

Status of HiLASE project: High average power pulsed DPSSL systems for research and industry

T. Mocek¹, M. Divoky¹, M. Smrz¹, M. Sawicka¹, M. Chyla¹, P. Sikocinski¹,
H. Vohnikova¹, P. Severova¹, A. Lucianetti¹, J. Novak² and B. Rus²

¹ *HiLASE Project, Institute of Physics ASCR, Prague, Czech Republic*

² *ELI Beamlines Project, Institute of Physics ASCR, Prague, Czech Republic*

Abstract. We introduce the Czech national R&D project HiLASE which focuses on strategic development of advanced high-repetition rate, diode pumped solid state laser (DPSSL) systems that may find use in research, high-tech industry and in the future European large-scale facilities such as HiPER and ELI. Within HiLASE we explore two major concepts: thin-disk and cryogenically cooled multislabs amplifiers capable of delivering average output powers above 1 kW level in picosecond-to-nanosecond pulsed regime. In particular, we have started a programme of technology development to demonstrate the scalability of multislabs concept up to the kJ level at repetition rate of 1–10 Hz.

1. INTRODUCTION

Diode pumping of solid state laser materials in general improves the stability and efficiency of solid state lasers in comparison to flash-lamp pumped laser sources. The main reason for this improvement is the fact that the rather small bandwidth emission of highly efficient semiconductor laser diodes can be perfectly matched to the absorption band of solid state laser materials. The laser is therefore pumped only with the “necessary” radiation. The laser materials under consideration for HiLASE show furthermore a small Stokes-shift between the absorption and lasing transitions. The two mentioned facts lead to a much smaller heat deposition in the active laser material in DPSSL in comparison to conventional flash-lamp pumping of active materials. The reduced heat deposition, stability and maturity of laser diodes as well as their over the years reduced prices allow nowadays to consider to work on the development of solid state pulsed laser sources entering and exceeding average power ranges in the order of 1–10 kW.

The main goal of HiLASE project (High average power pulsed LASERS) is to create a national platform for development of advanced laser technologies and support the implementation of ELI Beamlines project [1]. In general, those lasers will be significantly more powerful and efficient, compact, more stable and easily maintained than the currently available flash-lamp based systems. Two key concepts for DPSSL are being explored within HiLASE: thin-disk laser amplifiers to reach kW average output power, and multislabs cryogenically cooled laser amplifiers to reach 100 J / 10 Hz output scalable to kJ regime. Laser systems with these technical parameters are not yet commercially available and successful demonstration of scalability can make DPSSL the technology of choice for future commercial inertial fusion laser driver [2].

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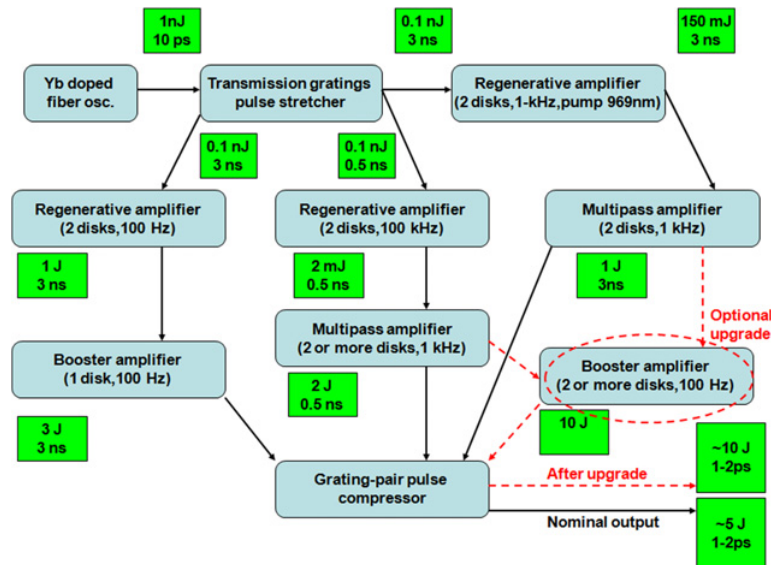


Figure 1. Schematic of the thin-disk DPSSL system for HiLASE.

2. MULTI-J, KW-CLASS THIN-DISK DPSSL SYSTEM

Generation of laser pulses in the ps regime with high average power and high repetition rate has been enabled by the use of DPSSL technology based on using Yb doped active medium in the shape of a thin-disk and operating at room temperature. Usual thickness of the gain medium in these laser heads reaches several hundreds of microns. Quasi-three-level active medium like Yb:YAG has very low energy difference between pump and laser photons, i.e., the portion of stored energy converted into heat is very low and laser efficiency high. In addition, upper laser level lifetime ~ 1 ms enables storing of vast amount of energy in Yb ions and is suitable for laser diodes pumping. Recently, energies of tens of mJ with multi-kHz repetition rate have been achieved using this technology and amplifiers which boost these values to multi-100 mJ level are now under construction.

Using the thin-disk technology we aim at generation of few ps laser pulses at repetition rate of 1–3 kHz with a total average power level exceeding 1 kW. The complex investigation of limits for maximum achievable output power includes the disk size scaling, cooling, doping and technical issues concerning the disk mounting. Figure 1 shows a global concept of the multi-J, kW-class thin-disk laser system designed for HiLASE. The starting component of the chain is an oscillator, which generates seed pulses for further amplification. We propose using a fiber oscillator because of high quality of its output beam. The oscillator stage of the chain may contain a fiber preamplifier which boosts energy of the output seed pulse from nJ to μ J energy level. Because of the gain narrowing in the following amplification stages, the oscillator should generate pulses only several hundreds fs. The chain of thin-disk laser amplifiers will be pumped by semiconductor laser diodes and favorable material of the thin-disk gain medium is Yb:YAG. Required output pulse energy from multipass amplifiers is on the level of 1 J at repetition rate of 1 kHz. Laser pulse duration will be 1–5 ps at the central wavelength of 1030 nm. The second area of our interest is the development of DPSSL amplifier providing pulses with an energy of a few J at a repetition rate of about 100 Hz. The setup ought to be expandable to higher pulse energies uses a regenerative amplifier with a large aperture architecture (LARA – Large Aperture Regenerative Amplifier) employing thin disks.

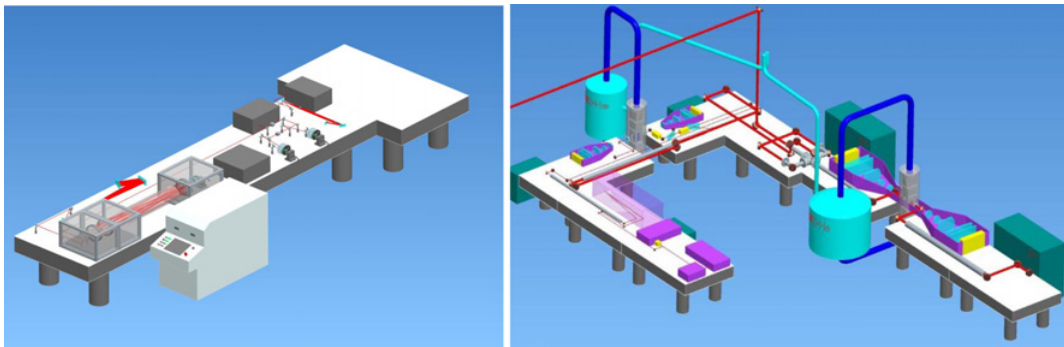


Figure 2. Visualization of the 100 mJ @ 1 kHz thin-disk regenerative amplifier (left), and 100 J @ 10 Hz cryogenically cooled multislab amplifier (right).

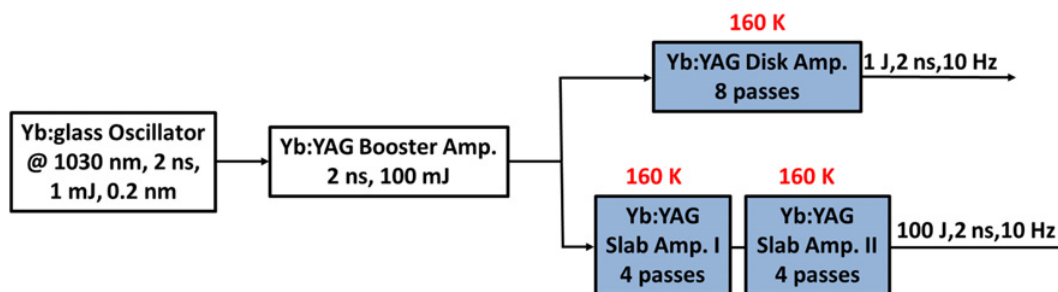


Figure 3. Schematic of the 100 J / 10 Hz cryogenically cooled multislab DPSSL system.

3. DEVELOPMENT OF 100 J / 10 HZ CRYO-COOLED MULTISLAB DPSSL

Currently, several high-energy-class DPSSL are being constructed worldwide with energetic goals of 100 J or higher [3–5]. The HiLASE facility will be also a 100 J-class DPSSL with the aim of developing innovative schemes for overcoming current technological barriers for scaling up to kJ level, which is required for future inertial fusion driver.

Figure 3 shows a concept of the 100 J multislab laser for HiLASE. The seed pulse is provided by a diode-pumped cavity-dumped Yb:glass laser oscillator generating narrow linewidth ~ 0.2 nm at 1030 nm. The temporal pulse shape is fixed with duration of 2 ns and the system is optimised to deliver ~ 1 mJ pulses at a repetition rate of 10 Hz. The oscillator output is then amplified in a separate diode-pumped multi-pass Yb:YAG booster amplifier using an active mirror configuration. The expected output from booster is over 100 mJ at repetition rates up to 10 Hz. The oscillator beam is coupled into the booster amplifier through a polarizer and the relay-imaging multi-pass is configured for either 6 or 8 passes. The designed laser system (Fig. 2, right) finally involves two beamlines with 1 J and 100 J output energy at 10 Hz, respectively.

The amplifier design we have chosen is based in a gas-cooled multi-slab concept. Cold He gas is forced through the gaps between the slabs for cooling and the amplifier is face-pumped from both sides. The Yb-doping level in the slabs is increased from 0.34 at. % to 1.34 at. % towards the center of the amplifier to ensure a uniform heat load in each slab. The input energy from the booster amplifier is 100 mJ.

The baseline amplifier design consists of 8 slabs with four different doping levels. The doping levels have been calculated to ensure that the product of the small signal gain coefficient and the diagonal transverse dimension of the square slabs is always less than or equal to 3. Our simulations show



Figure 4. Visualization of the HiLASE center to be constructed in Dolní Břežany, Central Bohemia.

that after 64 amplifying stages, the maximum extracted energy is 110 J, the maximum laser fluence is 5.3 J/cm^2 , and the $g_0 \cdot L$ product is less than 2.5 in all amplifying stages. We used the following values of cross sections at 180 K, laser emission at 1030 nm: $5.7 \times 10^{-20} \text{ cm}^2$, pump absorption at 940 nm: $1.3 \times 10^{-20} \text{ cm}^2$, laser absorption at 1030 nm: $5.8 \times 10^{-22} \text{ cm}^2$, pump emission at 940 nm: $9.75 \times 10^{-22} \text{ cm}^2$. Assuming a He mass flow inlet of 0.02 Kg/s, pressure of 5.10^5 Pa and inlet He temperature of 150 K, the expected maximum temperature reached in the clad material is 159.3 K, and the maximum temperature gradient in the active material will be as low as 1.6 K. Our preliminary results suggest that a cryogenic He gas cooling approach should be able to provide sufficient cooling capacity whilst introducing minimal optical distortions for the operation of a 100 J-class amplifier.

4. NEW LASER APPLICATIONS AT THE HILASE CENTRE

One of the long-term objectives of HiLASE is the identification of new and promising industrial applications and technologies using DPSSLs that are now being prototyped and developed. Once commissioned in the HiLASE center these advanced DPSSLs will enable e.g. research relevant to testing of new dielectric optical components with high-damage threshold, prototyping new pump lasers for OPCPA systems, driving high-yield secondary photon sources, and industrial applications related to efficient processing of materials (ablative removal of thin layers, cutting of optically transparent materials, laser peening).

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