# Effect of color converters on the performance of solar or light-emitting diode pumped solid-state lasers

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Изучено влияние использования внешних преобразователей частоты на интенсивность люминесценция кристалла Nd:YAG. Кристалл освещался светодиодом с материалом $Y_3Al_5O_{12}:Ce^{3+}$ и без него в качестве внешнего преобразователя. Полученные экспериментальные результаты показывают, что интенсивность люминесценция Nd:YAG увеличивается в 1.5 раза при освещении кристалла Nd:YAG светодиодом вместе с преобразователем цвета на основе $Y_3Al_5O_{12}:Ce^{3+}$, что свидетельствует о том, что внешние преобразователи частоты могут быть потенциальным кандидатом для создания более эффективных лазеров с солнечной или светодиодной накачкой.

**Ключевые слова**: лазеры с солнечной накачкой, люминесценция, Nd:YAG, $Y_3Al_5O_{12}:Ce^{3+}$

The effect of using external frequency converters on the luminescence intensity of an Nd:YAG crystal is studied. The crystal is illuminated by light-emitting diode (LED) with and without $Y_3Al_5O_{12}:Ce^{3+}$ material as an external converter. Obtained experimental results show that the luminescence intensity of Nd:YAG crystal increased by 1.5 times when Nd:YAG crystal is illuminated by LED together with color converter based on $Y_3Al_5O_{12}:Ce^{3+}$ demonstrating that external frequency converters can be a potential candidate for creating more efficient solar or LED pumped lasers.

**Keywords:** solar pumped lasers, luminescence, Nd:YAG, $Y_3Al_5O_{12}:Ce^{3+}$

## I. Introduction

It is well known that lasers generate monochromatic and coherent optical beams. On the other hand, they just convert one form of energy into another. In most cases, lasers convert electrical energy into optical energy (photons). This includes several intermediate conversion processes. For example, consider the following scenario: to get a laser beam, first solar panels convert solar radiation into electrical energy, secondly, electrical energy is used to power a light emitting or laser diode, then the last step is the conversion from optical to optical. Using a diode, an active medium is excited and finally, a laser beam is generated. It is inevitable that this multi-step transformation process significantly reduces overall efficiency. One way forward is solar pumped lasers (SPLs) that are directly solar pumped lasers offer a solution to improve efficiency [1-4]. However, some issues need to be addressed to make SPL a real alternative. One of these issues is that the solar spectrum is very wide in comparison with the absorption spectrum of currently existing laser mediums [5]. For example,

Nd:YAG can theoretically absorb roughly 15% of solar radiation [6]. It can be inferred that an overall energy efficiency of solar pumped Nd:YAG laser cannot be higher than 15%. In fact, several experimental studies already showed that it is around 5% [7]. In the case of Nd:YAG crystal, most of the solar spectrum, about 90%, is wasted, and worse, this puts a thermal load [8] on the crystal. In turn, thermal load problems limit the maximum output power of the laser and lead to many technical difficulties in cooling the medium. As shown in a recent numerical study [9-11], using an external frequency converter can significantly improve energy efficiency and pave the way for efficient solar pumped lasers. This is because that the preliminary external and/or internal optical conversion is required to make use most of solar spectrum, that is, it is required to convert incident solar radiation into an absorbable spectrum for a certain crystal [12]. In this article, we will experimentally study the effect of the use of external frequency converters on the efficiency of a laser. For this purpose, we illuminated an Nd:YAG crystal using an LED with and without an external converter, wherein we quantitatively tested how an external converter can increase the intensity of the emission spectrum of Nd:YAG at lasing wavelength.

## II. Experimental setup

The experimental setup for studying the external converter consists of a blue LED with the corresponding power supply, an Nd:YAG crystal placed in an illuminating chamber, and a high-resolution optic spectrometer (Fig. 1).

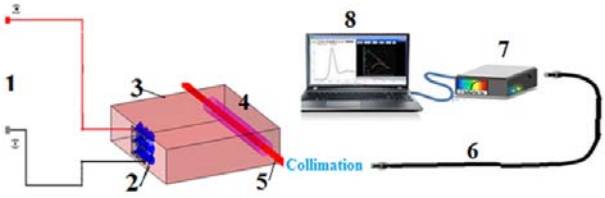



**Figure 1.** Experimental setup: 1 – DC power supply B5-49, 2 – LED, 3 – illuminating cavity, 4 – Nd:YAG crystal, 5 – luminescence, 6 – optical fiber, 7 – spectrometer, and 8 – personal computer.

A widely available blue LED chip has been chosen as an illuminating source (*2*). Nd:YAG rod (*4*) has been placed inside a rectangular cavity (*3*) which consist of highly reflective walls with reflectivity of around 90%. Its sizes are optimized with an intention of having the uniform illumination of the rod [13-14]. Length of Nd:YAG rod is 40 mm and its diameter is 5 mm with rough surface. Nd:YAG emission (*5*) is maximally collimated and directed to an optical fiber. The optical fiber is connected to a high-resolution spectrometer HR4000. The spectrometer is connected to PC, from where we can see spectra and analyze them.

## III. The converter: $Y_3Al_5O_{12}:Ce^{3+}$ yellow phosphorous medium

The color converters are becoming increasing popular in the white light emitting diodes. Extensive studies are being conducted to improve its conversion and resultant LED properties, such as luminescence efficiency, chromaticity, correlated color temperature and color gamut, as well as its stability [15]. Their fabrication related technical issues are investigated with the aim of increasing the emission intensity [16]. They also pave a way for high power, low cost, solid state lasers [17-21]. Similarly, in this paper, we are using $YAG:Ce^{3+}$ yellow phosphorous medium as the converter increasing the luminescence intensity of Nd:YAG rod with an intention of demonstrating versatility of converters in solar pumped solid state lasers. In Fig. 2, two types of illumination are shown: with and without converters. In the right side, LED chip without the converter and its emission spectrum are presented. In the left side, LED chip with the converter and its emission spectrum are presented.

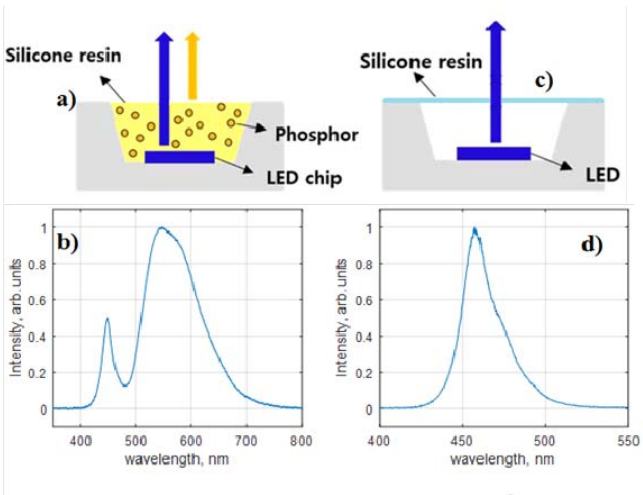



**Figure 2.** a) LED chip with the color converter and b) its emission spectrum; c) the blue LED chip without the color converter and d) its emission spectrum.

A detailed description of the converter is not the subject of this paper. However, it is worth noting that

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the converter used in this experiment is originally designed to achieve a white LED, which is a requirement in our daily life. It is intriguing to think that these converters can be tailored to produce an even more desirable emission spectrum that can find widespread use for pumping solid-state lasers.

## IV. Results and discussions

It is obvious that the overlap between excitation and absorption spectra determines how much is being absorbed in a particular medium. If we examine the overlap between the blue LED emission and Nd:YAG absorption, we can see that the emission spectrum covers 3 small peaks in the absorption spectrum (Fig. 3, left).

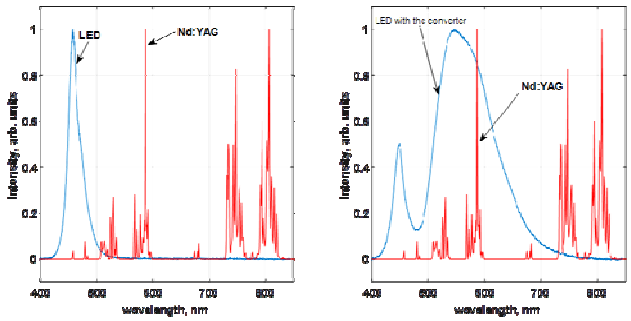



**Figure 3.** Comparisons between LED spectrum with Nd:YAG absorption spectrum.

Now looking into the overlap between the frequency converted (modified) LED emission and Nd:YAG absorption spectrum, we can see that the converted spectrum covers four small peaks and one strong peak around 587 nm (Fig. 3, right). The broad overlap leads to better absorption and consequently significantly increased Nd:YAG luminescence intensity. To experimentally verify that firstly we illuminated Nd:YAG rod with the blue LED and then the rod has been illuminated with the same blue LED but with external YAG:$Ce^{3+}$ phosphorus converter. Luminescence spectra for two cases are shown in Fig. 4.

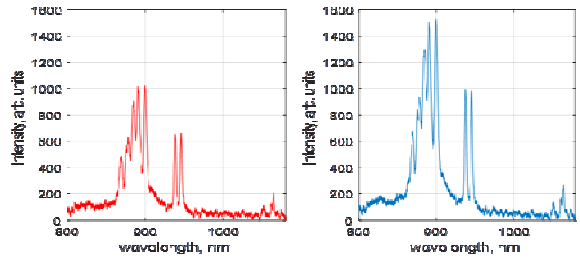



**Figure 4.** The emission spectrum of Nd:YAG rod with LED (left) and the color converted LED illumination (right).

Statistical analysis reveals that Nd:YAG luminescence intensity increased by 50%, which is 1.5 times an increase in intensity. From this experimental evidence, we can conclude that the use of color converters could potentially lead to more efficient solar or LED pumped lasers.

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## Ранг ўзгартиргичларининг қуёш ёки ёруғлик диодлари билан оптик дамланадиган қаттиқ жисмли лазер характеристикаларига таъсири

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Ташқи частота ўзгартиргичларидан фойдаланишнинг Nd:YAG кристаллининг люминесценция интенсивлигига таъсири ўрганилди. Кристалл ташқи ўзгартиргич вазифаси сифатида $Y_3Al_5O_{12}:Ce^{3+}$ материал билан ва ушбу материалсиз ёруғлик диоди ёрдамида ёритилди. Экспериментал натижалар Nd:YAG люминесценция интенсивлигининг 50% га яъни 1.5 баробарга ортганини кўрсатди, бу эса частота ўзгартиргичлари янада самаралироқ қуёш ёки ёруғлик диодлари ёрдамида оптик дамланадиган лазерлар яратиш учун янги имкониятлар пайдо бўлишини кўрсатади.

**Қалит сўзлар:** қуёш лазер, люминесценция, Nd:YAG, $Y_3Al_5O_{12}:Ce^{3+}$

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