21.7 J in 7 ns at 10 Hz Operation of Diode-Pumped Zig-Zag Slab Laser with Thermally Wavefront Correction

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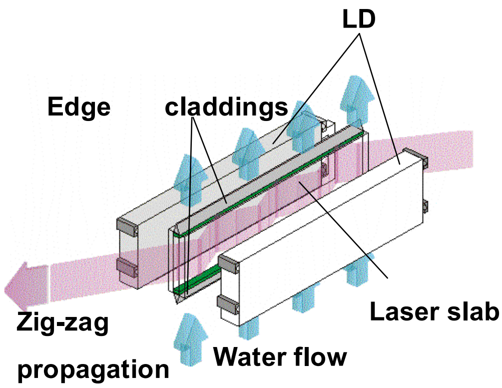
INTRODUCTION

In recent years there has been rapid progress in the development of high-intensity laser-driven applications, such as inertial fusion energy [1], metal surface peening [2], transmutation of nuclear waste [3] and radioisotope generation for positron emission tomography [4]. Diode-pumped solid-state laser (DPSSL) is one of leading candidates for these applications. The developments of several configurations of DPPSL have been proceed in the many laboratories[5], [6]. Zig-zag slab configurations excels at thermal management, because of its availability of higher cooling capability with larger aperture and averaging the thermo-optic effects in the direction perpendicular to total internal reflecting (TIR) surface by zig- zag optical path. Therefore it has a potential to scale up to the orders of giga-watt in peak power, kilo-watt in average power and good beam quality simultaneously [7]. In addition, a single or double slab amplifier head configuration results in the merits of compactness, stability and reliability of the system for industrial and medical applications.

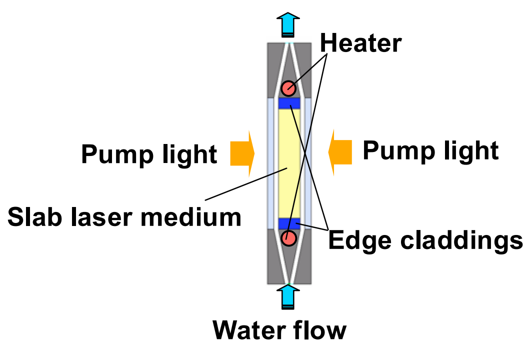
Our development plan including Nd:glass zig-zag slab amplifier scheme is based on the scaling law up to 100 J output energy[8]. In order to demonstrate the scalability of this concept, we have designed the new zig-zag slab laser system. The current goals of this system are (a) 20 J output energy in a 10 ns pulse, (b) 20 % optical to optical efficiency, (c) 200 W average power at 10 Hz and (d) five times diffraction-limited (TDL) beam quality. We decided the achievable beam fluence of 5-10 J/cm^2 as a criterion of the optical design, taking into account saturation fluence and extraction for the gain medium. Several architectural approaches including thermally managed slab amplifier, optical propagation and multi-pass extraction must be considered in mind for preventing parasitic and optical damages. In this paper we present the high average power operation of the diode-pumped zig-zag slab laser characterized by thermal management of laser wavefront distortion.

THERMALLY EDGE CONTROLLED SLAB (TECS) AMPLIFIER

Technical issues of high power DPSSL are optical damages, parasitic oscillation for high peak power operation. As for high average power operation, those are thermal wavefront distortion of laser amplifier, thermal birefringence in amplifier, Faraday rotator and Pockels cell. Particularly, zig-zag slab configuration excels at thermal management of solid-state amplifier, because of its availability of higher cooling capability with larger aperture and averaging the thermo-optic effects in the direction perpendicular to TIR surface by zig- zag optical path. Therefore it has a potential to obtain directly the orders of Tera-Watt in peak power, kilo-Watt in average power and diffraction-limited beam quality simultaneously. However, the averaging thermo-optic effects by zig-zag propagation geometry cannot affect parallel to the TIR surface. Thus thermal management of a slab with ASE absorbers to avoid stress fracture and optical degradation is the most exacting problem. To reduce this type of effects, we adopted the thermally-edge-controlled zig-zag slab laser amplifier (TECS) [9]. This configuration has the actively heated edge claddings on the top and bottom of the laser slab to flatten the temperature gradient as shown in Fig. 1.



(a)



(b)

Fig.1.(a)Schematic diagram of thermally-edge-controlled

zig-zag slab (TECS) laser amplifier. (b) Cross sectional view of TECS.

Edge claddings are bonded on the top and bottom of the laser slab to prevent parasitic oscillation. And the edge claddings are heated by additional heat sources. The dimension of Nd-doped phosphate laser glass (1.0 weight% Nd_2O_3:HAP-4, HOYA or 1.0 weight% Nd_2O_3:AGP-1, Schott) is 1 cm thick, and 37.5 cm long. The laser slab is pumped by the diode array modules, which have 8,000 diode bars and produce the peak power of 400 kW (80 J in a 200 μs pulse) in total.

Figure 2 shows the wavefront aberration suffered from single pass propagation of TECS in the direction parallel to the TIR surface by the Shack-Hartmann sensor (HASO 64, Imagine Optic).

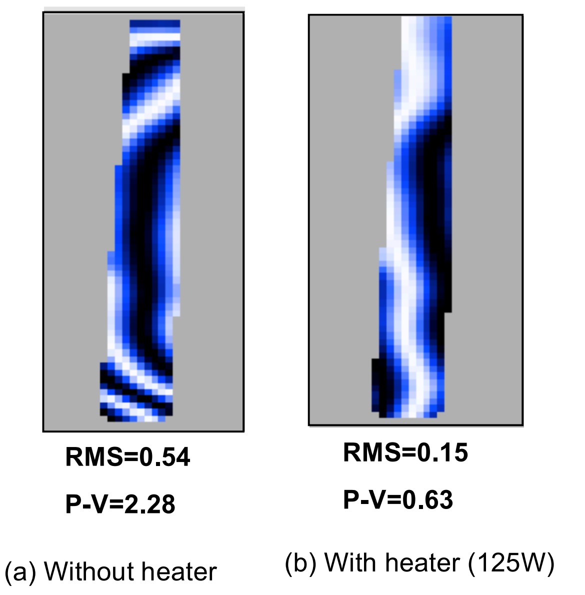


Fig.2. Cross sectional laser beam Interference patterns in the direction parallel to TIR surface as the result of zig-zag propagation through the slab medium. (a) 75 J pumping without heater. (b) With 125 W heating.

At 70 J (pumping duration : 150 μs) at 5Hz, wavefront aberration is 0.54 λ (RMS) and 2.28 λ (P-V). After optimization of heating power and pumping distribution, wavefront distortion was improved to 0.15 λ (RMS) and 0.61 λ (P-V). From these results, validity of TECS concept is confirmed.

LASER SYSTEM ARCITECTURE

For the diffraction-limited beam quality, Laser system is constructed by the master oscillator and power amplifier (MOPA) system. Front-end of the system is a combination of a single mode 1053-nm, diode-pumped Nd:YLF Q-switch oscillator and a diode-pumped Nd:YLF regenerative ring amplifier. The front-end yields a 1 J pulse energy in 12 ns (full width at half maximum, FWHM) at 10 Hz with a 8-mm diameter, of near flat-topped beam profile. The beam is optically expanded to the full aperture of a slab amplifier by the anamorphic telescope, and it is cut out by the rectangular serrated aperture of 0.8 cm wide x 4.8 cm high. A schematic diagram of the main multi-pass optical amplifier layout including two TECS amplifiers is shown in Fig. 3. The beam image at serrated aperture is relayed to the first slab amplifiers by use of the vacuum telescopes with a spatial filter (VSF), and subsequently it passes the slab1 four times in each of two symmetrical paths. After that, the output pulse is ejected from the first slab amplifier by a thin-film polarizer (28) and is guided to the boost amplifier (slab2). Finally amplified pulse is emitted from output mirror (43). This optical architecture needs no optical device such as a Pockels cell preventing parasitic oscillation. A double pass of the 45˚ Faraday rotator provides a passive 90˚ polarization rotation, and its cross-polarizing scheme compensates for thermally induced birefringence in the slabs.

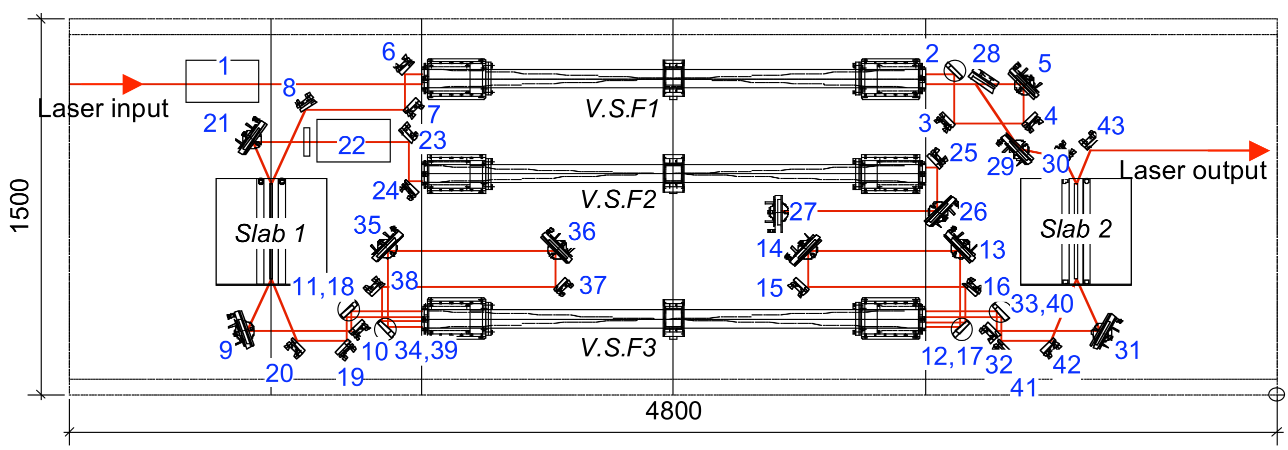


Fig. 3. A schematic diagram of the multi-pass optical amplifier layout. (1:Faraday isolator, 2-21:Mirror, 22:Faraday rotator, 23-27:Mirror, 28:Polarizer, 29-43:Mirror).

LASER SYSTEM PERFORMANCE

Figure 4 shows the extracted laser output energy from the laser system at 10 Hz repetition rate operation. The maximum output energy of 21.7 J in 7 ns (FWHM) pulse duration at 190.6 J pumping energy was obtained with o-o efficiency of 11.4 %, when the input pulse energy was 125 mJ. The far field pattern (FFP) is shown in the Fig. 5. The energy occupation was calculated as the total intensity in the encircled pixels to that of the entire pixels in the far-field image. 50 % of the entire energy is focused in a 5 times of the diffraction limit (TDL) spot. Therefore the intensity in this 5 TDL spot corresponds to 10^{14} W/cm2.

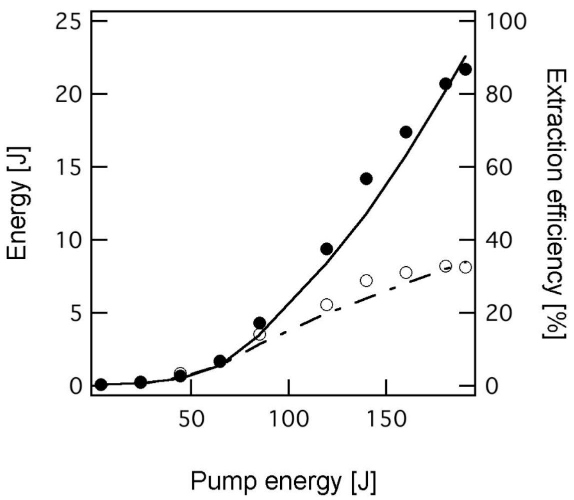


Fig. 4. Extraction energy from laser system of single amplifier configuration at 10 Hz. (Circle is experimental data with heating. Curve is computation data by used of modified Eggleston-Frantz model analysis.).

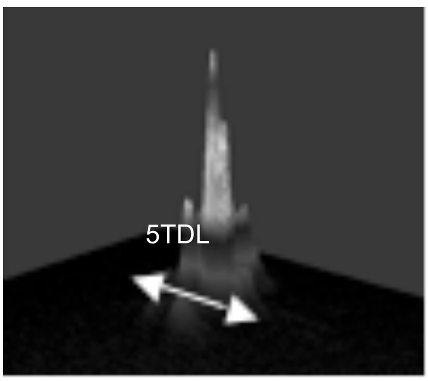


Fig. 5. FFP of laser output.

Figure 6 shows the near field beam image. The spatial profile of intensity in NFP is as uniform as 58% of filling factor, which was defined as the ratio of the average intensity in the encircled area to the peak intensity of the beam profile. Estimated beam fluence from output energy and NFP is 6.1 J/cm2.

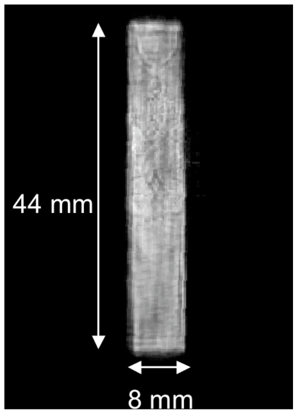


Fig. 6. NFP of laser output.

We have achieved the quarter 100 J level output energy with optical damege free operation by wavefront corrected technique by TECS and axisymmetric zig-zag slab scheme. Limitation of output beam quality of this system is thermal deformation of TIR surface that is indicated from thermal analysis based ray trace code. By additional wavefront corrected optics such as deformable mirror diffraction limited beam quality will be capable. In next stage we will demonstrate a 500 W average power (50 J at 10 Hz) operation with 1 MW laser diode power after modifying with wave front corrected optics.

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