Compact Passively Q-Switched Tm:KY$(WO_4)_2$ Laser

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Abstract

Diode-pumped thulium lasers emitting in the spectral range near 2 μm are attractive for applications in different areas: surgery, rangefinding, and environmental atmosphere monitoring. In this article the latest results of Tm:KYW laser performance with a polycrystalline Cr:ZnSe as the most available saturable absorber for 2 μm spectral region are presented.

A maximum continuous-wave output power of ≈ 0.65 W with a slope efficiency of 55 % was obtained at the wavelength of 1940 nm. Laser pulses with energy of 26 μJ and repetiotion rate of 6 kHz coresponding to 156 mW of average output power at 1910 nm were obtained at 2.2 W of incident puwp power for the Cr:ZnSe saturable absorber with initial transmission of 95 %. By using of saturable absorber with lower initial transmission of 90 % laser pulses with energy of 40 μJ and duration as short as 10 ns were realized. The maximal pulse repetition rate was 2.8 kHz at incident pump power of 2.2 W.

Based on the obtained results, it can be concluded that Tm:KYW crystals are promising active media for the compact passively *Q*-switched lasers emitting in the spectral range near 2 μm for the usage in surgery and rangefinding. Also, described laser is planned to be used as a laser source in laser-induced damage threshold measurements setup for investigation of damage threshold of saturable absorbers as well as nonlinear crystals at the wavelength near 2 μm.

Keywords: thulium, potassium-yttrium tungstate crystal, passively *Q*-switching mode, spectral range near 2 μm.

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Компактный лазер на основе кристалла $Tm:KY(WO_4)_2$, работающий в режиме пассивной модуляции добротности

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Тулиевые лазеры с диодной накачкой, работающие в спектральной области около 2 мкм, находят широкое применение в различных областях, таких как хирургия, дальнометрия и дистанционное зондирование атмосферы. В статье продемонстрирован макет твердотельного Tm:KYW лазера, работающий в режиме пассивной модуляции добротности с насыщающимся поглотителем на основе поликристаллического Cr:ZnSe, синтезированного методом химического газофазного осаждения.

Максимальная выходная мощность лазера в непрерывном режиме генерации достигала ≈ 0,65 Вт на длине волны 1940 нм при дифференциальной эффективности по поглощённой мощности накачки 55 %. В режиме пассивной модуляции добротности при использовании насыщающегося поглотителя Cr:ZnSe с начальным пропусканием 95 % энергия лазерных импульсов составила 26 мкДж, максимальная частота следования импульсов достигала 6 кГц при падающей мощности накачки 2.2 Вт. При использовании насыщающегося поглотителя с начальным пропусканием 90 % энергия лазерных импульсов достигала 40 мкДж, длительность импульсов не превышала 10 нс.

На основе полученных результатов можно сделать вывод, что данные кристаллы являются перспективными активными средами для лазеров, излучающих в спектральном диапазоне около 2 мкм, для применения в составе хирургических систем и систем лазерной дальнометрии. Предполагается использование разработанного макета лазера в составе комплекса по измерению порог оптического разрушения насыщающихся поглотителей и нелинейных кристаллов в области 2 мкм.

Ключевые слова: лазер, тулий, кристалл калий-иттриевого вольфрамата, режим пассивной модуляции добротности, спектральная область около 2 мкм.

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Introduction

Diode-pumped thulium lasers operating in the spectral range near 2 µm are attractive for applications in different areas: surgery, since their radiation is strongly absorbed by water, rangefinding, and environmental atmosphere monitoring due to the presence of absorption lines of a number of chemical compounds (benzol, ethanol, etc.) in the spectral region around 2 µm [1].

Interest in thulium-doped crystals is explained by the availability of powerful AlGaAs diode pump sources emitting at near 800 nm and cross-relaxation process $^3H_6 + {}^3H_4 \rightarrow {}^3F_4 + {}^3F_4$ leading to efficient excitation of $^3F_4$ laser level thus increase the quantum efficiency of the systems. Monoclinic potassium double tungstate crystals activated with thulium ions Tm:KY$(WO_4)_2$ (Tm:KYW) attract attention due to relatively high absorption and emission cross-section, broad emission bands, and the possibility to grow highly activated crystals [2]. The great potential of Tm:KYW laser crystal has been already demonstrated in continuous-wave [3], mode-locking [4] and *Q*-switch [5] regimes of operation.

Up today, many saturable absorbers (SA) based on nanomaterials and crystalline media have been proposed for realization of passive *Q*-switching. Passively *Q*-switched Tm:KYW lasers have been already demonstrated with Cr:ZnS with following characteristics of pulses: 57 ns, 3 µJ, 25 kHz, with Cr:ZnSe: 60 ns, 19 µJ, 5.6 kHz, and with PbS: 8 ns, 30 µJ, 4.2 kHz [5–7].

Here we report on the latest results of Tm:KYW laser performance with a polycrystalline chemical vapor deposited Cr:ZnSe as the most available saturable absorber for 2 µm spectral region.

Experimental laser setup and results

The experimental laser setup is presented in the Figure 1. The near hemispherical laser cavity consisted of a curved output coupler (OC) and a plane high reflector was used. The cavity length was about 24 mm. A laser crystal was N_g-cut Tm(3%):KYW with the thickness of 2.8 mm and antireflection coatings on it's working sides. The temperature of active element (AE) was kept at 14 °C by means of copper slab and thermoelectrical cooling of the elements with a water-cooled heatsink. A 3-W continuous-wave fiber-coupled diode laser (λ = 802 nm, Ø = 100 µm, N.A. = 0.15) was used for a longitudinal pumping of the active element. A pump beam was focused into a 200 µm spot inside the laser crystal. The cavity length was adjusted to get TEM_{00} transversal mode diameter at the active element close to the pump beam waist considering induced thermal lensing effects. A set of output couplers with different transmissions (T_{oc}) was used during continuous-wave laser experiments.

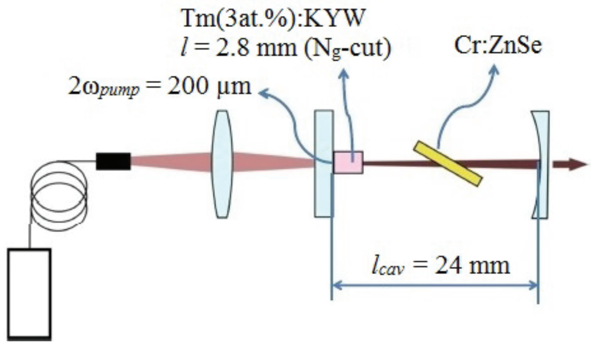

Figure 1 – Experimental laser setup

Initially, laser experiments were carried out in the continuous-wave regime of opeartion. The maximum output power of 645 mW at 1940 nm was measured with an output coupler transmission of 3 %. A slope efficiency (η) of 55 % with respect to the absorbed pump power was obtained. Laser emission was linearly polarized along N_m axis. Input-output diagrams for the CW Tm:KYW laser are shown in the Figure 2.

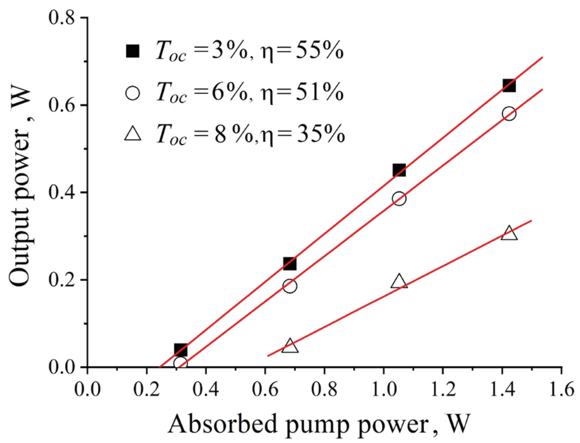

Figure 2 – Input-output diagrams of the continuous-wave Tm:KYW laser

The *Q*-switch laser experiments were performed taking into account comparatively low light induced damage threshold of the Cr^{3+}:ZnSe saturable absorbers (≈ 2.5 J/cm^2). The saturable absorber was inserted into the cavity between active medium and OC at Brewster angle. Two SAs with initial transmissions of 95 % and 90 % were used.

Laser pulses with energy of about 26 µJ and repetiotion rate of 6 kHz coresponding to 156 mW of average output power at 1910 nm were obtained at 2.2 W of incident puwp power for the SA with the initial transmission of 95 % nm and OC with transmission of 6 %. With the increase of incident pump power from the threshold to its maximal value the pulse energy and repetition rate varied from 20 to 26 µJ and 0.2 to 6 kHz, respectively. The dependence of pulse duration and repetition rate on incident pump power is shown in the Figure 3. The increase of pulse enegy with incident pump power can be explained by changing in the TEM_{00} mode size due to thermal effects in the gain medium. The spatial profile of the output beam was TEM_{00} mode with $M^2 < 1.2$ at maximal incident pum power (inset in the Figure 3).

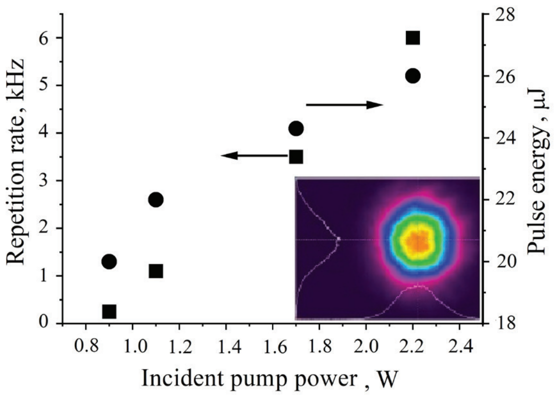

Figure 3 – Dependence of laser pulse characteristics on incident pump power for saturable absorber with initial transmission of 95 %

The shortest laser pulse duration was measured to be 14 ns. The oscilloscope traces of single pulse with the duration of 14 ns and output pulse train with maximal repetition rate of 6 kHz are presented in the Figure 4. It should be mentioned that maximum pulse repetition rate was limited by the laser-induced damage threshold of the SA.

The dependence of laser pulse characteristics on incident pump power for saturable absorber with initial transmission of 90 % is presented in the Figure 5.

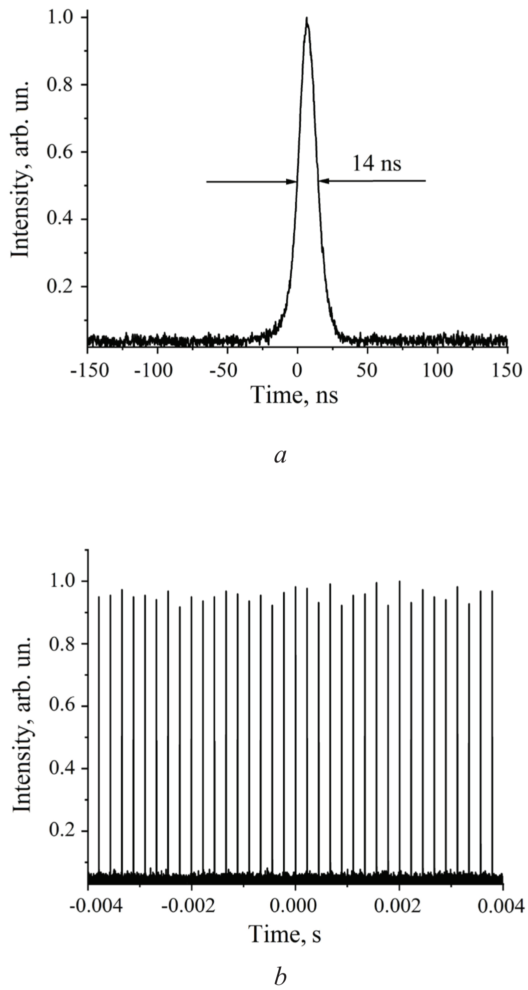

Figure 4 – Oscilloscope traces: *a* – single pulse with the duration of 14 ns; *b* – output pulse train maximal repetition rate of 6 kHz

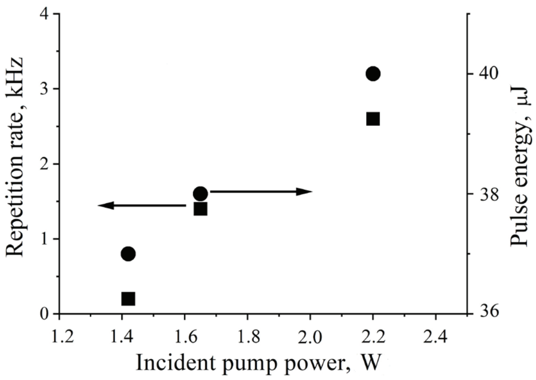

Figure 5 – Dependence of laser pulse characteristics on incident pump power for saturable absorber with initial transmission of 90 %

The laser wavelength shifts to 1940 nm that can be caused by a higher SA losses at shorter wavelength. Laser pulses with energy up to 40 μJ and duration as short as 10 ns were obtained in this case. The maximal repetition rate was 2.8 kHz at incident pump power of 2.2 W.

Conclusion

In conclusion, compact $Tm:KY(WO_4)_2$ laser was demonstrated. A maximum CW output power of about 0.65 W with a slope efficiency of 55 % was obtained at the wavelength of 1940 nm. In a passively *Q*-switched regime of operation laser pulses with energy of 40 μJ and duration of 10 ns were obtained at a repetition rate of 2.8 kHz at the incident pump power of 2.2 W.

Based on the obtained results, it can be concluded that Tm:KYW crystals are promising active media for lasers emitting in the spectral range near 2 μm for the usage in surgery and rangefinding. Also, described laser is planned to be used as a seed pulses source for future amplification and applying in laser induced damage threshold measurements setup for investigation of optical damage threshold of saturable absorbers as well as nonlinear crystals at the wavelength near 2 μm.

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