Passive Q-switching of a diode-pumped Tm,Ho:YLF laser using Cr:ZnSe saturable absorber

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Abstract: We report on passive Q-switching of a Tm,Ho:LiYF_4 laser with Cr:ZnSe saturable absorber achieving for the first time short (~50 ns) pulse durations and high (~640 W) peak power from such a diode-pumped Ho-laser.

OCIS codes: (140.5680) Rare earth and transition metal solid-state lasers; (140.3540) Lasers, Q-switched; (140.3480) Lasers, diode-pumped

Due to strong water absorption, the eye-safe emission of Tm^{3+}-doped, Ho^{3+}-doped, or Tm^{3+}, Ho^{3+}-co-doped lasers around 2 µm is interesting for many medical applications, remote sensing (LIDAR) as well as for pumping optical parametric oscillators (OPOs) for efficient frequency down-conversion into the mid-IR [1]. High pulse energy and peak power are advantageous for these applications since they can be achieved at relatively low average power if compared to continuous-wave (CW) regime of operation. For medical applications, the pulse duration and repetition rate are essential parameters that determine the interaction mechanisms with the tissue. Depending on the diagnostic findings and the art of therapy, most medical treatments are carried out either with a Tm- or a Ho-laser. Ho-lasers, both single and co-doped, have slightly longer emission wavelength than Tm-lasers, the difference is typically 50-150 nm. Although small, this difference results in quite different penetration depth in soft tissue, which could be, e.g., 3-4 times larger for Ho-lasers [1]. Taking advantage of the absorption band of Tm^{3+} ions around 800 nm and the efficient energy transfer between Tm^{3+} and Ho^{3+} ions, Tm, Ho-co-doped laser media can be diode-pumped (DP) by well established AlGaAs laser diodes designed for Nd^{3+}-ion pumping. Passive Q-switching of such DP solid-state lasers (DPSSL) by an intracavity saturable absorber (SA) is a common technique to generate short and high peak power pulses, mainly due to the simplicity and low cost. Combining those advantages a DP passively Q-switched (PQS) Tm, Ho-co-doped laser is a simple, inexpensive and reliable source of short pulses slightly above 2 µm.

In contrast to DP PQS Tm-lasers, where sub-10-ns pulses with energies >1 mJ were achieved [2], we are aware of only one demonstration of sub-1-µs DP PQS Tm, Ho-co-doped laser, where pulses as short as 354 ns were generated with cryogenically cooled Tm,Ho:GdVO_4 and the maximum pulse energy reached 70.5 µJ [3]. The situation is quite unsatisfactory and difficult to explain because such pulse durations are much longer than typically achieved with active Q-switching. Here we report on a Tm^{3+}, Ho^{3+}-co-doped LiYF_4 (Tm,Ho:YLF) laser, PQS with Cr^{2+}:ZnSe SA. YLF belongs to the family of fluoride crystals which exhibit longest energy storage times (~10 ms for the 2-µm Tm- and Ho-laser transitions) and with which we obtained the best results for Tm-based PQS DP lasers using Cr^{2+}:ZnS SAs [2,4]. With Tm,Ho:YLF we were now able to achieve stable Q-switching at 2051 nm with pulse durations as short as 40 ns and peak powers 3 to 200 times higher than in previous work on such co-doped lasers.

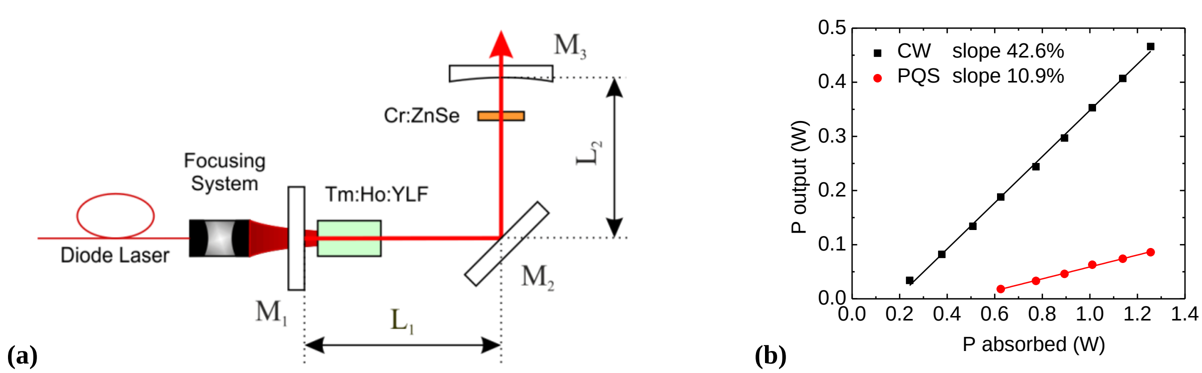

Fig. 1. (a) Setup of the PQS Tm,Ho:YLF laser. M_1: dichroic pump mirror, M_2: HR-laser, HT-pump mirror, M_3: output coupler. (b) Output power vs. absorbed pump power for 5.8% OC in CW and PQS regimes.

An L-shape hemispherical resonator as shown in Fig. 1a was employed in which the non-absorbed pump power cannot reach the SA, an effect causing instabilities in simple two-mirror cavities. The pump beam is delivered through the plane mirror (M_1), antireflection (AR) coated for the pump wavelength and high reflection (HR), >99.9%, coated for 1800-2090 nm. As output coupler (OC, M_3) we used curved mirrors with radius of curvature of -75 mm and transmission T_{OC}=1.5%, 3.5%, 5.8%, 10% and 18% (at 2050 nm). The bending mirror (M_2) was plane, highly transmitting (HT) the pump and HR for the laser radiation at 45°. The pump source was a fiber-coupled (NA=0.15, 105 μm core diameter) AlGaAs diode laser capable of delivering up to 11.6 W (incident on the laser crystal, unpolarized) at 792.5 nm. The focal spot achieved in the position of the crystal with an f=20 mm lens assembly had a diameter of 210 μm. The Tm:Ho:YLF crystal was doped with 5.2 at.% Tm and 0.5 at.% Ho. The active element (AE) had dimensions of 2.63(a)×3.07(c)×3.68(a-cut) mm^3. It was uncoated and mounted with two lateral surfaces in contact with a Cu holder cooled by circulating water at 16ºC for heat dissipation. Polycrystalline Cr^{2+}:ZnSe was chosen as SA because it shows about three times higher ground-state absorption at 2050 nm ($\sigma_{gsa}=2.1\times10^{-19}$ cm^2). Our sample (IPG Photonics) was specified with low signal transmission (corrected for Fresnel reflections) of T_0(1910 nm)=76% which is equivalent to T_0(2050 nm)=92%. It was AR-coated which reduced the Fresnel reflection to <0.5% per surface at 1910 nm. The SA element was 0.82 mm thick with lateral dimensions of 4.9×5.0 mm^2. The separation L_1 in Fig. 1a was fixed at 50 mm while L_2 was 25 mm in the case of CW lasing and 23 mm when the SA was inserted. The Gaussian diameter of the TEM_{00} mode was calculated to be 210 μm in the AE and 700 μm in the SA which ensured operation in the fundamental transversal mode.

The DP Tm:Ho:YLF laser performance was first studied in the CW regime with the 5 different OCs, up to an absorbed pump power of ~1.3 W. Maximum output power of 472 mW and slope efficiency of 42.6% were achieved with T_{OC}=5.8% (Fig. 1b). The AE absorption was measured to be ~64% in lasing conditions, almost independent of pump power. The laser wavelength shifted from 2065 to 2052 nm with increasing T_{OC}.

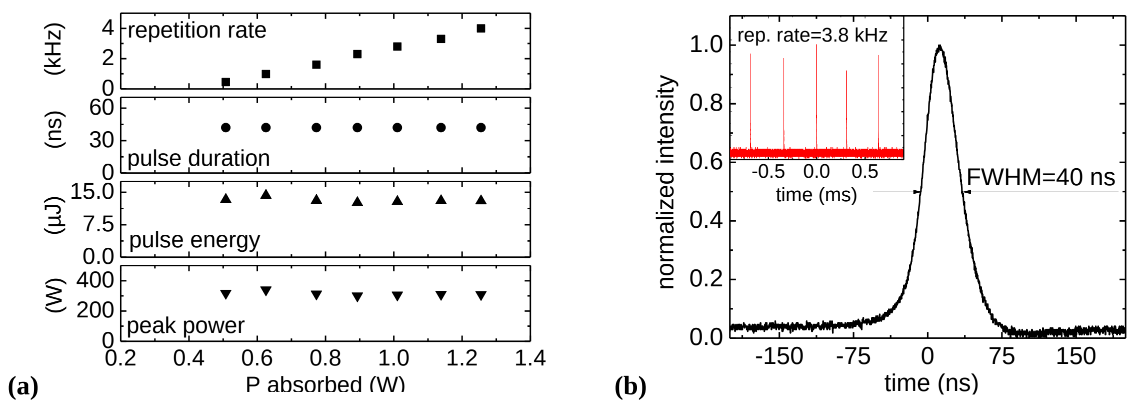

Fig. 2. Repetition rate, pulse duration, output energy and peak power of the PQS Tm,Ho:YLF laser vs. absorbed pump power for T_{OC}=1.5% (a) and Q-switched pulse shape and pulse train (inset) (b).

PQS operation was achieved for T_{OC}=1.5%, 3.5%, 5.8%, and 10%. The maximum average output power with T_{OC}=5.8% reached 86 mW at an absorbed pump power of 1.3 W, corresponding to slope efficiency of 10.9% (Fig. 1b) and 18.2% of Q-switching to CW extraction efficiency. The output pulses were monitored with a high speed InGaAs photodiode (>12.5 GHz at 2 μm) and a 1 GHz oscilloscope. The maximum pulse energy reached 33 μJ, the pulse duration varied slightly between 45 and 54 ns, and the repetition rate increased from 600 to 3400 Hz with the pump power. The maximum peak power achieved (~640 W at 2100 Hz) is more than 3-times higher than in [3]. Slightly shorter pulses of 40 ns were achieved with T_{OC}=1.5% (Fig. 2b). However, the average output power and pulse energy were almost twice lower – 46 mW and 14 μJ, respectively, at similar (600-3800 Hz) repetition rates, Fig. 2a. In contrast to the CW case the wavelength in PQS operation was the same (2051 nm) for all OCs.

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