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Efficient and high-power laser-diode single-end-pumped Nd:YVO_4 continuous wave laser at 1342 nm*

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A compact, efficient and high-power laser diode (LD) single-end-pumped Nd:YVO_4 laser with continuous-wave emission at 1342 nm is reported. With a single crystal single-end-pumped by fibre-coupled LD array, an output power of 7.36W is obtained from the laser cavity of concave-convex shape, corresponding to an optical-to-optical efficiency of 32.8%. The laser is operated in TEM_{00} mode with small rms amplitude noise of 0.3%. The influences of the Nd concentration, transmissivity of the output mirror and the cavity length on the output power have been studied experimentally.

Keywords: laser diode, single-end-pumped Nd:YVO_4 at 1342 nm, continuous wave, efficiency
PACC: 4255R, 4260D, 4260B

1. Introduction

High-power diode-pumped solid state lasers emitting around 1.3μm can find applications in several areas, including medicine, optical fibres, and production of red radiation by frequency doubling.

Nd:YVO_4 has been known as an attractive laser material because it is particularly suitable for the diode-pumped operation due to its large absorption cross section at 808 nm,[1] and because of its large stimulated emission cross section.[2,3] The stimulated emission cross section of Nd:YVO_4 at 1342 nm ($(6\pm18)\times10^{-19}$ cm^2) is of the order of that of Nd:YAG at 1064 nm (6.5×10^{-19} cm^2). Another merit is that the output beams of Nd:YVO_4 lasers are linearly polarized. These favourable properties make Nd:YVO_4 an important candidate for the realization of efficient 1342 nm sources.

There have been already some papers on diode-pumped 1342 nm Nd:YVO_4 lasers since 1993. Up to date the diode-pumped 1342 nm Nd:YVO_4 lasers have been developed greatly.[4−11]

In this paper, a compact, efficient and high-power laser diode (LD) single-end-pumped Nd:YVO_4 laser with continuous-wave emission at 1342 nm is reported. With a crystal single-end-pumped by a fibre-coupled LD array, an output power of 7.36W is obtained from the concave-convex cavity, corresponding to an optical-to-optical efficiency of 32.8%. The laser is operated in TEM_{00} mode with small rms amplitude noise of 0.3%. For the development of the lasers, we consider many parameters to search for an optimum configuration. The influences of the Nd concentration, transmissivity of the output mirror and the cavity length on the output power have been studied experimentally.

The key elements in attaining the best performances are the use of relatively long crystals with very low Nd doping and a careful design of the optical resonator.

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2. Experimental setup

A schematic diagram of the LD pumped Nd:YVO_4 laser is shown in Fig.1. The pumping setup (the fibre and the coupling system) is also sketched.

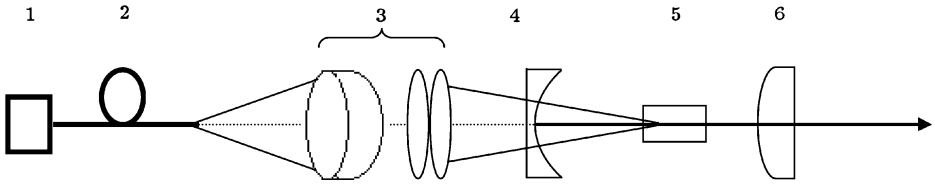


Fig.1. Experimental setup of the LD pumped Nd:YVO_4 laser. 1 pump source (diode laser), 2 fibre, 3 coupling system, 4 high reflection mirror, 5 Nd:YVO_4 crystal, 6 output coupler.

The pump source is a high brightness thermoelectrically cooled fibre-coupled LD with a centre wavelength of 808 nm from Coherent Corporation of model FAP-SYS-30. The maximum output power of the LD is 30 W. The core diameter of the optical fibre is 800μm with a numerical aperture of 0.22. The line width of the emitted radiation is comparable to that of the Nd absorption line and the central frequency can be tuned by changing the diode temperature.

A coupling system with a 40-mm focal length and 86% coupling efficiency is used to direct the pump beam onto the laser crystal.

The crystals used in the experiments are provided by Fujian Castech Crystals; they are all a-cut, have a square section of 3mm×3mm, and a length of 10mm. Each crystal is wrapped by an indium foil and tightened inside a small copper holder to insure a good thermal dissipation, and the holder is lodged into a copper housing cooled by water at an optimal temperature of 16°C. The crystal optical faces are anti-reflection coated at all the relevant wavelengths, namely 1342, 1064 and 808 nm.

The resonator shown in Fig.1 consists of only two end mirrors. The pump beam reaches the crystal after passing through the high reflection (HR) mirror, which is a plano-concave one that has a dichroic coating with a reflectivity larger than 99% at 1342 nm, lower than 30% at 1064 nm, and about 5% at 808 nm. The available output couplers (OC) have a transmissivity of 5% or 10% at 1342 nm and a reflectivity lower than 30% at 1064 nm. The OC mirrors are plano-convex mirrors, with a 100-mm radius of curvature. The dichroic coatings are necessary to prevent parasitic lasing at 1064 nm.

An optical power meter of model 8025C from Newport Corporation was used to measure the input and output power.

3. Selection of the Nd concentration of the laser crystal

In recent years, the availability of large, high-quality Nd:YVO_4 laser crystals with low Nd^{3+} doping concentrations ($<$ 0.5at.%) has stimulated renewed interest in power scaling of diode end-pumped Nd:YVO_4 lasers.[7−9,12] For low doping, the reduced absorption coefficient at the pump wavelength permits the deposited heat to be spread along the axis of the laser-crystal, reducing heat load, and consequent thermal lensing and other problems. Chen[13] has shown that the pump-power fracture limit of Nd:YVO_4 is inversely proportional to the concentration. Theoretical calculations[14−16] agree that the optimum concentration of a Nd:YVO_4 laser at 1064 nm is in the range 0.25–0.4 at.% for a pump power of the order of 30W. Experimentally, continuous wave output powers of 8 and 25W at 1342nm and 1064 nm respectively have recently been demonstrated for LD double-end-pumped Nd:YVO_4 lasers with doping levels as low as 0.3 at.%.[8,12] Considering that during laser action, the thermal loading is larger for single-end-pumped operation than that for double-end-pumped operation, and larger for operation at 1342 nm than that at 1064 nm, we used two crystals for comparison and optimization with Nd doping levels of 0.2 at.% and 0.3 at.%, respectively.

4. Design of the adjustable stable concave-convex resonator

The resonator stability and the mode spot size are crucially dependent on the thermal lens induced in the crystal by pump power dissipation. The thermal lensing effect of the laser crystal diminishes the mode

volume of the oscillating laser, brings about mode mismatch between the oscillating laser and the pumping laser, thus decreases the laser output power, its stability and the efficiency of the laser.

Therefore, the design principles of the adjustable concave-convex resonator are as follows: (1) The spot radius of the TEM_{00} oscillating laser at the position of the thermal lens should be as large as possible to obtain a large mode volume and achieve high power and efficiency. (2) The mode volume should be as insensitive as possible to the change of the thermal focal length in order that the resonator is thermal-insensitive. (3) Keep mode matching between the oscillating laser and the pumping laser so as to improve optical efficiency.

In our experiments, we have designed a concave-convex thermal-insensitive resonator structure according to the principles mentioned above and based on ABCD matrix method. For plano-convex mirror with proper curvature can adjust the radius, curvature and beam waist position of the oscillating laser, overcome the reduced efficiency induced by thermal lensing effect, and thus keep mode match between the oscillating laser and the pumping laser. In short, we use the concave-convex cavity to compensate the thermal lensing effect of Nd:YVO_4 crystal and eliminate the focusing effect of the laser rod effectively.

5. Experimental results and discussion

Figure 2 shows the output power versus pump power measured with laser crystals of 0.2 at.% and 0.3 at.% Nd concentrations. Though the crystal with Nd doping level of 0.3 at.% has the lower pump threshold of about 1.3W, the crystal with Nd doping level of 0.2 at.% shows the better performance than the former. This result corroborates the choice of designing a cavity based on long crystals with very low Nd doping level, and points out that the optimal concentration may be even somewhat lower (0.12%–0.15%) than the value estimated.

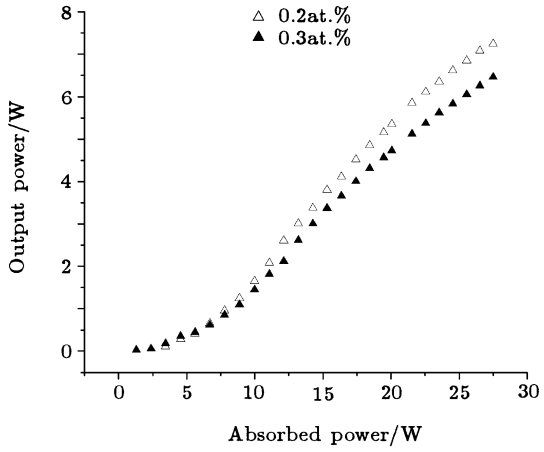


Fig.2. Output power versus pump power measured with laser crystals of 0.2 at.% and 0.3 at.% Nd concentrations.

Another important parameter affecting the laser performance is the transmissivity of the output coupler. There exists an optimum transmissivity. In the experiments, the available output couplers have transmissivities of 5% and 10%, respectively. With other experimental conditions being the same, Fig.3 shows the output power as a function of the absorbed pump power. A better result has been obtained using output coupler with transmissivity of 5%.

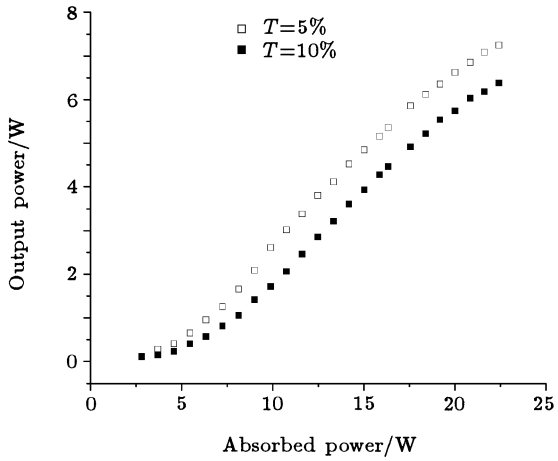


Fig.3. Output power versus pump power with T=5% and T=10% output couplers.

With the curvature of the input and output mirrors fixed, by adjusting the position of the input mirror, we can change the size of the focused pump spot and the radius of the beam waist, thus carry out the mode match adjustment under different pump powers and improve the output power and efficiency of the laser. Typical values of distance between the HR mirror and the nearer crystal face are between 5 and 35mm in our experiment, while the distance between the HR mirror and the output coupler (the cavity length) is around 80mm according to our calculation. By adjusting the position of the HR mirror, several cavity lengths of the resonator were tested in order to optimize the output power. With other experimental conditions the same, Fig.4 shows the output power as a function of absorbed pump power with the cavity

length of 84, 79, 75 and 70mm, respectively. The best result is obtained for cavity length of 79mm.

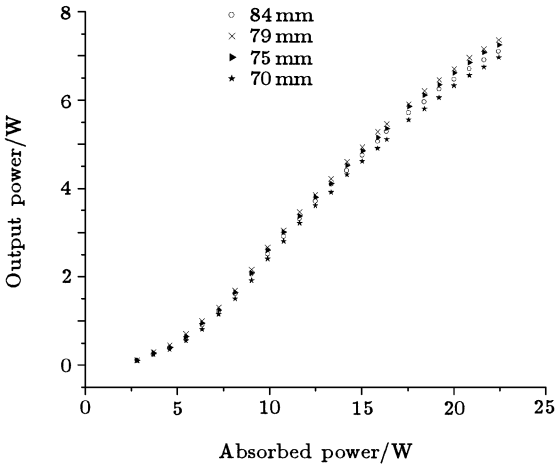


Fig.4. Output power versus pump power for different cavity length.

Diode pumping and careful cavity design result in a good stability of the output power, which is an urgent request in most applications. Figure 5 shows the stability of the output power of the 1342 nm laser with the best parameters selected above. We have measured the intensity fluctuations for the laser delivering about 6W and found that the rms amplitude noise is less than 0.3% for a total recording time of 1h.

In short, we have obtained the best result with laser crystal of 0.2 at.% Nd concentration, output coupler of T=5% transmissivity and cavity length of 79mm. An output power of 7.36W is achieved with the above mentioned parameters, corresponding to an optical-to-optical efficiency of 32.8%. The laser operates in TEM_{00} mode by observation.

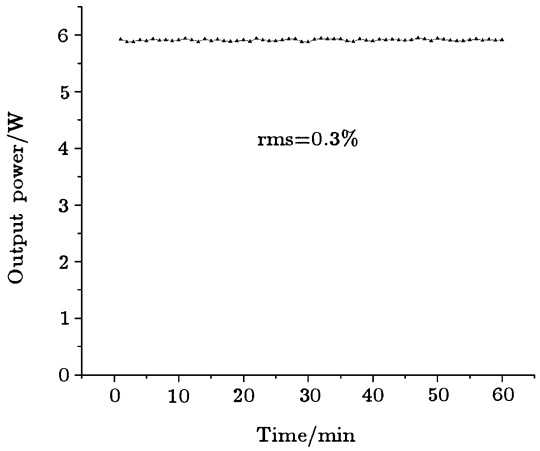


Fig.5. Stability of the output power of 1342 nm laser.

6. Summary

In this paper, by using relatively long crystals with very low Nd doping and a careful design of the optical resonator, a compact, efficient and high-power LD single-end-pumped Nd:YVO_4 laser with continuous-wave emission at 1342 nm is obtained. For the development of the lasers, we have considered many parameters in order to search for an optimum configuration. The influences of the Nd concentration, transmissivity of the output mirror and the cavity length have been experimentally studied. With a crystal single-end-pumped by fibre-coupled diode laser, an output power of 7.36W is achieved from the concave-convex resonator, corresponding to an optical-to-optical efficiency of 32.8%. The laser operates in TEM_{00} mode with small rms amplitude noise of 0.3%.

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