PRAMANA — journal of physics
© Indian Academy of Sciences
Vol. 76, No. 1
January 2011
pp. 119–125

Influence of the laser-diode temperature on crystal absorption and output power in an end-pumped Nd:YVO_4 laser

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MS received 20 November 2009; revised 6 July 2010; accepted 23 July 2010

Abstract. In this work, we studied the influence of heat loaded into the laser crystal in an end-pumped solid-state Nd:YVO_4 high power laser. We have shown experimentally that the optimum value of the laser-diode temperature for the maximum pump power absorption by the Nd:YVO_4 crystal and the maximum Nd:YVO_4 laser output power are approximately similar to that of a system of the low power type, but by increasing the pump power, different values can be obtained.

Keywords. Nd:YVO_4 laser; end-pumped; diode temperature.

PACS No. 42.60.-v

1. Introduction

In designing the high power continuous-wave (cw) end-pumped solid-state lasers, one of the most important problem is the heat loaded into the active material. The inhomogeneous temperature distribution and temperature gradient generate different thermal effects such as thermal stress, thermal fracture, photoelastic, thermal lensing, and so on. For a number of reasons the optical pump process in a solid-state laser material is associated with the generation of heat, for example; quantum defect heating, heating due to quenching mechanisms, absorption by the host material in the non-useful spectrum of pumping system (in arc lamps or flashlamps), and so on. One advantage of diode-laser pumping is that the waste heat dissipated in the laser rod is greatly reduced by the high efficiency of the pumping process. Quantum-defect heating is reduced because the pump wavelength is closer to the laser emission wavelength, and heating of the host material by pump radiation located outside the absorption bands of the active ions is completely eliminated.

Nd:YVO_4 is one of the most efficient laser host crystals for diode laser-pumped solid-state lasers. Optically, this is a uniaxial crystal and a four-level laser system. Its large stimulated emission cross-section at lasing wavelength, high absorption coefficient and wide absorption bandwidth at pump wavelength, high laser-induced damage threshold, as well as good physical, optical and mechanical properties make Nd:YVO_4 an excellent crystal for high power, stable and cost-effective diode pumped solid-state lasers.

In this paper we tried to compare the results of two methods for optimizing an end-pumped Nd:YVO_4 laser output power, first by maximizing the crystal absorption and second, by maximizing the output power by changing the laser diode temperature.

2. Theory

Ideally, the emission characteristics would be independent of the diode drive. In practice, however, this is not the case. As the diode drive current is increased, the junction temperature of the diode increases. The internal heating causes a shift in the band-gap energy. This in turn shifts the emission wavelength of the diode. Therefore, as the diode drive current increases, the peak emission wavelength of the diode array can be expected to change. In addition, individual diodes may exhibit variation in the thermal resistance between the diode junction and the heat sink. This would cause differential heating between the individual diodes. Thus, as the diode drives increase, the spectral half-width of the diode array can be expected to increase. The increase in spectral half-width will have the deleterious effect of decreasing the pumping coefficient.

When a pump beam of intensity $I_{\mathrm{pump}}(\lambda, L)$ (a function of laser-diode wavelength) falls on an absorbing sample of thickness *L*, a part is absorbed in the volume of the sample. The transmitted part of the pump beam can be calculated by

$$I_{\mathrm{pump}}\,(\lambda, L) = I_{\mathrm{pump}}(\lambda)\exp(-\alpha(\lambda), L)\,,$$

where α is the absorption coefficient of the sample and is a function of absorption wavelength.

Nd:YVO_4 is a uniaxial crystal, and absorption coefficients differ for polarizations oriented perpendicular (s) and parallel (π) to the C-axis [1,2]. A strong absorption coefficient occurs along the π polarization. Kintz and Bear in 1990 [3] experimentally measured and figured variations of the absorption cross-section (σ) for a sample with 3% Nd concentration vs. wavelength, for the spectral interval 805–815 nm, for two light polarizations, parallel and perpendicular to optical C-axis (see figure 1).

3. Experiments

In our set-up we used a fibre array package (FAP$^{\mathrm{TM}}$), consisting of a laser diode bar with collection and symmetrizing optics mounted within an environmentally sealed package. The output laser beam is suitable for fibre coupling using an industry standard SMA905 connector. The device is designed to operate under continuous wave operating conditions at high, multiwatt output powers.

We carefully studied the change in the spectral half-width of our laser diode due to change in the drive currents, using a spectrometer type Jobin Yvon HR 320 which operates with a 600 grooves/mm grating, and focally placed a CCD array (3717 pixels) assembly. Figure 2 shows results of these experiments. As it is seen, wavelength distribution of the laser-diode spectrum was changed and spectrum evolved but its maximum was

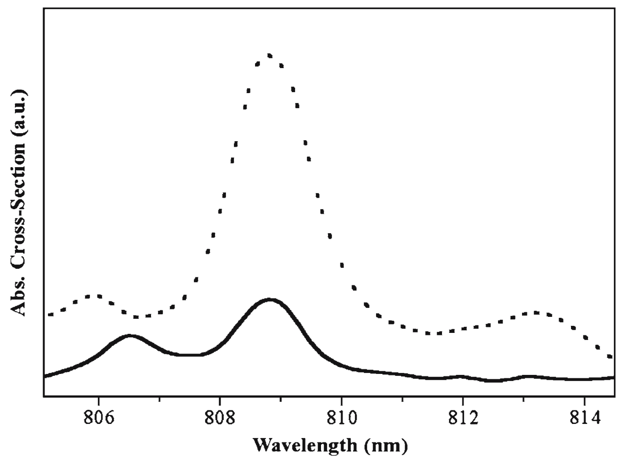

Figure 1. Absorption cross-sections of Nd:YVO$_4$ for polarization parallel (dashed line) and perpendicular (straight line) to the C-axis.

centred around 809 nm. Thus, by setting the laser-diode temperature for laser-diode power correspondent, we can get optimum crystal laser absorption, and prevent the deleterious effect caused by decreasing the pumping efficiency.

We selected a Nd:YVO$_4$ laser crystal of $3 \times 3 \times 12$ mm^3 dimension, and an Nd dopant concentration of 0.27 at.% [4]. The crystal was a-cut to obtain the high-gain π transition. The crystal was wrapped with indium foil and press fitted into a water-cooled copper housing. The water temperature was maintained at 20°C. One of the crystal end-surfaces had antireflection-coating only for 1.064 m ($R < 0.1\%$) and 808 nm ($R < 5\%$) (laser-diode wavelength), and the other had antireflection-coating only for 1.064 m ($R < 0.1\%$). Laser crystal was single end-pumped by the fibre-coupled (diameter 800 m and a numerical aperture 0.37) laser-diode. The focus pump-spot radius was measured around 450 μm.

3.1 *Maximum absorption*

In this case, we arranged a series of experiments for measuring the laser-diode intensity power absorbed passively in the crystal volume. The pump beam was focussed by means of telescope on the crystal and the transmitted light was collected by a lens (with suitable NA) focussed on a power meter.

By plotting transmitted intensity vs. LD temperature at constant LD power, we found the optimal temperature for the absorption of the crystal. This experiment was performed for different values of laser-diode pump powers and suitable temperature for different pump powers were obtained. The results of this series of experiments are shown in figure 3. We had lower temperature proportional to upper pump power.

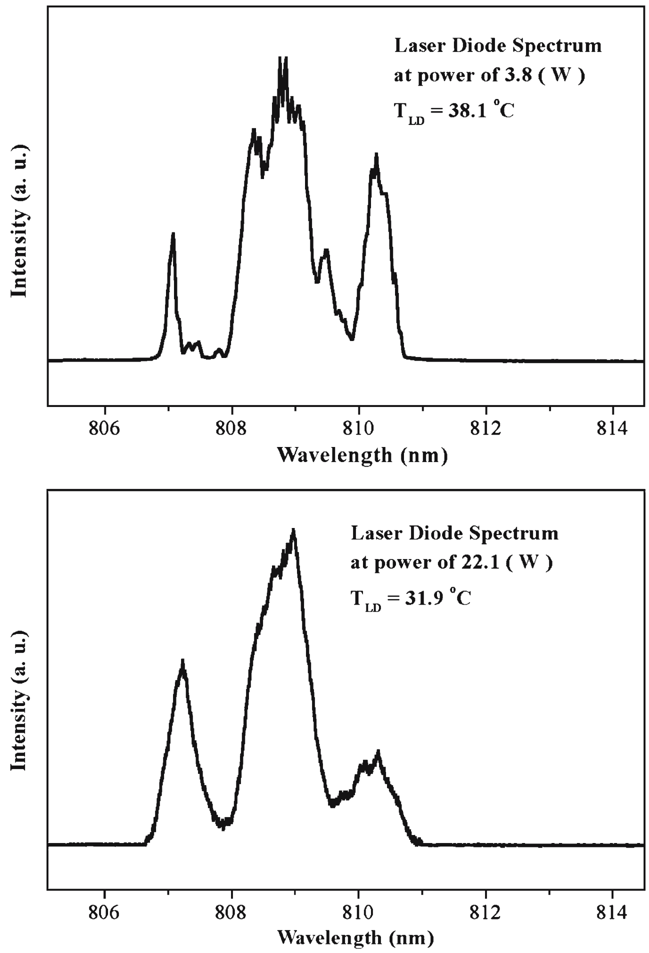

Figure 2. Laser diode spectrum evolution for different drive currents, that is centred around 809 nm at ambient temperature 25°C.

3.2 *Maximum output power*

In order to obtain a laser beam TEM_{00}-mode, we arranged a '*Z*-fold' linear standing-wave cavity by considering the thermal lensing effect with an analytical approach [5]. This cavity includes four mirrors, two extremity plane mirrors M1, M4 and two concave mirrors M2, M3 (For details, please refer [6,7].) Figure 4 schematically shows the pumping direction and cavity configuration. We needed a glass rhomb for astigmatism compensation.

Because the output mirror is flat, the laser beam size seen on it is minimum. Thus on a point outside the cavity in equal distance from a non-pumped crystal surface we have similar laser beam size.

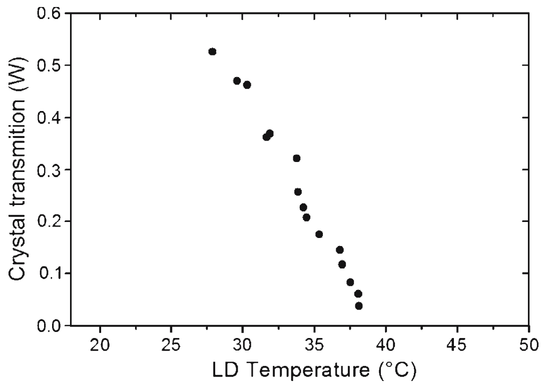

Figure 3. Experimentally, maximum Nd:YVO$_4$ crystal absorption for optimum laser–diode temperatures.

The experimental and simulation results are compared in figure 5 for laser beam waist diameters on non-pumped crystal surface due to different values of pump power, to obtain maximum output power.

We measured the optimum laser-diode temperatures having the maximum CW output power in TEM$_{00}$-mode depending on different pump power values. The results of this series of experiments are shown in figure 6.

3.3 *Comparison of the results*

Finally, the comparison of the results of two cases is shown in figure 7. It is seen that in lower pump power, they have approximately the same values, but increasing the pump power causes increasingly different values that is unexpected!

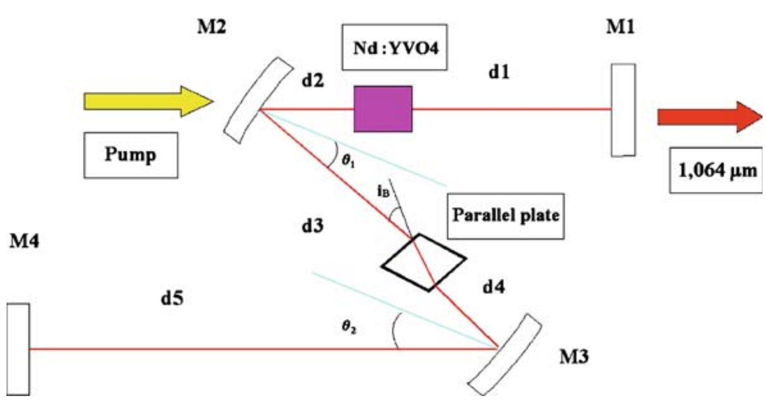

Figure 4. Schema of a *Z*-fold cavity for the Nd:YVO$_4$ laser.

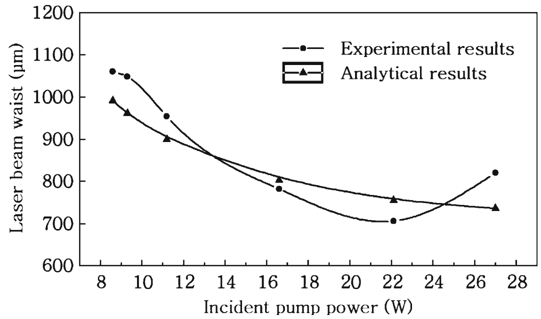

Figure 5. The TEM_{00}-mode diameter on the non-pumped crystal laser surface vs. varying incident pump powers that were obtained from different methods.

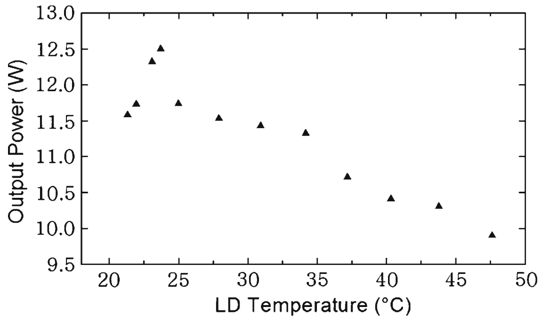

Figure 6. Maximum Nd:YVO_4 laser output power for optimum laser-diode temperatures.

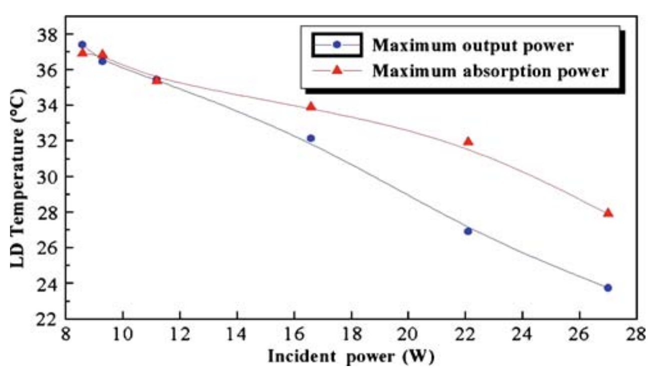

Figure 7. Comparison of optimum laser-diode temperature for Nd:YVO_4 laser in active and passive situations.

Indeed, the optimum laser-diode temperatures for maximum crystal absorption are practical only for primary setting, but for the diode-pumped laser in low power, and in high power these data are not suitable.

4. Conclusions

We have shown experimentally that optimum laser diode temperature for maximum absorption pump power and maximum Nd:YVO$_4$ laser output are approximately similar in low pump power, but increasing pump power causes more and more differences in their values. If we have experimental law of variation of optimum laser-diode temperature for having the maximum CW output power in TEM$_{00}$-mode depending on different pump power values, it is a practical data for laser set-up.

References

[1] J R O'Connor, *Appl. Phys. Lett.* **9**, 11 (1966)
[2] R A Fields, M Bibaum and C L Fincher, *Appl. Phys. Lett.* **51**, 23 (1987)
[3] G J Kintz and T Bear, *IEEE J. QE.* **26**, 9 (1990)
[4] Laser crystal guide, CASIX Inc.
[5] Y F Chen, Y P Lan and S C Wang, *Appl. Phys.* **B71**, 827 (2000)
[6] E Safari, A Kachanov and M Chenevier, In: *10th Photonics Co. Proceedings* (Kerman-Mahan, 2004) p. 14
[7] E Safari and A Kachanov, *Opt. Laser Tech.* **534**, 38 (2006)