

Diode-pumped Continuous-wave Nd:LuVO₄ Laser Emitting at 1086 nm in σ Polarization

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Abstract

A diode-pumped Nd:LuVO₄ laser emitted at 1086 nm in σ polarization has been demonstrated. A power of 2.37 W at 1086 nm has been achieved in continuous-wave (cw) operation with a fiber-coupled laser diode emitting 18.2 W at 809 nm. Moreover, intracavity second-harmonic generation in cw mode has also been demonstrated with a power of 528 mW at 543 nm by using a LiB₃O₅ (LBO) nonlinear crystal.

Keywords

Yellow-green Light; Nd:LuVO₄; Intracavity Doubling; Diode-pumped Laser

Introduction

Coherent cw light sources have extensive applications in high density optical storage, full-color display, medicine, Raman spectroscopy and underwater communication, and so on, because of their compactness, high efficiency, and stability. Nd-doped vanadate crystals are characterized by their high absorption and emission cross sections. Neodymium-doped vanadate crystals are characterized by their high absorption and emission cross sections. A well-known representative is Nd:YVO₄, which has been widely used both in research and commercial devices. Another vanadate crystal, Nd:GdVO₄, which was confirmed to be superior to Nd:YVO₄ in thermal properties, was also investigated extensively. Recently another member from the vanadate family, Nd:LuVO₄, has attracted much attention due to its larger absorption and emission cross sections compared to Nd:YVO₄ and Nd:GdVO₄. Moreover, Nd:LuVO₄ crystal has a high damage threshold, and it is easy to process. The research on Nd:LuVO₄ has been mainly focused on output wavelengths of 1066 nm, 1343 nm and 916 nm. However, through the analysis of a spectroscopic study it has been demonstrated that there are six or seven emission bands on the F₄^{3/2}–I₄^{11/2} transition of Nd:LuVO₄ crystal. The fluorescence spectrum at room temperature shows that one of the Stark components has a central emission wavelength

at 1086 nm in σ polarization and 1089 nm in π polarization, respectively (see Fig.1). It is worth noting that emission lines also occur near 1086 and 1089 nm with cross sections (about 20×10⁻²⁰cm²) that are comparable to those found in Nd:YAG at 1064 nm (28×10⁻²⁰cm²), a fact that might be interesting for some applications. Emission lines at 1084 and 1086 nm have already been carried out with Nd-doped YVO₄ crystal pumped by diode laser. In 2010, Y.F. Lü et al. reported a Nd:LuVO₄ laser with π polarization at 1089 nm. To the best of our knowledge, the Nd:LuVO₄ laser with σ polarization at 1086 nm has not been studied. Our purpose in this paper is to investigate laser oscillation at 1086 nm in Nd:LuVO₄ under diode pumping as well intracavity SHG is examined to reach the second harmonic radiation at 543 nm.

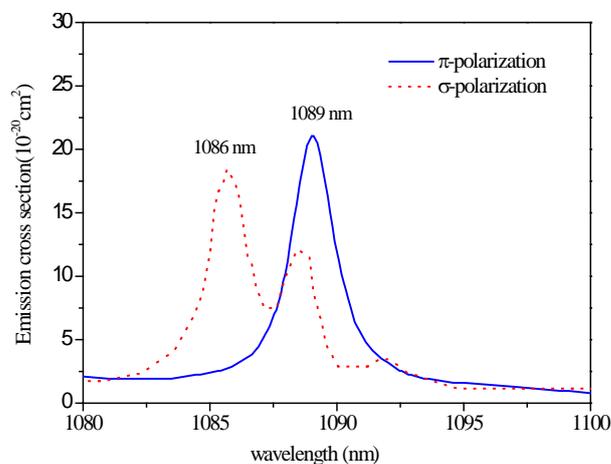


FIG. 1. FLUORESCENCE EMISSION SPECTRA NEAR 1080 AND 1100 NM IN THE ND:LUVO₄ CRYSTAL AT ROOM TEMPERATURE

Experimental Setup

The experimental setup of the fundamental 1086 nm laser used is described in Fig.2 (a). The pump source is a 20 W fiber-coupled diode laser with a core diameter of 400 μ m and a numerical aperture of 0.22 for cw pumping. Its emission central wavelength is 809 nm at room temperature and can be tuned by changing the

temperature of the heat sink to match the best absorption of the laser crystal. The spectral width (FWHM) of the pump source is about 1.6 nm. The coupling optics consists of two identical plano-convex lenses with focal lengths of 15 mm used to reimage the pump beam into the laser crystal at a ratio of 1:1. The coupling efficiency is 95%. A conventional a-cut Nd:LuVO₄ crystal with the dimension of 3×3×5 mm³ and doping concentration of 0.4 at.% was used in the experiment. Both surfaces of the Nd:LuVO₄ were highly transparent (HT) coated at 1086 and 809 nm crystal was wrapped in indium foil and clamped in a copper holder while the water temperature was kept at 15°C. The first mirror (M₁) of the cavity is HT at the pump wavelength and highly reflective (HR) at 1086 nm while the second mirror (M₂) is HR at 1086 nm. Finally, the third mirror (M₃) is an output coupler, which was coated with a transmission of 4.7% at 1086 nm, and HT at 1.06 and 1.34 μm to suppress the strong parasitical oscillation at these transitions. Brewster plane (BP) was used to have stable single-line operation at 1086 nm by adding additional losses for the π-polarization.

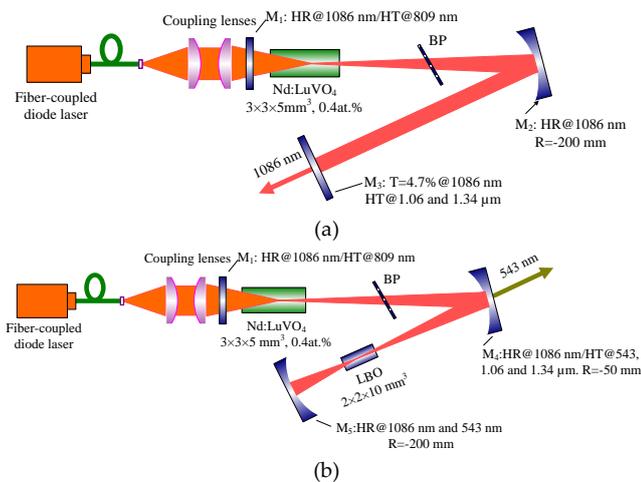


FIG.2. SCHEMATIC DIAGRAMS OF THE EXPERIMENTAL SETUP. (A) IS FOR FUNDAMENTAL 1086 NM LASER. THE DISTANCES OF M₁- M₂ AND M₂-M₃ ARE 40 AND 38 MM, RESPECTIVELY. (B) IS FOR THE FREQUENCY DOUBLED 543 NM LASER. THE DISTANCES OF M₁-M₄ AND M₄-M₅ ARE 64 AND 30 MM, RESPECTIVELY.

Results and Discussion

The laser performance is presented in Fig.3. The laser threshold was 3.6 W of incident pump power, and the maximum cw output power was 2.37 W, corresponding to a slope efficiency of 16.2% with respect to the incident pump power. We used other two -200mm radius-of-curvature output couplers, with transmissions of 3.4% and 8.5% at 1086 nm, and the

laser yielded maximum outputs of 1.32 W and 1.47 W for 18.2W of incident pump power at 809 nm, corresponding to the slope efficiency and the threshold were 7.8%, 11.3% and 1.2 W, 5.2 W, respectively. As the best performance was obtained at 1086 nm, SHG at this wavelength was tried. The cavity was modified to reduce the cavity losses and to add a second waist. The M₂ was replaced by a concave mirror (M₄) with HR at 1086 nm and HT at 543 nm, 1.06 μm and 1.34 μm, and a concave mirror (M₅) with HR at 1086 and 543 nm replaced the output coupler (M₃). Schematic for the intracavity frequency-doubled 543 nm laser is shown in Fig. 2 (b). The LBO crystal cut for type-I critical phase matching in the principal plane XY ($\theta=90^\circ$, $\phi=9.9^\circ$ with $deff=0.834$ pm/V) was chosen as the nonlinear crystal due to its high anti-damage threshold (18 GW/cm²) and much smaller walk-off angle (about 5.94 mrad). The size of the LBO crystal is 2×2×10 mm³ and both end facets of the LBO crystal are HT coated at 1086 and 543 nm to reduce the reflection losses in the cavity.

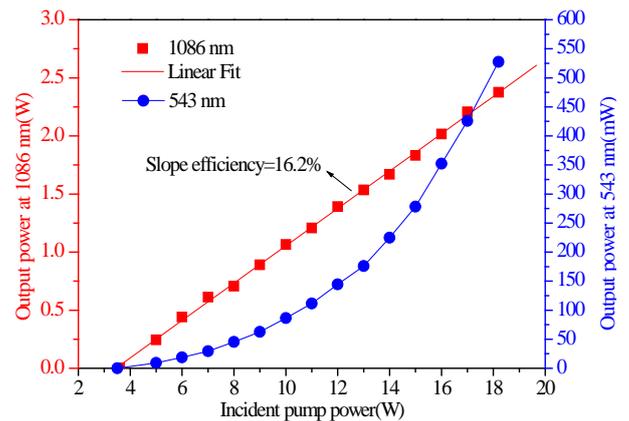


FIG. 3. OUTPUT POWERS AT 1086 NM AND 543 NM VERSUS PUMP POWER AT 809 NM.

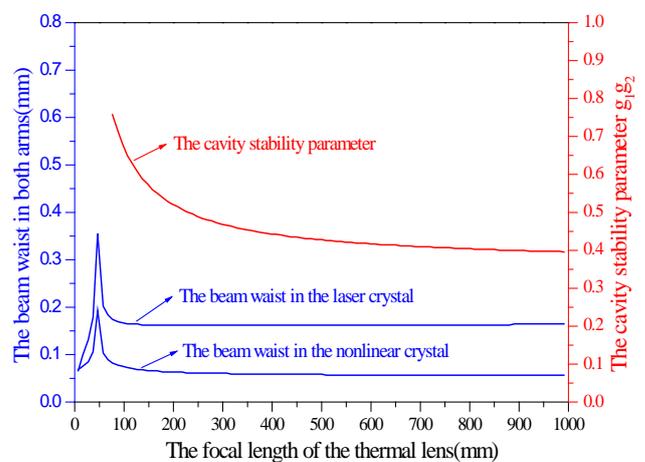


FIG. 4. BEAM WAIST IN BATH ARMS AND THE CAVITY STABILITY PARAMETER VERSUS FOCAL LENGTH OF THE THERMAL LENS RESPECTIVELY

The LBO is mounted in a copper block which is also fixed on a thermoelectric controller for active temperature control. The laser performance is also presented in Fig.3. The threshold of the 543 nm laser is about 3.2 W. With an incident pump power of 18.2 W, a cw SHG output power of 528 mW at 543 nm yellow-green laser has been obtained. The radius of the laser mode in both arms and the cavity stability parameter g_1g_2 versus focal length of the thermal lens, respectively are shown in Fig.4, calculated by the ABCD matrix formalism with the approximation of a thin lens in the middle of laser crystal. It can be seen from Fig.4 that the Nd:LuVO₄ laser is still in the stability zone and the cavity is a thermal-insensitive resonator when it operates with the maximum pump power (the thermal-lens focus of the Nd:LuVO₄ is about 200 mm measured by a method in which the transform circle theory of resonator is utilized proposed in Ref. [11]). Fig.5 shows the spectra of 543 nm yellow-green laser which was detected using the grating spectrometer. The M_2 factors are about 1.33 and 1.21 in X and Y directions respectively measured by knife-edge technique. The asymmetry of the M_2 factor in two directions is result of the walk-off between the fundamental wave and the second in the direction of the LBO. Some stability testing was carried out by monitoring the yellow-green laser with a Field-Master-GS powermeter at 10 Hz. The fluctuation of the output power is about 5.33% in 4h.

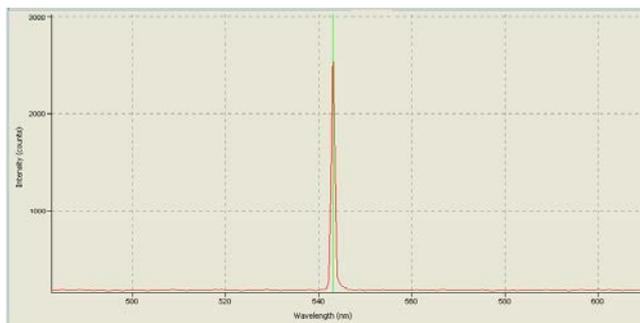


FIG. 5. SPECTRUM OF THE 543 NM YELLOW-GREEN LASER.

Conclusions

In summary, we have demonstrated for the first time, to the best of our knowledge, laser emission at 1086 nm in Nd:LuVO₄ crystal. For the 1086 nm emission, with a 5 mm long, 0.4 at. % doped crystal, a cw output power of 2.37 W was achieved at an incident pump power of 18.2 W. Further improvement of this result has been in progress by optimizing the output mirror transmission. After the SHG, second harmonic radiation power of 528 mW at 543 nm was obtained.

The use of more efficient nonlinear crystals, such as ppKTP or KNbO₃, should increase the second harmonic radiation power.

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