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Report on the effect of flooding a high-power thin-disk amplifier with Helium

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Dissemination Level	
PU = Public PP = Restricted to other programme participants (incl. the Commission Services) RE = Restricted to a group specified by the consortium (incl. the Commission Services) CO = Confidential, only for members of the consortium (incl. the Commission Services)	PU

A. Abstract / Executive Summary

At the Max Born Institute (MBI) we are working on the development of thin-disk lasers for high pulse energy at high average power. Our CPA laser system consists of an Yb:KGW oscillator with stretcher as front-end. In the subsequent Yb:YAG thin-disk based laser amplifiers the 1 ns chirped laser pulse is further amplified to several hundred millijoule pulse energy. A grating compressor re-compresses the laser pulses to about 2 ps (nearly bandwidth limited) pulse duration. The repetition rate is 100 Hz.

In general, we use a regenerative amplifier to increase the stretched laser pulse to about 200 mJ pulse energy and a ring amplifier as a booster amplifier to about 600 mJ pulse energy. However, we demonstrated a pulse energy of more than 300 mJ extracted from the regenerative amplifier with an rms stability of better 0.3% measured over several hours. Under optimized conditions this pulse energy was amplified to more than 1 J @ 100 Hz in the booster amplifier.

The thin amplifier disks are pumped with up to 12 kW peak power. The heat generated by the pump light causes fluctuation in density (refractive index) in the air in front of the laser disk. These fluctuations are visible in the laser beam profile. Since Helium gas has a nearly 10 times smaller index of refraction than air one would expect that also the fluctuations are a factor of 10 smaller (He: n-1 = 3.5×10^{-5}, Air: n-1 = 2.7×10^{-4}). Thus it is expected that perturbations in the laser beam profile can be significantly reduced by exchanging the air in front of the thin disk by Helium.

B. Deliverable Report

1 Introduction

Heat generated by the pump light causes fluctuations in the air density in front of the laser disk (s. Figure 1). These density fluctuations lead to unfavourable distortions in the laser beam profile. Since Helium gas has a nearly 10 times smaller index of refraction than air also the fluctuations are a factor of 10 smaller (He: n-1 = 3.5×10^{-5}, Air: n-1 = 2.7×10^{-4}). By exchanging the air in front of the laser disk by Helium the perturbation in the laser beam profile should be reduced on the same order of magnitude.

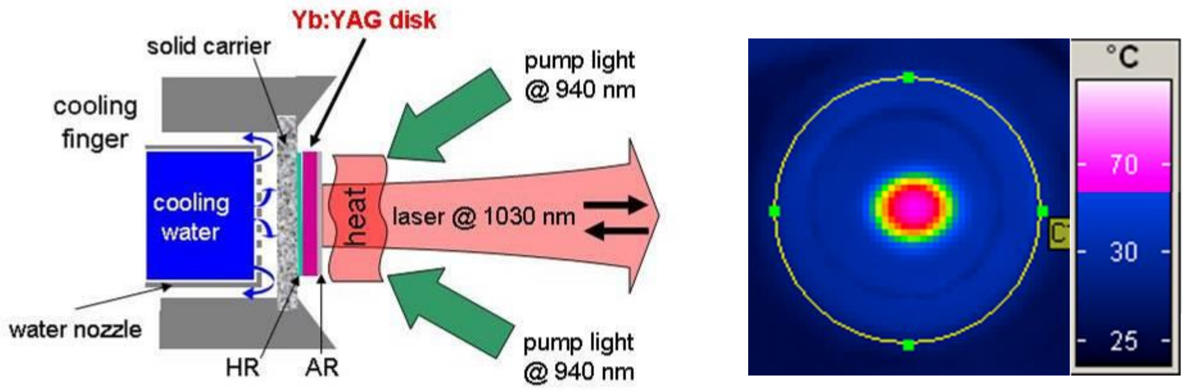

Figure 1: Heat (hot air) in front oft he laser disk causes perturbations in the laser beam profile. The pump spot on the laser disk has a temperature of more than 70° C.

Therefore, we have re-designed our thin-disk pump-heads (originally designed by IFSW Stuttgart) to be gas-tight. In that way the air in the vicinity of the laser disk can be replaced by another gas, such as Helium.

Furthermore, the air-tight design of the pump head has the advantage that neither turbulences from outside nor dust particles can disturb the beam in the pump head. This results in an additional protection of the amplifier disk against pollution.

2 Objectives

We are working on the development of a high average power laser amplifier based on thin-disk technology. Within this work we pay special attention on the stabilization of pulse energy and beam pointing.

In this report we describe the effect of using air-tight thin-disk pump heads in our booster amplifiers. The pump heads can be flooded with Helium gas.

3 Work performed / results / description

3.1 Re-design of the pump-head

As a first step we re-designed our high-power thin-disk amplifier heads to be gas-tight.

Figure 2 shows the re-designed pump-head. The following changes compared to the former pump head (designed at IFSW Stuttgart) were included.

- The entrance opening for the seed pulse has been closed by an AR-coated fused silica window (Figure 2 a). Fused silica has been selected over BK7 since the latter exhibits larger absorption of the laser beam at 1030 nm wavelength, which causes thermal lensing at larger average power.
- The laser disk on the cooling finger is inserted into the pump-head through a membrane bellow (Figure 2 b). In this way minor re-alignment of the thin-disk is supported inside the gas-tight pump-head.
- The entrance opening for the pump beam is closed by an AR coated window (Figure 2 c).
- The end-mirror where the pump light is reflected back is gas-tight covered (Figure 2 b).
- The open viewport at the top of the pump head for observing the pump spot and the seed pulse on the laser disk was omitted.
- Push-in fittings have been mounted at the front plate for gas inlet and outlet.

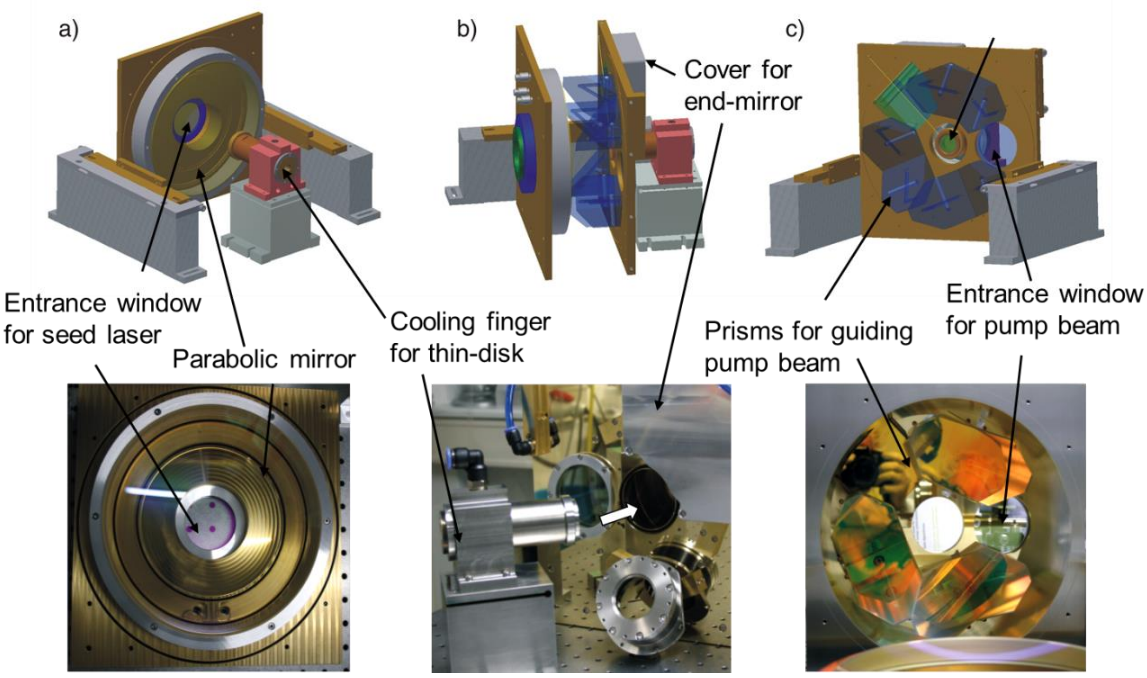

Figure 2: Drawings (top row) of the gas-tight pump-head and photographs of the manufactured pieces (bottom row).

The functionality turned out to fit very well. The degree of freedom for aligning the thin-disk within the amplifier is strongly reduced compared to the non-gas-tight version. Nevertheless, the remaining degrees for adjustment (tilt, rotation and distance to parabolic mirror in very limited extent) turned out to be sufficient for proper alignment of the amplifier. Since the pump light as well as the amplified laser pulse has to pass through an AR coated laser window there were concerns that this may be another source of beam instabilities or damages within the laser amplifier. These concerns were not approved.

3.2 Amplifier setup

In Figure 3 the scheme of the thin-disk laser amplifier system is shown. It is a two channel system with a common front-end for the two synchronized output pulses.

After the Yb:KGW oscillator and the grating stretcher, the chirped 1 ns laser pulse is split into two equal beams. The pulses in these beams are then amplified by two identical regenerative amplifiers to up to 300 mJ pulse energy. The following power amplifier increases this pulse energy to the final level. With both channels active, a pulse energy of 2x 600 mJ was demonstrated before the compressor. With only one channel and increased pump energy, we have reached a laser pulse energy exceeding 1 J.

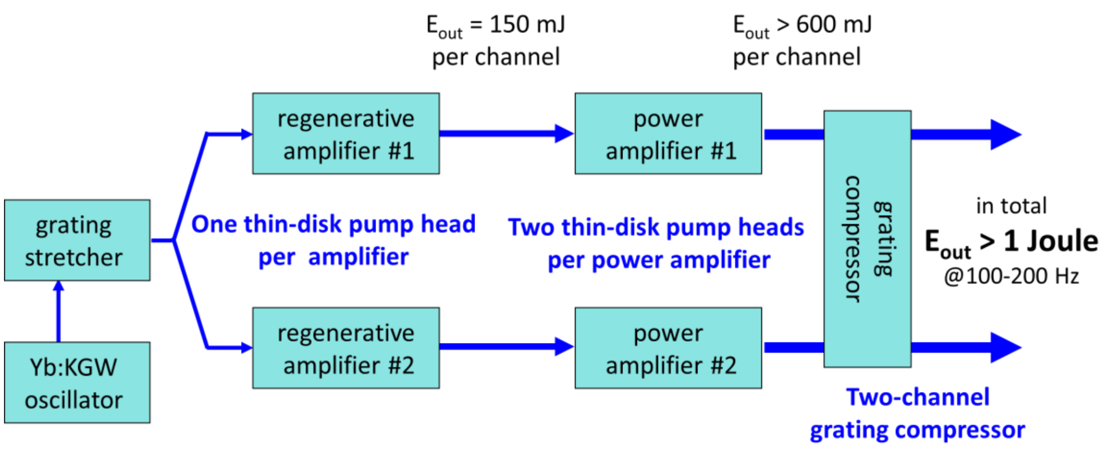

Figure 3: Scheme of the thin-disk laser system

The power amplifier is designed as a ring amplifier. Figure 4 shows the setup of the amplifier. It consists of a half-wave plate and Pockels cell for in- and out-coupling of the laser pulse. For the amplification we use two of the gas-tight pump-heads (described above). They can be operated with up to 12 kW peak pump power, each (24 kW for one ring amplifier). When both channels are active only half the pump power is available. Between the two pump-heads there is a vacuum spatial filter for cleaning the beam at every round-trip.

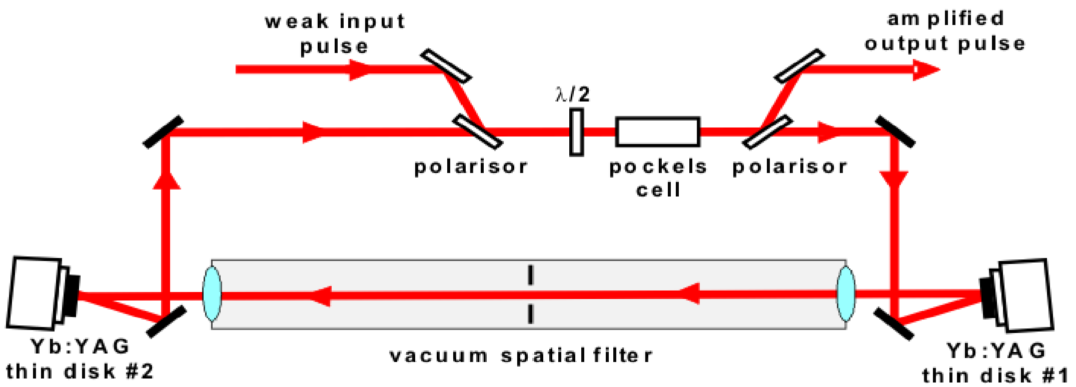

Figure 4: Setup of the power amplifier.

With only 4 round trips and a seed pulse energy from the regenerative amplifier of 80 mJ, an output pulse energy of 600 mJ (before re-compression) was achieved in both channels. Figure 5 shows the amplification curves of both channels. The declared pump power is here the full pump power for both pump-heads in the ring amplifier.

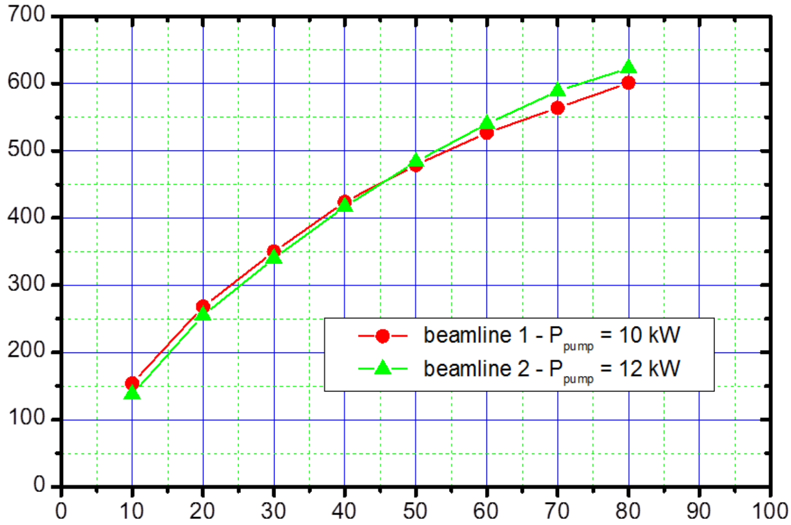

Figure 5: Amplification curve of both channels measured before re-compression.

The laser pulses in both channels are synchronized to each other with a jitter of about 0.3 ps (rms). The re-compressed pulse duration is close to the Fourier limit of 2 ps. Figure 6 shows the setup of the two-channel compressor and an auto-correlator measurement of the pulse duration.

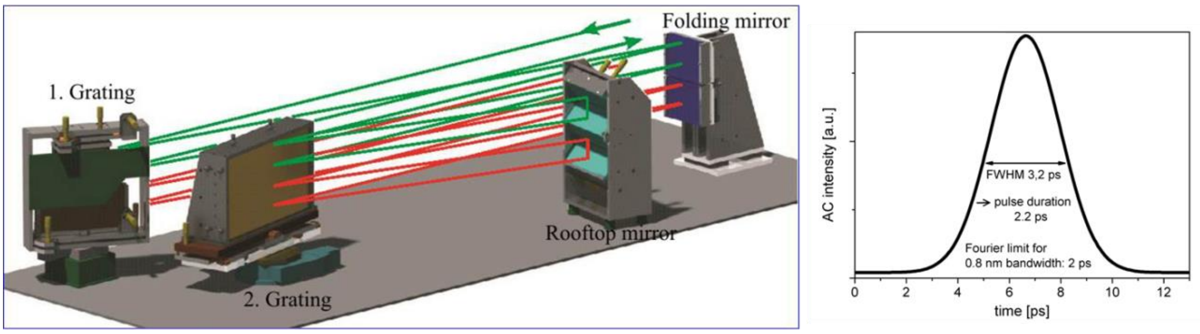

Figure 6: Compressor for two laser pulses. The pulses can be re-compressed to about 2 ps.

3.3 Results

The gas-tight pump-heads were installed in the ring amplifier. At first they were used under standard laboratory conditions filled with air. At the amplifier output the laser beam was observed by a camera.

Then the pump-heads were tested flooded with Helium with a constant Helium flow. When starting flooding the pump-head with Helium the laser beam drifted away at first very strongly, probably due to the cooling by the Helium flow. The drift was so strong that the amplifier had to be re-aligned but, fortunately, it stabilized within a few minutes. After re-alignment, the fluctuations observed in the beam profile were stronger pronounced than before. The permanent flow of Helium gas had a stronger influence on the beam profile than the heated air in the closed pump-head. Therefore, we stopped the Helium gas flow and used the pump-head flooded with Helium but without permanent flow. Now, the fluctuations in the laser beam were reduced again. Thus the difference between the air-filled and the

Helium filled pump chamber was actually undistinguishable, and both produced high-quality amplified laser beams.

The previous version of the pump head had an opening above the laser disk, which was used as a viewport. When the disk was pumped, the hot air flows upwards in front of the disk and leaves the pump head through this viewport. Fresh air is drawn in through the front opening of the pump chamber. In this way, a permanent airflow in front of the laser disk was established. In the new air-tight design of the pump head, this airflow is now strongly suppressed. Fluctuations within the beam profile are therefore already significantly reduced due to the air-tight design. It turned out that additional flooding with Helium gas gives no further benefit for the stability of the beam profile.

There are other important sources for beam profile fluctuations, e.g., in some parts of the ring amplifier the beam is not guided in a pipe. If these parts are not covered carefully it is clearly visible in the beam profile fluctuations.

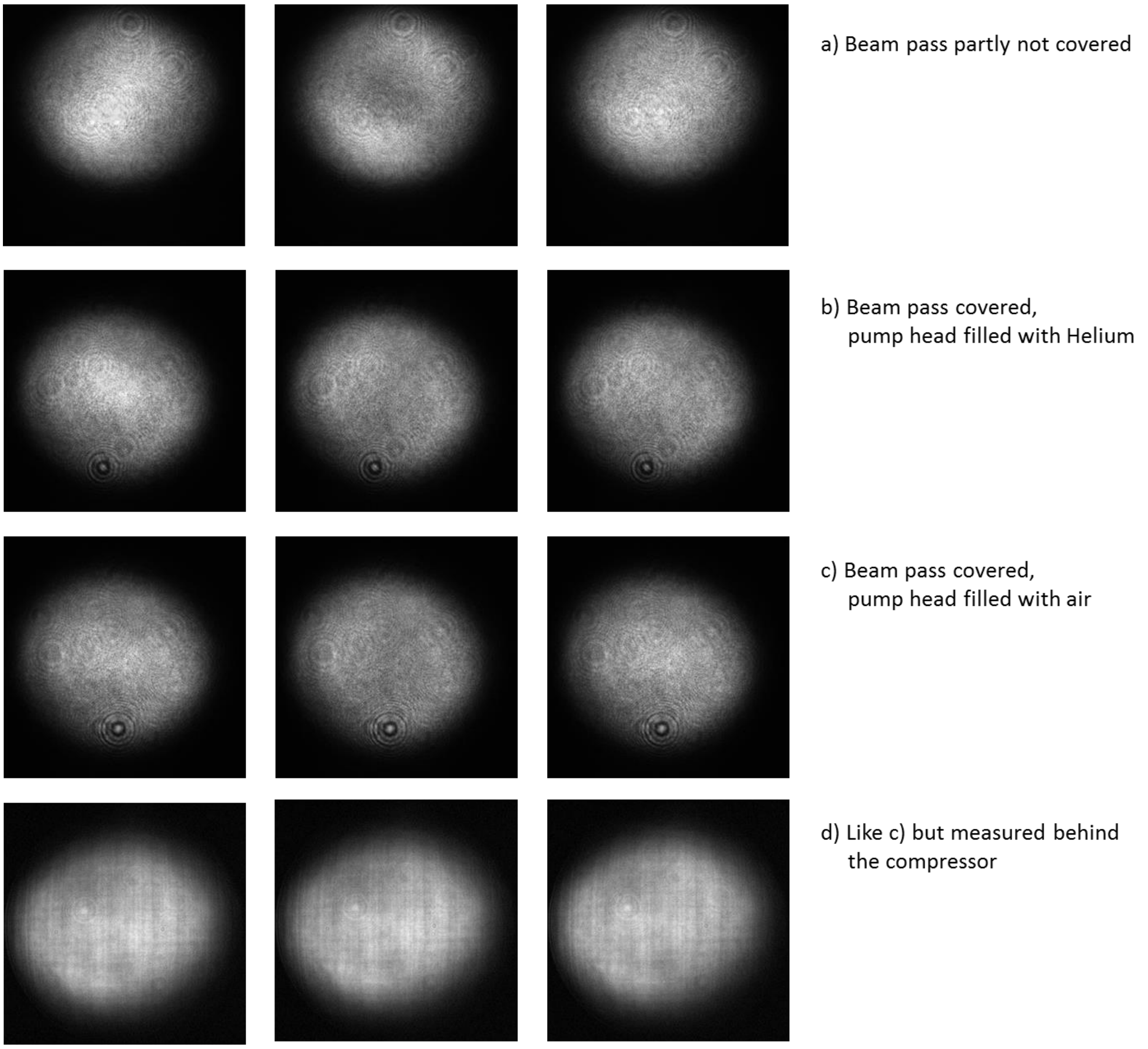

Figure 7: Beam profile fluctuations under different conditions. The diffraction patterns visible within the beam profiles are dust particles or optical imperfections on the filters in front of the camera.

Figure 7 shows single images of videos captured under different conditions. For the first row the beam pass is partly not covered. The profiles vary from a pronounced centre to a kind of doughnut. If the beam pass is covered carefully the fluctuations are reduced. The extreme values (high intensity and low intensity in the centre) are less pronounced and (not visible in the single images) the frequency of the fluctuation is reduced. The videos (b) and (c) can be described as a slow motion of (a). A clear difference between a Helium filled (b) and an air filled (c) pump-head is not visible. Row (d) shows the beam profile after the compressor under the same conditions as in (c) - pump-head filled with air and beam pass carefully coved. A fluctuation of the beam profile at the exit of the compressor is nearly not visible.

4 Conclusions

The re-designed pump-heads are very useful for reducing fluctuations within the beam profile. Operation with air already resulted in high beam stability. Thus additional flooding with Helium gas did not lead to further reduction of the remaining fluctuations.

Due to the air-tight design, a permanent air flow in front of the laser disk was avoided. In the older version of the pump heads, a permanent air flow was established by a kind of chimney effect due to the open viewport on top of the pump head and the opening for the laser beam in front of the laser disk. This permanent flow had a strong disturbing effect on the beam profile. By avoiding this flow, the fluctuation in the beam profile could be reduced significantly. Even without Helium filling, the new design of the pump head had shown a significant reduction of the fluctuation of the beam profile.

Acknowledgement

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