Available online at www.sciencedirect.com
ScienceDirect
Optik 121 (2010) 19–22
Optik Optics
www.elsevier.de/ijleo

Low-threshold diode-pumped CW passively mode-locked Nd:YVO_4 laser

Shihua Liu[a], Jie Liu[a,*], Guanggang Wang[a], Lei Li[a], Shushan Liu[a], Min Liu[a], Yonggang Wang[b]

[a]College of Physics and Electronics, Shandong Normal University, Jinan 250014, China
[b]Institute of Semiconductors, Chinese Academy of Sciences, Beijing 100022, China

Received 21 December 2007; accepted 12 May 2008

Abstract

A low-threshold passively continuous-wave (CW) mode-locked Nd:YVO_4 solid-state laser was demonstrated by use of a semiconductor saturable absorber mirror (SESAM). The threshold for continuous-wave mode-locked is relatively low, about 2.15 W. The maximum average output power was 2.12 W and the optical to optical conversion efficiency was about 32%. The pulse width was about 15 ps with the repetition rate of 105 MHz.

PACS: 42.55Xi; 42.55Rz; 42.60Fc; 42.60Gd

Keywords: Diode-pumped lasers; Nd:YVO_4; Mode-locked; SESAM

1. Introduction

Diode-pumped passively mode-locked all-solid-state laser have widespread applications in industry, military, medicine and scientific research because of their short pulse duration, simplicity, low cost and reliable operation. The most promising approach toward these goals is to develop passively mode-locked diode-pumped Nd^{3+} lasers with saturable absorber [1]. So far, a variety of solid-state saturable absorbers for passively mode-locked have been investigated, such as Cr^{4+}:YAG crystal [2], GaAs wafer [3,4], $LiF:F_2^-$ crystal [5], SESAM and saturable Bragg reflector [5–16] and so on.

Compared with other Nd host media, Nd:YVO_4 has a significantly larger emission cross section, a comparatively short lifetime of the upper level, and a strong and broad absorption at 809 nm, so it is very suitable for achieving continuous mode-locked operation. Introducing a saturable absorber, the laser is easy to operate in passively Q-switching mode-locked (QML) [17]. Generally, QML is an unwanted regime of operation for most applications. Sometimes the threshold of pump power for continuous-wave (CW) mode locking is very high and QML operation is always observed over a rather large range of pump power levels.

In Ref. [15], the author reports a low-threshold and highly efficient diode-pumped CW passively mode-locked Nd:YVO_4 laser, the corresponding threshold for CW operation and CW mode-locked operation were 0.25 and 2.42 W, respectively. In this paper, we demonstrated a diode-pumped passively mode-locked Nd:YVO_4 laser by using a highly reflective semiconductor saturable absorption mirror (SESAM), obtained a continuous-wave mode-locked with a repetition of 105 MHz, the threshold was 2.15 W for continuous-wave mode-locked; so far as we know this is the lowest threshold for CW mode-locked. Accordingly, the

*Corresponding author. Tel./fax: +86 531 86182521.
E-mail address: jieliu@sdnu.edu.cn (J. Liu).

0030-4026/$ - see front matter
doi:10.1016/j.ijleo.2008.05.006

threshold of CW was 0.204 W. The maximum average output power was 2.12 W at the incident pump power of 6.65 W, which corresponds to optical to optical conversion efficiency was about 32%, the pulse width was about 15 ps.

2. Experimental set-up

A schematic of the laser configuration is shown in Fig. 1. The pump source used in the experiment was a 30-W fiber-coupled diode-laser (LYPE30-SG-WL808-F400) with the output wavelength of the lasers at 27.5 °C ranging from 806 to 809.5 nm, and with the numerical aperture of 0.22. The radius of the pump beam was compressed to 200 μm on the host crystal. The host crystal used here was a-cut $Nd:YVO_4$ (with a $Nd:^{3+}$ concentration of 0.5 at.% and dimension of $4 \times 4 \times 8\,mm^3$), one of its light-passing face was coated for high reflection at the lasing wavelength of 1064 nm and high transmittance (HT) at pump wavelength of 808 nm, the other side was coated for HT both at 808 and 1064 nm. The laser crystal was wrapped with indium foil and mounted in a water-cooled copper block; the water temperature was maintained at 20 °C. The resonator consisted of a laser crystal; two highly reflective (at 1064 nm) mirrors, $M1$ and $M2$; one partially reflective mirror, output coupler (OC); and a highly reflective (at 1064 nm) SESAM. OC is a flat mirror; the radii of curvature for $M1$ and $M2$ are 50 and 10 cm, respectively. OC has a transmittance of 3.5% at 1064 nm, giving a total output coupling of 7%. The arm lengths of four branches, $L1$, $L2$, $L3$, and $L4$, were approximately 13, 30, 95, and 5.5 cm, respectively; thus the total cavity length should be about 143.5 cm. The mode radius in the crystal was about 210 μm; the mode radius on the SESAM was approximately 38 μm. In order to avoid astigmatism, the fold angle was designed to be less than 10°. The pulse temporal behavior was recorded by 1 GHz digital phosphor oscilloscope (TeKtronix TDS5104) and a fast photodiode detector (NEW FOUCS 1623) with a rising time of 2 ns.

The SESAM was grown on GaAs substrate by metal-organic chemical-vapor deposition. The SESAM consisted of 22 pairs of GaAs/AlAs quarter-wave Bragg layers with high reflectivity of 99.5% at lasing wavelength of 1064 nm and a 15 nm relaxed $In_{0.3}Ga_{0.7}As$ single quantum well (embedded in the topmost layer of the Bragg stack) for achieving saturable absorption at 1064 nm. The $In_{0.3}Ga_{0.7}As$ absorber was grown at temperature of 500 °C, a low temperature for a fast recovery time. The structure is shown in detail in Fig. 2.

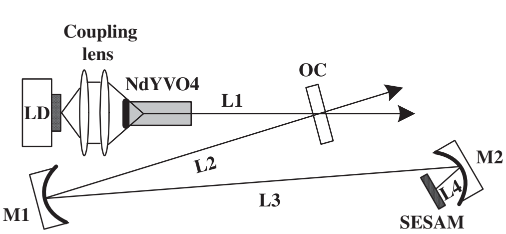

Fig. 1. Configuration of the $Nd:YVO_4$ laser with a SESAM.

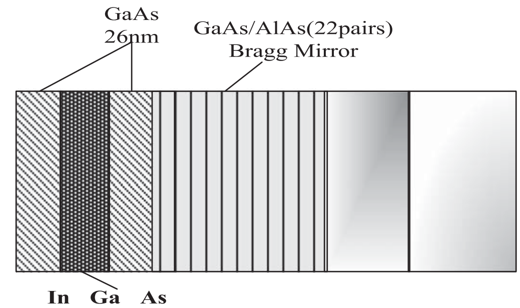

Fig. 2. Schematic structure of the SESAM.

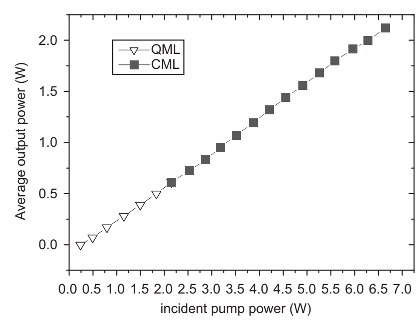

Fig. 3. Dependency of average output power on incident pump power.

3. Results and discussion

The behavior of laser average output power as a function of the incident pump power was investigated as shown in Fig. 3. The reported power is the sum of two output beams from the OC. The oscillation threshold was about 0.204 W; the low pump threshold indicates that the present SESAM did not induce significant nonsaturable losses. Near oscillation threshold the output was effectively CW. Within the range of pump power from 0.5 to 2.15 W, the picosecond pulses were superimposed on the long Q-switching pulse envelope. When the pump power was greater than 2.15 W, the laser exhibits CW mode-locked operation, and during our experiment the pulse was fairly stable. Fig. 4 showed the CW mode-locked pulse train in different time division, the repetition rate was about 105 MHz, and it was in good agreement with the theoretical results which is given by $f = c/2l$ (c is the speed of light, l is the optical