Jurnal
Teknologi

Full Paper

THE EFFECT OF PUMP PROFILE ON ABSORPTION EFFICIENCY OF A DIODE-SIDE-PUMPED ND:YAG LASER

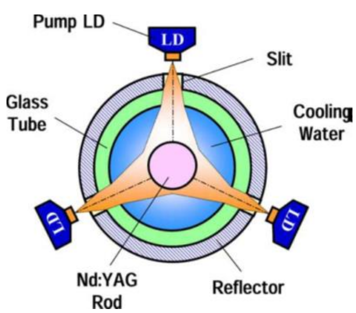
G. Honarasa[a*], B. Nakhaee[b], M. Hatami[a], M. Borhani[b]

[a]Department of Physics, Shiraz University of Technology, Shiraz, Iran
[b]Faculty of Physics, Yazd University, Yazd, Iran

Article history
Received
15 August 2015
Received in revised form
15 November 2015
Accepted
30 December 2015

*Corresponding author
honarasa@sutech.ac.ir

Graphical abstract



Abstract

In this paper, the Gaussian, Lorentz and Lorentz-Gaussian beams are used as the pump beam in a diode side pumped Nd:YAG leaser and the effects of these beams on the absorption efficiency of the laser are investigated. It is illustrated that the absorption efficiency for Lorentz-Gaussian profile is higher than the two others. Also has been shown that for entrance Lorentz-Gaussian profile, the absorption efficiency is increasing with decreasing the distance from the diodes to the slits and increasing the diameter of the laser rod. It is shown that there is an optimum slit width corresponding to the maximum absorption efficiency for any laser diode side-pumped solid-state lasers.

Keywords: Absorption efficiency, Lorentz-Gauss beam, Nd:YAG laser

Abstrak

Dalam kertas ini, Gaussian, Lorentz dan rasuk Lorentz-Gaussian digunakan sebagai rasuk pam dalam pasukan diod dipam Nd: YAG leaser dan kesan daripada rasuk pada kecekapan penyerapan laser disiasat. Ia menggambarkan bahawa kecekapan penyerapan untuk profil Lorentz-Gaussian adalah lebih tinggi daripada dua yang lain. Juga telah menunjukkan bahawa untuk profil pintu masuk Lorentz-Gaussian, kecekapan penyerapan semakin meningkat dengan mengurangkan jarak dari diod kepada belahan dan meningkatkan diameter rod laser. Ia menunjukkan bahawa terdapat lebar celah optimum sepadan dengan kecekapan penyerapan maksimum bagi mana-mana diod laser sampingan dipam laser keadaan pepejal.

Kata kunci: Kecekapan penyerapan, Lorentz-Gauss rasuk, Nd:YAG laser

1.0 INTRODUCTION

Solid-state lasers with high efficiency and access possibility to the high power have a variety of applications such as micromachining, ranging, remote sensing and microsurgery [1]. Compared with discharged-lamp pumping, laser diode (LD) pumping of solid-state lasers is more efficient. Diode pumped solid state lasers have also good beam quality and long operation time [2-4]. The pump structure has a great effect on the output power and performance of a diode pumped solid state laser [5]. Two main structure for diode pumped solid state lasers are end pumping and side pumping configurations. Although the end pumping scheme can provide efficient energy transfer, but it is not suitable for high power diode pumped solid state laser [5-10]. The side pumping configuration gives uniform absorption along the axis of the laser rod and spreads the absorbed power over a large area [11]. The most important factors in the design of a high-powered diode side pumped solid state laser are the absorption efficiency and the absorbed power distribution of the laser rod [12]. The absorption efficiency of a diode side-pumped Nd:YAG laser has been determined with two different approaches [12, 13]. The infinite convergence approach (ICA), is used to determine the total absorbed power of a Nd:YAG rod when random reflection takes place at the inner surface of the reflector wall [14]. When specular reflection occurring on the inner surface of the reflector, the absorption efficiency of the solid state laser medium can be computed; by the finite recurring approach (FRA) [13]. Based on ICA and FRA, an optimization algorithm for the pump structure of diode side pumped solid-state lasers has been introduced by Wang and Kan [5].

In the both ICA and FRA approaches, the beam intensity distribution or beam profile of Laser diode pump source in a plane normal to the rod axis was considered by a Gaussian distribution. Recently, the Lorentz-Gaussian beam, as a more generalized case of Lorentz beam, has been introduced by Gawhary and Severini [15]. The Lorentz-Gaussian beam can describe the radiation emitted by single-mode diode lasers [16, 17]. In this paper, with considering the Lorentz and Lorentz-Gaussian profiles for the diode laser, the absorption efficiency of a diode side pumped Nd:YAG laser is analyzed and compared it with Gaussian profile.

The paper is organized as follows. The Lorentz-Gauss beams and the absorption efficiency of the diode- side-pumped solid state lasers are reviewed in section 2 and 3, respectively. In section 4, the impact of pump profile on the absorption efficiency of the diode-side-pumped solid state lasers is investigated. Conclusion of the paper is also presented in section 5.

2.0 LORENTZ-GAUSS BEAMS

The electric intensity of the LD pump source in the plane perpendicular to the rod axis has been expressed by a Gaussian distribution as [14]:

$$E(\theta) = \exp\left[-2\left(\frac{\theta}{\theta_0}\right)^2\right] \quad (1)$$

where θ_0 is $1/e^2$ half angular beam divergence. The electric intensity distribution of the LD can be considered by Lorentz and Lorentz-Gauss beams. The electric intensity of Lorentz distribution is given by

$$E(\theta) = \left(\frac{\theta'_0}{\theta^2 + \theta'^2_0}\right)^2 \quad (2)$$

The Lorentz-Gauss beams as a more generalized case of Lorentz beam has been introduced by El Gawhary *et al.* with following electric intensity distribution [15]

$$E(\theta) = \left(\frac{\theta'_0}{\theta^2 + \theta'^2_0}\right)^2 \exp\left[-2\left(\frac{\theta}{\theta_0}\right)^2\right] \quad (3)$$

where θ_0 and θ'_0 are half angular beam divergence of the Gaussian and the Lorentz part, vertical to the LD junction, respectively. The Lorentz and Lorentz-Gauss beams properties are explored in several references [18, 19]. Electric intensities of the LD pump source in the plan normal to the LD junctions with the Gaussian, Lorentz and Lorentz-Gauss distribution have been plotted in Figure 1.

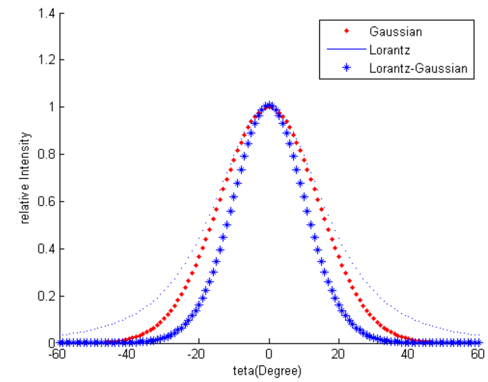


Figure 1 Electric distribution of the pump LDs in the plan normal to the LD junctions for the Gaussian, Lorentz and Lorentz-Gaussian beams

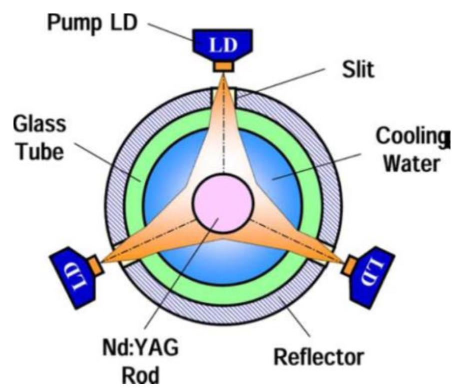


Figure 2 Schematic of the structure of 3 LDs side-pumped Nd:YAG laser

3.0 THE ABSORPTION EFFICIENCY OF A DIODE-SIDE-PUMPED SOLID STATE LASER

An important factor of a diode-pumped solid-state laser is the absorption efficiency. To calculate the absorption efficiency, a three laser diodes side-pumped Nd:YAG laser as shown in Figure 2 is considered. Three LD modules with the 808nm wavelength pump the Nd:YAG rod in three equally distribution directions. The distance between LDs and the outer surface of the reflector is d. The inner radius and thickness of the diffusing chamber are r and t_1, respectively. There are three slits with s width for transmission of LD beams to diffusing chamber. To avoid the cooling water leaking out from the diffusing chamber, a glass tube with thickness t_2 and outer radius r is used inside the diffusing chamber. The statistical reflectance of the reflector at the LD's wavelength is μ. The cooling water flow along the axial direction of a Nd:YAG rod with diameter ϕ. The absorption coefficient of the Nd:YAG rod at the wavelength of LDs is γ. The refractive indices of the glass tube, the cooling water and the Nd:YAG rod are n_1, n_2 and n_3, respectively.

The total power radiated from one the LD module can be obtained by

$$p_0 = \int_{-\infty}^{\infty} E(\theta) d\theta \qquad (4)$$

where $E(\theta)$ is the intensity distribution function of the laser diode can be considered by (1), (2) or (3).

The Figure 3 shows the rays emitted from laser diode in the plane perpendicular to the rod axis. The maximum divergence angle in slit can be expressed as follows:

$$\theta(s) = \tan^{-1}\left(\frac{s}{2b}\right) \qquad (5)$$

where the depth b is given by a function of LD distance from reflector, thickness of the diffusing chamber, outer radius of glass tube and slit width

$$b = d + t_1 + r - \sqrt{(d + t_1 + r)^2 - \left[\frac{s^2}{4} + (d + t_1)(d + t_1 + 2r)\right]}$$

The absorbed LD power is calculated by considering the multiple reflections inside the rod and using ICA to determine the absorption power while the random reflection occurs at the inner surface of the reflector [14]. Other required equations for calculating absorption efficiency can be found in [14] and to avoid duplication, they are not listed here. In compare with Ref. [14], the pump (LD) profile has been changed to Lorentz and Lorentz-Gaussian profiles.

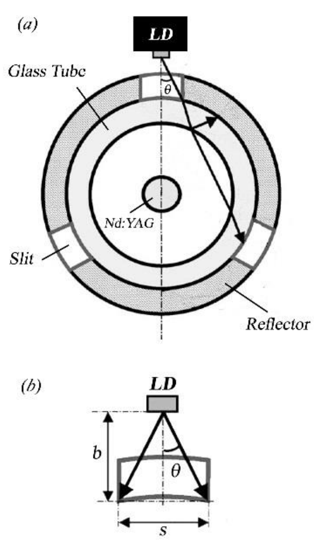


Figure 3 The LD ray trace (a) inside chamber and (b) in slit

4.0 INFLUENCE OF PUMP SHAPE OF A DIODE LASER ON THE ABSORPTION EFFICIENCY

In this section, the impact of beam profile of a diode laser on absorption efficiency of Nd:YAG rod is investigated. In our calculations, the absorption coefficient of the Nd:YAG rod is considered as $\gamma = 0.5\,mm^{-1}$. The outer radius and the thickness of glass tube are 5.5mm and 1.5mm, respectively. Also n_1, n_2 and n_3 are 1.510, 1.333 and 1.823, respectively. In Figure 4, the absorption efficiency has been plotted versus slit widths for Gaussian, Lorentz and Lorentz- Gaussian profiles. The figure shows that the absorption efficiency for the Lorentz-Gaussian profile is higher than Lorentz and Gaussian profile, and there is an optimum slit width corresponding to the maximum absorption efficiency as illustrated in Figure 4.

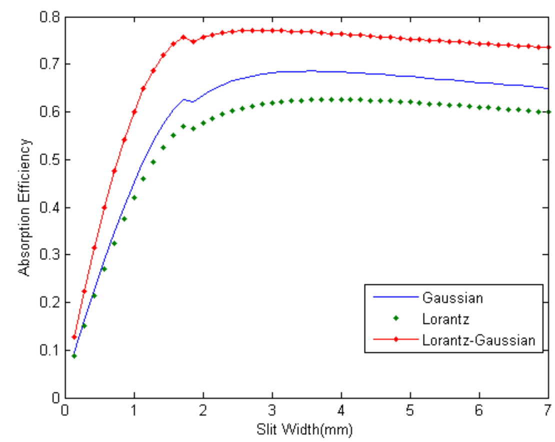


Figure 4 Absorption efficiency of the LD side-pumped Nd:YAG laser versus slit width for different field profiles with $\phi = 3.5mm$. and $d = 1.5mm$

The absorption efficiency versus slit width has been illustrated in Figure 5 for different values of distance from the diodes to the slit widths for Lorentz-Gaussian diode profile. The absorption efficiency increases with decreasing the distance between LDs and the outer surface of the reflector. In Figure 6, the absorption efficiency for different slit widths for Lorentz-Gaussian profile and for different values of laser rod diameters. It has been observed that the absorption efficiency increases with increasing the laser rod diameter through more absorption rays.

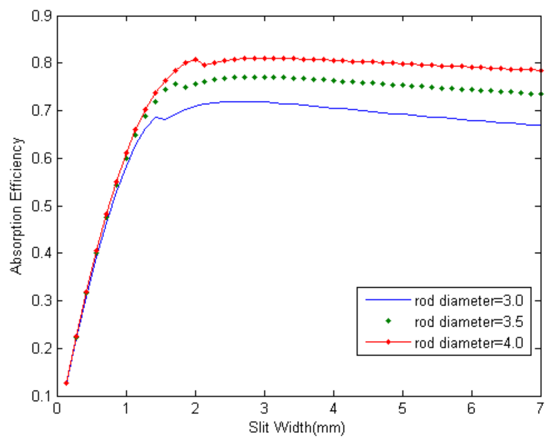


Figure 5 Absorption efficiency of the LD side-pumped Nd:YAG laser for different slit widths for different d and the Lorentz- Gaussian profile to $\phi = 3.5\text{mm}$

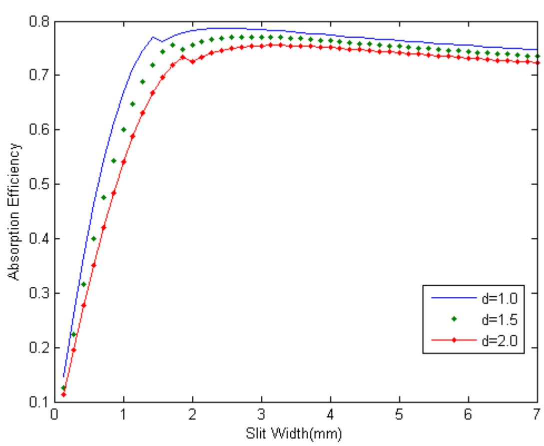


Figure 6 Absorption efficiency of the LD side-pumped Nd:YAG laser versus the slit width for different the laser rod diameter (ϕ) and the Lorentz Gauss profile for $d = 1.5\text{mm}$

5.0 CONCLUSION

In this paper, the absorption efficiency of A diode side pumped Nd:YAG laser for different pump profiles has been calculated. The results show that the absorption efficiency for Lorentz- Gaussian pump profile is higher than the absorption efficiency for the Gaussian and the Lorentz profiles. Also, it is observed that for the Lorentz-Gaussian profile, the absorption efficiency is increased with decreasing the distance between laser diode and outer surface of reflector and increasing the diameter of the laser rod. In all cases, there is an optimum slit width corresponding to the maximum absorption efficiency.

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