SOLID STATE AND LIQUID LASERS

Eye-Safe Raman Laser at 1532 nm with BaWO4 Crystal


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Abstract—A diode-end-pumped actively Q-switched eye-safe intracavity Raman laser at 1532 nm is demonstrated, with Nd:YVO4 as the laser crystal and BaWO4 as the Raman crystal. The highest average power of 1.5 W is obtained, with an incident pump of 12 W and a pulse repetition rate of 35 kHz, corresponding to a diode-to-Stokes conversion efficiency of 12.5%.

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1. INTRODUCTION

In recent years, Stimulated Raman scattering (SRS) in solid-state materials has become an effective method to generate laser radiations at new wavelengths [1, 2]. By selecting different pumping sources and Raman-active media, the laser spectrum reachable with SRS can extend from the ultraviolet to the near infrared. So far, the most widely used Raman crystals for SRS have involved nitrates [Ba(NO3)2] [3, 4], calcites (CaCO3) [3], iodates (LiIO3) [5], vanadates (YVO4 and GdVO4) [6–10], tungstates [KGd(WO4)2, SrWO4, BaWO4, CaWO4, and PbWO4] [11–21], and some new crystals [PbB4O7, YPO4, and Y2SiO5] [22–24].

Laser sources in the wavelength region longer than 1.4 μm are the so-called eye-safe laser, because the radiation in this region can be absorbed around the surface of the eyeball and little light reaches the retina. So the laser sources in this eye-safe region are of great interest in the fields of free-space communication, fiber-optics links, lidar, cleaning of artworks, medicine, and ecology [25]. These eye-safe laser sources can be generated by means of erbium-doped glass or crystals lasers, optical parametric oscillators, fiber lasers and Raman lasers [26–37]. One of the most important applications of SRS is to generate the radiation in the eye-safe spectral region. Eye-safe lasers from SRS frequency conversion have been successfully demonstrated in several Raman materials such as Ba(NO3)2, Nd:YVO4, Nd:GdVO4, Nd:SrWO4, Nd:KGdWO4, BaWO4, and PbWO4 [30–37].

As a promising Raman medium, BaWO4 crystal has many advantages of high Raman gain for both picosecond and nanosecond pulses [36, 38–44], good mechanical and optical properties [45], and large physical size. In 2005, T.T. Basiev and co-workers first reported a first Stokes conversion efficiency of 13.5% and an output power of 6 mJ when the BaWO4 crystal was external cavity pumped by a 40–50 ns, 1.34 μm acousto-optic Q-switched Nd:YAG laser [43]. In 2008, Wang et al. reported a 1.5 μm external cavity Raman laser based on BaWO4 crystal with 8.5 mJ of output energy [36]. Also in 2008, Zong et al. achieved a 220 ns 1.3 μm Nd:YAG laser pumped external cavity eye-safe Raman laser based on BaWO4 crystal. At an incident pump power of 4.14 W and a pulse repetition of 1.7 kHz, an average output power of 0.60 W at 1502 nm with a pulse width of 40 ns was obtained [44]. Up to now, all the reported eye-safe Raman laser using BaWO4 crystal as the Raman medium were based on the external cavity configuration.

In this paper, we report an efficient 808 nm diode-pumped actively Q-switched intracavity eye-safe Raman laser at 1532 nm. At an incident pump power of 12 W, the intracavity Raman laser system delivers 1.5 W average output power at 1532 nm at a pulse repetition rate of 35 kHz, corresponding to a diode-to-Stokes conversion efficiency of 12.5%. To the best of our knowledge, this is the first report about the actively Q-switched eye-safe Raman laser using BaWO4 crystal as the Raman medium based on the intracavity configuration.

2. EXPERIMENTAL ARRANGEMENT

Figure 1 shows the experimental setup of the 808 nm diode-pumped actively Q-switched intracavity eye-safe Raman laser employing BaWO4 crystal as the Raman medium. The pumping source employed in the experiment is a 25 W fiber-coupled 808 nm laser diode with a core diameter of 600 μm and an NA of 0.22. The front and output coupler are designed for the first-Stokes generation. The front mirror M1 is a concave mirror with a curvature radius of 1000 mm, which is antireflection (AR) coated at 808 nm on the
entrance face ($R < 0.2\%$), high-transmission (HT) coated at 808 nm ($T > 95\%$), and high-reflection (HR) coated at 1342 and 1532 nm on the other face ($R > 99.8\%$). Three different kinds of output couplers (OC1, OC2, and OC2#) are used in this experiment. OC1 and OC2 are plane mirrors, OC2# is a concave mirror with 1000 mm curvature. OC1 is coated for 70% reflectivity at 1532 nm, OC2 and OC2# have the same coating, which are coated for 87% reflectivity at 1532 nm. All mirrors have a transmission of $>90\%$ at 1064 nm to suppress the 1.06 µm laser line. The laser medium is an a-cut 0.3-at% Nd:YVO₄ crystal with a dimension of $3 \times 3 \times 9$ mm³. The Raman active medium is an a-cut BaWO₄ crystal with a length of 47 mm. Both sides of the laser crystals are AR coated at 1342 and 1532 nm ($R < 0.2\%$). The crystals are wrapped with indium foil and mounted in a water-cooled copper block. The water temperature is maintained at 20°C. A 35-mm-long acousto-optic (AO) Q-switch (Gooch and Housego, QS041-10H/J) driven at 41 MHz center frequency with 15 W of rf power is placed between the Nd:YVO₄ and BaWO₄ crystal. The overall laser cavity length is approximately 120 mm. The average output power is measured by a power meter (Molectron PM10) connected to Molectron EPM2000.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

We investigate the output performances of the Nd:YVO₄–BaWO₄ intracavity Raman laser in various situations, at different incident pump powers, for different output couplers of M2, and at different pulse repetition rates. Figure 2 gives the average output power at 1532 nm with respect to the LD pump power...