Influence of the neodymium glass parameters on the amplified spontaneous emission in slab amplifier

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ABSTRACT

Amplified spontaneous emission (ASE) causes the decrease of the inverted population density and the nonuniformity of gain in slab amplifier for high power laser systems. In this paper, a three dimension model, based on the data in SG-II, in which the residual reflection in the cladding and the ASE process are taken into consideration, is built to analyze the space distribution and time evolution of small signal gain coefficient using Monte Carlo algorithm and ray tracing. This model has been verified by comparing with the experimental data. The traverse size of slab is 68.2cm×36.3cm, which is usually decided by the clear aperture and the manufacture. By means of the model, the impact of thickness, residual reflectivity and the stimulated cross section of neodymium glass to the ASE are analyzed in detail.

Keyword laser amplifier; amplified spontaneous emission; Monte Carlo; small signal gain coefficient; gain uniformity

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1 INTRODUCTION

Reaching the target of inertial confinement fusion (ICF) needs laser beams with high energy, high optical quality, which is usually produced by a large laser system, such as the NIF[1] in America, LMJ[2] in France, SG[3][4] in China, etc. NIF, built in Livermore Laboratory (LLNL) in 2009, is the largest facility in the word. NIF has 192 beamlets and can produce 1.8MJ at 3ω. Slab amplifier, as the supplier of more than 99% output energy for the laser system, is the most important component, and has a significant influence on the performance of the laser output.

The slab amplifier changes from single pass such as Shiva, Nova to multi-pass such as MSA, Beamlet[5-6]. The main amplifier (MA) in NIF is a 4×2 multi-pass amplifier, with a clear aperture of 40cm, while the clear aperture of main amplifier of SG-II is 31cm. The Nd glass slab amplifier pumped by Xenon lamp is usually applied to get enough gain. During pumping, there are two processes: the particles in lower level are pumped to the upper level, the upper level particles drop to the lower level because of spontaneous emission (SE). The SE particles obtain energy amplification through the gain medium, so the energy in the medium is consumed which results in the loss of the average small signal gain coefficient (g_ave) and the gain uniformity, this is the amplified spontaneous emission (ASE). ASE is also the main reason confining the size of the gain medium. In 1972, John B Trenholme[7] did research on the fluorescence amplification and the parasitic oscillation on the medium with different shapes such as spheres, circular discs and elliptical discs, which show that the maximum practical size

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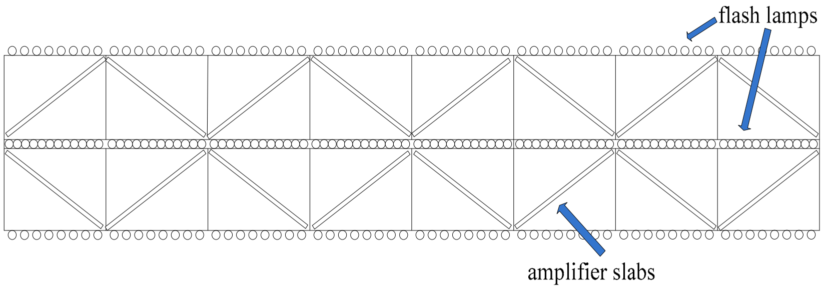
of the Nd glass is 30cm. D Albach[8]etc studied the ASE in the high gain medium Yb:YAG using Monte Carlo, and got the limitation for the value of $g(ave)\times l$ below 4.0. From 1975, the scientists in LLNL did a lot of work on the simulation of the amplification. ZAP[9]can calculate the energy stored in the slab and the transmission efficiency. Hagen[10]etc studied the performance of the single pass amplifier. Murray[11]studied the amplification in multi-pass amplifiers and developed the two dimension (2D) ray tracing codes. In 1999, G Le Touze[12]etc built a three dimension (3D) model that can do simulation for amplifiers in NIF and LMJ, they compared the results with 2.5D and 3D model, which showed 5% difference for gain prediction. Zhanghua[13-14]etc finished a model using 2D ray tracing and Monte Carlo which can calculate the energy conversion process in rod amplifier, the ASE process can also be studied using the 2D codes.

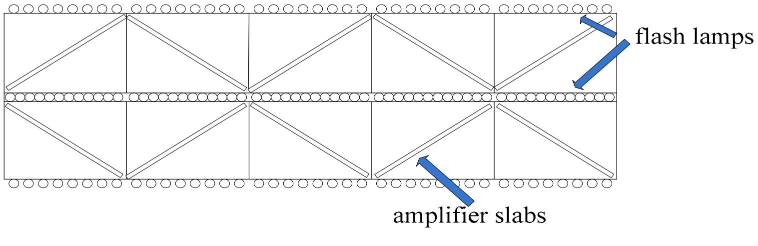
For studying the pump dynamics process, a 3D model using ray tracing and Monte Carlo, based on the SG-II laser system is built. Using the model, the influences of the parameters of the Nd glass such as the thickness, the residual reflectivity and the stimulated cross section to the ASE process and the distribution of the g(ave) are discussed.

2 MAIN AMPLIFIER of SG-II

The main amplifier chain in SG-II contains main amplifiers and power amplifiers, which have eight slabs and five slabs respectively. A bundle of light travels four times in main amplifiers and two times in power amplifiers. The transverse size of light is 31cm×31cm. The structures of the two kinds of amplifiers are shown in figure1.



(a) Main amplifier



(b)Power amplifier

Fig.1 Diagram of (a) main amplifier couple; (b) power amplifier couple

The shape of the glass changes from elliptical discs to rectangle slab. The glasses used in the SG-II amplifiers are N31 and the rectangle slab is shown in figure 2.

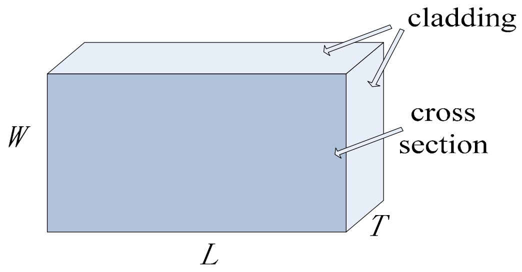


Fig.2 Rectangle slab glass with cladding

3 PARAMETERS CHANGE

The size of the slabs has influence on the average small signal gain coefficient and the gain uniformity. A cladding in the surface of the slab is applied to reduce the impact of ASE. In practical production, it is hardly to obtain a cladding with 100% absorptivity, so it should be taken into account during simulation.

The average small signal gain coefficient g(ave) is received from equation (1)

$$g(ave) = \sigma \times n \qquad (1)$$

n is the inverted population density, σ is the stimulated cross section of the slab. The gain (*G*) of the slab is shown in equation (2)

$$G = \exp(g(ave) \times l) \qquad (2)$$

l is the path the main laser travels in the slab.

The gain uniformity is defined in equation (3)

$$U_{uniformity} = g(\max) \big/ g(ave) \qquad (3)$$

When this value is low, the gain uniformity is high.

The energy stored in the slab can be obtained based on g(ave), as shows in equation (4)

$$E_{\text{stored}} = g(ave) \times L \times W \times T \times h \times \nu \big/ \sigma \qquad (4)$$

L, *W*, *T* are the size of the slab, *h* is the Planck constant, and ν is the frequency of the laser.

Based on 3D ray tracing model, the influence of the thickness, the residual reflectivity and the stimulated cross section of Nd glass are well studied.

3.1 Distribution of g(ave) in the clear aperture

The data is based on SG-II, and the space distribution of g(ave) in the clear aperture is shown in figure 3.

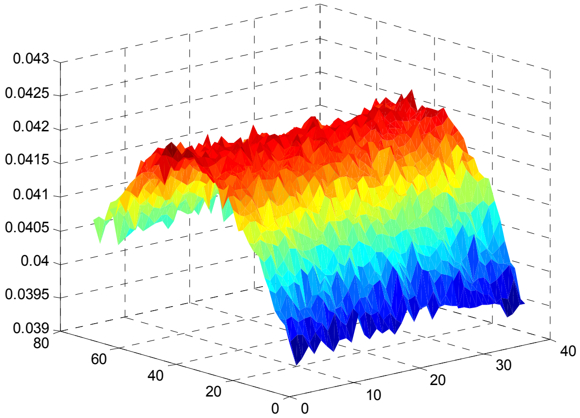


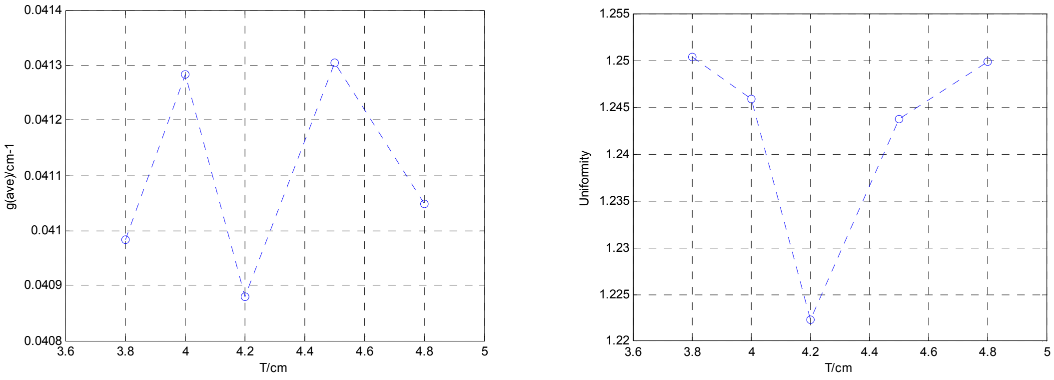
Fig.3 Distribution of g(ave) in the clear aperture

As the figure 3 shows, ASE consumes the inversion particles in the edge of the slab firstly more than the particles in the center of the slab. This performance results form the fact that the bundles travel to the edge have the longest distance. The calculated value of g(ave) is 0.0413/cm, which is smaller than the measured value (0.0442/cm). For the simplicity of the model we built, many situations are set in a ideal condition, for example, the spontaneous emission spectral line is not included in this model, and the rays of light may not enough and so on. The trend of calculated gain using our model is of same with the previous work [15], so our model is credible.

LLNL use $g(ave)\times l<3.5$ as the criterion to evaluate the influence of ASE, this value in NIF amplifiers has been expanded to 4.6[16]. The size of the slabs used in SG-II is 68.2cm×36.3cm×4.5cm, which is placed in Brewster angle and this value is about 3.4. The size of the slab have influence on the distribution of g(ave) in the clear aperture. The slab with bigger cross section area will face more energy lose because of ASE, so the transverse ASE become more serious with the enlargement of clear aperture. The thinner slab can not store enough energy while the thick slab may not be well pumped. The thickness of slab amplifiers are far less than length and width, so the longitudinal ASE can be ignored.

3.2 Vary Thickness *T*

Our thickness are changed under the foundation of a same initial energy storage density of 0.4783J/cm^3, a same residual reflectivity of 0.05% and a stimulated cross section of 3.8×10^{-20}cm^2. In SG-II facility, the traverse size of the slab is 68.2cm×36.3cm, which is reasonable to satisfy the need of clear aperture (31cm) and the practical manufacture. We vary the thickness from 3.8cm to 4.8cm. The results are shown in figure 4.



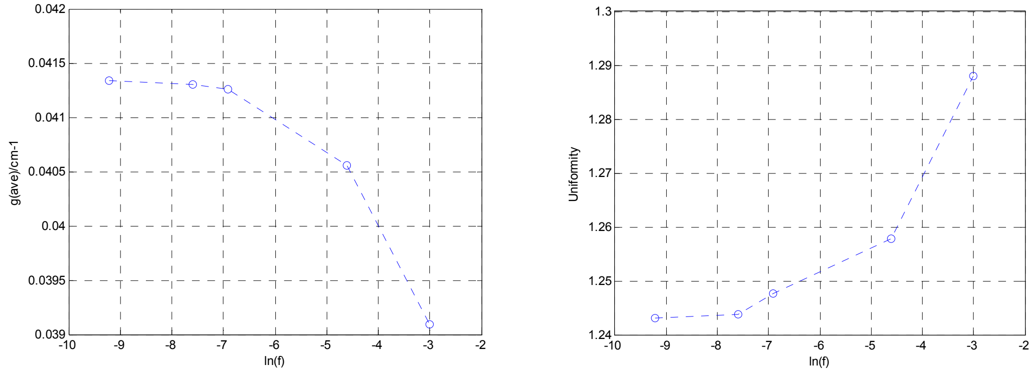
(a) (b)

Fig.4 Values of g(ave) (a) and gain uniformity (b) with different *T*

It is easy to see that, with the increase of thickness, the trend of g(ave) is not a single slope trend, the g(ave) gets the biggest value in 4.5cm, and gets the smallest value in 4.2cm. The gain uniformity gets a lowest value at 4.2cm. The stored energy is increasing with the enlargement of thickness. From these analysis we know, for concrete length 68.2cm and width 36.3cm in SG-II facility, the thickness 4.5cm is better compared with other thickness to get a high g(ave), a relatively good gain uniformity.

3.3 Vary residual reflectivity *f*

The second value we change is the residual reflectivity of the cladding. The values of the residual reflectivity we choose is 0.01%, 0.05%, 0.1%, 1%, 5%, which are shown in logs. The size of slab is 68.2cm×36.3cm×4.5cm, the initial energy storage density is 0.4783J/cm^3 and the stimulated cross section of 3.8×10^{-20}cm^2. The results are shown in figure 5.



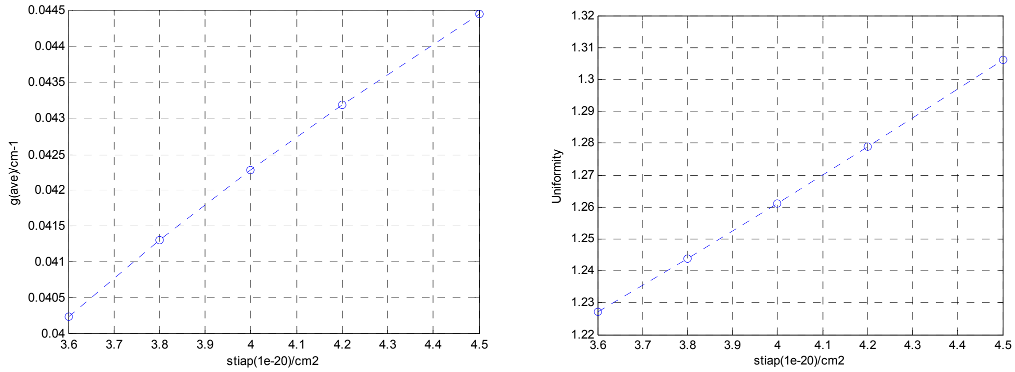
(a) (b)

Fig.5 Values of g(ave) (a) and gain uniformity (b) with different residual reflectivities

From the simulation results we can find that the g(ave), the uniformity and the stored energy have a same decreasing trend with the increase of the residual reflectivity. With bigger residual reflectivity, the light with more energy reflected from the cladding will travel in the gain medium and consume the energy stored in the slabs. With a residual reflectivity less than 0.1%, the slope of the g(ave) and uniformity trend are small. With a residual reflectivity more than 0.1%, the g(ave) and the gain uniformity decrease sharply with the increase of residual reflectivity. The residual reflectivity of the cladding should be lower than 0.1%.

3.4 Vary stimulated cross section σ

The third parameter we change is the σ. The values we choose are $3.6\times10^{-20}\text{cm}^2$, $3.8\times10^{-20}\text{cm}^2$, $4.0\times10^{-20}\text{cm}^2$, $4.2\times10^{-20}\text{cm}^2$, $4.5\times10^{-20}\text{cm}^2$, which are chosen depending on the usual value range of saturated energy density from 4.2J/cm^2 to 5.2J/cm^2. The size of the slab is $68.2\text{cm}\times36.3\text{cm}\times4.5\text{cm}$, the initial energy storage density is 0.4783J/cm^3 and the residual reflectivity is 0.05%. The results are shown in figure 6.



(a) (b)

Fig.6 Values of g(ave) (a) and gain uniformity (b) with different stimulated cross sections

From the figure above, the g(ave) and the values of gain uniformity have a nearly linear increasing trend with the add of σ. The g(ave) will add about 0.0009/cm when the σ has a increment of $0.2\times10^{-20}\text{cm}^2$. The gain uniformity get worse for the expanding of σ. Depending on the equation (4), the energy stored in the slab become less with the improvement of σ. So the choice of stimulated cross section should be a trade off between g(ave), gain uniformity and the stored energy.

4 CONCLUSION

The influence of the thickness, the residual reflectivity and the stimulated cross section to the small signal gain coefficient are studied using the 3D model we built. Changing thickness, there is a optimum value of 4.5cm with high g(ave) and better gain uniformity for the SG-II data we use. The results show that the g(ave), gain uniformity and stored energy decrease for a higher residual reflectivity which should be chosen below at least 0.1%. We can also find that for a concrete size of gain medium, g(ave) is increasing, the gain uniformity and the stored energy are both decreasing with the add of stimulated cross section.

5 ACKNOWLEDGMENTS

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6 REFERENCE

[1]Haynam C A, Wegner P J, Auerbach J M, et al.. “National ignition facility laser performance status”, Applied Optics, 46(16), 3276-3303(2007).

[2]Michel L. Andre. “The french megajoule laser project (LMJ)”, Fusion Engineering and Design, 44, 43-49(1999).

[3]Zheng Wanguo, Zhang Xiaomin, Wei Xiaofeng, et al.. “Status of the SG-III solid-state laser facility”, Journal of Physics: Conference Series, 112, 0320119(2008).

[4]Yanqi Gao, Weixin Ma, Baoqiang Zhu, et al.. “Status of the SG-II-UP laser facility”, IEEE Photonics Conference (IPC), 73-74(2013).

[5]HuntJ D, Speck D R. “Present and future performance of the Nova laser system”, Optical Engineering, 28(4), 284661-284(1989).

[6]Erlandson A C, Rotter M D, Frank D N, et al.. “Design and performance of the Beamlet Amplifiers”, UCRL-LR-105821-95-1.

[7]Trenholme John B. “Fluorescence amplification and parasitic oscillation limitations in disc lasers”, NRL Memorandum Report 2480(1972).

[8]Albach D, Chanteloup J C, Touzé G le. “Influence of ASE on the gain distribution in large size, high gain Yb3+:YAG slabs”, Optics Express, 17(5), 3792-3801(2009).

[9]Alexander J H, Troost M, Welch J E. “The ZAP laser analysis program”(1971).

[10]Hagen W F, Jancaitis K S, Powell H T. “Laser program annual report”, UCRL-50021(1984).

[11]Murry J R, TrenholmeJ B, HuntJ T. “Upgrade of the LLNL Nova laser for inertial confinement fusion”, Proc.SPIE, 1410, 28-39(1991).

[12]Touzé G Le, Cabourdin O, Mengué J.-F., et al.. “3D Gain Modeling of LMJ and NIF Amplifiers”, Proc. SPIE, 3492, 630-637(1999).

[13]Zhang Hua, Fan Dianyuan. “Investigation of the amplified spontaneous emission in Nd:glass disk laser amplifier”, Acta Physica Sinica, 49(6), 1047-1051(2000).

[14]Zhanghua, Fan Dianyuan. “Transient property of xenon flashlamp discharge”, Optics and Precision Engineering, 7(4), 28-34(1999).

[15]Chana Goren, Yitzhak Tzuk, Gilad Marcus, et al.. “Amplified spontaneous emission in slab amplifiers”, IEEE Journal of Quantum Electronics, 42(12), 1239-1247(2006).

[16]He Shaobo, Yu Haiwu, Zheng Wanguo, et al.. “Research of amplified spontaneous emission in high power slab laser amplifier”, High Power Laser and Particle Beams, 16(5), 603-606(2004).

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