# Ultrafast_RAZipol

## Thin-disk multipass amplifier delivering radially polarized beams with kW-class output power and femtosecond pulse duration

**The results presented here have been achieved within the project Ultrafast_RAZIPOL which aims at the development of ultrafast lasers with radial and azimuthal polarizations for high-efficiency micro-machining applications. Applications include drilling of holes (e.g. injection nozzles, spinnerets) with high aspect ratios (>20:1) with a decreased process time at high precision as well as large area structuring (e.g. lab-on-chip). Ultrafast_RAZIPOL will combine fast scanners with a three stage MOPA system to achieve 1 ps pulses at 20 MHz repetition rate and 500 W of average power. This system will be dedicated for the large area structuring applications. A second system which will be coupled to a trepanning optics for the drilling of high-aspect ratio holes shall deliver 5-6 ps pulses with 1 mJ pulse energy at an average power of 200 W.**

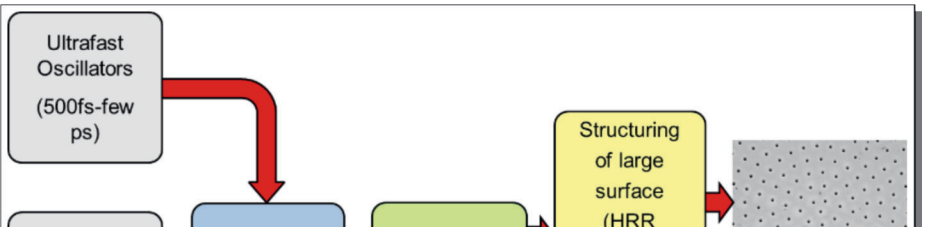


*Fig. 1: Schematic overview of the project structure.*

Ultrafast_Razipol comprises two laser technology research and development Centres (Universität Stuttgart, Institut für Strahlwerkzeuge and French National Center for Scientific Research (CNRS) - Laboratoire Charles Fabry), five SME partners and a laser process research institute (SLV M-V GmbH). The consortium is well balanced in comprising four partners providing the necessary expertise in laser sources, ultrafast technology and power-scaling (Universität Stuttgart, Institut für Strahlwerkzeuge, French National Center for Scientific Research - Laboratoire Charles Fabry, Lumentum and Fibercryst) and four partners (GFH GmbH, Next Scan Technology, Class 4 Laser Professionals AG, and SLV M-V GmbH) providing the necessary expertise in machines, optics and laser process development. Figure 1 shows the overall project structure.

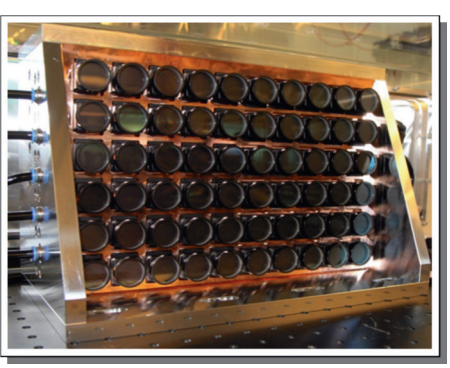

*Fig. 2: Photo of the array of 60 mirrors used within the thin-disk multipass amplifier.*

The Master Oscillator Power Amplifier (MOPA) system developed within Ultrafast_RAZipol combines an ultrafast oscillator (provided by Lumentum) together with a Single Crystal Fiber (developed by Fibercryst and CNRS-Laboratoire Charles Fabry) as 1st amplification stage and a thin-disk multipass amplifier (developed by Universität Stuttgart, Institut für Strahlwerkzeuge) as booster stage.

In the following, we present the amplification of femtosecond beams with radial polarization in a thin-disk multipass amplifier architecture as described in references [1,2]. Figure 2 shows a photo of the array of 60 mirrors used for the thin-disk multipass amplifier.

The Single Crystal fiber amplifier (SCF) delivers a linearly polarized beam with an output power of up to 60 W ($M^2 < 1.25$) at a pulse duration of 727 fs and a repetition rate of 20.5 MHz. In a sub-sequent step, the linear polarization of the seed laser is converted to radial by means of a linear to radial/azimuthal polarization converter (LRAC) composed of 8 half-wave segments. After the LRAC, a radially polarized beam with an output power of 50 W is obtained. Figure 3 shows the recorded intensity distribution of the converted beam without and with polarization analyzer at different orientation confirming the radial polarization behavior of the transmitted laser beam.

The multipass amplifier is similar to the one reported in [1] but it uses an array of 60 individually adjustable mirrors instead of 40, since the amplifier is operated in a single pass configuration due to the radial polarization. An Yb:YAG thin-disk

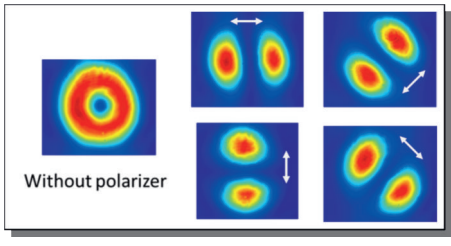


*Fig. 3: Intensity distribution of the radially polarized beam without and with polarizer implemented in the beam path and oriented at 0°, +/-45° and 90°.*

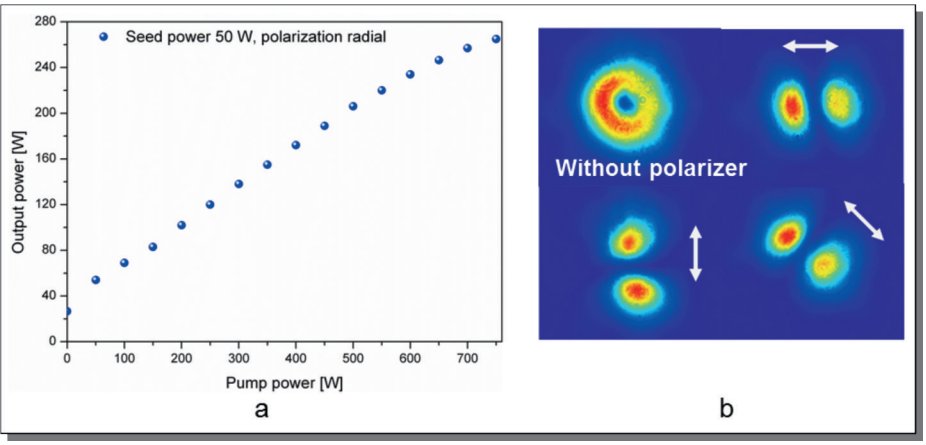


*Fig. 4: a) Extracted power versus pump power for 30 reflections over the disk with a 50 W radially polarized seed beam and b) polarization analysis of the output beam at 250 W of extracted power. White arrows indicate the transmission axis of the polarizer.*

with a diameter of 15 mm, a radius of curvature of around 20 m, and a thickness of approximately 110 µm (at a doping concentration of 11%) was mounted on a diamond heat sink at the IFSW and is used as amplifier medium. The disk is pumped at 969 nm wavelength (with stabilized laser diode provided by DILAS) by a multipass cavity with 24 passes (standard "G1- module" as commonly provided by IFSW). The pumped spot has a diameter of approximately 5.2 mm. The radially polarized seed beam is collimated with a beam diameter of 4.4 mm. Figure 4 a) shows the extracted output power versus the incident pump power at a seed power of 50 W. As can be seen, up to 265 W of average output power (at a pump power of 750 W) could be extracted in a single pass through the multipass amplifier. This corresponds to an amplification factor of 5.2 and an optical efficiency of 28.6%. The qualitative polarization analysis of the extracted beam at an output power of 250 W is shown in figure 4 b).

The measured pulse duration after the multipass as well as the measured optical spectra before and after the multipass amplifier are shown in figure 5 a) and b), respectively. Assuming a sech² temporal shape, a pulse duration of 727 fs was measured at the entrance of the multipass amplifier and 782 fs at the output of the multipass amplifier.

In a further optimization step of the SCF and the thin-disk multipass amplifier, we could extract beams with radial polarization with an output power of up to 580 W at an optical efficiency of 50.7%. Figure 6 shows the recorded intensity distribution of the amplified beam at 580W, without and with polarization analyzer at different orientation confirming the radial polarization behavior of the transmitted laser beam.

In conclusion, we have demonstrated an efficient amplification of beams with radial polarization in a thin-disk multipass amplifier. Laser pulses at femtosecond pulse duration with an average power of 580 W and an optical efficiency of 50.7% could be generated.

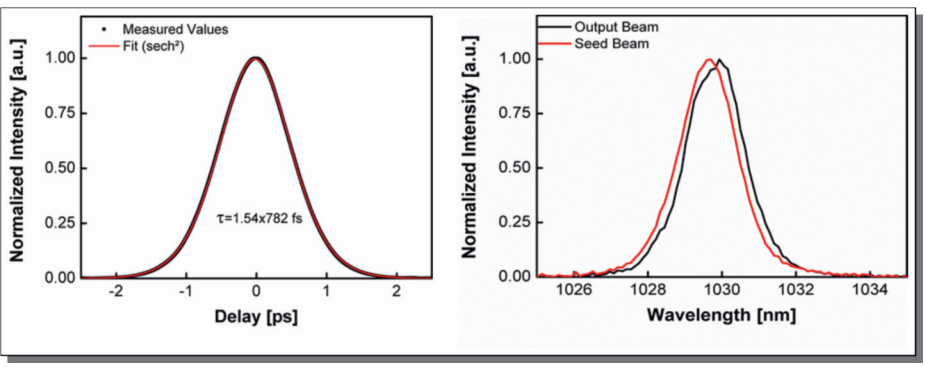


*Fig. 5: a) Autocorrelation trace of the output beam and b) spectra of the output and seed beam.*

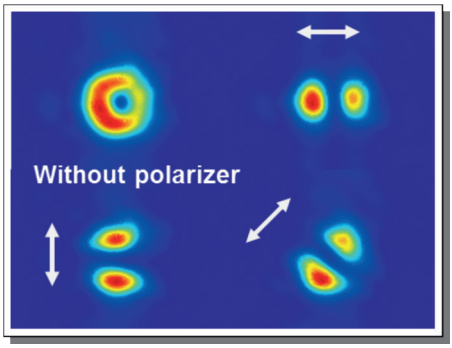


*Fig. 6: Polarization analysis of the output beam at 580 W of extracted power. White arrows indicate the transmission axis of the polarizer.*

**References**:

[1] J. Negel, A. Loescher, A.Voss, D. Bauer, D. Sutter, A. Killi, M. Abdou Ahmed, and T. Graf, "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).

[2] A. Loescher, J. Negel, T. Graf, and M. Abdou Ahmed, "Radially polarized emission with 635 W of average power and 2.1 mJ of pulse energy generated by an ultrafast thin-disk multipass amplifier," Opt. Lett. 40, 5758-5761 (2015).

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