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SIMULATION OF SOLAR PUMPED HIGHLY NEODYMIUM-DOPED CERAMIC YAG DISC LASER

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Неодим концентрацияси юқори бўлган шаффоф керамик YAG-лазер материаллари қуёш энергиясини лазер энергиясига айлантириш мақсадида фойдаланиш имкониятлари Монте-Карло нурларни кузатишни имитация қилиш усули ёрдамида тадқиқ қилинди. Юқори даражада легирланган Nd:YAG-лазер материаллардан қуёш нурида ишлайдиган диск лазерларга қўллаш қуёш энергиясини лазер энергиясига айлантириш самарадорлигини одатда ишлатиладиган 1% ат Nd:YAG–лазер материалига нисбатан ошириш мумкинлиги кўрсатилди.

Прозрачные керамические YAG-лазерные материалы с высоким содержанием неодима исследуются для применения в преобразовании солнечной энергии в энергию лазерного излучения с помощью метода имитации трассировки лучей Монте-Карло. Показано, что использование высоколегированных керамических Nd:YAG-лазерных материалов в дисковых лазерах с солнечной накачкой повышает эффективность преобразования солнечной энергии в лазерную по сравнению с обычно используемым 1% ат Nd:YAG.

The highly neodymium doped transparent ceramic YAG laser materials are examined to apply in solar-to-laser-power conversion by Monte-Carlo ray-tracing simulation method. It is shown that the use of highly doped ceramic Nd:YAG laser materials in solar pumped disc lasers increases the solar-to-laser-power conversion efficiency in comparison to commonly used 1% at Nd:YAG.

Progress in material’s science, particularly in development of transparent ceramic laser materials, has opened a huge opportunity for creation of advanced lasers with diode, lamp or solar pumping. It is worth to note that the possibility of fabrication of highly doped transparent ceramic laser materials which is impossible with usual single crystal growth technology was one of the main breakthroughs in this field. In connection with these recently researchs and developments of high efficient high power lasers using the advantages of ceramic laser materials are attracted many researchers. In parallel with other types of lasers the solar pumped solid state lasers have got a new impulse for further progress. However the advantage of possibility of highly doping in ceramics fabrication technology is less used or even not used yet to the best of our knowledge in solar powered solid state lasers. In this regard this work devoted to analysis of the influence of neodymium concentration in ceramic YAG (yttrium aluminum garnet, $Y_3Al_5O_{12}$) active medium on the performance parameters of solar lasers.

The increase of active ion concentration in YAG host materials usually leads to reduce lifetime of upper laser level (concentration quenching). Moreover the increase of active ion concentration also are accompanied with increased scattering loss. Both of these can raise the threshold pump power of a laser. On the other hand, with the increase of active ion concentration the probability of absorption increases linearly (in first approximation), proportionally to the concentration. The purpose of this study was to find some compromise between these three competitive processes where the effect of increase in absorption surpasses the cumulative effect of other two processes providing by that the enhancement in laser efficiency. To this different end and side-pumped configurations including disc type lasers have been considered, but the preliminary analysis have shown that the most promising configuration is the disc laser configuration. Simulation calculations have been conducted for the parabolic concentrator of a diameter of 1 m and double pass scheme of a disc laser as shown in Fig. 1 and 2. As an active medium a core doped 3 mm thick and 10 mm diameter disc is considered (Fig. 3). The diameter of active ion doped core was 7 mm. It is supposed that the heat generated in the active medium is dissipated through the heat sink with active water cooling commonly used in disc type lasers. Simulation of absorbed power distribution and pumping efficiency is performed with the use of Monte-Carlo ray-tracing method described in [1-3]. The laser power have been calculated by the use of well-known expression of four-level laser taking into account the dependence of upper laser level lifetime on the concentration of neodymium ions according to [4] (Fig. 4). The concentration dependences of absorption spectrum and scattering loss are assumed to be linear in first approximation, multiplying the absorption spectrum and loss coefficient of 1% at Nd:YAG by a factor of *n* equal to neodymium concentration for the higher concentration of neodymium ions based on analysis of the results of [4-6].

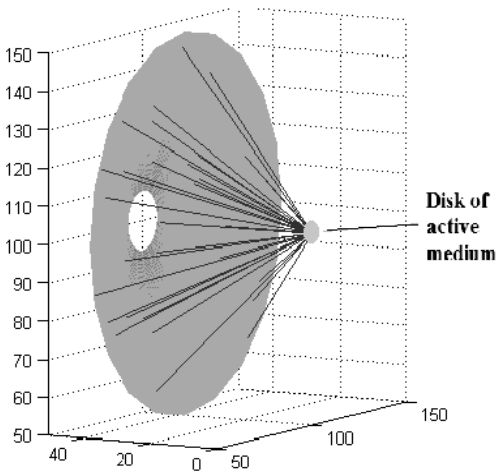

Figure 1. Scheme of a disc laser pumped by parabolic solar concentrator

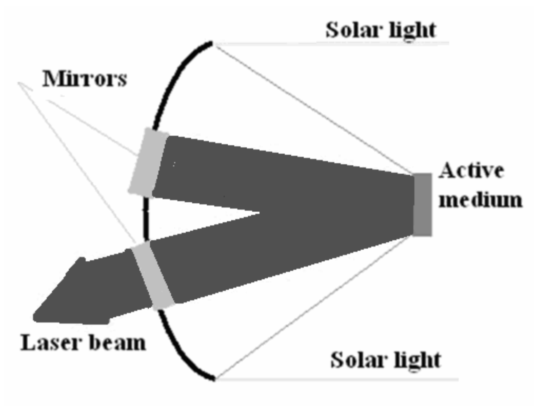

Figure 2. Double pass scheme used

The simulation results obtained for the Nd:YAG active medium are presented in Fig. 5. As can be seen from the figure there is a compromise, as expected, between the three competitive processes where the effect of increase in absorption surpasses the cumulative effect of the concentration quenching and increasing the loss providing by that the enhancement by almost in two times in laser efficiency at the maximum which corresponds to the concentration of 3% relative to the standard neodymium concentration in ceramic or crystalline YAG host materials.

Moreover, the collection efficiency of solar laser from unit area was about 34 W/m^2 at the maximum laser power from thin disc laser which is slightly higher than the recorded efficiency of about 32 W/m^2 achieved by present time. With the use of the same technique we have calculated the concentration dependence of output laser power for the Nd:Ce:YAG for the further increase the efficiency of the laser. It is known that the cerium ions are good sensitizers for the active ions of neodymium atoms in YAG host materials and the presence of cerium ions in the range of about 1% in ceramic Nd:YAG will not influence on its laser characteristic such as upper laser level lifetime. Therefore we assumed that the concentration dependence of above mentioned competitive processes for the Nd:Ce:YAG are the same as in Nd:YAG except for the additional absorption and sensitization due to the presence of cerium ions, concentration of which is assumed to be 1% in calculations. The results of simulation calculations are depicted in Fig. 6. As it is shown in the figure, the addition of cerium ions more than doubles the output power and the recorded efficiency

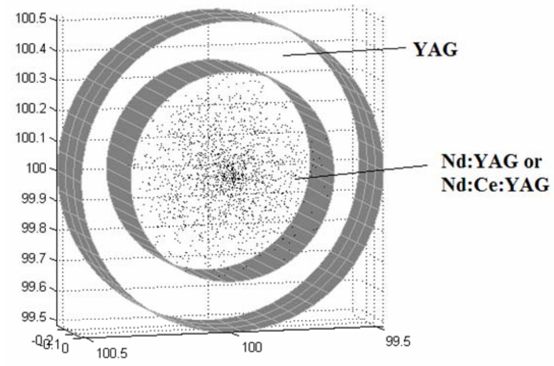

Figure 3. Core doped disc type active medium with distribution of absorbed photons

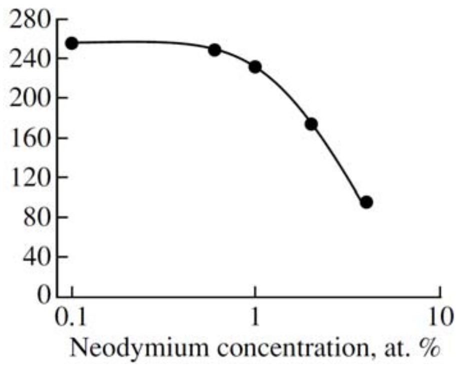

Figure 4. Dependence of upper laser level lifetime (in microseconds) on the neodymium concentration [4]

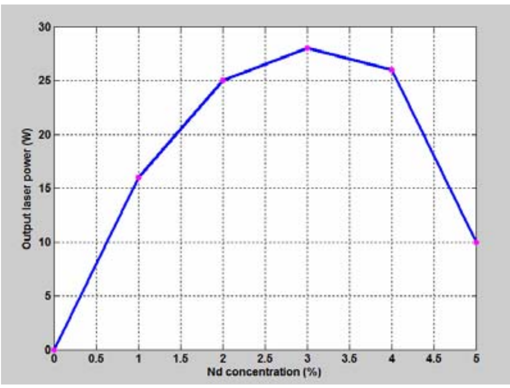

Figure 5. Dependence of output laser power on neodymium concentration for ceramic Nd:YAG disc laser

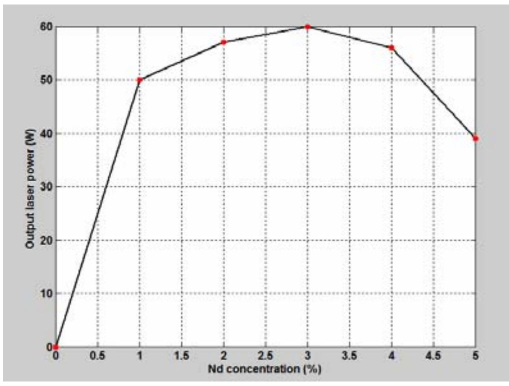

Figure 6. Dependence of output laser power on neodymium concentration for ceramic Nd:Ce:YAG disc laser

Conclusion. It was studied the dependence of solar pumped laser efficiency on neodymium concentration in ceramic YAG host material. It was shown that the use of high neodymium concentration in ceramic Nd:YAG laser provides the increase in efficiency of solar-to-laser power conversion. The use of ceramic Nd:Ce:YAG laser material with the increased neodymium concentration doubles the efficiency of ceramic Nd:YAG laser. Further progress in ceramic laser materials production technology can lead to improvement of optical quality by reducing the scattering loss. Reducing the scattering loss in ceramic laser materials is important factor for the further increase the solar-to-laser power conversion efficiency.

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