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Lasing characteristics of a CW Tm,Ho:YLF double cavity microchip laser

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Abstract

The lasing characteristics of a cw Tm,Ho:YLF microchip laser in a double cavity configuration are reported. The oscillation wavelength decreased continuously and periodic mode hopping occurred as the absorbed pump power increased. Furthermore, the output power could be changed by varying the thickness of the air gap distance at constant absorbed pump power.

Keywords: TmHo:YLF; Microchip laser; Double cavity; Mode hopping

1. Introduction

A Tm,Ho:YLF laser oscillates with high conversion efficiency at the eye-safe wavelength of 2100 nm [1]. This wavelength is included in the strong absorption lines of water vapor and carbon dioxide [2]. Therefore, the present laser is a good candidate for remote sensing and medical applications. In this paper, we present the results of lasing performance using a double cavity microchip laser in single mode oscillation at room temperature.

Fig. 1 shows the experimental scheme of the double cavity microchip laser and the single cavity microchip laser. The detailed configuration of the cavity was described previously [3,4]. The diameter and the thickness of the laser crystal are 3 and 1 mm, respectively. The doped concentrations of Tm and Ho are 6%, 0.6%, respectively. Both surfaces of the crystal are optical flat. The surfaces on the pumping side has a coating with high transmissivity at 785 nm and high reflectivity at 2100 nm, while the output side has a coating with 99% reflectivity at 2100 nm. This laser crystal is simple laser cavity itself, and we treat it as single cavity (configuration). The double cavity microchip laser (configuration) consists of single cavity microchip laser and additional output mirror mounted in a PZT ring-actuator, with a coating with 99%

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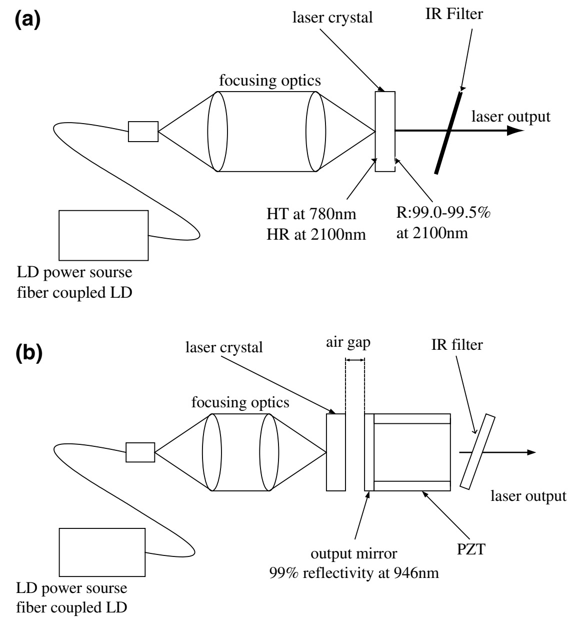

Fig. 1. Configurations of the simple cavity (a) and the double cavity (b). Laser crystal: diameter, 3 mm; thickness, 1 mm. The reflectivity of the output mirror was 99%.

reflectivity at 2100 nm, placed 200 μm from the output side of the single cavity. This distance between the output mirror and the laser crystal plays a role of air gap etalon, the distance of which can be varied easily by applying DC voltage directly to PZT. The pumping laser light is focused onto the crystal through the collimating and focusing lenses with a focal length of 8 mm. The minimum spot size of pumping beam, which is measured with a beam profiler, is 150 μm. This laser uses YLF host crystal, which has an optical anisotropy. Therefore, the cavity axis is parallel to the *a*-axis of the laser crystal. The output power is measured with a power meter after the Si-plate to attenuate 785 nm pump radiation, and the longitudinal mode is also measured with a Fabry–Perot Interferometer, while the lasing wavelength is measured using a monochromator. The temperature of the crystal is measured on the surface of the copper crystal holder, which is cooled by a TE-cooler. The absorbed power is measured by subtracting output laser power from the input laser power.

Fig. 2 shows the oscillation wavelength as a function of absorbed pump power for both single

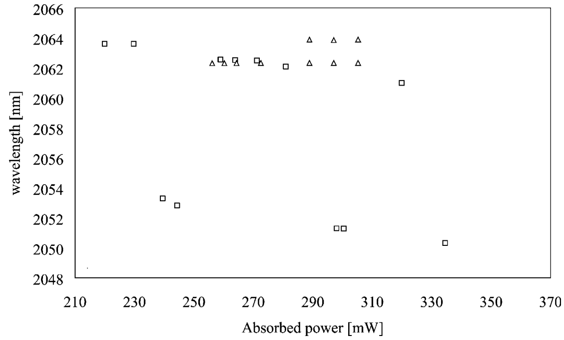

Fig. 2. Oscillation wavelength vs. the absorbed pump power in single and the double cavity configurations. △, single cavity: □, double cavity. Oscillation wavelength as a function of an absorbed pump power for both the simple cavity and the double cavity. Experiments were carried out at a temperature of 20 °C with an air gap distance of 200 μm in single mode oscillation.

and the double cavity microchip lasers at a temperature of 20 °C. This figure shows that there are marked differences in oscillation wavelength behavior between single and double cavity system. In the case of the single cavity microchip laser, the oscillation wavelength in single longitudinal mode increased slightly with increases in the absorbed pump power until two-mode-oscillation occurred. This implies that increases in the absorbed power cause the accumulation of heat in the laser crystal, resulting in slight expansion of the cavity length. The oscillation wavelength increased from 2062.32 to 2062.34 nm with an increase in absorbed power from 255 to 274 mW. Similar effects were also observed in measurement of the oscillation wavelength with increasing crystal temperature [1,5]. On the other hand, the oscillation wavelength in the double cavity microchip laser showed discrete variations which changes in absorbed pump power both upward and downward. As shown in Fig. 2, the oscillation wavelength of the double cavity microchip laser was gradually reduced as the absorbed pump power increased, although the oscillation wavelength alternated periodically between around 2050 and 2060 nm [6]. Increasing the absorbed pump power caused an increase in the temperature of the crystal. As a result, the distance of the air gap decreased because the crystal length was expanded due to the effect of the accumulation of heat. Therefore, the oscillation wavelength decreased as the absorbed pump power increased, which is differed from the case with the single cavity microchip laser. These observations indicated that the oscillation wavelength can be controlled not only by the length of the laser crystal, but also by the distance of the air gap. Both the upper and lower oscillation wavelengths decreased as the absorbed pump power increased, with the periodical mode hoping. The upper oscillation wavelength decreased from 2063.61 to 2061.00 nm when the absorbed pump power increased from 177.85 to 259.26 mW. The lower oscillation wavelength also decreased from 2053.29 to 2050.315 nm when the absorbed pump power increased from 193.73 to 271.17 mW.

This frequency difference of 760 GHz between both wavelengths of 2063 and 2053 nm corresponds to the longitudinal mode spacing calculated from the distance of the air gap of 200 μm. At the absorbed pump power of 185.8 mW the oscillation wavelength was 2063.6 nm. The oscillation wavelength changed from 2063 to 2053 nm, when the absorbed power decreased slightly from 185.8 to 193.7 mW. After the occurrence of mode hopping, the oscillation wavelength returned to the former value of about 2051 nm. These observations indicate that the mode that differs from longitudinal mode spacing determined by crystal length is determined by the distance of the air gap, The present results indicate that the gain profile is broader than the mode spacing between the two axial modes. The oscillation mode is the resonant frequency among three cavity conditions of crystal length, distance of the air gap, and the combined cavity length, which is the distance between the output mirror and the rear side of the crystal. The crystal length expands as the absorbed pumping power increases, and the distance of the air gap decreases because the length of the combined cavity is constant.

The frequency lengthened in the longitudinal modes, while the laser crystal shortened, because the length of the combined cavity was constant during the experiments. Under identical resonant conditions, the oscillation wavelength changes to another oscillation wavelength, e.g., the lower oscillation wavelength. This process is then repeated, and the oscillation wavelength shifts to a longer wavelength.

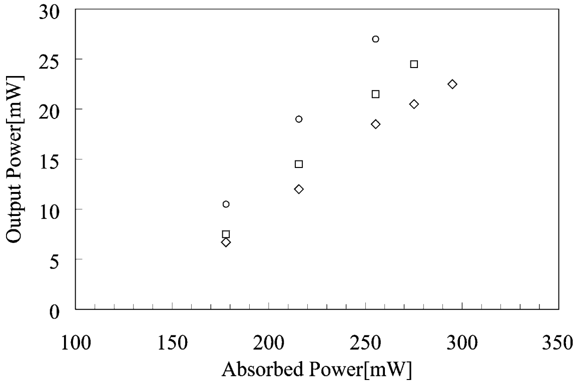

Fig. 3. Input–output characteristics under three different air gap distances, ○, 200 μm: □, 400 μm: ◇, 600 μm. Output power at a single longitudinal mode oscillation as a function of the absorbed pump power with three different air gap distances. Experimental conditions were maintained with single longitudinal mode oscillation at a temperature of 20°.

Fig. 3 shows the output power as a function of the absorbed pump power with three different air gap distances. All of these cases are single longitudinal mode oscillation and have a similar threshold power of 135 mW, although they show quite different tendencies of slope efficiency. The slope efficiency for air gap distances of 200, 400 and 600 μm were estimated to be 21.3%, 18.5%, 13.5%, respectively. The output power in the single longitudinal mode oscillation increased as the distance of the air gap decreased despite the fixed absorbing power. The output power also increased linearly as the absorbed pump power increased for all cases until an absorbed pump power of 300 mW. Above this value, the single mode oscillation was discontinued and reached continuous the multi-mode oscillation area. When the distance of the air gap was varied from 300 to 600 μm by applying DC voltage to the PZT at a constant absorbed pump power of 255 mW, the output power decreased from 27 to 18.5 mW through 21.5 mW. When the distance of the air gap was varied between 200, 400 and 600 μm with the absorbed pump power maintained at a constant value of 177.9 mW, the output power shifted from 10.5 to 6.7 mW through 7.5 mW. The single longitudinal mode oscillation remained, although the distance of the air gap was varied and the oscillation wavelength was shifted. These phenomena can be explained by changing the cavity loss due to the differences in the Fresnel number. Increasing the size of the air gap reduces the Fresnel number, which results in an increase in the diffraction loss in the laser cavity [6].

In the conclusion, mode hopping of oscillation wavelength occurred periodically with varying the size of the air gap, and the oscillation wavelength was shifted to the lower wavelength for the double cavity configuration as the absorbed pump power increased. These characteristics were quite different from those of the single cavity configuration. Furthermore, we found that single longitudinal mode oscillation continued, and the decreasing the air gap caused an increase in the output power under the condition where the absorbed pump power was constant value.

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