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A Single-Longitudinal-Mode CW 0.25 mm Tm,Ho:$GdVO_4$ Microchip Laser[1]

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Abstract—A single-longitudinal-mode of 0.25 mm Tm,Ho:$GdVO_4$ Microchip Laser was reported. The maximal continuous wave (CW) output power was 26.4 mW and the threshold of 118 mW. The Tm,Ho:$GdVO_4$ Microchip Laser output wavelength was centered at 2039.7598 nm with bandwidth of about 57.1 pm. The beam quality factor was M^2 ~ 1.52 ± 0.03 measured by knife-edge method. The Longitudinal-Mode was scanned by a FPI and the transverse mode was monitored by an infrared vidicon camera.

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1. INTRODUCTION

Thulium, Holmium-doped laser materials are suitable to be pumped by diode laser [1–6], the emission lie on $^5I_7 \longrightarrow {}^5I_8$ transition in Ho^{3+} ions at 2 μm lies in the eye-safe region and has potential used in various applications such as atmospheric remote sensing including Doppler lidar wind sensing, water vapor profiling by differential absorption lidar, medical applications [7–10], and so on. Recently, 2 μm is charming in differential absorption lidar and wavelength injection-locked laser which requires a single frequency laser source [11], in this region, there are several kinds of crystals doped with Tm ions and Ho ions together, such as Tm,Ho:YAG, Tm,Ho:FLY, Tm,Ho:YAP. As a host of Thulium and Holmium, $GdVO_4$ crystal has good physical and chemical properties of light, compared with other crystals. The absorption cross section of thulium in $GdVO_4$ is considerably stronger than in YAG, YAP, and YLF, and the absorption spectrum is broader (770–820 nm) which is suitable for commercially available AlGaAs laser diodes. Furthermore, the large thermal conductivity of $GdVO_4$ (10 W/m/K at 300 K) is very favorable for efficient cooling of the crystal.

The fluorescence spectrum of Tm,Ho:$GdVO_4$ with doped concentration of 5% Tm^{3+} and Ho^{3+} has been recorded under the surrounding temperature of 77 K in our laboratory, there are two stronger fluorescence peaks at wavelengths of 2038.9 and 2051.1 nm, and they have close emission cross section. In 2008, Wang et al. had been reported the Tm,Ho:$GdVO_4$ Microchip Laser experiment, but it was a Single-longitudinal-mode Dual-Wavelength Laser [12]. In this letter, making use of a diaphragm which is used to restrict the pumping beam, we obtain the Single-longitudinal-mode of 2039.7598 nm, with the threshold of 118 mW, the maximum output power is 26.4 mW when the incident power is 875 mW. The beam quality factor is M^2 ~ 1.52 measured by the traveling knife-edge method.

2. EXPERIMENTAL SETUP

The experimental configuration of Tm,Ho:$GdVO_4$ Microchip Laser is shown in Fig. 1. The laser was end-pumped by an InGaAs diode laser at 802 nm delivering a power of 1800 mW. Adjusting diode temperature up to 13.5°C, so that the emission wavelength of diode is turned to 802 nm, the diode output was coupled by fibers with core-diameters of 100 μm and numerical apertures of 0.22. The LD output is shaped and focused by a series of convex lenses, the mode matching between pump mode and laser mode is optimized by its location. A diaphragm which the radius of the hole can be controlled is used to shape the diode pump beam. The Tm,Ho:$GdVO_4$ Microchip crystal in experiment is a-cut with dimensions 4×4 mm^2 in cross section and 0.25 mm in length, and the doped concentrations is 5 at % Tm, 0.5 at % Ho, respectively. Both ends of the crystal are polished plane, paralleled and coated. The pump side is coated with anti-reflection (AR) at 800 nm and high-reflection (HR) at 2 μm, the other side is coated with AR at 800 nm and part transmission (1%) at 2 μm.

The cavity is formed by the sides of the crystal. The crystal is mounted on a copper heat sink and placed in a Dewar flask filled with the liquid nitrogen. M1 is Si-plate which is coated with anti-reflection at 2 μm, M2 is part-reflecting mirror. A cofocal spherical mirror Fabry–Perot interferometer (FPI) is used to scan the mode of laser. The wavelength is measured by WA-1500 wavemeter which the resolution is 0.7 pm.

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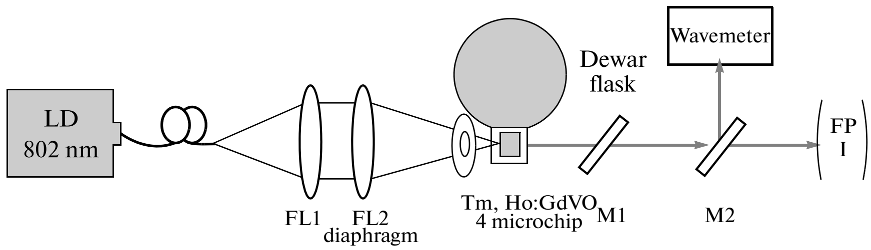


Fig. 1. The experiment configuration of Tm,Ho:$GdVO_4$ microchip laser.

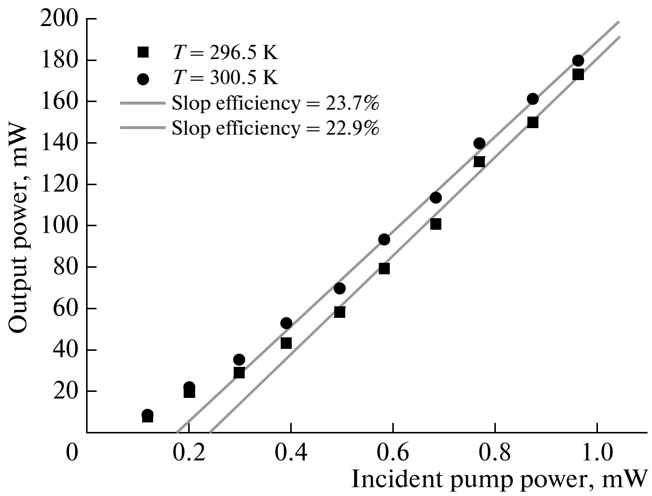


Fig. 2. Output power of Tm,Ho:$GdVO_4$ microchip laser versus incident pump power at temperature of 296.5 and 300.5 K.

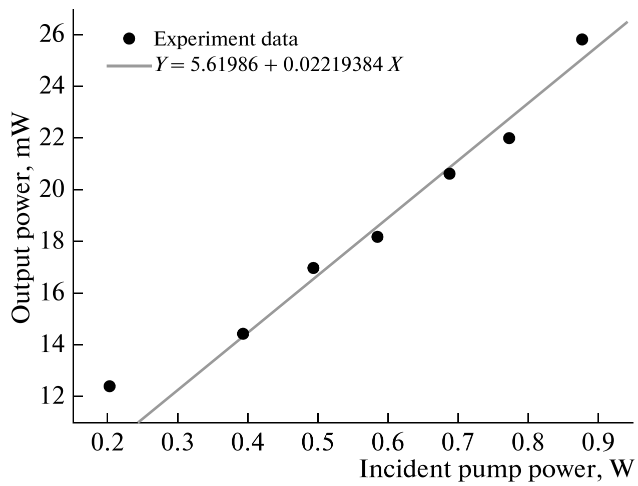


Fig. 3. Output power of single-longitudinal-mode laser versus incident pump power.

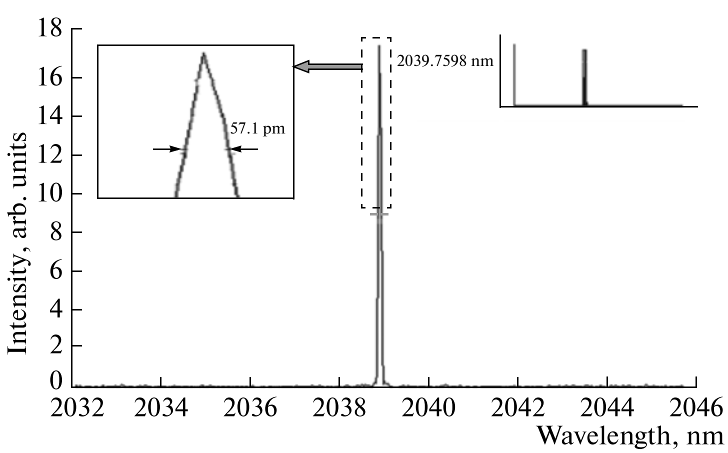


Fig. 4. Output spectrum of Tm,Ho:$GdVO_4$ microchip laser.

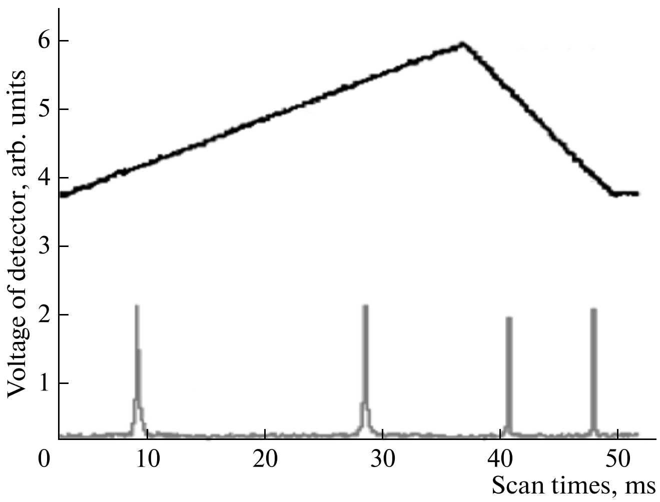


Fig. 5. Mode of single frequency Tm,Ho:$GdVO_4$ microchip laser output.

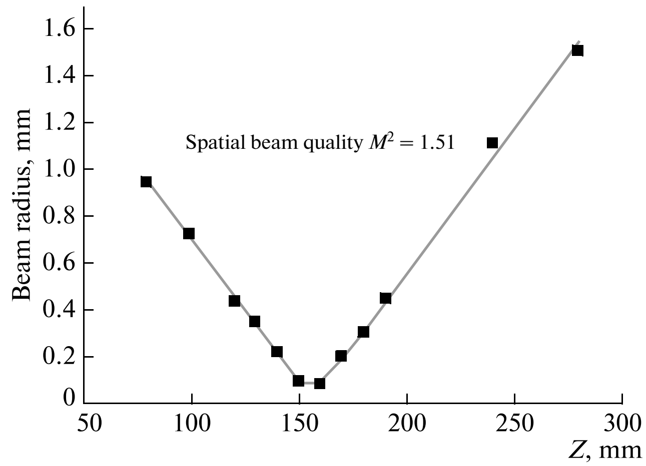


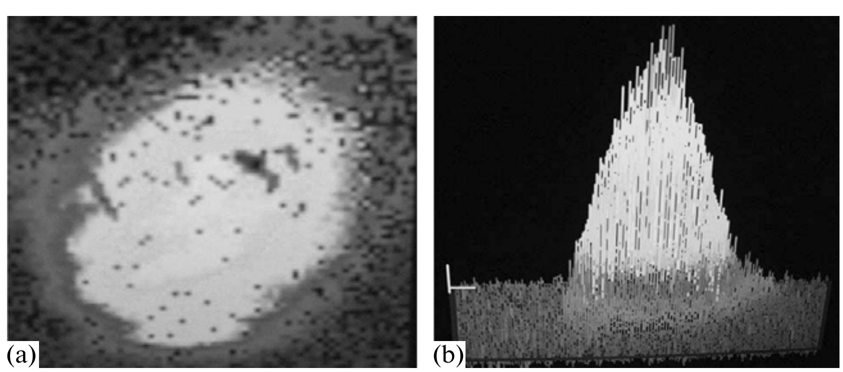
Fig. 6. Beam radius for the Tm,Ho:$GdVO_4$ microchip laser at he 22 mW output power level.

3. EXPERIMENTAL RESULTS

The output Laser power versus pump power is shown in Fig. 2 with different temperature of diode. The lasing threshold is 118 mW. Under the pump power of 1.06 W available from the LD, the highest output power achieved from the Tm,Ho:$GdVO_4$ Microchip is 196 mW under the temperature of 296.5 K. A linear fit to the data yielded a slop efficiency of 23.7%, 22.9% at the temperature of 296.5 K, 300.5 K. From the experiment data results indicated the output power was not effected by the LD temperature at low pump power, and showed the advantage of broad absorption bandwidth of Tm,Ho:$GdVO_4$ crystal. Figure 3 shows the output power of the single-longitudinal-mode laser versus pump power 26.4 mW with the pump power 875 mW.

The wavelength of Tm,Ho:$GdVO_4$ Microchip laser was measured with a WA-1500 wavemeter having a resolution of 0.7 pm at pump power of 1.06W. Figure 4 shows the output spectra of the Tm,Ho:$GdVO_4$ microchip laser. The emission oscillates at the resonant wavelength of 2039.7598 nm with full-width at half maximum (FWHM) of 57.1 pm. Figure 5 shows the output mode of Tm,Ho:$GdVO_4$ microchip laser which was measured by confocal Fabry–Perot interferometer with an 3.75-GHz free spectral range, the voltage differential which was relayed on the F–P interferometer was about 170 V, which could scan two FSR of the laser, the Single-longitudinal-mode was seen to be achieved, the linewidth of resonance curve was less 20.5 MHz can be estimated.

The beam radius for the Tm,Ho:$GdVO_4$ microchip laser at the 22 mW output power level was also measured by the 90/10 knife-edge method. The lens (f = 100 mm) was located at the position 200 mm away from the microchip. Figure 6 shows the measured



Output laser beam spot Output laser beam profile

Fig. 7. Transverse mode of single frequency Tm,Ho:$GdVO_4$ microchip laser output.

beam radius at different positions after the lens. We estimated the beam quality to be $M^2 = 1.52 \pm 0.03$ by Gaussian fitting. The Figure 7 shows the output laser beam spot and laser beam profile which was monitored by an infrared vidicon camera (Model PY-128-100A, Co. SPIRICON). From the figure, it was considered to be TEM_{00}, since the cavity length is only 0.25 mm, the laser beam divergence is large relatively, so the beam spot is not ideal.

4. CONCLUSIONS

A 26.4 mW LD pumped single-longitudinal-mode Tm,Ho:$GdVO_4$ microchip laser was realized based on the 0.25 mm crystal and a diaphragm. The maximum output power was 196 mW, the slope efficiency was 23.7, 22.9% at the temperature of 296.5, 300.5 K, respectively. The Tm,Ho:$GdVO_4$ microchip laser output wavelength was centered at 2039.7598 nm. The output laser linewidth was only 57.1 pm, and this was very important in the application of lidar.

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