EPJ Web of Conferences **267**, 01010 (2022) https://doi.org/10.1051/epjconf/202226701010
EUROPHOTON 2022

Influence of Disk Aberrations on High-Power Thin-Disk Laser Cavities

Moritz Seidel , Lukas Lang, Christopher R. Phillips and Ursula Keller
Department of Physics, Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

Introduction: High-power thin-disk lasers (TDLs) are commonly used in industrial, medical, and academic contexts both in continuous-wave (cw) or modelocked operation. Enabled by the thin-disk gain geometry, the power-scaling of TDLs is accomplished by simultaneously increasing the pump and laser mode size. However, as the sensitivity to thermal effects scales with the laser mode size on the disk [1], it is critical to understand these effects in order to further scale the performance of high-power ultrafast TDL oscillators [2].

Thin-disk oscillator cavities are often modeled using ray transfer matrix analysis by computing their ABCD matrix and solving for the complex beam parameter. This analysis can include temperature-dependent radii of curvature, but always assumes parabolic surface profiles. The reduction in beam quality due to aberrations in the cavity can thus not be captured. Here we present a numerical, spatially resolved split-step model that supports arbitrary non-parabolic surface profiles for cavity elements such as the thin-disk. We find that these aberrations have a critical impact on the resulting cavity mode shape. Our results show good qualitative agreement between experiment and simulations and are an important step to scaling modelocked thin-disk lasers to the kW-level.

Model and setup: Our model finds an optical resonator's steady-state electric field distribution by simulating many cavity roundtrips. The cavity is described as a series of cavity elements separated by free space propagation. For each cavity element, spatially varying amplitude and phase factors are applied to the electric field. We approximate the spherical mirrors with a parabolic phase profile. For the thin-disk we use phase profiles measured during laser operation with a Twymann-Green interferometer (TRIOPTICS μPhase-500). The resulting power-dependent surface profile is decomposed into Zernike polynomials up to the $n + |m| = 6$-th order and supplied to the simulation (illustrated in Fig. 1(a) with parabolic parts removed). While the disk is almost parabolic, some non-radially-symmetric aberrations are clearly visible towards the edge of the disk. Commercial kW-class lasers employ advanced proprietary thin-disk technology with even better flatness and close to perfect radial symmetry, which have enabled near-fundamental mode output powers beyond 10 kW in cw-operation [3], and 2.5 kW in ultrafast multipass amplifiers [4]. The amplitude factor of the disk is computed by solving the quasi-three-level rate equations for the laser gain medium including the pump and laser intensity.

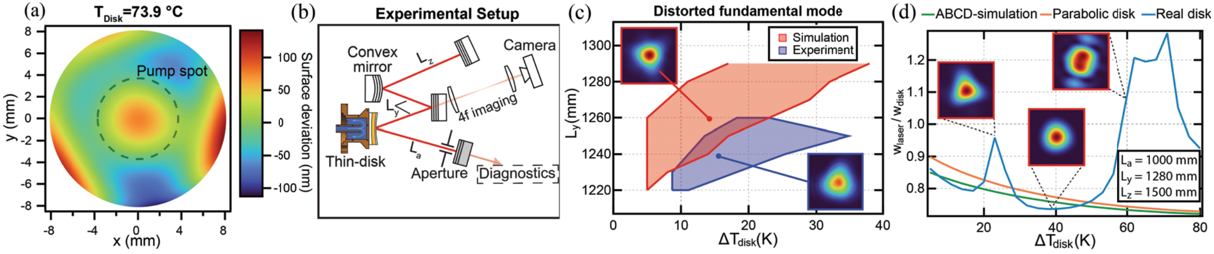

Fig. 1. (a) Non-parabolic parts of the surface profile of the thin-disk used in our experiment measured with the disk optically pumped to 73.9 °C. (b) the cavity configuration which includes a hard aperture. The arm lengths L_a, L_y and L_z are indicated. The laser mode on the disk is imaged onto a camera. (c) Comparison of simulation and experiment for cavities that produce triangular distorted fundamental modes with L_z=1500 mm. Insets show measured and simulated beam profiles. (d) Simulation of a cavity with arm length as indicated comparing the ray matrix approach (green), and our model for an ideal parabolic thin-disk (orange) and the disk with the measured phase profile (blue).

Results: The model is validated by experiment in a convex-concave thin-disk laser cavity (Fig. 1(b)). The convex mirror has a radius of curvature of −2 m. The thin-disk used is an Yb-doped disk contacted by TRUMPF Scientific Lasers, with a cold radius of curvature of 3.84 m. An output coupler with 10% transmission is used. The simulations predict distorted fundamental modes for certain cavity configurations, which were subsequently experimentally tested. Fig. 1(c) shows scans of T_{disk} (via changes to the pump power) and L_y (distance disk – convex mirror) for both the simulation and experiment. In the highlighted areas, we observe somewhat triangularly distorted fundamental modes, likely stemming from the trefoil symmetry of the disk phase profile (Fig. 1(a)). While the overall trends are well-reproduced, we observe a shift of the predicted zone to shorter L_y when comparing to simulation, potentially due to offsets in the curvature of the cavity elements. Fig. 1(d) shows the drastically different behavior predicted by our model when compared to simulations assuming a parabolic phase profile.

Conclusion: We present a spatially-resolved numerical model backed by experimental data to predict the output mode of a thin-disk laser oscillator. By including the disk's measured phase with its non-parabolic aberrations, we recover experimentally observed beam quality degradations not captured by simpler models.

References:

[1] V. Magni, "Multielement stable resonators containing a variable lens," JOSA A **4**, 1962-1969 (1987).
[2] F. Saltarelli et al. , "Power scaling of ultrafast oscillators: 350-W average-power sub-picosecond thin-disk laser," Opt Express **27**, 31465-31474 (2019).
[3] S. Nagel et al. , "Thin-disk laser system operating above 10 kW at near fundamental mode beam quality," Opt. Lett. **46**, 965-968 (2021).
[4] J. Dominik et al. , "Multi-kilowatt Ultrafast Laser with Thin-disk Technology," in *Laser Congress 2021 (ASSL,LAC)* AM2A.6.