficiency and wavelength control have all been dramatically improved. Today, there are many applications of laser diode in the field of military, industry, medical treatment and scientific research (Koechner, 2006 and Ying, 2008).

There are two main diode-pumped systems which are side-pumped and end-pumped. In the side-pumped geometry, the diode arrays are placed along the length of the laser rod or slab and pump the active material perpendicular to the direction of propagation of the laser resonator mode. In the end-pumped geometry, the pumped radiation is collimated and focused longitudinally into the laser material collinear with the resonator mode. High conversion efficiency and good beam quality are the characteristics of the end-pumped laser system according to Chen (1999). Hence, end-pumped laser-diode system is used in this research.

Yttrium Orthovanadate doped Neodymium ($Nd:YVO_4$) crystal have been identified as a promising active materials for use in diode-pumped laser. Compare to the others crystals, $Nd:YVO_4$ offers many advantages such as a larger emission cross-section, a broader absorption bandwidth, a higher allowed doping level and a polarized output. It is possible for a short $Nd:YVO_4$ to absorb most of the incident light around 809 nm since its absorption cross-section (2.7 x $10^{-19}cm^2$) is several times larger than the Nd:YAG (0.7 x $10^{-19}cm^2$) (Wang, 2001). 1 at % $Nd:YVO_4$ crystal at various length was utilized as an active material in this research.

Wang *et al.* (2001) compared the laser properties of four different doping levels of $Nd:YVO_4$ where each of the crystal have different lengths. The doping levels comprised of 1, 2, 3 and 5%. They found that the 2 at % 2 mm $Nd:YVO_4$ crystal was the best specification which has the advantages of economy, high efficiency and low threshold power. The threshold power and the slope efficiency were 39 mW and 50% respectively for this crystal. They reported that only the 1 at % $Nd:YVO_4$ crystals showed that the longer the crystal, the higher the slope efficiency and the lowest the threshold power. In this particular doping level, they had made comparison of the laser output for different crystal's length of 1, 3 and 5 mm. The slope efficiency and threshold power were varied with crystal's length for the other doping level. The best specification of the 1 at % $Nd:YVO_4$ crystals was longer than 3 mm. Wang also stated that the higher the doping level or the longer the crystal, the higher and broader their absorption peak near 809 nm which then influenced the laser properties of the $Nd:YVO_4$ crystal.

Mukhopadhyay *et al.* (2002) had carried out experiment using three $Nd:YVO_4$ crystals with different lengths and doping levels. The crystals were comprised of doping level of 1, 2 and 3% with length of 1.5, 1.0 and 0.5 mm respectively. Their result shows that the 1.5 mm for 1 at % doped Nd^{3+} ion crystal has the highest slope efficiency of 56% and the lowest threshold power of 40 mW. From this result, it was noted that the lower the doping level and the longer the crystal length the better the $Nd:YVO_4$ laser crystal performance.

1.2 Problem Statement

The $Nd:YVO_4$ crystal was considered to be one of the best laser crystal since its offer many advantages compared to the other laser crystal. The two outstanding features of the $Nd:YVO_4$ crystal are large stimulated emission cross section and strong broadband absorption at 809 nm. Previous research reported that the laser properties such as the slope efficiency and the threshold power were influenced by the absorption capabilities of the pump light, which have the dependence on the doping levels and lengths of the crystal. However which length actually suitable for inducing high efficiency and low threshold for low pump power still not known. Therefore, in this project, the appropriate length or/and thickness of the gain medium having such properties is determined.

1.3 Research Objective

The main objective of this project is to identify the appropriate length of the gain medium for high performance of Nd:YVO4 laser. In attempt to achieve these goals, the following works are carried out:

1. Calibrate the pumping source a laser diode
2. Pumping gain medium 1 at% Nd:YVO_4 bar at different length
3. Characterize the laser output of each of gain medium

1.4 Research Scope

In this study, Neodymium orthovanadate (Nd:YVO_4) with doping level 1 at % Nd^{3+} ions in YVO_4 host was employed as gain medium. Laser diode at 809 nm was utilized as a pumping source. The study was focused only at the parametric dependence on the length of the crystal at constant doping level. The pumping current also verified in the range of 8 A to 14 A during the output power measurement of both laser diode and Nd:YVO_4 crystal.

1.5 Chapter Outline

This report is divided into five chapters. The first chapter is the introduction of the project including the problem statement, research objective, research scope and chapter outline.

Chapter 2 is the theoretical aspects of the laser diode and its working principle, the properties of solid-state laser material, the slope efficiency and threshold power of the active medium.

Chapter 3 is the methodology of the project which includes the laser diode, the active material, the instrumentation, the experimental setup and finally a topic about how the data being analyzed.

Chapter 4 discussed the results obtained from the experiments. This includes the characteristics of the laser diode calibration curve and the output power measurement of the Nd:YVO_4 crystals. The different lengths of the crystal were compared in terms of slope efficiency and threshold power in this chapter.

The last chapter concludes the results of this project. Problems encounter during the experiments also stated in this chapter and followed by a few recommendation for a future study.

REFERENCES

Camargo, F. A., Wetter, N. U. (2008). High Power, Good Beam Quality Nd:YVO4 Laser Using A Resonator With High Extinction Ratio For Higher-Order Mode Treshold. *American Institute of Physics.*

Chen, Y., Zhengjun, X. & Gnian, C. (1999). High-Efficiency Nd:YVO_4 Laser End-Pumped With a Diode Laser Bar. *Proc. SPIE*, Vol. 3898: 148-15.5

Ding, X., Wang, R., Zhang, H., Yu, X., Wen, W., Wang, P. & Yao, J. (2009). High-efficiency Nd:YVO_4 laser emission under direct pumping at 880 nm. *Optics Communications*, 282: 981-984

Eakins, D. E., Lebret, J. B., & Norton, M. G. (2004). Dislocations in Yttrium Orthovanadate. *Journal of Crystal Growth*, 266:411–414

Ermeneux, F. S., Goutaudier, C., & Moncorge, R. (1999). Comparative of Various Nd^{3+}:YVO_4 single crystals. *Optical Material*, 13: 193-204

Fairuz, M. (2008*). Characterization of High Power Laser Diode as A Solid State Pumping Source*. Malaysia: UTM.

Ganesan, K. (2010). *Performances of the Nd:YVO_4 laser at various doping levels.* Malaysia: UTM.

Kaminskii, A. A., Ueda, K., Eichler, H. J. (2001). Tetragonal Vanadates YVO_4 and $GdVO_4$ - New Efficient $\chi^{(3)}$ – Active Crystals for Rahman Laser Converters. *Laser Physics,* Vol. 11: 1124-1133

Kasap, S. O. (2001). *Optoelectronics and Photonics Int. Ed*. New Jersey: Prentice-Hall, Inc.

Koechner, W. (2006). *Solid-State Laser Engineering* 6^{th} *edt*. USA: Springer Science+Business Media, Inc.

Kucytowskia, J., Wokulska, K., &Kazmierczak-Balatab, A. (2008). Influence of Nd dopants on lattice parameters and thermal and elastic properties in YVO_4 single crystals. *Thin Solid Films*, 516:8125–8129

Mukhopadhyay, P. K., George, J., Ranganathan, K., & Nathan, T. P. S. (2002). Experimental determination of effective stimulated emission cross-section in a diode pumped Nd:YVO_4 micro-laser at 1064 nm with various doping concentrations. *Optics and Laser Technology*, 34: 357-362

Sato, Y. & Taira, T. (2005). Comparative Study on the Spectroscopic Properties of Nd:$GdVO_4$ and Nd:YVO_4 With Hybrid Process. *IEE Journal of Selected Topics in Quantum Electronics,* Vol. 11, No. 3

Wang, Z., Lianke, S. & Shaojun, Z. (2001). Investigation of LD End-Pumped Nd:YVO_4 crytals with various doping levels and lengths. *Optics & Laser Technology*, 33: 47-51

Ying, Y., Zhang, H & Liu, Y. (2008). A Laser-Diode End-Pumped Nd:YVO_4 Slab Laser at 1342nm. *Chin. Phy. Lett*., vol. 26, No. 1 (2009) 014201.

Zhang, H., Chao, M., Gao, M., Zhang, L. & Yao, J. (2003). High power diode single-end-pumped Nd:YVO_4 laser. *Optics & Laser Technology*, 35: 445-449