JJ X-Ray

X-Ray instruments ranging from standard slits to full beamlines
The product range of JJ X-Ray

### Standard components
- Slit systems, including white beam slits with drain current capability
- Precision stages with nrad and nm resolutions
- Compound Refractive Lens systems

### Complete beamline solutions

### Custom designed instruments and end-stations
- Attenuators
- Beam Imagers and positioners
- Mirror systems
- Emission Spectrometers
- Diamond crystal-based optics
- Sample positioning stages
- Laue monochromators
The FXE instrument at European-XFEL
JJ X-ray standard slits: Air, HV and UHV
White beam slit system

Main Features

- 1500 W with drain current reading
- 4000 W without drain current reading
- Four independent blades
- Nano-polished beam defining entity
- Relative vibration less than 25 nrad RMS
- Compact: 455 mm end-to-end

On all beamlines on the new SIRIUS synchrotron in Brazil
3x Anti-vibration springs on each Nozzle end

Internal spiral forces the water to rotate
White beam slit system - Cooling
White beam slit system – Open loop performance

Unidirectional positioning repeatability R-POS = ±0.44 micron
Unidirectional positioning repeatability R-NEG = ±0.48 micron

Reversal Error: B = 3.3 micron

Resolution Test
Sat Feb 17 10:29:47 CET 2018 - SN#: 1017

- Commanded steps: mean step size = 0.208 micron
- Actual Position steps: mean step size = 0.205 micron (Last 40 steps: 0.217 micron)
- The step size ratio commanded/achieved: 1.02, TEST OK

Number of target points POS: 10
Number of cycles POS: 6
Number of target points NEG: 10
Number of cycles NEG: 6
White beam slit system - Vibration
White beam slit system - Vibration

18022 WB - Horizontal Roll Vibration - Stable

RMS vibration [nrad]

Cut frequency [Hz]

Flow [L/min]
- 1
- 2
- 4
- 5
- 6
- 10 divided by 2

Pressure drop: 3.1 bar

Pressure drop: 1.0 bar

Slope: 2.5 nrad/(L/min) · Flow = 11.9 nrad

RMS vibration over 1 - 1250 Hz [nrad]
Main Features

- 50 W with drain current reading
- Superb long-term stability - no vacuum forces influence the blade position
- Nano-polished beam defining entity
- Coating of beam defining entity possible: B4C, DLC or multilayer
- Compact: 238 mm end-to-end including reduction flanges

On all beamlines on the new SIRIUS synchrotron in Brazil
Pink beam slit system – cooling setup

Beam: 320µm x 80µm, 50 W

1. Nut
2. Tungsten rod
3. Gold sheet
4. Slit blade
5. Copper braid
6. Screw
7. Cooling base
8. Cooling wedge
9. Screw

Item 4, 5, and 7 are silver brazed for best cooling efficiency.

Electrical insulation while thermally conducting
CRL Transfocator systems - cooled and non-cooled

- We have more than 25 systems installed and in operation at 9 different facilities:
  - APS, NSLS-II, SSRF, ESRF, LCLS, European-XFEL, CAMD, SSRF, NSRRC
- First system installed in 2006
- 2D, 1D, Single Energy, Tunable Energy, HV, UHV, monochromatic, water cooled …
Refractive optics at European-XFEL

Linear accelerator
for electrons (10.5, 14.0, 17.5 GeV)

SASE 2
0.05 nm - 0.4 nm

SASE 1
0.05 nm - 0.4 nm

SASE 3
0.4 nm - 4.7 nm

MID
Materials Imaging and Dynamics

HED
High Energy Density Science

SPB
Single Particles, Clusters, and Biomolecules and Serial Femtosecond Crystallography

SFX
Femtosecond X-ray Experiments

SQS
Small Quantum Systems

SCS
Spectroscopy & Coherent Scattering

JJ X-Ray water cooled transfo
cator
Compound Refractive Lenses, CRL’s

- Easy to align
- Stable, < 100x less sensitive to vibrations than mirrors*
- Compact
- High thermal stability in the beam with a low settling time – superbly fitting white beam application
- Be, Al and Ni lenses available from RX Optics and integrated by JJ X-Ray
- Single Crystal Diamond lenses available from JJ X-Ray in-house production – 3rd party (Russian) raw diamonds welcome

\[ \frac{1}{p} + \frac{1}{q} = \frac{1}{f}, \text{where } f = \frac{R}{2N\delta} \]

*Lengeler, B. et. al. (1999). J. Synchrotron Rad. 6, 1153-1167*
The 10 lens cassettes mounted with lenses and aligned
Water cooled UHV Transfocator vibration

\[ Q = 2k \sin \vartheta \approx 2k \vartheta \]

\[ Q = \sqrt{N} k \delta \] **

Multiply scale with 0.01 to compare with mirrors!

** Lengeler, B. et. al. (1999). J. Synchrotron Rad. 6, 1153-1167.
Different lens materials available

- Example from ChemMatCARS with U-APS parameters
- CRL at 46.7 m, focus at 56.5 m, 1-95 lenses
- Transmission vs. energy

Mati Meron, 2018
JJ X-Ray Single Crystalline Diamond Lenses

APS measurements

Material: Diamond, Thickness $[\mu m]$

Strides = 2, 3

2D Dia Lens, Residual, $R = 68.56 \mu m$,
PV = 16.84 $\mu m$, SDV = 2.87 $\mu m$
Lenses for synchrotron experiment

Talbot interferometry

<table>
<thead>
<tr>
<th>RoC</th>
<th>50 µm</th>
<th>150 µm</th>
<th>225 µm</th>
<th>300 µm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean deviation RMS</td>
<td>(7.50 ± 1.14) µm</td>
<td>(2.78 ± 0.42) µm</td>
<td>(3.62 ± 1.43) µm</td>
<td>(2.10 ± 0.16) µm</td>
</tr>
<tr>
<td>Mean deviation RMS near apex</td>
<td>(1.39 ± 0.19) µm</td>
<td>(1.24 ± 0.17) µm</td>
<td>(1.15 ± 0.17) µm</td>
<td>(0.93 ± 0.14) µm</td>
</tr>
<tr>
<td>Fitted RoC of tilted lenses</td>
<td>(22.9 ± 0.94) µm</td>
<td>(72.0 ± 3.9) µm</td>
<td>(104.4 ± 3.9) µm</td>
<td>(144.8 ± 6.2) µm</td>
</tr>
</tbody>
</table>

Diamond Lens Holder alignment, Residual, R = 76.74 µm, PV = 15.89 µm, SDV = 1.74 µm

Diamond Lens Holder alignment, Residual, R = 152.1 µm, PV = 24.52 µm, SDV = 2.42 µm
Single Crystalline Diamond Lenses
APS measurements

2.1 x theoretical focus on generation II lenses
Synchrotron Beam monitoring – a JJ X-Ray and cividec collaboration

- Online feedback
- Full positional and angular beam characterization
- Beam intensity monitoring
- Detection of beamline and source instabilities
- Pink beam monitoring

- Single crystal CVD diamond
- 2 µm gap between the pads
Synchrotron Beam monitoring – a JJ X-Ray and cividec collaboration

Position measurement resolution 0.37 nm at the NanoMAX beamline at Max IV*

*https://doi.org/10.1063/1.5084683
Mirrors systems

- Full granite/Invar support for improved vibrational and thermal performance
- Optics sourced from all major vendors, e.g. Zeiss, Crystal Scientific, SESO and J-Tec
- Two and one actuator benders available
- Gravity compensation for vertical bounce systems
- Custom cooling schemes
- Transfer function testing included
and much more...

Questions?
The FXE instrument at European-XFEL

The JJ X-Ray team at the inauguration of European XFEL September 2017
Water cooled UHV Transfocator vibration
Different lens materials available

- Attenuation for different lens materials

- **Beryllium Lenses** (2-40 keV)
- **Aluminium Lenses** (40-80 keV)
- **Nickel Lenses** (80–150 keV)
- **Diamond** (5-90 keV)
Compound Refractive Lenses or CRL’s – the basics

Lens equation:

\[ \frac{1}{p} + \frac{1}{q} = \frac{1}{f} \], where \( f = \frac{R}{2N\delta} \)

where \( R \) is the radius of curvature at the apex, and \( \delta \) is the real part of the refractive index:

\[ n = 1 - \delta - i\beta \]

The transmission through \( N \) lenses is:

\[ T = \frac{R}{\mu NR_0^2} \left( 1 - e^{-\frac{\mu NR_0^2}{R}} \right) \cdot e^{-\mu Nd} \]
For a given beamline geometry the lens equation is fixed

\[ \frac{1}{p} + \frac{1}{q} = \frac{1}{f}, \text{where } f = \frac{R}{2N\delta} \]

but you want to minimize \( N \) and \( R \) and to choose \( \delta \) to be large or, in general, \( \mu/\delta \) to be small.

The geometrical aperture \( 2R_0 \) is limited by the effective aperture \( D_{\text{eff}} \) as:

\[ D_{\text{eff}} = \sqrt{\frac{2R}{\mu N}} \]
Water cooled UHV Transfocator box stability

- Main eigenmode at 289 Hz
- Compact design
- 4-way freedom
Features:
- Full UHV compatibility
- Renishaw encoding
- Two moment actuation
- High bending resolution through steel moment arms
- Gravity compensation
- Twist compensation
- Characterization at ALBA metrology lab
Mirror shaping

Ellipse:
\[ p = 37.225 \text{ m} \]
\[ q = 0.4467 \text{ m} \]
\[ \theta = 0.8^\circ \]

Si mirror:
Length = 43 cm
Height = 4 cm
Upstream bending moment = 600 N
Downstream bending moment = 600 N

Substrate shaping can be controlled down to few µm at little to no additional cost compared to rectangular substrates.