Global Advanced Research Journal of Arts and Humanities (GARJAH) Vol. 3(1) pp. 006-011, November 2014
Available online http://garj.org/garjah/index.htm

Full Length Research Paper

Obtaining Dynamical Gain of Nd: YAG Lasers for Determining Pump Threshold

S.N. Hosseinimotlagh

Department of Physics, Shiraz Branch, Islamic Azad University, Shiraz, Iran

E-mail: hoseinimotlagh@ hotmail.com; Tel No:00989171130929; Fax No:00987116248581

Abstract

Thin disk lasers are of the solid state lasers like Nd:YAG lasers which have been widely studied in recent years. Nd:YAGlasers produce high powers. In this paper, we first solve rate equations relating to this lasers in dynamic state and consequently obtain the gain of signal and pump of these lasers in time interval of 0-0.1S and our calculations in dynamic state show that Nd:YAG laser has low pump threshold and high gain of signal.

Keywords: Thin, gain,disc, pump, signal.

INTRODUCTION

Thin disk lasers are under intensive research for both continuous-wave (Dascalu et al., 2003; Stewen et al., 2000; Giesen, 2007; Kouznetsov et al., 2006; Kouznetsov et al., 2005; Kouznetsov and Moloney, 2003; Kouznetsov and Moloney, 2004) and pulsed operation. Such a geometry allows efficient heat sink with small wave front distortions, and is believed to be one of the most promising architectures for the high-average-power laser (Stewen et al., 2000; Giesen, 2007; Kouznetsov et al., 2005; Kouznetsov and Moloney, 2003; Kouznetsov and Moloney, 2004). The optimum design to maximize the power limit results from an interplay between heating, round-trip losses and amplified spontaneous emission (ASE) (Kouznetsov and Moloney, 2003). Concept of thin disk laser is a laser design for diode pump solid state lasers which allows construction of lasers with high output, the highest efficiency and good beam quality. These three advantages caused priority of this kind of laser over other solid state lasers. Since construction of the first thin disk laser in 1993 (Dascalu et al., 2003), output of a single disk increased in performance of continuous wave to more than 50Kw. Almost all laser classic materials can be used for design of think disk especially if pump radiation absorption is almost high and life of excited state is not very short. Thin disk lasers are seriously studied. Geometry of thin disk is specified with ratio of length size to thickness. For this reason, environment appears as a thin disk. Main advantages of disk lasers are effective cooling and reduction of thermal convergence so that it is possible to scale power with good beam quality. Effective achievements are made in thin disk lasers technology. Commercial 2-kw lasers are available using geometry of thin disk with a multi-pass pump configuration. For this reason, a much higher level power scaling seems to be easily accessible and suggestions for 100-kw laser have been recorded. In near future, it is predicted that successful power scaling to required values is performed for laser fusion stimulus. In late 1960, the first solid state neodymium laser was made. This laser was used for several years for

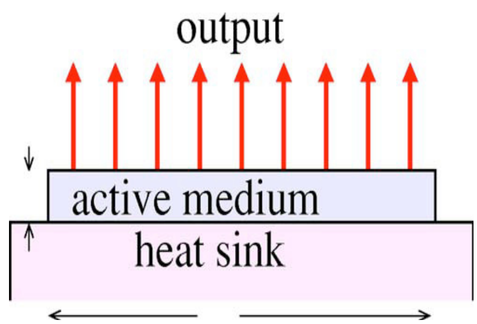


Figure 1. Simple Design of a Thin Disk Laser

facilitating research until Yttrium garnet was discovered as a group of neodymium material. In 1961,SNITZER detected the first neodymium glassy lasers which had been made in larger sizes and had better quality than bar lasers which was promising for delivery of much higher energies but the highest energy of these lasers was 100 kj which was not so high and scientists sought to find a laser with higher energy. In 1962, idea of Parametric Reinforcement and tunable light production was introduced. Some years later, the first test proving parametric gain was performed. The first optical fiber amplifier was obtained in 1963 using 1-m length of the injected neodymium fiber twisted around a flash Lamp. In 1964, the best group choice for neodymium ions mainly Yttrium aluminum garnet (YAG) was discovered by GEU: C. At that time, Nd:YAG was widely used as an active material for solid lasers. Nd:YAG has low threshold which allows continuous generation of heat and good optical and mechanical properties. Solid state lasers can generate very effective power but mean power was limited up to some watts or some ten watts. Although output of some hundred watts was commercially accessible from Nd:YAG lasers continuous pump in late 1967, it was a low power. In 70s, some actions were taken for improving engineering of life, power and quality of systems. Until 1980, some tunable lasers were discovered like fluoride crystals. These lasers could work with wavelengths of between 660 and 980 nm. In late 1980, combination of bandwidth of tunable lasers with very fast combined techniques like main lens led to generation of mode-lockedlasers with pulse width by order of Femtosecond. During these years, diode lasers became expensive. An example of these diode lasers was thin plane lasers. This kind of solid state laser was first introduced in 1990 by a group called and other Adolf Giesen in Germany Stuttgart University. Main difference between these lasers and bar lasers or laminate lasers was environmental geometry. In Figure 1, we show a simple design of thin disk.

The first material applied in thin-disk laser was Yttrium aluminum garnet (YAG) with impurity of Yb and the highest power or energy was obtained with this material. When Neodium is added as impurity to Yttrium aluminum garnet (YAG), it yields a highly efficient laser type (Stewen et al., 2000). In this paper, we solve rate equations of Nd:YAG laser in dynamic state and obtain relative population of their first and second balances with each other passage of time. Then, we calculate pump absorption of A and gain of signal G in terms of relative populations obtained in time interval of 0-0.1s. With this information, we calculate pump threshold which is dependent on the output of laser.

Environment of Laser

Almost all laser classic materials can be applied for design of thin disk laser especially if pump radiation absorption is quite high and life of the excited state is not very short. Almost all lasers are produced as result of electron diffraction from an excited level of energy in a radiating sample to lower energy level and as a result of this process, a light which radiates forms beam of laser as we show in Figure 2.

To introduce laser environment, it is necessary to introduce some parameters. N is concentration of active centers, $N_1$is the first level population and $N_2$is the second level population. We define relative population of the first and second levels as $n_1 = \frac{N_1}{N}$ and $n_2 = \frac{N_2}{N}$. The following relation is established forrelative population of two levels:

$$n_1 + n_2 = 1.$$

Nd:YAG Laser

When Neodium is added as impurity to Yttrium aluminum garnet (YAG) or glassy host material, it yields a highly efficient laser type. Main wavelength of laser is 1.06 µm for YAG and 1.05µm for glass. Lasers are optically pumped with flash lamps or with other lasers (especially GaAs semi- conductive diode lasers). YAG is a very attractive host material for Nd because it has very high thermal conduction and is a strong material, for this reason, laser can generate an average high power output

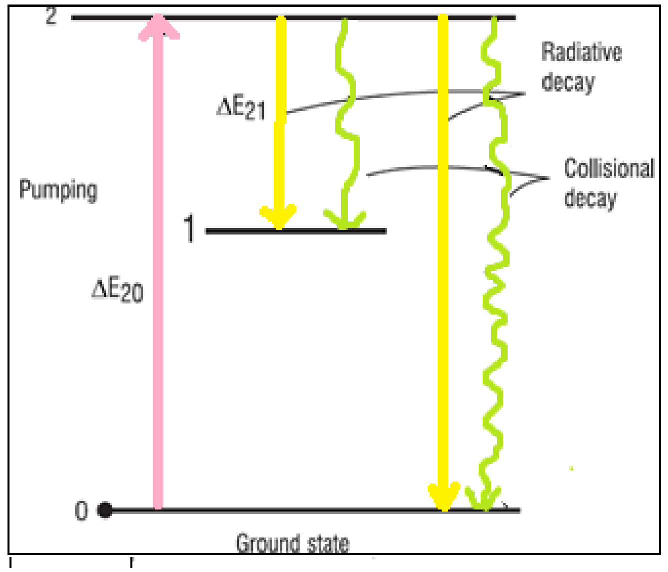


Figure 2. The simplified diagram of energy of an atom which indicates emission and excitation processes.

of crystal. Nd:YAG laser generates powers of cw up to 250 W and pulse energy up to 1 J/pulse.

Therefore, the goal was to reduce thermal problems and obtain a design which can extract high output with the minimum thermal distortion. Configuration (as observed later) is mainly independent of laser material and can be used with Nd, Tm and other laser ions and also with différent host materials.

3.Gain of Signal , Pump Absorption and Pump Threshold

Laser systems rate equations are expressed with the following relations: (Giesen, 2007)

$$\frac{dn_2}{dt} = (\sigma_{pa} j_p + \sigma_{sa} j_s) n_1 - \left(\sigma_{pe} j_p + \sigma_{se} j_s + \frac{1}{\tau}\right) n_2 \quad (1)$$

$$\frac{dn_1}{dt} = -(\sigma_{pa} j_p + \sigma_{sa} j_s) n_1 + \left(\sigma_{pe} j_p + \sigma_{se} j_s + \frac{1}{\tau}\right) n_2 \quad (2)$$

These rate equations have been also expressed in reference books relating to laser. In these equations, n_1 is the first level relative population of laser and n_2 is the second level relative population. $\sigma_{pa}, \sigma_{pe}, \sigma_{sa}, \sigma_{se}$ are cross sections of emission and signal absorption and pump respectively. τ is life of upper level of laser , j_p ، j_s are based on intensities of signal and pump. Equations of pump absorption and gain of signal are as follows:

$$A = (n_1 \sigma_{pa} - n_2 \sigma_{pe}) N = A_o \frac{u + s}{1 + p + s} \quad (3)$$

$$G = (n_2 \sigma_{Se} - n_1 \sigma_{Sa}) N = G_o \frac{p - v}{1 + p + s} \quad (4)$$

N is concentration of active center of laser, A_0 is absorption in powerful signal and G is gain in strong pump. U and V are cross sectional invariants, P and S are normalized intensities of pump and signal. Pump saturation intensity is expressed with relation (4) where ω_p is pump frequency (Kouznetsov et al., 2006).

$$I_{po} = \frac{\hbar\omega_p / \tau}{\sigma_{pa} + \sigma_{pe}} \quad (4)$$

$$I_{th} = I_{PO} \frac{V + \frac{G}{G_O}}{1 - \frac{G}{G_O}} \quad (5)$$

Relation (5) shows pump threshold when all of these equations are solved in terms of time , threshold will become dependent on time.We use from data of table 1 to solve these equations.

DISCUSSION AND CONCLUSION

By solving rate equations dynamically with maple software,since we sample that $n_1(0)=1$,we see that the second level relative population of Nd:YAG laser increase to reach approximate 1. We have drawn result of solution of this equation in Figure 3. We solve pump absorption equation in terms of time and conclude that Nd laser will have low absorption rate and we could draw

Table 1. General properties of media

Quantity	Expression	Nd:YAG
$\sigma_{pa}(m^2)$	Pump absorption cross section	7.6972×10^{-24}
$\sigma_{sa}(m^2)$	Signal absorption cross section	0.0002×10^{-24}
$\sigma_{pe}(m^2)$	Pump emission cross section	0.0001×10^{-24}
$\sigma_{se}(m^2)$	Signal emission cross section	26.2989×10^{-24}
$\lambda_p(m)$	Pump wavelength	808.5×10^{-9}
$\lambda_s(m)$	Signal wavelength	1064.2×10^{-9}
$I_p(\frac{W}{m^2})$	Pump intensity	127.7×10^{6}
$I_s(\frac{W}{m^2})$	Signal intensity	181.5×10^{6}
$\tau(s)$	Life time	0.25×10^{-3}
N $(\frac{1}{m^3})$	concentration	1.380×10^{26}

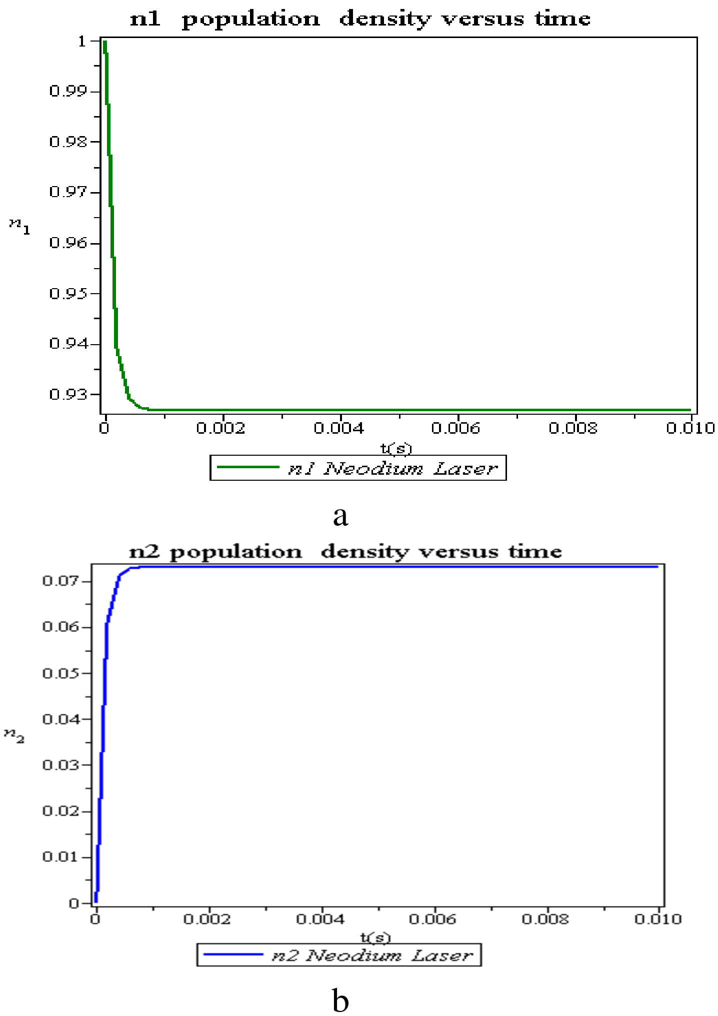
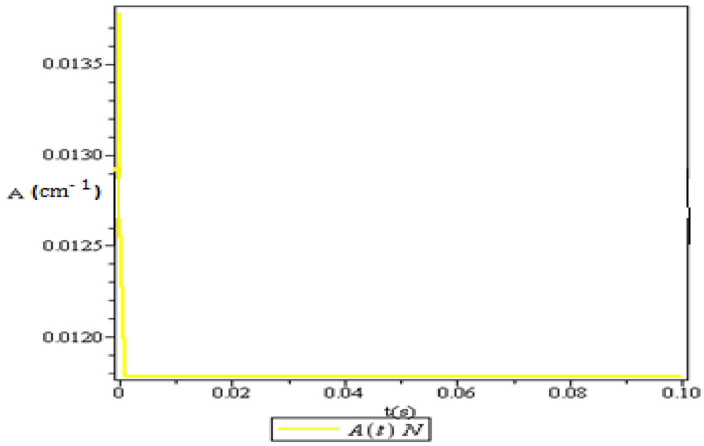


Figure 3. The first(a)and second(b)level relative population Neodium laser in terms of time



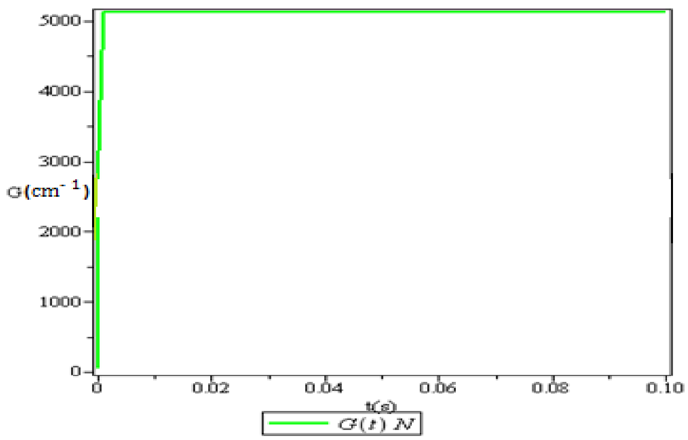


Figure 4. Pump Absorption and Gain of Signal of Neodium laser in terms of time

Table 2. Relative Population of the first and second levels of Nd:YAG as function of time

t (s)	0	0.001	0.002	0.004	0.006	0.008
$n_1 Nd$	1	0.9273	0.9272	0.9271	0.9270	0.9269
n_2Nd	0	0.0726	0.0727	0.0728	0.0729	0.0730

Table 3. A pump absorption and gain of signal G of Nd:YAG as function of time

t (s)	10^{-11}	0.01	0.02	0.04	0.06
G Nd	1000	5000	5069.95	5097.66	5125.37
A Nd	0.0138	0.01188	0.01186	0.01184	0.01183

a diagram for dynamic state of this equation in Figure 4 by solving absorption equation in terms of time so that Ndlaser has value of 0.00117. By solving gain equation in terms of time , we conclude that gain of signal of Ndlaser in terms of time has high value than has so that we could draw gain diagram in terms of time for these lasers after solving this equation with maple software. equation 5 shows that pump threshold is dependent on gain of signal, then, Nd laser which has high gain will have high pump threshold .We know that output of each laser has reverse relationship with threshold. The lower the threshold of a laser, the higher the output of laser would be. We conclude that Nd laser which has high threshold with passage of time will have low output.

Figure 4 shows diagram of gain of signal and pump absorption of these two laser systems in terms of time.

In Tables 2 and 3, we give our calculated numerical values which relate to the discussed quantities for time intervals of 0 to 0.1s. These tables have been directly read from diagrams 3 and 4. These numbers have not been published by any source. These numerical statistics shows domination of gain of signal for Nd laser in the given time interval.

REFERENCES

Dascalu T, Pavel N, Taira T (2003).`90W continuous-wave diode edge-pumped microchip composite Yb:$Y_3AL_5O_{12}$ Laser", Appl,phys ,let.,vol.83,4086-4088.

Giesen A (2007). "fifteen years of work on thin-disk lasers:Results and scaling law", IEEE,j,topic,Quantum,electrons., vol.13, 598-609.

Kouznetsov D, Bisson J-F, Dong J, Ueda K-I (2006). "surface loss limit of the power scaling of a thin-disk laser", j,opt,soc,Am. Vol.13,1074-1082.

Kouznetsov D, Bisson J-F, Dong J, Kuzunori T, Ueda K-I (2005). "High power single-mode solid-state laser with a short,wide unstable cavity," j,opt,soc.Am., vol.22,1605-1619.

Kouznetsov D, Moloney JV (2003). "Highly efficient, highgain,short-length, and power-scalable incoherent diodeslab-pumped fiber amplifier/laser," IEEE J. QuantumElectron. 39, 1452–1461.

Kouznetsov D, Moloney JV (2004). "Tapered slab delivery ofpump to the double-clad fiber amplifier: analytical approach," IEEE J. Quantum Electron. 40, 378–383.

Kano P, Kouznetsov D, Moloney JV, Brio N (2004). "Slabdelivery of incoherent pumplight to double-clad fiberamplifiers: numerical simulations," IEEE J. QuantumElectron. 40,1301–1305

Stewen C, Contag K, Larionov M, Giesen A, H¨ugel H (2000). A 1-Kw CW thin disc laser, IEEE J. Sel. Topics Quantum Electron,650-657.