Optica Applicata, Vol. XXXVI, No. 1, 2006

GaAs absorber grown at low temperature used in passively Q-switched diode pumped solid state laser

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We report, for the first time to the best of our knowledge, on a passively Q-switched $Nd:YVO_4$ laser with a GaAs absorber grown at low temperature (LT) by metal organic vapor phase expitaxy. Using the LT GaAs absorber as well as an output coupler, a passively Q-switched laser whose pulse duration is as short as 90 ns was obtained.

Keywords: GaAs, low temperature, Q-switch, $Nd:YVO_4$ laser.

1. Introduction

Q-switched all-solid-state lasers employing solid-state saturable absorber are desirable for many applications such as micromachining, ranging, microsurgery, and so on. Compared with active Q-switching, passive Q-switching techniques can significantly simplify the operation, improve the efficiency, reliability and compactness, and reduce the cost of laser sources [1]. So far, a variety of solid-state saturable absorption materials for Q-switch have been investigated, such as V^{3+}:YAG [1], tetravalent chromium-doped crystals [2], GaAs wafer [3, 4] and semiconductor saturable absorption mirror [5], and so on. GaAs wafer or semi-insular GaAs substrate is cheap for passive Q-switching. LI PING *et al*. [3] obtained 80 ns pulse duration from passive Q-switched flash-lamp-pumped Nd:YAG laser using GaAs substrate as a saturable absorber as well as an output coupler. However, its modulation depth is limited and its recovery time is hard to control. WANG *et al*. [6] report a 62 ns pulse generation from passive Q-switched flash-lamp-pumped Nd:YAG laser with ion-implanted GaAs absorber. The modulation depth can be modified by the dose and speed of implantation.

However, the ion-implanted GaAs is susceptible to damage by laser. In this paper, we present another method to improve the characteristics of GaAs absorber. A GaAs film of about 3 μm is grown at a temperature of 550°C by metal organic vapor phase epitaxy (MOVPE) on a semi-insulating GaAs substrate. With such an absorber we obtain a Q-switched Nd:YVO_4 laser pumped by diode laser.

2. GaAs absorber grown at low temperature

In this paper, GaAs absorber grown at low temperature (LT GaAs absorber) is presented (as shown in Fig. 1). The absorber was made mainly by MOVPE device. First, a 500 nm GaAs buffer layer was deposited on the semi-insulating GaAs substrate. Second, a GaAs of about 3 μm was grown on the buffer layer at a temperature as low as 550°C. Finally, both sides of the GaAs substrate were coated with partial transmission film and antireflection film separately near 1 μm. The growth rate for the LT GaAs layer is 40 nm/min and the precursors are TMGa and AsH_3. The As antisites (or As_{Ga}) and Ga vacancies (or V_{Ga}) are generated when As fluence exceeds Ga fluence during low-temperature growth, which can form the trapping energy levels in LT GaAs layer. These traps provide fast relaxation for the carriers generated by light. The photon energy at a 1.06 μm wavelength is far below the GaAs band gap of 1.42 eV, the absorption at this wavelength in the absorber is believed to be due to the EL2 defect that forms a deep donor level $EL2^0/EL2^+$ located 0.82 eV below the conduction band within the band gap. For such two effects, the LT GaAs absorber can provide nonlinear absorption as well as fast relaxation for 1.06 μm wavelength laser, which make it to ackt as an absorber for Q-switched solid-state lasers. In addition, the modulation depth of LT GaAs absorber can be increased by decreasing the temperature of the GaAs

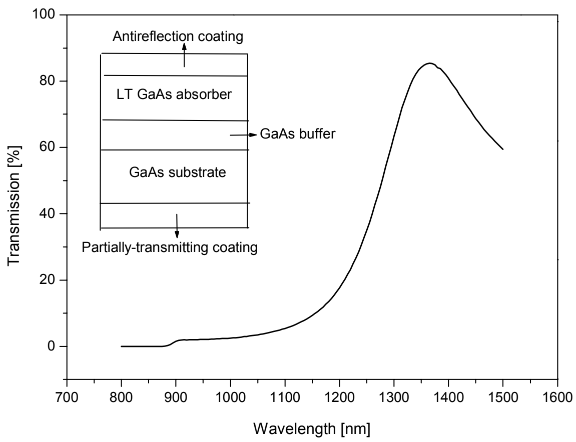

Fig. 1. Measured transmission spectrum of LT GaAs absorber and its schematic structure as given in the insert.

absorption layer or increasing the thickness of the layer, and the recovery time of the absorber varies with the temperature for growth. That is to say, the parameters for LT GaAs absorber are adjustable.

There is a procedure of annealing for three minutes after the growth in order to lessen the non-saturable loss. Due to some salient structural features, our LT GaAs absorber can be used as an output coupler directly. One side of the absorber is coated with partially transmitting coating and the other is covered with antireflection coating. In our experiment, we choose a multilayer coating of dielectric films of ZrO_2/SiO_2 as antireflection coating and Al_2O_3/SiO_2 as partially transmitting coating for they have higher damage threshold for laser than some other materials such as Si/SiO_2, even though the latter is easier to make in semiconductor industry. In addition, such an absorber is easily fabricated and its cost is lower than that of SESAMs [5]. The LT GaAs absorber has longer life for use than that of the SESAMs because there is no mismatch between LT GaAs absorption layer and GaAs substrate. The transmittance of the LT GaAs absorber is about 9% at 1064 nm and its modulation depth can be increased by decreasing the temperature of the GaAs absorption layer or increasing the thickness of the GaAs absorption layer and the recovery time decreases with the temperature for growth.

3. Experiment and discussion

Figure 2 shows a schematic diagram of the experimental set-up. The cavity length is 400 mm. We choose a three-fold mirror cavity structure in our work in order to focus laser upon the GaAs absorber grown at low temperature. The GaAs absorber is both a Q-switching absorber and an output coupler. In the figure, the following denotations

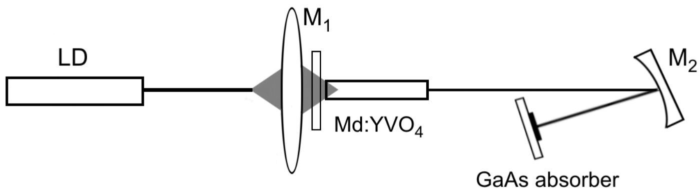

Fig. 2. Cavity set-up of the passive Q-switched Nd:YVO_4 laser.

are used: M_1 – plate mirror with dichroic coating, M_2 – folding mirror with radius of curvature of 50 mm. The pump source (Apollo Instruments, Inc.) is a fiber-coupled diode laser with core diameter of 0.6 mm and numerical aperture of 0.22. A coupled optical system is used to focus the pump beam into the gain medium.

A typical oscilloscope trace is presented in Fig. 3**a**, showing a train of Q-switched pulses. Figure 3**b** displays the Q-switching pulse series as short as 90 ns, which is

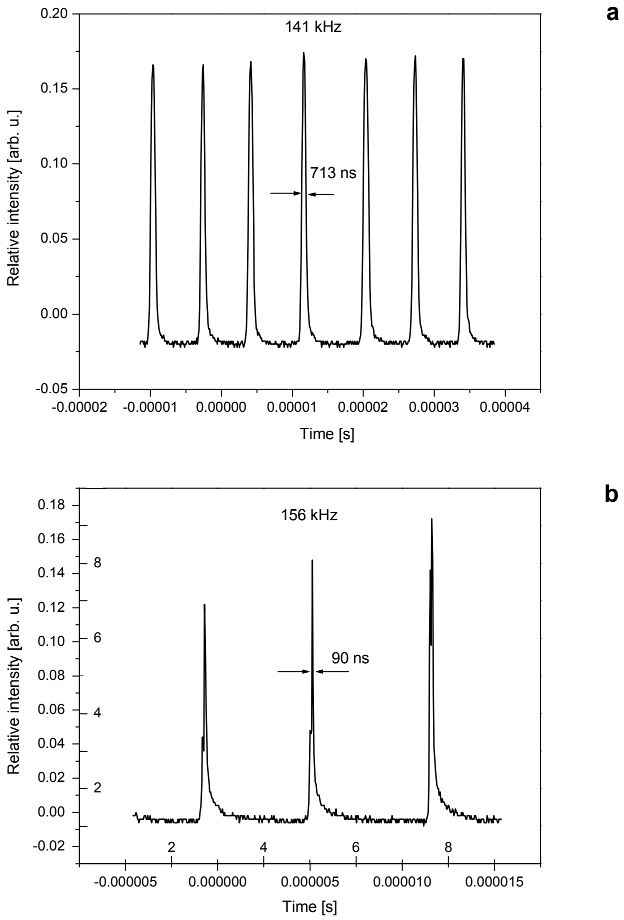

Fig. 3. Oscilloscope trace of a Q-switched pulse train; pulse train with general pulse duration (**a**), pulse train with the shortest pulse duration (**b**).

the shortest pulse obtained in our experiment. The oscilloscope trace observed from the oscilloscope is instable, we can obtain pulse duration from 90 to 800 ns or so.

In passively Q-switched laser, the relationship between pulse duration, cavity length, and modulation depth is [7]:

$$\tau_p = \frac{7nL}{c\Delta R}$$

where n is the index of refraction of the gain material, L is the cavity length, and c is the speed of light. The cavity round trip time is $2nL/c$ and the modulation depth is ΔR. So, the pulse duration in our experiment is not short enough and may result from the relatively long cavity and relatively higher growth temperature for the GaAs

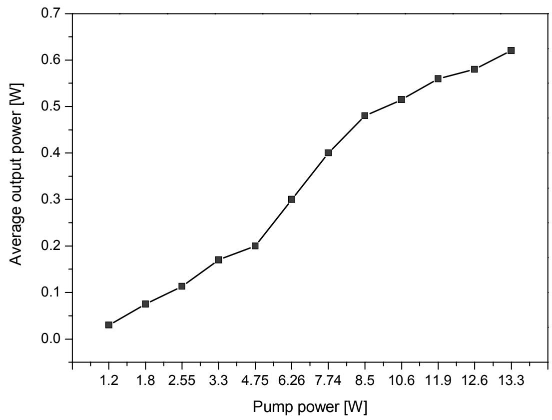

Fig. 4. Average output power of the passively Q-switched laser *vs.* pump power.

absorber. With the growth temperature being higher the density of the trap in LT GaAs decreases, so that the modulation depth of the LT GaAs absorber is limited.

Figure 4 displays the relationship between the average output power and the pump power. The threshold of Q-switching is 1.2 W and the corresponding average output pulse laser is 30 mW. The maximum average output power is 600 mW when the pump power is 13.3 W.

4. Conclusions

We have presented a GaAs absorber grown at low temperature by metal organic vapor phase expitaxy, with which we obtained a passively Q-switched diode-pumped Nd:YVO_4 laser. The shortest pulse duration is as short as 90 ns. At 13.3 W of pump power, a 600 mW average output power is obtained. The pulse duration in our experiment is not as short as might be obtained by some other method, which is related to higher growth temperature of the absorber and longer cavity length for Q-switching laser.

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Received April 4, 2005
in revised form October 29, 2005