New generation Laser amplifier system for FEL applications at DESY.

Franz Tavella
Helmholtz-Institut-Jena

Merging advanced solid-state Laser technology with FEL sources
Helmholtz-Institut-Jena – DESY
Overview

Novel Laser amplifiers systems at DESY

- applications
- requirements and Laser specifications
- The system

Development status

- OPCPA and it’s pump amplifier system
  .... development
- methods – enabling technologies
- outlook
Laser amplifier applications at FELs.

- Electron gun … photo-injector Laser
- LINAC (electron accelerator)
- Optical seed laser and HHG
- Undulator section
- FLASH II experimental hall (Pump probe lasers)
- FLASH II
### The seeding driving laser amplifier.

<table>
<thead>
<tr>
<th>Laser</th>
<th>Seed</th>
<th>X-ray</th>
<th>( \eta )</th>
<th>Rep.-rate</th>
<th>( P_{\text{ave}} )</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>EEHG</td>
<td>0.8 ( \mu \text{m} ) 100 GW &gt;10 fsec (mJ)</td>
<td>200 nm up to GW</td>
<td>2 nm</td>
<td>( &gt;10^{-1}) conv., 10% losses</td>
<td>1 MHz (burst)</td>
<td>100s W for burst</td>
</tr>
<tr>
<td>HGHG</td>
<td>0.8 ( \mu \text{m} ) 10 GW &gt;10 fsec (100 ( \mu \text{J} ))</td>
<td>200 nm 100 MW</td>
<td>20 nm</td>
<td>( &gt;10^{-1}) conv., 10% losses</td>
<td>1 MHz (burst)</td>
<td>100s W for burst</td>
</tr>
<tr>
<td>HHG+ HGHG or EEHG</td>
<td>0.8 ( \mu \text{m} ) 100 GW 10 fsec (mJ)</td>
<td>20 nm 100 kW</td>
<td>1 nm</td>
<td>( 10^{-5} ) conv., 10% losses</td>
<td>1 MHz (burst)</td>
<td>kW</td>
</tr>
<tr>
<td>HHG</td>
<td>0.8 ( \mu \text{m} ) 100 GW 10-30 fsec (&gt;1 mJ)</td>
<td>&gt;10 nm 100 kW</td>
<td>&gt; 10 nm</td>
<td>( 10^{-5} ) conv., 10% losses</td>
<td>1 MHz (burst)</td>
<td>kW</td>
</tr>
<tr>
<td>HHG</td>
<td>0.8 ( \mu \text{m} ) 1 TW &lt;10 fsec (&gt;10 mJ)</td>
<td>&lt;10 nm 1 MW</td>
<td>&lt;10 nm</td>
<td>( 10^{-6} ) conv., 10% losses</td>
<td>1 MHz (burst)</td>
<td>10s kW</td>
</tr>
</tbody>
</table>
Special needs...input from the future user community.

Pulse energy
few mJ

Burst repetition rate 100 kHz – 1 MHz
...continuous 100 kHz operation possible

Pulse duration (tunable?)
10 - 30 fs ...seeding

<7 fs ...pump/probe Laser

CEP stabilization?

synchronization precision to the FEL <10
24/7 operation

NIR Laser amplifier (~650-1000 nm)
Non-collinear amplification (NOPA)

- type-I phasematching in BBO
- pump wave: extraordinary axis
- signal / idler wave: ordinary axis

Optical parametric chirped pulse amplification

- broadband amplification
- instantaneous process → no energy storage, no inversion
- negligible absorption,… no thermal load → High repetition rates (high average power)
- conversion efficiency >20% in 2-pass OPCPA

…but requires a non-conventional pump amplifier!

\[ \Delta k = k_p - k_s - k_i \]
\[ \omega_s = \omega_p - \omega_i \]
Optical Parametric Chirped Pulse Amplifier: Setup.

Laser system Setup: combining OPCPA with ultra-short pump amplifiers

- Ti:Sa oscillator frontend
  → split for signal and pump seed

- adaptive dispersion control for signal (4-f SLM)
- Yb based CPA with high repetition rate
- sub-ps pump pulses from CPA
The OPCPA pump amplifier.
The challenge: OPCPA pump Laser

- central wavelength: 1030 nm
  (SHG @ 515 nm used for OPCPA)
- pulse energy: 20 mJ → 10 mJ @ 515 nm
- repetition rate: 100 kHz cw / burst (1 MHz final version)
- pulse duration: sub-1 ps

→ multi-kW average power Laser amplifier!
Pump amplifier: fiber amplifier front-end.

- 4 fiber amplifiers
  (2 Yb:glass rod type PCF amplifier)
- Chirped Pulse Amplifier (CPA), 2 ns → 1 ps
- current amplifier max 50 W continuous and burst repetition rate (100 kHz – 1 MHz)


Fiber amplifier
(IAP Jena)
Helmholtz-Institute Jena
Pump amplifier: fiber amplifier front-end.


Fiber amplifier
(IAP Jena)
Helmholtz-Institute Jena
Results: OPCPA with fiber pump laser.

1-Stage OPCPA
20 µJ, 6.9 fs
(F. Tavella et al, Opt. Exp. 18 4689-4694 (2010))

2-Stage OPCPA with CEP stabilization
70 µJ, 8.0 fs

2-stage OPCPA with optimized adaptive dispersion control
87 µJ, 4.8 fs

Fiber amplifier
(IAP Jena)
Helmholtz-Institute Jena
Pump amplifier: Innoslab amplifier.

Development from Amphos (spin-off from ILT)

Different sets of amplifier modules

- >1.5 kW currently installed at DESY (burst-mode and continuous operation possible)
- up to multi-kW burst mode planned XFEL/DESY
Pump amplifier: Innoslab amplifier.

Development from Amphos (spin-off from ILT)

Different sets of amplifier modules

- >1.5 kW currently installed at DESY (burst-mode and continuous operation possible)
- up to multi-kW burst mode planned XFEL/DESY


→ 250 W module tested between 12.5-100kHz

Innoslab amplifier (ILT Aachen)
Pump amplifier: Thin-disk amplifier.

Multipass design with max. 30 passes through the disk

Thin disk multipass amplifier (DESY)
Pump amplifier: Thin-disk amplifier.

Multipass design with max. 30 passes through the disk

Thin disk multipass amplifier (DESY)
Pump amplifier: Thin-disk amplifier.

- Energy increase to max. 44.5 mJ/pulse
  ...but asymmetric burst
- Amplification factor of 118 (1.17 per pass)
- 1.1% rms stability
- Flat burst at 25 mJ amplified pulse energy
  ...compressed to 820 fs
The challenge: OPCPA pump Laser

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  (SHG @ 515 nm used for OPCPA)
- pulse energy: 20 mJ → 10 mJ @ 515 nm
- repetition rate: 100 kHz cw / burst (1 MHz final version)
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→ OPCPA development
what can we do next?

- $E_p > 1 \text{ mJ}$
- $t_p = 5-30 \text{ fs}$
- $0.1-1 \text{ MHz}$

Diagram:
- Stretcher
- Fiber Amp.
- Innoslab
- ... (repeated)
- Comp.
- 2 stage OPA
- SHG
- > 5 W
- 100s of W
- multi kW
what can we do next?

ambitious project for the next years

10 Hz operation

E_p > 1 mJ
t_p = 5-30 fs
0.1-1 MHz

400 μJ
20 mJ
several 100 mJ (1 J possible?)

E_p > 40 mJ
t_p = <7 fs
10 Hz
The „Laser-Express“.

OPCPA
- kilowatt-burst pump amplifier
- next step is OPCPA
- ready to be used this year

Highly efficient QPM HHG source
- development & characterization
- dual gas jet target
- FLASH-II seeding planned in 2015
Seeding FLASH II.

development of high repetition rate, mJ-level, sub-10 fs laser amplifiers - enabling technologies -

Collaboration partners:
- Helmholtz Institut Jena
- Institut of Applied Physics Jena (IAP) group of A. Tünnermann
- Institut für Lasertechnik Aachen (ILT) H. Hoffmann group
- I LT-spinoff Amphos T. Mans, C. Schnitzler
- European XFEL M. Lederer

development of a laser-driven XUV source with high conversion efficiency (QPM-schemes)

Collaboration partners:
- Queens University of Belfast (QUB) group of M. Zepf
- Technical University of Crete (TEI) group of M. Tatarakis and N. Papadogiannis

_Laser Development_... F. Tavella, A. Willner, M. Schulz, R. Riedel, A. Hage, M. Prandolini (HI-Jena/DESY/Hamburg University)
_DESY-Hamburg University_... S. Düsterer, J. Rossbach, M. Drescher, H. Schlarb, J. Feldhaus