A beam shaping active optics system for FERMI@Elettra FEL

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FEL-1, based on a single stage High Gain Harmonic Generation (HGHG) scheme initialized by a UV laser, covers the spectral range from ~100 nm down to 20 nm.

FEL-2, is based on a double cascade of HGHG in order to be able to reach the wavelength range from 20 nm to ~4 nm.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>FEL 1</th>
<th>FEL 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength (nm)</td>
<td>100-20</td>
<td>20-4</td>
</tr>
<tr>
<td>Pulse length rms (fs)</td>
<td>30-100</td>
<td>&lt;100</td>
</tr>
<tr>
<td>Bandwidth rms (meV)</td>
<td>~20-40</td>
<td>~20-40</td>
</tr>
<tr>
<td>Polarization</td>
<td>variable</td>
<td>variable</td>
</tr>
<tr>
<td>Peak Power (GW)</td>
<td>1-5</td>
<td>~1</td>
</tr>
<tr>
<td>Photons per pulse</td>
<td>~4·10^{13} (100 nm)</td>
<td>~10^{13} (10 nm)</td>
</tr>
<tr>
<td>Source Size FWHM (µm)</td>
<td>290</td>
<td>140</td>
</tr>
<tr>
<td>Divergence rms (µrad)</td>
<td>50@40 nm</td>
<td>15@10 nm</td>
</tr>
<tr>
<td>Repetition Rate (Hz)</td>
<td>10-50</td>
<td>50</td>
</tr>
</tbody>
</table>
Experimental hall

PADReS

Beamlines

LDM: Low Density Matter
ref. C. Callegari, F. Parmigiani, S. Svenson, K. Prince, S. Stranges, J. M. Dyke, T. Möller, F. Stienkemeier...

DIPROI: Diffraction and PROjection Imaging
ref. M. Kiskinova, F. Capotondi, B. Kaulich, H. Chapman, J. Hajdu, A. Nelson...

EIS: Elastic and Inelastic Scattering
-TIMER: TIME-Resolved spectroscopy of mesoscopic dynamics in condensed matter
-TIMEX: ultrafast TIme-resolved studies of Matter under EXtreme and metastable conditions
ref. C. Masciovecchio, F. Bencivenga, A. Di Cicco, E. Principi, R. Cucini...
TIMEX: ultrafast TIMe-resolved studies of Matter under EXtreme and metastable conditions

Main scientific goals:

- ultrafast studies (conductance, reflectivity, transmission, scattering) of warm dense matter (WDM)

- transitions occurring in stable, metastable and excited states under extreme conditions
Beamline design

Top view

Ellipsoidal mirror

Sample

Plane mirror

FEL Sources

77.5 m

15 m

1.4 m
Beamline design

Expected a spot size ~ 3 µm

Up to $10^{17}$ W/cm$^2$
Beam-shaping

The natural spatial Gaussian distribution of the focused photon beam is not suitable for the TIMEX porpuses

Need for a versatile beam-shaping system

In the VUV/soft X-ray range the beam-shaping is possible by using reflective elements with peculiar shapes

Use a bendable-plane mirror as an active optics
“Lorentzian-like” mirror’s shape

\[ L_\alpha(A, \gamma, x_0) = \frac{A \gamma^{\alpha-1}}{\pi \left[ (x - x_0)^\alpha + \gamma^\alpha \right]} \]

- \( A \): amplitude
- \( x_0 \): center of symmetry
- \( \gamma \): scale parameter (HWHM)
- \( \alpha \): slope parameter

Mirror profile / nm
“Lorentzian-like” mirror’s shape

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- \( \gamma \) = scale parameter (HWHM)
- \( \alpha \) = slope-parameter
Some ray-tracing results

Almost **Flat-top** spot for irradiating the sample uniformly

\( \gamma = 80 \text{ mm}, \alpha = 4, A = 150 \text{ nm} \)
Some ray-tracing results

Flat-top spot with tales for irradiating the sample and probing the temperature with a pyrometer

\[ \gamma = 40 \text{ mm}, \ \alpha = 8, \ A = 100 \text{ nm} \]
Ray tracing Vs wavefront propagation

- Ray tracing (Shadow)
- Wavefront propagation (RSC)
The active mirror

The sides of the mirror are clamped and the shape is changed due to the effect of the applied forces below the substrate.

13 Piezo-actuators glued on the bottom of the mirror’s substrate
The active mirror

Substrate
400 mm x 40 mm x 10 mm

Optical area
360 mm x 20 mm

Residual slope errors (after best sphere subtraction):
Tang. < 0.5 µrad rms, Sag. < 5 µrad rms (within 70 mm length)

Micro roughness < 0.3 nm rms

Coating: Gold 50 nm
Straing-gauges and piezo
Strain-gauges and piezo
Strain-gauges and piezo
Metrology results

Central part (300 mm)

\[ P_t V = 2 \mu m \]

Torsion free
Metrology results LTP
Central part (300 mm) $P_t V = 4.5 \mu m$
The Adaptive Correction Tool (ACT) calculates

- the interaction matrix for a bimorph mirror with N piezos
- the voltage to apply to the piezo-actuators in order to obtain the desired mirror profile
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### Adaptive Correction Tool

<table>
<thead>
<tr>
<th>CH.</th>
<th>Voltage Correction</th>
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<tbody>
<tr>
<td>00</td>
<td>-12.4 V</td>
</tr>
<tr>
<td>01</td>
<td>-13.7 V</td>
</tr>
<tr>
<td>02</td>
<td>-2.6 V</td>
</tr>
<tr>
<td>03</td>
<td>-10.1 V</td>
</tr>
<tr>
<td>04</td>
<td>+4.6 V</td>
</tr>
<tr>
<td>05</td>
<td>-4.7 V</td>
</tr>
<tr>
<td>06</td>
<td>+16.6 V</td>
</tr>
<tr>
<td>07</td>
<td>+1.1 V</td>
</tr>
<tr>
<td>08</td>
<td>-9.1 V</td>
</tr>
<tr>
<td>09</td>
<td>-8.2 V</td>
</tr>
<tr>
<td>10</td>
<td>-9.8 V</td>
</tr>
<tr>
<td>11</td>
<td>-8.3 V</td>
</tr>
<tr>
<td>12</td>
<td>-7.0 V</td>
</tr>
</tbody>
</table>
The Adaptive Correction Tool (ACT) calculates the interaction matrix for a bimorph mirror with N piezos to obtain the desired mirror profile. Applying voltage +20 V
Metrology results LTP

\[ P_{TV} \sim 34 \, \mu m \]
Metrology results LTP
Summary and outlooks

Performed both ray tracing and wavefront propagation simulations

Mirror + Staining-gauges and piezo actuators work fine

Design a brand new holder (suggestions are very welcome)

We will use the same scheme for the KB system for correcting the FEL wavefront deformations (L. Raimondi tomorrow morning)

TIMEX beamline will be operative in a temporary configuration for the first user dedicated beamtime
Thank you for your attention!

Colleagues and collaborators
F. Bencivenga, R. Borghes, G. Bortoletto, C. Callegari, M. Cautero,
F. Cianciosi, R. Cucini, D. Cocco, F. D’Amico, A. Di Cicco,
N. Mahne, C. Masciovecchio, E. Principi, L. Raimondi, R. Sergo,
D. Spiga, G. Sostero, M. Zangrando