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A new wavelength laser at 1370 nm generated by Nd:YLF crystal

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ABSTRACT

We demonstrate a diode-end-pumped continuous laser operating a new wavelength at 1370 nm in Nd: YLF. It is a coherent radiation exactly lies in the absorption band of the C_{70} and water vapor. A maximum output power up to 4 W is achieved at an incident pump power of 14.6 W, with a slope efficiency of 35.5%, and the optical-optical efficiency of 27.4%. The laser output power instability in half an hour is less than 3%. Calculated by experimental threshold data, the stimulated emission cross section of 1370 nm transition in Nd: YLF crystal is determined to be 0.4437×10^{-20} cm^2.

1. Introduction

1370 nm coherent radiation lies exactly in the absorption band of the C_{70} [1] and water vapor [2]. It can be used not only as a new light source for detecting C_{70} in the research of astrophysics [1,3], but also providing an validate light source for detecting the water vapor from an aircraft platform or on the NASA satellite (NASA/USDA-FS FireMission). Compact and good beam quality laser operation at the wavelength of 1370 nm is required in all of these above applications. Compared with other lasers, diode-end-pumped crystalline laser possesses the advantages of good beam quality, high laser efficiency and compact configuration. However, as far as we know, there were no confirmed previous reports of lasing action at 1370 nm from any crystalline lasers before.

Neodymium-doped Yttrium Lithium Fluoride (Nd: YLF) laser crystal shows significant advantage with weak thermal lens effect [4,5], combining with its natural birefringence, which could possible provides a near TEM_{00} mode laser radiation around near-infrared region. Seen from experimental spectrum data in Fig. 1, fluorescence emission spectrum of Nd: YLF crystal from 1300 nm to 1400 nm was measured by an Edinburgh Instruments Spectro-fluore-meter, Model FLS920. An 1370 nm line was found in the transition of $^4F_{3/2} \rightarrow {}^4I_{13,/2}$ from Nd: YLF crystal.

The 1370 nm laser line is a weaker transition when comparing to 1313 nm and 1321 nm lines in the same transition $^4F_{3/2}$ - $^4I_{13/2}$. Furthermore, it was only 57 nm apart from 1313 nm line, which making it hard to realize CW operation at 1370 nm in the Nd: YLF crystal. There are many reports on 1313 nm and 1321 nm lasers already [6,7], but no research on this 1370 nm laser. In this paper, an a-cut Nd: YLF was used to produce this new wavelength laser by precisely designing coating films of the resonant cavity.

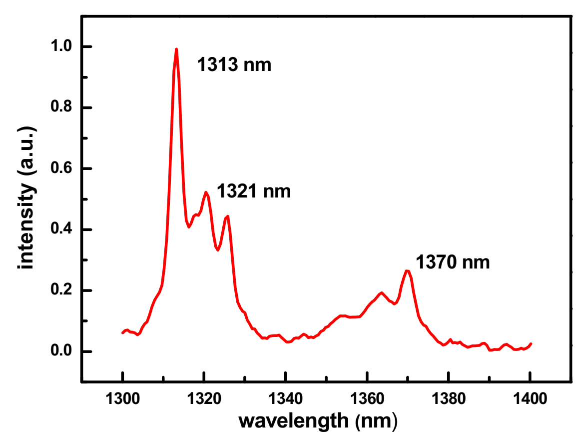

Fig. 1. Fluorescence spectrum of Nd:YLF crystal.

2. Experimental setup and results

An experiment was designed to demonstrate this. 808 nm fiber-coupled laser diode pump source with a core diameter of 200 μm and a numerical aperture of 0.22 was used. The pump beam was magnified by 1:2 proportion into the Nd: YLF crystal using a pair of plane-convex focusing lenses with the transmission at 808 nm of about 96%. The a-cut Nd: YLF crystal (1% Nd^{3+}, 3 mm × 3 mm × 10 mm) was mounted in a copper heat sink with a thermoelectric cooler module at a constant temperature of 18 °C.

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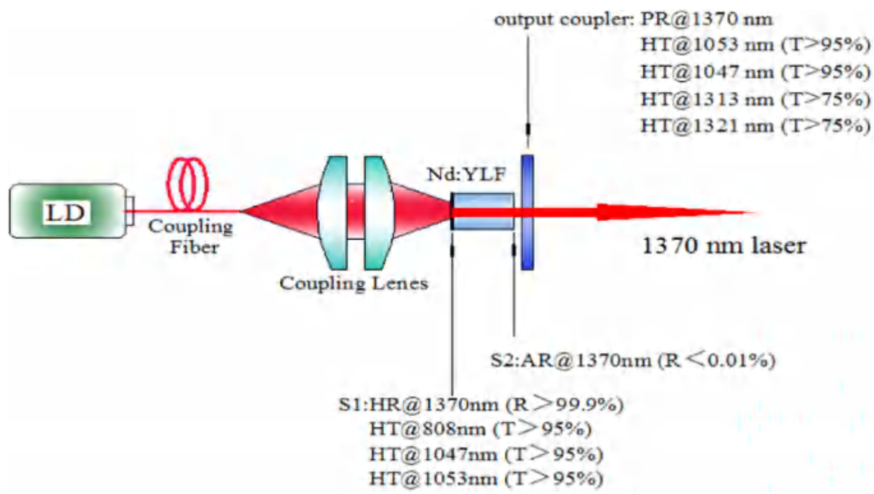

Fig. 2. Schematic of CW 1370 nm Nd:YLF laser setup.

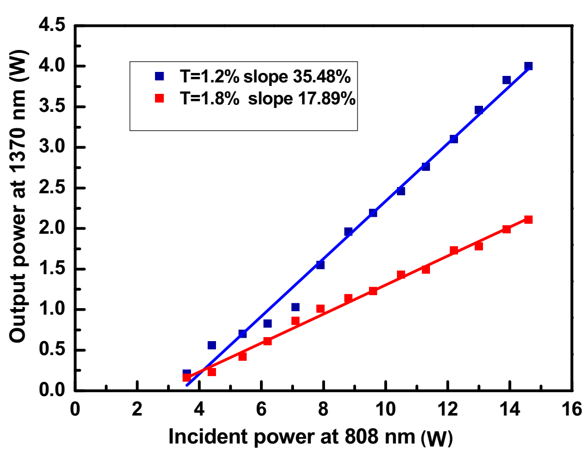

Fig. 3. CW 1370 nm laser output power.

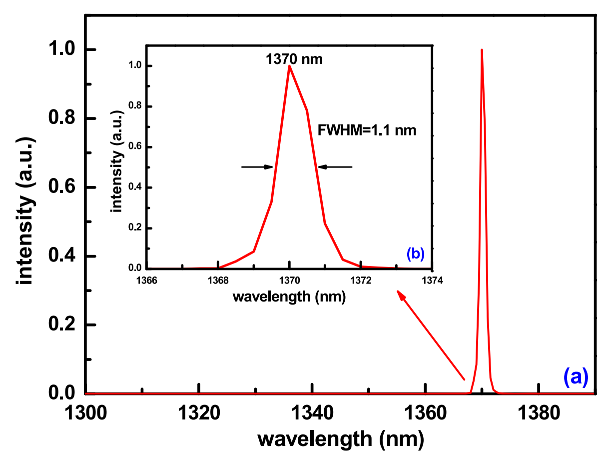

Fig. 4. (a) Spectrum of 1370 nm laser emission and (b) the FWHM of 1370 nm laser emission.

In order to get an efficient conversion in an compact configuration, the Nd: YLF laser oscillation cavity consisted a multi-chromatic coated Nd: YLF crystal and a separate plane output coupler, shown in Fig. 2.

The pumping facet of Nd: YLF crystal (S1) was directly coated with dielectric film of high-transmission (HT@808 nm& 1047 nm&1053 nm, T > 95%) and high-reflection dielectric film (HR@1370 nm, R > 99.9%), which were used to suppressed the oscillation of the 1047 nm and 1053 nm line. The other facet of the Nd: YLF crystal (S2) was coated with an anti-reflection dielectric film (AR@1370 nm, R < 0.1%). The output coupler, coated with partial-transmission dielectric film (PT@1370 nm, T = 1.2%& T = 1.8%) and high-transmission dielectric film (HT@1047 nm& 1053 nm, T > 95%; HT@1313 nm&1321 nm, T > 75%), was special designed for suppressing laser oscillation at 1313 nm and 1321 nm. The resonator, with a total length of 1.2 cm, was designed for optimizing the generation of 1370 nm laser radiation.

Based on above-mentioned theoretical analysis, we successfully demonstrated a CW diode-end-pumped Nd: YLF laser operating at 1370 nm. Fig. 3 shows CW output power obtained with two different output coupler transmissivity at 1370 nm as a function of diode pump power incident on the Nd: YLF crystal. Under a pump incident power of 14.6 W, the maximum CW 1370 nm laser output power of 4 W was generated (output coupler T = 1.2%), corresponding to an overall optical to optical conversion efficiency of 27.4%, and the slope efficiency of 35.5%. The laser output power instability is smaller than 3% in half an hour. To the best of our knowledge, this is the first demonstration of a diode-pumped Nd^{3+} doped crystalline laser at 1370 nm transition.

The spectrum of 1370 nm laser emission was measured by a Zolix Monochromator spectrograph (model Omni- λ500, 0.07 nm solution), which was depicted in Fig. 4. The spectrum of 1370 nm center at 1370 nm, with spectral width (Full Width at Half Maximum) of 1.1 nm, had a top-spike intensity distribution. It was shown that there is only one wavelength at 1370 nm obtained in the spectra range from 1300 nm to 1400 nm in half an hour. The polarization direction of 1370 nm laser was measured to be σ polarization.

3. Analysis and calculation

Using threshold data measured by laser experiment, stimulated-emission cross-section σ of this 1370 nm laser was calculated by Tucker's method [8]. The CW laser operation at threshold is described by

$$-\ln(R_1R_2) = \frac{2Lf_B\sigma\tau}{h\nu_pV}P_T - 2L\Delta \tag{1}$$

Where R_1 and R_2 represent the effective mirror reflectivities, L is the length of the laser crystal, f_B is fluorescence branching ratio. σ is the peak stimulated-emission cross-section of the laser transition. τ is fluorescence lifetime. $h\nu_p$ is the pump photon energy. V is

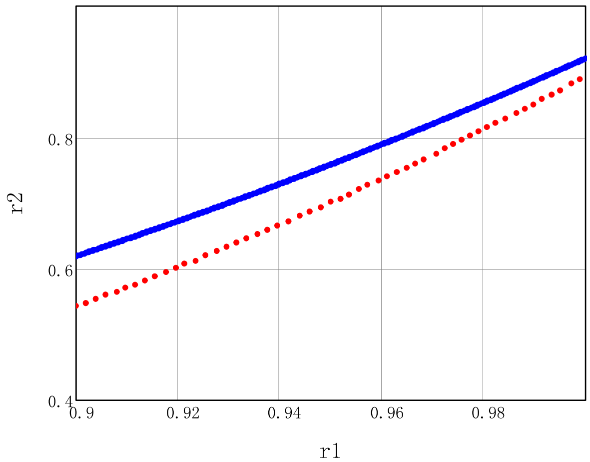

Fig. 5. The range of r1 vs r2 according to operating condition of SDWL oscillation in Nd:YLF.

the volume pumped. P_T is the laser threshold power. Δ is the total internal losses coefficient. Plotting the laser threshold power according to Eq. (1), the stimulated-emission cross-section is determined from the slope M_p by

$$M_p = \frac{d[-\ln(R_1R_2)]}{dP_T} = \frac{2Lf_B\tau\sigma}{h\nu_pV} \tag{2}$$

If the cross section of a particular crystal is known, the unknown stimulated-emission cross-section can be obtained by

$$\frac{\sigma_x}{\sigma_{std}} = \frac{(M_P)_x}{(M_P)_{std}} \tag{3}$$

We chose the 1313 nm of the Nd: YLF crystal as the standard stimulated-emission cross-section (STD)[9]. From the experimental data, the $(M_p)_{1370}$ and $(M_p)_{1313}$ were calculated to be 0.00508 and 0.0229, respectively. Thus the stimulated-emission cross-section of 1370 nm is determined to be 0.4437×10^{-20} cm^2, which shows a good agreement with the spectrum experimental data from Fornasiero[9].

The operating condition of continuous wave simultaneous dual wavelength laser (SDWL) was studied based on our previous research [10–12].

$$P_{th}^{(1)}\frac{2}{1+\frac{P_{in}}{P_{th}^{(1)}}} \le P_{th}^{(2)} \le P_{th}^{(1)}\frac{\sqrt{1+8\frac{P_{in}}{P_{th}^{(1)}}}+1}{4} \tag{4}$$

$$\ln\frac{1}{r_2} + 2\alpha L = \frac{\sigma_2\lambda_2}{\sigma_1\lambda_1}\left(\ln\frac{1}{r_1} + 2\alpha L\right) \tag{5}$$

In which $r_1$and r_2 are reflectivities of output coupler mirror at 1370 nm and 1313 nm respectively. λ_1 is 1370 nm. λ_2 is 1313 nm. σ_1 is the stimulated emission cross section of 1370 nm (0.4437×10^{-20} cm^2 from the result of this paper) and σ_1 for 1313 nm (2.0×10^{-20} cm^2) [9]. α is the loss for single pass (0.00151 per mm)[13]. L is the length of the laser crystal (10 mm). As seen from Fig. 5, assumed that $P_{in}=1.3\ P_{th}^{(1)}$, if the reflectivity of the output coupler mirror is controlled under the zone of the curve 1 (red), the CW laser operating on the single wavelength of the 1370 nm could be obtained by suppressing the stronger line 1313 nm in Nd: YLF crystal. In addition, as diode-end-pumped provides strong power density, it has the potential to realize CW 1370 nm weak transitions operation in Nd: YLF laser crystal.

4. Conclusion

In summary, a diode-end-pumped high efficient CW 1370 nm Nd: YLF laser has been demonstrated successfully. The output power increases almost linearly with the pump power until 14.6 W. The maximum output power of the CW 1370 nm is up to 4 W with the incident pump power of 14.6 W at 808 nm, with the optical to optical conversion efficiencies of 27.4% and the slope efficiency of 35.5%. The laser output power instability is less than 3% in half an hour. We calculated the stimulated-emission cross-section of the 1370 nm line in the Nd: YLF crystal, which was 0.4437×10^{-20} cm^2.

Acknowledgements

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