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GAIN COEFFICIENT AND ROUND TRIP RESONATOR LOSSES IN Nd:YAG LASER SYSTEM

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ABSTRACT

Resonator losses and gain coefficient in laser material play an important role in the optimization process of a laser system. Findlay & Clay analysis is a powerful and easy method to characterize the gain and the losses of the active medium. The resonator losses and gain coefficient could be determined by using output coupler mirror with different reflectivity, *R*, and determining threshold input energy, P_{th} for lasing for each mirror. In this work, the Nd:YAG crystal was pumped by xenon flashlamp. The laser chamber was deposed in the plano-concave resonator. The output energy of the laser was verified by using different reflectivity output coupler. The result obtained showed that, the resonator loss is 0.667 and the gain of threshold energy is 0.033 cm^{-1}.

Keywords: Gains coefficient, resonator losses, Findlay & Clay analysis, Nd:YAG laser system.

INTRODUCTION

The excitation efficiency and the round trip losses determine the pump power necessary to reach the laser threshold. The higher the losses due to diffraction and output coupler, and the lower are the excitation efficiency, the higher laser threshold has to be achieved by the pump. The Findlay-Clay analysis [1] uses this relationship between loss and threshold gain to determine the performance of the laser system. The Findlay & Clay analysis is a powerful and easy method to characterize the gain and the losses of the active medium [2]. It can be used in both continuous wave (CW) and pulse laser. The accuracy strongly depends on the technique used to determine the threshold. The resonator losses and the gain in the laser material play rule in the optimization process of a laser system especially in Q-switching [3-5]. These two parameters also could measure laser performance [6] as well as a key parameter for optimization of Q-switching system [4].

FINDLAY AND CLAY METHOD

A fraction of the intracavity power is coupled out of the resonator and appears as useful laser output and laser output is given by Koehner, 2006 as;

$$P_{out} = A\left(\frac{1-R}{1+R}\right)I_s\left(\frac{2g_0 l}{\delta - \ln R} - 1\right) \tag{1}$$

where, *A* and *l* are the cross section and length of the laser rod respectively, *R* is the reflectivity of the output coupler, η is the efficiency of factor, I_s is the flux in active material that given as *2888 J/cm*^{2}. These quantities are usually known, whereas the unsaturated gain coefficient g_0 and the resonator losses δ are not known.

Findlay and Clay (1966) had proposed a method to determine resonator losses by using output coupler with different reflectivities and determining threshold power for lasing for each mirror. The electrical input threshold is given;

$$P_{th} = \left(\frac{\delta - \ln R}{2} \right) \frac{AI_s}{\eta} \tag{2}$$

From this equation, the mirror reflectivity can be written as;

$$-\ln R = \frac{2\eta}{AI_s} P_{th} - \delta \tag{3}$$

By extrapolation of the straight line plot of – *ln R* versus P_{th} , at $P_{th} = 0$, the round trip resonator losses δ could be obtained. From the slope of the straight line we can also calculate the efficiency factor η. From Equation 3, the higher resonator losses δ, is caused by reflection, scattering or absorption, increase the threshold input power and decrease the slope efficiency. At threshold operation the losses equal to the gain and is given by;

$$-\ln R = 2g_o l - \delta \tag{4}$$

where, R is the reflectivity, g_0 is the small gain coefficient, l is the cavity active material length and δ is round trip resonator losses. By comparising Eq. 3 and Eq. 4, we can obtain the gain coefficient, g_o by using;

$$2g_0 l = \frac{2\eta}{AI_s} P_{th} \tag{5}$$

Generally, we can rewrite Eq.5 as $2g_0 l = \frac{2\eta}{AI_s} P_{in}$ that the gain coefficient as a function of the input power. In this work, we try to estimate the gain and resonator losses for developed Nd:YAG laser system by using Finday & Clay analysis.

EXPERIMENTAL SETUP

In the present work, the laser output of the developed resonator of flashlamp pumped Nd:YAG laser measured by a digital power meter (Melles Griot 13 PEM001). Figure 1 shows the experimental setup for this work. The flashlamp driver was set in free-running mode with single shot operation. The active medium (Nd:YAG crystal) and the linear xenon flashlamp were placed in laser pumping chamber and cooled by water cooling system. The diameter of Nd:YAG crystal is 4 mm with 75 mm length.

The pumping chamber was placed in plano-concave resonator which consisted of a plane mirror as an output coupler and spherical 100% reflecting mirror with 5-m radius placed 500 mm.. The percentage of output coupler's reflection, *%R* was verified by using different reflectivity of the output couplers. For this experiment,the reflectivity output of 90%, 75 %, 70%, 60 %, 50%, 45%, 40 % and 16 % were used. Once the resonator is well aligned, the output energy of the laser was verified by changing the operation voltage of flashlamp driver. The data of this experiment was recorded for further analysis.

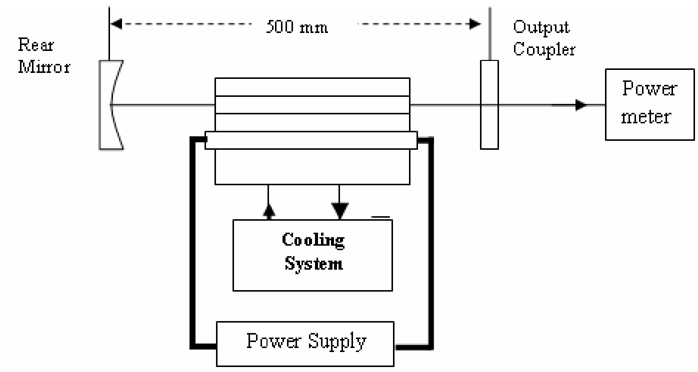

Figure 1: Experimental setup for resonator losses measurement**.**

RESULT AND DISCUSSION

In this work, the output energy measurement was repeated for 5 times and the average was calculated. The data were collected for average output energy for different percentage of output coupler. The data corresponding this finding was plotted as shown in Figure 2. For simplicity, the operation voltage as the input power was converted to input energy by using $E = \frac{CV^2}{2}$, where C is the capacitance of capacitor bank (100μ) and V is the operation voltage.

To determine the threshold energy, P_{th}, a graph of output energy versus input energy for each percentage of output coupler was considered. For example, input-output graph for 90% R output coupler as shown in Figure 2 have linear graph. The straight line equation is $y = 1.5379\,x - 5.2283$. When output energy is zero or y = 0, we could estimate the threshold input energy. For this case, the threshold input energy is of 3.3996 J. The same procedures have been carried out for other percentage. The threshold energy for different percentage of output coupler are listed Table 2.

The graph of mirror reflectivity versus threshold input power was plotted as shown in Figure 4. A linear graph of was obtained with graph equation of

$$y = 0.2053\,x - 0.6647 \qquad (6)$$

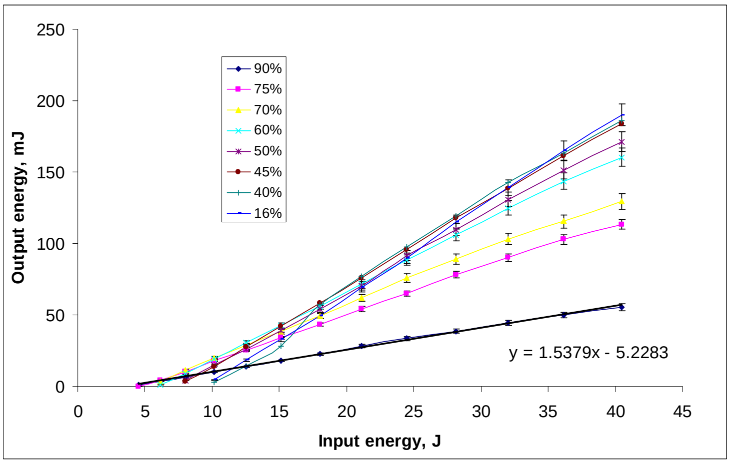

Figure 2: The graph of output energy

Table 3: The threshold energy for different percentage of output coupler

Mirror reflectivity, %R	-ln R	Threshold energy, P_{th}, J
90	0.1053	3.3996
75	0.2877	4.5940
70	0.3567	4.6570
60	0.5108	5.9955
50	0.6932	7.4013
45	0.7985	7.5056
40	0.9163	9.4544
16	1.8326	9.6999

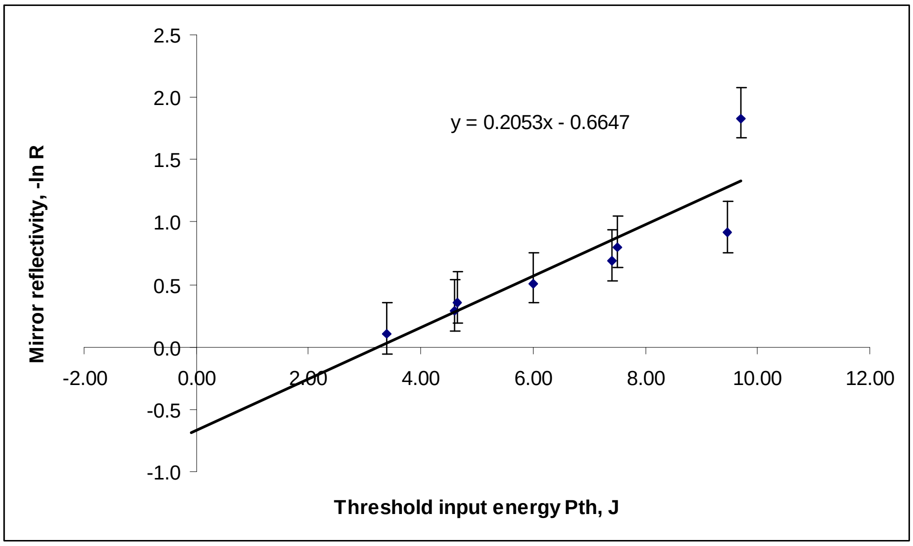

Figure 4: Log plot of the output mirror reflectivity versus the extrapolated laser energy threshold for Nd:YAG laser rod.

From Equation 3, measurement reveals, the combined round trip resonator losses δ is 0.6647. From the slope of the straight line also, we can also calculate the efficiency factor η, and the gain the gain coefficient as a function of the input power is given as;

$$g_0 = \frac{2\eta}{2lAI_s} P_{in} \qquad (7)$$

However, the slope of the straight line was, $m = \frac{2\eta}{I_s A} = 0.2053 J^{-1}$. In this study, the diameter of the active medium rod is 4 mm and surface area, $A = 0.1256\ cm^2$. So that, the efficiency factor, η, of the system is;

$$\eta = \frac{m.A.I_s}{2} \qquad (8)$$
$$= 0.9979 \ \ or \ \ \approx 1\%$$

The gain coefficient of this system is given by $2g_0 l = 0.1375 P_{in}(J)$ and for input energy is 3 J, the gain coefficient of the system is;

$$g_0 = \frac{0.1375(J^{-1}).3(J)}{0.75cm} = 0.033cm^{-1} \qquad (9)$$

The value of gain coefficient for this system and the round trip losses were determined to be approximately equal to 0.033 cm^{-1} and 0.6647. The value of gain coefficient at threshold is similar with Kushawaha [6]. However the value of determined round trip losses is highes compared to other researcher.The reasons could be due to the misalignment and dust on the optical components. For further study, the laser cavity needs to be aligned precisely as well as the clean of optical components.

CONCLUSION

In conclusion, were studied the performance of Nd:YAG laser system pumped by a single xenon flashlamp. The laser was operated in the free running mode operation and threshold and efficiency were measured at 1064 nm. From the extrapolation and calculation, the round trip resonator losses and the gain coefficient at threshold were determined to be approximately 0.667 and 0.033 cm^{-1} respectively.

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