New compact pump geometry for thin disk lasers with a tilted optical long-pass filter

Benjamin Ewers[a], Raoul-Amadeus Lorbeer[a], Alexander Fischer[a], and Jochen Speiser[a]

[a]Deutsches Zentrum für Luft- und Raumfahrt e.V., Pfaffenwaldring 38-40, 70569 Stuttgart, Germany

ABSTRACT

Due to the low absorption of pump light in a thin disk laser, the pump light has to be redirected multiple times onto the active medium in order to achieve high pumping efficiency. Therefore, the pump optics in current systems require a large volume compared to the thin disk itself and multiple optics have to be aligned correctly with each other. Our wedged optical lasing chamber for ytterbium disks (WOLCYD) consists of an optical long-pass filter placed at a small angle directly in front of the thin disk. By this, an in-place multiplication of the number of pump passes is achieved. This results in a compact pump optic without the need of sophisticated alignment efforts. We demonstrate a laser oscillator setup and a laser amplifier setup on the basis of the WOLCYD geometry.

Keywords: thin disk, laser, WOLCYD

1. INTRODUCTION

Thin disk lasers can emit high brightness laser light with powers up to several kilowatts by allowing high pump power densities.[1–4] These high pump power densities are technically feasible due to the thin active medium, which can be cooled efficiently from one side. The thin active medium on the other hand limits the light matter interaction for the lasing process per pass, so that photons need to be redirected onto the thin disk multiple times to allow for efficient implementations.[3,5,6] This pass multiplication leads to rather large pump optics encapsulating the thin disk and raising the setup size and weight. To overcome this side effect, it would be desirable to generate multiple passes in a compact design, or even within the thin disk. Recently, we were able to demonstrate the trapping of laser light for multiple reflections within a Wedged Optical Light Interference-filter Trap (WOLIT).[9] This concept is adaptable for the thin disk laser and will now be referred to as Wedged Optical Lasing Chamber for Ytterbium Disks (WOLCYD).

With WOLCYD as a variant of WOLIT a long pass interference filter is used here as well. It may be characterized by its edge-wavelength λ_e and transmission (T) edge steepness $dT/d\lambda$. With a pump laser of the wavelength λ_p below λ_e, at an angle of incidence Θ equal to zero the edge-filter will reflect the laser light (Figure 1 dotted line). By tilting the pump laser beam the filter edge shifts its transmission edge towards shorter wavelengths.[10] The wavelength shift is different for s- and p-polarized light and therefore the pump laser source, should be polarized too. At the edge angle $\Theta_{e_p,\lambda_p=\lambda_e}$ the filter will transmit the pump laser light (Figure 1 solid line). In a WOLCYD arrangement the transmitted pump laser light then reaches the thin laser disk with a highly reflective coating on the backside. By passing through the disk, a portion of the pump light is absorbed and redirected due to reflection on the HR-surface. A normal incidence angle would lead to a re-transmission of the remaining pump laser light back through the filter. As depicted in figure 1, it is also possible to redirect the pump laser light back to the interference filter with a tilted angle creating an effective Θ of 0 degrees. Through this arrangement the pump light will be reflected at the filter surface (Figure 1 solid line). The pump laser beam has performed one additional reflection at the HR surface and is absorbed again by the disk. By choosing a smaller wedge angle α between edge filter and laser-disk, the number of passes can be increased. This results in multiple absorption passes of the pump light in the disk.

Further author information: (Send correspondence to B.E.)
B.E.: E-mail: benjamin.ewers@dlr.de, Telephone: +49 (0)711 6862 414
R.-A.L.: E-mail: raoul.lorbeer@dlr.de, Telephone: +49 (0)711 6862 8263

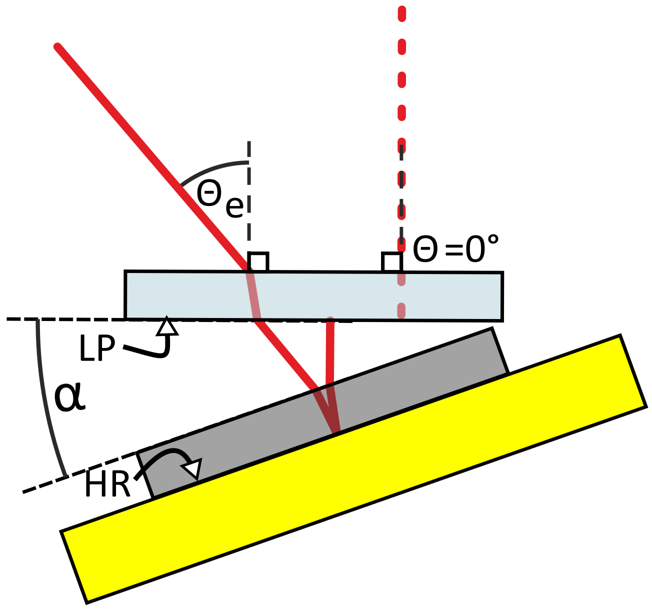

Figure 1. Schematic arrangement of the WOLCYD. Edge filter (light blue) and laser Disk (dark grey) mounted on a copper heat spreader (yellow) with wedge angle α. Shown are a light beam with normal incidence (red dotted) and a light beam with an incidence angle of Θ_e (red solid). Surfaces with long pass (LP) and highly reflective (HR) coating are indicated by their abbreviations.

Next to the necessary multiplication of pump passes the thin active medium has a second consequence. The output coupling mirrors of the laser may only possess a transmission of several per cent[4,7,8] resulting in high laser intensities inside the resonator. Furthermore, large amplifier arrangements using well above 10 additional optical mirrors are necessary to reach a significant gain factor. For laser wavelengths between edge- (λ_e) and pump- (λ_p) wavelength there are intermediate angles $\Theta_{e_l,\lambda=\lambda_e} < \Theta_{e_p,\lambda_p=\lambda_e}$ where the coating of the edge filter will switch between transmission and reflection. That implies that the emitted laser light at λ_l with a longer wavelength than the pump light λ_p from the thin disk substrate will be transmitted by the edge filter with a reduced angle Θ_l smaller than $\Theta_{e_p,\lambda_p=\lambda_e}$. Equivalent to the pump light the emitted Laser light is reflected several times within the WOLCYD arrangement which results in multiple passes through the thin laser disk medium.
We were able to utilize this behavior to pump a thin Yb:YAG disk through a 1064 nm edge long pass filter at a wavelength of 969 nm. At a reduced angle, laser light of 1030 nm wavelength was transmitted through the same optical filter which allowed the laser light within the laser resonator to enter and exit the pumped region of the thin disk, while also experiencing a multiplication of thin disk passes. Finally, we were able to demonstrate gain factors surpassing the simple reflection at the thin disk utilizing the WOLCYD geometry as an amplifier.

2. SETUP

The experimental setup (figure 2 left) includes a 969 nm laser diode ensemble as pump light source. The pump laser light is guided through a optical fiber with 1000 μm core diameter to the experimental setup. The emitted pump light is collimated by an f=50 mm convex lens and guided by highly reflective mirrors through a polarization beam splitter. Light reflected by the beam splitter is guided to a thermal power meter acting as a beam block and pump power reference. The transmitted light is projected into the WOLCYD device with an approximate pump spot diameter of 6 mm x 8 mm.
The WOLCYD device itself (figure 2 right) consists of an edge filter (Edmund Optics ⌀ 25 mm, 1064 nm Raman edge filter) glued onto a wedged polished copper ring. The copper ring is further glued onto the copper heat spreader. On the one hand, the copper ring acts as a wedged mount to fix the angle of the edge filter relative to the thin disk. On the other hand, the copper ring transports heat from the edge filter to the copper heat spreader. The Yb:YAG laser-disk is glued onto the copper heat spreader. The laser-disk is coated with a highly reflective coating on the cooling side and an anti reflective coating on the free space side. Water cooling of the

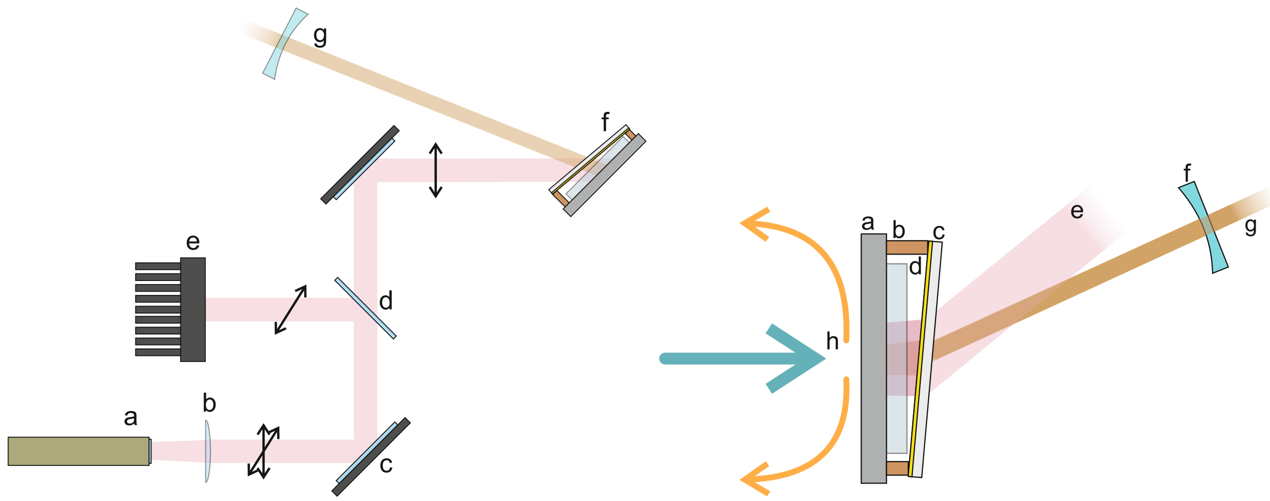

Figure 2. Left: Experimental Setup. (a) Pump laser fiber output, (b) collimation lens, (c) mirror, (d) polarization sensitive beam splitter, (e) beam dump and power meter, (f) WOLCYD device, (g) laser cavity output coupler concave mirror. Right: Schematic arrangement of the WOLCYD. (a) Copper head spreader, (b) wedged copper ring, (c) edge filter, (d) laser-disk, (e) pump laser beam, (f) outcoupling mirror, (g) laser, (h) water cooling of the copper head spreader.

copper heat sink provides sufficient cooling of the laser-disk and the edge filter.

The pump laser light is coupled into the WOLCYD assembly through the edge filter and kept inside for approximately 12 round trips. The main portion of the pump light is absorbed by the laser disk while a small portion (less than 10 %) is coupled out again into a slightly tilted direction relative to the incoming pump laser light. The filter edge at a wavelength of 1030 nm is shifted to a smaller angle in comparison to the pump light and therefore the assembled laser cavity is angularly separated from the pump light direction. Due to the small gap between the edge filter and the laser-disk, the drift of the pump laser spot as well as the laser spot, every reflection is small with respect to the spot diameter and leads only to a slightly asymmetric pump profile (figure 3).[9] The laser cavity is formed by the edge filter coating under almost normal incidence and a concave mirror with a transmission of 12.5 %.

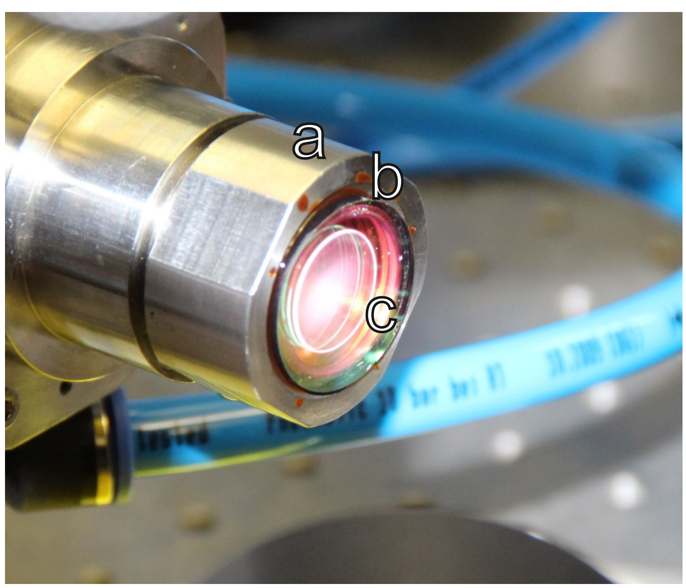

Figure 3. Photography of WOLCYD. (a) Cooling assembly, (b) copper ring with mounted edge filter, (c) laser-disk with pump spot.

3. RESULTS

The main portion of the pump light was coupled into the WOLCYD device. A minor portion of the pump light was reflected at the edge filter coating because of the angular and polarization tolerances of the pump light. The optical power of the reflected pump light was in the order of 5 % of the entire pump laser power.
The main portion of the introduced pump laser light was absorbed within the WOLCYD device. Furthermore, a portion in the order of 2.5 % of the entire pump laser power was not absorbed by the laser disk but coupled out of the WOLCYD device after a full round-trip. Thus, the portion of the pump light which is absorbed within the WOLCYD device was about 92 %.
The power of the emitted 1030 nm laser light was recorded with respect to the power of the pump light (figure 4). As can be seen, the laser threshold is reached at a pump laser power of about 160 W. The laser output power grows proportional to the pump power. By reaching a pump power of about 450 W, the output power deviates from this linear growth by a significant decrease in its slope. To calculate a slope efficiency of the output laser a linear fit was performed within the interval of [175, ..., 425] W (grey shaded rectangle in figure 4) of the pump power. The linear fit results into a calculated slope efficiency of 0.23.

The WOLCYD device can not only act as a laser resonator but also as a multi pass laser amplifier. For this the concave output mirror was removed and a 1030 nm low power (50 mW) seed laser beam was coupled into the WOLCYD device. After passing through the whole WOLCYD device, the out-coupled laser beam power was measured in respect to the induced pump laser power (figure 5). The gain factor curve shows a typical drop of in gain increase for higher pump powers as experienced with other thin disk amplifiers up to a gain factor of 1.3 for one single WOLCYD pass.

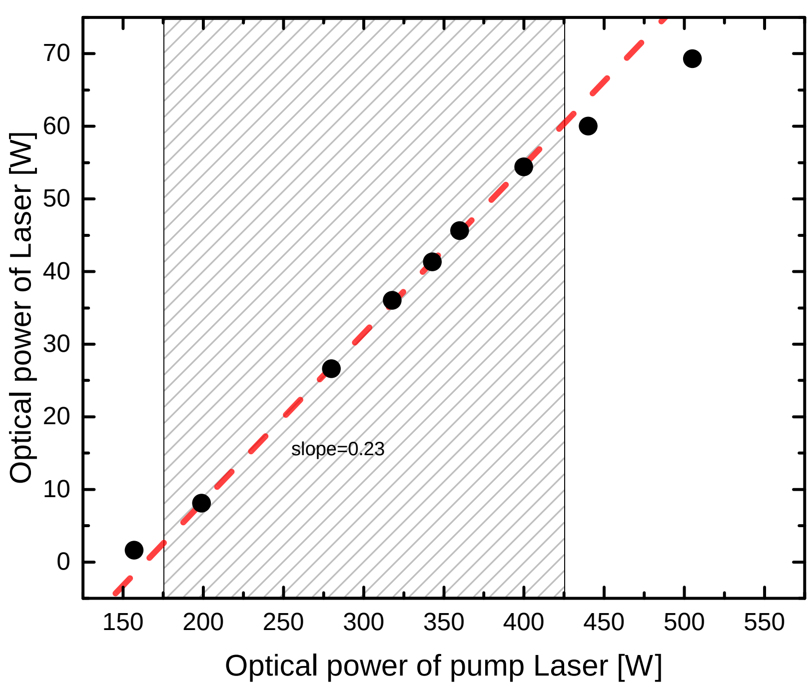

Figure 4. Out-coupled laser power in respect to the optical pump laser power. A linear fit was calculated within the grey shaded area.

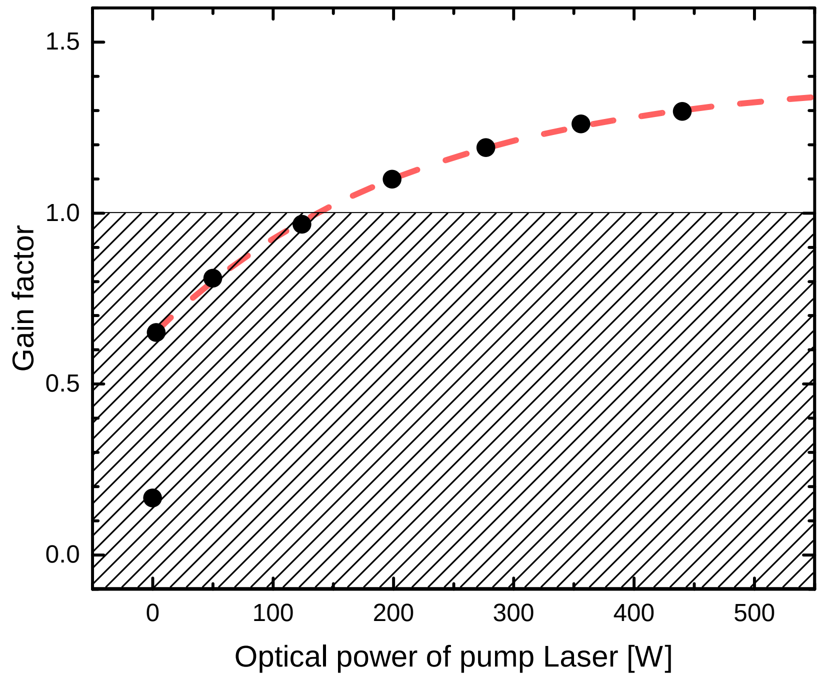

Figure 5. The gain factor of the WOLCYD amplifier setup in respect to the optical pump laser power.

4. CONCLUSION

We were able to show the principal operation of a WOLCYD system up to an output power of 70 W continuous wave, as well as a power amplifier with a total gain factor of 1.3. While both values stand back behind typical achievements in thin disk laser systems pumped at 969 nm[6,8] it should be pointed out that the components used were of the shelf components, which are not optimized for this type of concept. The absolute values suggest, that losses in the order of 15 to 20% are introduced within the system which, at least partially, originate in the un-optimized coatings. We expect further improvements by iterating the design choices. Nevertheless, the system did prove the feasibility of the WOLCYD concept and gave a first insight into the challenges which can be expected. Furthermore, it became clear that the WOLCYD indeed does work with a small amount of optical components.

REFERENCES

[1] Stewen, C., Contag, K., Larionov, M., Giesen, A., and Hugel, H., "A 1-kw cw thin disc laser," *IEEE Journal of selected topics in quantum electronics* **6**(4), 650–657 (2000).

[2] Schuhmann, K., Ahmed, M., Antognini, A., Graf, T., Hänsch, T., Kirch, K., Kottmann, F., Pohl, R., Taqqu, D., Voss, A., et al., "Thin-disk laser multi-pass amplifier," in [*Solid State Lasers XXIV: Technology and Devices*], **9342**, 93420U, International Society for Optics and Photonics (2015).

[3] Schuhmann, K., Hänsch, T. W., Kirch, K., Knecht, A., Kottmann, F., Nez, F., Pohl, R., Taqqu, D., and Antognini, A., "Thin-disk laser pump schemes for large number of passes and moderate pump source quality," *Applied optics* **54**(32), 9400–9408 (2015).

[4] Brauch, U., Giesen, A., Karszewski, M., Stewen, C., and Voss, A., "Multiwatt diode-pumped yb: Yag thin disk laser continuously tunable between 1018 and 1053 nm," *Optics letters* **20**(7), 713–715 (1995).

[5] Erhard, S., Karszewski, M., Stewen, C., Giesen, A., Contag, K., and Voss, A., "Pumping schemes for multi-kw thin disk lasers," in [*Advanced Solid State Lasers*], MB16, Optical Society of America (2000).

[6] Negel, J.-P., Voss, A., Ahmed, M. A., Bauer, D., Sutter, D., Killi, A., and Graf, T., "1.1 kw average output power from a thin-disk multipass amplifier for ultrashort laser pulses," *Optics letters* **38**(24), 5442–5445 (2013).

[7] Mende, J., Schmid, E., Speiser, J., Spindler, G., and Giesen, A., "Thin disk laser: power scaling to the kw regime in fundamental mode operation," in [*Solid State Lasers XVIII: Technology and Devices*], **7193**, 71931V, International Society for Optics and Photonics (2009).

[8] Weichelt, B., Voss, A., Ahmed, M. A., and Graf, T., "Enhanced performance of thin-disk lasers by pumping into the zero-phonon line," *Optics letters* **37**(15), 3045–3047 (2012).

[9] Ewers, B. and Lorbeer, R.-A., "Interference filter based beam confinement for increased mechanical phase modulation," *in review* .

[10] Lequime, M., "Tunable thin film filters: review and perspectives," *Advances in Optical Thin Films* (2004).