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Performance Simulations for Flashlamp-Pumped Pulsed Q-switched Nd: YAG Laser with Unstable Resonator

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Abstract　Generally Q-switched laser is always characterized with empirically derived mathematical model. In this paper laser action at Q-switch with flashlamp pumping in Nd:YAG laser rod has been modeled and simulated with the code GLAD. The laser uses folded positive branch confocal unstable resonator with electro-optical Q-switcher. It provides an output pulse width of 4.5 ns at 1 Hz repetition rate and the full width of 0.21 mm at $1/e^2$ of the peak energy with a near-diffraction-limited beam. The results calculated can be used to direct designs and experiments for solid-state laser.

Key words　Nd: YAG laser; Q-switch; unstable resonator

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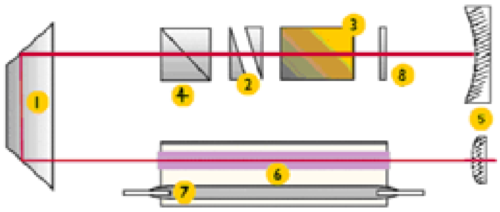
1　Introduction

Flashlamp-pumped solid-state lasers for rangefinder applications are attracting ever-growing interest, owing to the high energy, reliability and compactness of those all laser systems. The neodymium-doped yttrium aluminum garnet (Nd: YAG) pulsed laser has been the workhorse of armed forces worldwide for laser rangefinder and target designator applications, with Raman shifting or optical parameter oscillation providing a compatible eye-safe mode for training [1, 2]. At present, people often use unstable resonators instead of flat-flat resonators to achieve higher output energy per pulse in single laser rod in order to explore further target, and electro-optical Q-switch KD*P crystal is widely used as an active Q-switcher due to some advantages over passively devices, such as narrow pulse width and high stability at high repetition frequencies. In this paper, we simulated a pulsed actively Q-switched Nd: YAG laser composed of unstable resonator based on the diffraction integral equation and the rate equation model with the code GLAD.

2　Laser modeling

The cavity configuration is shown in Fig.1.



1) folding prism; 2) alignment prism; 3) KD*P crystal; 4) cube polarizer; 5) resonator mirrors; 6) Nd:YAG rod; 7) flashlamp; 8) quarter waveplate

Fig.1　Schematic diagram of the Q-switch laser

The Nd:YAG rod, with antireflection coating ends at 1064 nm, is 100 mm long with an aperture of 6 mm and provides longitudinal path through the medium. The positive branch confocal unstable resonator with a magnification M=2 consists of two circular mirrors hard-mounted side by side in the same plane, with a folding prism at the other end. The choice of the magnification results from a trade-off analysis among output losses, mode-intensity discrimination ratio and angular misalignment sensitivity. The geometric cavity length is 300 mm, and the radii of curvature of the output coupler and of the totally reflecting rear mirror are –1.1m and 2.2 m respectively. The mirrors whose apertures are 3 mm and 7 mm remain co-aligned while the folding prism gives additional compensation. Placing the resonator mirrors at opposite ends of a

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longer, unfolded resonator makes alignment much more sensitive to temperature and vibration effects. The Pockels cell must be kept temperature stabilized and is susceptible to moisture. Alignment prisms require a considerable amount of angular displacement to cause any significant misalignment compared to mirrors.

Consider a confocal unstable resonator with circular mirrors. The collimated and equivalent Fresnel numbers are

$$N_c = \frac{Ma^2}{B\lambda}, \qquad N_{eq} = \frac{M^2-1}{2M}\frac{a^2}{B\lambda}$$

The choice of the magnification resulteds from a trade-off analysis among output losses, mode-intensity discrimination ratio, and angular misalignment sensitivity. The equivalent Fresnel numbers are substituted into the diffraction integral equation and the Prony method used is the same as one described in Siegman and Miller [3]. In GLAD, we treat the laser as consisting of a discrete and efficiency loss due to outcoupling and other factors. Some parameters are used in the solution of rate equation calculation as follows.

Table 1 Parameters for rate equation calculation[4]

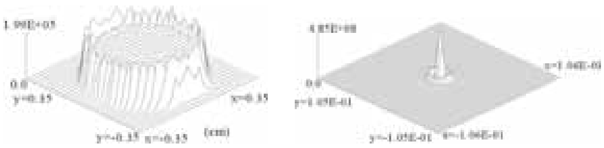
Parameter	Value
Wavelength/μm	1.064
Index of refraction	1.6
Atomic line width/Hz	1.2e10
Atomic line center/Hz	2.83e14
Spontaneous decay time/s	3e-4
Transition rate for level 2 to 0/s	0.3
Transition rate for level 1 to 0/s	1e-5
Longitudinal mode separation/Hz	5e8
Initial population inversion/(J/cm^3)	0.1875

3 Results

The resonator takes about 30 passes to converge. Figure 2 (a) shows 3D distribution of the near-field energy profile together with contour lines in the transverse plane, where the output beam pattern is annular whose external diameter is approximately 6 mm. The corresponding 3D profile of far-field beam measured at the focal plane of a converging lens (1 m focal length) is shown in Fig. 2(b), where the full width at $1/e^2$ of the peak energy is 0.28 mm in the transverse plane. The laser divergence is found to be 0.28 mrad and it is in good agreement with the prediction of geometric optics for the unloaded resonator, in which, there is

$$\Delta\theta = 0.51\frac{\lambda}{M\,D_2/2},$$

where, $\Delta\theta$ represents angular radius of spot center in far field, λ denotes the laser wavelength, M is the magnification, and D_2 is aperture of the convex mirror.



(a) (b)

Fig.2 (a) near-field and (b) far-field energy profile at pass 30 corresponding to 60 ns

In Fig. 3, it can be observed that the pulse width after Q-switch is 4.5 ns which is consistent with our past experimental results. It shows that narrower pulse width can be achieved with electro-optic Q-switch than with passive BDN dye Q-switch.

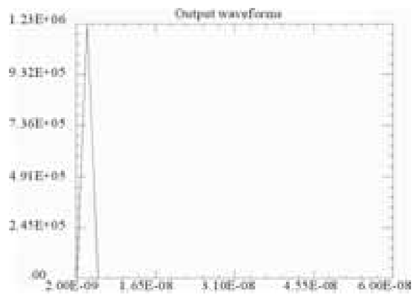


Fig.3 Output power of Q-switch versus time

4 Conclusion

In conclusion, we have developed a rugged and compact flashlamp-pumped, Q-switched Nd: YAG laser oscillator with folded positive branch unstable resonator. The pulsed solid-state laser with unstable resonator is simulated based on rate equation with the code GLAD and it takes 30 passes to converge. In the modeling folding prism, cube polarizer, quarter waveplate and electrooptic Q-switch are considered with Jone's matrix. The results demonstrate that the laser outputs a near-diffraction-limited beam whose divergence is 0.28 mrad and can be used to design appropriate resonator.

Unfortunately, we ignore the thermal effects including thermal lensing and stress birefringence owing to high power at high pulse repetition frequency rate, which may lead to power reduction and more severe divergence. In the future more actual modeling should be established to take them into account.

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灯泵浦非稳脉冲调 Q Nd: YAG 固体激光器特性模拟

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摘 要 对实际固体激光器谐振腔的特性分析常常采用经验公式的模型进行预测和研究。从非稳腔衍射积分方程和激光介质速率方程出发，利用 GLAD 程序计算并模拟了电光调 Q 非稳折叠腔 Nd: YAG 激光器的输出光束特性，得到了近场和远场的能量分布以及脉冲宽度波形，计算结果对试验具有指导意义。

关键词 Nd: YAG 激光器；调 Q；非稳腔

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具有独特的传输特性。在常参数光纤系统中，这种光孤子能够体现“呼吸”特性，而在特殊的分布参数光纤系统中，则能比较平稳地传输。

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Numerical Study of Picosecond Optical Soliton with Weak “Platform”

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Abstract In this paper, the transmission properties of picosecond optical soliton with weak “platform” are studied, by solving nonlinear Schrödinger equation with varying coefficients numerically. The soliton has “breath” character in the constant fiber parameter system, however, it can be propagated comparatively stably in the certain distributed parameter system.

Key words weak “platform”; optical soliton; distributed parameter; numerical study