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A tunable and longitudinal mode oscillation of a Tm,Ho:YLF microchip laser using an external etalon

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Abstract

The lasing performance of a Tm,Ho:YLF microchip laser with an external etalon is examined. The configuration is featured by its high finesse in comprising multiple etalons. An output power of 27 mW in single mode operation is achieved, although the oscillation is very sensitive to deviation of the external etalon. The idea of an oscillation mechanism suggests the possibility of passive Q-switching.

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A Tm,Ho:YLF microchip laser can operate at 2 μm eye-safe wavelength. Therefore, this laser was chosen as a candidate for remote sensing, range finding and optical communication. Several papers on a Tm,Ho:YLF lasers have been published to date [1–3]. However, the single longitudinal mode oscillation has been found to be difficult because the gain profile of this laser is far wider than that of a Nd:YAG laser [4].

In this paper, we report lasing performance of a single longitudinal mode oscillation in the Tm,Ho:YLF with an external etalon. Fig. 1 shows its experimental set-up. The laser was pumped by a 1 W diode operating at 781 nm. Its output beam was focused onto the end surface of the Tm,Ho:YLF microchip (Ho microchip laser). The concentration of Tm and Ho dopant in YLF host crystal is 6% and 0.6%, respectively. The laser crystal was oriented with the a-axis perpendicular to the end face. The pumping beam was tailored using a collimating lens of f = 4.5 mm and a cylindrical lens of $f = 400$ mm. The spot size on the surface of the Ho microchip laser was measured to be 170×40 μm and this value was retained during present experiments even though the pumping power was changed. The Ho microchip laser is a disc of 0.7 mm thickness and 3 mm diameter, whose surfaces were both flat and parallel. One surface of the Ho microchip laser was coated with a high transmission at 781 nm and a high reflectivity at 2.1 μm. The opposite surface of

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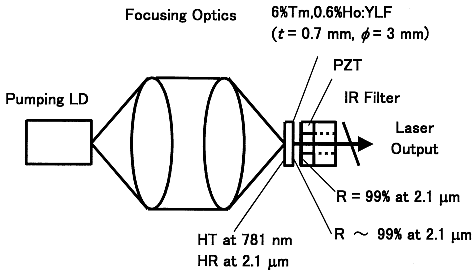

Fig. 1. Experimental set-up.

the laser crystal was coated so as to have 99% reflectivity at 2.1 μm lasing wavelength, which composed of a single cavity configuration. This single cavity configuration can operate as a 2 μm laser. Another flat output mirror was added about 100 μm apart from the end surface of the laser disc, having a 99% reflectivity at 2.1 μm. The air gap, being 100 μm long, between the high reflectivity surface of the Ho microchip laser crystal and the output mirror works as a high finesse etalon at a wavelength of 2.1 μm. This cavity configuration was named for the Ho microchip laser with the external etalon. The temperature of the Ho microchip laser was controlled by a thermoelectric cooler to cool the laser crystal and control the temperature of the microchip laser crystal. The laser power of the Ho microchip laser was examined with a power meter with and without an external etalon respectively. The pumping LD beam of 781 nm was blocked there with an optical filter. The longitudinal mode structure was also observed with the Fabry–Perot interferometer and the spectrometer, simultaneously.

Fig. 2 presents the output powers as a function of absorbed pump power for the Ho microchip laser with and without the external etalon shown in Fig. 1. The output power for the double cavity configuration with the external etalon has a large deviation from a linear line, compared with that of the single cavity configuration without the external etalon. This resulted from the fluctuation of the thickness of the external etalon against the applied voltage to the PZT on the output mirror holder. In the case of the double cavity configuration, the output power is sensitive to the thickness of the external etalon. For the case of the single cavity configuration, dual mode oscillation took place above 10 mW. The employment of the external etalon allowed the single longitudinal mode oscillation to exceed 10 mW by tuning the distance of the air gap of the high finesse external etalon, so that it canceled the change of the length of the laser crystal due to the increase of the pumping power. The threshold of the oscillation for the Ho microchip laser with the external etalon was lower than that of the case without the external etalon. It can be explained by the etalon effect of the double cavity configuration. By adding the external air gap etalon, the laser cavity seems to have a periodic reflectivity depending on the optical wavelength, though it retains a plain flat surface. In the double cavity configuration, the effective reflectivity of the output mirror with the external etalon, R_{eff}, is given as Eq. (1).

$$R_{\text{eff}} = \left\{ \sqrt{R_1} - \frac{\sqrt{R_2}\,(1-R_1)\left(\cos\phi - \sqrt{R_1 R_2}\right)}{\left(1 + R_1 R_2 - 2\sqrt{R_1 R_2}\cos\phi\right)} \right\}^2 + \frac{R_2 (1-R_1)^2 \sin^2\phi}{\left(1 + R_1 R_2 - 2\sqrt{R_1 R_2}\cos\phi\right)^2} \qquad (1)$$

where R_1 is the reflectivity of the surface of the laser crystal, R_2 is the reflectivity of the output mirror, d is the thickness of the external etalon, and λ is the oscillation wavelength. In our experimental condition R_1 and R_2 are 99%, therefore the maximum R_{eff} is calculated to be 99.9975%, which is larger than R_1.

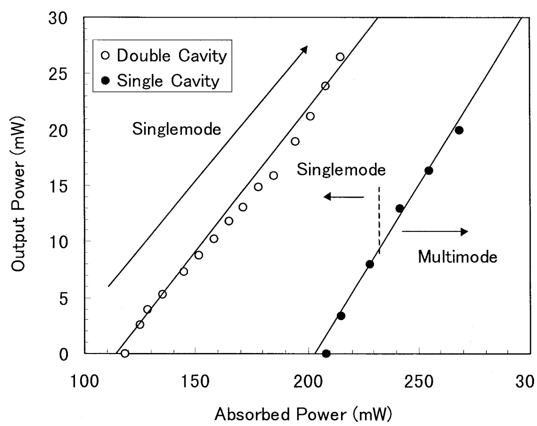

Fig. 2. Output power in a single longitudinal mode oscillation as a function of absorbed pump power for the Ho microchip laser with and without the external etalon.

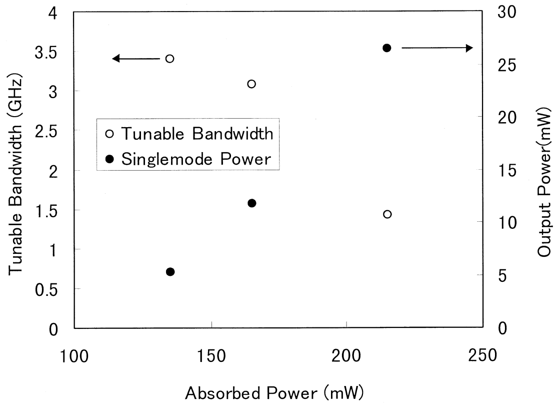

Fig. 3. Tunable bandwidth of the Ho laser and the output power as a function of absorbed power.

Since we can get the high reflectivity, the threshold power decreases for the double cavity configuration. The double cavity configuration extends the single mode oscillation up to 27 mW output. This was limited by the capacity of the pumping LD. On the other hand, the output power of the single mode oscillation for the single cavity configuration was limited to 7 mW, because a multiple mode operation took place above 7 mW. This improvement was achieved by the pertinent etalon effect. The slope efficiencies for both cavity configurations in Fig. 2 have a similar tendency for absorbing pump power, which means the cavity loss of the Ho microchip laser with the external etalon is very small. The slope efficiencies for both cases are estimated to be the same amount, ~ 30%, which is almost the same value published in previous papers [5].

Fig. 3 depicts only the tunability and the output power of the Ho microchip laser with the external etalon as a function of the absorbed pump power. With an increase in the absorbed power, the range of the tunable oscillation wavelength becomes narrower. When the absorbed power was 140 mW, the tunable bandwidth at the oscillation wavelength of 2.065 μm was 3.5 GHz. But for the case of 220 mW absorbed power, the range decreased down to 1.5 GHz. The increases in the absorbed power makes the tunable range narrower because the increase in the absorbed power causes the large population in the upper laser level and, as a result, lowers the threshold of lasing, which allows multiple-mode oscillation. Careful control of the absorbed power is necessary to change an oscillation wavelength smoothly, unless the external etalon is employed. Introduction of the external etalon, allows easier wavelength control.

Fig. 4 shows the output power as a function of the relative distance of the air gap of the external etalon. First of all, we had to obtain a maximum output power in the single longitudinal mode oscillation by tuning the distance of the air gap of the external etalon, by observing the Fabry–Perot interferometer and the power meter, simultaneously. In this process, the distance of the air gap was varied by hand, slowly. When achieving the maximum power, we recorded the position, and named for it for a standard position ‘0’. The periodic change in the output power was observed by introducing a deviation of −0.4 to 0.15 μm for the standard position ‘0’ into the distance of the air gap etalon. This phenomena showed the typical mode hopping, which resulted from the change of the distance in the etalon. The average spiking frequency calculated from Fig. 4 was determined to be 0.083 μm, from which we could estimate an oscillation wavelength of 2.062 μm. This value is a good agreement with the value derived from the experimental set-up. In addition, when we decreased the distance of the air gap of the external etalon, the lasing stopped drastically without changing the other experimental conditions such as the pumping power. When returning the distance of the air gap of the external etalon to the former position,

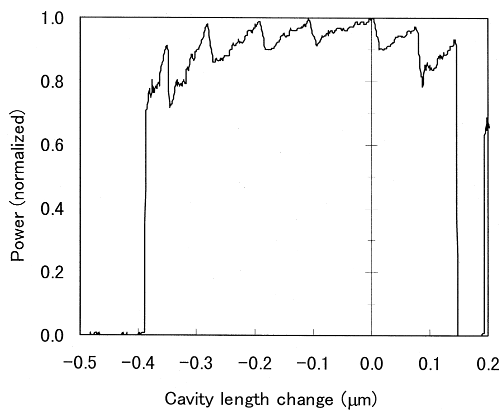

Fig. 4. Output power as a function of the relative distance of the air gap of the external etalon.

the oscillation occurred again, still keeping the former wavelength and output power. On the contrary, when we increased the distance of the air gap of the external etalon, lasing also stopped suddenly, though the pump conditions ware not varied. When keeping this distance, no lasing was observed. The reproducibility was kept during the experiments. This phenomena [6] can be explained by a mismatch between the oscillation modes of two cavities and the gain profile of the Tm,Ho:YLF laser. For 100 μm of the thickness of the air gap etalon, the oscillation modes of two cavities match each 20 nm of wavelength, which is larger than the gain profile of the Tm,Ho:YLF laser. Therefore, the lasing could only happen when the modes of the two cavities matched in the gain profile of the Tm,Ho:YLF laser simultaneously, by the tuning of the thickness of the air gap etalon. We can operate the Ho microchip laser with a passive Q-switching [6] by using this phenomena. When changing the distance of the air gap of the external etalon, we adopted the PZT mirror holder previously explained. The repetition rate of this Q-switching laser is expected to be 10 kHz, which depends on the performance of the PZT holder.

In conclusion, we carried out the experiments on the lasing performance of the Tm,Ho:YLF microchip laser with an external etalon. A high power in a single longitudinal mode oscillation was observed. In addition, we found the probability of the passive Q-switching operation for this laser.

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