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Efficient 1047 nm CW laser emission of Nd:YLF under direct pumping into the emitting level

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ABSTRACT

We demonstrate a 1047 nm Nd:$LiYF_4$ (Nd:YLF) laser by directly pumping into the upper lasing level with a tunable Ti:Sapphire laser. The results obtained for direct upper laser level pumping at 863, 872 and 880 nm of Nd:YLF were compared with traditional 806 nm pump band excitation. Highly efficient 1047 nm continuous-wave (CW) laser emission under direct pumping at 880 nm in an 8 mm thick, 1.0 at.% Nd:YLF crystal is obtained. The slope efficiency is improved from 55.6% for traditional pumping at 806 nm to 76.3% for direct pumping at 880 nm.

1. Introduction

The energy difference between the pumping and lasing photons, the non-unity coupling between the pump band and the upper lasing level and some parasitic effects such as concentration quenching, upconversion and dark sites [1,2] always generate heat in the gain material in the excitation and lasing process in solid-state lasers. Heat generation can affect laser beam quality and thermal stability of the laser cavity. In addition, it limits the maximum emission power and the slope efficiency. The heat generated during the pumping process, therefore, is a severe limitation to the construction of high efficiency and high power solid-state lasers. Recently, a direct pumping scheme, which was to pump Nd^{3+} ions directly into the $^4F_{3/2}$ upper lasing level, has attracted much attention for its advantages in increasing the slope efficiency and decreasing the heat generation. The idea of direct pumping was first demonstrated in 1968 by Ross [3]. In the last decade, more efficient Nd^{3+} lasers have been demonstrated. In 2000, laser action was achieved in a Nd:YAG laser directly pumped by a Ti:Sapphire laser at 885 nm; compared with traditional pumping at 808 nm, the slope efficiency was increased by 12% while it was suggested that heat generation was reduced by 40% [4]. In 2001, an efficient 885 nm diode-pumped Nd:YAG laser with slope efficiency of 63% was obtained [5]. In 2002, Lupei et al. reported slope efficiencies with respect to the absorbed pump power of 67% for Nd:YAG under 885 nm diode-laser pumping [6] and of 70% for Nd:YVO_4 under Ti:Sapphire laser pumping at 879 nm [7]. In 2003, Sato et al. reported a direct-pumped Nd:YVO_4 laser with 80% and 75% slope efficiencies with respect to the absorbed pump power under continuous-wave Ti:Sapphire laser and laser diode pumping at 880 nm, respectively [8]. A comparison of heat generation and laser performance of Nd:YAG oscillators pumped by Ti:Sapphire laser at 802 and 884.5 nm was reported in 2004 [9], the corresponding slope efficiencies being 52% and 57%. Moreover, the heat generated during lasing was found to be 27% lower with 884.5 nm pumping as compared with 802 nm pumping. In 2006, Pavel et al. reported an end-pumped Nd:YAG laser at 1064 nm with 61% slope efficiency with respect to the absorbed pump power under diode-laser pumping at 885 nm [10]. Recently, Ding et al. reported a direct-pumped Nd:YVO_4 laser with 75% slope efficiency with respect to the absorbed pump power under all-solid-state Q-switched Ti:Sapphire laser pumping at 880 nm [11]. Pati and Rines reported a direct-pumped Nd:YLF laser at 1047 nm with 60% slope efficiency under 863 nm diode-laser pumping [12]. Schulz et al. reported an end-pumped Nd:YLF laser at 1053 nm with 63% slope efficiency with respect to the absorbed pump power under diode-laser pumping at 880 nm [13].

In this work we report, to the best of our knowledge, the laser emission in Nd:YLF at the 1047 nm $^4F_{3/2}$ to $^4I_{11/2}$ transition under direct pumping into the $^4F_{3/2}$ upper level. The slope efficiency increases from 55.6% pumping by the traditional diode at 806 nm to 76.3% by the direct pumping at 880 nm.

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2. Laser experiment

The schematic of the traditional 806 nm band pumping together with the direct pumping to upper lasing level of the Nd^{3+} ion is shown in Fig. 1. For Nd:YLF crystal the most intense transition in the room temperature $^4I_{9/2} \rightarrow {}^4F_{3/2}$ absorption spectrum (π-polarization) is at 872 nm (Fig. 2). The peak absorption coefficient at this transition, 1.6 cm^{-1} is more than half of the $^4I_{9/2} \rightarrow {}^4F_{5/2}$ pump transition at 806 nm. The use of 880 nm instead of the 806 nm pumping leads to an increase of the quantum defect ratio η_{qd} from 0.77 to 0.84 in case of the 1047 nm $^4F_{3/2} \rightarrow {}^4I_{11/2}$ emission. This increase contributes to an enhancement of laser emission parameters, reducing the threshold by about 8.4% and increasing the slope efficiency by almost 9.2% compared with the pump at 806 nm. Moreover, it induces a reduction of the fractional thermal loading during laser emission by about 30% (from 0.23 for the pump at 806 nm to 0.16 for the pump at 880 nm), enabling a corresponding increase of the maximum extractable output power.

The experimental setup of the 1047 nm Nd:YLF laser is shown schematically in Fig. 3. A CW Ti:Sapphire laser with tunable range from 700 to 950 nm was used as the pump source. The maximum output power is 2.43 W at 806 nm, 1.46 W at 863 nm, 2.03 W at 872 nm and 2.21 W at 880 nm, respectively, with full width at half maximum of ∼2 nm.

In our experiment, F was a focus lens with the focal length of 120 mm, which was used to enhance the density of pump power and obtain better volume matching between the pump and oscillating beam. The pump beam was focused into the Nd:YLF crystal with a waist spot radius of around 100 μm. The value of the laser-to-pump beam overlap efficiency is 0.9. In experiment, a plano-concave cavity was carefully designed. The plane-reflector mirror M^1 was high reflectivity ($R > 99\%$) coated at the lasing wavelength of 1047 nm and high transmission ($T > 99\%$) coated at the pump wavelengths. A plano-concave mirror M^2 with a curvature-radius of 200 mm was employed, with a transmission of 10% at 1047 nm. The Brewster plate was used to have stable single-line operation at 1047 nm by adding additional losses for the σ-polarization. A conventional a-cut Nd:YLF crystal has dimensions of 3 mm × 3 mm × 8 mm and a 1.0 at.% doping. The Nd:YLF crystal, both surfaces were antireflection (AR) coated at 1047 nm and high transmission ($T > 99\%$) coated at 806, 863, 872 and 880 nm, was wrapped in indium foil and clamped in a copper holder through which water circulated at 15 °C.

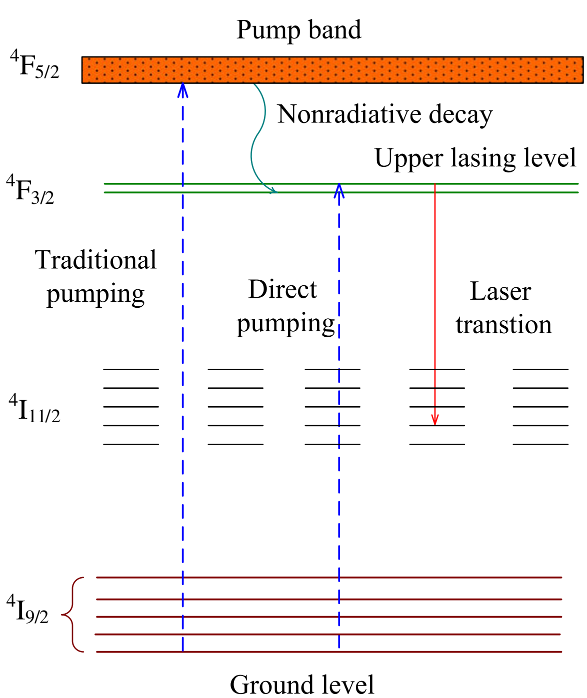

Fig. 1. Transition involved in the traditional band pumping and the direct pumping together with emission at 1047 nm Nd:YLF laser.

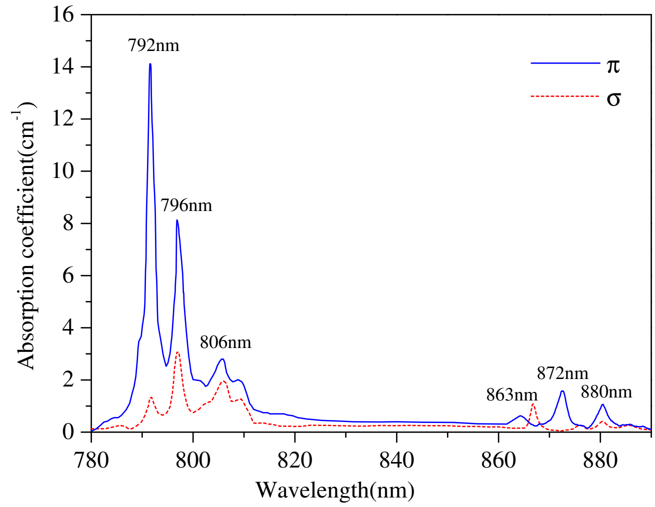

Fig. 2. Absorption spectrum of Nd:YLF (doping of 1.0 at.%) at room temperature.

3. Results and discussion

The 1047 nm laser was operating when the pump laser was tuned at 806, 863, 872 and 880 nm, respectively. The dependence of the output power on absorbed pump power is presented in Fig. 4. The slope efficiencies with respect to the absorbed pump power are 55.6%, 65.1%, 71.2% and 76.3%, respectively, and the

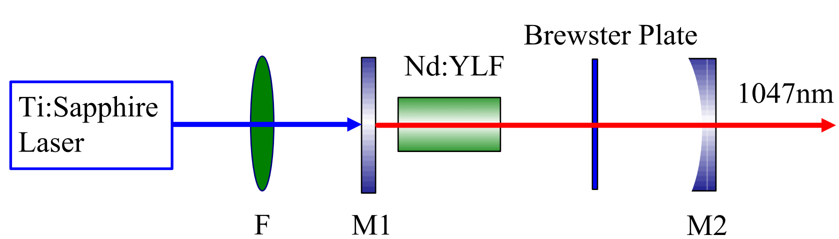

Fig. 3. Schematic diagram of the 1047 nm Nd:YLF laser. The distances between F and mirror M^1, M^1 and mirror M^2, were 110, and 56 mm, respectively.

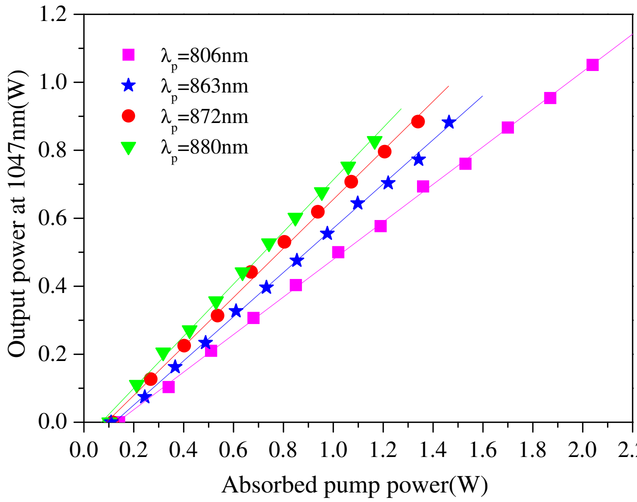

Fig. 4. Output power versus absorbed pump power for Nd:YLF with different pump wavelengths.

corresponding pump threshold powers are 141, 114, 109 and 102 mW, respectively. Under 880 nm pumping, the beam quality factor M^2 is 1.2 measured by the knife-edge technique.

The experimental results shown above demonstrate that the thermally boosted pumping at 880 nm contributes significantly to increasing slope efficiency and reducing the threshold in solid-state lasers. Due to the higher quantum efficiency and the lower heat generation under thermally boosted pumping at 880 nm, an all-solid-state Nd:YLF laser operating at 1047 nm with high efficiency and high beam quality can be achieved by thermally boosted pumping.

4. Conclusion

In conclusion, laser action at 1047 nm in a Nd:YLF system has been compared for pumping at two different wavelengths: the traditional band pumping at 806 nm and direct pumping at 880 nm. As was expected, the direct pumping scheme gives rise to a higher slope efficiency (76.3% versus 55.6%), improved transverse mode quality and excellent thermal stability. Furthermore, this will allow realization of other efficient Nd:YLF laser sources that generate the transition around 1313 or 1321 nm.

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References

[1] T.Y. Fan, IEEE J. Quant. Electron. 29 (1993) 1457.
[2] D.C. Brown, IEEE J. Quant. Electron. 34 (1998) 560.
[3] M. Ross, Proc. IEEE 65 (1968) 196.
[4] R. Lavi, S. Jackel, Appl. Opt. 39 (2000) 3093.
[5] R. Lavi, S. Jackel, A. Tal, E. Lebiush, Y. Tzuk, S. Goldring, Opt. Commun. 195 (2001) 427.
[6] V. Lupei, N. Pavel, T. Taira, Appl. Phys. Lett. 80 (2002) 4309.
[7] V. Lupei, N. Pavel, T. Taira, Opt. Commun. 201 (2002) 431.
[8] Y. Sato, T. Taira, N. Pavel, V. Lupei, Appl. Phys. Lett. 82 (2003) 844.
[9] S. Goldring, R. Lavi, A. Tal, E. Lebiush, Y. Tzuk, S. Jackel, IEEE J. Quant. Electron. 40 (2004) 384.
[10] N. Pavel, V. Lupei, J. Saikawa, T. Taira, H. Kan, Appl. Phys. B 82 (2006) 599.
[11] X. Ding, R. Wang, H. Zhang, X.Y. Yu, W.Q. Wen, P. Wang, J.Q. Yao, Opt. Commun. 282 (2009) 981.
[12] B. Pati, G.A. Rines, Advanced Solid-State Photonics (ASSP) 2009 Paper: WB10, OSA Technical Digest Series (CD).
[13] B. Schulz, M. Frede, D. Kracht, Advanced Solid-State Photonics (ASSP) 2009 Paper: WB15, OSA Technical Digest Series (CD).