Efficient, high peak power Tm:YLF laser

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Abstract—We demonstrate efficient generation of a diode pumped, passively cooled Tm:YLF laser, end-pumped by a 25-W fiber coupled laser diode. Over 5W of output power was achieved for a 25-W pumping laser and for an elongated 120-mm cavity. For the free-running and Q-switching regimes, the output spectrum was centered at 1908-nm with a linewidth less than 7nm. In the experiments on active Q-switching, up to 5.5mJ of output energy was demonstrated with a pulse duration of 11ns, corresponding to ~0.5 MW of peak power.

The mid-infrared spectral range (~1800-5000 nm) is an area of particular interest in leading laboratories in the world. This interest has been mainly driven by the fact that this spectral band contains many characteristic absorption lines of numerous chemical and biological compounds, which makes it vital for applications in e.g. spectroscopy, chemical fingerprinting, security, remote sensing and many others. Many of these applications usually require the use of suitable laser sources operating at wavelengths beyond 1.8µm, like thulium solid-state [1-2] and fiber [3-5] lasers, holmium lasers [6,7], semiconductor crystals lasers with chromium or iron doping ($Cr:A_{II}B_{VI}$) [8], parametric generators [8] and mid-infrared supercontinuum sources [e.g. 10-12].

The main goal of this research was to develop the laser set-up showing the feasibility of q-switched, diode pumped bulk laser based on Tm^{3+}:YLF crystal, operating at ~1.9-2 µm wavelength. As a result of the cross relaxation process (quantum efficiency ~ 2), the effective optical efficiency of diode pumped Tm lasers can be comparable to typical efficiencies of diode pumped neodymium lasers. Moreover, owing to a wide absorption bandwidth of thulium doped crystals, the same pumping diodes operating at ~0.8 µm wavelength can be used.

In the experiment we used a thulium-doped crystal with a 3.5% thulium ions concentration and cylindrical geometry with a 3mm diameter and 10mm length. The crystal was cut along the a-axis. The medium was mounted in a copper heat sink, which was placed on an aluminum radiator. The radiator was cooled by two 3W electrical fans providing an air flow of about 67m^3/h.

Two different fiber coupled bars were used as pump sources. The maximum available output power of the first one (PD1) was about 70W at a wavelength of 792nm. The diode was mounted on a copper heat sink which temperature was stabilized by four Peltier's elements (each one 50W). The hot surface of the TEC was connected to the central water cooling system. The output power of the second diode (PD2) was about 25 W. It was cooled in the same way as the previous one. The central wavelength of the pump light changed with the temperature of the diode (which was utilized to match the laser linewidth to the absorption band of Tm:YLF crystal), but also with a current amplitude and duty factor. Due to the significant influence of current parameters influencing the wavelength of pump radiation, the optimal operation was possible only for one working point. The laser diode spectrum and absorption spectrum of one of the crystals are presented in Fig. 1.

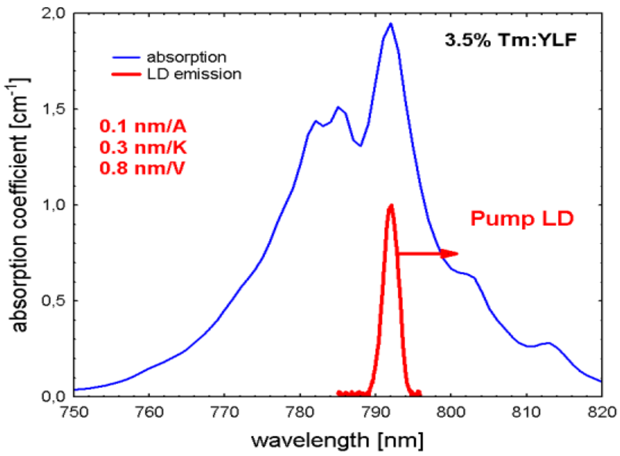

Fig. 1. Pumping diode emission spectrum and active medium absorption spectrum for non polarized pump.

Laser diode marked as PD1 was used to investigate absorption properties of the laser crystal and PD2 was used in generation characterization.

Figure 2 presents the scheme of a laser resonator. The diode radiation coming out of the pigtail fiber (200µm core, 0.22NA) was focused into the active medium by a set of two lenses with anti-reflection coatings (22mm and 33mm focal length), throughout a flat dichroic mirror, resulting in approximately an 0.3mm pump beam diameter inside the crystal. The output coupler was characterized by a transmission of 30%. To obtain pump and laser

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resonator mode matching, the radius of the mirror curvature was 200mm. The fundamental resonator mode diameter inside thulium doped crystal was about 280µm.

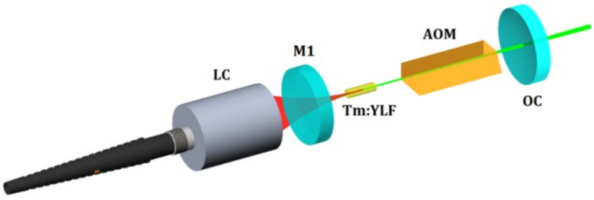

Fig. 2. Scheme of the resonator

The preliminary experiments included absorption spectrum measurements and absorption saturation determination. The absorption properties of investigated samples were determined in the setup shown in Fig. 3. For the estimation of unabsorbed pump power, a dichroic mirror was used. It also prevented recording spontaneous emission affecting the accuracy of the laser output. Absorption efficiency measurements are presented in Fig. 4. The decrease in the absorption with an increase in the pump power is due to the pump beam saturation.

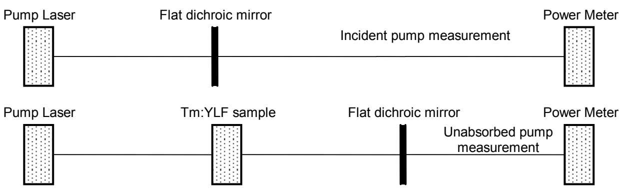

Fig. 3. Experimental setup for the pump absorption measurements.

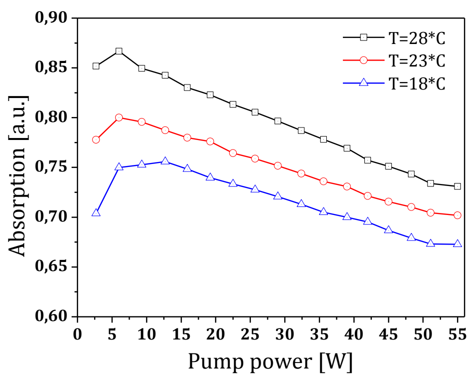

Fig. 4. Absorption efficiency of the Tm:YLF crystals measured for different temperature of pumping laser diode.

In free-running regime examination, Tm:YLF sample was placed inside a linear resonator (Fig. 2). The length was about 120mm to provide space for placing an AO-modulator. The pump repetition rate was set to be 20Hz and the pulse duration was about 5ms. This configuration, for 10% duty factor, enabled us to completely diminish laser generation by an AO-modulator when the radio frequency power was on. For the optimized laser, the output power was measured to be over 5W by 50% of slope efficiency. The results of the experiment are presented in Fig. 5.

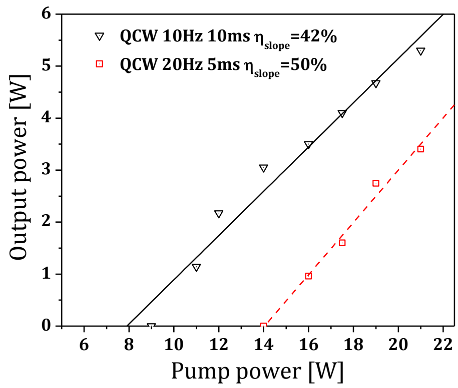

Fig. 5. Output power vs. incident pump power, 10% pumping duty factor.

An acousto-optic modulator, mounted on a copper heat-sink, and operating at a radio frequency of 40.7MHz with a maximum power of 20W was used for Q-switching. For the maximum RF power of acousto-optic modulator, the diffraction angle was about 7mrad. At the maximum output of the laser at 10ms pumping pulses, the AO modulator was unable to hold off generation. Our first step was to determine the maximum available output energy in free-running, for which the acousto-optic modulator can hold off oscillations for switch on state by shortening pumping pulse duration to 5ms. The laser output was horizontally polarized (perpendicularly to c-axis of the Tm:YLF crystal).

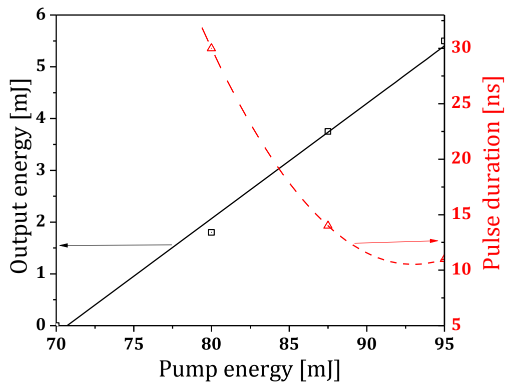

Fig. 6. Output energy and pulse duration vs. incident pump energy.

The results of measurements of pulse duration and energy for a low duty factor of 10% (20Hz pump repetition rate and 5ms pump duration) are shown in

Fig. 6. The shortest pulses of 11ns duration and 5.5mJ energy corresponding to 0.5MW of peak power were demonstrated for the best case of stable output (Fig. 7).

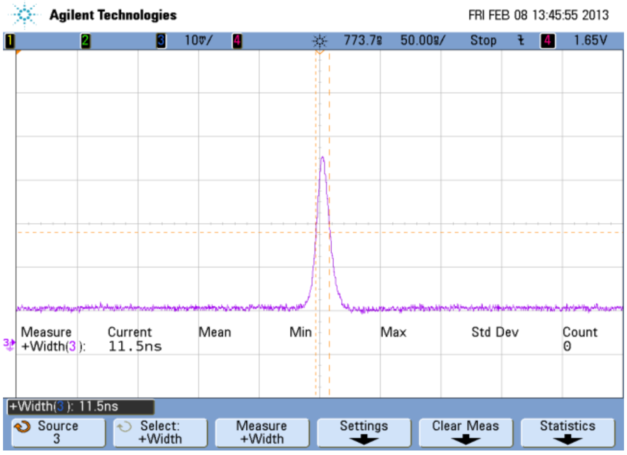

Fig. 7. Half megawatt laser pulse with energy 5.5mJ.

Beam quality measurements were conducted by means of a Spiricon3 Pyrocam camera. The output laser beam diameter was measured along the propagation axis after focusing lens (300 mm focal length). The results were approximated with a parabolic propagation law for the Gaussian beam (Fig. 8). Laser beam parameters were calculated to be: 3.5 mrad divergence angle and M^2 parameter less than 1.15.

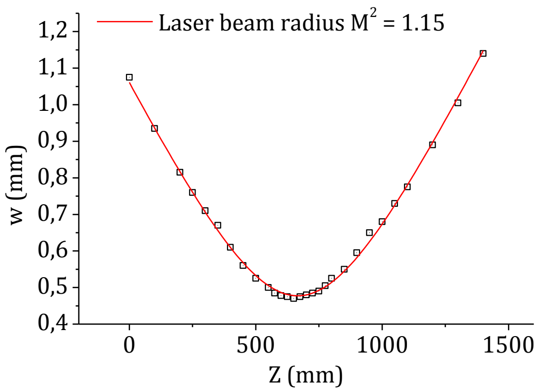

Fig. 8. Output beam radius as a function of the distance from the focusing lens.

We demonstrated efficient generation of a diode pumped Tm:YLF laser, end-pumped by a 25W fiber coupled laser diode bar. The incident pump density exceeded the saturation pump density over 5 times. As a result, the drawbacks of quasi-three-level scheme were mitigated. The best output characteristics (slope and maximum power) were obtained for out-coupling losses of 30% evidencing a high roundtrip gain for maximum pump power. Over 5W of output power was demonstrated for a 25W pumping laser for a 120mm cavity. For the free-running and Q-switching regimes, the output spectrum was centered at 1908nm with linewidth less than 7nm. In the experiments on active Q-switching realized with the use of an acousto-optic modulator, up to 5.5mJ of output energy was demonstrated. Further pulse energy scaling up was limited by the damage of laser components. For a 20Hz repetition rate and a 10% pump duty cycle, near 0.5MW of peak power in a 11ns duration pulse was achieved. The output laser beam was of very good quality. The divergence angle and M^2 factor were measured to be 3.5 mrad and 1.15, respectively.

The output parameters of the developed lasers, especially relatively high pulse energy in the q-switched regime, make the laser a promising pumping source for e.g. Cr^{2+}:ZnSe laser, holmium lasers or ZGP-based optical parametric oscillators operating in the mid-IR spectral region.

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