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Characteristics of Nd:YGG Laser Operating at ${}^4F_{3/2}-{}^4I_{9/2}$

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The laser properties of the Nd:YGG crystal are investigated. The absorption spectrum from 500 to 900 nm and emission spectrum from 850 to 1400 nm of Nd:YGG are measured. As much as 1.35 W output power of fundamental laser operating at 935 and 938 nm with a slope efficiency of 15.7% and 105 mW output power of frequency doubled blue laser are successfully obtained.

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The determination of the spatial distribution of water vapour in the atmosphere is important for meteorological and climatological studies. The measurement with sufficient vertical resolution and global accuracy, particularly in the presence of clouds is a difficult problem. However, the differential absorption lidar (DIAL) in the wavelength regions of either 935 nm, 942 nm or 944 nm can overcome this problem because other components in the atmosphere have no absorption at these wavelengths.^[1,2] The DIAL technique makes use of laser probing of the atmosphere at two wavelengths; one wavelength is centred on a water-vapour absorption line, and the other wavelength is positioned at a nearby value outside the absorption to act as a reference. The water-vapour mixing ratio is then determined from the slope difference of the backscattered signals of the two wavelengths. Although these wavelength lasers can be easily obtained by an OPO, a Ti:Sapphire-laser or a Raman-shifter, but such systems are rather complicated and expensive for use in DIAL. If we can find a kind of appropriate laser crystal pumped by LD to obtain the above laser wavelengths directly, apparently, this compact and cheap laser is an attractive choice. A variety of mixed garnets have been grown and investigated for realizing a laser around 944 nm for water vapour detection (the so-called compositional tuning).^[3,4] In this Letter, we reported the elementary experimental results about LD pumped Nd:YGG laser emitting at the wavelengths of 935 and 938 nm. The YGG crystal is a good laser host.^[5-10] The advantage of YGG crystal is that it could be highly Nd-doped without luminescence quenching, so we could expect to obtain higher laser conversion efficiency in this crystal. We measure the absorption spectrum from 500 to 900 nm and emission spectrum from 850 to 1400 nm of Nd:YGG crystal. As much as 1.35 W output power of fundamental laser operating at ${}^4F_{3/2}-{}^4I_{9/2}$ and 105 mW

output power of frequency doubling blue laser are successfully obtained.

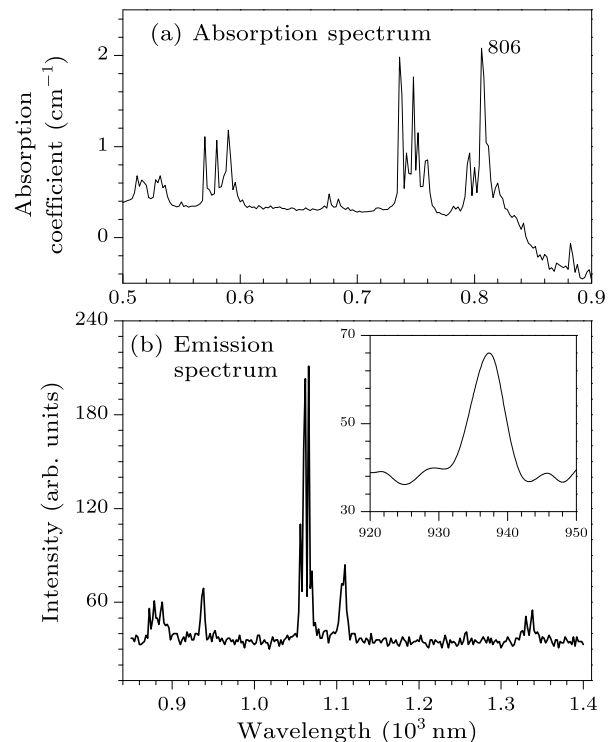


Fig. 1. Absorption and emission spectra of Nd:YGG crystal.

Figure 1 shows the absorption spectrum from 500 to 900 nm and emission spectrum from 850 to 1400 nm of Nd:YGG crystal. From Fig. 1(a), we can see that there is a strong absorption peak near 806 nm with absorption coefficient of about 2 cm^{-1} , and the Nd:YGG crystal can be efficiently pumped by an LD of 806 nm. The absorption coefficient in the range of 830 nm to 900 nm is meaningless because of low sensitivity of the spectrometer in this range. The emission spec-

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trum was measured under pumping with an LD of 806 nm. From Fig. 1(b), we can see that there is an emission peak near 938 nm for the Nd:YGG crystal and it is possible to realize laser operation in the range from near 932 nm to 941 nm. For the laser experiments a linear resonator was employed to make the system very simple and compact. The experimental setup is shown in Fig. 2. The pump source used in our experiment was a high-brightness fibre-coupled diode laser emitting at 806 nm. The pump laser from the fibre with a core diameter of 200 μm and a numerical aperture of 0.22 was coupled into the gain medium by the coupling system. The input flat mirror M_1 was coated with high transmission (HT) at 806 nm and high reflection (HR) at 935 nm. The laser crystal Nd:YGG had 0.6 at.% Nd^{3+} concentration and dimensions of $\Phi 4 \times 4 \text{ mm}^3$ and was not anti-reflection (AR) coated. The Nd:YGG crystal was mounted in a water-cooled heat sink ($T = 6^\circ\text{C}$). The output coupler was different in fundamental light and blue light experiments. It had 2% transmission at 935 nm in fundamental light experiment, whereas it was coated with HR at 935 nm and HT at 468 nm in blue light experiment. To suppress lasing at wavelength of 1064 nm, reflectivity coatings at 1064 nm with $< 10\%$ for all mirrors were also specified.

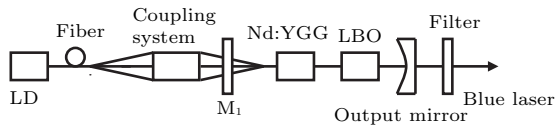


Fig. 2. Schematic diagram of the diode-pumped intracavity-doubled Nd:YGG laser.

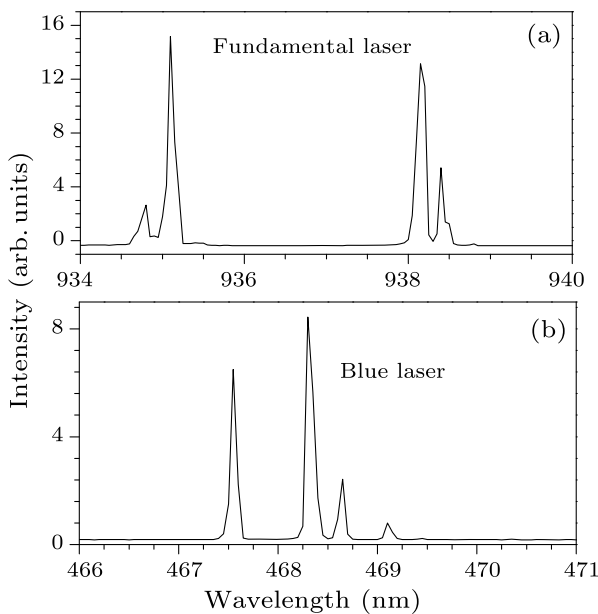


Fig. 3. Laser spectra of Nd:YGG laser in fundamental and blue light experiments.

The fundamental light experiment was carried out in the absence of the LBO crystal and the filter. The output coupler was a concave mirror with a curvature radius of 250 mm and transmission of 2% at 935 nm. We tested the laser behaviour with the cavity length of 40 mm. With the help of a monochromator (Spectra Pro 500i), we measured the laser emission spectrum of Nd:YGG laser in fundamental light experiment, and the result was shown in Fig. 3. From this figure, we can see that the fundamental laser was composed of 934.8 nm, 935.1 nm, 938.2 nm and 938.4 nm. Figure 4 shows the output power of fundamental laser as a function of the incident pump power. The maximum output power was 1.35 W at an incident pump power of 10.2 W with a slope efficiency of 15.7% and an optical conversion efficiency of 13.2%.

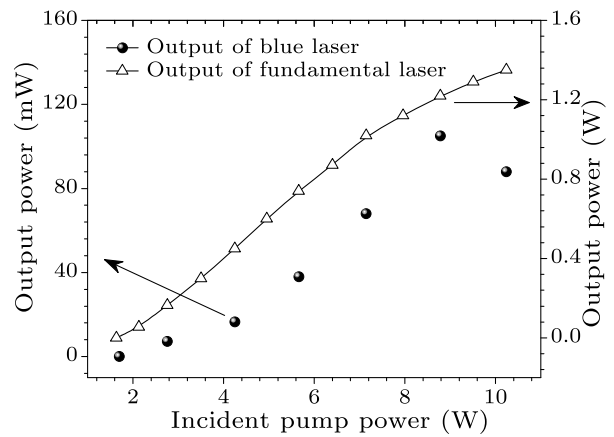


Fig. 4. Output power of fundamental and blue lasers as a function of the incident pump power.

In the blue laser experiment, the output coupler was replaced by a mirror with 200 mm radius of curvature coated for HR at 935 nm and HT at 468 nm. A filter was placed after the output coupler in order to reflect the fundamental light that leaked out of the cavity. The frequency doubler of an LBO crystal ($3 \times 3 \times 14 \text{ mm}^3$) was inserted into the laser cavity. It was wrapped with indium foil and fixed inside a copper block that was mounted upon a thermoelectric cooler for active temperature control. The LBO crystal was cut for room temperature type-I phase matching ($\theta = 90^\circ$, $\phi = 20.2^\circ$, $\lambda = 935 \text{ nm}$). In order to reduce the loss of the laser cavity, both sides of the crystal were AR coated for 936–943 nm and 468–472 nm. The laser emission spectrum of Nd:YGG laser in blue light experiment is shown in Fig. 3. The blue laser was composed of 467.6 nm, 468.3 nm, 468.7 nm and 469.1 nm. These wavelengths and their intensity varied with the change of cavity status and pumping level. This behaviour is also true for the fundamental light. The light of 467.6 nm and 469.1 nm is frequency doubled from 935.1 nm and 938.2 nm, respectively. Whereas the wavelength of 468.3 nm is the

sum-frequency from 935.1 nm and 938.2 nm. Figure 4 also shows the output power of the blue laser as a function of the incident pump power. The maximum blue laser output power of 105 mW with a slope efficiency of 1.5% and an optical conversion efficiency of 1.2% was generated at an incident pump power of 8.8 W. The output power of blue laser began to drop with further increased incident pump power. This indicates that thermal-lensing effect dominated in high pump power which resulted in the change of beam-size in the LBO and thus change of the conversion efficiency. The optical conversion efficiency of the blue laser is low as it is the property of quasi-three-level lasers and relative large beam-size. We monitored the output power and the beam quality of the blue laser. We observed fluctuation in output power of the blue laser and the quality of the laser beam was not very good at high pump power. The above phenomena are probably because the fundamental laser has the multi-mode structure as well as the thermal effect and these fundamental laser wavelengths have strong competition especially in the case of frequency doubling.

In conclusion, we have experimentally demonstrated the laser emission of the Nd:YGG crystal. Laser emission at absorption band around 935 nm for DIAL water vapour detection can be directly obtained using diode pumped Nd:YGG solid state laser. The laser usually emitted both at 935 and 938 nm wave-

length. The laser wavelengths around 935 nm can easily be chosen using a wavelength selective component like an etalon. The absorption spectrum from 500 to 900 nm and emission spectrum from 850 to 1400 nm of Nd:YGG were measured. As much as 1.35 W output power of fundamental laser operating at ${}^4F_{3/2} - {}^4I_{9/2}$ and 105 mW output power of frequency doubling blue laser were successfully obtained.

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