

THERMAL LENSING INDUCED BY END-PUMPED 1.5 at % Nd:YVO<sub>4</sub>  
LASER CRYSTAL

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This dissertation is dedicated to my family for their endless support and encouragement.

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## ABSTRACT

The aims of the research is to study the thermal lensing induced by end-pumped 1.5 at % Nd:YVO<sub>4</sub> Laser crystal. Diode laser centered at 808 nm was employed as an optical pumping source. Using CCD camera, the laser beam spot was recorded. And it was found that the beam spot diameter linearly increased as the pumping power. The crystal has poor thermal conductivity compared to the other laser crystal. Neglecting the thermal birefringence effect on the gain medium, and using the optical characteristics of the a-cut of the Nd: YVO<sub>4</sub>, thermal lensing due to heat deposited in diode end-pumped a 1.5 at % Nd:YVO<sub>4</sub> crystal was investigated. The focal length of the thermal lens was obtained to be exponentially decreasing with respect to pumping power, implies that the higher the pumping power the shorter the focal length thus the greater the aberration effect which degrade the beam quality.  $M^2$  factor technique was used to measure the beam quality. The results proved that the beam quality become poor as indicates by the increasing of  $M^2$  factor.

## ABSTRAK

Matlamat penyelidikan adalah untuk mengkaji perkantaan terma yang diaruhkan oleh pengepaman hujung terhadap 1.5% kistal laser Nd:YVO<sub>4</sub>. Laser diode yang berpusat pada 808 nm digunakan sebagai sumber pengepaman. Menggunakan kamera CCD, laser spot dirakamkan dan ia didapati bertambah secara linear dengan kuasa pam. Kristal mempunyai konduktiviti terma yang lemah berbanding dengan laser Kristal yang lain. Dengan mengabaikan kesan birefringen terma bagi medium perolehan, dan menggunakan ciri-ciri optik bagi Nd:YVO<sub>4</sub> yang dipotong pada a axis, perkantaan terma yang disebabkan oleh haba yang didepositkan oleh diode pengepaman hujung pada Kristal ND:YVO<sub>4</sub> 1.5 % dikaji. Panjang fokus bagi kanta terma diperolehi mengurang secara eksponen terhadap kuasa pam. Ini menandakan semakin tinggi kuasa pam semakin pendek panjang fokus dengan demikian semakin besarlah kesan aberasi yang mengurangkan kualiti alur. Teknik faktor  $M^2$  digunakan untuk mengukur kualiti alur. Keputusannya membuktikan bahawa kualiti alur semakin lemah dengan peningkatan faktor  $M^2$ .

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**LIST OF ABBREVIATIONS**

<b>CCD</b>	Charge Coupled Device
<b>CW</b>	Continuous Wave
<b>DPSS</b>	Diode Pumped Solid State Lasers
<b>HT</b>	High Transmission
<b>HR</b>	Highly Reflective
<b>LD</b>	Laser Diode
<b>Nd: YAG</b>	Neodymium-Doped Yttrium-Aluminum-Garnet
<b>Nd: YVO4</b>	Neodymium Doped Yttrium Orthovanadate
<b>OC</b>	Output Coupler
<b>OPD</b>	Optical Path Deference
<b>TEC</b>	Thermoelectric Cooler
<b>TEM<sub>00</sub></b>	Transverse Electromagnetic Mode

**LIST OF SYMBOLS**

$\lambda$	Wavelength,
$w_0$	Beam Waist radius
<b>f</b>	Focal Length of the Lens
$\xi$	Fractional Thermal Loading Coefficient
<b><math>n_0</math></b>	Refractive Index of the Medium
<b><math>dn/dt</math></b>	Thermal Optic Coefficient
$K_c$	Thermal Conductivity
$w_{pa}$	Spot Size of the Input Power
<b><math>P_{abs}</math></b>	Absorbed Pump Power,
<b><math>\alpha_t</math></b>	Thermal Expansion Coefficient
<b><math>M^2</math></b>	Beam Quality
<b><math>P_{in}</math></b>	Incident Pump Power of the Diode Laser.
<b><math>f_{th}</math></b>	Thermal Lens Focal Length

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Background of Study**

The optimum efficiency and long life time of the pump source led to increase in interest of using laser diode as a pump source. Gain medium of a laser can be excited either by end pumping or side pumping using flash lamp source or laser diode. Diode end-pumping of solid state laser allows high efficiency, high output power, and good spatial beam profile, as well as good stability [1]. It is highly desired and an interest in material processing and other scientific applications.

For high-power pumped solid state lasers, an appreciable amount of the optical pump energy is lost in the gain medium as heat and the temperature of the pumped spot starts to increase. The heat will flow towards the low temperature region. The crystal is interfaced with the heat sink, so an inhomogeneous temperature distribution occurs in the crystal. The temperature gradient in the pumped crystal induced refractive index change. Mechanical deformation occurs including stress induced by the heat generation inside the crystal.

Due to variation of refractive index make the active media acts as a lens which known as a thermal lensing effect. The heat deposition in the laser crystal significantly effects on the laser performance. For example the thermal loading induced by the pump power in the laser material reduces the slope efficiency of the system. The thermal lensing increases the diffraction losses which causes degradation of the beam quality. High efficiency and high beam quality of the diode end pumped solid state lasers is favorable in many applications. However when the laser works at high pump power, the thermal lens effect of active medium is one of the serious problem and cannot be neglected. In order to design high power laser this thermal lens effect need to be reduced and optimize the overlap between the pump beam and laser beam [1, 2].

The good properties such as large stimulated emission cross-section at 1064 nm, high absorption coefficient, wide absorption bandwidth at 808 nm, a short upper state life time, and a strong pump absorption, as well as good physical, optical and mechanical properties, make the neodymium doped yttrium Ortho-vanadate (Nd: YVO<sub>4</sub>) one of the excellent crystal for high power diode end-pumped solid-state laser. It has attractive laser performance which is much better than Nd: YAG crystal. For example, the stimulated emission cross-section of an a-axis cut Nd: YVO<sub>4</sub> crystal at 1064 nm is  $5 \times 10^{-19} \text{cm}^2$ , this is about four times that of Nd: YAG at 1064 nm. The property of strong absorption lead to high lasing efficiency, and the Nd: YVO<sub>4</sub> also has good upper state life time that is desired in some laser system designs such as the Q-switching laser. The upper state life-time of Nd: YVO<sub>4</sub> was estimated

around 90  $\mu\text{s}$  while around 230  $\mu\text{s}$  is the upper life time of Nd: YAG. This allows a faster Q-switching to be achieved [3].

## 1.2 Problem Statement

Using a laser diode end-pumped technique to pump the Nd:YVO<sub>4</sub>, the output power scaling to higher level is possible because of its high gain cross-section and wide absorption bandwidth. However, thermal conductivity of the vanadate is low, which causes the localization of thermal at the center of the gain medium leading to the generation of thermal lensing and thermal damage. This affects all the major aspects of solid state laser such as the output beam quality, oscillating mode size, efficiency as well as induces the laser to deviate the stability state (affect the resonator stability). Therefore, the quantification of pump-induced thermal focal length in end-pumped Nd: YVO<sub>4</sub> laser crystal is important in solid state laser design and optimization. This is our main aim in this work.

## 1.3 Research Objective

In this work thermal lensing induced by end-pumped a 1.5 at.% Nd: YVO<sub>4</sub> Laser Crystal is investigated. In attempt to achieve this goal, the following tasks will be performed:

1. The measurement of the pumped beam size.
2. The estimation of the focal length of thermal lens.
3. The measurement of the laser output beam waist.
4. The estimation of the beam quality factor.



## **1.4 Significance of the Study**

In this work, it is anticipated that the results will provide additional information on the body of knowledge on thermal lens, beam quality degradation of 1.5 at % of the Nd : YVO<sub>4</sub> laser crystal using diode end-pumped laser technique.

## **1.5 Scope of Study**

Thermal lensing will be investigated on 1.5 at % doping level of yttrium vanadate crystal Nd: YVO<sub>4</sub>. Diode laser centered at 808 nm will be employed as a pumped source using end pumping technique. The beam quality of the laser output will be estimated using  $M^2$  factor technique

## **1.6. Thesis Outline**

Chapter 1 reviews some background of the thermal effect and the importance of Nd:YVO<sub>4</sub> laser crystal among other laser materials. The objectives and scope of the study are also discussed.

Chapter 2 covers a short overview of the diode pumped solid state lasers, end-pumped configuration, thermal lens effect in diode pumped solid state laser, and the equation used to estimate the thermal lens.

Chapter 3 discusses the method and the equipment used in this project. Basically, this chapter consists of the diode laser which was employed as a pump source for Nd:YVO<sub>4</sub> crystals. Beam profiler and infrared card are utilized to measure the beam spot.

Chapter 4 presents the results obtained from experimental works. The data are analyzed and used to estimate the focal length of the thermal lens. The beam quality is calculated base on the spot size at different distance of beam propagation.

Chapter 5 concludes the finding of this study and suggests the works to be carried out in the future that related to this research.

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