High power and uniform distribution of pump-radiation absorption in Nd: YAG solar-laser system with end-side-end pumping method

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ABSTRACT:

Solar-pumped-laser (SPL) is an appropriate system which can transform the broad-band sunlight into the narrow-band laser directly, with the advantages of simple structure, high efficiency and long lifetime, in an environmentally friendly way, especially in places where the solar-energy is abundant and other energy sources are scarce such as the space.

In order to produce the solar-laser light, we must excite the active medium by the solar- light. There are two major techniques for solar-pumping solid-state-lasers: side-pumping and end-side-pumping methods. The solar-laser efficiency advances were achieved by employing end-side-pumping configurations, since they can lead to much higher efficiencies compared to side-pumping configurations. Nevertheless, most of the advances in solar-laser brightness and stability were achieved by side-pumping configurations. The side-pumping method is an effective configuration for power scaling as it allows uniform absorption along the rod axis within the laser medium, hence decreasing the thermal load effects on solar-laser systems. Besides, the free access to both rod ends of side-pumped lasers permits the optimization of more laser resonator parameters, improving largely the laser beam quality and enabling the efficient extraction of solar laser at low modes, when compared to end-pumping configurations.

By using the end-side-end pumping configuration, we aimed to benefit from the advantages of the two pumping methods cited above and that's what we effectively achieved and that we report here, a symmetrical and a uniform distribution of radiation along the laser rode axis, as well as a high radiation absorption, which increase the efficiency of the solar-laser system and improve the laser-beam quality.

Keywords: Solar-pumped-laser, end-side-end pumping configuration, solar-laser efficiency, solar-laser brightness, thermal load effects.

1. INTRODUTION

Our planet receives more energy from the Sun in one hour than all humankind consumes in an entire year. And yet despite this, solar power still only contributes towards a tiny fraction of our energy requirements. The idea of directly converting broad-band solar radiation into coherent and narrow-band laser radiation has gained an ever-increasing importance in recent years.Among the potential applications of solar lasers are earth, ocean, and atmospheric sensing; detecting, illuminating, and tracking hard targets in space; and deep space communications. Renewable lasers have a large potential for many terrestrial applications, e.g., high-temperature materials processing, renewable magnesium–hydrogen energy cycle and so on.Since the report of the first solar-pumped Nd:YAG laser [1], researchers have been exploiting parabolic mirrors and Fresnel lenses to attain enough concentrated solar radiation at focal point and several pumping schemes have been proposed for enhancing the solar laser output performance [2–9].Nevertheless, boosting the solar laser collection efficiency have occurred the most significant efforts in the last decade [3–9] , the output power emitted per unit primary collection area [10], which describes the laser efficiency. The present record for this parameter is 32.1 W/m^2 [9], obtained by end-side-pumping a 6-mm-diameter, 95mmlength bonding Nd: YAG/YAG crystal rod pumped by Fresnel lens solar energy collection and concentration system. For 1.03 m^2 effective solar radiation collection area. This result surpassed slightly the fomer record with by a heliostat – parabolic mirror system in 2018 [11]. Despite the fact that solar laser aggregation efficiency is generally considered as a primary figure of excellence for lasers, the solar laser beam brightness figure of merit [12] – described by the output power divided by the square of the beam quality factors is also a critical parameter to characterize the possible usefulness of the laser output. While 120W solar laser power was achieved in 2012 [5], poor laser beam M^2 factors of 137 were found. In the side-pumping configuration, the multimode collection efficiency was very low; in opposite, the beam quality factors are much reduced. Low beam quality factors of (M^2_x = 8.9) and (M^2_y = 9.6) are gained by pumping a 4mm diameter, 30mm length, Nd:YAG rod with 2.88 m^2 area parabolic mirror with only 9.6 W/m^2 multimode collection efficiency. The highest multi-mode collection efficiency fulfilled with this pumping method is 11.7 W/m^2 by pumping a 7mm diameter, 30 mm length, Cr:Nd:YAG rod with 2.88m^2 area parabolic mirror. In the TEM_{00} mode regime, using the side-pumping method, the maximum collection efficiency is 4.0W/m^2 by pumping a 4mm diameter, 25-mm length, Nd:YAG rod with 1.13 m^2 area parabolic mirror. Beam quality factors <1.05 are reached by pumping a slender and long Nd:YAG rod (3 mm diameter and 50mm length), with 1.18m^2 area parabolic mirror. More importantly, a TEM_{00} mode solar-laser with 1.7% laser power stableness is produced, being significantly more stable than the earlier TEM_{00} mode solar lasers.

Despite the most efficient laser systems have end-pumping approaches, the thermic loading influences caused by non-uniform distribution of pump light in these pumping configurations in negative way affect their efficiencies. Side pumping is an effective configuration for power scaling and for brining high laser beam quality as it allows regular absorption distribution along the laser rod axis and disperses the absorbed power within the laser medium, decreasing the combining thermal loading problems. In our this report, we suggest a different solar lasers pumping method, named end-side-end pumping approach, this method will combine the advantages of the two pumping methods mentioned above, Where the sunlight will be leaded and focused towards the ends of the laser rod.

2. FLAT MIRROR-FRESNEL LENS SOLAR ENERGY ORIENTATION AND CONCENTRATION SYSTEM

The system of orientation and concentration of expandable solar energy system, as demonstrated in Fig. 1, is shaped by both two flat mirrors (M1–M2) intended for reflection of the arriving solar radiation from the source toward Fresnel lenses and two Fresnel lenses (F1–F2) in order to concentrate solar radiation from the flat mirrors on the way to the laser head. In afterwards sections ,a detailed description of the laser head will be presented in both Figs. 2 and 3.Each Fresnel lens has 0.9m diameter, 3mm thickness, and 1.2m focal length. With two Fresnel lenses, total collection area would be 1.3 m^2.

The center of each Fresnel lens is located 1.3m away from the center of the laser head, as exposed in Fig 1. The plane folding mirrors are positioned ahead of their relevant Fresnel lenses, forming 45° angle with the Fresnel lens optical axis, converting the solar radiation at an angle of 90°, as shown in Figs. 1. The Fresnel lenses are made of polymethyl methacrylate (PMMA) material, being transparent at observable and near infrared wavelengths and cuts unwanted solar radiation further than 2200 nm and below 350 nm. numerical calculation of transmission efficiency average of 78% for each Fresnel lens. with consideration of each Fresnel lens with 0.64m^2 collection area, 950 W/m2 terrestrial solar irradiance, 95% reflectance for each plane folding mirror, 450 W solar power can be spotlighted on the focal zone. For the 1.3 m^2 area collection system, 900 W solar power is supposed to attain the large input faces of the fused silica secondary concentrators.It would be of more use to scale the 1.3 m^2 area approach to a more powerful pumping scheme, subsequent to using two Fresnel lenses with outsized diameters. Solar tracking can be accomplished by mounting the complete optical system onto a one -axis solar tracker that tracks the sun incessantly in direct tracking mode. The stepper motors of the tracker are managed by an electronic control unit with G.P.S guidance for rapid solar orientation and a photo-sensing unit for precise solar tracking.

3. ND:YAG SOLAR LASER HEAD FORMED OF THE TWO CONICAL MIRROR COUPLED TO THE TWO CONICAL PUMPING CAVITY

The laser head formed of the conical coupled to the conical pumping cavity where the 3 mm diameter ND: YAG rod is mounted. Chromatic aberration of the Fresnel lens spread the focal spots of diverse wavelengths along its largest focal region, so it is no easy to couple resourcefully all the concentrated radiations within this area into a small laser rod Without second-stage conical concentrator, as specified in Fig. 2.For end-pumping, one part of the radiationis focused onto the upper end face of the rod by either the direct focusing from the side walls face of the second-stage conical concentrator.For side-pumping, another part of the radiation not hitting the end faceof the rod, is also guided into the small conical cavity with D_3 = 24 mm input diameter, D_4 = 10 mm output diameter and H_1 = 26 mm cavity height. a multi-pass side-pumping to the rod is ensured by The zigzag passage of the rays within the cavity .

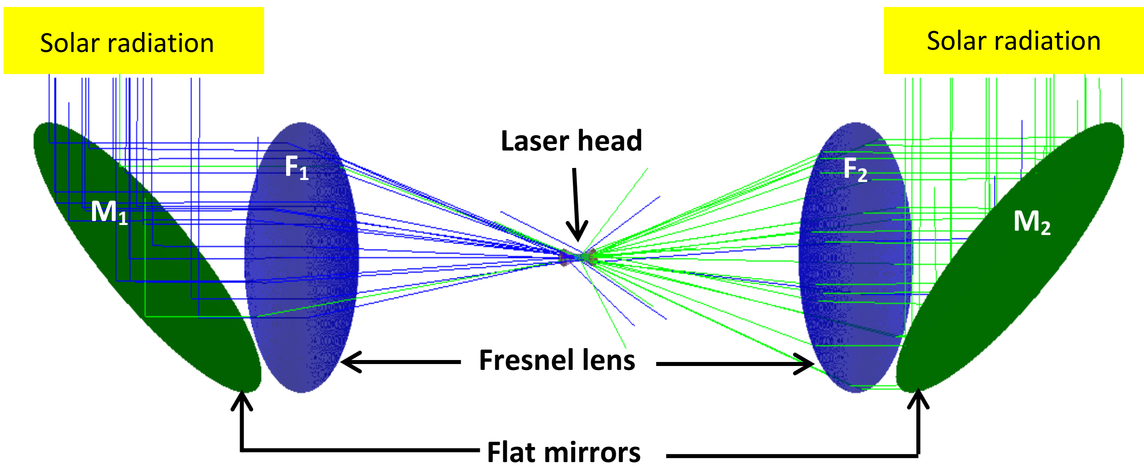

Fig. 1.two flat mirror-two Fresnel lens end-side-end-pumping solar laser approach. the solar light collection and concentration by F1–M1 and F2–M2.

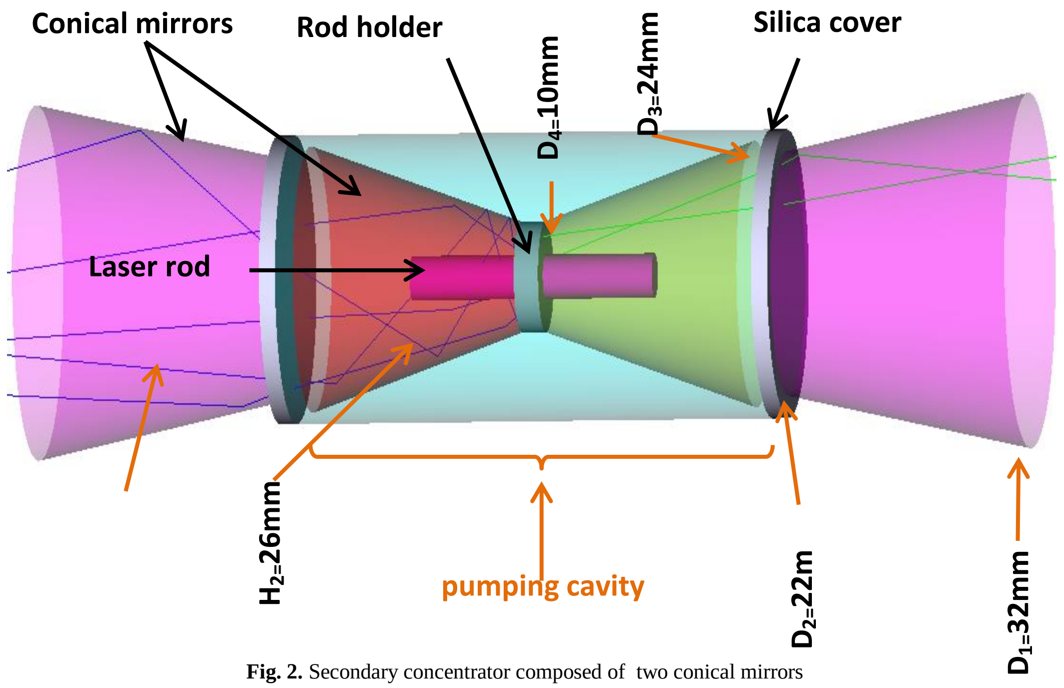

Fig. 2. Secondary concentrator composed of two conical mirrors

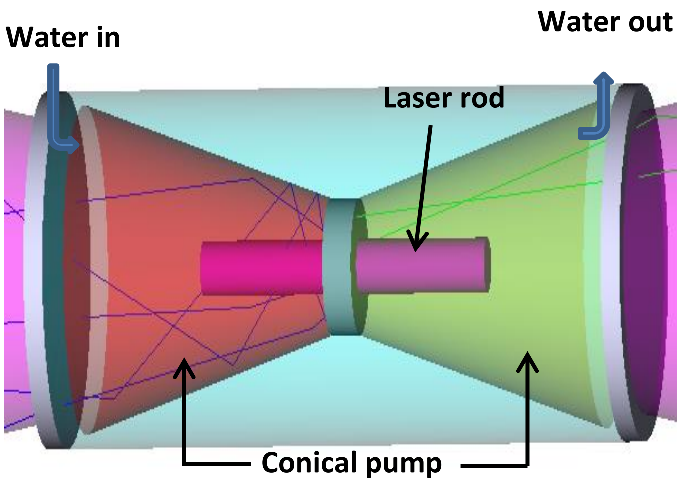

Fig. 3. Design of Nd: YAG laser pumping cavity, composed the two conical pump cavity and the Nd: YAG rod, which were all actively cooled by water.

Non sequential ray-tracing software ZEMAX™ does all optimisation of All the design parameters in Fig.1. 2.3. to obtain the maximum absorbed pump power within the Nd:YAG rod

4. DISCUSSION

All the design parameters of the proposed solar pumping laser system were optimized through ZEMAX non-sequential ray-tracing software. In this design we have focused on the horizontal and vertical symmetry, where all the system parts were placed symmetrically to the center of the laser rod, in order to ensure the most uniform absorbed pump flux distribution within the laser rod, reducing the associated thermal loading problems worsening the efficiency as well as the beam quality. By choosing a laser rod with 4 mm diameter, high-order resonator modes can be suppressedand 30 mm length, thermal loading problems can be reduced. Consequently, the beam quality improves.

Unfortunately, this design presents a problem associated to the resonator cavity mirrors position, that block a part of the incident pump radiation to the laser medium.. However, there are many appropriate solutions which overcome this problem by processing the system by the LASCAD software and determine the distance separating the two mirrors. The mirrors shading effect will be weak as the distance between themirrors and the secondary concentrator system increases, due to the small mirrors dimensions. This is why we propose practical solutions to this problem in order to make the system more feasible.Among these solutions, the use of double-coated mirrors, which are antireflection (AR) coated for the pumping wavelength (AR @ 808nm) and one of these mirrors is highly, the other is partially antireflection coated for the laser emission wavelength (HR and PR @ 1064nm).The terrestrial solar irradiance of 950 W/m^2 and the 16% overlap between the absorption spectrum of the Nd:YAG medium and the solar spectrum are considered in ZEMAX software. For the calculation of absorption pump power in the Nd:YAG rod in ZEMAX™ analysis, the crystal rod was divided into 18000 discrete sectors. The path length for each sector was found. With this value and the effective absorption coefficient of 1.0 at.% Nd:YAG material, the total absorbed pump radiation was finally calculated by summing up each sector's absorbed pump power. 5 million solar rays were simulated. Using ZEMAX™ software.The false-color absorption distributions of the 4mm diameter Nd:YAG rod is shown in Fig. 4. red signifies near maximum absorption for these plots, whereas Blue signifies little or no absorption. Symmetric absorption distribution is achieved by the modified approach, concentrating more radiation into the central core region of the rod. The absorption profiles can also be evaluated by the absorbed flux/ volume distributions along both the central cross-section row and the central cross-section column. The absorbed flux peaks along the central core region of the rod, favoring the generation of TEM00 laser power. Maximum absorbed pump power of 94 W is numerically achieved, This value represents more than a third of the pumping power. Comparing this result with that of the pumping system [4] in which the laser rod was pumped at one end, We can see that

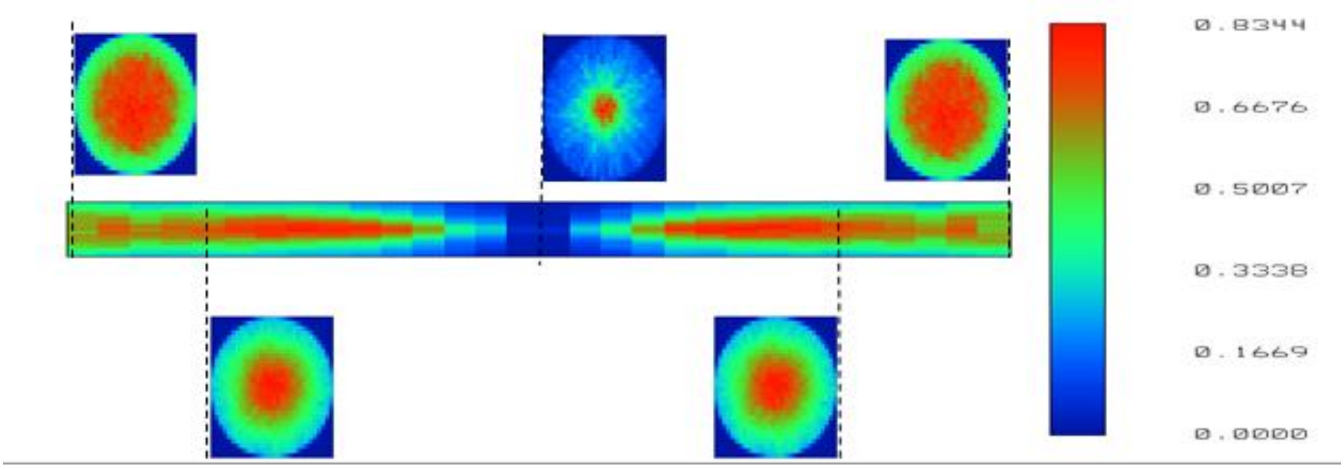

Fig. 4. Absorbed pump-flux distribution along both eight transversal cross-sections and one longitudinalcentral cross-section along the 4.0 mm diameter, 30 mm lengthNd:YAG rod. The maximum absorbed pumpedsolar flux (about 16% of thewhole solarspectrum)within therod canreach 0.83 W.

the absorbed pump power is increased by about 52w. This is a significant value that can increase the output power of the laser system and improves its brightness.

The pump light distribution along the laser rod and its cross sections exposed in Figure 4, shows a uniform and a symmetrical distribution along the rod axis.This ensures that the thermal loading effects are avoided, which will improves the laser beam quality.

5. CONCLUSIONS

An end- side end solar laser pumping approach was presented in this paper to improve the solar laser power and the solar beam brightness. Two plane mirrors, two Fresnel lens and two secondary concentrators conical mirrors are used to focused the sun light at the two laser rod ends, the laser rod is placed inside an optical cavity of two conical mirrors.All the solar laser system dimensions are determined by using ZEMAX non- sequential software to achieve maximum absorbed pump power and optimal uniform light distribution along the laser rod.

The technical issues of the system can be overcome by several practical solutions. The obtained pump power of 94w is considered as adequate value for improving the output laser power and consequently the laser brightness.The distribution of absorbed pump power along the laser rod is uniform and symmetrical, that can reduces the thermal loading effects, which improves the laser beam quality.

In comparison with systems with the same concentrator dimensions and adopting the pumping approach from one end, the proposed system gave a significant increase in the absorbed pump power value of 52 W, which inevitably leads to increase both the laser output power and laser brightness.

6. **DIFFICULTIES**

Inability to complete the system study with the LASCAD software.

Difficulty of the practical realization of the system.

7. REFERENCES

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