International Journal of Current Engineering and Technology
ISSN 2277 - 4106

Available at http://inpressco.com/category/ijcet

Research Article

Improvement Model study of High Efficiency Diode Pumped Solid State Laser

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Accepted 4 Jan. 2013, Available online 1March 2013, **Vol.3, No.1 (March 2013)**

Abstract

Diode pumped solid state lasers are becoming increasingly attractive because of its compactness, high efficiency and good beam quality. Here, we design the mathematical model consists of the different equations (deviated from main equations)described the diode pumped solid state laser oscillator performance. In this model the work was concentrated on the main design parameters which have a high influence on laser system performance such as beam overlap efficiency, energy transfer efficiency, and output coupling reflectivity on input threshold power and output power.

Keywords: *diode-pumped solid-state lasers, overlap efficiency, energy transfer efficiency, and output coupling reflectivity*

Introduction

In recent years, diode-pumped solid-state lasers have attracted great attention owing to their excellent properties, such as high efficiency, compactness, and good laser frequency stability. There are many important industrial applications of these lasers, as well as applications in medical treatment and scientific research. The use of diode lasers instead of flashlamps as optical pump sources for solid state lasers offers significant advantages such as higher efficiency and longer lifetime. Interest has increased in the past few years in using semiconductor diode lasers to excite solid state lasers based on rare-earth ion-doped transparent solids such as neodymium-doped yttrium aluminum garnet (Nd:YAG) (Mak A. A. et al, 1996)(Zagumennyi et al, 2003).

The main advantages of diode lasers over flashlamps as pump sources are overall laser efficiency and extended pump-source lifetime. The increase in efficiency is due to improved use of the optical pump radiation. Figure 1, which shows the absorption spectrum of the most common solid state laser material (Nd:YAG), and the output spectrum of both a pulsed flashlarnp and a diode laser, illustrates the increased efficiency(W. Koechner et al,1999).

The development and improvement of laser diode and its stacking technique are being proceeded with attentions on efficiency, frequency control, and suppression of chirping, life, and manufacturing cost. The performance characteristics are satisfactory for laser pumping. The cost reduction is the future technical issue which is most important figure for the application to laser.

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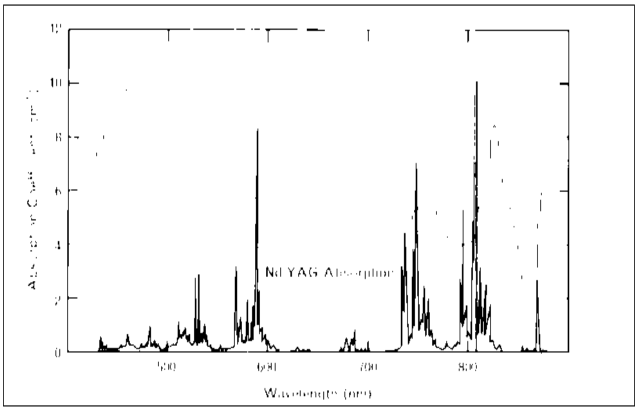

Fig. 1 Absorption spectrum of Nd:YAG and the emission spectra of a diode laser and a pulsed flash lamp

Theoretical concepts

Ideally, the emission characteristics would be independent of the diode drive. As the diode drive current is increased, the junction temperature of the diode increases. The internal heating causes a shift in the band-gap energy. Thus, as the diode drives increase, the spectral half-width of the diode array can be expected to increase. The increase in spectral half-width will have the deleterious effect of decreasing the pumping coefficient (N. Zu et al,2008).

The most efficient diode-pumped lasers that operate in the lowest-order transverse mode, however, have been end-pumped lasers in which the pump radiation is directed into the gain medium colinear with the laser output. Good beam quality and high efficiency are simultaneously achieved by overlapping the pumped volume in the gain medium with the laser mode(Ryan Feeler et al,2010) (Michael Bass et al,2005).

Energy Transfer Mechanisms

The flow of energy from electrical input to laser output radiation is illustrated schematically in fig (2). Also listed are the principle factors and design issues that influence the energy conversion processes. The energy transfer from electrical input to laser output can conveniently be expressed as a four – step process (W. Koechner et al,1999):

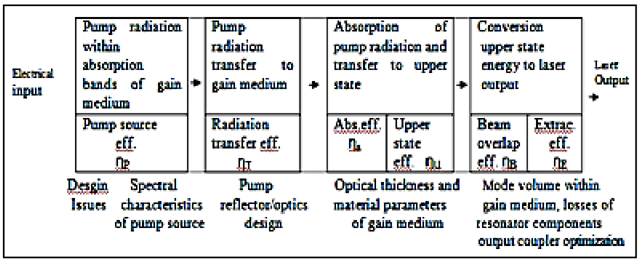

Fig.2 Energy flow in a solid state laser system.

Input Versus Output Characteristics

The optical losses in the diode structure determines the threshold current *i*s that has to be exceeded before amplification can take place. A diode laser that is operating above threshold will exhibit a linear relationship between output power and electrical current as shown in Fig.3. The optical output power as a function of current input can be expressed by

$$Pout = \eta d(\Delta E/e)(i - is)$$

where ηd is the differential quantum efficiency characterized by the number of photons emitted per injected electrons, ΔE is the bandgap of the recombination region, and e is the electron charge. The slope efficiency σ_s, determined from the slope of the output power versus input current.

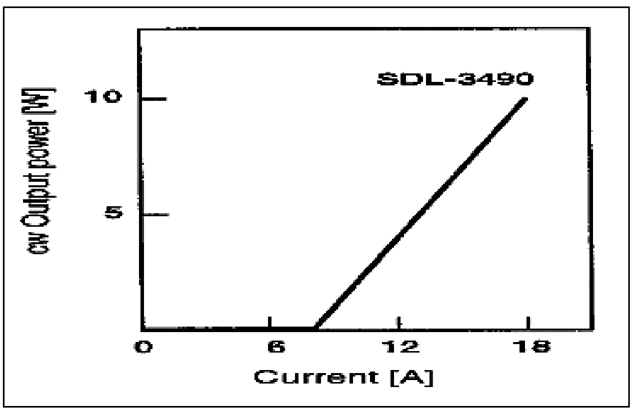

Fig.3. The cw output power versus input current for a 1 cm bar.

Laser Output

After the pump source in a laser oscillator is turned on, the radiation flux in the resonator, which builds up from noise, will increase rapidly. As a result of this increase, the gain coefficient decreases and finally stabilizes . A fraction of the intracavity power is coupled out of the resonator and appears as useful laser output[7]
The form represent that:

$$P_{OUT} = A_x \frac{(1-R)}{(1+R)} I_S \left[\frac{(2g_O \ell)}{(L - \ln R)} - 1 \right] \quad (1)$$

Here, IS is a material parameter, A and ℓ are the cross section and length of the laser rod respectively and R is the reflectivity of the output coupler. These quantities are usually known, whereas the unsaturated gain coefficient go and the resonator losses L are not known, we will now relate go and the losses L in an oscillator.

Four level system

The population inversion in a four level system as a function of pump rate is given by

$$\frac{n_2}{n_1} = \frac{W_P T_f}{W_P T_f + 1} \approx W_P T_f \quad (2)$$

Making the assumption that $W_p T_f << 1$ and multiplying both sides of equation (2) by the stimulated emission cross-section σ_{21} yields

$$g_o = \sigma_{21} W_p n_0 T_f \quad (3)$$

$W_p n_0$ gives the number of atoms transferred from ground level to the upper laser level per unit time and volume, i.e.

$$W_P n_O = \eta_Q W_{03} n_O = \frac{\eta_Q \overline{P}_{ab}}{h \upsilon_L V} = \frac{\eta_Q \overline{P}_{ab}}{h \upsilon_L V} \quad (4)$$

Where $\overline{P}_{ab} / h\upsilon_p$ is the number of atoms transferred to the pump band per unit time and volume . If we introduce (4) into (1), we can express the small signal gain coefficient in terms of absorbed pump power:

$$g_o = \sigma_{21} T_f \eta_Q \eta_S P^{\backslash}_{ab} / h\upsilon_L V = \eta_Q \eta_S \eta_B P_{ab} / I_S V \quad (5)$$

Where $\overline{P}_{ab}$ is the absorbed pump power in the gain region, this is related to the total absorbed pump power P_{ab} in the laser rod by:

$$\overline{P}_{ab} = \eta_B P_{ab} \quad (6)$$

From equations (1) and (5) we have:

$$P_{OUT} = \frac{(1-R)}{(1+R)} A_x I_S \left[\frac{2\eta_U \eta_B P_{th}}{(L - \ln R) A I_S} - 1 \right] \quad (7)$$

The absorbed pump power in the laser material is related to the electrical input to the pump source by:

$$P_{ab} = \eta_p \eta_T \eta_a P_{in} \tag{8}$$

With (5) and (8) we can establish a simple relationship between the small signal, single pass gain and lamp input power.

$$\ln G_o = g_o \ell = K P_{in} \tag{9}$$

Where for convenience, we have combined all the terms or the right hand side into a single conversion factor:

$$K = \eta_p \eta_T \eta_a \eta_u \eta_B / A_x I_S \tag{10}$$

With the value of (K) either calculated or measured. It is important to note that Go = exp ($g_o \ell$) is the one – way gain for a given pump input P_{in} that would be reached in the absence of saturation effects. In the literature, the term (Go) is referred to a small signal, or unsaturated single pass gain.

If we introduce (10) into (1) the output power of the laser can be expressed as:

$$P_{out} = \delta_S (P_{in} - P_{th}) \tag{11}$$

Where δ_S is the slope efficiency of the output versus input curve, and it is equal to:

$$\delta_S = \frac{2(1-R)\eta_P \eta_T \eta_a \eta_U \eta_B}{(1+R)(1-\ln R)} \tag{12}$$

And P_{th} is the input power at threshold given by:

$$P_{th} = \frac{(L - \ln R) A_x I_S}{2\eta_P \eta_T \eta_a \eta_U \eta_B} \tag{13}$$

If we introduce the material parameters for I_S into (13) and relate the energy absorbed to energy emitted at the laser transition $h\upsilon_L = \eta_u h\upsilon_p$ and further combine the remaining efficiency factors into an overall pump efficiency η_{pe}

where:

$$\eta_{pe} = \eta_p \eta_T \eta_a \eta_B \tag{14}$$

Then we can express the laser threshold condition in the form of:

$$P_{th} = (L - \ln R) \frac{A_x h\upsilon_P}{2\sigma \eta_U \eta_{Pe} T_f} \tag{15}$$

Where υ_p is the frequency of the pump photons (Mak A. A. et al, 1996)(Zagumennyi et al, 2003)(W. Koechner et al,1999).

Results and discussion

Relationship of P_{th} with (η_T and η_B)

Fig (4) shows the influence of η_T on P_{th} (at fixed values of R= 0.94, L= 0.1).

We can see that the decrease in threshold input power values are due to the increase in overlap between the gain area and pumping area (increasing η_B). Also, it seen from this figure that, due to the increase of system gain, and the decrease of the power, which was employed in starting of the laser process. The same figure shows the influence of η_T beside the influence of η_B , the increasing of the first one added additional decreasing in P_{th} values. .

That is due to efficient transfer of useful energy, which is pumped, to laser medium from the sources (the decrease in losses of the pumping energy).

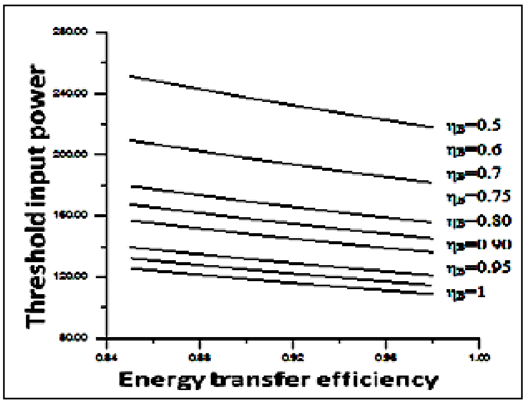

Fig .4 The influence of ηT on Pth

Relationship of P_{th} with (R, η_B)

Figure (5) shows the relation between P_{th} and (R) for different values of (η_B), at fixed values of η_T =0.85 , L=0.1.

Here we can see that, the decrease in P_{th} with increasing the (R) values, in the other hand the increase in η_B beside the increase of R lead to additional decreases in P_{th} values. The reason of this influence, is the increase in system gain, because there is an increase in extracting power from the medium by increasing the number of the photon round trips (this is true for specific values of R).

The decrease here is larger than that obtained from the last relation (relationship of P_{th} with η_B and η_T), this is means that, the influence of R is more effective than η_T.

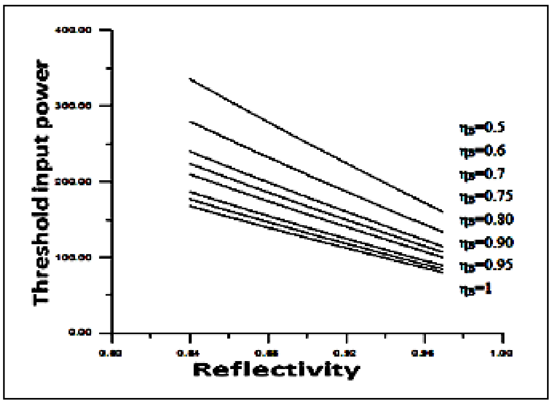

Figure (5) shows the relation between Pth and (R) for different values of (ηB)

Relationship of P_{out} with (η_T and η_B)

Figure (6) shows the influence of (η_T) beside the influence of η_B . The reason of increasing the P_{out} with increasing (η_T) is the increase of the optimum energy transfer to the active medium in addition to the excess in the overlap efficiency . The calculations was made at fixed values of (R = 0.84, L=0.1).

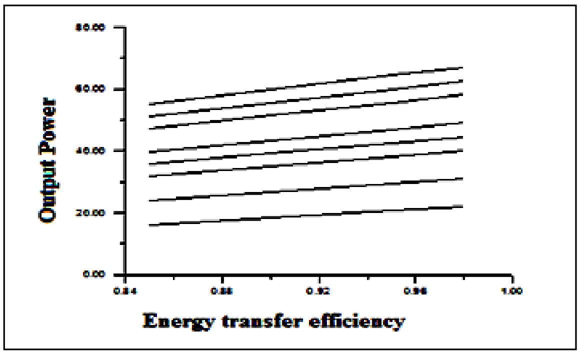

Fig. 6 Influence of (ηT) beside the influence of ηB .

Conclusions

From the three figures we can conclude the following :

1. The threshold input power (P_{th}) decrease with increasing of energy transfer efficiency (η_T) and beam overlapping efficiency (η_B) because the efficient transfer of pumping energy to the laser active medium therefore the losses power in minimum value.
2. When we increase the(η_T and η_B) the output power (P_{out}) increase that is returned to increasing in pumping efficiency and then the most of the pumping transfer to output power

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