1. INTRODUCTION

Solid-state lasers working in 2 µm eye-safe spectral regions have attracted general interest, since 2 µm lasers could be applied in many applications, such as atmosphere sensing, range-finding, and coherent laser radar [1–3]. In addition, 2 µm Q-switched lasers are attractive sources for optical parametric oscillators (OPOs) and solid-state lasers further in mid-infrared spectral region like Cr2+:ZnSe lasers [4–6]. Tm lasers, Ho lasers and Tm–Ho co-doped lasers emerging as efficient and potential 2 µm sources have been investigated by many researchers [7–14]. Compared with singly doped Tm3+ or Ho3+ lasers, the Tm–Ho co-doped lasers benefit of the two-for-one pumping of the Ho3+ ions into the upper laser level via cross relaxation and efficient energy transfer from Tm3+ to Ho3+ [15] and display remarkable properties such as long fluorescence lifetime, large cross section and excellent energy storage capability [16]. Among the rare-earth doped host materials, GdVO4 is a promising host to achieve high-power output because of its excellent properties such as large stimulated emission cross-section and thermal conductivity (11.7 W/m K) [17]. Numbers of researches about high power, single longitudinal mode, application in ZGP pump source and the thermal focal length of Tm, Ho:GdVO4 have been reported before [18–22].

AO Q-switch and EO Q-switch are two main convenient laser Q-switch manners. On one hand, AO Q-switch has been widely applied to obtain pulsed coherent radiation. In 2006, Y. Z. Wang et al. reported a Tm, Ho:GdVO4 laser with a continuous-wave (CW) output power up to 10.5 W, and average power of 10.1 W at 10 kHz in AO Q-switched mode [23]. As much as 12.2 W output for the CW operation in Tm, Ho:GdVO4 laser, and 11.6 W output for AO Q-switched operation at 10 kHz have been obtained [24]. However, limited by the long travel time of acoustic waves and the single-pass dynamic losses, AO Q-switch is not suitable for high-gain lasers with unfocused beam. On the other hand, EO Q-switch can be efficient for high-gain and high-repetition rate solid-state lasers. Ferroelectric oxide RTP has superior non-linear optical properties: good electro-optic characteristics, low dielectric constant, low optical insertion loss and high laser damage threshold. In 2008, S. So et al. reported an RTP Q-switched Ho:YAG laser which obtained 14 mJ with a pulse duration (FWHM) of 18 ns at 100 Hz [25]. In 2009, up to 5.6 mJ at 100 Hz was obtained by use of RTP Q-switch in Tm:YAG laser [26]. However, to the best of our knowledge, there is no report on the comparison between AO Q-switch and EO Q-switch in Tm, Ho:GdVO4 laser.

In this letter, we compared performances of the AO Q-switched and RTP EO Q-switched Tm, Ho:GdVO4 laser at 300 Hz, 500 Hz, 1 kHz, and 10 kHz. At relatively low PRF (300 Hz, 500 Hz, and 1 kHz), AO Q-switch and RTP EO Q-switch operation performed similarly to each other. Up to 1.7 mJ with pulse width of 28 ns and 17.2 ns was achieved under pump power of 6.96 and 8.87 W in RTP EO Q-switch mode and AO Q-switch mode, respectively. At 10 kHz, the pulse width of EO Q-switch scheme was narrower than that of AO Q-switch scheme. At the pump power of 8.87 W, the pulse width of 85 and 110 ns was achieved in EO Q-switch and AO Q-switch, corresponding to the peak power of 2.6 and 1.6 kW, respectively. The hold-off capability of RTP EO Q-switch was better than that of AO Q-switch at high pulse repetition rate.

DO: 10.1134/S1054660X11030157

Abstract — In this paper, we demonstrated the comparison of acousto-optic (AO) Q-switch and RTP electro-optic (EO) Q-switch in Tm (5 at %), Ho (0.5 at %) : GdVO4 laser at different pulse repetition rate. At relatively low repetition rate (300 Hz, 500 Hz, and 1 kHz), AO Q-switch and RTP EO Q-switch operation performed similarly to each other. Up to 1.7 mJ with pulse width of 28 ns and 17.2 ns was achieved under pump power of 6.96 and 8.87 W in RTP EO Q-switch mode and AO Q-switch mode, respectively. At 10 kHz, the pulse width of EO Q-switch scheme was narrower than that of AO Q-switch scheme. At the pump power of 8.87 W, the pulse width of 85 and 110 ns was achieved in EO Q-switch and AO Q-switch, corresponding to the peak power of 2.6 and 1.6 kW, respectively. The hold-off capability of RTP EO Q-switch was better than that of AO Q-switch at high pulse repetition rate.
power of 2.6 and 1.6 kW, respectively. To some degree, the hold-off capability of RTP EO Q-switch is better than that of AO Q-switch at high pulse repetition rate.

2. EXPERIMENTAL SETUP

Figure 1 shows the experimental setup of the Q-switched Tm, Ho:GdVO₄ laser. The pump source laser diode with temperature tuned emission wavelength to 802 nm was coupled with a fiber of which the diameter and numerical aperture was 400 µm and 0.22, respectively. The pump beam was reimaged to a diameter of ~800 µm within the crystal by a telescope (L1 and L2 in Fig. 1). The Tm, Ho:GdVO₄ crystal of 7 mm in length and 4 × 4 mm² in cross section was doped with 5 at % Tm and 0.5 at % Ho. Both end faces of the crystal were anti-reflection (AR) coated with the laser wavelength around 2.0 µm and the diode-pump wavelength around 800 nm. The crystal was wrapped in indium foil and held in a copper heat-sink connected with a small dewar filled with 350 mL liquid-nitrogen for cooling. An L shaped cavity with a physical length of 195 mm was adopted. The input mirror of M1 was coated with high reflection (R > 99.5%) at 2.05 µm, and high transmission (T > 99%) at pump wavelength. The 45° folding mirror was highly reflected at 2.05 µm and highly transmitted at pump wavelength. The output coupler coated with 40% transmission at 2.05 µm was a concave mirror with radius of curvature of 500 mm. The Q-switch was inserted between M2 and M3.

3. EXPERIMENTAL RESULTS

For AO Q-switch operation, a 40 mm long AO Q-switch (Gooch and Housego, Ltd.) with an acoustic aperture of 1.4 mm was used and it was made of quartz. The rated radio frequency power was 50 W with a radio frequency of 40.7 MHz. For EO Q-switch operation, two 3 × 3 × 21 mm³ RTP crystals were set with mutually perpendicular orientations of the z-axis for compensating thermo. The transmission at laser wavelength of the AR coated RTP crystals and the AO Q-switch was measured to be about 97%. The quarter wavelength voltage of RTP EO Q-switch was nearly 1 kV.

In the experiment, the laser pulse temporal signal was detected by an InGaAs detector connected with a 350 MHz digital oscilloscope (wavejet 332, Lecroy). The performance of AO Q-switch and RTP EO Q-switch Tm, Ho:GdVO₄ laser at 300 Hz, 500 Hz, and 1 kHz is shown in Figs. 2–4, respectively. At 300 Hz, under the pump power of 8.87 W, the maximal output average power of 517 mW and pulse energy of 1.7 mJ in AO Q-switch scheme was achieved. In the RTP EO Q-switch scheme, maximum output was 512 mW at the pump power of 6.96 W and the pulse energy was 1.7 mJ. The pulse width was 28.1 ns, which was broader than that of AO Q-switch operation (17.2 ns). Both the schemes existed the phenomenon that slope efficiency decreased with increasing input power. It may be caused by the thermal effects in the laser crystal. At 500 Hz or 1 kHz, the two Q-switch schemes performed similarly with respects to threshold, efficiency and output power. The maximal output was the same (~740 mW) at 500 Hz, corresponding to the