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Latest developments in Lastronics Yb-doped amplifiers and pump engines

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Introduction

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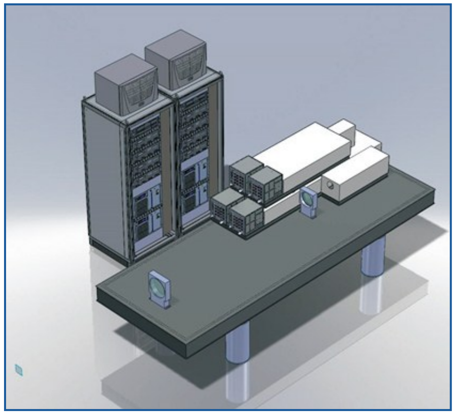
- Lastronics started building Ytterbium-based amplifiers in May 2013
- Our staff has accumulated experience in building Yb-based laser amplifiers since 1998 (POLARIS, IOQ Jena)
- Amplifiers are build on the basis of our pump engines, which are produced since 2009
- Lastronics pump engines are available with output peak powers from 2 kW up to several hundred kW, repetition rates of (0 … 250 Hz), duty cycles of up to 22% for pulsed pumping, c.w. pumping solutions and all suitable wavelengths for Yb and Nd pumping



Overview of the presentation

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1 – Recently completed LTX products & current development

1.1 – 80 mJ Yb:YAG ns front end with square output beam profile

1.2 – 150 mJ Yb:YAG ns multipass amplifier

1.3 – 80 kW, hexagonally homogenized pump engine

1.4 – 2 kW, 100 Hz pump engine with 20% duty cycle

1.5 – 3.3 kW cw pump engine

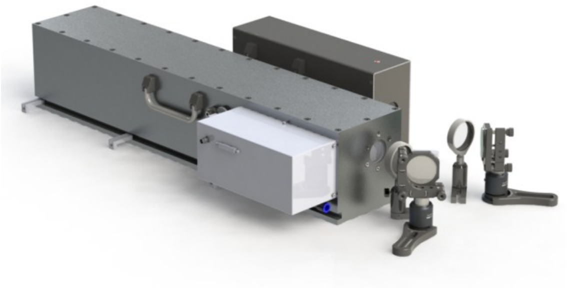
2 – Future projects & Outlook

2.1 – 10 J Yb:YAG amplifier (Ti:Sa pump)

2.2 – Pump modules with higher brightness and higher output power

- ELI beamlines Prague: 100 J Amplifier chain for OPCPA pumping

- Lastronics to build two front-end amplifiers:
  - 0.5 mJ regenerative amplifier
  - 80 mJ multipass relay imaging amplifier

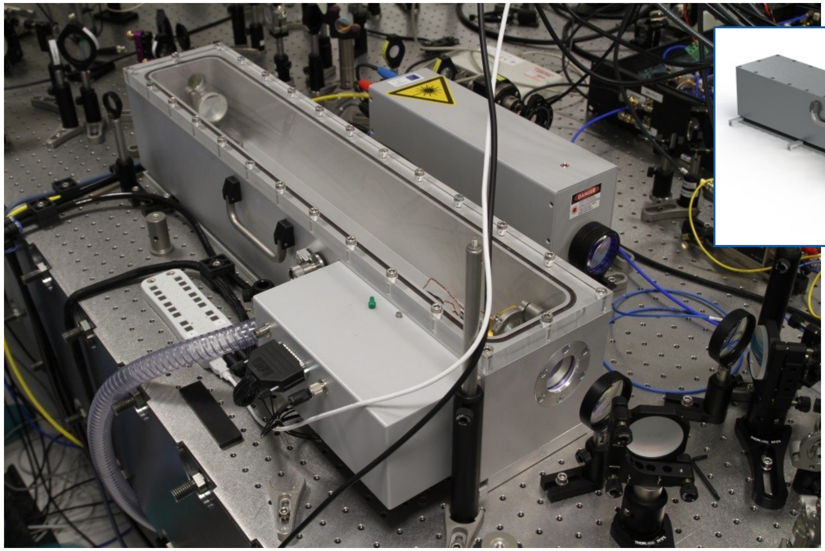


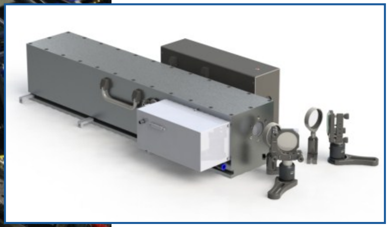
- Requirements of front-end output after Multipass:
  - Output beam profile: square top-hat, <7% rms intensity, Beam quality: $M^2 < 1.2$
  - Pulse duration: 2 ns … 20 ns
  - Pulse-to-pulse stability: Standard deviation within ± 1% of mean pulse energy from continuous sample of 1,000 pulses
  - Pulse energy drift over 8 hours: <1.5%

1 – Recently completed LTX products & current development

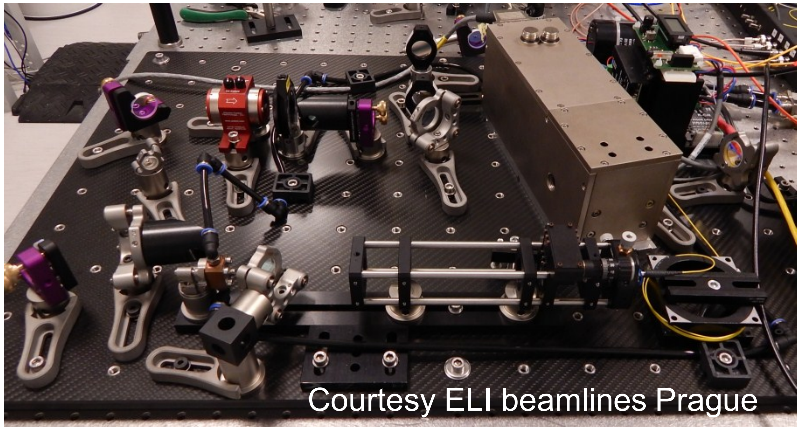
1.1 – 80 mJ Yb:YAG ns front end with square beam profiles

Installation of the 80 mJ multi-pass system





Installed Multipass amplifier (February 2014)



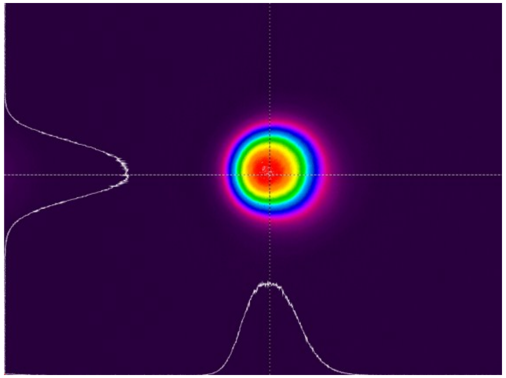
Installed preliminiary regenerative amplifier
(December 2013)

1 – Recently completed LTX products & current development

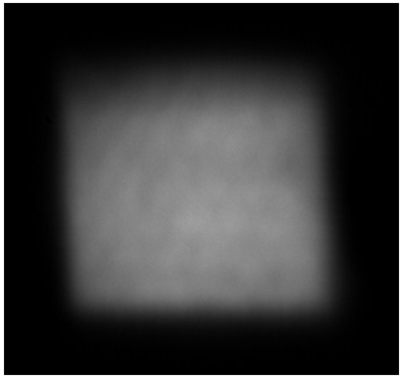
1.1 – 80 mJ Yb:YAG ns front end with square beam profiles

Measurements at the front-end:

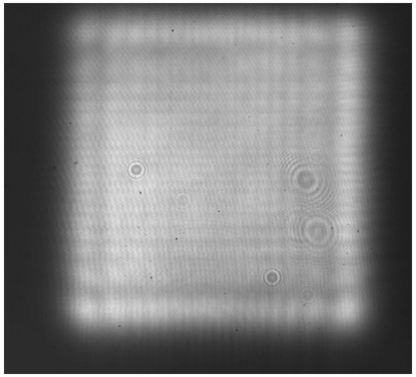
Beam Profiles



Regenerative amplifier
330 µJ



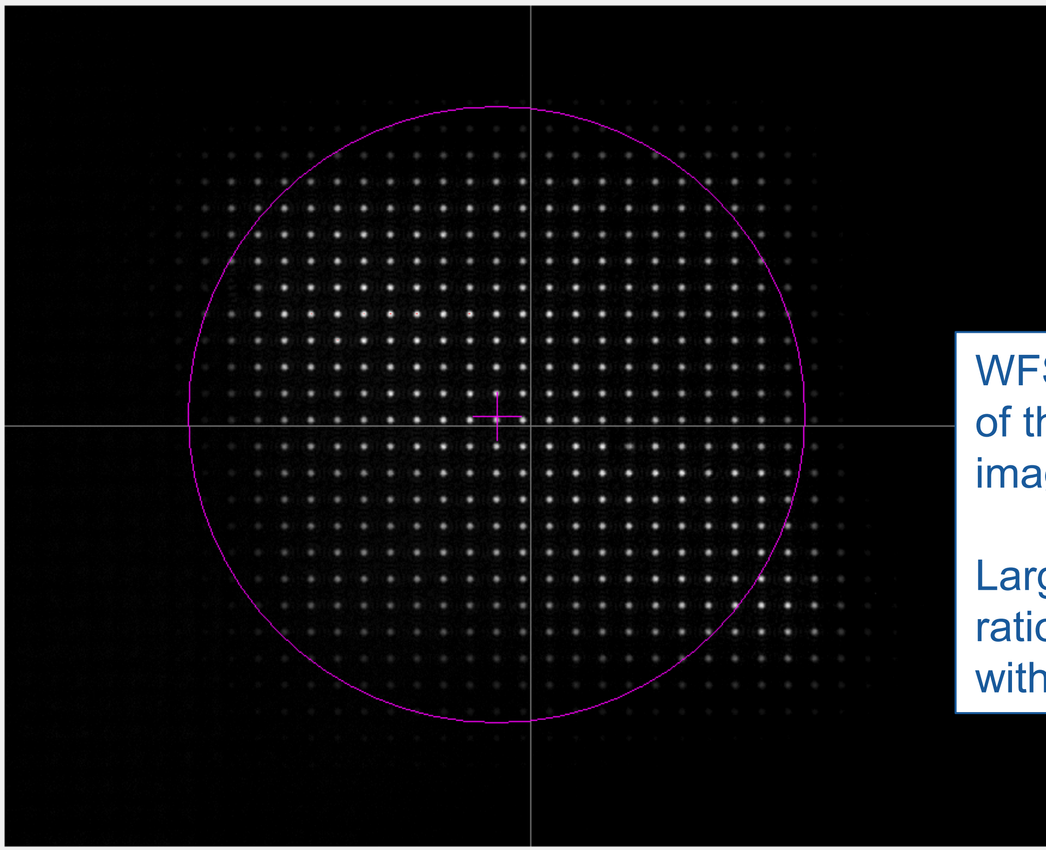
Multipass amplifier
max. 110 mJ
7% rms
2x2 mm²



First results with
serrated aperture
22x22 mm²
(Mar 19, 2014)

Measurements at the Prague front-end (2):

Beam data/mm	
Ctr x	-0.189
Ctr y	0.058
Dia x	3.967
Dia y	3.317
Wavefront/μm	
(User Cal. Ref.)	
(entire area)	
PV	84.175
RMS	19.952
wRMS	18.408
Fourier	
M	0.008
J0	0.040
J45	0.077
Optometric	
Sphere	0.094
Cyl.	-0.173
Axis	31.340°
RoC (	123.9m)
RMS Variations/μm	
RMS(n = 0)	
RMS(n = 1)	
RMS(n = 2)	0.054
RMS(n = 3)	0.014
RMS(n = 4)	0.026
RMS(n = 5)	0.006
Zernike Modes/μm	
Z 1(0/ 0)	
Z 2(1/-1)	
Z 3(1/ 1)	
Z 4(2/-2)	-0.048
Z 5(2/ 0)	-0.004
Z 6(2/ 2)	-0.025
Z 7(3/-3)	0.008
Z 8(3/-1)	-0.008
Z 9(3/ 1)	-0.004
Z10(3/ 3)	-0.006
Z11(4/-4)	-0.009
Z12(4/-2)	0.013
Z13(4/ 0)	0.019
Z14(4/ 2)	-0.003
Z15(4/ 4)	0.009
Z16(5/-5)	0.000
Z17(5/-3)	0.003
Z18(5/-1)	0.003
Z19(5/ 1)	0.004
Z20(5/ 3)	-0.001
Z21(5/ 5)	0.003



WFS measurements of the 80 mJ output in the image plane:

Largest wave front aberration is **astigmatism** with Z(2,2) = $\lambda/40$

1 – Recently completed LTX products & current development

1.1 – 80 mJ Yb:YAG ns front end with square beam profiles

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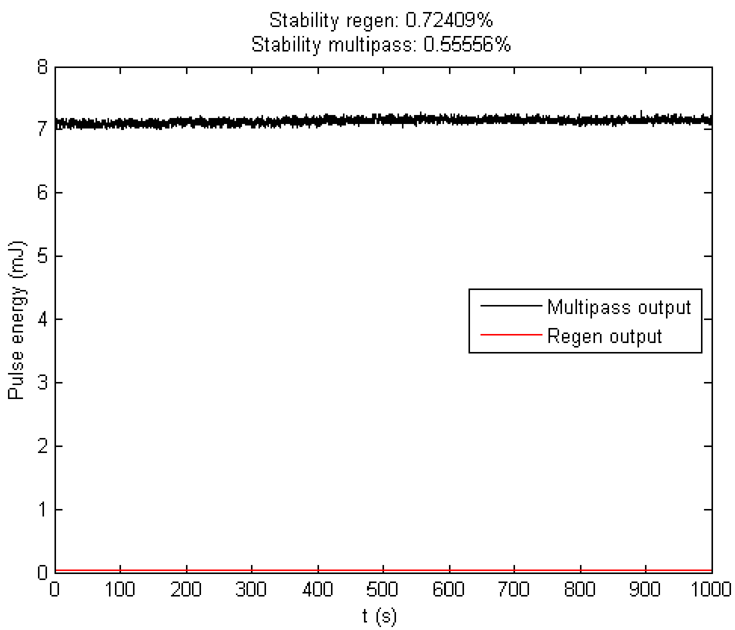
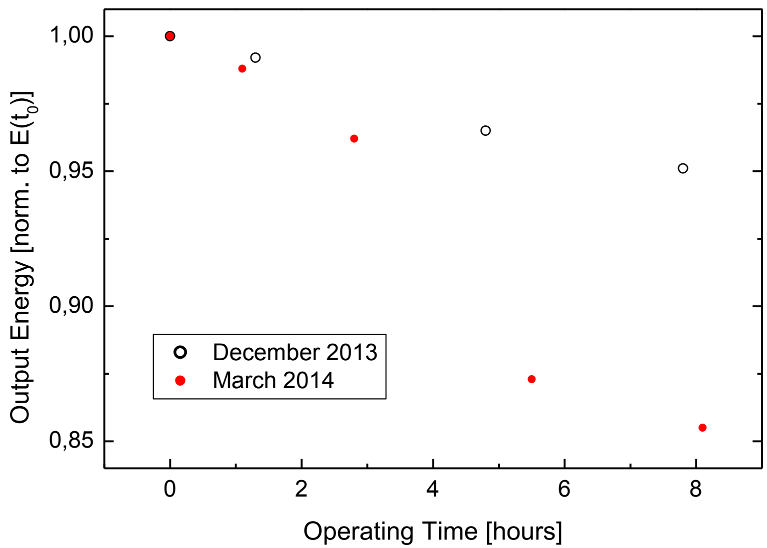
Measurements at the Prague front-end (3)·



Stability over 1.000 shots: Comparison of Regenerative und Multipass amplifier



Long term stability over 8 hours of operation:
Regenerative amplifier (Unchanged for three months)

Long term stability improvements:
- Housing of the amplifier (final version)
- Closed loop on pump current/duration (small changes)
- Quarterly maintenance

1.2 – 150 mJ Yb:YAG ns multipass amplifier

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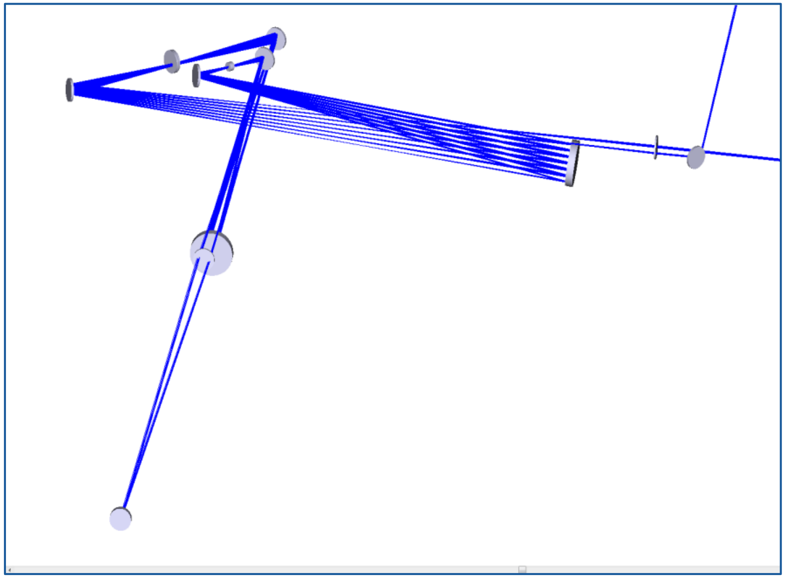
150 mJ Preamp – modified design of the previously presented multipass system

Additional requirements:

- No spatial overlap in active medium allowed
- Narrow bandwidth case (70 kHz) – any change of temporal profile is not desired
- Shorter pulse duration (1 ns) → LIDT issues!
- Birefringence compensation

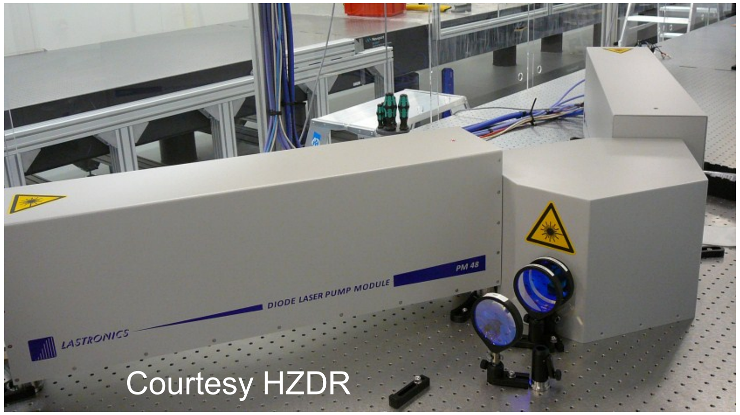


Customized solutions:

- New folded design with longer arm length and polarization rotation
- Increased beam size at damage-critical components
- Programmable internal thermal lens compensation
- Improved diagnostics with interfaces for closed loop regulation

1 – Recently completed LTX products & current development

1.3 – 80 kW, hexagonally homogenized pump engine

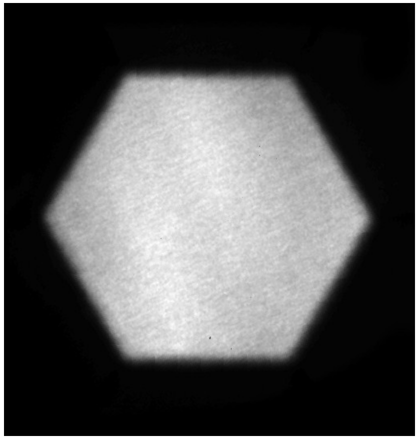


Coupling of two PM 48 with a common beam delivery

- Brightness @target 1.2 MW cm^{-2} sr^{-1}
- 80 kW at 330 A pump current

General improvement of the pump engines:

- Fast axis pointing correction of individual stacks to ±0.3 mrad
- Increased spectral overlap of individual stacks



Imaged pump profile

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1.3 – 80 kW, hexagonally homogenized pump engine

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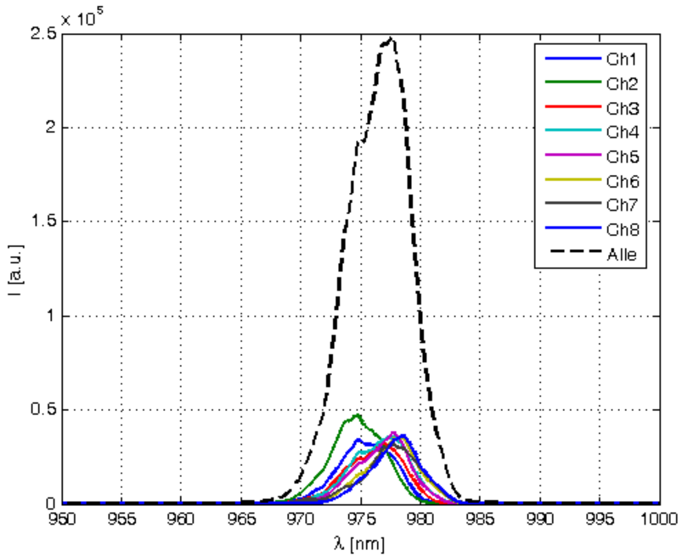
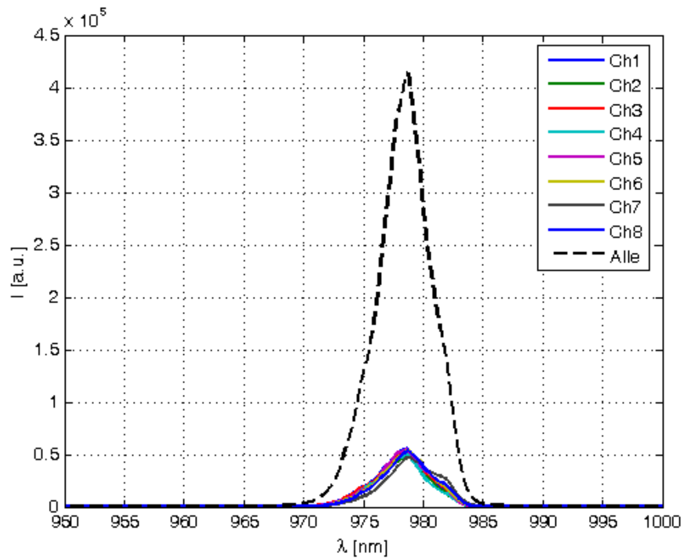
Increase of spectral overlap in multi-stack pump modules



Typical spectrum without BIAS current



Individual BIAS current applied

Spectral Correction:

- **Correction of single channels (decrease of cumulated bandwidth)**
- **Shift of averaged (global) central wavelength for absorption optimization**

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1.4 – 2 kW, 100 Hz pump engine with 20% duty cycle

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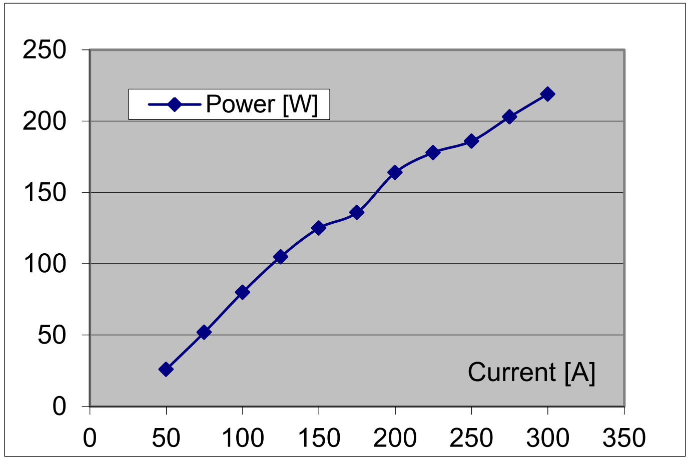
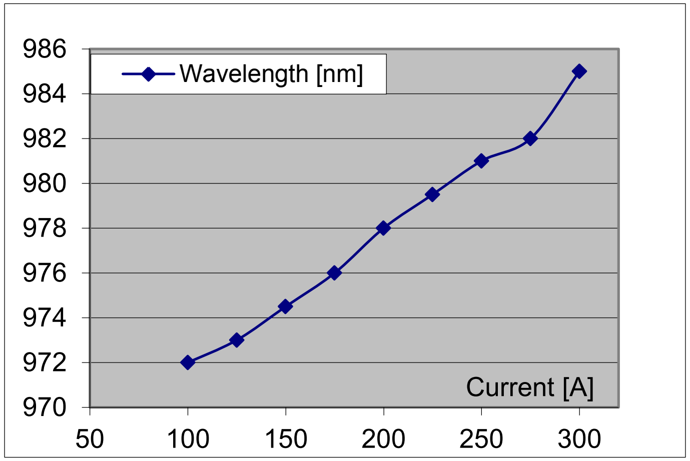


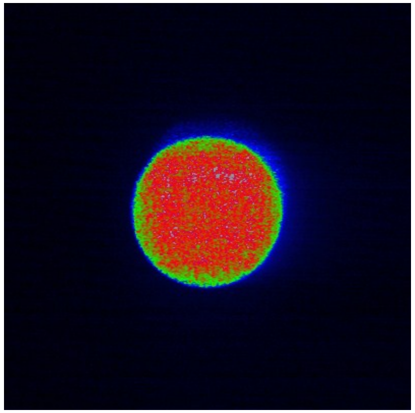


Increasing interest in high repetition rate laser applications → 100 Hz and more

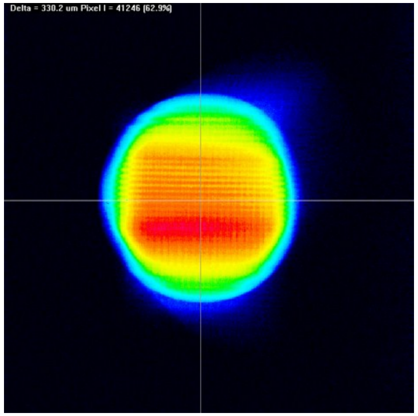
<u>Development of a prototype:</u>

- 2 kW, 100 Hz, 2 ms pump engine with homogenized circular profile
- Higher thermal load on stacks and optical components – active cooling of transmissive and reflective optics required
- Improvement of homogenization unit with respect to „standard“ 10 Hz solution is necessary

Pump profiles of the 100 Hz pump engine:



Factory accept. test
(November 2013)



Actual profile
(March 2014)

→ Service visit in April 2014

In case of problems:

A solution <u>will</u> approach you!

<u>In this case:</u>

- Checking the stack for diode bar failure
- Replacement of the homogenizer unit from square to hexagonal (newly developed MLAs with high damage resistivity and better robustness with regard to alignment)

1 – Recently completed LTX products & current development

1.5 – 3.3 kW cw pump engine

Even more repetition rate? → c.w. pump engines

Lastronics has developed a c.w. pump source with 3.3 kW average output, based on a new pump module PM 9.6 with maximum output of 4.5 kW c.w.

Stacks are interleaved and polarization coupled for higher brightness.

LDD 1312HDLC

Laser diode driver: LDD 1312HDLC:

- Single channel, max. 210 A DC (200W/bar)
- Pulsed regime is also possible with maximum of 22% duty cycle

2 – Future projects & Outlook

2.1 – 10 J Yb:YAG amplifier (Ti:Sa pump)

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- With the 150 mJ front end available, Lastronics intends to tackle the next stage of amplification in the second half of 2014.
- In the concrete this will be a 10 J, 10 Hz, 10-20 ns power amplifier, based on a Yb:YAG design
- Designated pump engine is the PM 48 from Lastronics, combined with the 4-channel LDD 4312LC, which allows for spectral correction via bias current
- A laser head is currently under development @IOQ Jena, will be commercially build under license
- 50% SHG gives a 5 J, 10 Hz, Ti:Sa pump laser with homogenized beam profile
- At low repetition rates Ti:Sa pump laser based on DPSS media are still by a factor of 1.6 more expensive than flashlamp pumped (without efficiency considerations)

BUT

2 – Future projects & Outlook

2.1 – 10 J Yb:YAG amplifier (Ti:Sa pump)

- With new diode stack technology the price ratio will shift more in favor of diode pumped tech
- There is a growing demand for affordable 100 Hz Ti:Sa pumps
  No flashlamps available for these repetition rates – Ti:Sa will likely become DPSSL technique

Example: **500 mJ, 100 Hz – components:**

Oszillator	1 mJ, 10 ns, Yb:YAG
Pre-amplifier	1 mJ → 10 mJ (Yb:YAG, thin disc, pump multipass, 4-6 passes in air)
Main amplifier	1 J, 10 ns CaF_2 @ 100 K, 2 ms pump duration, 10% extraction efficiency (optical-optical)
SHG	50% conversion efficiency
Costs:	50% of costs are incurred by the laser head

2.2 – Pump modules with higher brightness and higher output power

Two possibilities:

1. New diode bars mentioned yesterday by J. Neukum (DILAS), driven at 500 A can be made compatible with current PM design:

   → 1.5x more output and slightly decreased slow axis divergence

   → Brightness increase of 1.7 … 2

   PM 48 → PM 72, PM 80 → PM 120

2. Brightness:

   Redesign of stack geometry for higher filling factors + measures Lastronics already takes for brightness increase

Note of thanks

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<u>Lastronics wants to thank the following institutions/companies for a fruitful collaboration:</u>

- PEnELOPE group, Helmholtz – Zentrum Dresden-Rossendorf
- IOQ / HI Jena
- ELI beamlines Prague
- Attosecond group MPQ Garching
- LULI Palaiseau, Paris
- IAP Vienna
- DILAS

Thank you for your attention!