Laser-Diode Pumped Nd:Glass Slab Laser for Inertial Fusion Energy

M. Yamanaka 1), T. Kanabe 1), H. Matsui 1), R. Kandasamy 1), Y. Tamaoki 1), T. Kuroda 1), T.Kurita 1), M. Nakatsuka 1), Y.Izawa 1), S. Nakai 1), T. Kawashima 2), Y. Okada 2), T. Kanzaki 2), H. Miyajima 2), M. Miyamoto 2), H. Kan 2)

1) Institute of Laser Engineering,Osaka University, Osaka, Japan
2) Hamamatsu Photonics K.K., Shizuoka, Japan

e-mail contact of main author : masanobu@ile.osaka-u.ac.jp

Abstract. As a first step of a driver development for the inertial fusion energy, we are developing a laser-diode-pumped zig-zag Nd: glass slab laser amplifier system HALNA 10 (High Average-power Laser for Nuclear-fusion Application) which can generate an output of 10 J per pulse at 1053 nm in 10 Hz operation. The water-cooled zig-zag Nd: glass slab is pumped from both sides by 803-nm AlGaAs laser-diode(LD) module; each LD module has an emitting area of 420 mm x 10 mm and two LD modules generated in total 218 (max.) kW peak power with 2.6 kW/cm^2 peak intensity at 10 Hz repetition rate. We have obtained in a preliminary experiment a 8.5 J output energy at 0.5 Hz with beam quality of 2 times diffraction limited far-field pattern, which nearly confirmed our conceptual design.

1. Introduction

A diode pumped solid-state laser (DPSSL) is a promising candidate of reactor driver [1-3] for Inertial Fusion Energy (IFE). The specifications required for IFE driver are 2-5 MJ in output pulse energy, 10-20 Hz in repetition rate, 500-200 nm in laser wavelength, and > 10 % in electrical efficiency. We have newly designed a DPSSL driver module [4] based on a water cooled Nd:glass zig-zag path slab amplifier HALNA 10k (High Average-power Laser for Nuclear-fusion Application), which can deliver 10 kJ output energy at 350 nm with 12 Hz repetition. The module consists of 15 beamlets and each beamlet is a double 4-pass amplifier system as it plays a role of both pre-amplifier (4-pass) and main amplifier (4-pass). A DPSSL IFE driver generating 4 MJ output will consist of 400 sets of 10-kJ modules.

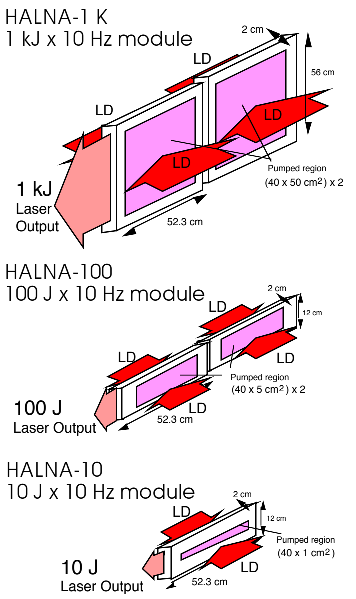
As a first step of a driver development, we are developing a small scale DPSSL amplifier module HALNA 10 which has a 10 J x10 Hz laser output at 1053 nm (Fig.1). The module composed of a water-cooled zig-zag path Nd: glass slab amplifier has a small but enough size to investigate the key issues and to confirm our conceptual design. That is, the pump laser-diode (LD) intensity (2.5 kW/cm^2), the thickness (2 cm) and length (52.3 cm) of Nd:glass slab are kept same as those of the 10 kJ driver module, as shown in Fig.1.

2. Experimental

We constructed a 200-kW LD pumped 10 J x 10 Hz 1053-nm Nd:glass (HAP-4,HOYA) zig-zag slab laser driver module HALNA 10 [5] (Fig.2). For the laser gain medium, we have adopted the glass host which can be produced in large sizes with good optical quality. The Nd:glass slab is cooled on both sides with flowing water having higher cooling capability than He-gas cooling. The water-cooled Nd:glass slab thickness and the stored energy density were chosen to be same values as those of the 10 kJ driver module. The 803-nm AlGaAs laser diodes (Hamamatsu Photonics) [6] to pump the Nd:glass slab amplifier have been successfully constructed, which generate in total over 200kW peak power with 2.6 kW/cm^2 peak power intensity at duty cycle 0.2 % (10 Hz) (Fig.3). The 1053-nm small signal gain of main amplifier was measured to be 15.9 per pass with 0.35-ms LD pumping, which is large enough to obtain the output over 10 J. The stored energy (21J) and pumping efficiency (34 %) of main amplifier at 1053 nm showing the design points are nearly attained.

3. Experimental Results and Discussion

The 8.5 J x 0.5 Hz 1053-nm output energy was obtained in a preliminary experiment(Fig.4). The extraction efficiency was 41 % in this case. The optical to optical conversion efficiency



Module output	Slab number	Thick -ness	Width	Length	Gain	Beam size	Fluence	Opt.-opt. efficiency	Technical issue
10 kJ	1 kJ x 10, 10 kJ x 400 = 4 MJ	2 cm	50 cm	40 cm x 2	33	50 x 2.5 cm^2 x 10	8 J/cm^2	28 %	Coherent coupling
1 kJ	2	2 cm	50 cm	40 cm x 2	33	50 x 2.5 cm^2	8 J/cm^2	28 %	Parasitic osc. (50 x 40 cm^2)
100 J	2	2 cm	5 cm	40 cm x 2	33	5 x 2.5 cm^2	8 J/cm^2	28 %	Large area distortion Higher gain Higher extraction
10 J	1	2 cm	1 cm	40 cm	12	1 x 2.5 cm^2	4 J/cm^2	20 %	LD intensity 2.5 kW cm^2 pump eff. >40 % E_{stored} 0.2 J/cc Rep. rate 10 Hz x1/3 fracture limit

FIG.1. Scale-down modules of laser-diode pumped Nd:glass slab driver to confirm the conceptual design. Here, the pump LD intensity (2.5 kW/cm^2), the thickness (2 cm) and length (52.3 cm) of Nd:glass slab are kept same as those of the 10 kJ driver module.

FIG.2. Photograph of laser-diode pumped 10 J x 10 Hz, Nd: glass slab laser module, HALNA 10.

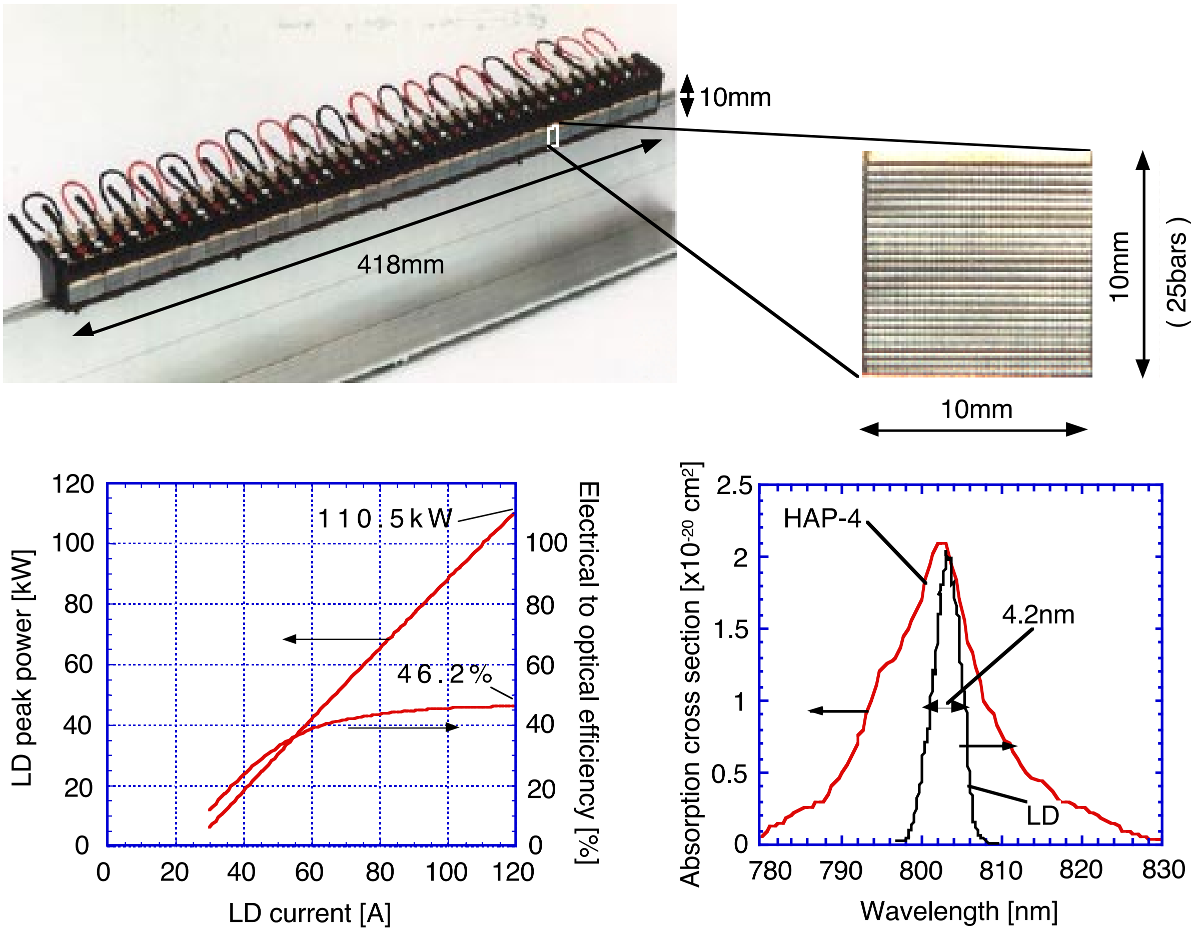


FIG.3. Photograph of quasi-CW 110 kW AlGaAs laser diode module (top), measured total peak power and electrical to optical efficiency (bottom left), and comparison between measured lasing wavelength of module and absorption line of HAP-4 Nd: glass (bottom right).

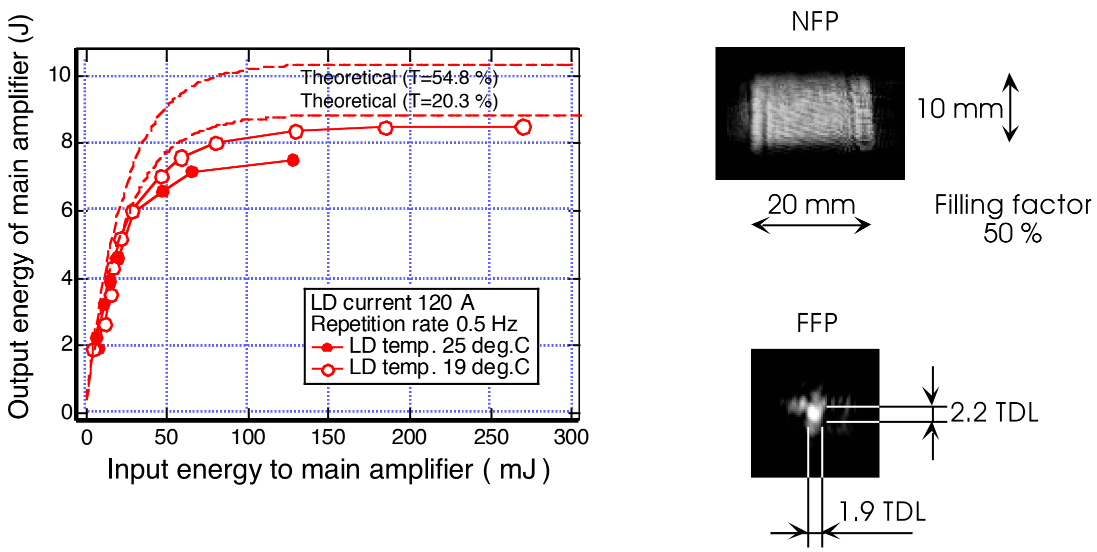


FIG.4. 1053-nm output energy at 0.5 Hz versus input energy (left), and near field(NFP) and far-field (FFP) patterns at 8.5-J output energy at 0.5 Hz (right).

was 11 %. The output pulse width was measured to be 20 ns (FWHM). The near-field pattern of 20 mm x 10 mm with a filling factor of 50 % and two times diffraction limited far-field pattern were observed. With increasing the system transmission to 55 % in the multi-path amplification, the 10 J x 10 Hz output at 1053 nm can be realized by compensating for simultaneously the thermal lens, thermal birefringence, and thermal aberration.

The resistivity of Nd:glass surface against flowing water versus time was evaluated by measuring the scattering loss at 632.8 nm. After over one year, the scattering loss was as low as 1.3 % through 14 bounce path with HAP-4 Nd: glass, verified using the scattering loss measurement.

Designed and obtained performances of the laser-diode pumped 10 J x 10 Hz Nd: glass slab laser module, HALNA 10 are summarized in TAB.I. The performances, except the output,

TAB. I: DESIGNED AND OBTAINED PERFORMANCES OF THE LASER-DIODE PUMPED 10 J x 10 Hz Nd: GLASS SLAB LASER MODULE, HALNA 10.

Item	Design	Obtained results
Small signal gain	12 (0.25 ms pumping) 21 (0.35 ms pumping)	15.9 (0.35 ms pumping)
Output	10 J x 10 Hz	8.5 J x 0.5 Hz
Pulse width	10 ns	20 ns
Beam quality	5 TDL (10 Hz)	2 TDL (0.5 Hz)
η_{pump}	41 % (0.25 ms) 37 % (0.35 ms)	34 % (0.35 ms)
$\eta_{extraction}$	60 % (0.25 ms) 48 % (0.35 ms)	41 % (0.35 ms)
$\eta_{o\text{-}o}$	18 % (0.25 ms) 13 % (0.35 ms)	11 % (0.35 ms)
Temperature rise	69 °C (Fracture limit x 1/3)	68±5 °C
Thermal lensing	Compensatable	Yet to be compensatable using telescope ($f_{th.v}$= 26 cm at 10 Hz)
Thermal birefringence	Compensatable	Yet to be compensatable using 45° FR

extraction efficiency and optical to optical conversion efficiency, nearly confirmed our conceptual design. We have a confidence that a next 100 J x 10 Hz DPSSL module HALNA 100 (Fig.1) can be constructed using 2-MW LD pumping, where the vertical thermal lensing, observed strongly (26 cm focal length) with the 10 J x 10 Hz module, will become smaller (25-m focal length) due to increased LD pump width from present 1 cm to 5 cm.

4. Conclusion

We have constructed a small-scale test-version of 10 J x 10 Hz DPSSL (HALNA 10) for the research on IFE driver module. As the IFE DPSSL driver module, the key issues regarding small signal gain (15.9), pulse width (20 ns), beam quality (2 TDL), pumping efficiency (34 %), temperature rise (68˚C) were satisfactory. However, output energy, repetition frequency, extraction efficiency, optical-to-optical efficiency will be improved by increasing system transmission from 20% to 55% and by simultaneousy compensating for the thermal lens, thermal birefringence and thermal aberration. We have a confidence that a next 100 J x 10 Hz DPSSL module (HALNA 100) can be constructed.

References

[1] Krupke,W.F. , "Solid state laser driver for an ICF reactor", Fusion Technol. **15** (1989) 377.

[2] Naito,K., et al.,"Conceptual design studies of a laser diode pumped solid state laser system for the laser fusion reactor driver", Jpn. J. Appl. Phys. **31** (1992) 259.

[3] Orth,C.D., et al.,"A diode pumped solid laser driver for inertial fusion energy", Nuclear Fusion **44** (1996) 75.

[4] Matsui,H.,et al., "Conceptual design of a laser-diode-pumped Nd: glass slab laser driver for inertial fusion energy", Fusion Engineering and Design **44** (1999) 401.

[5] Yamanaka,M.,et al., "Laser-diode pumped 10J x 10Hz Nd: glass slab laser for inertial fusion energy", Inertial Fusion Sciences and Applications 99, Editors: Labaune, C., Hogan, W.J., Tanaka, K.A., Elsevier, Paris (2000) 644-649.

[6] Kawashima, T., et al., "Development of 100 kW laser diode module for 10 J x 10 Hz Nd: glass slab laser", Proc.SPIE **3889** (2000) 596.