HiLASE: a scalable option for Laser Inertial Fusion Energy

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Abstract. The goal of the HiLASE project is to design and optimize parameters for 100 J/10 Hz Yb:YAG laser amplifiers that are scalable to the kJ regime. The HiLASE power amplifier design is based on a cryogenic, gas-cooled multi-slab concept. Simulation results of the 10 J pre-amplifier agree very well with experimental measurements. In order to fulfil the very demanding requirements, which include wall-plug efficiency > 12% and repetition rates up to 10 Hz, HiLASE and RAL teams are closely working together and developing the approach described here.

1. Introduction

The energy challenge is one of the most urgent – and difficult – tests facing our society today. High energy DPSSL programs like HiPER (High Power laser Energy Research) [1] in Europe, LIFE (Laser Inertial Fusion Engine) [2] in the United States of America and HALNA (High Average-power Laser for Nuclear Fusion Application) [3] in Japan are scientific programs dedicated to demonstrate the feasibility of laser driven fusion as a future energy source. Such laser drivers should be able to deliver 1 to 10 kJ at a repetition rate about 10 Hz and a wall-plug efficient of more than 10 %.

A high repetition rate, single-beam, diode-pumped 100 J class laser system is now under development at the Central Laser Facility (CLF) in collaboration with the Institute of Physics (IoP), Prague. This high energy pulsed laser amplification system for the HiLASE project (High average power pulsed LASers) is based on a gas-cooled cryogenic, diode-pumped Yb:YAG multi-slab architecture [4]. The pre-amplifier and the power amplifier consist of two stacks of quadratic ceramic Yb:YAG slabs. Cold helium gas flowing at initial temperature of about 170 K is forced through the gaps between the slabs for cooling. The amplifiers are end or face-pumped from both sides. Employing slabs with increasing doping level towards the centre of the amplifier reduces the required overall thickness for a given maximum gain coefficient and also equalises the heat load for all slabs [5,6].
2. Optical layout of the HiLASE laser system and preliminary experimental results

The HiLASE multi-slab laser system consists of temporally-shaped fiber front end, regenerative amplifier, 10 J/10 Hz cryogenically-cooled pre-amplifier and 100 J/10 Hz cryogenically-cooled power amplifier. Model predictions developed at HiLASE [5] indicated maximum output energy of 10 J at pump energy of 48 J. This is in very good agreement with the experimental results recently obtained at CLF, as shown in Figure 1.

![Figure 1](image1.png)

**Figure 1.** Output pulse energy as function of pump energy at 10 Hz repetition rate.

An isometric view of the 10 J pre-amplifier and 100 J power amplifier systems is shown in Figure 2.

![Figure 2](image2.png)

**Figure 2.** Isometric view of 10 J and 100 J/10 Hz HiLASE laser systems.

The details for a cryogenic gas-cooled 100 J/10 Hz laser are summarized in Table 1.
Table 1. Output parameters for 100 J / 10 Hz HiLASE laser.

| Parameter               | Specification         |
|-------------------------|-----------------------|
| Pulse energy            | > 100 J               |
| Average output power    | > 1 kW                |
| Pulse length (FWHM)     | 2-10 ns               |
| Pulse shape             | Programmable (150 ps steps) |
| Repetition rate         | 1-10 Hz               |
| Output beam size        | 51 mm x 51 mm         |
| RMS modulation          | < 1 %                 |
| Wavefront quality       | lambda/10             |
| E-o efficiency          | > 12 %                |

The baseline power amplifier design consists of 6 slabs with three different doping levels. In order to ensure that the impact of ASE loss in the amplifier is kept to a minimum, the doping levels have been calculated to ensure that the product of the small signal gain coefficient ($g_0$) and the diagonal transverse dimension of the square slabs (D) remains below 3.0 at all positions through the stack of gain slabs.

3. Thermal analysis of HiLASE slab amplifiers

We have undertaken extensive energetics, thermal and fluid-mechanical modelling in order to optimize the parameters of various amplifier configurations. Figures 3 and 4 show the calculated gas flow into the amplifier head and the predicted temperature distribution in the 100 J-class amplifier slab, respectively. The inlet flow velocity is 10 m/s and maximum of 33 m/s is achieved as the gas flows through the amplifier.

Figure 3. Calculated gas flow into the amplifier head.
The variation of temperature across the pumped area is less than 1.5 Kelvin. The asymmetric temperature profile in the gain medium is due to the fact that the majority of the absorbed pump power is deposited as heat in the cladding and, in addition, the heat exchange coefficient decreases along the helium flow direction.

4. Summary

A conceptual design for a fully diode pumped, 100J-class DPSSL amplifier system capable of efficient generation of nanosecond pulses at 10 Hz repetition rate has been developed. Preliminary experimental results on the 10 J pre-amplifier agree very well with model predictions. This offers the potential for high electrical-to-optical efficiency of more than 12 %, which should enable the target overall efficiency necessary for cost-effective IFE production to be achieved.

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