Diode-Pumped Long-Pulse-Width Tm:YAG Laser at Room Temperature


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Abstract—We report the pulsed-diode-pumped and acoustics-optically Q-switched operation of a long-pulse-width Tm:YAG laser at room temperature. Output energy for single pulse of 48 mJ is obtained under the incident pump energy of 217.3 mJ, corresponding to a slope efficiency of 30.2% and an optical conversion efficiency of 22.1%. For the Q-switched regime, maximum pulse energy of 3.25 mJ and the pulse width of 232.8 ns at the repetition rate of 30 Hz are achieved. The wavelength of the Q-switched laser is 2.013 μm. A beam quality factor of $M^2 < 1.4$ is measured using the traveling 90/10 knife-edge method.

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1. INTRODUCTION

Diode-pumped Tm-doped solid-state lasers operating at 2 μm have numerous applications in areas ranging from remote sensing, medicine to laser radar [1–6]. The requirement for high power has restricted the scope for choice in laser material to crystals, such as Tm:YAG, which have good thermo-mechanical properties and hence a high fracture limit. In common with many other Tm-doped crystals, Tm:YAG has the attraction of a quantum efficiency of 2, when it is doped with high concentrations of Tm³⁺ sufficiently, due to efficient cross-relaxation with neighboring Tm³⁺ ions, which results in two excited Tm³⁺ ions for each absorbed pump photon. In addition, Tm:YAG also benefits from a long fluorescence lifetime of 11 ms, which is attractive for high-energy Q-switched operation [7]. However, Tm:YAG is a quasi-three-level laser material at room temperature, the thermally populated of the lower laser level affects the laser characteristics when the pump power becomes higher. Many researchers reported the laser characteristics of the continuous-wave operation of the Tm:YAG laser by now [8–11]. By the improvement of releasing thermal effect, in 2002, K.S. Lai and W.J. Xie achieved 150-W continuous-wave diode-side-pumped Tm:YAG laser by using the compound parabolic concentrator [12]. But the reports about the pulse laser operation of Tm:YAG laser were not much. Low gain and high saturable reabsorption loss in Q-switched system may still be the main problems. As well known, the pulse laser with short pulse width and high peak power is used to be the pump sources for mid-infrared optical parametric oscillators. In 2002, Sharone Golding et al., reported a diode pumped 2-μm Tm:YAG laser operating in a pulsed mode, with an RTP Pockels cell as the Q-switch generator [13]. A maximum output of 2.4 mJ with a pulse width of 57 ns was achieved. In 2008, Marc Eichhorn and Antoine Hirth reported on an RTP Q-switched Tm:YAG which produced 4 mJ of 2.013 μm pulse energy in 80 ns FWHM pulses at a pulse repetition frequency of 100 Hz as a pump source of a ZGP-OPO to generate mid-IR 3–5 μm radiation [14]. But for accurate wind velocity measurements, commercial aircraft safety or global wind monitoring, long pulse lengths Tm:YAG laser is required to achieve the narrow transform-limited bandwidths, which is needed to measure wind velocity to within ±1 m/s [15]. In 1991, Paul J. M. Suni and Sammy W. Henderson reported a Tm:YAG laser with a compact acousto-optic (PbMoO₄) as the Q-switch generator, produced 1.05 mJ of energy in 330 ns FWHM pulses at a pulse repetition frequency of 100 Hz [16].

In this paper, we demonstrated the pulse-diode-pumped and acoustics-optically Q-switched operation of a Tm:YAG laser at room temperature. Pulse output energy of 48.0 mJ is obtained under the incident pump energy of 217.3 mJ, corresponding to a slope efficiency of 30.2% and a conversion efficiency of 22.1%. For the Q-switched regime, maximum pulse energy of 3.25 mJ and pulse width of 232.8 ns at the repetition rate of 30 Hz are achieved. The wavelength of the Q-switched laser is 2.013 μm. A beam quality factor of $M^2 < 1.4$ is measured using the traveling knife-edge method.

2. EXPERIMENTAL SETUP

The cavity configuration is shown in Fig. 1. One YAG laser rod with 4 mm diameter and 10 mm length doped with 3.5 at % Tm is used in our resonators. The
faces are polished plane, parallel and coated antireflection near 785 nm and 2.01 µm. A peak-to-peak power of 30-W fiber-coupled laser-diode (LD) is used as the pump source. The output wavelength of the LD is centered at 785 nm, whose wavelength coincides with the 785 nm Tm³⁺ absorption band. The fiber core has a diameter of 400 µm and a numerical aperture of 0.22. The mode matching between pump mode and laser mode is optimized by changing the pump beam waist radius and its location. The fiber-coupled diode laser output beam is shaped and focused by a series of convex lenses. The pump waist is imaged to 800 µm, and is positioned ~2 mm inside the Tm:YAG crystal. The pulse repetition rate and the pulse width of the pump laser can be changed to achieve high efficiency laser output. The radius of curvature of the convex input mirror is selected as ~300 mm to provide partial compensation of the thermal lens in the laser rod. The pump input mirror is high reflective at the wavelength near 2.01 µm (R > 99.5%) and high antireflective at the wavelength about 790 nm (R < 0.5%). A 46 mm long fused silica fused-silica acoustic-optical Q-switch with low insertion loss is used to produce Q-switched operation. The resonator is then completed with a concave output coupler. The radii of curvature and the transmission at 2.01 µm of the output coupler are 300 mm and 5.8%, respectively. Many cavity lengths are used to achieve long pulse width. The operation temperature of the crystal is 288.7 K.

3. EXPERIMENTAL RESULTS

The output pulse energy of Tm:YAG laser at 30 Hz repetition rate as a function of pump energy at room temperature is illustrated in Fig. 2. The slope efficiencies are 25.3, 15.0, 20.7, and 18.4% for the cavity lengths of 120, 170, 195, and 220 mm, respectively. When the cavity length is up to 275 mm, a maximum optical-to-optical efficiency of 22.1%, corresponding to laser output energy of 48.0 mJ for pump energy of 217.3 mJ, is achieved with a 94.2%-reflecting output coupling mirror. The slope efficiency for this case is 30.2%. Even higher overall efficiencies can be obtained by increasing the pumped length of laser rod.

![Fig. 1. Experimental setup of the Tm:YAG laser at room temperature.](image)

![Fig. 2. The pulse output energy of Tm:YAG laser at 30 Hz repetition rate at room temperature.](image)

![Fig. 3. The pulse width versus output energy at different cavity length at the repetition rate of 30 Hz.](image)