Deliverable 5.1: Design of the multipass amplifier

Dissemination Level: Public (PO)

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Context

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Work Package: WP5

Task: 5.1 design of the thin-disk multipass Amplifier

Document Status

Version: 0.1

Last modified: 12.07.2016

Status: Final

Approved by: Marwan Abdou Ahmed

Date Approved: 28/07/2016

Declaration: Any work or result described therein is genuinely a result of the Hiperdias project. Any other source will be properly referenced where and when relevant

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1 Version History

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0.1				
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0.7				
0.8				
0.9				
1.0				
1.1.				

2 Introduction

This document should provide an overview about the design of the thin-disk multipass amplifier. Here, the goal is to design a multipass amplifier being able to amplify the pulses of the 50 W laser described in WP 3 to 500 W in a first step. In a second step, the upgraded 200 W laser shall be amplified to 1 kW of output power using the same amplifier. The design of the thin-disk multipass amplifier which was elaborated in this Work Package will be useable in both experiments.

3 Design results

3.1 Amplification considerations

The basic design of the amplifier is based on the concept of using a mirror array opposing a thin-disk crystal. This concept was developed at IFSW for high energy ns pulses with a pulse on demand operation and lower output power [1]. Later, this concept was extended to reach kW level output power at picosecond pulse duration [2,3]. Therefore, it is also expected to be very suitable for the desired amplification of fs pulses to the kW output power level and was chosen as the basic concept for the multipass amplifier in Hiperdias.

With a desired amplification factor of 10, it was decided to use 80 mirrors mounted in the array. This will lead to 40 reflections on the disk using a single multipass through the amplifier. Deriving from our theoretical investigations and previous experiments a single multipass is expected to be sufficient to reach the desired output power and amplification factor. A single multipass would be very advantageous for later pulse picking applications. However, the concept allows using a double multipass through the amplifier which would result in 80 reflections on the disk. Therefore, the risk of not reaching the goal is mitigated with this concept.

The choice of the number of mirrors determines the dimension of the multipass amplifier. The estimated size is currently 1.5 m x 0.6 m x 0.4 m (LxWxH) while investigations will be performed to reduce this size. Taking the seed source, the stretcher and compressor, the modulator and the multipass amplifier into account the total size of the complete laser system is estimated to be about 2.2 m x 1.2 m x 0.4 m.

The available pump power in the project will be 2 kW which determines the minimum pump spot diameter and therefore the diameter of the laser beam (about 4 mm). Furthermore, the Yb:YAG thin-disk crystal will be pumped on the zero-phonon-line at a wavelength of 969 nm which significantly reduces heat load on the disk during high power pumping. Therefore, the influence of thermal lensing or thermally induced air wedges in front of the disk will be smaller than with conventional pumping at 940 nm wavelength.

Another important aspect for gain considerations and thermal handling is the thickness of the disk. With higher disk thickness higher gain per reflection on the disk is possible while the thermal load will grow and therefore beam quality will degrade. Therefore, the thickness needs to be optimized and we prepared and will explore different disk thicknesses to reach the project goals while maintaining a close-to-diffraction limited beam quality. Furthermore, to increase pump absorption we will explore the use of a 24 or 48-pump pass thin-disk pump cavity that has been developed.

3.2 Optical design

The available pump power of 2 kW determines a minimum pump spot diameter on the disk of about 5.2 mm. This leads to the choice of the seed beam diameter at the entrance of the multipass amplifier of 4 mm. For the propagation scheme we decided for a quasi-collimated approach [2,3] which has the advantage of rather large beam diameters during the propagation inside the amplifier (see Fig. 1). This will reduce nonlinearities caused by high intensities and prevent damages to the optical surfaces. This will also enable us to explore the limits of this approach if no CPA technique is applied.

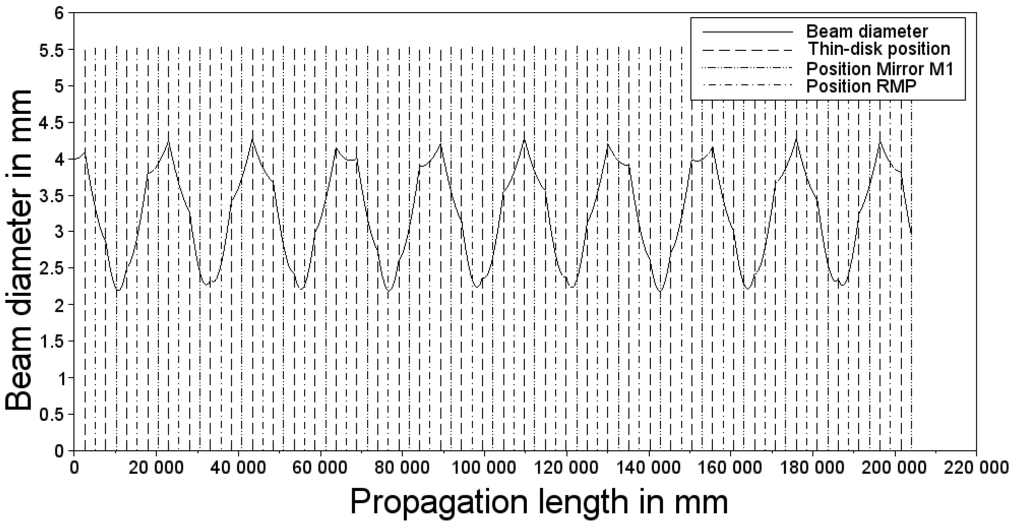

Fig. 1: Beam diameter vs. propagation length inside the amplifier for a single multipass through the amplifier (40 reflections on the disk).

In case this propagation scheme will not be sufficient to meet the project goals, the basic chosen concept of the amplifier will allow us to change the propagation scheme with the adaption of just a few mirrors. Therefore, risks are again mitigated here.

3.3 Mechanical design

Former experiments on multipass amplifiers proved that the thermal stability of the mechanical components is crucial for long-term operation of the system. During high power operations these components warm up and expand slightly. With the long propagation distances inside the multipass amplifier this angular derivation leads to a movement of the beam. These influences reduce output power as well as beam quality and beam pointing stability over a time interval of several minutes.

To overcome this problem all mechanical components were designed thoroughly to minimize thermal deviations. This includes all mirror holders, especially on the mirror array which were designed now to show improved thermal and long-term stability. Furthermore, the breadboard on which the setup is based was designed to be manufactured out of a single cast aluminum block. This breadboard will be temperature controlled using water chillers. All parts of the later laser system (seed source, stretcher, compressor, beam modulation and multipass amplifier) will be placed on this breadboard to increase the stability of the system.

Any movement of the air inside the amplifier will also influence beam pointing. Therefore, external air flows will be shielded by an air tight and dust free housing. This housing will also be integrated into the laser safety concept which is an important aspect to be considered at kW-level output power. Additionally, the setup will be shielded using sandwich structure barrier materials. Electronic controls and emergency switch offs will also be implemented.

4 Conclusion and Summary

In conclusion, a design of the thin-disk multipass amplifier was elaborated which is highly expected to meet the project goals. In case the goals are not achieved with a single multipass through the amplifier, a double pass can be implemented. Furthermore, the propagation scheme can easily be adapted. These measures will mitigate the risk not to reach the desired goals. Additionally, a lot of effort was put into the thermal and long-term stability of the system. Next steps will include manufacturing of the designed components and experiments on the system.

References:

[1] A. Antognini et al.,"Thin-Disk Yb:YAG Oscillator-Amplifier Laser, ASE, and Effective Yb:YAG Lifetime“, IEEE J. Quant. Electron., 45 (8), 2009

[2] J. Negel et al., "1.1 kW average output power from a thin-disk multipass amplifier for ultrashort laser pulses," Opt. Lett. **38**, 5442-5445 (2013)

[3] J. Negel et al., "Ultrafast thin-disk multipass laser amplifier delivering 1.4 kW (4.7 mJ, 1030 nm) average power converted to 820 W at 515 nm and 234 W at 343 nm," Opt. Express **23**, 21064-21077 (2015)