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Mode control of a Tm:YLF microchip laser by a multiple resonator

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Abstract

We have studied the lasing mode control of a diode-pumped Tm:YLF microchip laser with a multiple resonator consisting of a laser crystal and the air gap as an etalon. The range of the tuning wavelength was measured to be 4.6 nm for a change of the air gap length of 200 nm. © 1998 Elsevier Science B.V.

Keywords: Microchip laser; Tm:YLF laser; Eye-safe laser; Multiple resonator; Wavelength tuning

A microchip laser is an important candidate for producing a compact laser and obtaining a single longitudinal mode oscillation [1] because it has a very short resonator length of about 1 mm. Therefore only a few modes are allowed within its fluorescence spectrum. Single longitudinal mode oscillation of the microchip laser was successfully obtained for the Nd:YAG laser [2] and the Nd:YVO_4 laser [3] because of their narrow fluorescence spectrum. However, Tm and Ho lasers have much broader fluorescence spectra and cannot produce single longitudinal mode oscillation easily. Only a few mW of power was obtained [4] above the threshold in a single longitudinal mode. The tuning range of a monolithic microchip Tm or Ho laser in a single longitudinal mode is likewise very limited.

In this Letter, we report on a Tm:YLF laser having a multiple resonator [5,6] so that single mode oscillation at several frequencies over a broad range is obtained with a simple construction. Fig. 1 shows a schematic diagram of the multiple resonator. This resonator consists of two optical regions, C_{12} and C_{23}. The resonator C_{12} consists of a Tm(12 at%):YLF microchip crystal, a coated total reflection mirror M_1 and an uncoated crystal surface M_2. The reflectivity of M_2 is 3.37%. The resonator C_{12} acts as the active resonator having the gain medium. The resonator C_{23} is composed of M_2 and a coupling mirror M_3 at a distance L_{23} from M_2. Resonator C_{23} can be considered as an output mirror with frequency dependent reflectivity. Therefore, the oscillation wavelength of this multiple resonator can be controlled by changing the length of C_{23}. The Tm:YLF laser was pumped through M_1 by a CW laser diode (LD). The LD (SLD-2482-P1 with active area of 500 μm × 1 μm) had a maximum output power of 3 W. The oscillation wavelength of the LD was tuned to 781 nm for pumping the Tm:YLF. A collimating lens with 6 mm-focal length, a cylindrical lens with 400 mm-focal length and a focusing lens with 50 mm-focal length were used to focus the emitted light from the LD onto the laser crystal. The incident power was controlled by an attenuator and an iris placed in front of the LD. The spot size of the pumping beam on the crystal was measured to be about 150 μm × 40 μm (FWHM) and kept constant during the experiments. The output beam was measured by a power meter or a monochromator after a Si plate for the elimination of the pump light. The output laser beam could also be introduced into a Fabry–Perot interferometer (Berleigh model RC-110IR) for the measurement of the small shift of the single mode output wavelength of the Tm:YLF multiple resonator laser.

Fig. 2 shows a lasing spectrum of the multiple res-

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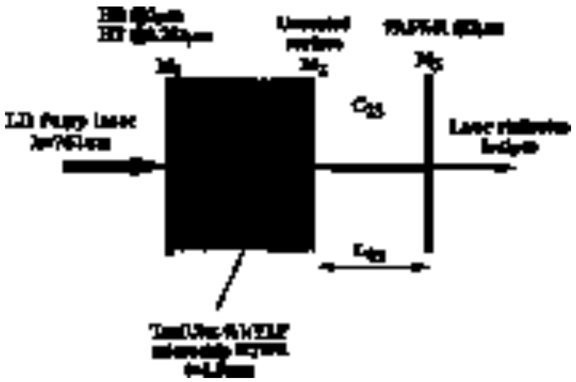

Fig. 1. Schematic diagram of the multiple resonator.

onator. The typical lasing wavelength was around 2010 nm. The maximum output power was 130 mW when the absorbed pump power was about 1 W. The slope efficiency was 36% and the threshold power was 250 mW. We observed about 10 longitudinal modes when the output power was 440 mW. Fig. 2a shows the longitudinal modes for 4 mW of output power. There were two pairs of longitudinal modes separated by about 0.7 and 10 nm, respectively. They corresponded to the mode spacing of L_{12} and L_{13} respectively. The side mode due to L_{12} was first suppressed by the etalon effect of C_{23} when the pump power decreased as shown in Fig. 2b. And finally single mode lasing was achieved when the output power fell down to 1.3 mW. The spectrum of a single mode lasing is shown in Fig. 2c.

Fig. 3 shows the oscillation wavelength shift $\delta\lambda$ as a function of the change in L_{23} which is labeled $\mathrm{d}L_{23}$. We could control $\mathrm{d}L_{23}$ by changing the DC voltage on the PZT holding the M_3 mirror. The input power had to be adjusted by monitoring the Fabry–Perot interferometer in order to obtain single longitudinal mode oscillation. After it was obtained, an increase of the PZT voltage leads to the oscillation of two longitudinal modes. However, further increase of the PZT voltage give us single longitudinal mode oscillation again, at a different wavelength. During these experiments, the absorbed power was kept at a constant value of 620 mW. When $\mathrm{d}L_{23}$ varied from 0 to 150 nm, $\delta\lambda$ increases linearly from 0 nm to 2.7 nm. For $\mathrm{d}L_{23}$ above 150 nm, $\delta\lambda$ increased nonlinearly. When L_{23} was 206 nm, the shift of the oscillation wavelength was 4.6 nm. The single mode output power was typically of the order of 1 mW. The power slightly decreased with the increase of $\mathrm{d}L_{23}$ as shown in Fig. 3. The maximum ratio of the wavelength shift $\delta\lambda$ to the change in L_{23} was determined to be 1.6 GHz/nm in the present experiments. The change in $\mathrm{d}L_{23}$ results in a change of the oscillation wavelength because M_2 and M_3 play the role of an etalon coupler in the multiple resonator. The wavelength of the reflection peak closest to the gain peak changes as L_{23} is varied, leading to selection of the oscillation of the different modes.

The effective reflectivity, R_{23}, looking into C_{23} from

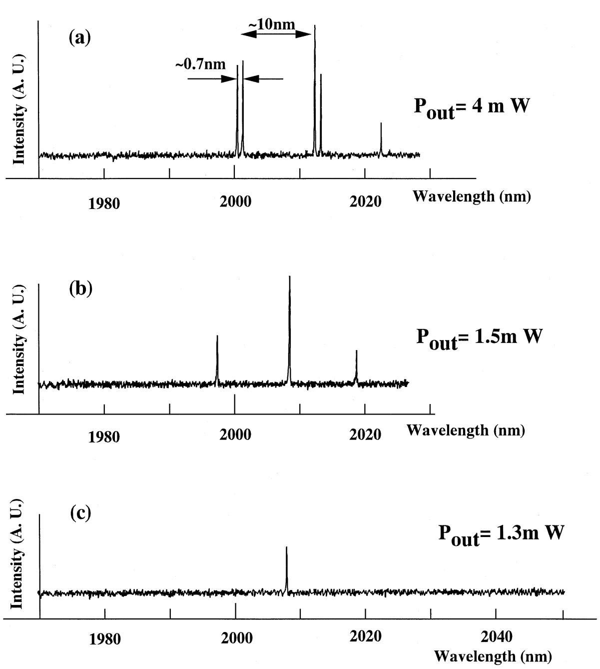

Fig. 2. Typical lasing spectrum of the multiple resonator for some output conditions.

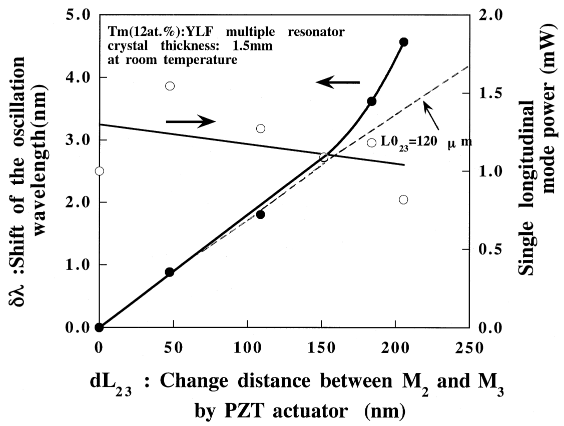

Fig. 3. Shift of the oscillation wavelength as a function of the change of the distance between M_2 and M_3. The change of the distance, dL_{23}, was calculated from the value of the voltage applied to the PZT. The absorbed power was 620 mW for all points.

the left is calculated from the following formula [7,8].

$$R_{23}(\chi)=\frac{R_2-2\sqrt{R_2R_3}\cos\chi+R_3}{1-2\sqrt{R_2R_3}\cos\chi+R_2R_3}, \qquad (1)$$

where $\chi=4\pi L_{23}/\lambda$, R_2 $(=0.0337)$ is the reflectivity of M_2, R_3 $(=0.995)$ is the reflectivity of M_3, χ is the round trip phase change in C_{23}, and λ is the wavelength. The resonator length L_{23} can be separated into two parts, $L0_{23}$ and dL_{23}. The initial distance between M_2 and M_3 is $L0_{23}$, and dL_{23} is the change of the distance between M_2 and M_3, which can be controlled by the PZT actuator. Accordingly, L_{23} can be written as $L_{23}=L0_{23}+dL_{23}$, and a change in dL_{23} leads to a shift of the maxima of R_{23}. From Eq. (1), R_{23} is calculated to vary between 99.25% and 99.65%. The corresponding transmission loss of the etalon coupler thus changes from 0.75% to 0.35%. This represents a loss modulation of more than a factor of two.

Fig. 3 also shows the calculated $\delta\lambda$ as a function of dL_{23}. The experimental results agree with the calculated ones when a value of 120 nm is used for $L0_{23}$ in Eq. (1). Above dL_{23} of 150 nm, the experiments do not agree with the calculated results from Eq. (1). This could be due to nonlinearity in the PZT actuator.

A few papers have been published on the tuning of a single frequency 2 μm microchip laser. Those results were obtained by changing the temperature of the laser crystal or the pumping power. The temperature tuning of 1.97 GHz/C [9] and the tuning of ∼140 MHz/mW [10] by changing the LD pump power were obtained for the Tm, Ho:YAG lasers. In contrast, in the present experiments the tuning of a single frequency Tm laser was obtained by changing the resonator length electronically. Furthermore, a wide step-wise tuning range was obtained by direct control of the PZT actuator. We believe that by coating the M_2 surface with a slightly higher reflectivity could further broader that range and also lead to higher single mode output power. This occurs because the finesse of C_{23} increases with the increase of R_2 [11] which leads to improved mode selectivity.

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