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Simulation of a new solar Ce:Nd:YAG laser system

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ABSTRACT

A simulation model for a solar laser is designed using Ce:Nd:YAG as an active medium. A system of a parabolic concentrator, a glass light guide and a secondary concentrator is simulated to concentrate the solar radiation on to a laser head of the type Ce:Nd:YAG. The results show that adding Ce to the Nd:YAG increases the slope efficiency of this laser. Accordingly, an increase of the output laser power by a factor of about two is obtained.

1. Introduction

Solar lasers or solar pumped lasers are becoming increasingly very important in the recent years. This is because of its depending of the sun which is a clean renewable source of energy comparing with the conventional fossil energy sources which are damaging the environment. The use of the solar energy in the field of laser generation represents the main strategy of the world in using the new and renewable energy sources in every energy demands. There are many applications of such systems like space research [1–5] and generating hydrogen as an energy fuel and a huge thermal energy through magnesium-hydrogen cycle [6,7].

During the last fifty years since the first solar laser have been launched by Young [8], many developments have been introduced and adopted to exceed the efficiency and accordingly the output obtained from these systems. Some researchers went in the direction of developing new types of concentrators. Others went in the direction of discovering and manufacturing new types of crystals having physical and optical properties leading to decrease the threshold pumping power and increase the slope efficiency of the systems.

The sensitizer Cr^{3+} ions have broad absorption bands in the visible region. Despite the interests in Cr:Nd:YAG ceramic medium, researchers have achieved significant laser efficiencies with different Nd:YAG single-crystal rods. While it is clear about the effectiveness of Nd:YAG single-crystal rods for solar laser operation, there still exist some concerns about the advantages of Cr:Nd:YAG ceramics in solar-pumped lasers.

In this paper, we introduce the Ce:Nd:YAG as a new laser material which has a relatively higher slope efficiency. The effect of adding Ce^{3+} ions to the Nd:YAG will be significantly noticed. Through a simulation model, we will study the slope efficiency of this crystal and the quality of the output laser as well.

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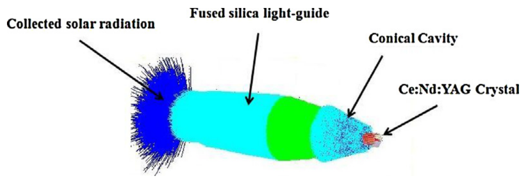

Fig. 1. Model of the solar Ce:Nd:YAG laser.

2. Model scenario

In order to check the possibility of increase the efficiency of solar pumped Nd:YAG lasers, the laser system reported in Almeida et al. [9] is modeled using the simulation model [10] which was improved by adding there a sensitizing process.

A large plane mirror with 36 segments (0.5 m × 0.5 m each) mounted on a two-axis heliostat which tracks the Sun continuously, redirecting the incoming solar radiation towards a horizontal axis parabolic mirror with 2 m diameter was used by Almeida et al. [11]. As an improve of the concentration process aiming to obtain a laser beam with relatively higher power values from a solar concentration system, a fused silica light guide of a 3D-CPC end part is involved to further collect and redirect the concentrated solar radiation onto the conical cavity in which a laser rod of type Ce:Nd:YAG is immersed coaxially as shown in Figs. 1 and 2 [9]. The dimensions of the light guide and the Ce:Nd:YAG crystal are the same used by Almeida et al. [9]. A 70 mm fused silica light guide was simulated by Monte-Carlo ray-tracing technique to optimize the concentrated solar radiation reaching the laser crystal. Fig. 1 shows the light guide and laser cavity collecting the concentrated solar radiation onto the laser rod.

A MATLAB© simulation model was designed for this system to test its performance limits and to compare them with the laser output in the case of using Nd:YAG crystal. Main part of the model is described in our preceding work [10]. In this paper, we simulate a sensitizing process which has not been considered before. It is known that sensitizing is the process where the excitation energy absorbed by the sensitizing ions (donors) is transferred to the active ions (acceptors) via radiative and/or non-radiative energy transfer mechanisms. In the case of Ce:Nd:YAG, the ions of Ce are the sensitizing ions. The radiative energy transfer depends on size and shape of the crystal. The structure of donor fluorescence depends on the acceptor concentration but the donor life time does not change with the acceptor concentration. The non-radiative energy transfer between donor and acceptor ions can be accompanied by direct transfer of excitation or by more complicated processes including migration of excitation energy between donor ions. The efficiency of the non-radiative energy transfer resulting in shortening of the donor life time can be derived from donor fluorescence decay curve as [12]:

$$\eta_{NET} = 1 - \tau_x / \tau_0 \tag{1}$$

where τ_0 represent the decay life time of Ce^{3+} of samples with Nd doping concentration of x and $x = 0$, respectively. The non-radiative energy transfer mechanism between these two ions can be explained by the energy level diagram shown in Fig. 2.

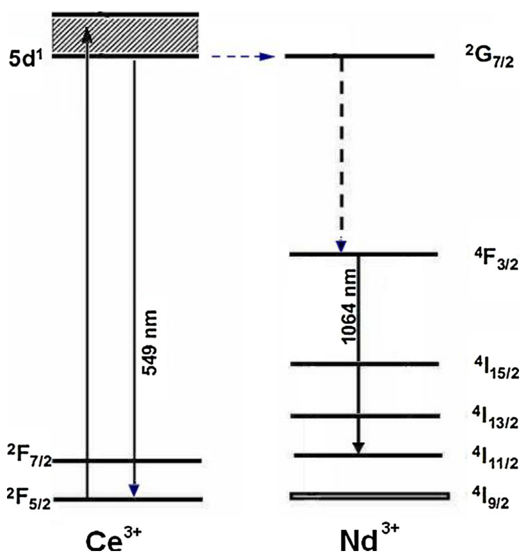

Fig. 2. Schematic energy level diagram of Ce^{3+} and Nd^{3+} in YAG.

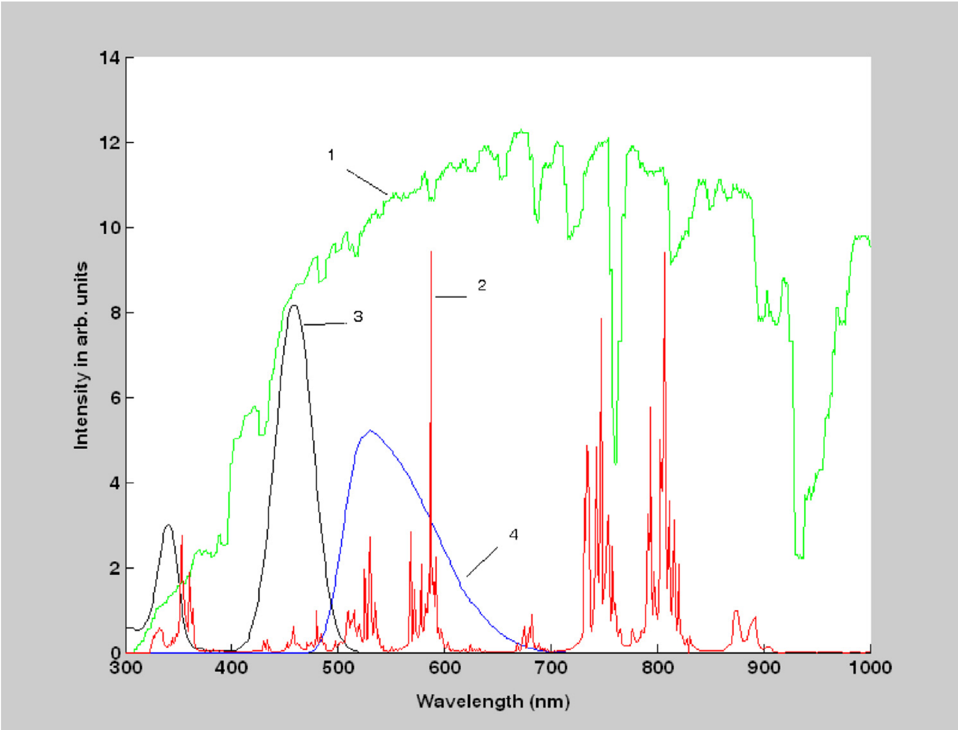

Fig. 3. 1-Standard solar spectrum, 2-Nd:YAG absorption spectrum, and 3 and 4-Ce:YAG absorption and emission spectrums, respectively.

Radiative energy transfer process from Ce^{3+} to Nd^{3+} through reabsorption of the Ce^{3+} luminescence due to Nd^{3+} is defined by the overlap between emission spectrum of Ce^{3+} and absorption spectrum of Nd^{3+} in YAG as shown in Fig. 3.

In order to simulate both of the radiative and non-radiative energy transfer processes, we select an absorption length l using the procedure described in Payziyev and Makhmudov [10].

$$l = -\frac{ln\xi}{\mu} \tag{2}$$

(where ξ is a random number and μ is the absorption coefficient for the given wavelength). We use the absorption spectrum of Ce:Nd:YAG with the assumption that:

$$\mu = \mu_1 + \mu_2 \tag{3}$$

where μ_1 and μ_2

$$p_2 = (1 - \eta_{NET})(1 - \exp(-\mu_2 l) \tag{4}$$

accordingly. Where $p_{Ce} = p_1 + p_2 = 1 - \exp(-\mu_2 l)$ is the probability of absorption in Ce:YAG and similarly we can define the probability of absorption in Nd:YAG as $p_{Nd} = 1 - \exp(-\mu_1 l)$.

Then using these probability definitions for the portion of radiative energy transfer, we can write:

$$\delta = \frac{p_2}{p_{Nd} + p_{Ce}} \tag{5}$$

As the both absorption in Nd:YAG and non-radiative part of absorption in Ce:YAG contributing directly in creating of inverse atoms in upper laser level after that the solar photon is absorbed the model checks the occurrence of radiative energy transfer process. To this, it is generated a random number in the interval of [0..1] and compared with the δ. If the random number is more than δ (direct pumping) the tracing process is terminated with the registration of results. Otherwise (indirect pumping), the emission process is modeled using emission spectrum of Ce:YAG and the tracing of a new photon is continued until the photon is reabsorbed or left the system.

We simulated the solar laser system in the both cases (Nd:YAG and Ce:Nd:YAG) and got the graph shown in Fig. 4, the input-output dependencies with and without taking into account of the radial distribution of absorbed power. The absorbed power distribution obtained is depicted in Fig. 5.

Our simulation results for Nd:YAG correspond to the experimental results of Almeida et al. [9] with adequate accuracy confirming that the model is a good representation of real system. The use of the Ce:Nd:YAG active medium instead of Nd:YAG showed a significant increase in the performance of the laser.

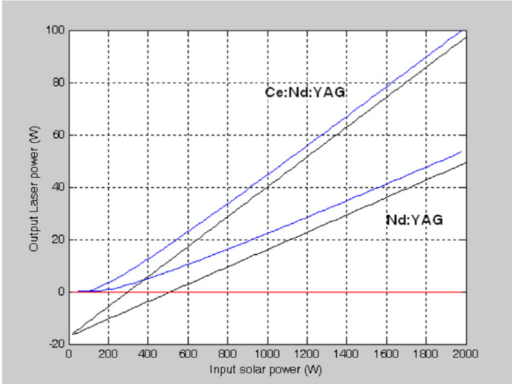

Fig. 4. The simulated performance of solar Nd:YAG and Ce:Nd:YAG lasers. Input-output dependencies with (curved lines) and without (linear dependences) taking into account of radial distribution of absorbed power. Non-radiative energy transfer efficiency η_{NET} in case of Ce:Nd:YAG was 67.6 [13].

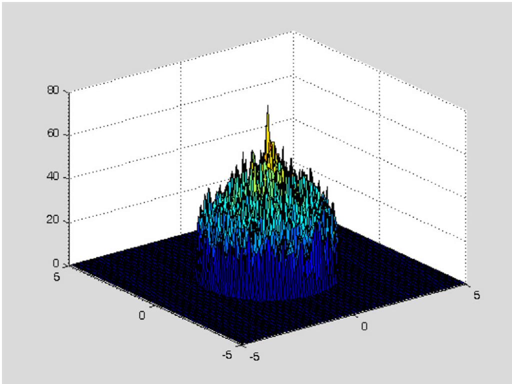

Fig. 5. The radial distribution of absorbed power.

3. Conclusion

The use of the Ce:Nd:YAG laser showed a significant increase in the performance of the laser. This increase is represented in the following:

1 A decrease in the threshold pumping power needed to start the laser action by a factor of about 0.6.
2 A duplication of the output laser power.
3 A duplication of the slope efficiency of the solar laser system.

The simulation model described can be useful in development of solar pumped lasers on the base of composite active mediums as well as in investigations of energy transfer mechanisms for accurate determining the contributions of different parts of energy transfer process.

References

[1] U. Brauch, et al., Solar-pumped solid state lasers for space to space power transmission, Space Power Resour. Manuf. Dev. 10 (3–4) (1991) 285–294.
[2] U. Brauch, et al., "Hochleistunglaser für Raumfahrtaufgaben", DLR-Nachrichten, Institut für Technische Physik, Deutsche Forschungsanstalt für Luft- und Raumfahrt (DLR), Stuttgart, Heft 65, 1991, November.
[3] R.J. De Young, et al., Preliminary design and cost of a 1-megawatt solar-pumped iodide laser space-to-space transmission station, NASA Techn. Mem. 4002 (September) (1987).
[4] R.J. De Young, et al., Comparison of electrically driven lasers for space power transmission, NASA Tech. Mem. 4045 (June) (1988).
[5] R.J. De Young, et al., A lunar rover powered by an orbiting laser diode array, Space Power 10 (1) (1991) 103–127, Proceedings of the eighth symposium on space nuclear power system, AIP Conference Proceedings, 217, pp. 253–257, 1991.
[6] T. Yabe, et al., Demonstrated fossil-fuel-free energy cycle using magnesium and laser, Appl. Phys. Lett. 89 (2006) 261107.
[7] T. Yabe, et al., Experimental study of solar pumped laser for magnesium-hydrogen energy cycle, J. Phys. (Conf. Ser.) 112 (Part 4) (2008) 042072.
[8] C.G. Young, A sun-pumped CW one-watt laser, Appl. Opt. 5 (June (6)) (1966) 993–997.
[9] J. Almeida, et al., A 40Wcw Nd:YAG solar laser pumped through a heliostat: a parabolic mirror system, Laser Phys. 23 (6) (2013) 065801, http://dx.doi.org/10.1088/1054-660X/23/6/065801 (6 pages).
[10] Sh Payziyev, Kh Makhmudov, A new approach in solar-to-laser power con- version based on the use of external solar spectrum frequency converters, J. Renew. Sustain. Energy 8 (1) (2016).

[11] J. Almeida, D. Liang, E. Guillot, Improvement in solar-pumped Nd:YAG beam brightness, Opt. Laser Technol. 44 (2012) 2115.
[12] X. Liu, Y. Teng, Y. Zhuang, J. Xie, Y. Qiao, G. Dong, D. Chen, A.J. Qiu, Broadband conversion of visible light to near-infrared emission by Ce3+, Yb3+-codoped yttrium aluminum garnet, Opt. Lett. 34 (2009) 3565–3567.
[13] Lulu Wang, Changtai Xia, Peng Xu, Juqing Di, Qinglin Sai, Fei Mou, Energy transfer in Ce, Nd, and Yb co-doped YAG phosphors, Chin. Opt. Lett. 11 (June (6)) (2013) 061604.