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Efficient thermal induced birefringence compensation in a QCW diode pumped Nd:YAG laser

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ABSTRACT

Thermal induced birefringence in a QCW diode pumped Nd:YAG laser is experimentally investigated. The isogyre pattern is analyzed in a polariscopic arrangement and at 1 kHz pulse repetition rate. The depolarization loss was significantly reduced and efficient compensation of birefringence effect, about %75, was attained by using a double-rod configuration and a 90° polarization rotator with a suitable imaging optical telescope. The laser output energy per pulse before compensation was 10 mJ, whereas after compensation, this energy was enhanced to more than 16 amJ.

1. Introduction

Thermal characteristics of solid-state laser materials such as thermal expansion, thermal capacity, thermal conduction and diffusivity show the thermal load properties. Thermal gradients lead to thermal stress, and a change in refractive index. Thermal dependent refraction index leads to thermal lensing, and thermal stresses lead to non-homogeneity in refractive index. This effect also leads to birefringence effect that has a degrading effect on laser beam profile causing a decrease in laser output energy. Therefore, in high power laser design, this effect should be considered, and suitable approaches should be proposed. This problem is investigated for solid-state Nd:YAG lasers in different works [1–6]. Q.lu presented a method for compensation of induced thermal birefringence in a CW Nd:YAG laser based on double-laser rod and a 90° polarization rotator configuration [2]. In another work by Park et al., simulation for transmitted isogyre pattern of crossed polarizers is presented [3]. In [7], Pei et al. investigated the beam quality and thermal depolarization loss of an all-solid-state heat-capacity Nd:YAG laser with repetition rates of 50 Hz. They minimized the depolarization loss caused by thermo-optical effects. This is definitely considerable in steady-state Nd:YAG lasers by heat-capacity method. A novel laser resonator for compensating depolarization loss was reported by Ji and colleagues [8]. The structure is applied to an electro-optic Q-switched laser diode array side-pumped Nd:YAG laser operating at a repetition rate of 1000 Hz, substantial reduction in depolarization loss is observed, and the output pulse energy is improved about 56% from that of a traditional optical resonator without compensation structure.

In a few works, the thermally induced birefringence effect and the double-rod compensating method are numerically investigated, and different configurations are analyzed [9–11] for a laser system based on double-rod and a 90° polarization rotator is fabricated by ostermeyer group. Using such configuration, the laser system works in a good beam quality with $M^2 = 1.2$ [12]. The double-rod configuration was analytically used in a few works, and it was observed that there was about

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Table 1
Nd:YAG laser rod properties.

parameters	Value
α (thermal coefficient of expansion)	$7.5 \times 10^{-6}/^{\circ}$
K(Thermal conduction)	$0.14\,{}^{W}\!/_{cm^{\circ}}$
n_0	1.82
λ(nm)	808
P_h (heat load in Watts)	150
(heat load in Watts)	3 × 60 mm

25–30% depolarization loss because of thermal induced birefringence [6,13]. Recently a diode-pumped solid state (DPSS) high peak power laser with output energy of 300 mJ, operating frequency of 300 Hz presented by Wu. A compensation method was proposed for the MOPA system laser in the four pass amplifier section [14].

In [15,16] the effect of quarter wave plate is investigated. A theoretical model for birefringence compensation is presented in [17,18] and an efficient compensation of thermally induced birefringence with thermal lensing in a rod geometry Nd:YAG laser amplifier was developed in [19].

So far, in some papers the thermal induced birefringence has been investigated for CW diode pumped Nd:YAG lasers. To the best of our knowledge, there is no detailed work on depolarization compensation of QCW diode pumped Nd:YAG lasers. In this work, we experimentally analyzed the thermal induced birefringence of a QCW diode pumped Nd:YAG laser in a double-rod laser configuration. The laser system works at 1000 Hz pulse repetition rate. The optical optimization procedure is performed for a fixed pumping power of diode lasers at 808 nm.

2. Review of theory

A short theory of thermal induced birefringence compensation will be presented. In flash lamp or diode pumping of Nd:YAG laser rod, thermal induced birefringence occurs in the laser medium, which has some degrading effects on laser beam profile and finally reduces the effectiveness of laser output power. During this effect in Nd:YAG laser rod, the index of refraction will be different in two radial (n_r) and tangential (n_φ) directions, and optical axes of the crystal change radially and tangentially. In other words, there are two different values for index of refraction ($\Delta n_r \neq \Delta n_\varphi$). In addition, it can be shown that there will be a quadratic dependence (r^2) for birefringence effect:

$$\Delta n_r = -\frac{1}{2} n_0^3 \frac{\alpha Q}{k} C_r r^2 \quad (1)$$

$$\Delta n_\varphi = -\frac{1}{2} n_0^3 \frac{\alpha Q}{k} C_\varphi r^2 \quad (2)$$

In these equations n_0 is refractive index at the center of the rod, α is thermal coefficient of expansion, Q is heat load, k is thermal conductivity and C_r and C_φ are functions of the elasto-optical coefficients of Nd:YAG.

The stress-induced birefringence, which is a consequence of optical pumping of active medium, can be seen in both oscillator and amplifier of high power lasers. Principle axes of induced birefringence are directed tangentially and radially in each point of laser rod, and the birefringence amplitude is increased quadratically with radius. Consequently, a linearly polarized beam that is propagated in laser rod will be affected by an intrinsic depolarization. Depolarization loss and compensation methods are discussed in detail in Ref [1]. The loss can be evaluated by Eq. (3):

$$\delta_{depol} = 0.25[1 - \text{sinc}(2C_T P_h)] \quad (3)$$

In this equation, $C_T = 2n_0^3 \alpha C_B / \lambda K$ and P_h is the heat load. In agreement with previous works, we calculated the values in electrical pump power. Using constants and parameters of a Nd:YAG laser from Table 1, we simulate the depolarization loss for corresponding electrical pump power of 150 W at 808 nm, and the results are shown in Fig. 1. The calculated depolarization loss for our case is about 25% (although measured loss will be more than simulated value).

Some solid-state laser processes such as electro-optical Q-switching, second harmonic generation and external modulation need a polarized beam. A homogeneous optical material like Nd:YAG should be inserted to the laser resonator of the system, that could produce a polarized output beam. In absence of birefringence, no loss in laser output should be seen. However, thermal induced birefringence causes a large loss in laser output and changes the laser beam profile and beam quality.

Birefringence effects in pumped laser rods can be understood by using a polariscopic arrangement in which a parallel He-Ne laser is used as a rod illuminator, and the rods are placed between two crossed polarizers. Because of thermal induced birefringence, the probe beam is depolarized and propagates through the analyzer. The transmitted beam makes a cross pattern whose points have a fix phase difference with respect to the geometrical center of pattern.

In this work, we used a double-rod configuration with a 90° polarization rotator and a 1:1 imaging telescope between them. In this setup, laser beam depolarized in the first rod, then imaged into the second rod by the 1:1 telescope. On the way to the second rod, the phase and amplitude of the radial and tangential components of the polarization state are exchanged by the 90° rotator. Therefore the phase shift between the radial and tangential components in the second rod has the opposite