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DIODE-END-PUMPED LINEAR-POLARIZED SINGLE-LONGITUDINAL-MODE OPERATION OF A Tm:LuAG LASER AT ROOM TEMPERATURE

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Abstract

We present a novel method to achieve linear-polarized single-longitudinal-mode (SLM) operation of a Tm:LuAG laser. Linear polarization of output laser can be guaranteed by placing one 0.1 mm F-P etalon at the Brewster angle in the cavity. The other 1 mm F-P etalon is turned to obtain an SLM laser. The maximum output power of the linear-polarized SLM laser is 84 mW. The central wavelength is 2,022 nm. The polarization degree is 30 dB. The output beam is at the fundamental mode. The power instability is less than 1%. The long-term frequency stability of the SLM laser is $3.56 \cdot 10^{-7}$.

Keywords: diode-end-pump lasers, single-longitudinal mode (SLM), Tm:LuAG.

1. Introduction

The 2 μm all-solid-state laser is known for operating in the eye-safe spectral region. It can be used as the pumping source of mid-infrared optical parametric oscillator or coherent laser radar. Because of the long upper laser-level lifetimes and small laser-transition effective cross-sections, Tm,Ho co-doped or Tm-doped lasers are usually taken as an ideal source of LIDAR systems. A Tm-doped laser is preferred to a Tm,Ho co-doped laser for operation at room temperature. Due to the up-conversion effect, Tm,Ho co-doped lasers are intense.

A Tm:LuAG laser, which has high mechanical strength and good thermal shock parameter, like a Tm:YAG laser, is a wonderful source for atmospheric LIDAR [1]. Furthermore, the Tm:LuAG emission wavelength is at 2.022 nm, which is closer to the atmospheric transmission window than a Tm:YAG laser. The terminal laser level of the Tm:LuAG laser is higher than that of the Tm:YAG laser, which means that the relatively lower population density makes it a more attractive laser medium for scaling the output power of 2 μm laser at room temperature [2].

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Some characteristics of Tm:LuAG lasers have been reported in the literature. A total optical-to-optical efficiency of 7.3% was obtained by a diode-pumped Tm:LuAG laser in 1995 [3]. A maximum output of 0.92 W was achieved from a diode-pumped Tm:LuAG laser in 2000 [4]. Output powers of 205 and 51 mW were, respectively, obtained for a diode-pumped Tm:LuAG laser under free-running and single-longitudinal-mode (SLM) operation in 2004 [5]. A maximum output power of 4.91 W and a slope efficiency of 25.4% from a diode-pump Tm:LuAG laser was demonstrated in 2008 [6]. Then a 148 mW single-longitudinal-mode Tm:LuAG laser was realized by combined use of a 0.1 mm silica etalon and a 1 mm YAG etalon [7]. However, the polarization of Tm:LuAG lasers was not discussed in these papers. For the seed laser used in LIDAR systems, the polarization is an important parameter, which affects the stability of the injection-locking laser. The Tm:LuAG laser has a circular polarization without an additional instrument because of its isotropy. One can achieve linear polarization employing a Polaroid, but the power will suffer a significant loss because of the low gain of the SLM-operated Tm:LuAG laser.

In this paper, we demonstrate a diode-pumped linear-polarized SLM Tm:LuAG laser employing a novel method. The maximum output power of a linear-polarized SLM laser is 84 mW, and the wavelength is 2,022 nm. The polarization degree is 30 dB, the power instability is less than 1%, and the long-term frequency stability reaches $3.56 \cdot 10^{-7}$.

2. Experimental Setup

The experimental setup is shown in Fig. 1. The pumping source is a fiber-coupled LD with a fiber core of 100 μm and a numerical aperture of 0.22. The maximum output power of the LD is 2 W. The central wavelength is at 788 nm, which coincides with the absorption peak of the Tm:LuAG crystal. Two coupling lenses with 25 mm focus are used to direct the pump-laser beam into the Tm:LuAG crystal. The mode matching between the pump and laser modes is optimized by changing the pump-beam waist radius and its location. The resonator is a plano-concave cavity. A Tm:LuAG crystal with dimensions $3{\times}3{\times}2.5$ mm and a Tm doping concentration of 4% is used as the laser material. The pumping side of the crystal, being a cavity mirror, is coated to provide a high transmission at 788 nm ($R < 0.5\%$) and high reflectivity at 2.02 μm ($R > 99.5\%$). The opposite surface of the laser crystal is coated, providing antireflection at 785 nm ($R < 0.5\%$) and 2.02 μm ($R < 0.5\%$). The crystal is placed in a copper mount, whose temperature is controlled by a TE cooler. The temperature is fixed at 291 K, with fluctuation of ± 0.01 K. The radius of curvature and the transmission at 2.02 μm of the output coupler are 100 mm and 2%, respectively. The resonator length is 42 mm. Two solid, uncoated fused silica etalons are used to control the laser wavelength and polarization. The angle of the 0.1 mm F-P is designed to be 56.4°. In such a way, we achieved a linear-polarized Tm:LuAG laser.

This novel method is quite useful and easy. It is not necessary to insert another element, say, a polarizer into the cavity, and, due to this fact, the SLM-output power can be improved. The 1 mm F-P is inserted into the cavity to realize SLM operation.

3. Experimental Results

To measure the spectral output of the Tm:LuAG laser, we use a Burleigh WA-650 spectrum analyzer combined with a WA-1500 wavemeter (0.7 pm resolution). The spectral output in the free-running regime consists of seven peaks. A 0.1 mm F-P is inserted into the cavity at a designed angle of 56.4°.

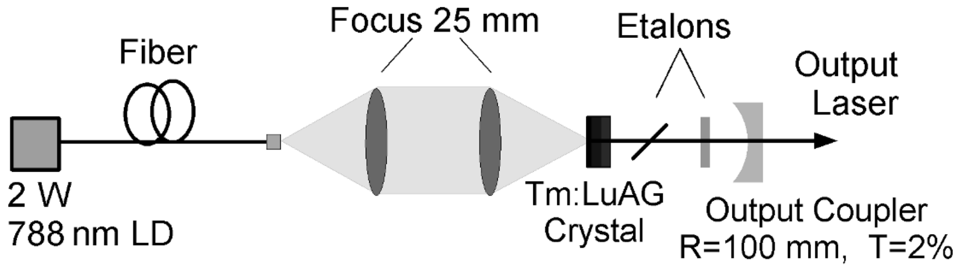

Fig. 1. Experimental setup of the Tm:LuAG laser.

In spite of the fact that the laser operates not at a single laser mode, the laser output has a linear polarization measured by a Glan-Taylor prism. When a 1-mm F-P etalon is inserted into the cavity, a single wavelength is achieved by turning the angle of the 1-mm F-P, as shown in Fig. 2. The central wavelength is 2,021.9 nm, and with the help of the Glan-Taylor prism, we reach a polarization degree of 30 dB.

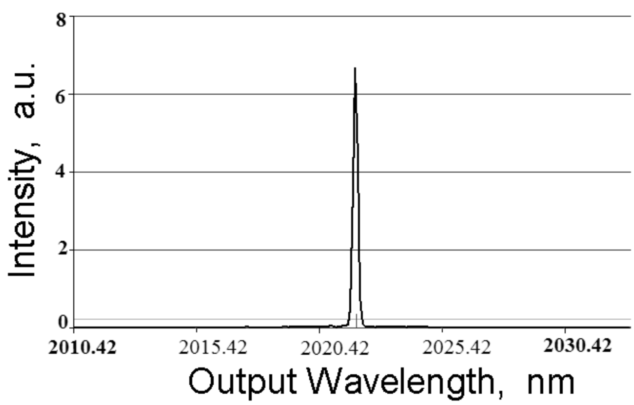

Fig. 2. Output wavelength of the Tm:LuAG laser with two etalons in the cavity.

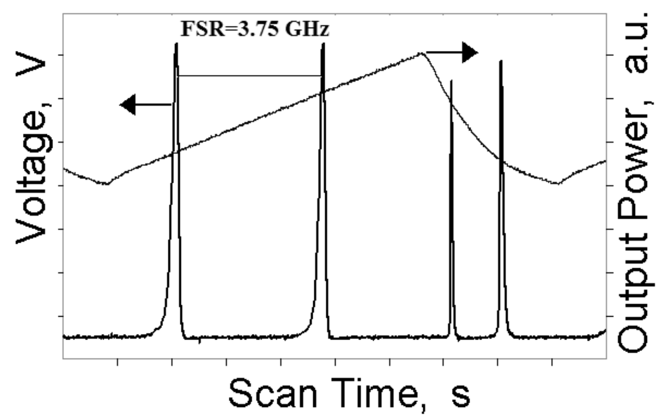

Fig. 3. F-P spectrum of the SLM Tm:YAG laser.

A diagnostic air-gap scanning F-P interferometer (free spectral range 3.75 GHz) is used to provide the longitudinal-mode operation of the Tm:LuAG laser. The collimated continuous output beam of the Tm:LuAG laser is propagating through the F-P interferometer, and the transmitted intensity is detected by a 9 V biased InGaAs detector. The signal from the detector is fed into a digital oscilloscope through a preamplifier, as shown in Fig. 3, where the upper trace is the F-P ramp voltage and the lower trace is the voltage of the InGaAs detector, which measures the Tm:LuAG laser transmission through the F-P interferometer. The laser operates at a single longitudinal mode.

The SLM output power versus the absorbed pump power is shown in Fig. 4. At an absorbed pump power of 1.14 W, the maximum power of the SLM laser is 84 mW. The SLM output has a linear polarization. The SLM-output laser threshold is 994 mW. This low threshold is due to the relatively low population density.

The far-field laser distribution of the SLM Tm:LuAG laser was measured by an infrared camera (LBS-100, Spiricon), as shown in Fig. 5. Fluctuations of the output wavelength are also observed by

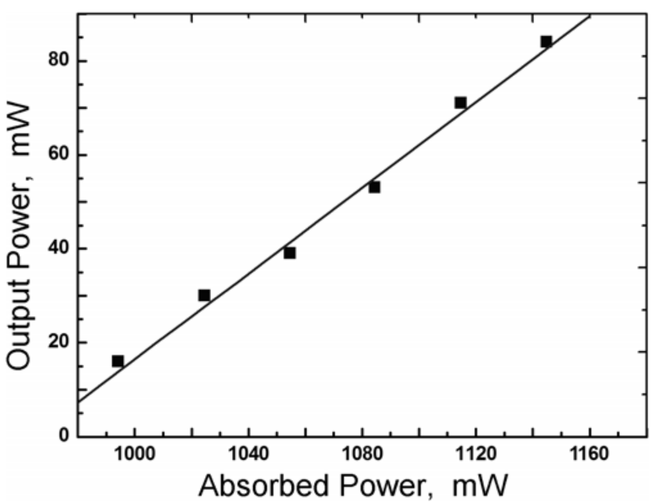

Fig. 4. Output power performance of the SLM laser at room temperature with experimental data (■) and linear fit shown by the solid line.

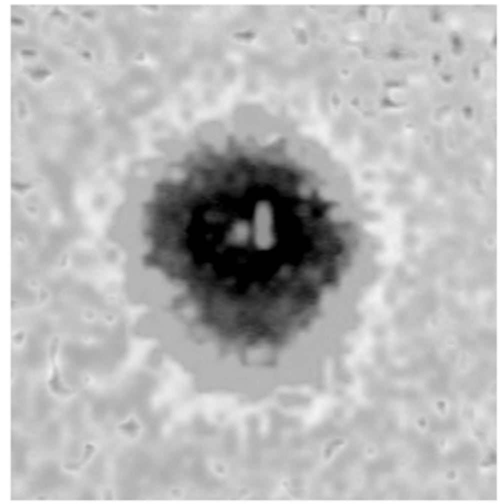

Fig. 5. The spot distribution of the SLM Tm:LuAG laser (far field).

the wavemeter. In view of the experimental data and numerical calculations, the long-term frequency stability of this SLM Tm:LuAG laser is about $3.56 \cdot 10^{-7}$. The power instability of the linear-polarized SLM laser is less than 1%.

4. Conclusions

In conclusion, we have designed a linear-polarized single-longitudinal-mode-operated Tm:LuAG laser. The novel method to achieve a linear-polarized laser output is to keep the 0.1 mm F-P etalon at an angle of 56.4° (or close to this angle). By turning the 1 mm F-P etalon, we designed an SLM Tm:LuAG laser operating at the fundamental mode with output power 84 mW, center wavelength at 2.022 μm, polarization degree 30 dB, power instability less than 1%, and long-term frequency stability $3.56 \cdot 10^{-7}$. In the future, to improve the frequency stability, we use an integrative configuration and a high-accuracy temperature-control system.

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