High-peak-power flashlamp-pumped passively Q-switched Nd:YAG laser with AlGaInAs quantum wells as a saturable absorbers

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ABSTRACT

We demonstrate an AlGaInAs saturable absorber with a periodic quantum wells (QWs)/barrier structure that can be used to achieve an efficient high-peak-power and high-pulse-energy passively flashlamp-pumped *Q*-switched Nd:YAG laser at 1.06 um. The barrier layers are designed to locate the QW groups in the region of the nodes of the lasing standing wave to avoid damage. With an incident pump voltage of 14.5 J, a single pulse was generated with a pulse energy of 14 mJ and a *Q*-switched pulse width of 13 ns. The maximum peak power was greater than 1.08 MW.

Keywords: flashlamp-pumped laser; semiconductor saturable absorber; passively Q-switched

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1. Introduction

Neodymium-doped(Nd^{3+}) gain mediums are the most widely used solid-state laser materials. Generally, the optical conversion of lamp-pumped Nd^{3+}-doped is lower than diode-pumped. Whereas a laser diode(LD) pumping scheme can be provide a high efficiency because the pump light from the LD can be efficiently absorbed by the laser gain medium with small quantum defect. However, a flash lamp is much more cost-effective than the LD today, so lamp-pumped lasers are widely used in high peak power and high pulse energy industrial application. Therefore, the flashlamp pumping is still prevailing for pulsed high peak power sources operated at low repetition rates. [1-6] Furthermore, the Q-switched laser can be obtained higher output pulse energy and peak power.

Q-switching is a widely used laser technique in which allow a laser pumping process to build up a larger population inversion inside a cavity and generate a short pulse with high pulse energy and peak power. Solid-state Q-switched lasers are of great interesting because of their applications in the field of laser ranging, laser cutting and drilling, micromachining, microsurgery, and nonlinear optical studies. However, the passive Q-switch laser that use saturable absorbers has some advantages in comparison with the active one : they are compact, inexpensive and simplicity in operation. In the past, the passively Q-switched lasers were mostly formed by dyes dissolved in various solvent. As the saturable dyes have to fulfill the requirement that they can absorb laser radiation resulting in bleaching, no such dyes are available for every type of laser. Even if the absorbers with proper saturable absorption exist, mostly they have disadvantages of temperature and long-time instability. Therefore solid-state materials possessing reliable saturable absorption, good chemical and physical properties are the object of constant interest of researcher. Numerous saturable absorbers have been developed to replaced the dyes used in solid-state lasers, such as Cr^{4+}-doped materials [7-13] and semiconductor saturable absorber mirrors (SESAMs) [14,15]. Nowadays, Cr^{4+}:YAG crystals are no doubt the most used saturable absorbers in the 0.9-1.2 μm spectral region and are making it suitable for the 0.946μm and 1.064μm Nd^{3+} transitions. In the pass, the InGaAs/GaAs quantum wells (QWs) have been utilized as SESAMs, but the lattice mismatch leads to the limitation of the modulation depth. As a consequence , the output pulse energies and the conversion efficiencies with InGaAs/GaAs SESAMs are generally lower than those with Cr^{4+}:YAG crystals. Recently, the quaternary alloy of InGaAsP is an important material because it can be grown epitaxially on an InP substrate without lattice mismatch in the 0.84-1.65 μm. An InGaAsP multiple QW/barrier structure grown a transparent InP substrate has been successfully used as a semiconductor saturable absorber (SESA) in a 1.3 μm laser with a Q-switched efficiency of 27.6%[16]. Compared with InGaAsP materials, the AlGaInAs quaternary alloy with a large conduction band offset can provide a better electron confinement covering the same wavelength region. An AlGaInAs saturable absorber with a periodic QW/barrier structure also has been used to achieve an efficient high-peak-power passive Q-switched 1.06 μm laser with the Q-switched efficiency of 80%[17]. In this letter, we report a high-peak-power and high pulse energy flashlamp-pumped passively Q-switched Nd:YAG laser with AlGaInAs quantum wells as a saturable absorbers at 1.06 μm. With an incident pump energy 10.2 J, a single pulse was generated with a pulse energy 14 mJ and a Q-switched pulse width of 13 ns. The maximum peak power was greater than 1.08 MW.

2. Experimental setup

Figure 1 depicts the experimental configuration of the flashlamp-pumped passively Q-switched Nd:YAG laser. A Nd:YAG rod and a Xe Flashlamp were placed inside a pumping enclosure consisting of reflectors. The Xe flashlamp has an arc length of 70 mm, the normal pressure 450 Torr, and maximum flash energy of 20 J at 850 voltage. The AlGaInAs SESA structure was monolithically grown on a Fe-doped InP substrate by metalorganic chemical vapor deposition (MOCVD) to simultaneously serve as a saturable absorber. The saturable absorber region consists of 50 groups of three QWs with luminescence wavelength around 1060nm, spaced at half-wavelength intervals by InAlAs barrier layers with bandgap wavelength around 805 nm. The backside of the substrate was mechanically polished after growth. Both sides of the SESA were antireflection coated to reduce backreflections. The initial transmission of the SESA device at the wavelength of 1064 nm was measured to be approximately 57%. It was experimentally found that the SESAM device has a modulation depth of 35%. The laser crystal is 50 mm lomg with 3-mm diameter and doped with a 1.18 % Nd^{3+} concentration. Both sides of the Nd:YAG was were cut at angle 2∘and were antireflection coated at 1064 nm. The polarized laser output power is obtained with a BK-7 Brewster plate placed in the cavity. Two mirrors were used to form the laser cavity. The front mirror with radius of curvature of 500 mm was coated with high reflectivity at 1064 nm. The reflectivity of the concave output couple with radius of curvature of 600 mm is 40 % at 1064 nm. The spectral information of the laser was monitored by an optical spectrum analyzer (Advantest Q8381A). The spectrum analyzer employing diffraction lattice monochromator can be used for pulse light with the resolution of 0.1 nm. The pulse temporal behavior was recorded by a LeCroy digital oscilloscope (Wavepro 7100, 10 GS/sec, 1 GHz bandwidth) with a fast InGaAs PIN photodiode.

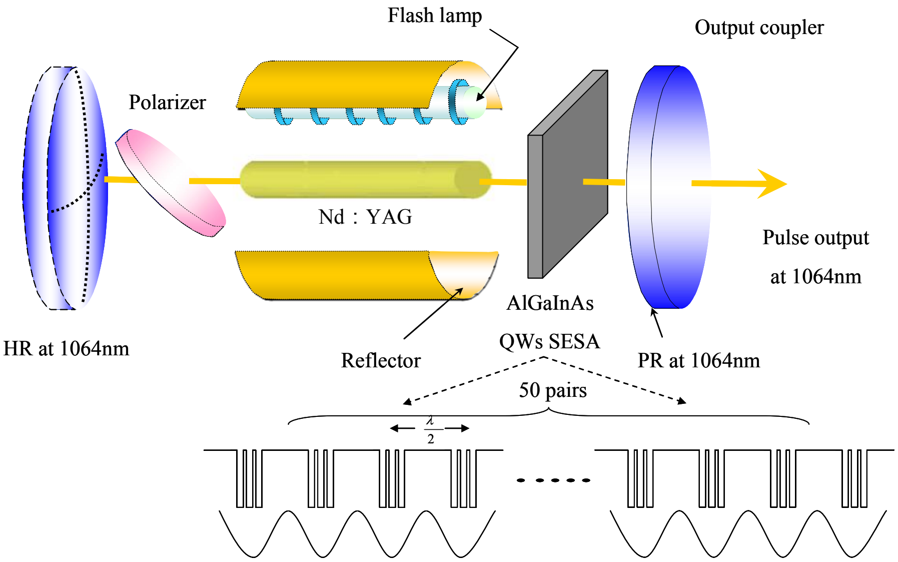

Fig. 1 Schematic of a flashlamp-pumped passively Q-switched Nd:YAG laser using a periodic AlGaInAs QW/barrier structure as a saturable absorber : HR, high reflection; HT, high transmission.

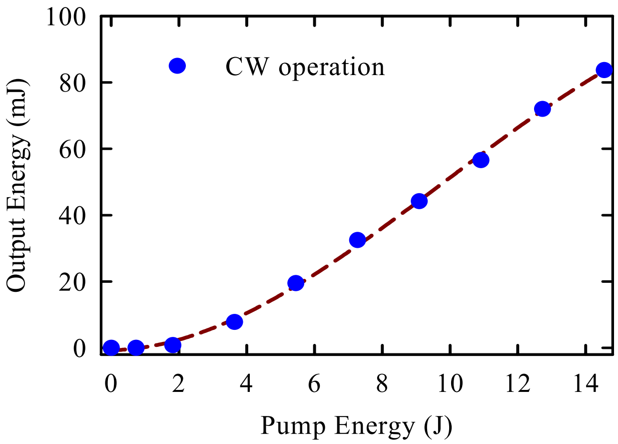

Fig. 2 Experimental results of the CW operation for the output pulse energy as a function of the pump energy.

3. Experimental results and discussion

First of all, the quasi CW free-running operation without saturable absorber was performed to confirm the quality of the laser crystal. Figure 2 shows the experimental results of the CW operation for the output energy at 1064 nm as a function of the pump energy. It can be seen that the output energy of 83.7 mJ was achieved at an incident pump energy of 14.5 J. The overall slope efficiency was found to be nearly 0.7%. Figure 3 depicts the experimental pulse at 14.5 J of pump energy. The temporal shape of the single pulse exhibits relaxation-oscillation driven spikings. Although the pump pulse width is around 200μs, the lasing threshold leads to the output pulse width to be approximately 120μs. With the experimental pulse width and pulse energy, the on-time average output power can be estimated to be 0.7 KW at 14.5 J of pump energy corresponding to 72.5 KW average pump power.

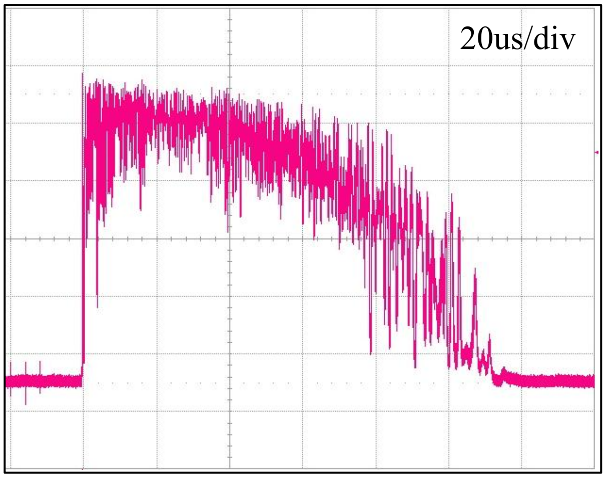

Fig. 3 Experimental result of the CW operation for

We estimated the performance of the passively Q-switched Nd:YAG laser with AlGaInAs quantum wells as a saturable absorbers. For this investigation an output couple with partial reflection at 1064 nm was used, and the optimum reflectivity of the output couple was found to be approximately 40%. The threshold of the Q-switched laser operation was found to be 9.09 J, and the output pulse energy at 1064 nm was measured to be 14 mJ.

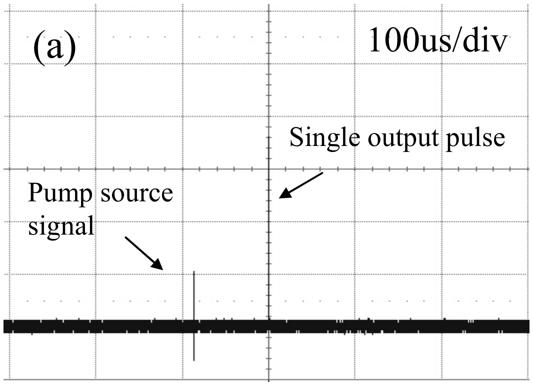

Fig. 4 (a) Typical oscilloscope trace of a single output pulses in the passively Q-switched Nd:YAG laser with AlGaInAs as a saturable absorber

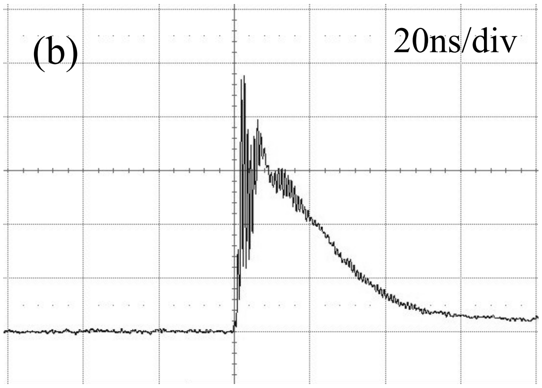

Fig. 4 (b) Typical oscilloscope trace of a expanded shape of the single pulse in the passively Q-switched Nd:YAG laser with AlGaInAs as a saturable absorber

Figure 4 shows the temporal shape of the Q-switched laser and single pulse. It can seen that the pulse width was found to be 13 ns; consequently , the peak power was approximately 1.08 MW. As shown in Figure 2, the output pulse energy in CW regime is 44.2 mJ at 9.09 J of pump energy. Therefore, the extraction efficiency with respect to the output pulse energy from the CW operation is approximately 31.7%. The typical result for the optical spectrum measurement is depicted in Figure 5. Finally, the spatial distribution of the signal output was recorded with an infrared CCD and displayed in Figure 6. The beam quality M^2 factor was estimated to be approximately 1.5.

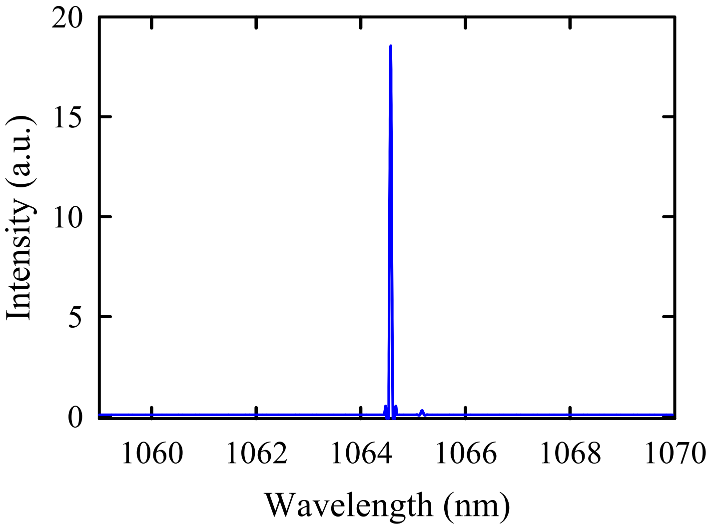

Fig. 5 Experimental results for the lasing spectra of the passively Q-switching operation.

(a)

Fig. 6(a) Experimental 2D far-field pattern of the signal output pulse.

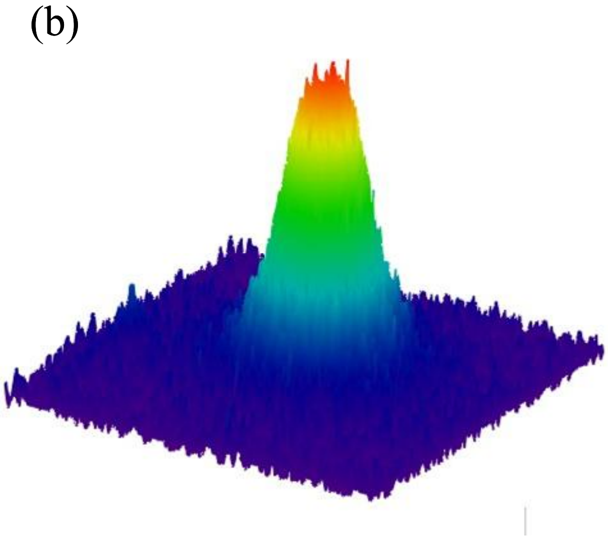

Fig. 6(b) Experimental 3D representation far-field pattern of the signal output

4. Conclusion

In summary, a periodic AlGaInAs QW/barrier structure grown on a Fe-doped InP substrate was used as a saturable absorber for the passively Q-switching of a high-power falshlamp pumped Nd:YAG laser operating at 1064nm. A slope efficiency of 0.7% has been obtained for the CW operation. For the passively Q-switching operation, the cavity produced 14 mJ of output pulse energy at 1064nm with a pump energy of 9.09 J. With the experimental pulse width of 13 ns and the pulse energy, the peak power is 1.08 MW. As the result the extraction efficiency with respect to the Q-switched output pulse energy from the CW operation is approximately 31.7%.

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