Passively Q-switched Diode-Pumped Thulium Laser at 2305 nm

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In recent years, there is a growing interest to thulium (Tm) lasers operating at $\sim 2.3 \mu\text{m}$ according to the $^3\text{H}_4 \rightarrow ^3\text{H}_5$ transition [1, 2]. Such short-wavelength infrared emission is of practical importance for sensing of atmospheric species (HF, CO, CH₄ and H₂CO). Guillemot *et al.* reported on a continuous-wave (CW) Tm:KY₃F₁₀ laser delivering 0.84 W at 2331–2346 nm with a slope efficiency of 53.8% [1]. Canbaz *et al.* developed a Kerr-lens mode-locked Tm:LiYF₄ laser emitting femtosecond (514 fs) pulses at 2303 nm [2]. However, so far, little attention was paid to passively Q-switched (PQS) Tm lasers at $\sim 2.3 \mu\text{m}$. In the present work, we report on a diode-pumped PQS Tm:LiYF₄ laser operating on the $^3\text{H}_4 \rightarrow ^3\text{H}_5$ transition and delivering stable pulsed output without any colasing at $\sim 1.9 \mu\text{m}$.

The scheme of the laser is shown in Fig. 1(a). A hemispherical cavity was formed by a flat pump mirror (PM) coated for HT at $\sim 0.78 \mu\text{m}$ and for HR at $2.12 - 2.50 \mu\text{m}$ and two concave output couplers (OCs, RoC = -100 mm) having a transmission T_{OC} of 0.7% or 1.3% at $2.18 - 2.35 \mu\text{m}$. The OCs also provided HT at $\sim 1.9 \mu\text{m}$. The laser crystal was an *a*-cut 3.5 at.% Tm:LiYF₄ (thickness: 8.1 mm). The pump source was a fiber-coupled $\sim 788 \text{ nm}$ AlGaAs laser diode. As a saturable absorber (SA) material, we have selected Cr²⁺-doped ZnSe. The small-signal (unsaturated) absorption due to the Cr²⁺ ions at the laser wavelength α'_{SA} was 0.5%, the ground-state absorption cross-section σ_{GSA} was estimated to be $0.024 \pm 0.01 \times 10^{-18} \text{ cm}^2$ and the saturation fluence $F_s = 3.6 \pm 1 \text{ J/cm}^2$.

Fig. 1 Diode-pumped Tm:LiYF₄ laser operating on the $^3\text{H}_4 \rightarrow ^3\text{H}_5$ transition passively Q-switched by a Cr²⁺:ZnSe SA: (a) scheme of the laser: LD – laser diode, PM – pump mirror, OC – output coupler, F – filter; (b) input-output dependences, η – slope efficiency; (c) typical spectra of laser emission, $T_{\text{OC}} = 1.3\%$. The laser emission is π -polarized.

In the CW regime, the laser generated 1.41 W at 2302–2308 nm with a slope efficiency η of 20.8% and a laser threshold of 1.39 W ($T_{\text{OC}} = 1.3\%$), Fig. 1(b,c). After inserting the Cr²⁺:ZnSe SA, stable Q-switching was achieved. The maximum average output power amounted to 357 mW at 2304.6 nm (the spectrum was narrowed) with smaller η of 5.0% and an increased threshold of 3.24 W (for the same OC), Fig. 1(b,c). The laser emission was linearly polarized (π -polarization). The dependence of pulse characteristics (duration and energy) on the pump power is shown in Fig. 2(a,b). The shortest pulses (870 ns / 4.4 μJ) were achieved at an intermediate pump level corresponding to a pulse repetition frequency (PRF) of 45.9 kHz using 1.3% OC. Single Q-switched pulses possessed a nearly Gaussian temporal shape, Fig. 2(c). The PQS Tm laser exhibited excellent long-term stability and less than 5% intensity fluctuations in the pulse train, Fig. 2(d). The laser operated in the fundamental transverse mode (the measured $M^2_{x,y} < 1.4$). The laser performance was simulated using a model of a quasi-four-level gain medium and a “slow” SA showing good agreement with the experiment. Laser experiments with Fe²⁺:ZnSe SAs are ongoing.

Fig. 2 Pulse characteristics of the passively Q-switched Thulium laser: (a) pulse duration (FWHM), (b) pulse energy; (c) oscilloscope traces of single Q-switched pulses, $T_{\text{OC}} = 1.3\%$; (d) oscilloscope trace of a pulse train, PRF – pulse repetition frequency, $T_{\text{OC}} = 0.7\%$, $P_{\text{abs}} = 6.23 \text{ W}$.

References

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