Laser for the Future, towards 1kW USP Power

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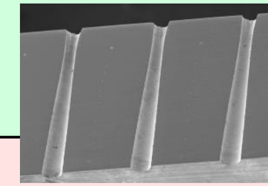
Laser Development und Optics

Dr. Marwan Abdou Ahmed

- Thin-Disk Lasers
  Dipl. Phy. J.-P. Negel
- Beam Shaping and Beam Diagnostics
  Dipl. Ing. S. Piehler
- Fiber Optics and Fiber Lasers
  Dr. M. Abdou Ahmed
- Semiconductor Thin-Disk Lasers
  Dr. U. Brauch

Scientific Fundamentals

Akad. Oberrat Peter Berger



Process Development

Dr. Rudolf Weber

- Precision Machining
  Dipl. Ing. V. Onuseit
- Macro Machining
  Dipl. Ing. P. Stritt
- Modeling, Diagnostics and Control
  Dipl. Ing. P. Stritt

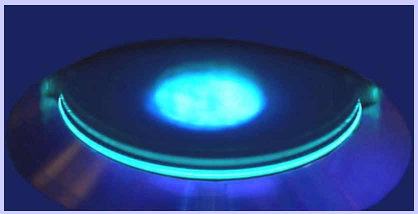
Infrastructure and Administration

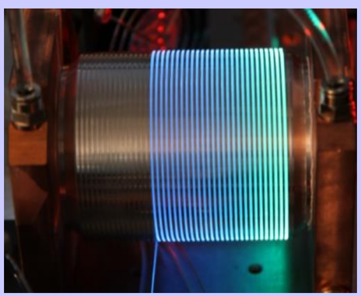
- Technical Services and Safety
  A. Esser
- Metallography
  C. Kizler
- Administration
  R. Fischer

Laser Development & Laser Optics

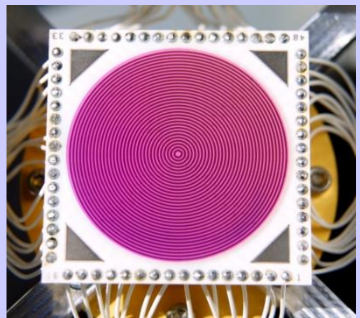
Industrial Applications

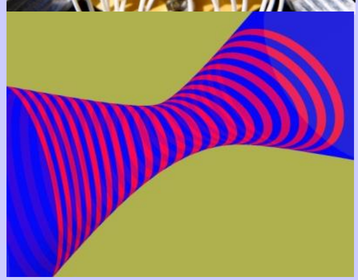
Disk Lasers & Fiber Lasers



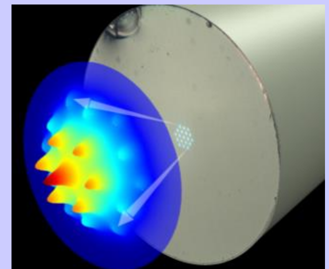


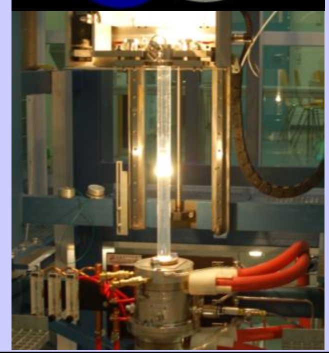
Beam Guiding & Beam Shaping



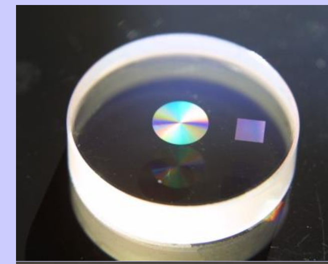


Fibre Delivery & Fibre Fabrication





Polarization & Resonant Wave-guide Devices



Fundamentals

- Overall
  - 13 scientists
  - 3 technicians

Outline

- Motivation
- State of the Art (thin-disk technology & Yb:YAG/LuAG laser active) media)
- Ultrafast Thin-disk Multipass Amplifiers
  - **Amplification of Cylindrically Polarized Laser Beams**
- Future ultrafast thin-disk laser development

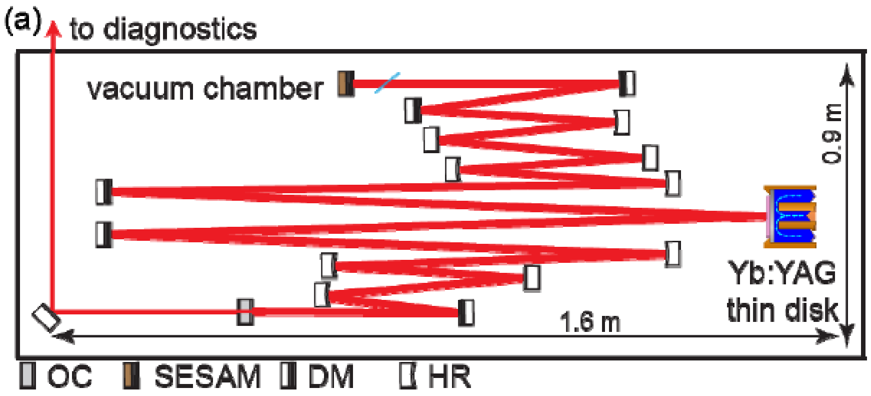
Motivation

- **Aim:** Building sources for ultrashort laser pulses with **kilowatt class average output power**

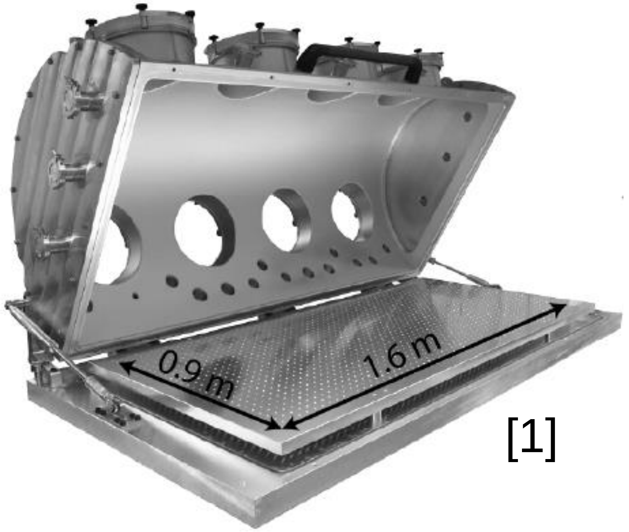
- **Application:** Material processing (microstructuring, cutting CFRP)

- **Benefit:**
  - high average power➔ higher productivity
  - high energy➔ higher process efficiency
  - Green and UV sources: better focussability, potentially better absorption

Oscillators for ultrashort pulses (SESAM)



[1]

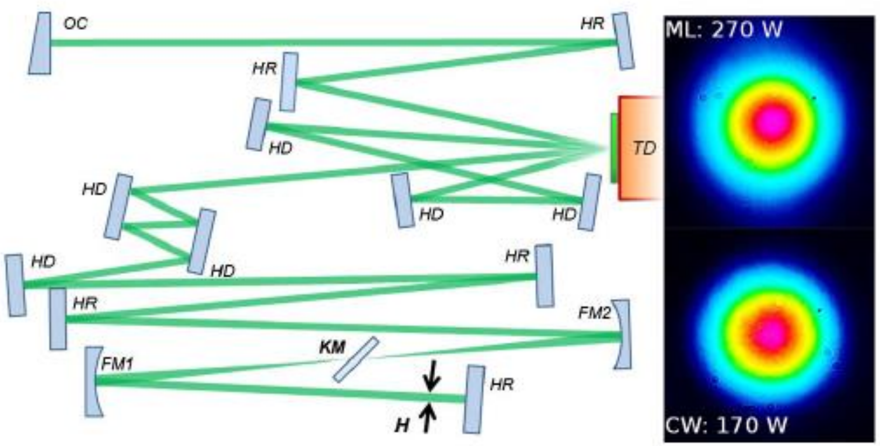


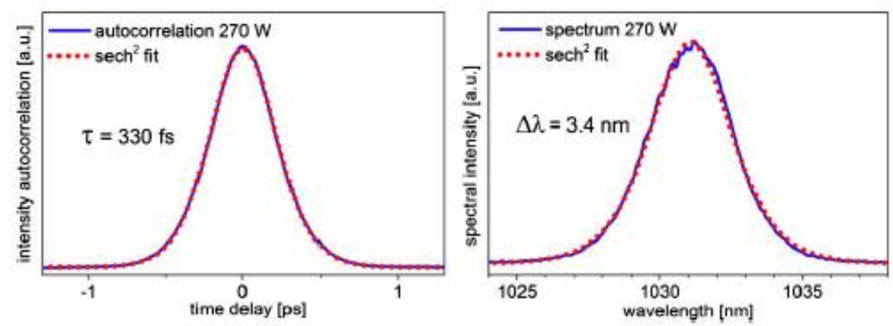
[1]

- Highest average power: 275 W, 583 fs, 16.7 µJ [1] (ETH)
- Highest pulse energy: 242 W, 1.07 ps, 80 µJ with Herriott-cell [2] (ETH)
- SESAM mode-locking
- SPM (introduced mainly by air) has to be compensated ➔ vacuum environment

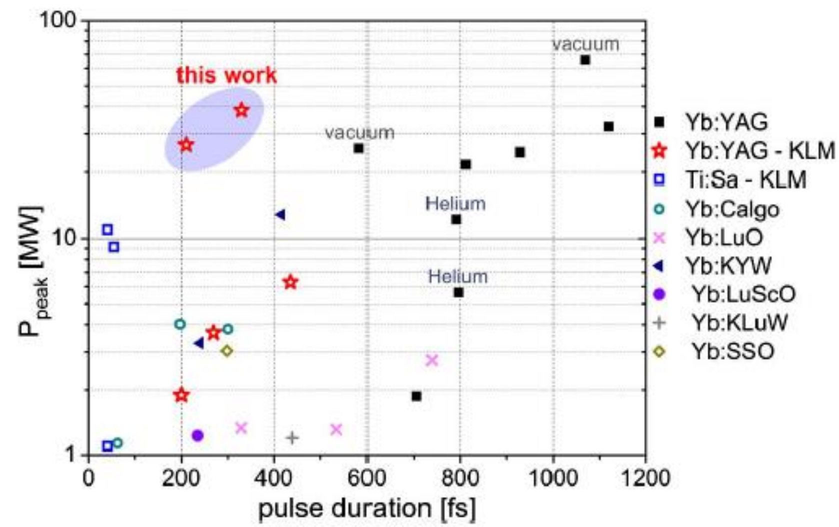
[1] C. J. Saraceno et al., Opt. Express **20**, 23535-23541 (2012).
[2] C. J. Saraceno et al., Opt. Lett. **39**, 9-12 (2014)

Oscillators for ultrashort pulses (Kerr-lens)





[1]

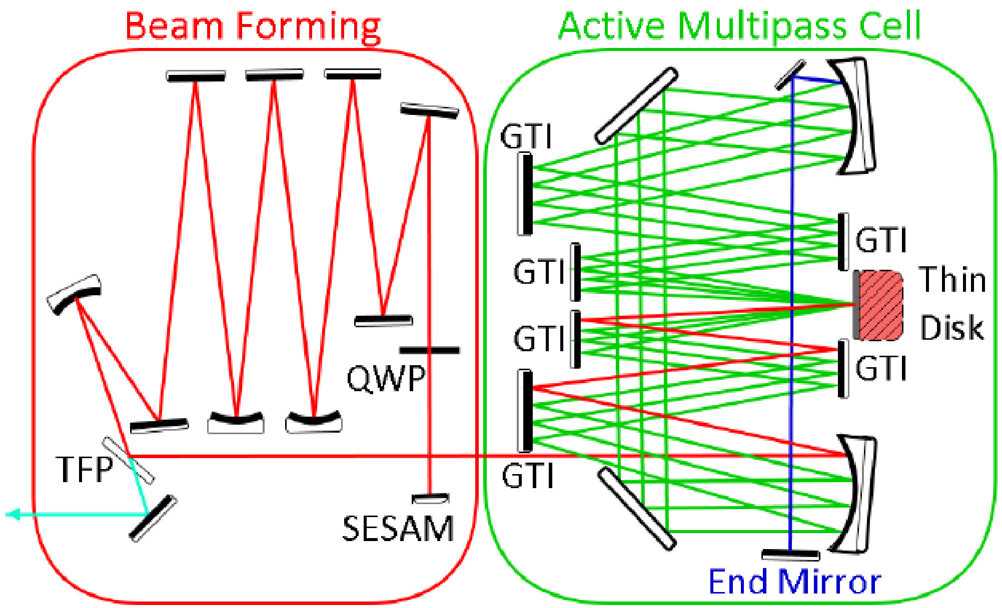


- 270 W, 330 fs, 14 µJ [1] (MPI, Munich)
- Nonlinearity mainly in Kerr-medium
- Ambient air environment
- Comparably very short pulse durations

[1] J. Brons et al., Opt. Lett. **39**, 6442-6445 (2014)

State of the art Yb:YAG / Yb:LuAG

Oscillators for ultrashort pulses (Active multipass)



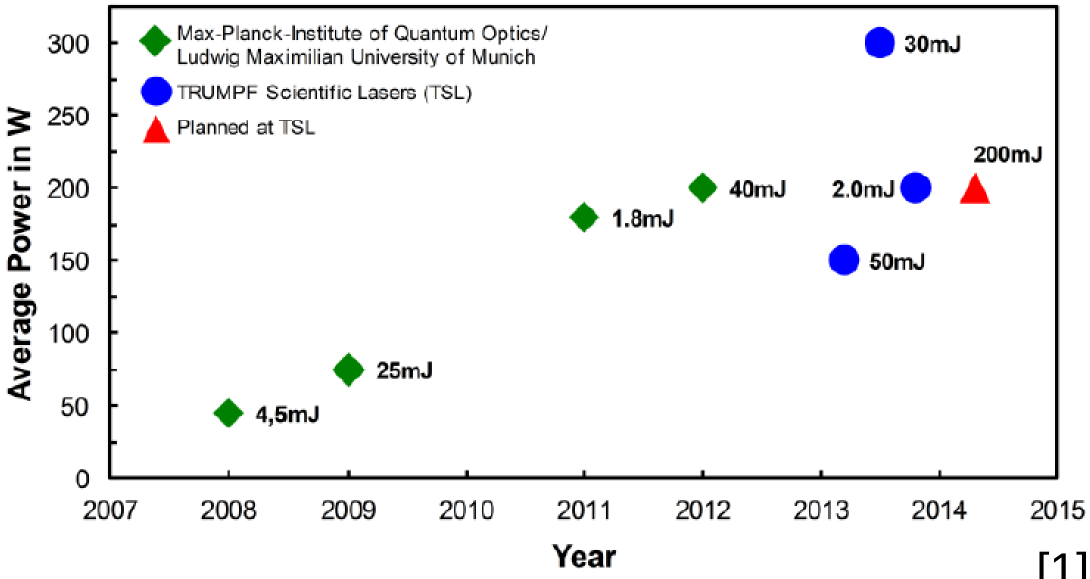
[1]

- 145 W, 1.1 ps, 41 µJ [1] (Trumpf)
- Aim: Reduce nonlinearities inside the cavity
- Approach: More passes over the disk ➔ higher gain ➔ higher outcoupling ➔ lower intra-cavity power ➔ lower SPM

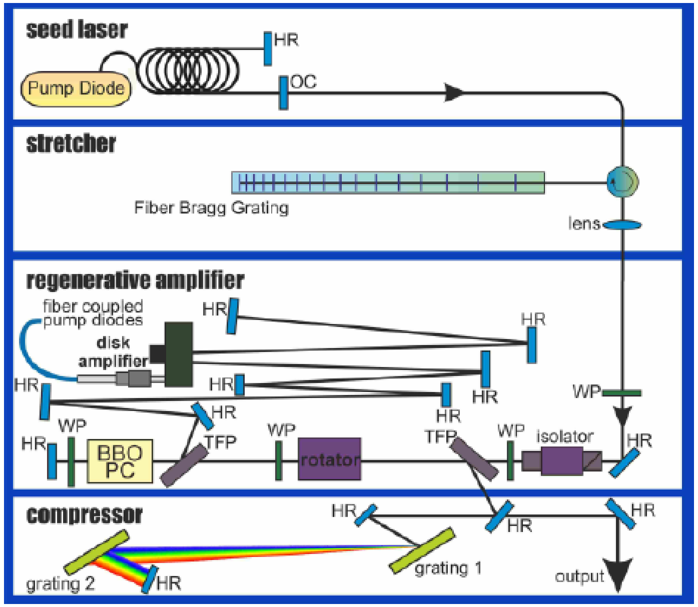
[1] D. Bauer et al., Opt. Express **20**, 9698-9704 (2012).

State of the art Yb:YAG / Yb:LuAG

Regenerative amplifiers for ultrashort pulses



[1]



- 300 W, 30 mJ, 1.6 ps (CPA) [1] (Trumpf Scientific Lasers, MPI)
- Recently: >600 W and pulse energies exceeding 100 mJ

[1] T. Metzger et al., Conference on Lasers and Electro-Optics CLEO 2014, invited paper JTh4L1

Ultrafast Thin-Disk Multi-Pass Amplifier

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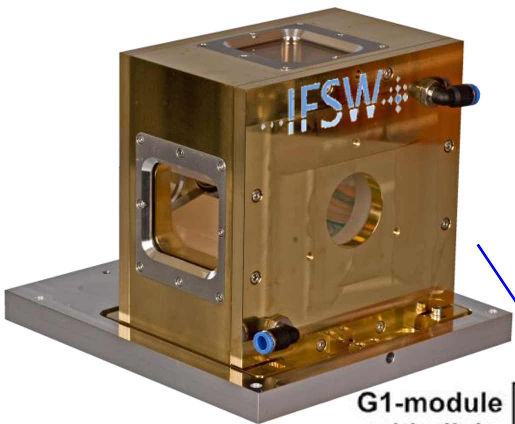
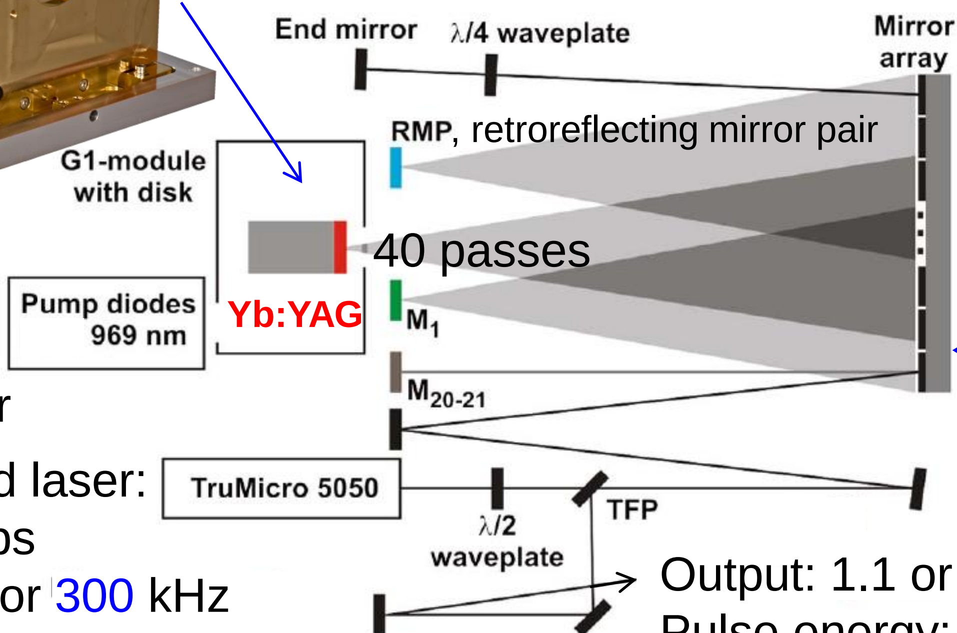
- In collaboration with TRUMPF Laser GmbH



Set-up of the multi-pass amplifier



2.3 or 2.7 kW of pump power

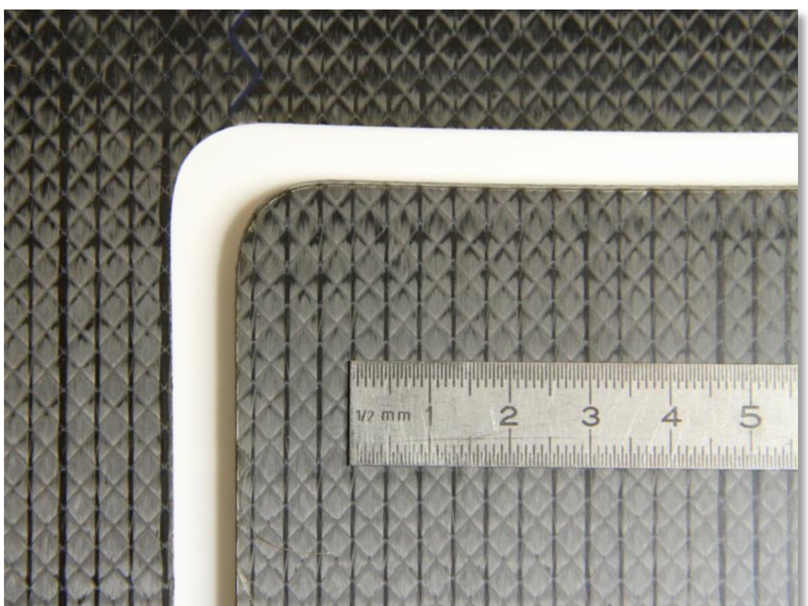
Seed laser:
6.5 ps
800 or 300 kHz
80 or 115 W

Output: 1.1 or **1.4 kW**
Pulse energy: 1.4 or **4.7 mJ**
Pulse Duration: 7.3 or **7.7 ps**
$M^2 < 1.25$

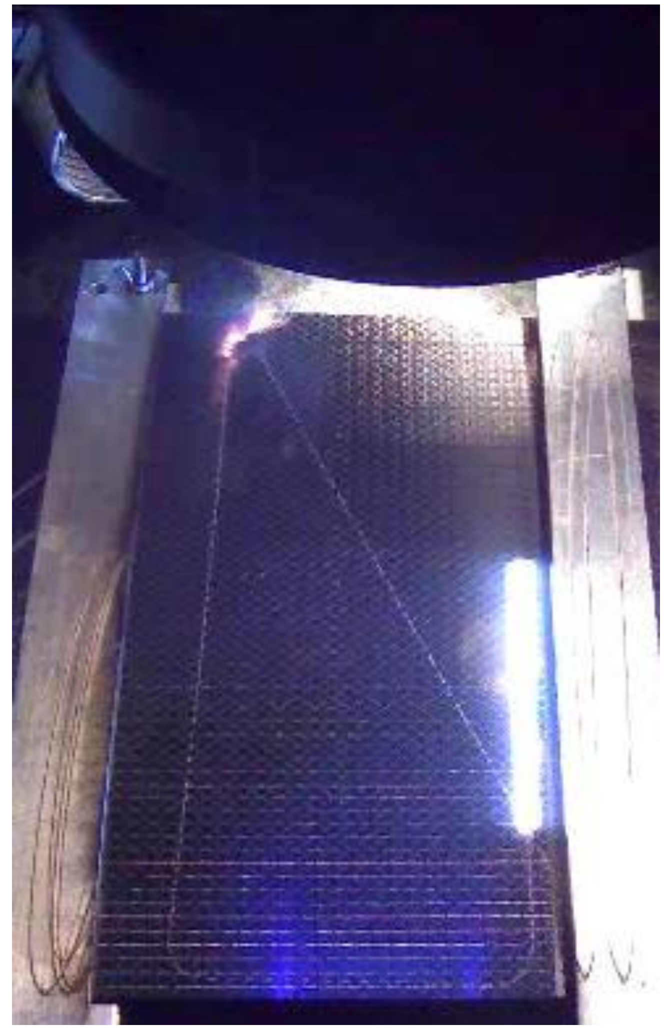
Negel et al. Optics Letters 38 (24), 5442 (2013)
Negel et al. Optics Express 23 (16), 21064 (2015)

Multi-Pass Amplifier: Material Processing

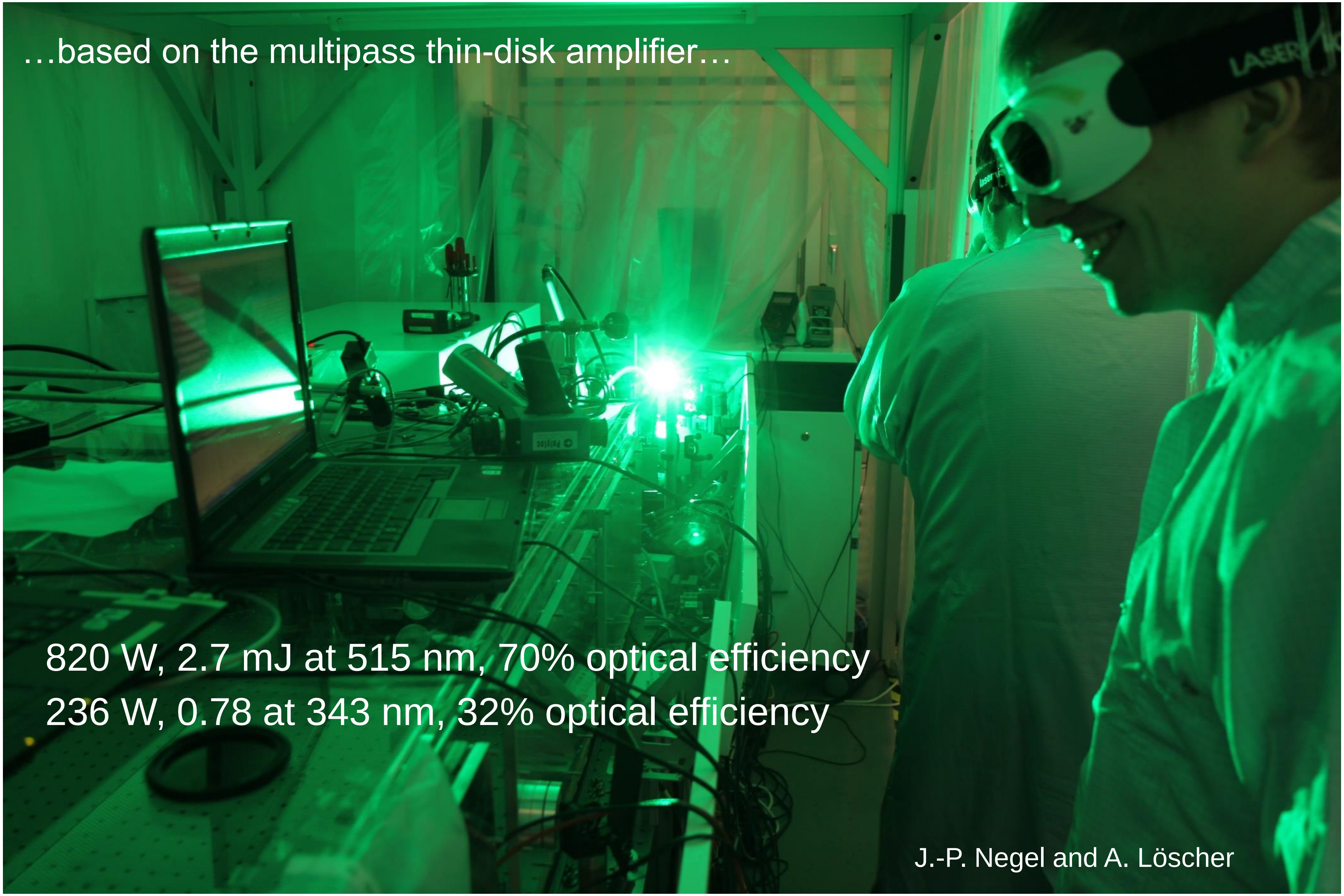
Freitag, Negel, Löscher, Wiedenmann



- Cutting of 2 mm thick carbon fiber reinforced plastic (CFRP) at $v_{eff} \approx 0.9$ m/min (not yet optimized)



Ultrafast Thin-Disk Multi-Pass Amplifier



Amplification of cylindrically polarized laser beams

- All this work was achieved within the European Project „Ultrafast_RAZipol (GA 619237)“:

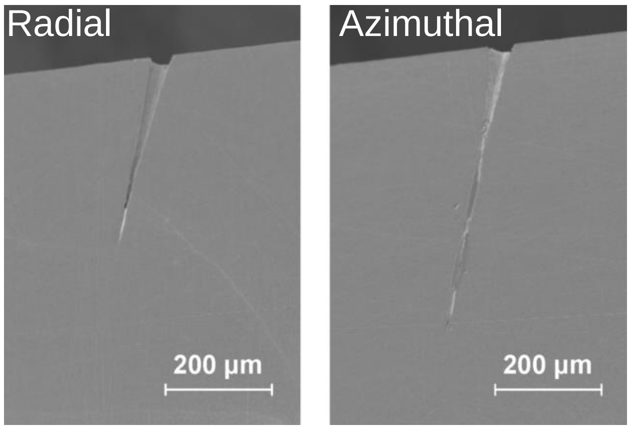
- The setup and experimential results presented in this contribution were performed by the IFSW, University of Stuttgart

- The seed laser was provided by the project partners:
  - Lumentum
  - Laboratoire Charles Fabry, Institut d‘Optique, CNRS
  - Fibercryst SAS

The Ultrafast_RAZipol project has received funding from the European Community’s Seventh Framework Programme under Grant Agreement No. 619237

Amplification of cylindrically polarized laser beams

- Ultrafast Lasers for micromachining with radial or azimuthal polarization
  - Demonstration of high levels of productivity and precision in drilling[2] and large area surface structuring

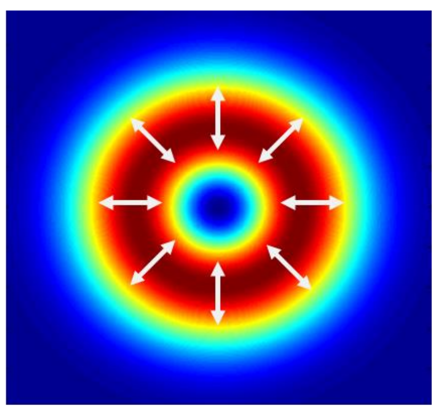


[2]

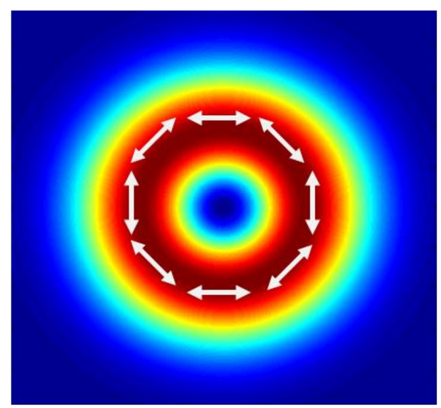
for injection nozzles, air bearings, spinnerets, …

[1]

for LOCs, MEMs, filters, …



Radial polarization state



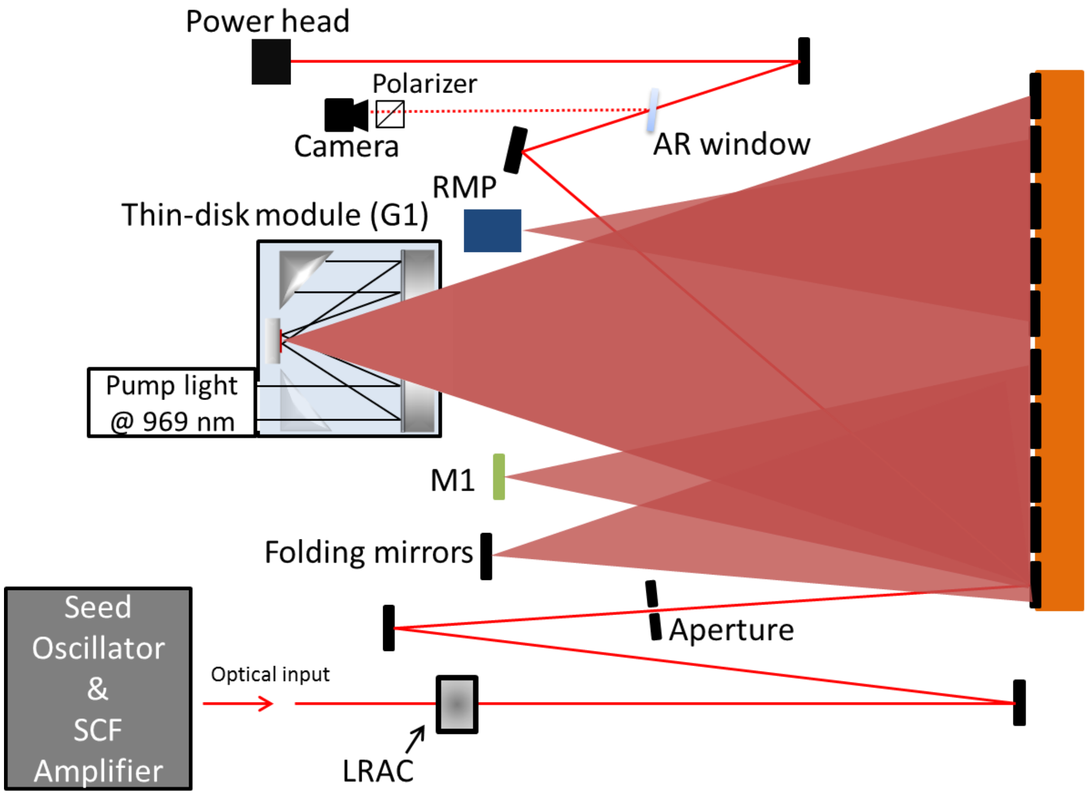
Azimuthal polarization state

[1]SLV M-V GmbH

[2]Opt. Express. ***18****, 22305-13 (2010)*

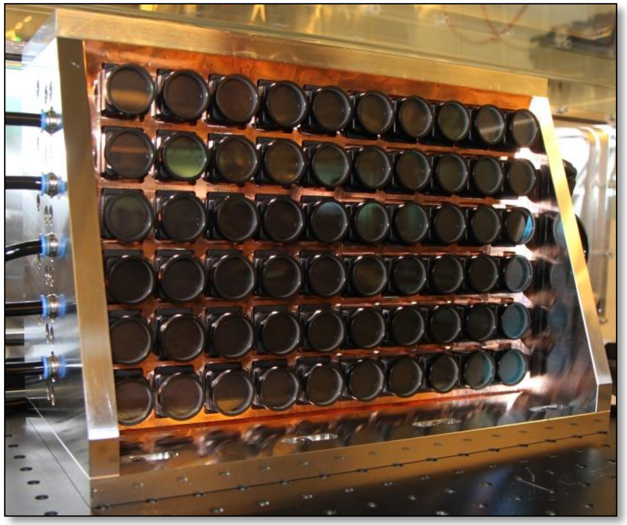
Amplification of cylindrically polarized laser beams

- Experimental Setup: Yb:YAG thin-disk multipass amplifier[3]
  - Folding mirrors are plane
  - RoC of the thin-disk is around 20 m



Reflecting mirror pairs (RMP)

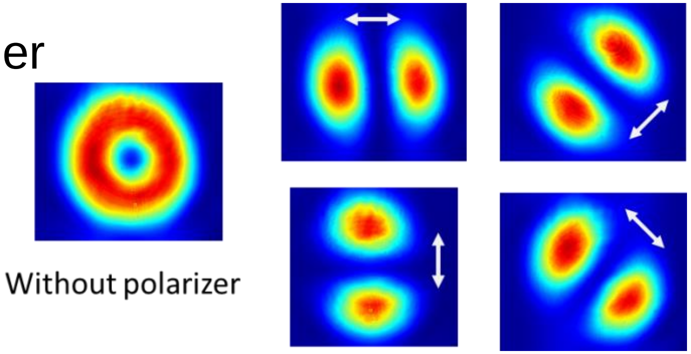
Mirror array, 10x6



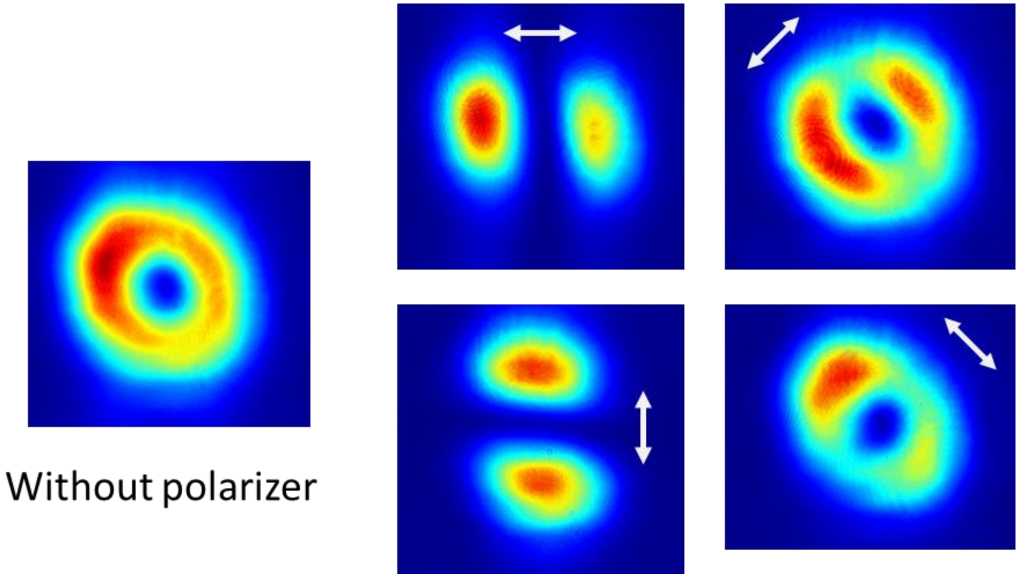
[3]*Opt. Express.* ***23***, *21064-77 (2015)*

Amplification of cylindrically polarized laser beams

- Polarization analysis of the beam
  - Laser beam <u>before</u> entering the amplifier
  - around 50 W



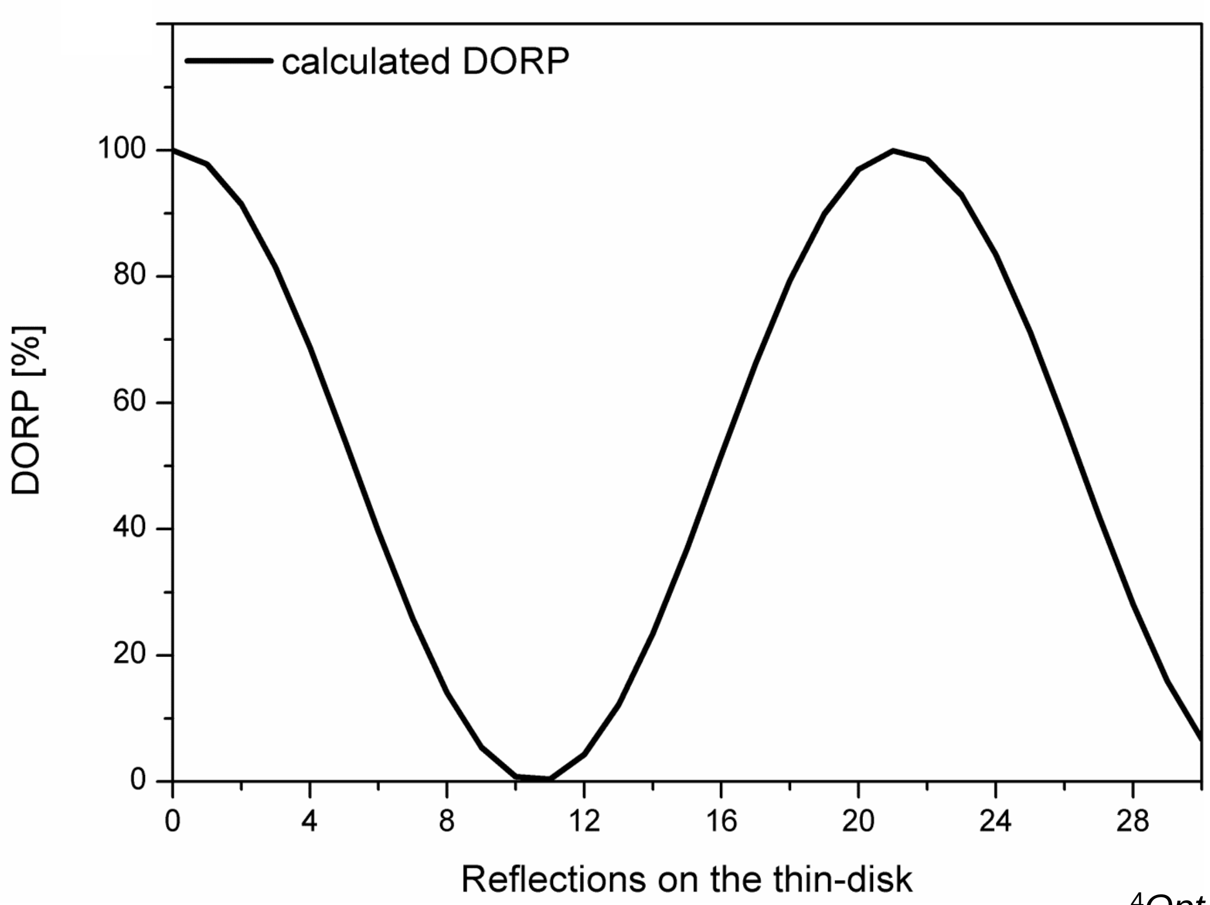
  - Laser beam <u>after</u> the amplifier (without amplification!)



→ Strong depolarization during propagation in the multipass amplifier

Amplification of cylindrically polarized laser beams

- Main cause: Phase shift introduced by the 45° tilting mirrors (RMP)
  - Measurement shows it amounts to 17° +/- 2°
- Evolution of the degree of radial polarization (DORP) during propagation[4]
  - Assuming an incident beam with DORP = 100% and phase-shift per pass=17°

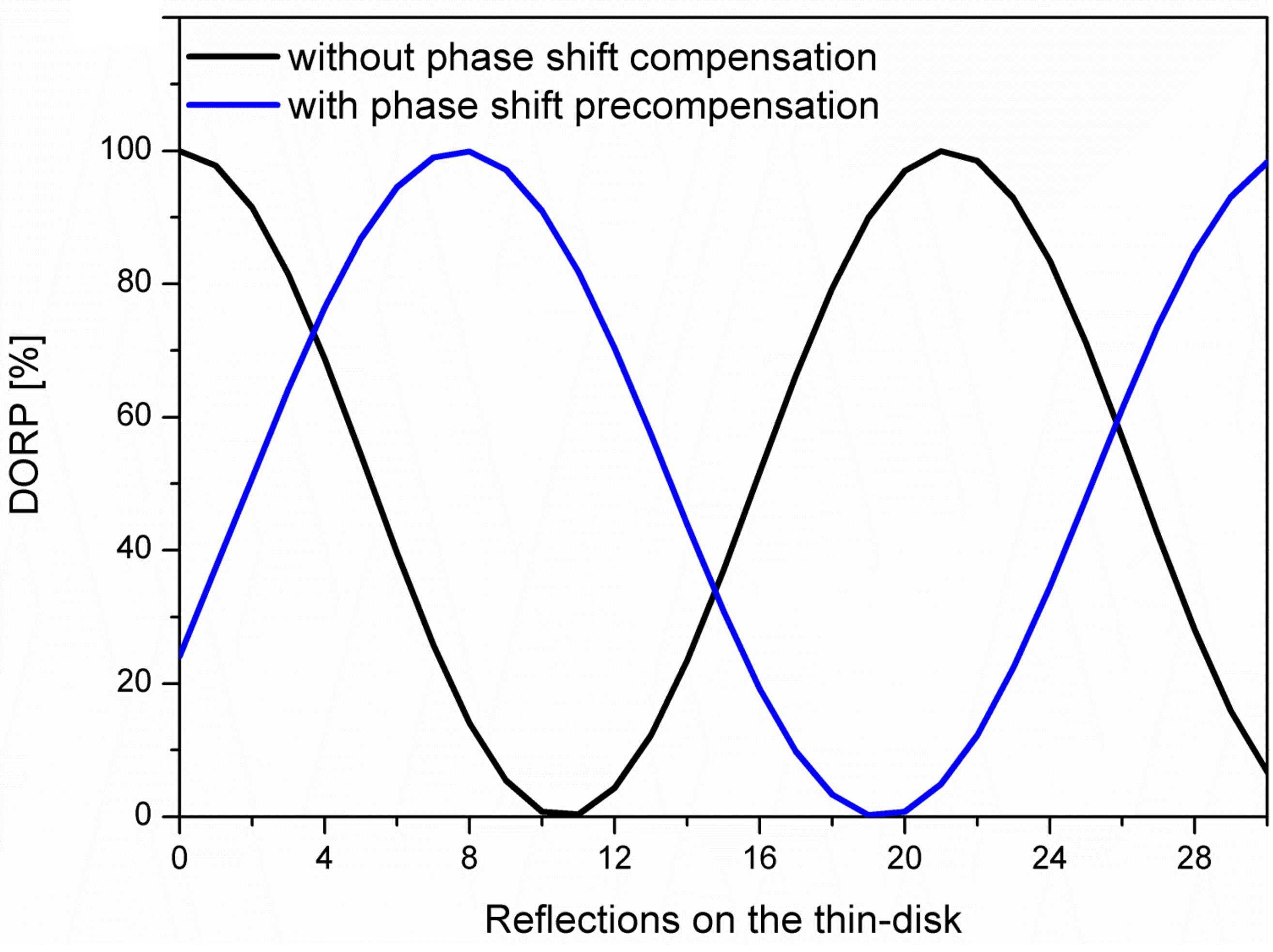


Radial polarization state degraded !

[4]*Opt. Lett.* ***32****, 83-85 (2007)*

Amplification of cylindrically polarized laser beams

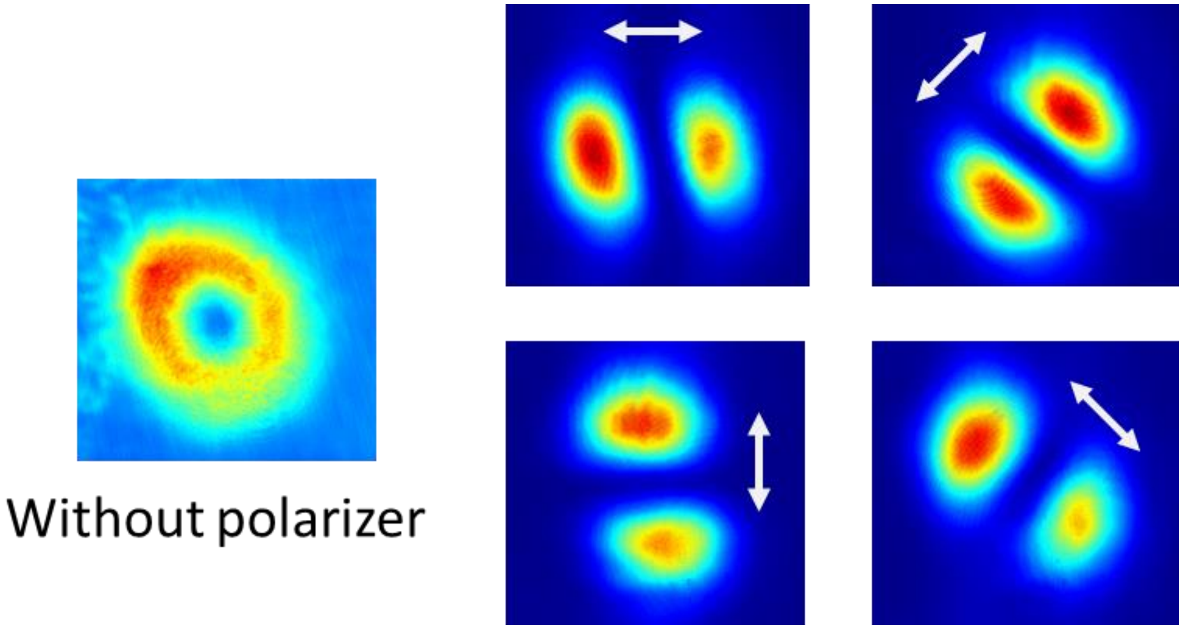
- Integration of compensation scheme (tunable waveplate) in the beam path (before the multipass amplifier)



Good Radial polarization state!
> 90 %

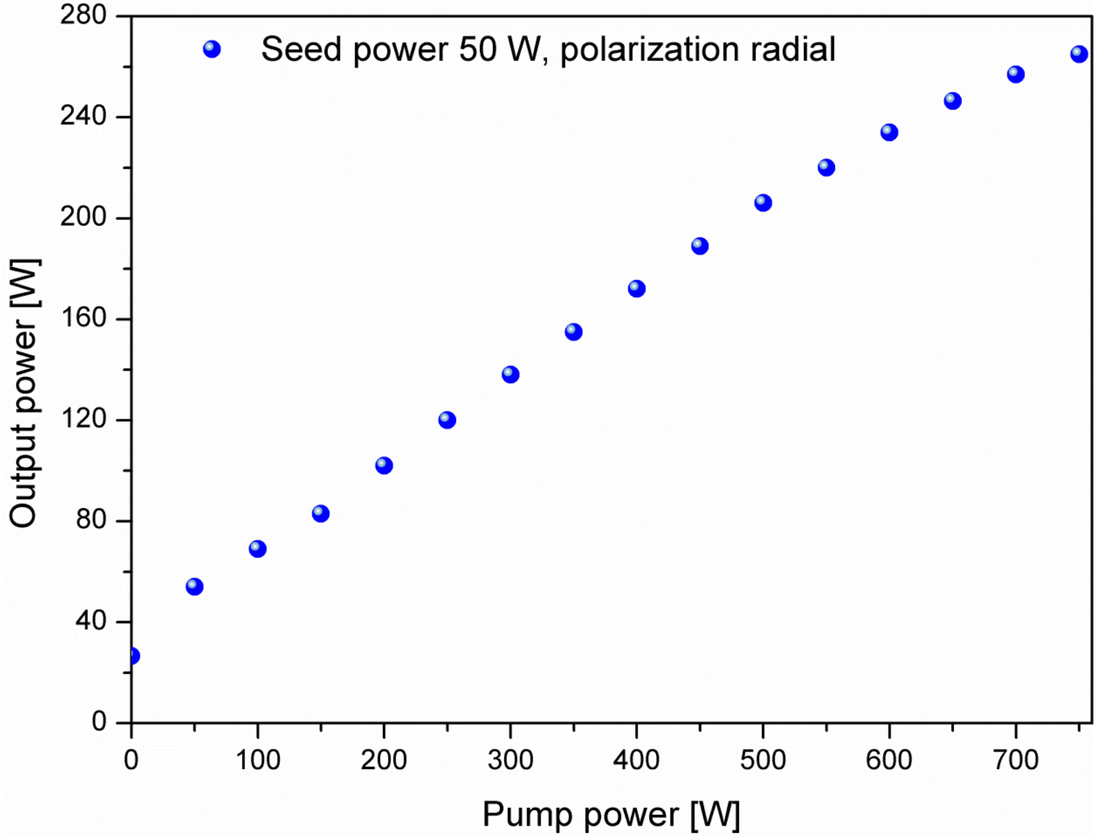
Amplification of cylindrically polarized laser beams

- Integration of compensation scheme (tunable waveplate) in the beam path (before the multipass amplifier): <u>without amplification</u>
    - Recovery of the high degree of radial polarization (>90%): clearly separated lobes



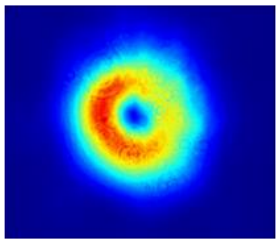
Amplification of cylindrically polarized laser beams

- Amplication experiments
  - Seed: 50 W, 20 MHz, 727 fs
  - Output power: **265 W, 13.25 µJ @ 750 W pump power**
  - Amplification factor of **5.3**, slope efficiency of **32.3 %**, optical efficiency of **28.7 %** at max. output power

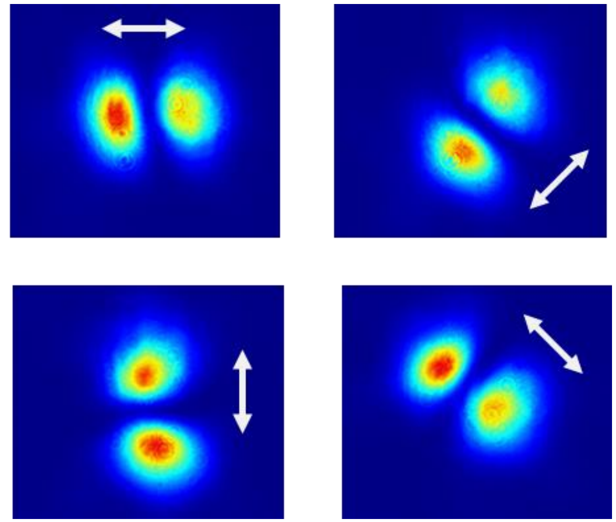


Amplification of cylindrically polarized laser beams

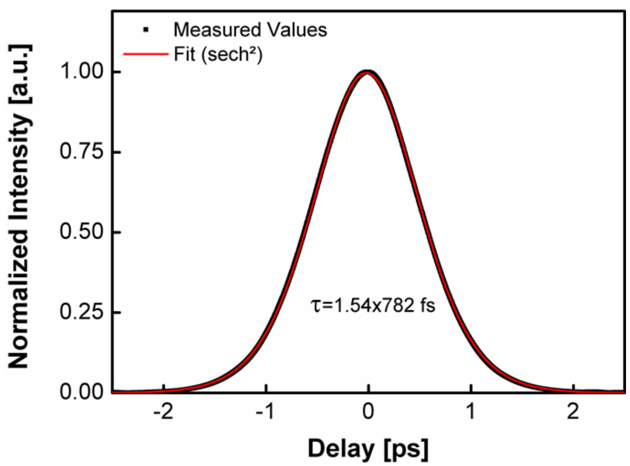
- Polarization analyisis of the amplified beam
  - High degree of radial polarization @ 250 W of average output power

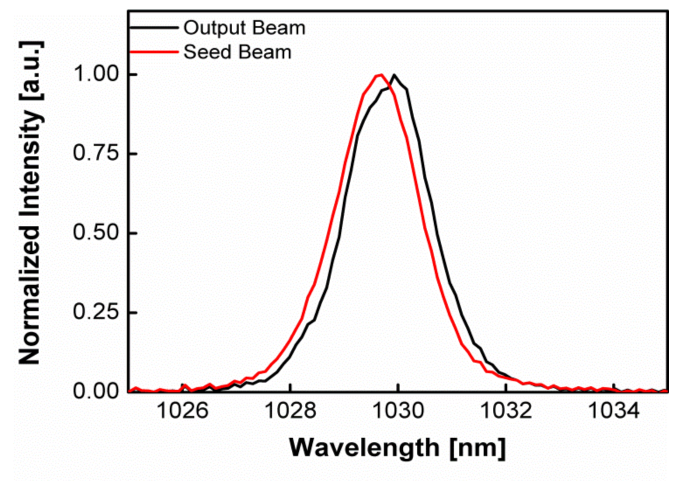


Without polarizer



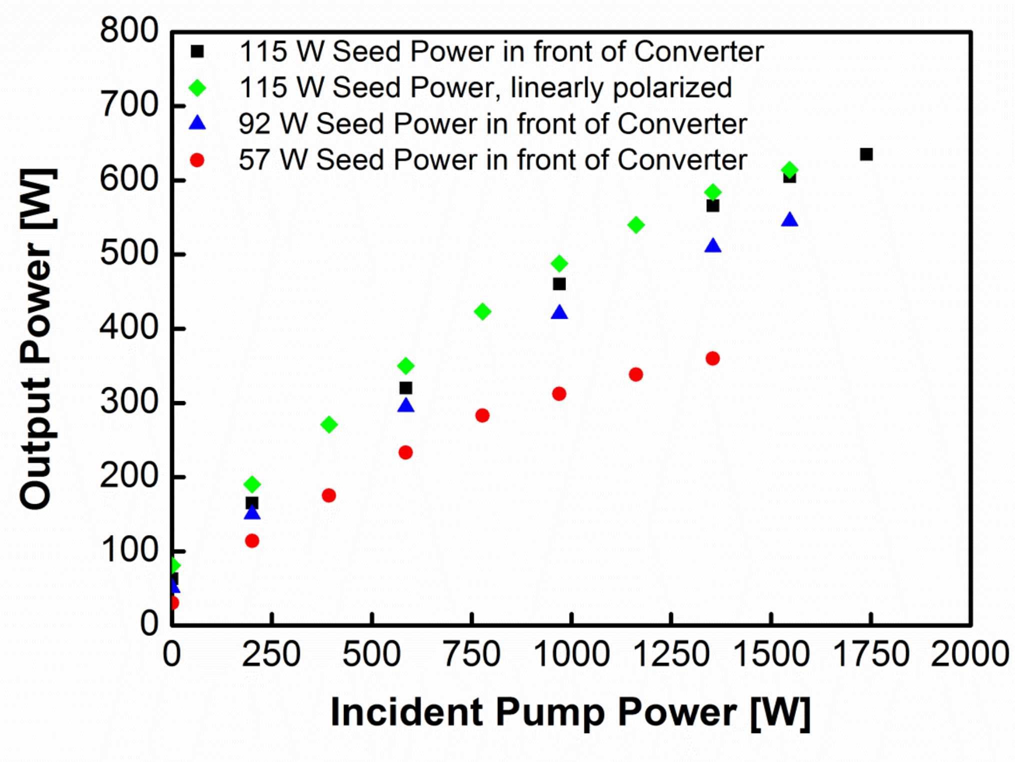
- Pulse duration: **782 fs**

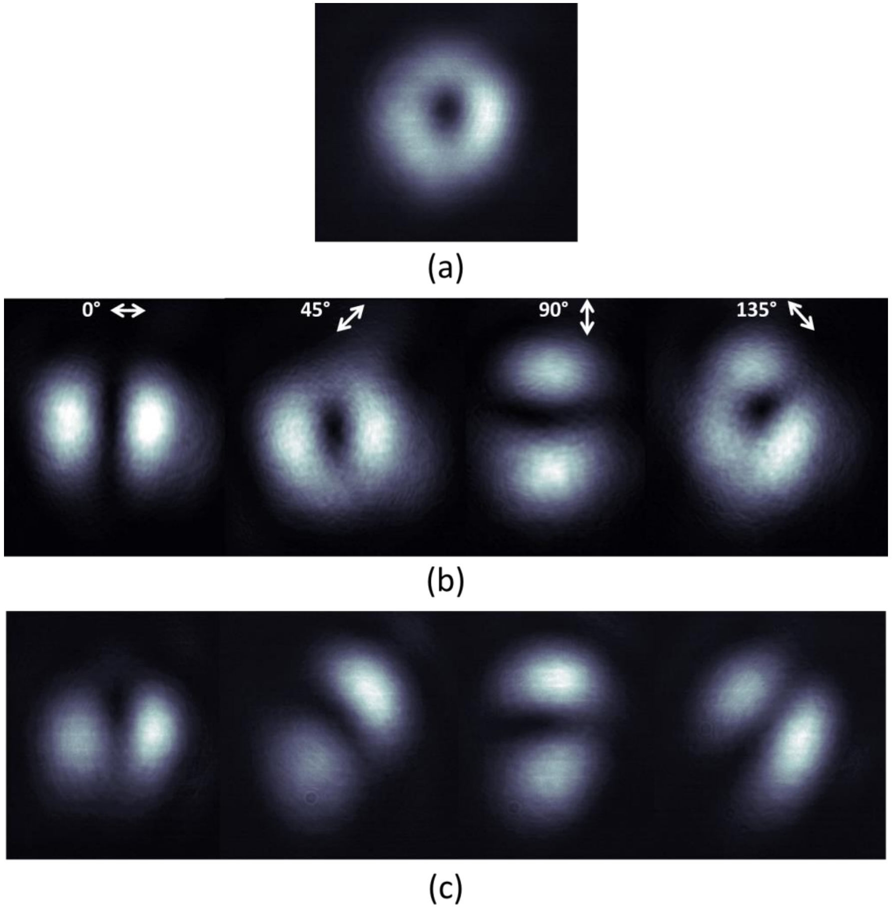




Amplification of cylindrically polarized laser beams

- High-power and high energy results





- **635W, 300kHz, 2.1 mJ**

Future thin-disk laser development

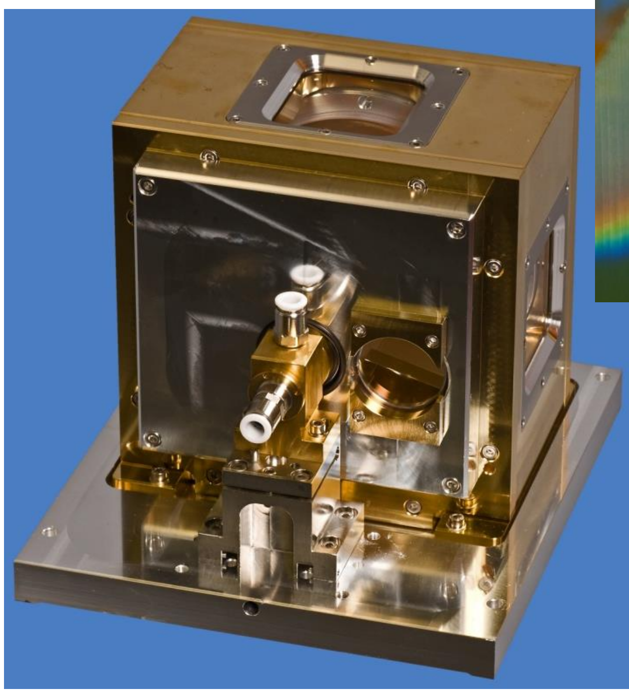
- > 2KW ps/fs thin-disk multipass amplifier
  - >1kW green & >500W UV
- thin-disk multipass amplifier with1kW ps/fs cylindrically polarized
- Industrial implementation of kW-class ps/fs system (at least 500W) based on thin-disk multipass amplifier...in the near future?

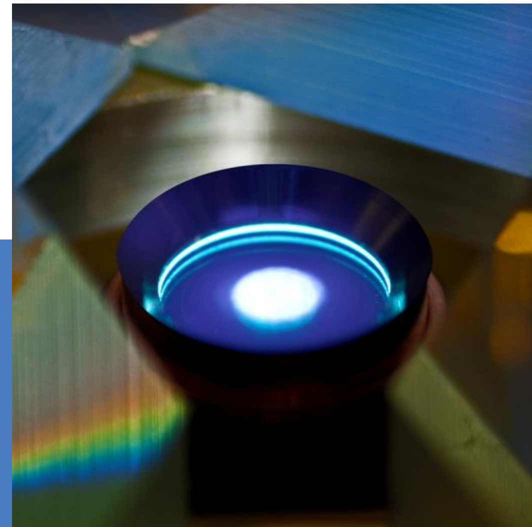
Acknowledgment

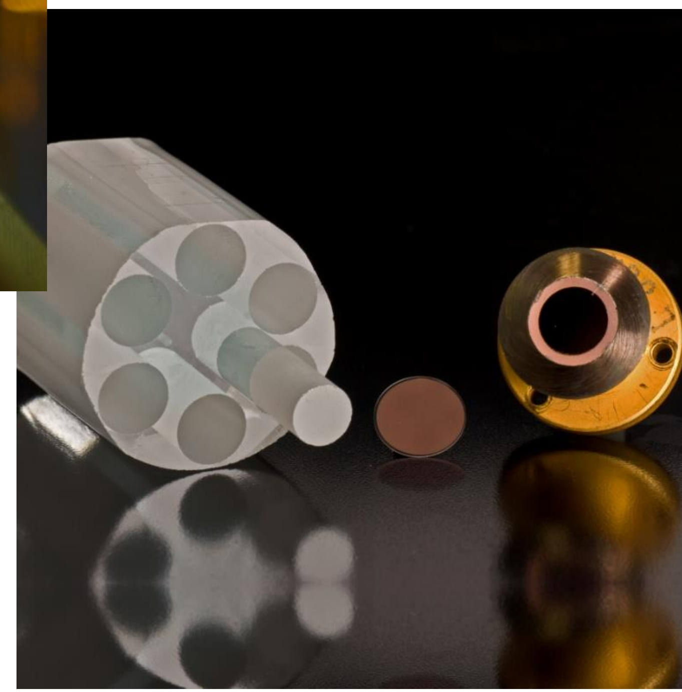
The research leading to these results has received funding from the European Union Seventh Framework Programme [ICT-2013.3.2- Photonics] under grant agreement n°619237. Ultrafast_RAZipol : www.razipol.eu

- TRUMPF Laser GmbH
- German Federal Ministry of Education and Research (BMBF)

Thank you for your attention







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