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AN EFFICIENT SOLAR-PUMPED Ce:Nd:YAG LASER WITH FRESNEL LENS

A.A. Sherniyozov, M.Z. Ismailov, G.A. Khalikov, Sh.D. Payziyev

Institute of Ion-Plasma and Laser Technologies of Uzbekistan Academy of Sciences, 100125, Tashkent, Uzbekistan; anvarsher87@yahoo.com

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Бу мақолада Ce:Nd:YAG кристаллининг қуёш лазерларидаги имконияти ўрганилди. Тадқиқотда яқинда таклиф қилинган кўп-марта ўтиш имконини берадиган оптик дамлаш конфигурацияси ишлатилди. Бунда Монте-Карло ёрдамида статистик тарзда фотонлар изини топиш методидан фойдаланилди. Натижалар 1000 Вт/м^2 қуёш нурланишида 60 Вт ли лазерига эришиш мумкинлигини кўрсатди. 7.5% ли умумий ва 8.5% ли нишаб (slope) самарадорликка эришилди.

Изучен потенциал кристалла Ce:Nd:YAG в лазерах с солнечной накачкой. В исследовании недавно предложенная конфигурация многопроходной накачки и линза Френеля, 0.8 м^2, были рассмотрены с использованием статистического метода отслеживания фотонов Монте-Карло. Наши результаты показывают, что лазерная мощность 60 Вт может быть достигнута при солнечной радиации 1000 Вт/м^2, где общая и дифференциальная эффективность составляют соответственно 7.5% и 8.5%.

We studied the potential of Ce:Nd:YAG crystal in solar pumped lasers. In the study, recently proposed multi-pass pumping configuration and the Fresnel lens, 0.8 m^2, have been considered using statistical Monte-Carlo photon-tracing method. Our results show that 60 W laser power can be achieved at 1000 W/m^2 solar radiation while overall efficiency is 7.5% and the slope efficiency is around 8.5%.

I. INTRODUCTION

Extracting energy from natural resources cheaply and efficiently is an important and challenging task for humankind. Since the solar energy is abundant and free, it is a primary candidate for the exploration. Therefore, it is not surprising that researchers around the world are studying various ways and means of using solar energy. One of them, directly converting solar radiation to laser beams, is getting renewed attention. Besides being a promising direction in renewable energy industry, this solar pumped laser field by itself is an interesting subject in improving laser effectiveness and engineering efficient pumping schemes. Directly solar pumped lasers are anticipated to have a preference in extra terrestrial applications. So far, suggested terrestrial applications include materials processing and magnesium-hydrogen energy cycle [1]. In remote places, where electricity is not available, solar pumped lasers are real alternative to usual electricity-powered lasers. However, overall power-to-power efficiency of existing solar pumped lasers, which is still well below landmark two digital percent, remains a big research problem. Here, main problem is the low overall power-conversion efficiency. This is due to the low overlap between the solar spectrum and the existing lasing medium's absorption spectrum. Another major issue is that mostly used pumping schemes (pump cavities-secondary concentrators) are inefficient because of sunray's single pass or double pass through the active medium, directly lowering absorption rate

and consequently results in low overall power-conversion efficiency. In this paper, our intention is to study the potential of Ce:Nd:YAG with multi-pass pumping configuration on Fresnel lens.

II. Ce:Nd:YAG CRYSTAL

Nowadays various crystals, made from rare earth materials, are being tested as lasing medium in different setups. Here of course, final aim is to find an optimal crystal in terms of spectral, thermal and mechanical properties to design efficient lasers. In the attempt of addressing these issues, here we examine the potential of Ce:Nd:YAG crystal rod [2-4] as the active medium instead of widely popular Nd:YAG in solar pumped lasers. Reasoning usage of Ce co-doped Nd:YAG instead of pure Nd:YAG is that, in Nd:Ce:YAG, because cerium acts as a good sensitizer for Nd^{3+} ions because of its strong absorption in UV spectral region (Figure 1) and efficient non-radiative energy transfer to the Nd^{3+} excited state.

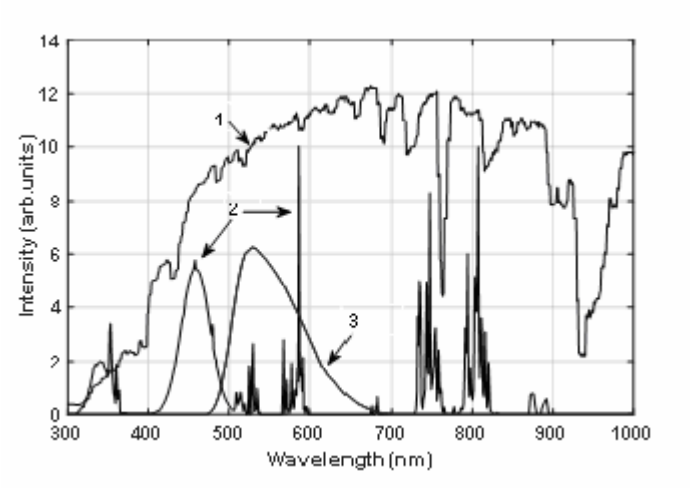


Figure 1. Standart solar spectrum (1), absorption spectrum of Ce:Nd:YAG (2), emission spectrum of Ce:YAG (3).

At the same time, the fact that emission spectrum of Ce overlaps Nd:YAG's spectrum in a region of 500–600 nm gives additional increase in the excitation of Nd atoms due to radiative energy transfer (Figure 1, curves 2 and 3). As a result, in Nd:Ce:YAG the slope efficiency can be significantly greater than that in Nd:YAG at solar pumping. Therefore, we considered solar pumped Ce:Nd:YAG laser using Fresnel lens with 1 m diameter and focal length of 0.9 m as a primary concentrator. In this study, the multi-pass side-pumping chamber, which recently proposed by our group, is being used as pumping cavity.

III. MULTIPASS PUMPING CHAMBER

Absorption length of solar photons in a crystal varies from several micrometer to hundreds of meters depending on wavelength and material properties. For example, if we consider Nd:YAG rod crystal with 2.5 mm radius and 5 cm length, absorption length varies approximately from 5 μm to 400 μm, an average or mean value is being around

100 m. Our theoretical analysis shows that 8% portion of the entire solar spectrum becomes absorbable in single or double pass through a crystal. Taking into account other losses, it can be assumed that 5% of absorbed solar photons become useful and results in around 2% overall power-conversion efficiency. It can be presumed that this is the theoretical efficiency limit of single or double pass pumping schemes [5]. As a side note, we can conclude that this 8% absorbability of solar photons point to the experimental observation that, in most cases, end pumping provides more efficient solar pumped lasers than side pumping. Here, it should be cautioned that end pumping has its own disadvantages compared to side pumping. The simple approach for the increase the absorption efficiency of side-pumped solar lasers which allows providing multi-pass pumping as effective as a multiple pass absorption technique (retro-reflector) in thin-disk lasers [6-7] have been recently proposed in [8]. It is based on the use of a special pump chamber (cavity) with silver-coated internal walls. The pump chamber is a rectangular box whose front side plays the role of a retro-reflector, which is the main difference from the existing pump cavities used in side-pumped solar lasers. Another distinctive feature of the pump cavity is that it also plays the role of a homogenizer (metallic light-guide), which ensures a uniform distribution of the pump along the length of the active medium. In order to improve the efficiency, solar photons must go through the active medium several times, that is multi-pass pumping scheme, increasing the photon absorption probability. For the case of Nd:YAG, solar spectrum's ~16% portion is absorbable solar photons, which corresponds to several meters of absorption length. For comparisons, we studied two pumping schemes as shown in Figure 2. In the considered pumping schemes it can be seen that Nd:YAG rod is located at the bottom. As already mentioned, this done with the intention of maintaining homogeneous sunray incidence on the surface of crystal. One side (wall) of the first pump cavity is left open whereas of second one is closed with circular aperture in it. Walls of pump cavities are silver coated with reflectivity of 97%.

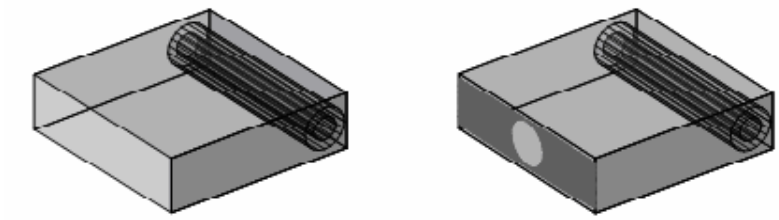


Figure 2. Pumping schemes. Left – double pass pumping scheme, right – multi-pass. Laser rod is located far side of pump cavities.

Another very important motive for choosing this simple pumping chamber is that they can be easily modified. For example, one can insert a stack of crystal rods and different kind of external solar spectrum frequency converters (down-shifters, down and/or up converters).

IV. RESULTS AND DISCUSSIONS

Using statistical Monte Carlo photon tracing method, we conducted comparative studies by simulation calculations with the use of Ce:Nd:YAG and Nd:YAG to demonstrate of the power Ce doped crystals and the versitality of multi-pass pumping

configuration. Our model gives for the first pump cavity 4.5% absorption rate of 8% absorbable solar photons in double pass. This corresponds to 2.3% overall power efficiency (Figure 3, Nd:YAG with double pass line). For the second pump cavity, 8.8% absorption rate of 16% absorbable solar photons in multi-pass. This improves absorption efficiency almost two times and provides 4.7% overall efficiency (Figure 3, Nd:YAG with multi pass line). Using Fresnel lens, 0.8 m^2, as first concentrator and double pass and multi pass pumping schemes, respectively, we showed that 18.7 W and 37.7 W output powers are achievable. This almost two times improvement in output power confirms efficiency of multi-pass pumping configuration.

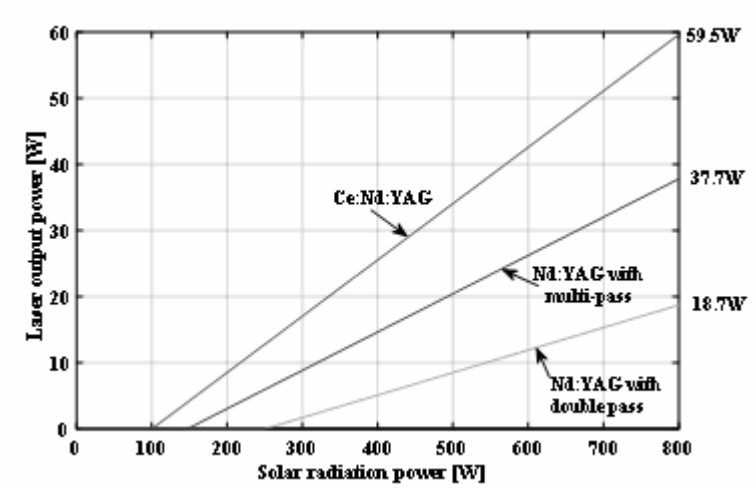


Figure 3. Laser power vs. solar power for Ce:Nd:YAG rod with a diameter of 5 mm and length of 4 cm.

After establishing versatility of the pumping scheme, Ce:Nd:YAG material which has a broad absorption band in visible region of solar spectrum has been examined. Our analysis shows more than 12% absorption rate in multi-pass in Ce:Nd:YAG crystal. As a result, 59.5 W laser power can be achieved at 1000 W/m^2 solar radiation. That is 7.5% overall efficiency (Figure 2, Ce:Nd:YAG line). Here the slope efficiency is around 8.5%, which is much higher than currently existing [5] solar pumped lasers in side pumping regime.

VI. CONCLUSION

So, we demonstarted applicability of Ce:Nd:YAG crystal with size of 5 mm diameter and 5 cm length in solar pumped lasers. Scalable and easiliy modifiable multi-pass pumping configuration and the Fresnel lens, 0.8 m^2, have been considered using statistical Monte-Carlo photon-tracing method. Our results show that 60 W laser power can be achieved at 1000 W/m^2 solar radiation while 7.5% overall efficiency and the slope efficiency is around 8.5%.

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