# 500-W high average power, high beam quality Nd:YAG solid-state laser with one focusing reflector

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In order to explore a 56-J high energy, high frequency lamp-pumped pulsed Nd:YAG solid-state laser, the main factors influencing the higher laser output energy are analyzed, the relation between output power and input power and reflectivity is simulated theoretically, and the effective measures to improve the efficiencies of the laser are brought forward. As a result, pulse width is tunable between 0.1 and 10 ms, frequency between 1 and 1000 Hz. When the input electrical power is 12 kW, the laser can output maximum single pulse energy of 56 J and average power of 500 W with the beam quality of 16.5 mm·mrad, total electro-optic efficiency of 4.2%, and the in stability of ±2% output power. It is indicated that the parameters corresponds with the results of theoretical analysis and simulation.

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Pulsed Nd:YAG solid-state laser has high peak power and high beam quality, and can be transferred through fiber etc., so it is applied extensively in industry. Now the best high average power pulsed laser with average power of 550 W is made by Trumpf[1] in German. But beam quality is 25 mm·mrad and very expensive. In China, it was reported that Huazhong University of Science and Technology got the 345-W average power in laboratory[2], and Beijing Focus Laser Co. fetched in series of IQL YAG laser made by Quantel in France, the highest average power was 400 W and single pulse energy was 45 J[3], the total electro-optic efficiency was less than 4%, and the volume of the facility was very huge. This paper reports a novel pulsed laser. Its single pulsed energy is 56 J, beam quality is 16.5 mm·mrad, and the total electro-optic efficiency is as high as 4.2%.

We suppose that $P_{\rm excit}$ is the power that excites Nd ions into the upper laser level and $P_{\rm in}$ is the total electrical power for the lamp discharge. The excitation efficiency is defined as[4]

$$\eta_{\rm excit} = P_{\rm excit}/P_{\rm in}. \tag{1}$$

The conclusion of the continuous wave (CW) laser can be also applied to pulsed laser if the pulse width is longer than Nd's lifetime in upper level, then the threshold power and the output power of the laser oscillator can be expressed as[5]

$$P_{\rm th} = \frac{1}{\eta_{\rm excit}} \left|\ln(V\sqrt{R})\right| FJ_{\rm s}, \tag{2}$$

$$P_{\rm out} = \left|\ln\sqrt{R}\right| FJ_{\rm s}\left(\frac{P_{\rm in}}{P_{\rm th}} - 1\right), \tag{3}$$

where $V$ is the loss factor of the cavity, $R$ is the reflectivity of output mirror, $F$ is the laser beam cross area, $J_{\rm s}$ is the saturation intensity. Because the output power has a maximum for the optimized reflectivity $R_{\rm opt}$, we can get

$$\ln(\sqrt{R_{\rm opt}}) = \ln V\left[\left(\frac{P_{\rm in}}{P_{\rm min}}\right)^{1/2} - 1\right]^2. \tag{4}$$

If the reflectivity of front and rear mirrors is 100%, the gain factor has only to overcome the internal loss factor $V$, the minimum electric power to operate the laser can be expressed as

$$P_{\rm min} = \frac{1}{\eta_{\rm excit}} FJ_{\rm s}\left|\ln V\right|. \tag{5}$$

So when $R = R_{\rm opt}$, we can get maximum output average power

$$P_{\rm max} = (\sqrt{P_{\rm excit}} - \sqrt{FJ_{\rm s}\left|\ln V\right|}\ )^2. \tag{6}$$

According to above theoretical analysis and classical parameters, supposing that $\eta_{\rm excit} = 0.07$, $V = 0.95$, $J_{\rm s} = 1620$ W/cm$^2$, $F = 0.5$ cm$^2$, and beam diameter is 8 mm, simulating the relation between output power and input power and reflectivity, the results are shown that the maximum output power is 507 W, when input power is 12 kW and the reflectivity has a best one, as shown separately in Figs. 1 and 2.

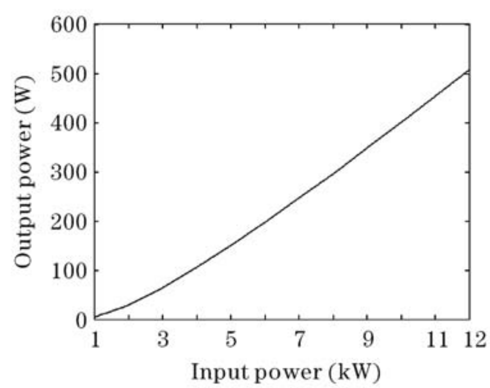


Fig. 1. Output power versus electrical input power.

 

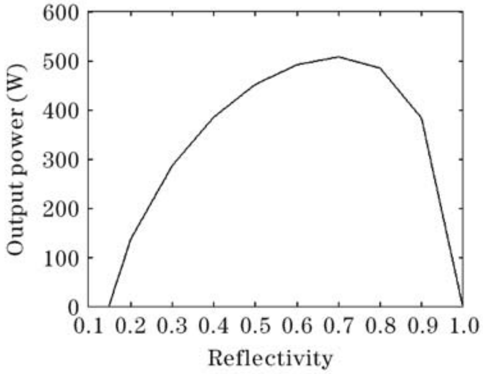


Fig. 2. Output power versus reflectivity .

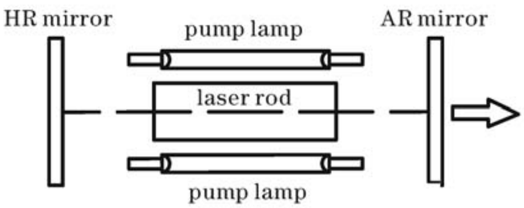


Fig. 3. Experimental setup of laser.

Based on the above analysis, output laser power depends on the laser cavity efficiency. Those factors of the laser components are synthetically considered. To the single rod high power laser, symmetrical parallel plane resonator is adopted and overlay gold metal cavity is applied. The laser medium dimension of 1% doping concentration is $\phi 8 \times 160$ (mm) with two Kr : Xe = 9 : 1 pumping lamps, whose size is $\phi 9 \times 150$ (mm), and the total power of the power supply is 12 kW. The experimental setup is shown in Fig. 3.

The thermal lens focal length[6] of the crystal is measured when working under input 12-kW electric power with the way of He-Ne laser, $g_1$[7] $= g_2 = 1 - d/f = -0.5$[5] for large stable region, where $d$ is the distance between surface of mirror and main plane of the rod, $f$ is the thermal lens focal length, then the effective optic length of the resonator is $L^* = 2d - d^2/f$[8], finally choosing the optimized reflectivity to make sure the maximum output power of the laser, the reflectivity of the output mirror is 70% and the geometrical length is 800 mm. The output power versus the lamp discharge voltage is presented in Fig. 4. Measured single pulse energy versus repetition frequency in different pulse widths is presented in Fig. 5. These figures show that the output power of laser increases nearly linearly with the pump power, the maximum average output power is 500 W (measured through 146 model power meter made by Beijing Institute of Opto-Electronic Technology) when inputting maximum electric power of 12 kW (power supply displaying 100 V), when the pulse width is 10 ms the maximum single pulse energy reaches 56 J (measured through M2000 model energy meter made by Beijing Institute of Opto-Electronic Technology). It is interesting that with different pulse widths and repeat frequencies, the laser can also output 500 W.

The beam quality of the laser is measured with photosensitive image (see Fig. 6), the spots radii are 3.9 and

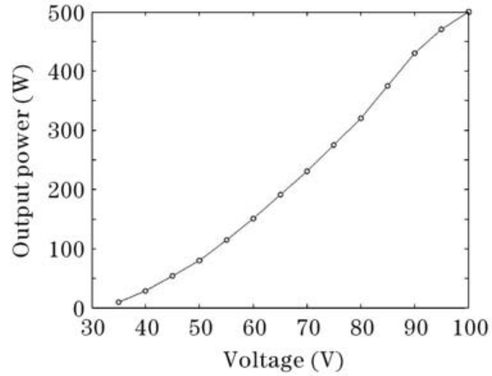


Fig. 4. Output power versus the power supply displaying voltage.

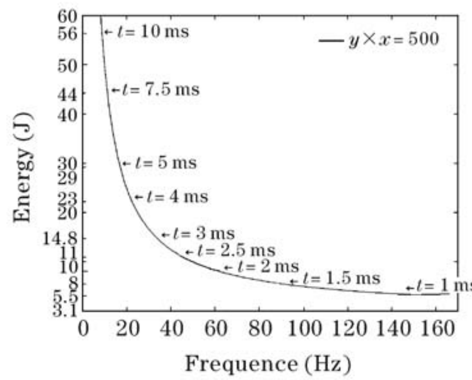


Fig. 5. Measured single pulsed energy versus repeat frequency in different pulse widths.

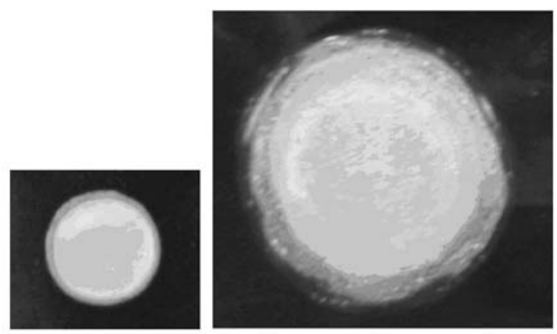

Fig. 6. Spots at the position of output mirror and one meter away.

9.5 mm in radius at the position of output mirror and one meter away, respectively. The beam quality of 16.5 mm·mrad is achieved, which can be transferred by 400-$\mu$m fiber. The total electro-optic conversion efficiency calculated is 4.2%.

The laser can work stably for 12 hours under pulse width of 1 ms, repetition frequency of 160 Hz, average power of 500 W, and the power decreases less than 10 W, the fluctuation is less than ±2%, which satisfies the industrial requirements.

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