LASER SYSTEMS FOR NEXT GENERATION LIGHT SOURCES

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OUTLINE

• Introduction
• Main laser systems in the FEL light sources under development
• General requirements
• Specific issues
  A. Photoinjector laser
  B. Laser Heater
  C. Seed Lasers
• New laser developments
  (high rep rate /average power, VUV-soft tuneable X-ray seed)
• Jitter and drift problems: strategies for reduction
Main laser systems in the FEL light sources under development

- Photoinjector laser
- Seed laser
- User lasers
- Laser Heater
- Optical master oscillator
- Electro-optical sampling laser
- Short pulse ‘chirping laser’
- …more to come!
GENERAL REQUIREMENTS

- Wavelength: mostly UV, IR in LH; tuneable in SL
- Rep rate 10 Hz-120 Hz normal conducting; up to MHz superconducting
- Synchronization to external reference with jitter 20-200fs RMS; no phase (CEP) stabilization requested so far
- Pulse duration: 50fs-15 ps FWHM (risetime < 1 ps)
- Pulse energy: 10 - 500 μJ
- Pulse shaping: flat-top, increasing quadratic ramp, very short gaussian with low TBWP
- Beam shaping: flat-top; gaussian; well-behaving in propagation
- Pulse-to-pulse stability: < 4% RMS, goal <2% -> diode-pumping!
- High reliability (>99% uptime)-> must be based on a mature technology
- Commercial units available
- Easy to integrate in a facility -> Remote control/diagnostics

In general: no commercial system meeting all!
PHOTOINJECTOR LASER

- Pulse energy requirements depend on the type of gun
  
  1. Cu-based gun on normal conducting machines
     - 0.4 mJ at 260 nm on cathode -> >15 mJ in IR (12% THG efficiency, 25% transmission pulse/beam shaping and beam transport)
     - Bandwidth at least 4 nm in IR to allow <1 ps rise/fall times
     - Commercially available units

At present only choice Ti:Sapphire based femtosecond oscillator+regenerative amplifier +2 stage multipass amplifier, pumped by diode-pumped Nd:YLF Q-switched lasers

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1. PULSE SHAPING SCHEMES
   **FREQUENCY DOMAIN:**
   - 4-f dispersive system (or other geometries)
   - DAZZLER (acousto-optic dispersive Filter), Fastlite
   **TIME DOMAIN**
   - Pulse stacking

2. TWO STAGE SETUP FOR FERMI
UV PULSE SHAPING

MAIN ISSUES:

a. High UV energy/peak power -> aging and damage gratings and other optics
   Solution: use large beam diameter, transmission gratings, multilayer deformable mirror and CaF2 optics

b. Narrow spectrum: long focal length lenses in the 4-f system

Development of genetic algorithm for pulse shape optimization
Aging of the deformable mirror

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2. Pulse stacking: in UV the final shape is obtained by the addition of a number of delayed pulses; polarisation splitting used to avoid interference effects.

Issues: complexity increases with number of stages; sensitivity to alignment.

Courtesy: H. Tomizawa

New scheme based on birefringent crystals
Dispersion compensation needed.
PIL Beam Shaping

- Transformation of gaussian into flat-top beam in UV
  - Aspheric shaper Newport (used at SLAC)
  - Optimized aspheric shaper MBI (less sensitive to alignment)
  - Shaper MOLTECH (based on spherical lenses) Elettra
  - Circular aperture to select only the central part of the beam SLAC, SPARC
  - Adaptive shaper (e.g. deformable mirror, Tomizawa, SPring8)
- Why not producing the flat-top in IR?
  Advantages: better HG efficiency and no spatial chirp
  Problems: very large size needed to avoid nonlinear effects; the flat-top develops a modulation which would be a problem for the 4-f system
Important: in the FERMI PI design last mirror is outside the vacuum.
Lasers for high rep rate machines

- MBI scheme, used at FLASH, to be used for the European XFEL (low rep rate macrobunches, up to 800 micropulses)

First version: Nd:YLF linear amplifier
Chain; upgraded recently to diode
Pumping
Next generation: Yb:YAG based

- Lasers for true CW operation
  Cu-based 1 nC machine: at least 3 mJ needed in the IR
  - Ti:Sapphire - > based on existing technology good to 10-20 KHz
  (50 W level systems are available, based on crio-cooling and
downchirped amplification)
  - If pulse rise-time requirement is decreased to 2 ps, Nd:YLF could be used
  - Yb:KYW; Yb:Lu2O3 promising, literature reports 10μJ, MHz range
  - Yb-fibre based systems - 100 μJ

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SEED LASER

- In general, a laser pulse interacting with the e-bunch in an undulator to create bunching at a (short) wavelength.
- FERMI is the first FEL entirely based on seeding, with two FEL lines having configurations based on a single seed laser operating in the 200-300 nm range.

Courtesy E. Allaria

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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specs</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunability range (nm)</td>
<td>240-360</td>
<td>195-350</td>
</tr>
<tr>
<td>Peak power (MW)</td>
<td>100</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Pulse duration (fs)</td>
<td>100</td>
<td>&lt;100</td>
</tr>
<tr>
<td>Pulse Energy Stability RMS 5000 shots</td>
<td>&lt;4%</td>
<td>&lt;2%</td>
</tr>
<tr>
<td>Timing jitter (fs RMS)</td>
<td>&lt;100 fs</td>
<td>TBM</td>
</tr>
<tr>
<td>Pointing stab. (μrad)</td>
<td>&lt;20 (goal 10)</td>
<td>&lt;20</td>
</tr>
<tr>
<td>Wavelength stab.</td>
<td>10⁻⁴</td>
<td>&lt;10⁻⁴</td>
</tr>
<tr>
<td>Beam quality (M²)</td>
<td>&lt;1.5</td>
<td>TBM</td>
</tr>
</tbody>
</table>
FERMI SEED LASER PERFORMANCE

100MW level Tuning curve in UV

TOPAS Regen Amp Seed fibre laser

Typical Spectrum and crosscorrelation with short Visible pulse

Spatial distribution at focus

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Recent upgrade to shorter wavelength

Near future Upgrade:
- Extension to 165-195 nm region by using KBBF (Mixer 4)
- Upgrade of the pump laser to 8-10 mJ range by adding one multi-pass stage
- Controlled pulse delay at the exit with wavelength tuning
VUV/EUV UPGRADE UNDER STUDY

SEED BY HG IN GASES

Required:
- Tunability in the range 40-70 nm (by full tunability between two harmonics);
- Peak power in the 1MW range pulse energy: 150 nJ range if HHG chamber is in the laser room, 50 nJ range with HHG chamber close to the undulator entrance and aligned;
- Pulse duration 25-30 fs

Main options for the pump laser under consideration
- Use of UV or VIS pulses from an upgraded version of the present parametric amplifier/HG system: expected 200 μJ, 80 fs in UV and 800 μJ, 50 fs in VIS
- Use of a commercially available tuneable Ti:Sapphire amplifier, tuning range ±30 nm around 790 nm, pulse duration: 50 fs; pulse energy 10 mJ
- Use of fixed wavelength pump and tuning of the HG output by controlling other parameters

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Main idea: replace Ti:Sapphire oscillators with amplified frequency doubled timing pulses for seeding the regen amplifiers.

Main issues:
- Power (>0.5 nJ at 780 nm needed)
- Bandwidth (>8 nm for a 100 fs system, >20 nm for seeding a 50 fs range amp)
Tests Laser Jitter

Test of PIL locking to an external fibre laser by optical cross-correlation.

Phase noise measurement

Distribution of arrival time at the second x-corr

Jitter $32\, \text{fs}_{\text{RMS}}$

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CONCLUSIONS

- Ultrafast lasers are becoming crucially important part of new VUV and X-ray FELS
- Ti:Sapphire based systems will continue to be the most popular for up to 10 kHz rate
- Higher rep rate facilities will most probably need an alternative technology. Promising candidate Yb-doped thin-disk media and especially fiber based oscillators and amplifiers
- Tunable seeding with HHG in the 40 nm range feasible
- Dedicated R&D on ultrafast lasers applied to FEL technology may substantially improve the performance

THANK YOU FOR THE ATTENTION
BACKUP SLIDES
HHG SEED BASED ON TUNABLE Ti:SAPPHIRE AMPLIFIER

PROPOSED APPROACH FOR REACHING THE PARAMETERS REQUIRED FOR FEL SEEDING
- HHG in Xe in the 45-75 nm range
- Use of Tunable Ti:Sapphire based regen+multipass amplifier with the following parameters:
  Tunability ±25 nm around 800 nm
  Use of bi-chromatic pump (800 nm +400 nm) for production of odd+even harmonics
  Pulse duration 50 fs
  Pulse energy : 10 mJ (up to 15 mJ) at 800 nm /2 mJ at 400 nm
Approach for obtaining the amplifier tunability developed by Amplitude Technologies:
  Broadband seed oscillator (>100 nm)
- Spectral phase shaping before Regenerative Amplifier (Dazzler)
- Spectral amplitude shaping in the Regenerative amplifier (Mazzler)
- Pulse/spectrum measurement after multipass amplifier and closed loop control of the Dazzler/Mazzler for remote controlled wavelength tuning

Tunability curve demonstrated by Amplitude Technologies (courtesy F.Canova, G.Riboulet)

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Seed a Ti:sapphire amplifier after pulse shaping/amplification:
~100 fs (~3 nJ @ 1550 nm & ~1 nJ @ 775 nm)

Where we are:
- SHG unit based on chirped PPLN developed
- Tests of the amplifier setup started

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SHG results

Input spectrum (Menlo TC1550)
CrossCorrelator Test Bed

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Locking setup

Optical Phase reference
157MHz
Delay line

10GHz PD
BPF 2998MHz
Phase Shifter

OMO-OSO x-correlation
Low speed PD
LPF

LNA
Regulator
HV Ampli
Piezo
Galvo
Amplifier

Optical Slave Oscillator

Trigger
78.895MHz

78.895MHz - Sinewave

Trigger (50Hz)

BPF 79MHz
Low speed PD

50Hz
delay box

Control System

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Balanced Crosscorrelator