Performance Analysis of Laser Diode Single-End-Pumped Solid State Laser

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Abstract:

In this work, results are presented for a continuous wave diode laser single-end-pumped $Nd:YVO_4$ laser with maximum output power of 240mW in the TEM_{00} mode at an optical pump power of 850mW. The laser performance under different output couplers has been studied both analytically and experimentally. The theoretical analysis provides a good prediction of the laser performance parameters which are in broad agreement with the experimentally observed results. An optical to optical conversion efficiency of 28% and an average optical slope efficiency of 29% were obtained. The fluctuation of the output power is less than 1.5% in 10 min.

Keywords: $Nd:YVO_4$ laser, Slope efficiency, Diode end pumping, Conversion efficiency.

الخلاصة :

تم في هذا العمل عرض نتائج ليزر $Nd:YVO_4$ مستمر الموجة ومضخ طولياً بواسطة ليزر الدايود. حيث بلغت أعظم قدرة خارجة لهذا الليزر 240mW بنمط كاوسي TEM_{00} عند قدرة ضخ بصرية قدرها 850mW. تمت دراسة أداء الليزر عملياً وتحليلياً باستخدام مرآيا اقتران خرج ليزري ذات انعكاسيات مختلفة ، لقد أعطى التحليل النظري تكهناً جيداً لمعلمات أداء الليزر وكانت النتائج النظرية في تطابق جيد مع النتائج المقاسة عملياً بكفاءة تحويل بصرية– بصرية بلغت 28% وبمعدل كفاءة ميل بصرية 29%. وقد بينت الحسابات إن التذبذب الحاصل في القدرة الخارجة كان أقل من 1.5% خلال 10 دقائق.

الكلمات الدالة: ليزر $Nd:YVO_4$, كفاءة الميل, الضخ النهائي لليزر الدايود, كفاءة التحويل.

1- Introduction:

As the output power of the semiconductor diode lasers increases, a diode laser pumped solid state laser providing an all solid state laser becomes an active research field (Svelto,1998).The diode pumped solid state laser(DPSS) offers many advantages over traditional flash lamp pumped especially in efficiency and compactness that make it attractive tool for various applications (Ishimori *et al*., 1992).

Many diode laser pumped solid state lasers have been reported using various host crystals and dopants. Various pumping geometries were employed in the DPSS lasers. Among various pumping schemes, the longitudinal end pump may be the most preferred (Hwang *et al*.,1992),particularly at relatively low powers, as it can provide higher pump densities and an excellent overlap between pump and lasing modes than that of other pumping schemes (Peng *et al*.,2002;Tidwell *et al*,1991).These give the potential to realize lasers that are compact and have both a possible high efficiency and high beam quality (Xiong *et al*.,2003).Recently there has been great interest in the $Nd:YVO_4$ crystal as lasing media for low power DPSS laser and it becomes one of the mostpopular laser crystals especially in end pumped configurations(Chen *et al*., 2002). In this letter, we report a 240mW CW 1.064μm laser output from an $Nd:YVO_4$ crystal with lower Nd concentration. We have investigated the laser performance for different output couplers. We also carried out some stability testing of IR laser by monitoring the output power with power-meter. The fluctuation of the output power was less than 1.5% in 10 min.

2- Theoretical Model:

In this section, we will describe the basic relationships between externally measurable quantities, such as laser output, threshold pump intensity and slope efficiency and internal system and material parameters using a space-dependant rate equation analysis.

2.1.1- P_{th} , P_{out} and η_s in terms of internal system parameters:

Based on the space-dependent rate equations and for optimal power deposition, the threshold pump power P_{th}, the laser output power, P_{out}, and slope efficiency, η_s, can be expressed by (Xiong et.al., 2003; Koechner, 2006):

$$P_{th} = \frac{I_s}{\eta_s}\frac{\gamma_2}{2}\pi w_o^2 \ \ldots (1)$$

$$P_{out} = I_s \frac{\gamma_2}{2}\pi w_o^2 \left[\left(\frac{P_p}{P_{th}}\right) - 1\right] \ \ldots (2)$$

$$\eta_s = \frac{\gamma_2}{2\gamma}\eta = \frac{T}{\delta + T}\eta \ \ldots (3)$$

Where γ_2 is the logarithmic loss of the output coupler of reflectivity R_2 and I_s is the saturation intensity.

2.1.2- Optimum Output Coupler:

For a fixed rate of pump power, there is some value for the transmission, T of the output mirror that maximize the output power (Csele, 2004).The optimum output coupling γ_{2opt} then turns out to be given by (Svelto, 1998):

$$\gamma_{2opt} = 2\gamma_i\left(\chi_m^{1/2} - 1\right) \ \ldots (4)$$

which corresponds to an optimum reflectivity of:

$$R_{2opt.} = \exp[-\gamma_{2opt.}] \ldots (5)$$

Where $\chi_m = \frac{P_p}{P_{out}}$ is the ratio between the actual pump power P_p and the threshold pump power corresponding to zero output coupling, i.e. to γ_2=0.

3- Experimental setup:

The laser experiments were carried out in a plano-concave resonator, as shown in Fig. 1. The cavity length was experimentally optimized to be 100 mm. The fundamental mode radius in the laser crystal was calculated to be about 0.184 mm. A commercially available diode-laser was employed as the pump source. It delivered a maximum output power of 1 W at the wavelength of 808 nm. The pump beam was focused into the laser crystal with a spot radius of about 0.2 mm by special focusing optical system (collimator f=8mm and focusing lens f=60mm). The pump mirror M_1 was a concave mirror with radius of curvature of 200 mm, antireflection (AR) coated at 808 nm on the flat face, high-reflectance (HR) coated at 1.064μm, and high-transmittance (HT) coated at 808 nm on the curved face. The output couplers M_2 were flat mirrors with different transmissions at 1.064μm of 5%, 10%, and 20%. The laser crystal was a-cut, AR coated at 808 nm and 1.064μm on both of its faces, and placed closely to M_1. To remove the heat generated from the crystal, it was wrapped with indium foil and held in copper blocks, which were cooled by thermoelectric coolers.

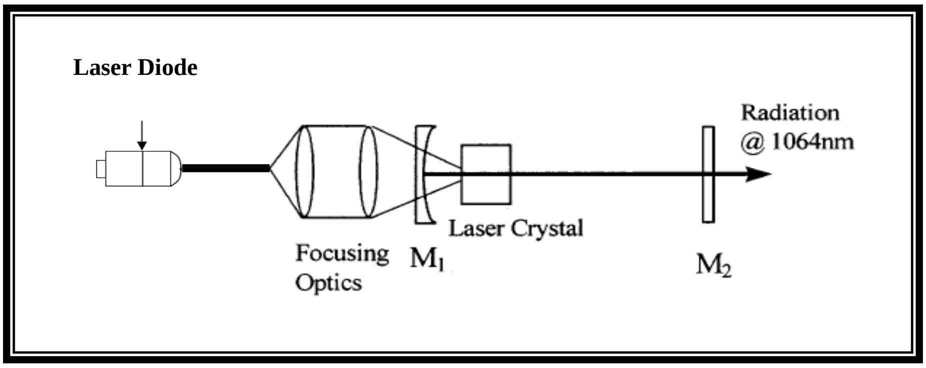

Figure.1 Schematic of the Laser Experimental setup

4- Results and Discussions:

A 3×3×2mm^3, 0.3 at.% Nd:YVO_4 crystal were cut with a-axis parallel to optical axis of the laser system was used to investigate the 1.064μm output power with the three different output couplers. Fig. 2 shows the CW output power at 1.064μm as a function of the incident pump power. From Fig. 2, we can see that the laser was optimized with the 5% transmission coupler in the whole range of incident pump power. The threshold pump power was measured to be about 121.35mW. Above threshold, the output versus input power relation can be fitted by the equation: $P_{out}=35[(P_{in}/P_{th})-1]$.The average optical slope efficiency above threshold is then easily obtained from this equation as $\eta_s = dP_{out}/dP_{in} = 35/P_{th} = 29\%$.

The above equation can be readily compared to Eq.(2) where $\sigma = 15.6\times10^{-19} cm^2$ and $\tau = 98\mu s$ we then obtain the value of saturated intensity as $I_s = 1.22$ kW.cm^{-2}. For 5% transmission of the output mirror, we get $\gamma_2 = 0.0513$. Comparing the two equations yields $w_o = 0.188$mm which compared well to the calculated value of 0.184mm.

By using the values obtained by our calculations for I_s, η_s, γ_2 and w_o of 1.22kW.cm^{-2}, 27%, 0.0513 and 0.184mm respectively in Eq.(1) we find that P_{th}=123mW which is very close to the measured value of 121.35mW. This shows that the pump beam is well matched to the intracavity laser mode and confirms the fact that in an end-pumped laser a near perfect mode overlap could be achieved.

The overall electrical - to – optical system efficiency $\eta_{sys.}$ of 9% was calculated assuming the average diode radiative efficiency η_r of 33% (Svelto, 1998; Koechner, 2006; Csele, 2004). The optimum reflectivity of the output coupler, $R_{2opt.}$ was calculated using Eqs.(4 and 5) at the maximum input power of 852.56mW for the three different measured values of threshold pump power: 121.35mW, 172.63mW and 392.15mW respectively. In all the three cases we found that the optimum reflectivity of the output coupler is 94% which confirms the experimental data.

The temperature of Nd:YVO_4 crystal could still be effectively controlled at such pump power, and the output power did not begin to fluctuate and saturate. This insures that the thermal lens was not strong enough to drive the resonator close to the stability boundary. For 10% and 20% transmission couplers, the maximum output powers were 224.36mW and 149.36mW with corresponding optical conversion efficiencies of 26.3% and 17.5% respectively. We also carried out some stability testing of IR laser by monitoring the output power with power-meter. The fluctuation of the output power was less than 1.5% in 10 min. as shown in Fig.3. The output light showed a quite stable behavior and did not show any large-amplitude fluctuation on the very short time scale. The maximum amplitude of the fluctuation was less than 2.5%.

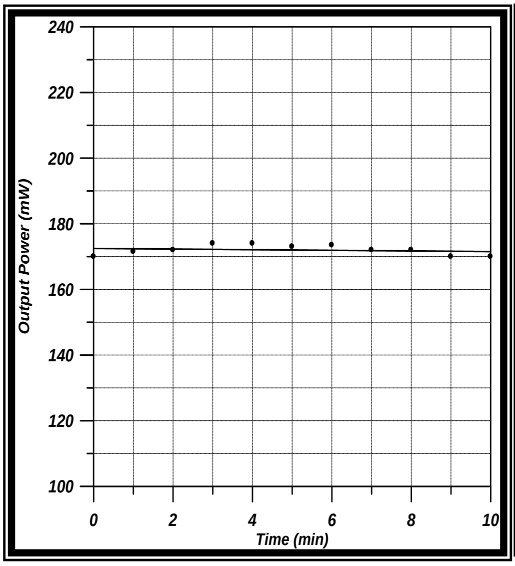

Figure .3 Stability monograph of $Nd:YVO_4$ laser output power

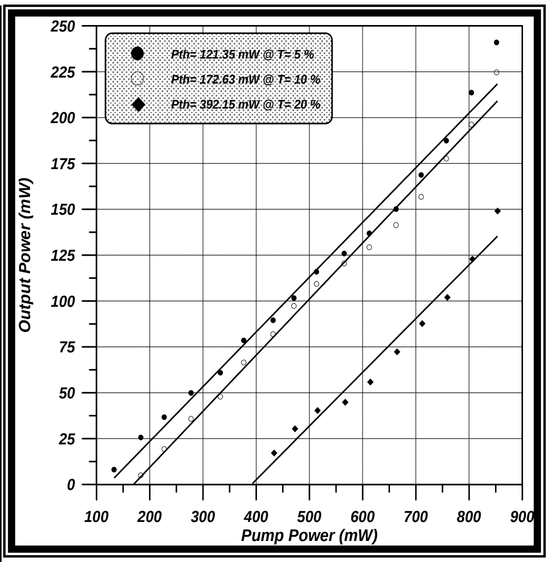

Figure .2 $Nd:YVO_4$ laser output Power versus pump power

5- Conclusion:

We have formulated a simple model for diode laser pumped $Nd:YVO_4$ laser which is based on space-dependent rate equation analysis and supported by experimental data. The main relevance of this paper lies in its comprehensive analysis of the different laser parameters.

The agreement between the calculated and the experimentally measured values of the laser parameters such as threshold pump power, pumping efficiency, slope efficiency and output mirror coupler is generally good. Such results confirmed that this laser can be used as a standard power source laser for different experiments.

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