Pulse Stabilization in Multi-longitudinal Mode Passively Q-Switched Microchip Laser

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Abstract: Pulse stabilization in multi-longitudinal mode Yb:YAG enhanced Cr,Yb:YAG passively Q-switched microchip lasers has been achieved by carefully controlling the number, intensities of longitudinal modes and applied pump power intensity.

OCIS codes: (140.3425) Laser stabilization; (140.3615) Laser, ytterbium; (140.3480) Laser, diode-pumped; (140.3580) Laser, solid-state; (140.3540) Laser, Q-switched

1. Introduction

Diode laser pumped Cr^{4+}:YAG passively Q-switched solid-state lasers have potential applications on remote sensing, pollution detection, lidar, material processing, engine ignition, and so on[1, 2]. Yb:YAG crystals have been widely used in passively Q-switched laser for efficient high peak power laser generation [3, 4]. However, owing to the asymmetrical broad emission spectra of Yb:YAG materials, multi-longitudinal-mode oscillation is dominant in Cr^{4+}:YAG passively Q-switched Yb:YAG lasers, competition between longitudinal modes usually causes fluctuation of peak power and time jitters among laser pulses, which may cause damage to the coating or laser materials and strongly affect the stable oscillation of lasers. Multi-longitudinal modes oscillation induced laser pulse instabilities have been observed Cr,Nd:YAG self-Q-switched microchip laser [5]. Stable output pulses in Cr,Yb:YAG self-Q-switched microchip lasers were achieved due to antiphase dynamics between longitudinal modes [6]. Periodical switching laser pulses were observed experimentally in passively Q-switched Yb:YAG microchip laser with Cr^{4+}:YAG as saturable absorber[7]. The effects of the structure (intensity, wavelength, and separation of longitudinal modes) of longitudinal modes, pump power and transmission of output coupler on the stable oscillation of passively Q-switched microchip lasers have not been investigated.

In this paper, the relationship between longitudinal modes and laser pulse train in Yb:YAG enhanced Cr,Yb:YAG self-Q-switched microchip lasers was investigated. The effects of longitudinal modes, pump power levels and transmission of output coupler (T_{oc}) on the stability of laser pulse strains have been studied. Stabilized laser pulse trains with small fluctuation of peak power and time jitter between pulses have been achieved by adjusting the pump power levels and longitudinal mode structures.

2. Experiments

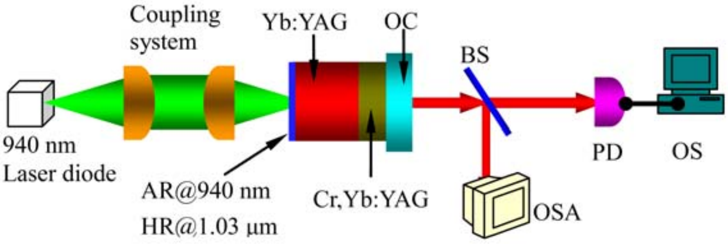

Fig. 1. Schematic diagram of laser-diode pumped Yb:YAG/Cr,Yb:YAG self-Q-switched microchip laser to study the stabilization of laser pulses. OC is the output coupler, OSA is the optical spectral analyzer, PD is the photodiode, OS is the oscilloscope, BS is the beam splitter.

The schematic diagram of experimental setup for investigation of laser pulse stabilization in laser-diode pumped Yb:YAG enhanced Cr,Yb:YAG self-Q-switched microchip lasers is shown in Fig. 1. A plane-parallel 1.2-mm-thick Yb:YAG crystal plate doped with 10 at.% Yb^{3+} ions was used as gain medium. One uncoated 0.5-mm thick Cr,Yb:YAG crystals were attached together to Yb:YAG crystal to conduct Q-switched laser oscillation and further absorb residual pump power for enhancing laser performance. The doping concentrations of Yb^{3+} and Cr ions in Cr,Yb:YAG crystal are 10 at.% and 0.025 at.%. The initial transmission of Cr,Yb:YAG crystal was measured to be 94%. Four 2-mm-thick plane-parallel mirrors with T_{oc} of 30, 40, 50 and 60% at 1030 nm were used as output couplers. A high-brightness 940 nm laser diode with a 1 µm × 50 µm emission cross section was used as the pump source. Two lenses with 8-mm focal length were used to collimate and focus the pump beam, the footprint of the pump beam spot was measured to be 80 × 80 μm^2. The laser emitting spectra were measured with ANDO (AQ6317B) optical spectral analyzer. Average output power and pulse characteristics were measured with a Thorlabs PM200 power meter and 6 GHz TDS6604 Tektronix digital oscilloscope, respectively.

3. Results and discussion

The enhanced performance of laser-diode pumped Yb:YAG/Cr,Yb:YAG self-Q-switched microchip lasers have been reported [4]. The slope efficiencies were measured to be about 34, 36, 38, and 31% for T_{oc}= 30, 40, 50, and 60%, respectively. The best laser performance was obtained in laser-diode pumped Yb:YAG/Cr,Yb:YAG microchip lasers with T_{oc} = 50%. Maximum average output power of 0.8 W was achieved at the absorbed pump power of 2.5 W with T_{oc}= 50%, corresponding optical-to-optical efficiency of 32%. The Yb:YAG/Cr,Yb:YAG self-Q-switched laser with pulse energy of 12.4 μJ, pulse width (FWHM) of 1.68 ns and peak power of 7.4 kW was obtained at the repetition rate of 65 kHz for T_{oc} = 50%.

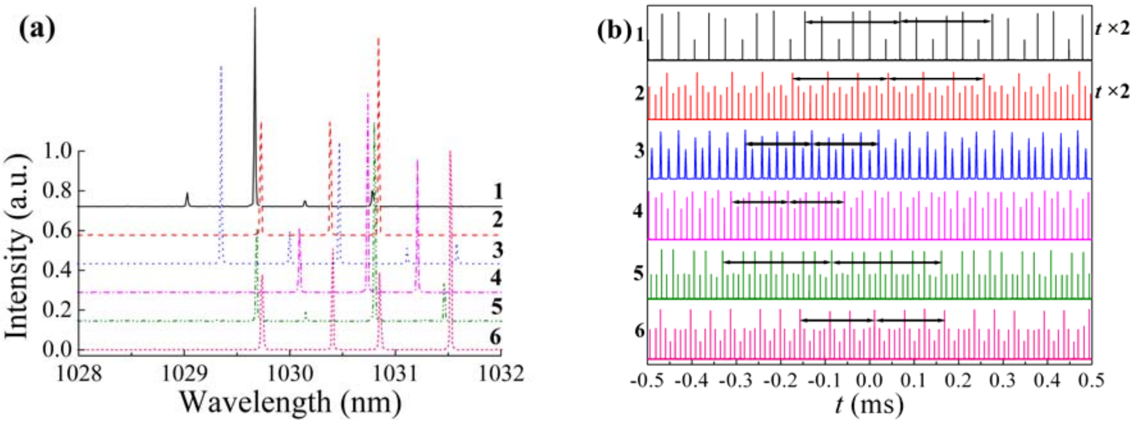

Fig. 2. (a) Laser emitting spectra and (b) Oscilloscope traces of laser pulses generated in Yb:YAG/Cr,Yb:YAG self-Q-switched microchip laser for T_{oc} = 50% at different absorbed pump power levels. Trace–1, P_{abs} = 0.48 W; Trace–2, P_{abs} = 0.89 W; Trace–3, P_{abs} = 1.3 W; Trace–4, P_{abs} = 1.7 W; Trace–5, P_{abs} = 2.1 W; Trace–6, P_{abs} = 2.53 W.

The emitting spectra and the corresponding laser pulse trains have been measured in Yb:YAG enhanced Cr,Yb:YAG microchip laser under different pump power levels for different T_{oc}. The similar multi-longitudinal mode oscillation and variation of the laser pulses were observed for different T_{oc}. Fig. 2 shows one typical example of the laser emitting spectra and corresponding laser pulse traces of Yb:YAG/Cr,Yb:YAG self-Q-switched microchip lasers for T_{oc} = 30% at different absorbed pump power levels. Four longitudinal modes oscillated at the absorbed pump power of 0.48 W. The laser emitting wavelength of the main mode, λ_L is 1029.67 nm which is just the peak emission wavelength of Yb:YAG crystal. The other three longitudinal modes oscillate at λ_L–4$\Delta\lambda_c$, λ_L+3$\Delta\lambda_c$, and λ_L+7$\Delta\lambda_c$ with relative weak intensities, as shown in trace-1 in Fig. 2(a). The corresponding laser pulse trains exhibit stable period-6 pulsation. The laser pulses generated by the side modes alternatively follows the laser pulses generated by the main longitudinal mode. Because the side modes are weak and need more time to accumulate inversion population to oscillate, the time interval between laser pulses generated by the side modes are relatively longer than that by the main mode. With further increase of the pump power, mode competition between longitudinal modes causes the intensities of longitudinal modes comparable. The side mode at λ_L–4$\Delta\lambda_c$ disappears, and three longitudinal modes oscillated at the absorbed pump power of 0.89 W, as shown in trace-2 in Fig. 2(a). Other two side modes oscillate at λ_L+3$\Delta\lambda_c$ and λ_L+7$\Delta\lambda_c$. And the intensities of the three longitudinal modes are comparable. The competition for the gain from Yb:YAG and Cr,Yb:YAG becomes severely, the time interval for alternative generation of the laser pulses becomes long, therefore, stable laser pulse train with period-16 pulsation was observed at the absorbed pump power of 0.89 W, as shown trace-2 in Fig. 2(b). Five longitudinal modes appeared simultaneously when the absorbed pump power was 1.3 W, as shown in trace-3 in Fig. 2(a). One side mode at λ_L–4$\Delta\lambda_c$ has the highest intensity compared to the main mode; the other three modes oscillating at λ_L+3$\Delta\lambda_c$, λ_L+7$\Delta\lambda_c$, and λ_L+10$\Delta\lambda_c$. The corresponding laser pulse trains exhibit period-8 pulsation, as shown in trace-3 in Fig. 2(b). Further increase of the pump power, two side modes oscillating at λ_L – 3$\Delta\lambda_c$, and λ_L+10$\Delta\lambda_c$ disappear owing to the strong mode competition, three longitudinal modes oscillated, as shown in trace-4 in Fig. 2(a). The corresponding laser pulse trains exhibit period-10 pulsation, as shown in trace-4 in Fig. 2(b). When the laser worked at the absorbed pump power of 2.12 W, the main mode with weak intensity oscillates at λ_L = 1030.15 nm, another side mode appears at λ_L–3$\Delta\lambda_c$, the other two side modes oscillate at λ_L+4$\Delta\lambda_c$, and λ_L+8$\Delta\lambda_c$. The corresponding laser pulse trains with period-20 pulsation were observed. When the absorbed pump power was 2.53 W, the Yb:YAG/Cr,Yb:YAG self-Q-switched microchip laser oscillated in four-longitudinal modes. The main mode oscillates at λ_L = 1030.41 nm, while other three longitudinal modes oscillate at λ_L–4$\Delta\lambda_c$, λ_L+3$\Delta\lambda_c$, and λ_L+7$\Delta\lambda_c$. The laser pulse trains appear as period-14 pulsation, as shown in trace-6 in Fig. 2(b).

The transmission of the output coupler has great effect on the multi-longitudinal modes and pulse trains of passively Q-switched Yb:YAG microchip laser. Fig. 3 shows the laser emitting spectra and corresponding laser pulse trains of Yb:YAG/Cr,Yb:YAG self-Q-switched microchip lasers for different T_{oc}. Under the absorbed pump power of 2.53 W, the number and the intensities of the longitudinal modes are different for different T_{oc} (as shown in Fig. 3(a)). Four longitudinal modes oscillate with 1030.41 nm as main wavelength for T_{oc} = 30%, six longitudinal modes oscillate with main wavelength of 1030.29 nm for T_{oc} = 40%, four longitudinal modes oscillate with main wavelength of 1030.31 nm for T_{oc} = 50%, five longitudinal modes oscillate with main wavelength of 1030.19 nm for T_{oc} = 60%. The number and the relative intensity of longitudinal modes vary with T_{oc}. The corresponding laser trains exhibit different variation of the pulse intensity and time jitters. Although five longitudinal modes oscillate simultaneously, the stable laser pulse train with relative low pulse intensity variation was achieved for T_{oc} = 60%. The intensity of the main mode centered at 1030.19 nm is strongest compare four side modes, the separation of longitudinal modes are relatively comparable, therefore the main mode contributes more to the laser pulse train than those side modes, therefore, the laser pulse train was stabilized.

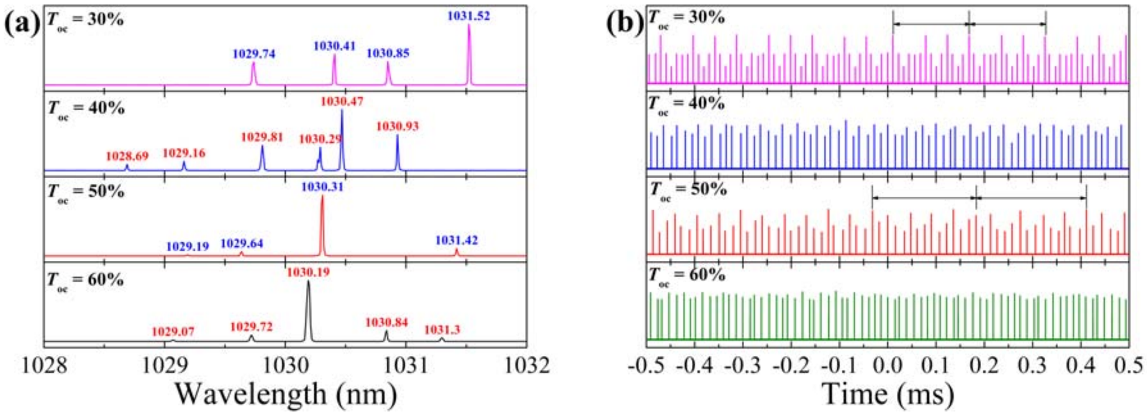

Fig. 3. (a) the laser emitting spectra and (b) laser pulse trains of Yb:YAG/Cr,Yb:YAG self-Q-switched microchip laser for different T_{oc} at the absorbed pump power of 2.53 W.

4. Conclusions

The number, separation, relative intensity of the longitudinal modes have great effect on the pulse stabilization in passively Q-switched Yb:YAG microchip lasers. The longitudinal mode structure can by adjusted by selecting proper pump power, transmission of the output coupler. The stable laser pulse trains have been achieved in passively Q-switched Yb:YAG microchip laser with 60% transmission of the output coupler at absorbed pump power of 2.53 W. The stabilization of laser pulse in passively Q-switched multi-longitudinal-mode Yb:YAG microchip laser opens a window for developing stable high peak power passively Q-switched microchip lasers based on broad emission spectra laser materials.

[1] H. Kofler, J. Tauer, G. Tartar, K. Iskra, J. Klausner, G. Herdin, and E. Wintner, "An innovative solid-state laser for engine ignition," Laser Phys. Lett. **4**, 322-327 (2007).

[2] J. J. Zayhowski, "Q-switched microchip lasers find real-world application," Laser Focus World **35**, 129-136 (1999).

[3] J. Dong, P. Deng, Y. Liu, Y. Zhang, J. Xu, W. Chen, and X. Xie, "Passively-Q-switched Yb:YAG laser with Cr^{4+}:YAG as a saturable absorber," Appl. Opt. **40**, 4303-4307 (2001).

[4] Y. Cheng, J. Dong, and Y. Y. Ren, "Enhanced performance of Cr,Yb:YAG microchip laser by bonding Yb:YAG crystal," Opt. Express **20**, 24803-24812 (2012).

[5] J. Dong, and K. Ueda, "Longitudinal-mode competition induced instabilities of Cr^{4+},Nd^{3+}:$Y_3Al_5O_{12}$ self-Q-switched two-mode laser " Appl. Phys. Lett. **87**, 151102 (2005).

[6] J. Dong, A. Shirakawa, S. Huang, Y. Feng, T. Takaichi, M. Musha, K. Ueda, and A. A. Kaminskii, "Stable laser-diode pumped microchip sub-nanosecond Cr,Yb:YAG self-Q-switched laser," Laser Phys. Lett. **2**, 387 - 391 (2005).

[7] J. Dong, A. Shirakawa, and K. Ueda, "Switchable pulses generation in passively Q-switched multilongitudinal-mode microchip laser," Laser Phys. Lett. **4**, 109 - 116 (2007).