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DIODE-PUMPED SELF-INJECTION Tm:LuAG LASER AT ROOM TEMPERATURE

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Abstract

We report on the design of a diode-pumped self-injection Tm:LuAG laser at room temperature. At a pump energy of 142 mJ and a Q-switched operating repetition of 100 Hz, we achieve an output energy of 2.85 mJ, pulse width of 204.5 ns, and pulse building-up time of 3.45 μs for the self-injection laser. Our results also show that the spectrum is purer for the self-injection Tm:LuAG laser.

Keywords: diode-pumping laser, self-injection, Tm:LuAG.

1. Introduction

Two-micrometer lasers are useful for coherent Doppler LIDARs. In a LIDAR system, high spectral purity and a narrow line width pulsed laser is required. Injection seeding is an effective method to obtain a high-power Q-switched laser with pure spectrum [1–3]. In 1998, a flash-lamp-pumped injection-seeded 1.552 μm Er:glass laser was reported with an output energy of 1 mJ and a pulse width of 400 ns [4]. Tm-doped lasers are suitable for realizing a wider pulse width at room temperature [5]. Because of the advantages of high mechanical strength and large heat conductivity (0.13 W/(cm·K)), a Tm:YAG laser provides the possibility to obtain high-power laser output without thermal fracture [6]. In 2011, an injection-seeded Tm:YAG laser was designed by our group, and nearly transform-limited pulsed single-frequency 2,013 nm with an output energy of 2.0 mJ and a pulse width of 356.2 ns was achieved at a repetition rate of 15 Hz [7]. Compared to a Tm:YAG laser, the output wavelength of thulium-doped $Lu_3Al_5O_{12}$ (Tm:LuAG) laser is much closer to the atmospheric transmission window. The terminal-laser level of the Tm:LuAG crystal is higher than that of the Tm:YAG laser, and the relative lower population density gives it the advantage of a scaling output power of 2 μm laser. In 2014, an injection-seeded Tm:LuAG laser was designed. An output energy of 1.8 mJ and a pulse width of 293.0 ns was achieved at a repetition rate of 50 Hz.

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In this paper, we report our results on the design of a self-injection Tm:LuAG laser. At a pump energy of 142 mJ and a Q-switched repetition of 100 Hz, an output energy of 2.85 mJ, a pulse width of 204.5 ns, and a pulse building-up time of 3.45 μs were achieved for the self-injection laser. Our result also showed that the spectrum was purer for the self-injection Tm:LuAG laser.

2. Experimental Setup

The experimental setup is shown in Fig. 1.

The pump source is a 30 W pulsed fiber-coupled laser-diode (LD). The diameter and numerical aperture of the fiber core are 400 μm and 0.22, respectively. The pumping laser beam is shaped and focused by two lenses, and the beam diameters in the Tm crystal are about 0.8 mm. The mode matching between the pump and oscillating lasers was optimized by changing the pump beam waist radius and its location. The Tm:LuAG crystal with dimensions 4×4×7 mm has a doping concentration of 4%. The faces are antireflection coated near 788 nm ($R < 0.5\%$) and 2.02 μm ($R < 0.5\%$). The Tm:LuAG was wrapped with indium foil and held in a brass heat sink, whose temperature was controlled at 290 K with a thermoelectric cooler. The oscillator is a rectangular cavity. The resonator consists of three plane mirrors and one curved output mirror. The radius of curvature of the output coupler is 400 mm, which provides a transmission of 5%. The total resonator length is about 260 mm. A 46 mm long fused-silica acousto-optical Q-switch is used to produce Q-switched operation. In this paper, the repetition rate of Tm:LuAG laser is set at 100 Hz. The bidirectional fashion of the rectangular oscillator is convenient for self-injection. One direction output of the ring laser is the seed laser, which is fed back by a mirror coated with high reflection at 2.02 μm.

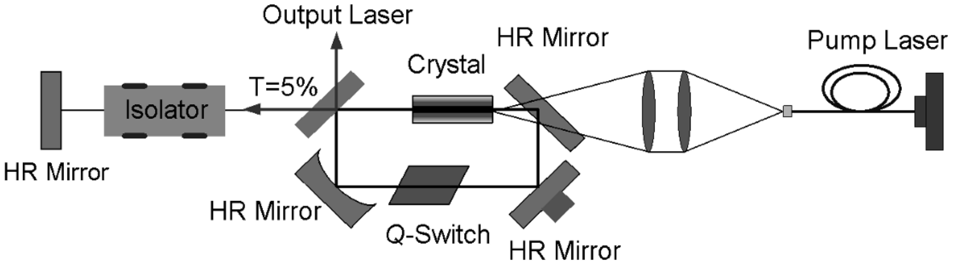

Fig. 1. Schematic of the self-injection Tm:LuAG laser.

3. Experimental Results

The output energy of the Tm:LuAG laser in the free-running regime was measured by a power meter; the result is shown in Fig. 2.

In the absence of feedback, the output energy from two directions of the Tm:LuAG laser is different and unstable, which means that the mode competition is quite intense. However, the output energy from direction A under the condition of self-injection is close to the total energy of directions A and B without feedback. Under the self-injection operation, the Tm:LuAG laser threshold was lower, and a maximum output power of 47.3 mJ was achieved at a pump energy of 289 mJ; the slope efficiency was 26%. At the same pump energy, a maximum output energy of 50.2 mJ was achieved. However, compared with the bidirectional output without feedback, the energy stability was obviously improved after self-injection.

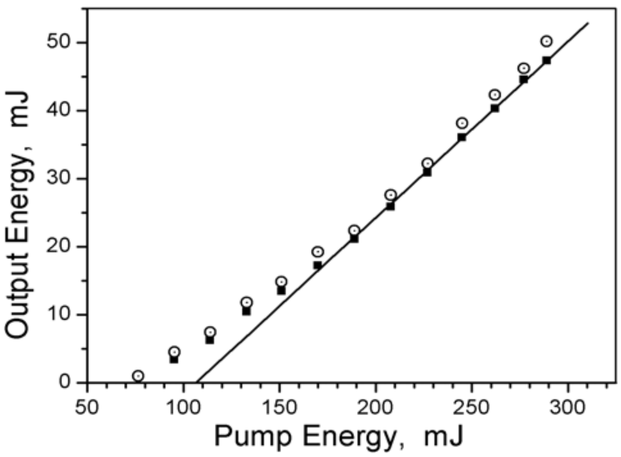

Fig. 2. Output energy versus the pump energy in the free-running regime (■) and without injection (⊙); linear fit is shown by the solid line.

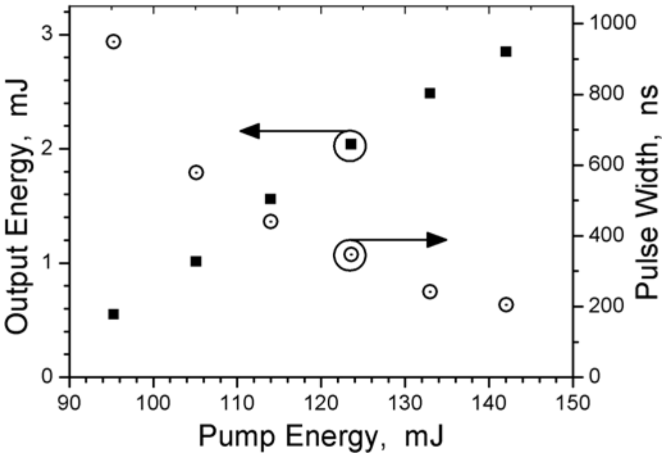

Fig. 3. Output energy (■) and the pulse width (⊙) versus the pump energy under *Q*-switching.

The output energy of the self-injection Tm:LuAG laser was measured by an energy meter. The pulse width was measured with a digital oscilloscope and a room-temperature mercury cadmium telluride photoconductive detector. Figure 3 shows the output energy and pulse width versus the pump energy under *Q*-switching of the self-injection Tm:LuAG laser. At a pump energy of 142 mJ, a maximum output energy of 2.85 mJ was achieved with a pulse width of 204.5 ns. The typical pulse shape is shown in Fig. 4, where the output energy is 2 mJ and the pulse width is 350.1 ns.

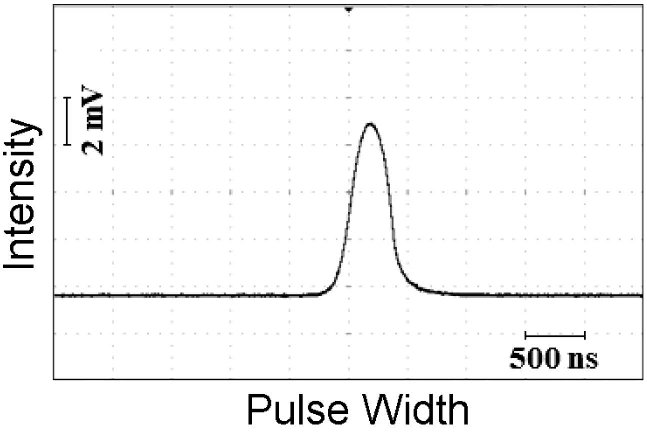

Fig. 4. Typical pulse shape.

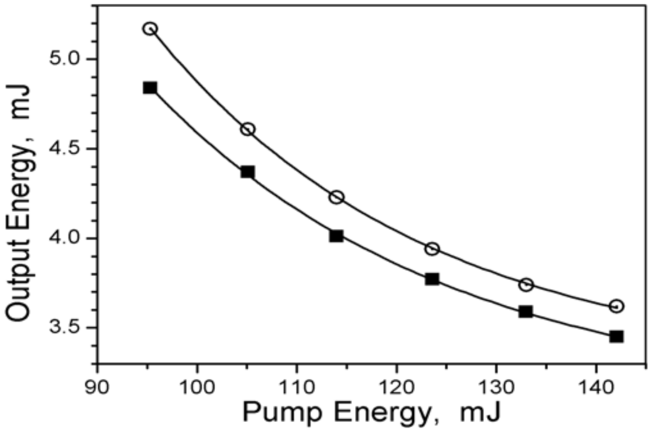

Fig. 5. Output energy (■) versus the pump energy under *Q*-switched operation and without injection (⊙).

The pulse build-up time was measured by a Tektronix TDS3032B oscilloscope and an InGaAs detector with a response time of 1 ns. The build-up time of the output pulse laser under no injection and self-injection versus the pump energy are shown in Fig. 5. We see that the build-up time of the output pulse is shortened when the pump energy increases. At the same pump energy, compared with no feedback, the build-up time of the pulse for the self-injection laser is shorter.

The output wavelengths of the *Q*-switched Tm:LuAG laser were recorded with a monochrometer.

The input laser was detected by an InGaAs detector connected with a digital oscilloscope. Compared to the condition without feedback, the spectrum purity was improved to some degree when the self-injection was realized.

4. Conclusions

In conclusion, we demonstrated a diode-pumped self-injection Tm:LuAG laser at room temperature. At a pump energy of 142 mJ and a Q-switched repetition of 100 Hz, we achieved an output energy of 2.85 mJ, a pulse width of 204.5 ns, and a pulse building-up time of 3.45 μs for the self-injection laser. Compared with no injection, the Q-switched Tm:LuAG laser threshold was lower for the self-injection state, the pulse build-up time was shorter, and the output spectrum was purer. This means that if there is no strict requirement on the laser spectral purity, self-injection without precise timing control could be used to improve the output performance to some degree.

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