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Research Paper

Influence of Pump Pulse Duration on the Output Performance of a LED-Pumped Nd:YAG Laser

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Abstract:
In this paper, we performed an experimental study of a LED-pumped Nd:YAG laser that works in QCW and Q-switch modes. We examined how the pump pulse duration affects the laser output. The laser rod was a Nd:YAG crystal with a diameter of 7 mm and a length of 95 mm, side-pumped by 30 LED arrays, each with 18 single dies at 810 nm. The maximum output energy at 1064 nm was 10.5 mJ in the QCW mode, with a pump energy of 81 mJ (230 µs pulses at 1 Hz). The optical conversion efficiency and the slope efficiency were 12.5% and 18%, respectively. In the PQS mode, the output energy was 250 µJ, with a pulse width of 190 ns (FWHM), corresponding to a peak power of 1.31 kW. The beam divergence was 0.3 mrad with TEM_{00} mode. This LED-pumped Q-switched Nd:YAG laser can be used for laser range finder applications.

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1. INTRODUCTION

LED-pumped Solid-state lasers have attracted the attention of researchers as an interesting and valuable research topic since the very beginning of laser invention [1-11]. There are many reports the employment of different materials as an active medium [12-17], using LEDs with different wavelength pump light [18,19], applying luminescent concentrator [20], This case, despite the conversion of the visible wavelength to the appropriate region of the optimal absorption wavelength, due to its large volume, it prevents the assembly of LED-pumped solid-state lasers in a small volume and size. There have also been reports of active [21], and passive [22], Q-switching of LED-pumped solid-state lasers. In the optimal design of a LED-pumped solid-state laser, three key points must be observed, first: selecting the appropriate wavelength that has the most absorption overlap with the absorption diagram of the laser crystal, for this reason we chose the best available wavelength, 810 nm. second: Increasing the light intensity of LEDs, which as far as we know, the highest output peak power of LEDs that can be produced is about 3 watts, which is made possible the highest output power of the Nd:YAG laser that has been reported [19]. Third: the design of the optimal coupling of the light emitting diode with respect to the laser crystal, which has been carried out in different research activities [23, 24]. The paper is organized as follows: Section 2 explains the experimental setup, Section 3 shows the results and observations, and Section 4 concludes the paper.

2. EXPERIMENTAL SETUP

We used a side-pumped scheme to increase the pump power of a LED-pumped Nd:YAG laser operating in QCW and Q-switch modes. We investigated the influence of pump pulse duration on the laser output. The pump source was a near-infrared LED (SFH4780S, OSRAM) with a peak wavelength of 810 nm and a FWHM of 32 nm. The LEDs had lenses to optimize the coupling of the pump light to the laser rod [23]. The LEDs were arranged in thirty arrays, each with 18 dies. The total length of each array was 92 mm and the width was 4 mm. The LEDs were placed at 18.9 mm from the center of the Nd:YAG rod. A focal lens on each LED die narrows the beam angle to ±10 degrees, reducing light dispersion. The pump pulse duration of the LEDs was selected to be 230, 320, 500 and 1000 microseconds. Each LED die required a voltage of 3.8 V and a current of 2 A to operate. The maximum peak irradiance of all LEDs was 352 W, corresponding to a total energy of 81 mJ. The electrical-to-optical conversion efficiency of the LEDs was about 7.4%.

The total length of the optical resonator was selected to be 225 mm. The back mirror was a concave mirror with a radius of curvature of +2000 mm and a high-reflectivity coating at 1064 nm. The output mirror was a flat mirror with a reflectivity of 91%, 94% or 98% at 1064 nm. The reason for choosing the output mirror and the amount of its reflection was to achieve the high output energy and the low laser threshold

The laser rod was a Nd:YAG crystal with a length of 95 mm, a diameter of 7 mm and a Nd^{3+} doping concentration of 1.1%. The rod faces were flat-flat and anti-reflective (AR, R < 0.2%) coated at 1064 nm reduces the intra-cavity losses. The lateral surface on the pump side was frosted.

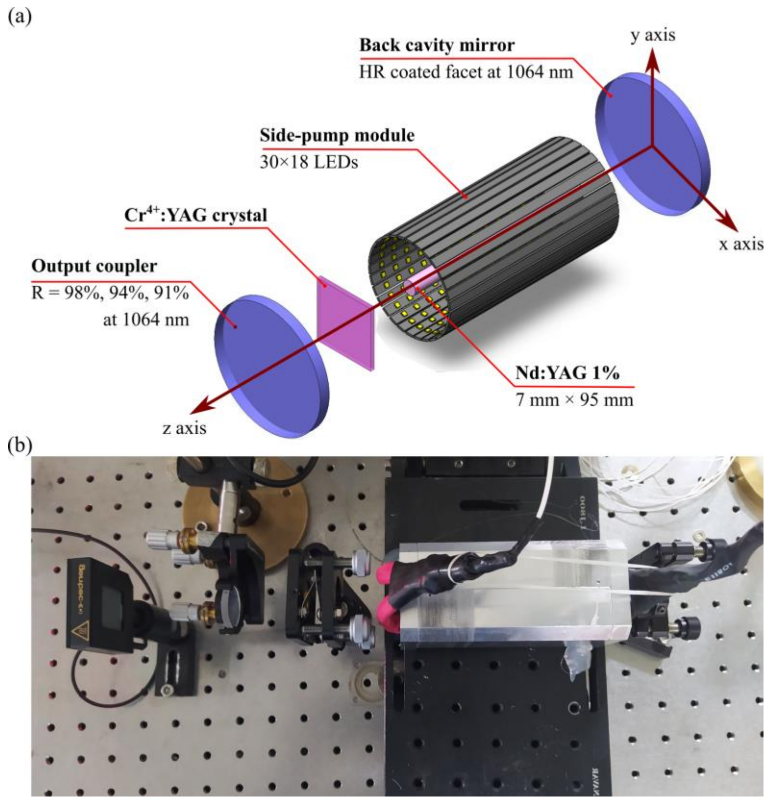

Fig. 1. Side LED-pumped Nd:YAG laser setup: (a) schematic drawing and (b) picture of the setup.

We inserted a saturable absorber (Cr^{+4}:YAG crystal) with an initial transmission of 95% into the cavity after testing the QCW regime. Fig. 1 shows the schematic

drawing (a) and the picture of setup (b) of the LED-pumped passive Q-switched Nd:YAG laser.
we used equation (1) for calculating electrical pump energy in terms of different pump pulse durations

$$E_p = V \times I \times T, \tag{1}$$

(E_p: is electrical pump energy, V: is total applied voltage, I: is total current, T: is pump pulse duration).
Fig. 2 shows how the output power of a single LED die in QCW mode varies with the input current for a pulse duration of 230 µs.

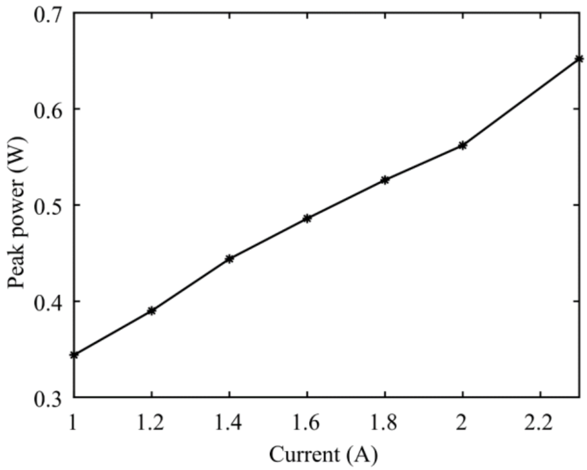

Fig. 2. Peak power of single LED die (SFH4780S OSRAM CO.) as a function of input current in QCW mode.

The absorption spectrum of Nd:YAG and the emission spectrum of 810 nm LEDs are shown in Fig. 3. The LED emission spectrum overlaps well with the wide and strong absorption band of Nd:YAG around 810 nm, which means that Nd^{3+} can effectively absorb the LED light at this wavelength. The inset shows an image of the physical spot without focusing. We used a spectrum analyzer (Ocean, HR4000) with a resolution of 0.02 nm to measure the output spectrum of the Nd:YAG laser at different drive currents. We observed that the laser had a peak wavelength of 1064.68 nm and a FWHM of 2.1 nm at 30 A. The peak wavelength shifted to the blue and the FWHM decreased as we increased the current from 30 A to 70 A, reaching 1063.65 nm and 1.03 nm, respectively, at 70 A. These results indicate how the pump power of the LED or LD system affects the Nd:YAG crystal laser emission.

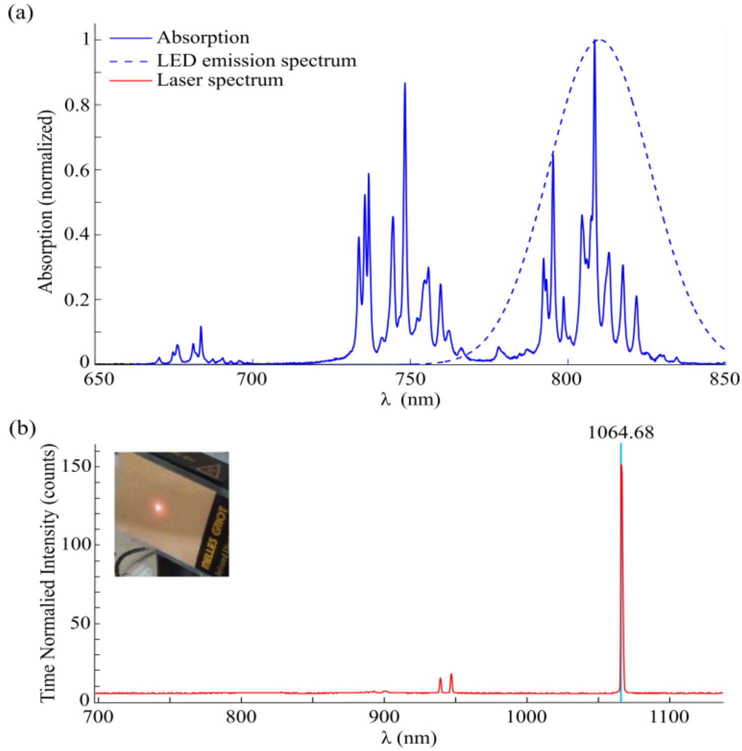

Fig. 3. (a) Nd:YAG crystal absorption coefficient and 810-nm LED pump spectra, (b) Nd:YAG lasing spectrum in QCW mode, with an inset showing the unfocused spot image.

The effective absorption efficiency of the LED-Pumped laser, which is related to the spectral overlap between the LED emission and the Nd:YAG absorption, was calculated by us. This helped us determine the optimal pump spectral condition. The formula for the effective absorption efficiency is [25]:

$$\eta_{eff} = \int \left(1 - e^{-\alpha(\lambda)L}\right) S_{LED}\left(\lambda_0, \Delta\lambda, \lambda\right) d\lambda \tag{2}$$

The effective absorption efficiency, η_{eff}, is the fraction of pump light absorbed by the gain medium. It depends on the crystal length, L, the target wavelength, λ, and the absorption coefficient, $\alpha(\lambda)$, of the Nd:YAG. It also depends on the normalized pump spectrum, $S_{LED}(\lambda_0,\Delta\lambda,\lambda)$, which is a Gaussian function of the central wavelength, λ_0, and the FWHM, $\Delta\lambda$, of the LED. The formula for $S_{LED}(\lambda_0,\Delta\lambda,\lambda)$ is:

$$S_{LED}\left(\lambda_0, \Delta\lambda, \lambda\right) = \sqrt{2 \big/ \pi\Delta\lambda^2 \exp\left(-2\left(\lambda - \lambda_0\right)^2 \big/ \Delta\lambda^2\right)} \tag{3}$$

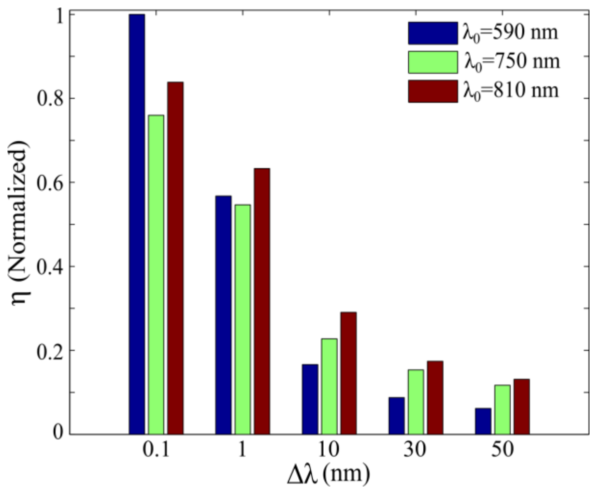

Fig. 4. effective absorption efficiency in terms of LED spectral band width (FWHM).

Figure 4 shows the normalized absorption coefficient of Nd:YAG for three LED wavelengths: 590 nm, 750 nm, and 810 nm. The 810 nm LED has the highest absorption coefficient when the FWHM is about 30 nm. This means that the 810 nm LED is the most suitable pump source for the Nd:YAG laser.

In this paper We have conducted an experimental study of how the pump pulse duration influences the output performance of a LED-pumped Nd:YAG laser.

3. RESULTS AND DISCUSSION

We explored how the pump pulse duration affects the output energy and the pulse shape of the laser in Q-switching and free-running modes. We used LED drivers to set the operating frequency of the LEDs to 1 Hz with pulse widths of 230 µs, 320 µs, 500 µs and 1000 µs. The maximum total drive current for the LEDs was 70 A. We measured the output energy of the laser in free-running mode with output couplers with reflectivity of 91%, 94% and 98 % for pump pulse widths of 230 µs, 320 µs, 500 µs and 1000 µs (Fig. 5).

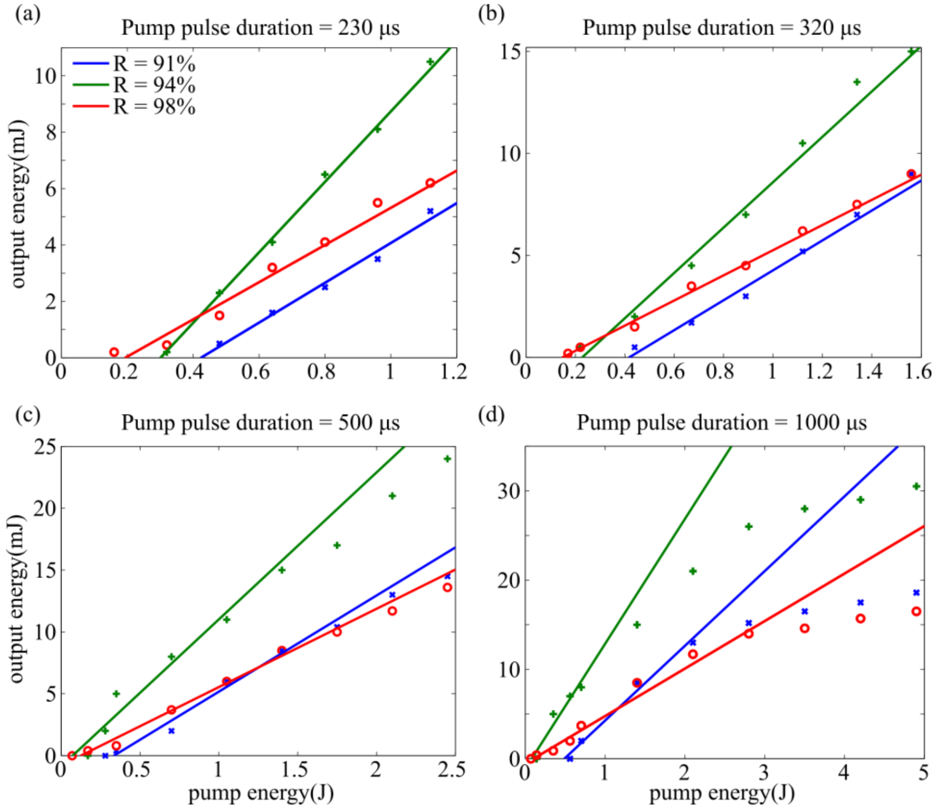

Fig. 5. QCW output energy as a function ofelectrical pump energy for (a)230 µs, (b) 320µs, (c) 500 µs and (d) 1000 µs.

In Fig. 5, the slope of the graph when using a mirror with 94% reflectivity (green line), and during the pump pulse durations (a to d) is obtained as 12.5, 11.12, 11.88, and 13.99, respectively. This is more than the mirror with 91% and 98% reflection. The slope of the graph for the mirror with 91% reflectivity (blue line) is 7.062, 7.332, 7.774, and 8.372, respectively, and also for the mirror with 98% reflectivity (red line) is 6.594, 6.167, 6.328, and 5.321.

The output energy of the laser grows as the pump pulse duration increases, but it reaches gain saturation at the pump pulse width of 1000 µs, and further increasing the pulse width and the electrical pump power does not result in a significant increase in the output energy. As shown in Fig. 5, the mirror with 94% reflectivity produces the highest laser output energy [23], and the mirror with 98% reflectivity has the lowest pump threshold energy.

We added a passive Q-switch to the cavity after measuring the free-running results. The output energy of the laser in Q-switching mode in terms of pump pulse durations for different output reflectivities 91%, 94% and 98% in the Fig. 6 can be displayed. The highest output energy value of 1.2 mJ per pump pulse width of 1000 microseconds was obtained with a mirror with a reflectivity of 94%.

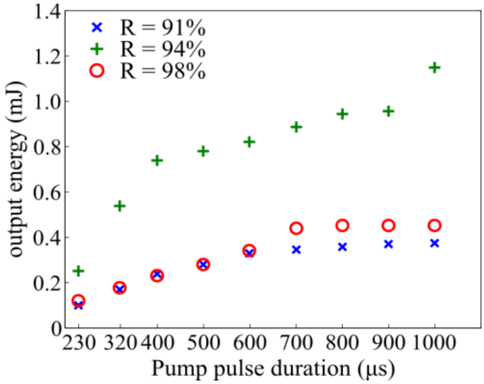

Fig. 6. Q-switch output energy in terms of different pump pulse durations.

A Si biased detector (Thorlabs, DET025A) and an oscilloscope (Hameg HMO2024) were used to measure the temporal pulse shape of the passive Q-switched laser. The temporal pulse shape is shown in Fig. 7.

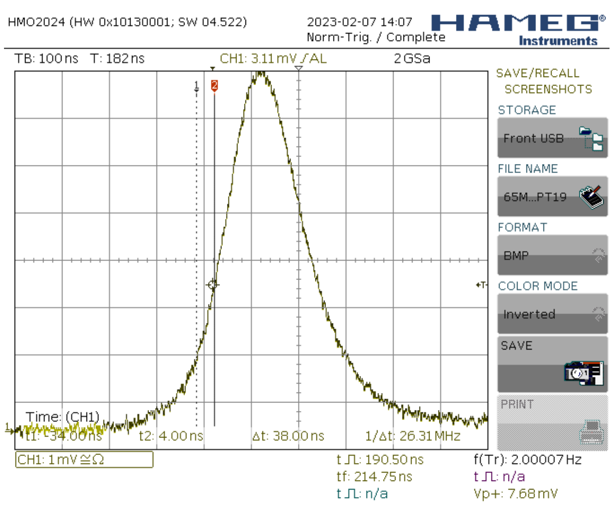

Fig. 7. Temporal Pulse shape of the Nd:YAG laser with passive Q-switching and LED-pumped.

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One of the important points in the design of laser sources used in laser range finders is of the single pulse output in the Q-switching mode. And the oscilloscope was measured in three pump pulse widths of 230, 320 and 1000 microseconds (Fig. 8).

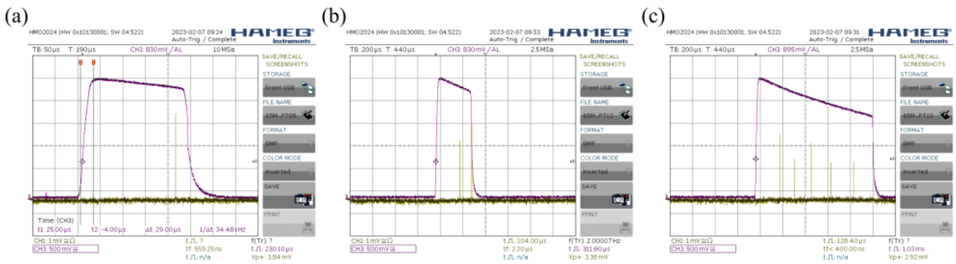

Fig. 8. Modes of the LED-pumped Nd:YAG laser for different pump pulse durations: (a)230 μs, (b) 320μs, and (c) 1000 μs.

To improve the beam quality, we placed a 3.2 mm diameter aperture in the cavity. We obtained a TEM_{00} mode Gaussian beam with a pulse energy of 250 μJ and a pulse width of 190 ns. A spot analyzer (wincam D_UCD12 Dataray Co.) captured the beam spot, as shown in Fig. 9. We plotted the relative intensity distribution and the Gaussian beam-fitting results, and they matched very well. The Gaussian fit coefficient was 90.1 and 89.6 in the two directions.

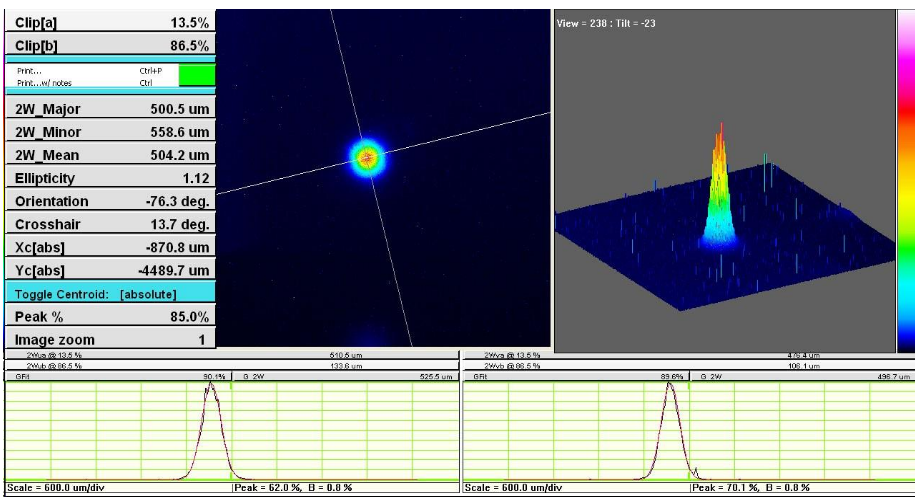

Fig. 9. Q-switched laser beam profile in near field at 44 cm from the output mirror, measured by a CCD camera. The 2D and 3D plots show the spatial distribution of the beam intensity.

We measured beam diameters at two points with respect to output coupler mirror that indicates divergence angle in Q-switch mode is 0.3 mrad.

4. CONCLUSION

We have demonstrated a TEM_{00} mode LED-pumped passive Q-switching Nd:YAG laser with a low divergence of 0.3 mrad. We have achieved a pulsed laser energy of 250 µJ with a pulse width of 190 ns by Passive Q-switching (PQS) in an efficient pump scheme. We have shown that the Q-switched laser produces only one pulse in the temporal output for pump pulse durations less than 320 µs. We have suggested that high-power LEDs can be used as a pump source for solid-state lasers, which can enable the development and production of intense pulsed lasers with high peak power.

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