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New lasers enabling next generation micro-processing

P. Russbueldt[1], T. Mans[2], H.D. Hoffmann[1] and R. Poprawe[1,2]

[1] Fraunhofer Institute for Laser Technology, Steinbachstr. 15, 52074 Aachen, Germany

[2] Chair for Laser Technology RWTH Aachen, Steinbachstr. 15, 52074 Aachen, Germany

Abstract

We demonstrate a compact diode-pumped Yb:YAG Innoslab femtosecond oscillator-amplifier system with nearly transform and diffraction limited 636 fs pulses at 620 W average output power and 20 MHz repetition rate. By cascading two amplifiers an output power of 1.1 kW and peak power of 80 MW is achieved. To our knowledge this is the highest average power for fs-pulses reported up to now.

Introduction

Mainly due to the improvements of power and brightness of laser diodes new solid state laser designs capable of kW average power pave the way to ultrafast lasers of much higher average power than the familiar Ti:sapphire lasers. Innoslab and fiber technology already demonstrated almost diffraction limited 400 W [1] resp. 830 W [2] average power at 700 fs pulse duration. In this paper we present an Innoslab based setup generating 1.1 kW average power.

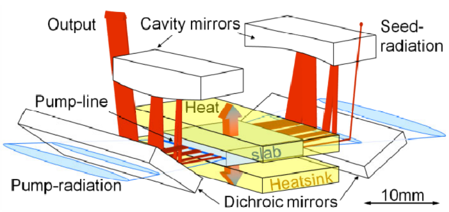

Fig. 1: *Cavity setup of an Innoslab amplifier*

An Innoslab laser or amplifier consists of a longitudinally, partially pumped slab crystal [1]. The short distance between the pumped gain volume and the large cooled mounting surfaces allow efficient heat removal and supports diffraction limited beam quality (Fig.1). One-dimensional heat flow establishes a homogeneous cylindrical thermal lens and avoids depolarization. In an amplifier two cylindrical mirrors fold the laser radiation several times through the gain volume. In the plane of the pump line the beam is expanded each passage through the laser crystal by a constant factor (Fig. 1). In the perpendicular plane the thermal lens reproduces the laser mode on every roundtrip. The thin gain volume matches beam characteristic of commercial laser diode bars, whose power and brightness enable strong excitation of the ytterbium ions. Innoslab lasers are single-pass amplifiers. With up to 9 passes inside the confocal cavity amplification factors up to 1000 are achieved. Beam expansion on every passage through the slab balances the increase of power, avoids optical damage and minimizes the B-integral.

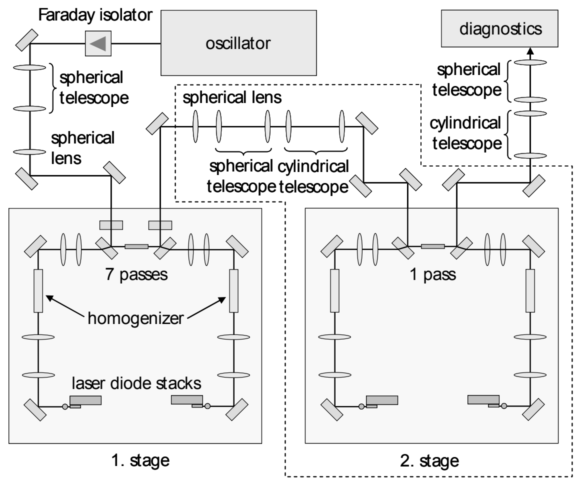

Fig. 2: *Single and dual stage amplifier setup*

In the setup presented here, in both amplification stages two horizontal laser diode stacks (JOLD-720-HSC-4L) providing up to 660 W at $\lambda_p = 940$ nm each are imaged into a planar waveguide for homogenization in slow axis (Fig.2). Afterwards the exit of the waveguide is imaged by a relay optic into the 1x10x10 mm^3 Yb:YAG crystal (2.5 % doping level). The two pump modules enclose the cavity of the two amplifier modules in Fig. 2. In the first stage the confocal cavity of magnification $M = 1.6$ consists of two cylindrical mirrors and two plane dichroic folding mirrors. For even higher output power the 7-pass first stage is imaged by three spherical and two cylindrical lenses to second stage (Fig.2). The imaging ensures power independent mode matching of the second amplifier stage. The high output power of the first stage allows for efficient power extraction out of the second stage by one pass.

The amplifier was seeded by a Yb:KGW oscillator (HighQ Laser Innovation GmbH) at $\nu = 20$ MHz repetition rate. No stretcher or cylindrical beam transformation were employed. An optical isolator was inserted to protect the oscillator. Up to $P = 620$ W average power has been extracted from the first stage at $P_S = 2.3$ W seed power and 2x 200 A diode current corresponding to $P_P = 1250$ W pump power. Pulse duration has been $\tau = 636$ fs (FWHM, sech^2-fit, $\tau\Delta\nu = 0.365$) and pulse energy $E = 31$ µJ. The radiation after the first stage can be transformed by a cylindrical telescope into a circular beam. Beam quality was measured (Spiricon M2-200/v.4.2, 2nd momentum method) to be $M_x^2 = 1.43$ and $M_y^2 = 1.35$ respectively.

With the two stage setup up to $P = 1.1$ kW of linearly polarized fs-radiation has been extracted at $P_P = 1249 + 1180$ W pump power. After 7+1 passes the laser pulses of $\tau = 615$ fs duration (FWHM, sech^2-fit) stay transform limited ($\tau\Delta\nu = 0.362$; Fig.3). At 20 MHz repetition rate and $E = 55$ µJ pulse energy there is no sign of self phase modulation, the single pass in the second stage only slightly increases the B-integral from $B = 1.6$ to $B = 1.8$. Gain narrowing reduces the spectral bandwidth $\Delta\lambda_S = 4.4$ nm of the oscillator to $\Delta\lambda = 2.02$ nm after amplification(Fig.3).

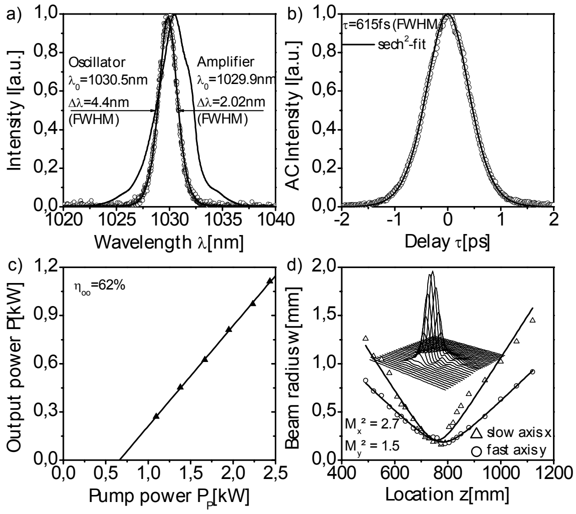

Fig. 3: *Power characteristic (c) of amplifier chain seeded by 2.3 W. Spectra of fs-oscillator and amplifier (a), autocorrelation fitted by sech² (b), beam radius and profile (d) at $P_{out} = 1.1$ kW output power.*

After amplification a cylindrical telescope transforms the radiation into an almost circular beam. Beam quality behind transformation was measured to be $M_x^2 = 1.5$ and $M_y^2 = 2.7$ respectively at $P = 1.1$ kW output power (Fig.3)

Acknowledgements

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References

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