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Diode-side-pumped, passively Q-switched Yb:LuAG laser

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ABSTRACT

A high-gain, diode-side-pumped Yb:LuAG slab laser was designed and investigated for use at room temperature. Pumping occurred from a fast-axis collimated 2D laser diode stack emitting at a wavelength of 970 nm, with 0.8 J over a duration of 0.8 ms. The pump scheme, which enabled efficient mode matching and high gain, was analysed and experimentally verified for different dopant levels. An energy of 100 mJ with 23% slope efficiency in a near fundamental mode was achieved in the free-running regime. A peak power of 2.5 MW and a pulse energy of 10.1 mJ were demonstrated in passive Q-switching by means of a Cr:YAG saturable absorber with 39% initial transmission. The study defined the indications for optimizing such a system.

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1. Introduction

Ytterbium-doped laser media have attracted much interest for the last two decades, because of their significant advantages (low quantum defects, long fluorescence lifetimes, negligible up-conversion losses, possibility of a high-doping level, etc.) in comparison to Nd laser media [1–16]. Their main deficiencies, resulting from a quasi-three-level scheme, can be overcome via cryogenic operation [4,5,8,10] or by applying special architectures such as thin disks [6,13,16], slabs [7–11] or fibers [12]. Excluding a few cases [9,10], the end-pumping scheme has dominated high-power Yb laser systems because of the specific requirements of quasi-III-level media and the relative simplicity and compactness of beam-shaping optics currently available for high-power laser diode stacks. Our particular aim in this work is to show the feasibility of the side-pumped scheme for Yb oscillators operating at room temperature. These have to deliver energies of several dozens of mJ in the Q-switching regime. It is well known that efficient, high-energy operation in the Q-switching mode requires high gain and results in high fluencies inside the cavity [17–21]. In the Q-switching regime, efficient extraction in the case of Yb oscillators (72% of energy in the free-running regime as demonstrated in [11]) is possible despite the limitation imposed by a quasi-III-level scheme. However, compared to Nd gain media, the saturation fluency in Yb-doped media is significantly larger (for instance, it is as high as 10 J/cm^2 for Yb:YAG); this poses a risk of damage to the laser elements inside the cavity. Therefore, we have chosen as a gain medium the relatively novel Yb:LuAG crystal [13–16], which has comparable thermo-optical and mechanical parameters as Yb:YAG but about 25% higher gain cross-section,$\sigma_{em}=2.5\times10^{-20}$ cm^2. We present an analysis that aims to decrease the gain in such a laser system concurrently with efficient energy extraction. Moreover, we focus here on exploring the potential offered by novel, fast-axis-collimated, low-duty-factor, 2D laser diode stacks with up to 200 W per 1 cm bar. For pump units consisting of 8 bars, power densities above 50 kW/cm^2 are feasible if used in an elongated rectangle format, as this seems to be better matched to the side-pumped slab than to end-pumping architecture. Section 2 describes the laser scheme, an analysis of the pump unit and gain distribution, and the results of the characterization with free running for different doping levels. We have shown that, with the proper choice of laser mode size and pumping channel shape, efficient generation with reduced internal laser power density is possible. The third section presents the analysis and experiments on passive Q-switching. In the final section we provide concluding results and formulate the directions for optimization of these types of oscillators.

2. Design and analysis of a laser oscillator

The analysed laser oscillator (see Fig. 1) consists of a slab-shaped gain medium, which was side-pumped by a 2D laser diode stack (DILAS C3Y-976.3-2400Q-V051.1). We examined three $3\times3\times13$ mm^3 Yb:LuAG media with 6 at%, 9.35 at% and 15 at% doping concentrations. The active medium was located inside a half-symmetrical cavity with a concave rear mirror ($r=150$ mm) and a flat output coupler. The output transmission T_{oc} was optimized to get the highest energy at the output. The parameters of applied Cr:YAG modulators are described in Section 3. In order to

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omit thermal effects pump duration was $t_{pump}=0.8$ ms and pulse repetition rate was $PRF=2$ Hz. The excited volume cross-section was 11.7×0.1 mm^2. The size of the gain channel can be controlled by the choice of cylindrical lens (HCL) and the effective absorption coefficient of the gain medium at the pump wavelength.

Assuming a quasi-stationary pumping condition (see details in [22]), a qualitative model for estimation of the inversion, gain profiles, internal fluency and stored energy was elaborated. A typical 2D image of a gain profile (cross-section of the side-pumped active medium) truncated to laser mode is shown in Fig. 2. The model was applied to analyse and optimise the pumping scheme in order to maximize the stored energy, assuming fundamental mode of the cavity. The exemplary results of the stored energy and gain for different mode radii (w_{mode}) inside a gain medium are presented in Figs. 3 and 4, relatively.

As shown in Fig. 3, the wider the fundamental mode, the higher the output energy can be obtained – in contrast, the higher the gain is obtained for the smaller mode area (Fig. 4). This is caused

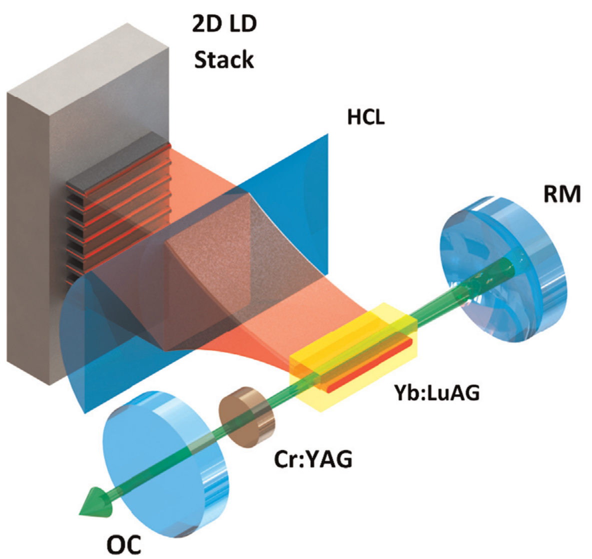

Fig. 1. Scheme of the laser oscillator: HCL – cylindrical lens, RM – concave rear mirror, OC – flat out-coupling mirror, Cr:YAG – passive Q-switch, Yb:LuAG – slab shape gain medium, and 2D LD Stack – 2D, fast-axis-collimated laser diode array.

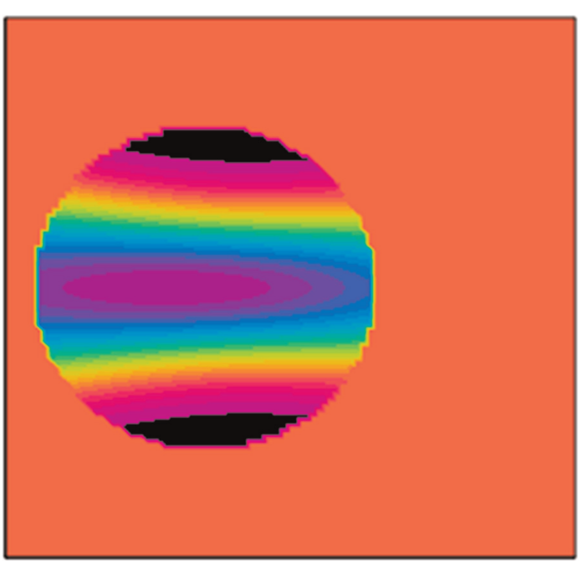

Fig. 2. 2D plot of gain distribution truncated to the fundamental mode area: radius – 0.25 mm, distance from the edge – 0.35 mm, pump power – 300 W, vertical width of pump – 0.25 mm, and frame size – 1×1 mm^2.

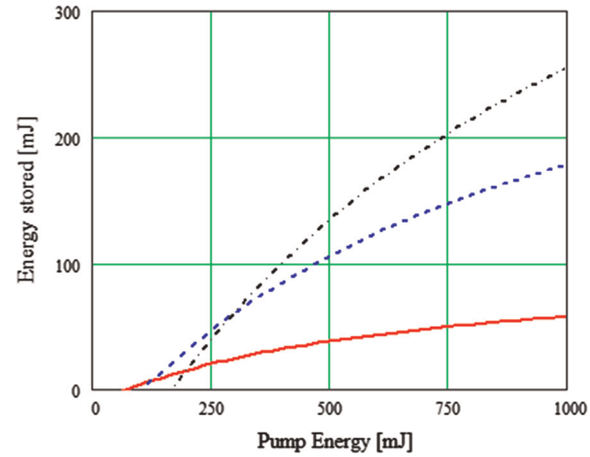

Fig. 3. Stored energy in the fundamental mode vs. pump energy: $w_{mode}=0.1$ mm – red continuous curve, $w_{mode}=0.2$ mm – blue dashed curve, $w_{mode}=0.3$ mm – black dashed-dot curve, pump width – 0.2 mm, and slab length – 12 mm. (For interpretation of the references to colour in this figure caption, the reader is referred to the web version of this paper.)

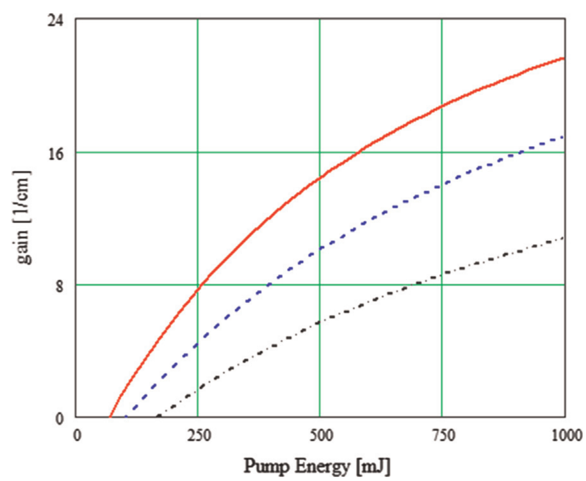

Fig. 4. Small signal gain coefficient vs. pump energy: $w_{mode}=0.1$ mm – red continuous curve, $w_{mode}=0.2$ mm – blue dashed curve, $w_{mode}=0.3$ mm - black dashed-dot curve, pump width – 0.2 mm, and slab length – 12 mm. (For interpretation of the references to colour in this figure caption, the reader is referred to the web version of this paper.)

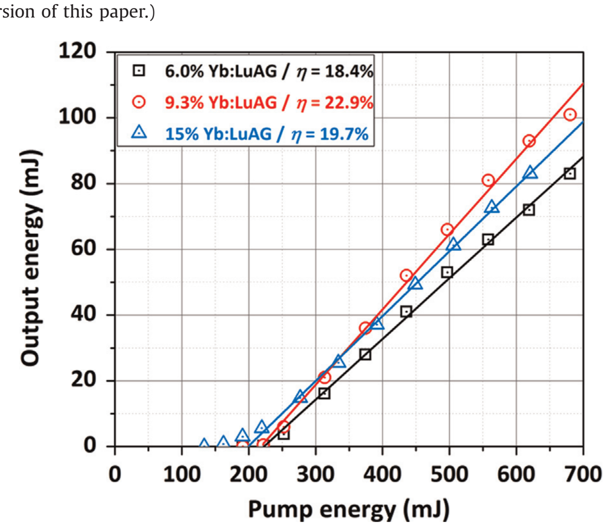

Fig. 5. Output energy vs. incident pump energy experiments: blue triangles – 15% Yb:LuAG, $T_{oc}=60\%$, $w_{mode}=0.202$ mm; red circles – 9.35% Yb:LuAG, $T_{oc}=10\%$, $w_{mode}=0.256$ mm; black squares – 6% Yb:LuAG, $T_{oc}=10\%$, $w_{mode}=0.324$ mm; pump width – 0.2 mm, and slab length – 12 mm. (For interpretation of the references to colour in this figure caption, the reader is referred to the web version of this paper.)

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