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SCIENCE DIRECT

Optik 117 (2006) 163–166

Optik Optics

www.elsevier.de/ijleo

Q-switched and mode-locked diode-pumped Nd:YAG laser with an LT-GaAs

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Received 4 March 2005; accepted 16 June 2005

Abstract

Simultaneous Q-switching and mode-locking (QML) is accomplished in a diode-pumped Nd:YAG laser using low-temperature GaAs (LT-GaAs) as the saturable absorber, which also acts as an output coupler at the same time. The repetition rate of the Q-switched envelope increased from 25 to 40 kHz as the pump power increased from 2.2 to 6.9 W. The mode-locked pulses inside the Q-switched pulse envelope had a repetition rate of 714 MHz. A maximum average output power of 770 mW was obtained.

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

Keywords: LT-GaAs; Nd:YAG; Diode-pump laser; Mode-locking; Q-switching

1. Introduction

High repetition rate Q-switched and mode-locked (QML) lasers with high peak power are required for various applications like telecommunications, non-linear frequency conversion, Mid-IR remote sensing, ranging, and so on. Q-switched mode-locked pulses can have peak powers many times higher than that of mode-locked pulses for similar current injection, and much better second harmonic generation could be obtained. Diode-pumped passively Q-switched mode-locked lasers can supply this kind of pulses and have the advantages of simplicity, compactness, low cost and high efficiency. So far, a variety of solid-state saturable absorption materials for Q-switch and mode-locking have been investigated, such as Cr^{4+}:YAG crystals, LiF:F_2, GaAs wafer and semi-conductor saturable absorption mirror [1–16] and so on. GaAs wafer or semi-insular GaAs substrate is cheap for passive Q-switch and mode-lock. The modulation depth can be varied by the dose and speed of implantation. However, the ion-implanted GaAs is easy to be destroyed by laser. In this paper, we present another method to improve the modulation depth of GaAs. GaAs film is grown at a temperature of 550 °C by metal organic vapor phase epitaxy on a semi-insular GaAs substrate, one side of which is coated with high-reflectivity film. With such an absorber, we obtain Q-switched mode-locked Nd:YAG laser pumped by diode laser.

Nd:YAG crystal is an efficient diode-pumped solid-state laser material. It is now widely used in many commercial lasers. Diode-pumped passively Q-switched mode-locked Nd:YAG with Cr^{4+}:YAG have been

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0030-4026/$ - see front matter © 2005 Elsevier GmbH. All rights reserved.
doi:10.1016/j.ijleo.2005.08.008

successfully demonstrated [1,2]. Q-switched mode-locked Nd:YAG laser with low-temperature GaAs (LT-GaAs) absorber have not been reported. In this paper, we firstly report, as far as we know, the performance of a diode-pumped passively Q-switched mode-locked Nd:YAG laser at 1064 nm with high repetition rate, using LT-GaAs as saturable absorber.

2. The growth of LT-GaAs

During low-temperature (LT) growth of GaAs by molecular beam epitaxy or metal organic chemical vapor deposition, antisites (or As_{Ga}) and Ga vacancy (or V_{Ga}) will be generated when As fluence is excessive over Ga fluence, which can form the trapping energy levels similar to EL2 defect in semi-insulated GaAs wafer [16]. So we can analyze defect energy level in LT-GaAs as same as the EL2 level. The difference between them is that the defect density in LT-GaAs is much more than that of the EL2 level in GaAs wafer grown by liquid encapsulated Czochralski or vertical gradient freezing methods. Therefore, the modulation of LT-GaAs absorber can reach tens of hundredth as long as the LT-GaAs is thick enough.

The absorption for this process is saturable with the increase in laser irradiance in GaAs. This absorption is taken as the single-photon absorption (SPA). There is a general understanding that GaAs can be used as passive Q-switch as a result of this saturable absorption. However, apart from SPA, there are also two-photon absorption (TPA) and free-carrier absorption (FCA) at higher laser irradiance. TPA generates free electrons in conduction band and free holes in valence band whereas FCA promotes electrons into the higher conduction band and holes into the deeper valence band.

TPA plays an important role in the formation of Q-switched pulse for GaAs wafer as well as LT-GaAs. The difference is that in LT-GaAs the density of As_{Ga} is very high and its recovery time is as short as several picoseconds, which provides the conditions for Q-switch even picosecond level mode-locking for solid-state lasers or fiber lasers.

In order to make LT-GaAs an absorber as well as an output coupler, one side of it is coated with high-reflectivity film. Multiple layers of dielectric films such as ZrO_2/SiO_2 are superior to Si/SiO_2 multiple layers because the former has higher damage threshold for laser.

3. Experimental results and analysis

When the intracavity intensity of the laser is low, LT-GaAs crystal is an effective saturable absorber only for Q-switching. To generate a Q-switched and mode-locked pulse, the intracavity intensity of the laser must be sufficiently strong. Therefore, a cavity is required that has a small beam area in the LT-GaAs crystal. Increasing the spot size in the absorber leads to a decrease of the pulse energy of the whole Q-switched pulse and the modulation depth of the mode-locking pulse train. In order to acquire high intracavity intensity we adopted folded cavity.

A schematic diagram for passively Q-switched and mode-locked Nd:YAG laser is shown in Fig. 1. It was based on a three mirror folded resonator. The Nd:YAG crystal was pumped by a fiber-coupled semi-conductor laser at 808 nm with the maximum available output power of 8 W and a numerical aperture of 0.12. A 1.0 at% Nd:YAG crystal with dimensions of $4 \times 4 \times 6\,mm^3$, was utilized as laser medium. The output from the semi-conductor laser was focused with a collimating lens onto the Nd:YAG crystal. They were AR coated at 808 nm and 1.06 μm. The pump mirror M1 was a concave mirror with radius of 200 mm, high reflectivity ($R > 99.8\%$) coated at 1.06 μm and high transmittance ($T > 95\%$) coated at 808 nm. The total cavity length accounted suitable was about 210 mm. The physical length between M2 and M3 was about 45 mm. M2 was a concave mirror (radius of 80 mm) with high reflection at 1.06 μm. The LT-GaAs absorber is as both self-starting mechanics and output coupler M3, with the initial transmittance (T_0) of 5% at 1.06 μm, which makes the insertion loss lower and the laser much more compact.

According to the theoretical results of Q-switched mode-locking, we calculated the TEM_{00} Gaussian modes for the resonators used in the experiments by applying the ABCD-matrix formalism, and assuming that the pumped crystal can be modeled as a paraxial lens-like medium. The mode radius in the LT-GaAs (output mirror) was calculated. The mode radius on the LT-GaAs is about 115 μm at the incident pump power of 6.9 W. We found in our experiments that such a folded cavity could satisfy the Q-switched and mode-locking condition. We obtained QML, not cw mode-locking. The intracavity pulse energy (power) must be

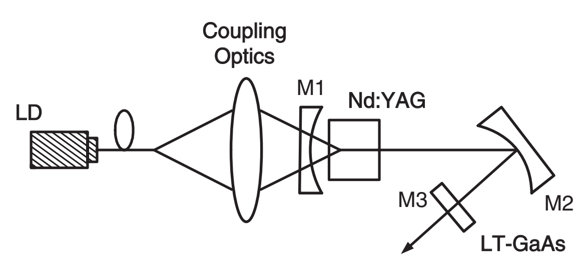

Fig. 1. Configuration of a passively Q-switched and mode-locked Nd:YAG laser.