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Passively *Q*-switched, intracavity frequency-doubled YVO_4/Nd : YVO_4/KTP green laser with a GaAs saturable absorber

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Abstract. **A diode-pumped, passively Q-switched, intracavity frequency-doubled YVO_4/Nd : YVO_4/KTP green laser is realised using a GaAs saturable absorber. Two pieces of GaAs wafers are employed in the experiment. In using a 400-μm-thick GaAs wafer and an incident pump power of 10.5 W, the maximum output power of the passively *Q*-switched green laser is 362 mW at a pulse repetition rate of 84 kHz and a pulse duration of 2.5 ns. When use is made of a 700-μm-thick GaAs wafer, the minimum pulse duration is 1.5 ns at a repetition rate of 67 kHz, pulse energy of 4.18 μJ and peak power of 2.8 kW.**

Keywords: *green laser, passive Q-switching, saturable absorber.*

1. Introduction

Diode-pumped solid-state lasers (DPSSLs) have attracted much attention owing to the low-cost, simple and compact structure and potential applications such as communications, surgery, etc. Nd : YVO_4 is a common and well-studied laser medium for DPSSLs. However, in comparison with Nd : YAG, the main drawback is its small thermal conductivity, which may result in serious thermal effects in the laser crystal and reduce the output power at a high diode pump power. A breakthrough has been diffusion bonding of the Nd : YVO_4 crystal with undoped YVO_4. Several groups have demonstrated [1–3] that the YVO_4/Nd : YVO_4 composite crystal can dramatically reduce thermal effects and, therefore, this active element can be a promising candidate for high output power lasers.

Intracavity frequency doubling based on a DPSSL is an efficient method to obtain green lasers [4]. These green lasers with a high energy and a high peak power have a lot of potential applications: High-precision materials machining can be implemented by high peak power green lasers; for the ocean exploration and underwater communication, this kind of laser is also a key tool because of the weak water absorption at this spectral band in the blue-green window. In order to obtain a high peak power and a short pulse duration, *Q*-switching is a common technology. Plenty of *Q*-switched green lasers have been reported in the last two decades [5–13]. According to the modulation technique, *Q*-switching can be classified to active and passive. The latter uses low cost saturable absorbers in the resonator and is of considerable interest for the green pulse generation because it does not need high-voltage or RF drivers and can be simply operated. Up to date, several saturable absorbers such as Cr^{4+} : YAG [8–10], single-walled carbon nanotubes (SWCNTs) [11] and GaAs wafers [12, 13] have been successfully employed for *Q*-switching. As for GaAs, it has become an attractive saturable absorber due to the simplicity of fabrication, low cost and large nonlinearity. The first green laser with a GaAs saturable absorber, emitting 25-ns pulses with a repetition rate of 12 kHz and a peak power of 800 W, was reported in 1997 [12]. Subsequently, Chen et al. [13] demonstrated a passively *Q*-switched Nd : NYW/GaAs green laser with a minimum pulse duration of 50 ns and a pulse energy of 0.66 μJ. However, owing to the limitation of the pump power and the cavity configuration, a high peak power green laser with a short pulse duration (~1 ns or less) has not been realised for a GaAs saturble absorber.

Apart from a saturable absorber and intrinsic losses, the roundtrip time in the cavity is also an essential factor for the short pulse generation. The main purpose of this paper is to demonstrate a compact, intracavity frequency-doubled YVO_4/Nd : YVO_4/KTP green laser with a GaAs saturable absorber for the generation of short pulses. By using a composite YVO_4/Nd : YVO_4 crystal, the thermal effect can be minimised. For the experimental investigation of the effect of a saturable absorber on the pulse characteristics, we have used two pieces of GaAs wafers. The shortest pulse duration has been measured to be 1.5 ns at a repetition rate of 67 kHz and an incident pump power of 10.5 W, corresponding to a single pulse energy of 4.18 μJ and a peak power of 2.8 kW.

2. Experimental setup

Figure 1 shows a schematic setup of a *Q*-switched YVO_4/Nd : YVO_4/KTP green laser. The pump source was a commercial laser diode (LD) with a centre wavelength of 808 nm (LA-820, LYPE Co. Ltd, China). The pump beam

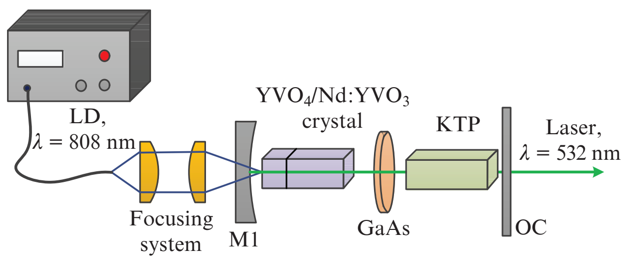

Figure 1. Schematic of the experimental setup.

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with a spot diameter of 400 μm was focused and collimated into the composite crystal by an optical focusing system. The core diameter of the coupled fibre was 400 μm with a numerical aperture (NA) of 0.22. The input mirror M1 was a concave mirror with a radius of curvature (ROC) of 150 mm, which was anti-reflectivity (AR) coated at 808 nm and high-reflectivity (HR) coated at 1064 nm and 532 nm. The output coupler OC was HR-coated at 1064 nm and high-transmission (HT) coated at 532 nm.

The total physical length of the plane-concave resonator was about 3 cm. The composite crystal was a 3×3×8 mm, a-cut, 1 at.% Nd : YVO_4 crystal diffusion bonded with a 3×3×3 mm, undoped YVO_4 crystal. The input facet of the composite crystal was AR-coated at 808 nm and 1064 nm, while the other surface was only AR-coated at 1064 nm. The crystal wrapped by a thin layer of indium foil was placed in a copper holder kept at 15 °C. The KTP crystal cut for type-II phase matching (Crystech Inc., China) (θ = 90°, φ = 23.5°) measured 3×3×10 mm and both of its surfaces were AR-coated at 1064 nm and 532 nm. The temperature of KTP was kept at 20 °C by a water-cooling system. Two pieces of GaAs wafers with thicknesses of 400 and 700 μm were employed in the experiment. The output characteristics of the green laser, including the output power, the pulse duration and the pulse repetition rate, were measured with a PM100D power meter (Thorlabs Inc., USA), a 500-MHz digital oscilloscope (TDS 5052B, Tektronix Co., USA) and a fast InGaAs photodetector (Newfocus 1601, Newport Co. Ltd, USA).

3. Experimental results and discussions

The continuous-wave (cw) green laser was first studied without a GaAs saturable absorber. Figure 2 shows the average output power versus the incident pump power P_{in}. The threshold pump power for cw operation was about 150 mW, while the maximum cw output power was 648 mW at P_{in} = 10.5 W, corresponding to an optical-to-optical efficiency of 6.17% and the slope efficiency η_s of 6.4% (in comparison with the efficiency of 20% reported in Ref. [4]). The low cw output power was attributed to the induced losses by the absent AR coatings at 532 nm of the composite YVO_4/Nd : YVO_4 crystal. When the GaAs wafer was inserted into the laser cavity, a passively Q-switched green laser can be realised easily. One can see from Fig. 2 that the threshold pump powers for Q-switched operation with 400- and 700-μm-thick GaAs wafers increase to about 1.21 and 1.5 W, respectively. The highest output power of 362 mW was obtained with a 400-μm-thick GaAs saturble absorber at P_{in} = 10.5 W. The corresponding slope efficiency η_s was about 3.9%.

The dependences of the pulse duration and pulse repetition rate on the incident pump power are shown in Fig. 3, from which one can see that the pulse duration decreases with increasing P_{in}, and the pulse repetition rate rises. When a 700-μm-thick GaAs wafer was employed, the pulse duration can be significantly reduced. The minimum pulse duration of 1.5 ns was obtained at P_{in} = 10.5 W. On the other hand, a higher pulse repetition rate can be yielded by using a 400-μm-thick GaAs wafer. In this case, the measured highest pulse repetition rate was 84 kHz.

Once the average output power, pulse duration and pulse repetition rate were measured, the single pulse energy and peak power can be obtained (Fig. 4). At a high pump power, there were small differences between the pulse energies of different GaAs wafers, although the peak power in the case of a

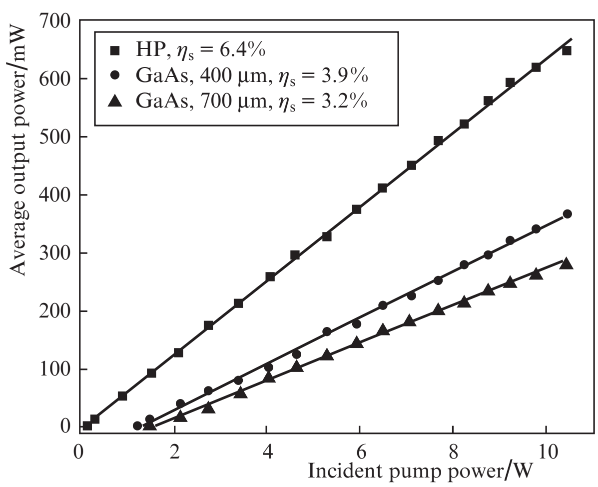

Figure 2. Average output power of the green laser vs. incident pump power.

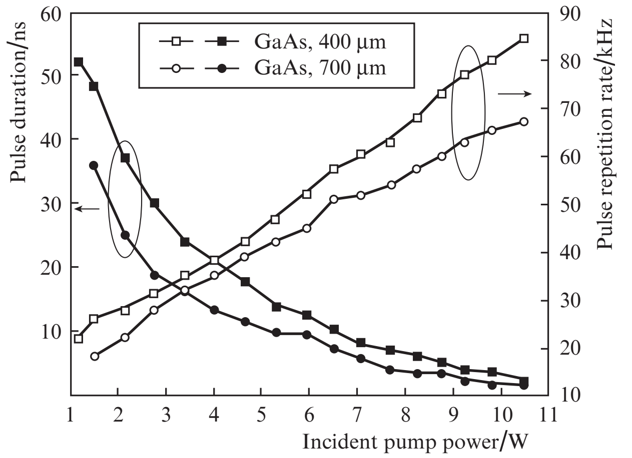

Figure 3. Pulse duration (filled symbols) and pulse repetition rates (open symbols) vs. incident pump power.

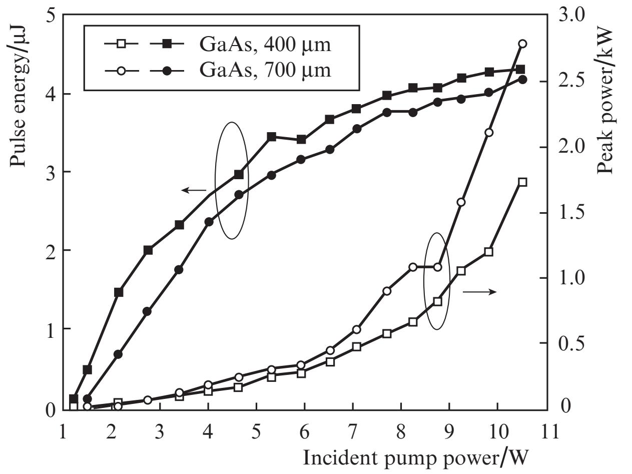

Figure 4. Pulse energy (filled symbols) and peak power (open symbols) vs. incident pump power.

700-μm-thick GaAs sarutable absorber was much higher than in the case of a 400-μm-thick GaAs wafer. The maximum peak power was calculated to be about 2.8 kW at P_{in} = 10.5 W with a thicker GaAs wafer as a saturable absorber. Therefore, a passively Q-switched green laser with a thinner GaAs saturable absorber can be used for the applications requiring high repetition rates, and a laser with a thicker GaAs wafer can be applied in the fields where a high peak power is needed.

The typical pulse characteristics are illustrated in Fig. 5. With P_{in} = 10.5 W and a 700-μm-thick GaAs saturable absorber, a minimum pulse duration of 1.5 ns was achieved. The inset in Fig. 5 shows a corresponding pulse train with a repetition rate of 67 kHz, demonstrating stable Q-switching.

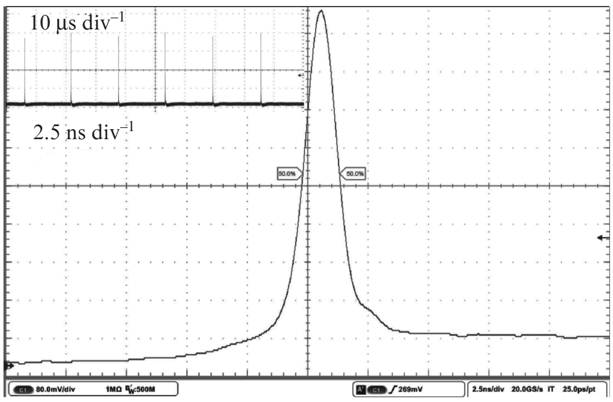

Figure 5. Typical pulse train and pulse shape in the case of a 700-μm-thick GaAs wafer; P_{in} = 10.5 W.

4. Conclusions

Thus, we have realised a diode- pumped, passively Q-switched YVO_4/Nd : YVO_4/KTP green laser with a GaAs wafer as a saturable absorber. In the case of a 400-μm-thick GaAs wafer, the maximum output power in the Q-switched regime is found to be 362 mW at an incident pump power of 10.5 W. The measured shortest pulse duration is 1.5 ns at a repetition rate of 67 kHz, corresponding to a pulse energy of 4.18 μJ and a peak power of 2.8 kW. A passively Q-switched YVO_4/Nd : YVO_4/KTP green laser with a 400-μm-thick GaAs wafer can be used to generate pulses with a high repetition rate, while the Q-switched green laser with a 700-μm-thick GaAs wafer can yield a much higher peak power.

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References

1. Tsunekane M., Taguchi N., Inaba H. *Electron. Lett*., **32**, 40 (1996).
2. Li T., Zhuo Z., Li X., Yang H., Zhang Y. *Chin. Opt. Lett.*, **5**, 175 (2007).
3. Zhuo Z., Li T., Li X., Yang H. *Opt. Commun*., **274**, 176 (2007).
4. Kitaoka Y., Ohmori S., Yamamoto K., Kato M., Sasaki T. *Appl. Phys. Lett*., **63**, 299 (1993).
5. Taira T., Kobayashi T. *Appl. Opt*., **34**, 4298 (1995).
6. Liu J., Wang C., Wang C., Meng X., Zhang H., Zhu L., Wang J., Shao Z., Jiang M. *Appl. Phys. B*, **72**, 171 (2001).
7. Yang K., Zhao S., Li G., Zhao H. *IEEE J. Quantum Electron*., **40**, 1252 (2004).
8. Chen Y. *IEEE Photon. Technol. Lett.*, **9**, 1481 (1997).
9. Liu J., Yang J., He J. *Opt. Laser Technol*., **36**, 31 (2004).
10. An J., Zhao S., Li G., Yang K., Li D., Wang J., Li M., Zhuo Z. *Laser Phys. Lett.*, **5**, 193 (2008).
11. Cheng K., Zhao S., Yang K., Li G., Li D., Zhang G., Wang Y., Zheng L., Wu F., Su L., Xu J. *Laser Phys. Lett.*, **10**, 055807 (2013).
12. Kajava T., Gaeta A. *Opt. Commun*., **137**, 93 (1997).
13. Chen L., Zhao S., Zhao H. *Opt. Laser Technol*., **35**, 563 (2003).