The optical laser facility at the VUV FEL at DESY

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Roadmap of the talk

- Aim and basic characteristics of the optical laser facility
- Two building blocks -> two output channels:
  - Picosecond pulses from a Nd:YLF laser
  - Femtosecond pulses from an OPCPA system
- Parameters of the available pulses
- Remarks on synchronization between VUV FEL and optical laser
- Present status
- Future plans and possibilities
Aim and characteristics of the optical laser facility

- **Aim:**
  - Provide optical radiation that has the **same pulse structure** and that is **in tight synchronism to the VUV FEL**
  - Secondary, optical source for pump/probe experiments

- **Emphasis put on generation of long pulse trains**
  - Long pulse trains: important **advantage of the cold linac against the warm machine**

- **Flexibility** in wavelength and **tunability** over a certain wavelength range
  - 1047 nm
  - 523 nm
  - 349 and 262 nm (on special request)
  - 790…830 nm
  - 395…415 nm (on special request)

- **Generation of**
  - Picosecond pulses from Nd:YLF laser: \( \tau = 10\ldots15 \text{ ps} \)
  - Femtosecond pulses from OPCPA stage: \( \tau = 150 \text{ fs} \)

- **Several parameters can be adapted to the requirements of the users within a certain range**
Basic layout of the optical laser at the VUV FEL: Wavelength-tuneable OPCPA system

OPCPA combines:
- Chirped-Pulse amplification (CPA)
- Optical Parametric amplification (OPA)

Advantages for TTF/TESLA:
- Broad amplification bandwidth: -> amplification of femtosecond pulses
  -> large tunability in wavelength
- No thermal lensing in the amplifier crystals:
  -> supports amplification of long pulse trains
\[ \tau = 14 \text{ ps (FWHM)} \]
\[ E_{\text{micro}} = 1.2 \text{ mJ} \mu J @ f = 1 \text{ MHz} \]
\[ E_{\text{single pulse}} > 8 \text{ mJ} \]

**Scheme of the optical laser**

**Diode-pumped Nd:YLF oscillator**

- \( f_{\text{round trip}} = 27 \text{ MHz} \)
- \( \tau = 12 \text{ ps (FWHM)} \)
- \( E_{\text{micro}} = 600 \mu J @ f = 1 \text{ MHz} \)
- \( E_{\text{single pulse}} = 4 \text{ mJ} \)

**Two-stage diode-pumped Nd:YLF amplifier**

- Pulse picker
- Pump diodes
- Faraday isolator
- Pulse picker 1 MHz

**Three-stage flashlamp-pumped booster amplifier**

- Ti:Sa oscillator
- Grating stretcher
- SHG crystal
- Grating stretcher

**Optical-parametric amplifier (OPA)**

- Three-crystal optical-parametric amplifier
- \( \tau \leq 100 \text{ fs} \)
- \( \tau = 15 \text{ ps} \)
- \( G > 5 \text{ } 000 \)
- \( G \approx 20 \)

**Primary synchronization loop**

- Master clock \( f = 1.3 \text{ GHz} \)
- Photodiode
- Mixer \( 1.3 \text{ GHz} \)
- Piezo

**OPCPA stage**

- Output pulse trains
- 800 µs long,
- \( \lambda = 523 \text{ nm} \)

**Pump laser**

- Fast current controller
- Fast current controller
- Pump diodes
- AOM
- EOM
- AOM
1. The Nd:YLF pump laser

- Actively-modelocked oscillator (combination of three modelockers)
- 2-stage diode-pumped preamplifier
- Flashlamp-pumped booster amplifier
- Control system (VME crate with SUN/SOLARIS embedded computer)

Pump laser is similar to the TTF photocathode laser
Diode-pumped oscillator and two-stage preamplifier of the pump laser
The three-stage booster amplifier
The Nd:YLF laser and its output

- Generates trains of picosecond pulses ($\tau = 10 \ldots 15$ ps FWHM)
- Synchronization accuracy (phase noise): $\sigma < 0.5$ ps
- Very reliable synchronization
- Rectangular envelope of the pulse trains
  -> energy of the micropulses is stable within 1%
- Large flexibility in:
  - Duration of the pulse train
  - Repetition rate within the pulse train
  - Number of micropulses in one train
- Wavelengths available to the user
  - $\lambda = 1047$ nm,
  - $\lambda = 523$ nm
  - on special request: $\lambda = 349$ and $262$ nm
## Parameters of the Nd:YLF pump laser available to the users

<table>
<thead>
<tr>
<th>Operational mode</th>
<th>$\lambda = 1047$ nm</th>
<th>$\lambda = 523$ nm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\tau = 15$ ps (FWHM)</td>
<td>$\tau = 12$ ps (FWHM)</td>
</tr>
<tr>
<td>energy of one micropulse</td>
<td>energy of the whole pulse train</td>
<td>energy of one micropulse</td>
</tr>
<tr>
<td>trains of 800 micropulses, 1 $\mu$s spacing, $f_{\text{train}} = 1$ MHz</td>
<td>1.2 mJ</td>
<td>0.96 J</td>
</tr>
<tr>
<td>trains of 400 micropulses, 2 $\mu$s spacing, $f_{\text{train}} = 0.5$ MHz</td>
<td>2 mJ</td>
<td>0.8 J</td>
</tr>
<tr>
<td>trains of 200 micropulses, 2 $\mu$s spacing, $f_{\text{train}} = 0.25$ MHz</td>
<td>3 mJ</td>
<td>0.6 J</td>
</tr>
<tr>
<td>single pulse</td>
<td>8 mJ ((\tau \sim 30) ps)</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

- Average power during pulse train exceeds 1 kW at 1 $\mu$s pulse spacing
- Larger pulse energies available for $E_{\text{micro}} > 10$ mJ: lengthening of the pulse and/or modified amplifier required
- Nd:YLF laser has been completely installed at DESY in July 2004.
Part 2: OPCPA stage generating femtosecond pulses

**OPCPA**: Optical Parametric Chirped-Pulse amplification

- Generates femtosecond pulses
  \[ \tau \leq 150 \text{ fs FWHM} \]
- Pulse energy available at present:
  \[ E_{\text{micro}} = 50\ldots100 \text{ \( \mu \)J} \]
- Available wavelength:
  - \( \lambda = 790\ldots830 \text{ nm} \)
  - On request: \( \lambda = 395\ldots415 \text{ nm} \)
Part 2: OPCPA stage generating femtosecond pulses

- Ti:Sa oscillator
- OPA crystal #1 and #2
- OPA crystal #3
- stretcher
- compressor
- phase detectors
Tuning the wavelength of the OPCPA output

- Wavelength of the output pulses is determined by:
  - Wavelength of the pulses from Ti:Sa oscillator (position of a slit in the resonator)
  - Tilt of the OPY crystals (phase matching angle)

- Present wavelength range:
  - $\lambda = 790 \ldots 830$ nm
  - On special request: $\lambda = 395 \ldots 415$ nm

- Challenge of future work:
  - Fully remote-controlled scan of the wavelength
Synchronisation of the laser to the linac/VUV FEL

- Technology: electronic feedback loops + periodical re-calibration based on an absolute timing measurement system
- **synchroscan streak camera** can be used for absolute timing measurement between two optical pulses
  - Repeatability in determination of the delay between two pulses: \( \sigma(\tau) < 40 \text{ fs} \)
  - Calculation of the “center of mass” is essential to reach this accuracy.

![Diagram showing time and delay with standard deviation](image)

- \( \sigma_{\text{delay}} = 0.034 \text{ ps} \)
- \( \sigma_{\text{delay}} = 0.035 \text{ ps} \)
- \( \sigma_{\text{delay}} = 0.035 \text{ ps} \)

**Note:**
- Blue lines: measured data
- Red lines: fitted data (sum of two Gaussian pulses)
- \( \sigma_{\text{delay}} \): standard deviation of the measured delay in a series of 20 shots
Future plans

- Adapt the OPCPA stage to the different operational modes of the Nd:YLF pump laser
  - Long pulse trains (typ. 800 micropulses) with different pulse spacing (1-10 µs):
    -> requires flexible telescopes between pump laser and OPA

- Single pulses with an energy as high as possible (up to several mJ)
  - Demonstration of a diode-pumped single-pulse booster amplifier in progress
  - Aim: several mJ from the OPA with a fully diode-pumped Nd:YLF laser in 2005

- Other topics of our future work:
  in dependence on the requirements of the users of the optical laser:
  - Remote-controlled scan of the wavelength
  - Extending the tuning range of the wavelength
Summary

The optical laser facility at the VUV FEL is being installed, with emphasis on
  • pulse trains with the same temporal structure as the VUV FEL
  • large flexibility in laser parameters
    – wavelength
    – temporal structure of the trains

The optical laser has **two output channels**

1. **Nd:YLF burst-mode laser** generating trains of **picosecond pulses** \( (\tau = 10 \ldots 15 \text{ ps FWHM}) \)
   – micropulse energy up to of several mJ
   – very reliable, best energy stability
   – \( \lambda = 1047 \text{ nm and } \lambda = 523 \text{ nm available} \)
   – \( \lambda = 349 \text{ and } 262 \text{ nm (on request)} \)
   – Installation was already finished in July 2004.

2. **OPCPA system** generating **femtosecond pulses** \( (\tau \leq 150 \text{ fs FWHM}) \)
   – \( \lambda = 790\ldots830 \text{ nm} \)
   – on request: \( \lambda = 395\ldots415 \text{ nm} \)
   – Installation presently ongoing, will be in operation in October 2004.

Emphasis of future work on:
  • increased energy of the micropulses,
  • enlarged tuning range in wavelength.