Fiber-coupled diode end-pumped Q-switched $Tm,Ho:YLiF_4$ laser

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Received December 17, 2003

At liquid-nitrogen temperature, at 10-kHz pulse repetition rate, Q-switched 36-ns pulses with average output power of 4 W at 2.05 μm and 4.5-W continuous wave output power with a total optical-optical conversion efficiency of 30%, were achieved from a 6% Tm, 0.5% $Ho:YLiF_4$ laser. This laser was end-pumped by a fiber-coupled laser diode emitting up to 15 W around 792 nm. The 1-m-long optical fiber carrying the pump radiation has a core diameter of 700 μm with a numerical aperture of 0.22.

OCIS codes: 140.3480, 140.3540, 140.0140.

The first demonstration of laser operation in rare-earth doped YAG was reported at cryogenic temperature[1]. Eye-safe diode-pumped holmium lasers operating at 2 μm are regarded as promising sources for use in Doppler wind sensing, differential absorption lidar (DIAL) water vapor profiling[2], low altitude wind shear detection[3], pump sources for optical parametric oscillators and medical instrumentation. Additional applications for short duration optical pulses at 2 μm include altimetry, topographical and nonlinear optical studies. These holmium lasers are conducive to operate in Q-switched mode due to its 10-ms fluorescence lifetime compared with 230 μs in Nd:YAG. However, up-conversion is a deleterious influence in many hosts, which results in the reduction of effective lifetime, reduction of the energy storage capacity, and loss of conversion efficiency. For research we choose the thulium, holmium sensitized yttrium-fluoride ($Tm,Ho:YLiF_4$) crystal as the laser gain medium. $Tm,Ho:YLiF_4$ provides both high-energy storage capability and efficient Q-switching operation due to long lifetime of the upper laser level Ho^{3+}:$^5I_7$. It also has lower up-conversion losses than Tm,Ho:YAG[4]. In this letter we report a study of Q-switched operation of a $Tm,Ho:YLiF_4$ laser.

The $Tm,Ho:YLiF_4$ crystal used in our experiments has a dopant concentration of 6% for Tm^{3+} ions and 0.5% for Ho^{3+} ions, respectively. Its dimensions were 5×5×10 mm^3. A schematic diagram of the relevant energy levels for both the Tm^{3+} and Ho^{3+} ions in the $YLiF_4$ host is shown in Fig. 1. The upper and lower laser levels are $^5I_7$ and $^5I_8$ of Ho^{3+} ions. The $^3H_6$ level of Tm^{3+} ion absorbs pumping photon at 792 nm, giving a $^3H_6 \rightarrow {}^3H_4$ transition. Two Tm^{3+} ions in the $^3F_4$ excited state are created by means of cross-relaxation process between the Tm^{3+} levels $^3H_4 \rightarrow {}^3F_4$ and $^3H_6 \rightarrow {}^3F_4$. The population inversion in the Ho^{3+} system is obtained by means of a resonance energy transfer process between the Tm^{3+} ($^3F_4 \rightarrow {}^3H_6$) and Ho^{3+}($^5I_8 \rightarrow {}^5I_7$) ions[5].

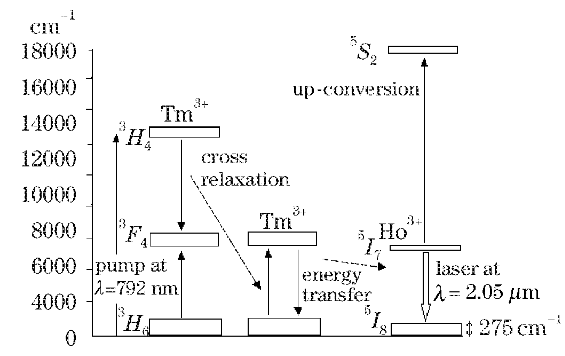

Fig. 1. Schematic diagram of the energy levels of Tm^{3+} and Ho^{3+} ions in the YLF host.

To build the laser cavity, we used an end-pumped plat-concave resonator, as shown in Fig. 2. The end facets of the active material are polished flat. The first facet of the crystal is coated for high reflectivity at the laser wavelength ($R > 98\%$) and for high transmission at the pump wavelength ($T > 85\%$), the second facet is anti-reflection coated at the laser wavelength ($R < 0.2\%$). The pump input end of Tm,Ho:YLF crystal serves as the plano high reflector. A spherical output coupling mirror with the radius of curvature of −300 mm is placed at 150-mm geometrical distance from the flat mirror (pump entrance facet of the crystal). Optimum short pulse, high repetition rate, Q-switched performance was obtained with a 40% transmission mirror. Total round trip intracavity losses were estimated at 8%.

The laser was end-pumped by a fiber-coupled laser diode emitting up to 15 W around 792 nm. The 1-m-long optical fiber carrying the pump radiation has a core diameter of 700 μm with a numerical aperture of 0.22. The pump beam with a beam waist of 280 μm was focused into the laser crystal by two achromatic lenses with focal lengths of 50 and 35 mm, respectively. A high-brightness fiber-coupled pump diode has been used instead of the previous device in the non-fiber-coupled end-

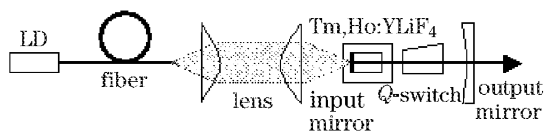

Fig. 2. Optical schematic for fiber-coupled diode end-pumped Q-switched $Tm,Ho:YLiF_4$ laser.

pumping configuration. With this more intense pump beam, the population inversion within the active medium reaches a much higher value than in the previous cases. This results in lower threshold power and higher laser efficiency. The pump wavelength is tuned to the Tm^{3+} absorption peak, near 792 nm. The 10-mm-long crystal was oriented with the a-axis parallel to the polarization vector of the pump laser to utilize the higher π-spectrum absorption. A liquid-nitrogen-cooler controls the temperature of the laser crystal at 100 K. The $YLiF_4$ crystal is held in a copper structure, which is used to spread the heat generated by the pump and to actively control the crystal temperature. The Dewar contains a block of copper in thermal contact with the stainless steel walls of liquid nitrogen container. A thin (120 μm) indium sheet squeezed between the crystal and copper provides a good thermal contact for cooling the $YLiF_4$ crystal. Two CaF_2 windows provide the vacuum seal on the liquid nitrogen cooled Dewar. The pressure inside the Dewar is 10^{-3} Torr (1 Torr = 133 Pa) to prevent condensation on the CaF_2 windows.

Infrared fused silica acousto-optic Q-switch is located between the crystal and the output coupler. The optical polarization and acoustic wavevector are mutually orthogonal for optimum scattering. The Ho-beam diameter at the Q-switch is 280 μm, comfortably less than the transducer width of 5 mm. Pulsed operation was measured with the use of a photodetector connecting to TEK TDS684A oscilloscopes.

The continuous wave (CW) laser data obtained using this configuration are shown in Fig. 3. The maximal output power was 4.5 W for 15-W pump power, corresponding to a total optical-optical conversion efficiency of 30%. The temporal profile of the Q-switched pulse is shown in Fig. 4, which was recorded at Q-switched pulse repetition rate of 10 kHz. The pulse width (full-width at half-maximum (FWHM)) is 36 ns. Q-switched maximal average output power of 4 W can be seen in Fig. 5.

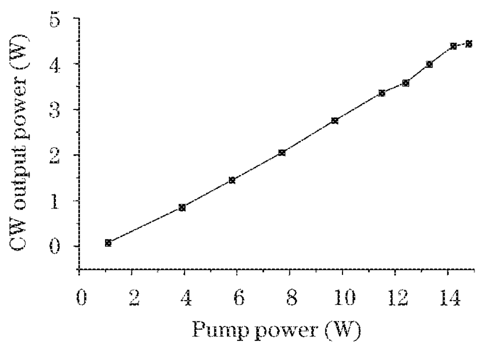

Fig. 3. CW output power of the Tm,Ho:$YLiF_4$ laser versus pump power.

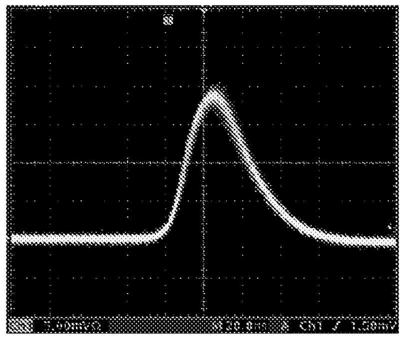

Fig. 4. Q-switched laser pulse profile at 10-kHz repetition rate.

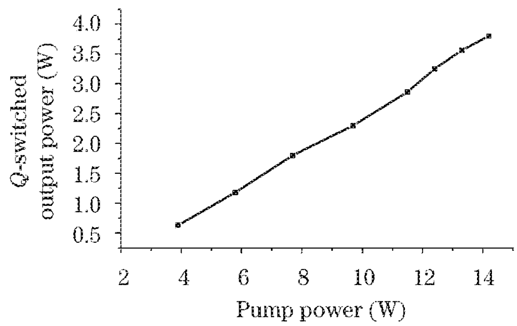

Fig. 5. Q-switched output power of the Tm,Ho:$YLiF_4$ laser versus pump power.

In conclusion, we have demonstrated a fiber-coupled diode end-pumped Q-switched Tm,Ho:$YLiF_4$ laser, which generates 36-ns pulses with average output power of 4 W at 2.05 μm. The maximal CW output power with an slope efficiency of 30% is 4.5 W. For the use in the space-based coherent wind lidar system, more shorter pulse performance is required, more studies on Q-switched Tm,Ho:$YLiF_4$ laser are needed.

This work was supported by the Scientific Research Foundation of Harbin Institute of Technology. X. Zhang is the author to whom the correspondence should be addressed, her e-mail address is zxbljh@sohu.com.

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