Analytical Study for the Design Parameters of Diode – pumped Solid State Lasers

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Abstract

The mathematical model design consists of 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.

The parameters are the threshold input power, output power and optimum transmission of output coupler.

دراسة تحليلية للعناصر الداخلة بتصميم ليزرات الحالة الصلبة التي تضخ بليزر الثنائي

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الخلاصة

من خلال تصميم نموذج رياضي يتكون من معادلات مختلفة تصف أداء مذبذب ليزر الحالة الصلبة الذي يضخ من الليزر الثنائي والتي تم اشتقاقها من المعادلة الرئيسية . في هذا النموذج تركز العمل على عناصر التصميم الرئيسية التي تعطي تأثير عالي على أداء نظام الليزر مثل كفاءة تخطي الشعاع (beam overlap efficiency) , كفاءة نقل الطاقة (energy transfer efficiency) , و كفاءة ارتباط الخرج(output coupling reflectivity).

أما عناصر تشغيل النظام التي اعتمدت فهي قدرة الدخل لحد العتبة , القدرة الخارجة , و انتقال ربط الخرج

1-Introduction and theoretical concepts

The flow of energy from electrical input to laser output radiation was illustrated schematically in fig (1). The principle factors and design issues that influence the energy conversion processes were conveniently be expressed as a four – step process [1]:

listed also. The energy transfer from electrical input to laser output could be

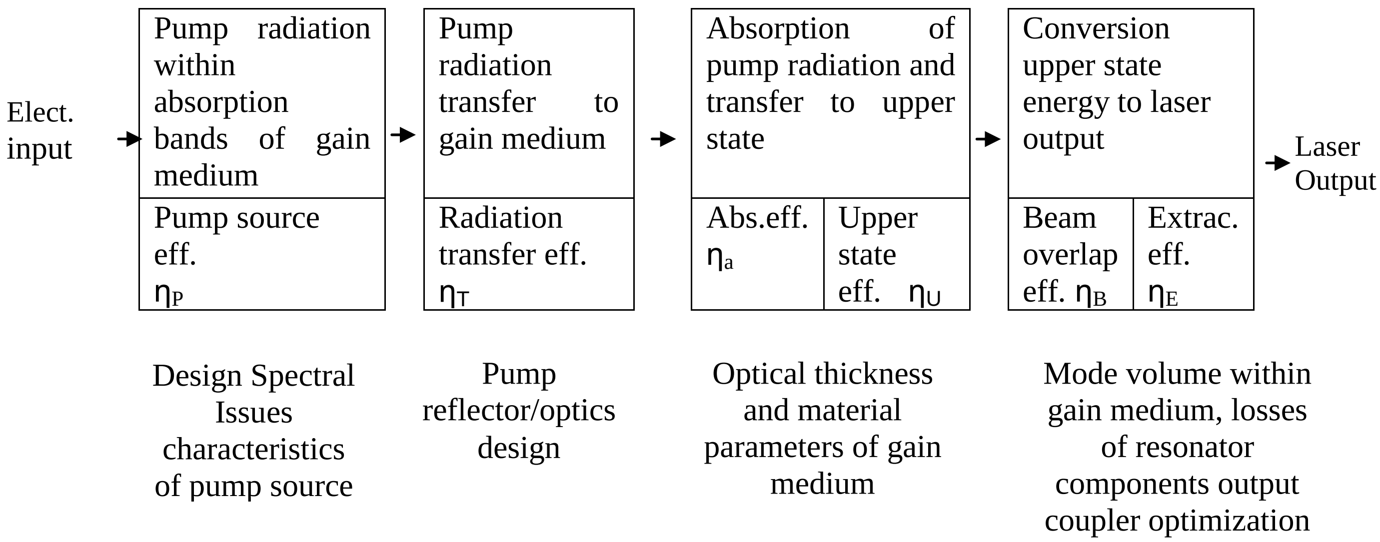

Fig (1) Energy flow in a solid state laser system [1]

Here, I_S 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 g_o and the resonator losses L are not known, we will now relate g_o with the losses L in an oscillator[2].

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

After the pump source in a laser oscillator was turned on, the radiation flux in the resonator, which builds up from noise, increased rapidly. As a result of this increase, the gain coefficient decreased and finally stabilized. A fraction of the intracavity power was coupled out of the resonator and appeared as useful laser output. The form represented as:

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

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

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

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

Where P_{th} the input power at threshold .

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

$$P_{ab} = \eta_p \eta_T \eta_a P_{in} \quad (8).$$

With (5) and (8) we can establish a simple relationship between the small signal, single pass gain G_o and lamp input power P_{in} as :

$$\ln G_o = g_o \ell = K P_{in} \quad (9).$$

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

$$K = \eta_p \eta_T \eta_a \eta_u \eta_B / A_x I_S \quad (10).$$

With the value of (K) either calculated or measured, η_p, η_T, η_a ,η_u, and η_B are the Pump source, radiation transfer, absorption, and beam overlap efficiencies respectively . 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 refereed to a small signal, or unsaturated single pass gain[3 ,4].

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

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

Where n1 and n2 are the total number of ions per unit volume of lower and upper levels respectively, Wp is pumping rate , and Tf is fluorescence time. 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 $\overline{P}_{ab}$ is the absorbed pump power in the gain region, $\overline{P}_{ab} / h\upsilon_p$ is the number of atoms transferred to the pump band per unit time and volume and η_Q is the quantum efficiency. If we introduce (4) into (3), 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 , η_S is the Stokes factor, and η_B is Beam overlap eff. , this is related to the total absorbed pump power P_{ab} in the laser rod by:

(14).

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

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

(15).

Where υ_p is the frequency of the pump photons [6,7].

2- Results and discussion

2-1.Relationship of P_{th} with (η_B and η_T)

Fig (2) shows the influence of η_B on P_{th} (at fixed values of R= 0.95, 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). This is a logical result, due to the increase of system gain, and the decrease of the power, which was employed in starting 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

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

(11).

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

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

(12).

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

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

(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} [5]

where:

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

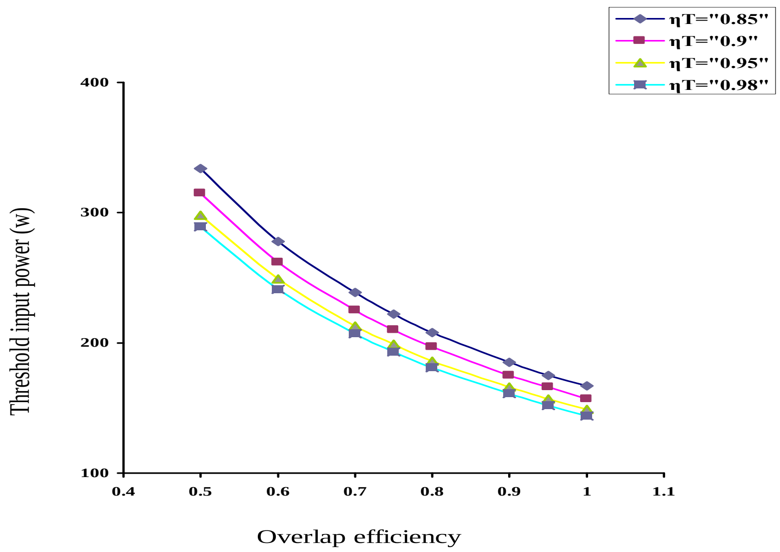

Fig (2)Threshold input power versus overlap efficiency for diffrent values of transfer efficiency laser medium from the sources (the decrease in losses of the pumping energy).

additional decreasing in P_{th} values. That is due to efficient transfer of useful energy, which is pumped, to

2-2 .Relationship of P_{th} with (η_B ,R)

Figure (3) shows the relation between η_B and P_{th} for different values of (R), at fixed values of η_T =0.85, L=0.1.

Here we show the decrease in P_{th} with increase the (R) values, on the other hand the increase in η_B beside the increase of R leads to additional decrease in P_{th} values.

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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

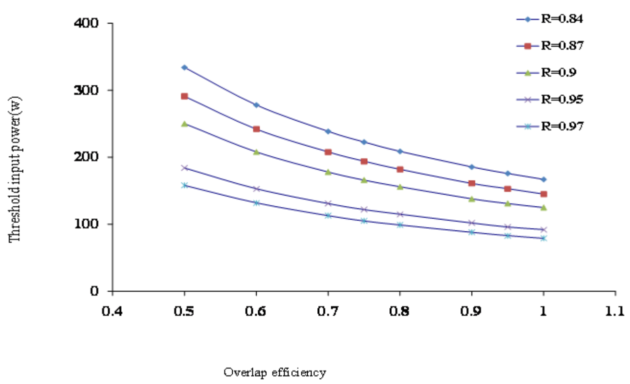


Fig (3)Threshold input power versus overlap efficiency for different values of output coupling reflectivity

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

2-3 *.Relationship of P_{th} with (lnR and η_T)*

Here we plotted the relationship of P_{th} as a function of the natural logarithm of reflectivity values. Usually this relation can be used in calculating the resonator losses, from the extension line for linear relation, and takes the value of its intersection with the axis of (-lnR).

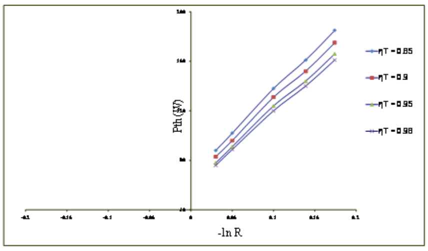


Fig (4) Threshold input power versus (-lnR) for variable value of transfer efficiency

Figure (4) shows the influence of η_T on P_{th} and on values of resonator losses, the losses decrease with the increase of η_T , and this leads to decrease in P_{th} values. These relations were calculated at fixed value for (η_B = 0.9

2-4 . Relationship of P_{th} with (lnR and η_B)

Figure (5) shows the relation of (-lnR) and (P_{th}) under the influence of increasing η_B. From this figure we calculated the resonator losses at different values of η_B, and we saw the influence of increasing the η_B on the decrease of losses values and then decrease the P_{th} values.

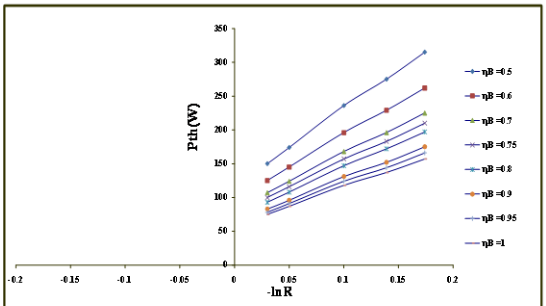


Fig (5) Threshold input power versus output coupler reflectivities for different values of overlap efficiency .

2-5 .Relationship of P_{out} with (η_B and η_T)

The output power represents the main aim in designing and constructing of any laser system therefore, these parameters must be considered to cover such study.

Figure (6) shows the influence of increasing the η_B on P_{out}. This increase of output power is a logical result, due to the increasing in large number of ions in active medium are contributed in laser process. The calculations were performed at fixed values of (R=0.95, L=0.1). Also we observe an increase in P_{out} with increasing the η_T, which is due to the decrease in pumping losses.

2-6 .Relationship of P_{out} with (η_B and R)

Figure (7) shows the influence of (R) beside the influence of η_B .
The reason of increasing the P_{out} with increasing R is the increase of the number of round trips, which lead to increase the number of photons, which extracted from excited medium, that is for certain values of R. The calculations was made at fixed values of (η_T = 0.85, L=0.1).

2-7 *.Relationship of P_{out} with (T and η_B)*

This relation is very important since it enables us calculating the optimum transmission of output coupling of the laser system and the optimum power.

Figure (8) explains the influence of η_B and T on variation of output power. Also we can see, from this figure that the optimum value of T (the values of T at which the output power reach the maximum value) takes the different values with the different values of η_B , beside the increasing of output power , that is due to the influence of η_B in increase the resonator gain. This figure was plotted with fixed value of (η_T =0.85 ,L=0.1)

2-8 .Relationship of P_{out} with (T and η_T)

Figure (9) shows the relation of transmission with output power under influence of η_T. Also from this figure we can see the optimum values of output coupler transmission and the optimum output power under different values for η_T. The reason of decreasing values of T with increasing of η_T is the large amount of power, reached to the active medium. Here the fixed values are (L = 0.1, η_B = 0.80

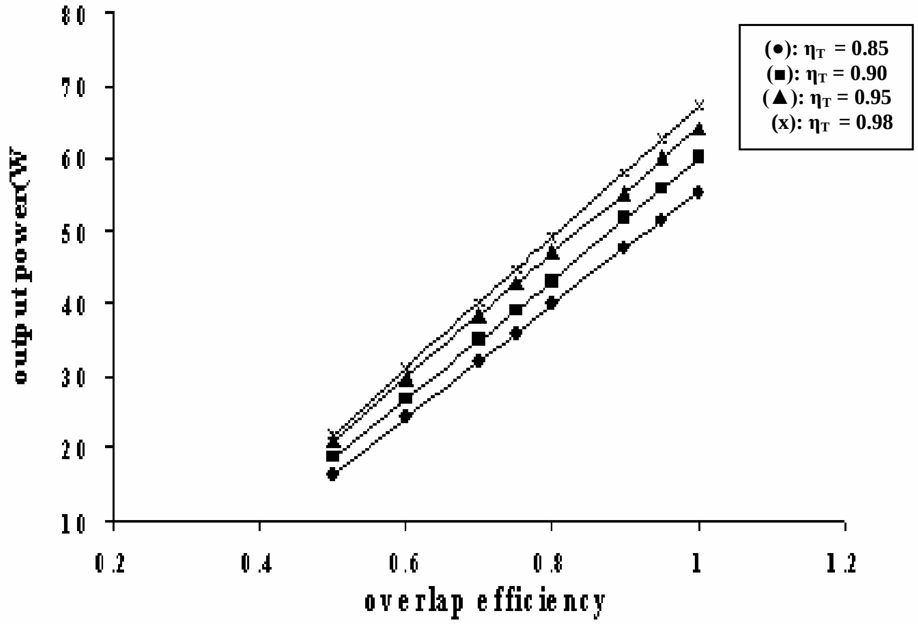
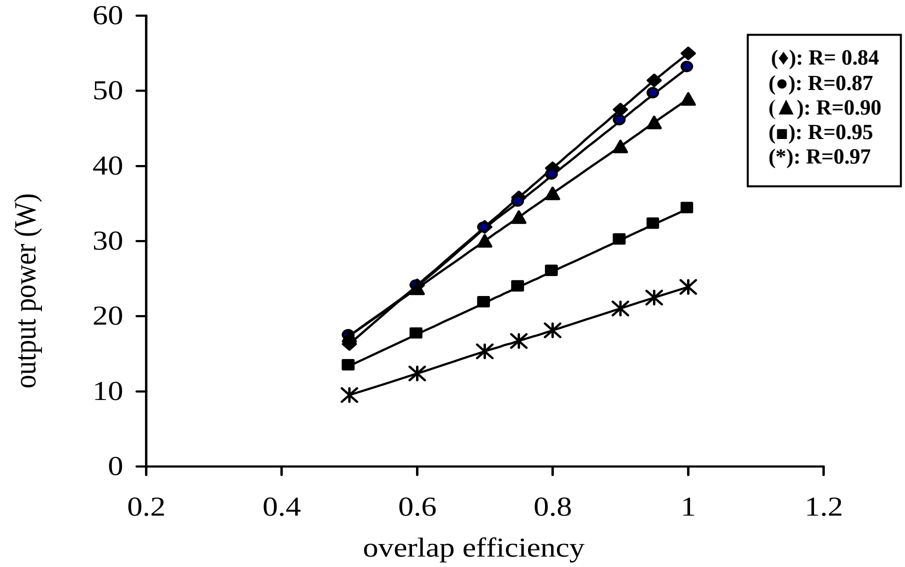
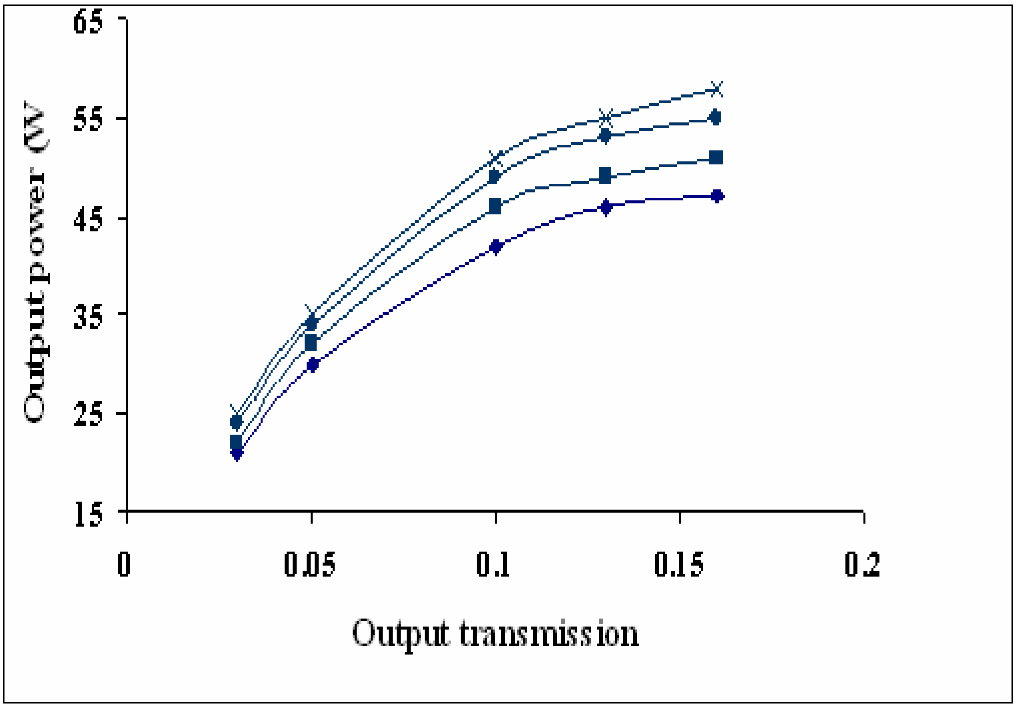


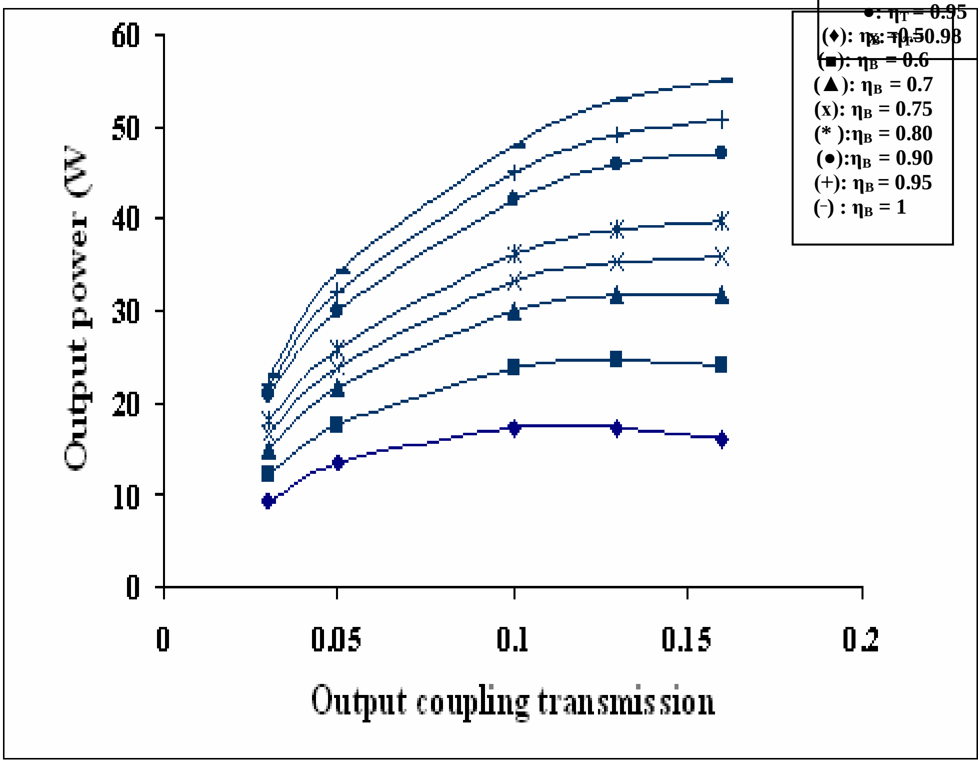
Fig (6)   Output power versus overlap efficiency for different values of transfeefficiency



Fig(7) Output power versus overlap efficiency for different values of output coupling reflectivity



Fig(8)   Output power versus output coupling transmission for different values of transfer efficiency



Fig(9)   Output power versus output coupling transmission for different values of overlap efficiency

3- There is an optimum value of output coupler transmission (T) ,around this value the losses are greater than the gain . These losses by more less number of photo round trips . The first one increase the losses by diffraction . The other one corresponds the lower value of gain .

4- Increase the overlap efficiency η_B means the increased the power transferred to active media and the increased the output power .

3- Conclusion:

From this research we can conclude the following :-

1- When the energy transfer from pumping source to the active media increasing (decrease in losses) that leads to decrease the value of power which required to start the lasing .

2- The influence of reflectivity (R) or (T) is more than the η_T because the feedback operation covers the losses caused by the η_T

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