**HXR monochromators**

<table>
<thead>
<tr>
<th>Micro wave</th>
<th>I.R.</th>
<th>Visible</th>
<th>U.V.</th>
<th>Soft X-ray</th>
<th>Hard X-ray</th>
</tr>
</thead>
</table>

- **Soft X-ray**
- **I.R.**
- **U.V.**
- **Visible**

**Zero order**

**Internal Orders (+)**

**External Orders (-)**

\[ n\lambda = d\left(\sin(\alpha) - \sin(\beta)\right) \]

**Bragg's Law**

\[ n\lambda = 2d \sin \theta \]

**Incident plane wave**

\[ \theta \]

\[ d \sin \theta \]

\[ 2d \sin \theta \]

\[ d \]

\[ \alpha \]

\[ \beta \]
Radiation of wavelength $\lambda$ is reflected by the lattice plane. The outgoing waves interfere. The interference is constructive only if the difference of optical path is a multiple of $\lambda$:

$$2d \sin \theta = n \lambda$$

**Limits:**

$$\sin \theta = 1 \Rightarrow \lambda_{\text{max}}$$

$$\lambda_{\text{max}} = 2d \quad @ \theta = 90^\circ$$

**EXAMPLES:**

- $\text{Si (111)} \ d = 3.13 \text{Å} \rightarrow \text{E}_{\text{min}} \approx 2 \text{ keV}$
- $\text{InSb (111)} \ d = 3.74 \text{Å} \rightarrow \text{E}_{\text{min}} \approx 1.7 \text{ keV}$
- $\text{Si (311)} \ d = 1.64 \text{Å} \rightarrow \text{E}_{\text{min}} \approx 3.8 \text{ keV}$
- $\text{Beryl (10\overline{1}0)} \ d = 7.98 \text{Å} \rightarrow \text{E}_{\text{min}} \approx 0.8 \text{ keV}$
Energy Resolution

\[ \frac{\Delta \lambda}{\lambda} = \frac{\Delta E}{E} = \Delta \theta \cot g(\theta) \]

\[ \delta \lambda = \frac{2d \cos \theta}{\delta \theta} \]

\( \Delta \theta \) has two contribution:

- \( \Delta \theta_{\text{beam}} \) beam angular divergence
- \( \omega_{\text{crystal}} \) intrinsic reflection width of the monochromator

\[ 2d \sin \theta = n \lambda \]
Beam divergence

$$2d \cdot \sin \vartheta = n \lambda$$

$$2d \cdot \sin \vartheta_{\text{min}} = n \lambda_0$$

$$\Delta \vartheta = \vartheta_{\text{max}} - \vartheta_{\text{min}}$$

$$2d \cdot \sin \vartheta_{\text{max}} = n \lambda_1$$

$$\Delta \lambda \propto \Delta \vartheta$$
Beam divergence

\[ \frac{\theta_{\text{min}}}{E_{\text{max}}} \]

\[ \frac{\theta_{\text{max}}}{E_{\text{min}}} \]

monochromator
Collimating mirror

$\theta_{\text{min}} / E_{\text{max}}$

$\theta_{\text{max}} / E_{\text{min}}$

Collimating premirror

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Collimating mirror
The Darwin curve

\[ \frac{\Delta \lambda}{\lambda} = \frac{\Delta E}{E} = \Delta \theta \cot g(\theta) \]

\( \Delta \theta \) has two contributions:
- \( \Delta \theta_{\text{beam}} \): beam angular divergence
- \( \omega_{\text{crystal}} \): intrinsic reflection width of the monochromator
The Darwin curve

\[ \omega_s = \frac{2}{\sin 2\theta} \frac{r e \lambda^2}{\pi V} F_{hr} e^{-M} \]

- \( n \) order of the reflection
- \( \lambda \) wavelength of the fundamental
- \( e^{-M(n)} \) temperature factor
- \( V \) volume of the unit cell
- \( \theta_B \) Bragg angle
- \( R_e \) radius of the electron \( e^2/mc^2 \)

- \( F_{hr} \) real part of the structure factor related to the diffracted direction \( h(h,k,l) \)

**absorption effects**

**angular shift due to the refractive effect**
SR = source divergence
slit = angular acceptance of the slit

Typical resolving power:
E/ΔE ≈ 10^3 - 10^4
for non collimated beam
E/ΔE ≈ 10^4 - 10^5
for collimated beam

2d \cdot \sin \vartheta = \lambda

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Crystal Monochromator

All rays accepted by the first crystal are accepted also at the second.

Second crystal in non dispersive configuration
Channel cut
Much easier to align!
Exit beam displacement!
Impossible to detune (No more true)
Double Crystal monochromator

Fixed exit beam direction
0.2-2keV (0.2-4keV desired) photon energy range
Moderate resolving power, high flux.
Fulfil the requirement of full field imaging and scanning mode
Zone Plate

Fresnel lens
Zone Plate

\[ \sin \theta_m = \frac{m \lambda}{d}; \quad m = 0, \pm 1, \pm 2, \pm 3, \]

\[ \eta_m = \begin{cases} 
\frac{1}{4} & m = 0 \\
\frac{1}{m^2 \pi^2} & m \text{ odd} \\
0 & m \text{ even}
\end{cases} \]

(50\% absorbed)
\[ r_n^2 = fn \lambda \]

\[
q_n + p_n = q + p + \frac{n\lambda}{2}
\]

\[
q_n = (q^2 + r_n^2)^{1/2} \approx q + \frac{r_n^2}{2q}
\]

\[
p_n = (p^2 + r_n^2)^{1/2} \approx p + \frac{r_n^2}{2p}
\]

\[
\mathcal{A}' + \frac{r_n^2}{2q} + \mathcal{P}' + \frac{r_n^2}{2p} \approx \mathcal{A} + \mathcal{P}' + \frac{n\lambda}{2}
\]

\[
\frac{1}{q} + \frac{1}{p} \approx \frac{n\lambda}{r_n^2}
\]

\[
\frac{1}{q} + \frac{1}{p} \approx \frac{1}{f}
\]

\[ M = \frac{p}{q} \]
\[ r_n^2 = f n \lambda \]

\[ f = \frac{r_n^2}{n \lambda} = \frac{f_0}{n} \quad n \text{ odd} \]

\[ \lambda = \frac{r_n^2}{nf} = \frac{\lambda_0}{n} \]

Higher order focused at different longitudinal positions
Zone Plate

Reachable minimum outermost zone width ≈ 20-30 nm
Microscopes

Undulator U 5.6 short

Plane gratings 18m from source

Pin hole 22m from source

M3, Sagittal toroidal focusing mirror 20m from the source

Source

PR-ZP

OSA

Scanning

Sample (scanned) Detecor

Monochromatic light

ED Fluorescence detector

Full-field imaging

Sample (fixed)

Aperture

ZP

CCD

Monochromatic light

OSA

ZP

+ versatile detectors can run simultaneously;
+ easier optics set-up;
- long exposure time;
- complex electronics.

Ideal for spectromicroscopy

+ short exposure time;
+ higher resolution - static system;
- complex optical alignment.

Ideal for dynamic studies and tomography

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Small spots - Large acceptance

Demagnification 120X20

240 X 40 $\mu$m²

$2 \times 2$ $\mu$m²

Side view

Top view

Pin hole
Prefocusing
Entrance slit
Monochromator
Exit slit
Deflection mirror
VFM
HFM
Vertical focusing
Horizontal focusing
KB mirrors
Small spot with KB

<table>
<thead>
<tr>
<th>Shape</th>
<th>Length</th>
<th>rms errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spherical/flat</td>
<td>Up to 500 mm</td>
<td>&lt; 0.5 (\mu)rad</td>
</tr>
<tr>
<td>Spherical/flat</td>
<td>&gt; 500 mm</td>
<td>1-2 (\mu)rad</td>
</tr>
<tr>
<td>Toroidal</td>
<td>Up to 500 mm</td>
<td>&lt; 1 (\mu)rad</td>
</tr>
<tr>
<td>Toroidal</td>
<td>&gt; 500 mm</td>
<td>&gt; 1 (\mu)rad</td>
</tr>
<tr>
<td>Aspherical</td>
<td>Up to 500 mm</td>
<td>2 (\mu)rad</td>
</tr>
<tr>
<td>Aspherical</td>
<td>&gt; 500 mm</td>
<td>3-5 (\mu)rad</td>
</tr>
<tr>
<td>Spherical/flat</td>
<td>&gt; 500 mm</td>
<td>&gt; 1 (\mu)rad</td>
</tr>
</tbody>
</table>

2.5 \(\mu\)rad slope errors

Plane elliptical mirrors in KPB configuration

Single elliptical mirror

Spherical mirrors in KPB configuration
Approach best ellipse

Two unequal moment applied at the edges
Correction by polishing

![Diagram of a polishing process with graphs showing profile variation and polishing effect over different positions.](image)
Correction by polishing

Sample tilted by 76°

2X7 µm²
Flux 1x10¹³ ph/sec
Corrected by variable width

micro-fluorescence & micro-diffraction (HXR)

Bending system

The mirror must be shaped according to the required working distance and angle of incidence constant thickness but linear width variation.

Open clamping system to let the beam pass through

Picomotors for the bending driving system (2 for each mirror)
Two different moments are applied at the end of the flat polished substrate
Corrected by variable width
Corrected by variable width

2001  
Beamline: ID 19  
Energy 19 KeV  
Gain $3.5 \times 10^5$
Hybrid systems

Higher order corrected by:
Dynamic variation of the moment of Inertia
Correction of low frequency shape errors
Hybrid Systems

12 mm thickness, 400 mm long

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From flat to less than 1 m image distance
Angle of incidence above 2°
Other systems (larger dynamical range)
**Bimorph mirrors**

- Thin metallic electrode (deposited)
- Inert plate (optical material)
- Piezo ceramic

Optical surface polished after gluing
Bimorph mirrors

Dimension: from 150 mm (single element) to 1400 mm.

Radius variation: 370 m (+1500V) to 2300 m (-1500V)

Stability: $\Delta R/R \approx 0.8\%$ on 1 day scale
$\Delta R/R \approx 2.0\%$ on 10 day scale
Bimorph mirrors

2 mirrors in KB configuration (300 mm)
Bimorph mirrors

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photon Energy</td>
<td>33.167 KeV</td>
</tr>
<tr>
<td>Grazing angle</td>
<td>2 mrad</td>
</tr>
<tr>
<td>Coating</td>
<td>Pt</td>
</tr>
<tr>
<td>Source size</td>
<td>510 x 30 μm²</td>
</tr>
<tr>
<td>Footprint</td>
<td>260 mm</td>
</tr>
<tr>
<td>VFM Demag</td>
<td>40</td>
</tr>
<tr>
<td>HFM Demag</td>
<td>62</td>
</tr>
<tr>
<td>Spot dimension</td>
<td>8.5 x 6.0 μm²</td>
</tr>
</tbody>
</table>
The only way to have a real micro-focus is to start from a flat or spherical surface and bent it to an monodimensional ellipse.
Out of focus

1 μrad slope errors

Bendable plane elliptical mirrors
in KPB configuration

Focusing beam

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Out of focus

Slope error of the internally cooled mirror

Slope error bendable mirror
Out of focus

10 cm defocus

INTERNAL LIMITS

GOOD ONLY

INTENS = 7629.00
TOT = 25000
LOST = 17371

Horizontal: X [user unit]
Vertical: Z [user unit]

HistHorzFWHM: 0.00817366
HistVertFWHM: 0.0511315
Different mirror materials

- actual glidcop mirror $5\mu$rad
- SiC toroids $2\mu$rad

slope (rad)

x (mm)

$-10 \times 10^6$
Out of focus with Silicon mirrors

10 cm defocus with the SiC mirror and an ellipsoid with a real BIMORPH residual profile (SILICON)

Residual height: 18 nm P-V; 5 nm rms

The bimorph mirror is property of GM/CA CAT at the APS (funded in whole or in part with Federal funds from the National Cancer Institute (Y1-CO-1020) and the National Institute of General Medical Science (Y1-GM-1104)). ACCEL instruments GmbH is the main contractor for the realization of the GM/CA CAT beamlines.
Metallic vs Silicon

Residual slope (rad)

Relative mirror position (mm)
In physics, coherence is a property of waves, that enables stationary (i.e. temporally and spatially constant) interference. More generally, coherence describes all correlation properties between physical quantities of a wave.
Coherence

Coherence & Wave front Preservation

FERMI beamlines

- Shutters
- Plane mirrors
- Safety Hutch
- FEL 1
- FEL 2
- Spectrometer
- EIS Switching
- Delay Lines
- Monochromator
- TIMEX
- KB System
- LDM
- TIMEX-LDM
- Diproii
- Coherence & Wave front Preservation

\[ \lambda = \infty \]

\[ \Delta x = \frac{\lambda}{L_c} \]

\[ \Delta \lambda = \frac{\lambda}{L_c} \]

\[ x_1 \]

\[ x_2 \]

\[ L_c = \infty \]

\[ \Delta \lambda \]

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Coherence & Wave front preservation

\[ \varphi = \frac{2 \delta h \cdot \sin \theta}{\lambda} \]

\(\lambda/4\) deformation (after all mirrors) needed
\(\lambda/10\) deformation (at each mirrors) accepted

D. Cocco X-Ray optics, Erice, 6-15 April 2011
## Coherence & wave front preservation

### Fermi@elettra case

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Angle of incidence</th>
<th>shape error p-v $\psi = 0.25$</th>
<th>shape error p-v $\psi = 0.1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 nm</td>
<td>6°</td>
<td>47</td>
<td>18</td>
</tr>
<tr>
<td>40 nm</td>
<td>3°</td>
<td>95</td>
<td>38</td>
</tr>
<tr>
<td>40 nm</td>
<td>1.5°</td>
<td>191</td>
<td>76</td>
</tr>
<tr>
<td>10 nm</td>
<td>3°</td>
<td>23</td>
<td>9</td>
</tr>
<tr>
<td>10 nm</td>
<td>2°</td>
<td>35</td>
<td>14</td>
</tr>
<tr>
<td>10 nm</td>
<td>1°</td>
<td>71</td>
<td>28</td>
</tr>
<tr>
<td>5 nm</td>
<td>3°</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>5 nm</td>
<td>2°</td>
<td>18</td>
<td>7.2</td>
</tr>
<tr>
<td>5 nm</td>
<td>1°</td>
<td>36</td>
<td>14</td>
</tr>
<tr>
<td>1.67 nm</td>
<td>3°</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

### Xfel(s) case

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Angle of incidence</th>
<th>shape error p-v $\psi = 0.25$</th>
<th>shape error p-v $\psi = 0.1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 nm</td>
<td>1°</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>0.5 nm</td>
<td>1°</td>
<td>3.6</td>
<td>1.4</td>
</tr>
<tr>
<td>0.1 nm</td>
<td>0.33°</td>
<td>2</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>
Mirror shape errors

2 nm P-V

residual height (mm)
mirror position (mm)

Typical SR mirrors

Required FEL mirrors
Mirror polishing
1) Classical polishing (Computer Controlled Polishing-CCP)
2) High precision metrology (NOM-Bessy)
3) Ion Beam Figuring or CCP
4) Second iteration with metrology
5) Second IBF or CCP
6) Third.....
7) ......
8) .......

Classical polishing

---

<table>
<thead>
<tr>
<th></th>
<th>PV /nm</th>
<th>RMS /nm</th>
<th>slope RMS /arcsec</th>
</tr>
</thead>
<tbody>
<tr>
<td>before</td>
<td>48.4</td>
<td>10.3</td>
<td>0.37</td>
</tr>
<tr>
<td>after</td>
<td>14.9</td>
<td>3.9</td>
<td>0.22</td>
</tr>
<tr>
<td>after -0.5 mm</td>
<td>13.9</td>
<td>3.6</td>
<td>0.17</td>
</tr>
<tr>
<td>after +0.5 mm</td>
<td>18.5</td>
<td>4.4</td>
<td>0.31</td>
</tr>
</tbody>
</table>

Height 4. It.: 61 nm pv  
Height final.: 22 nm pv
1) Classical polishing
2) High precision metrology
3) Error correction by Rh controlled deposition
4) Second iteration with metrology
5) Second differential coating deposition
6) Third.....
7) ......
8) ......
9)

nn) Final required slope/shape error reached (hopefully)
Elastic emission machining

Chemical reaction are induced between top-site atoms of mirror and fine powders

**Problem:** max dimension 100mm (400 with lower precision)

*mirror substrate: Quartz Glass Silicon*

Before machining
- 1.3 nm rms

After machining
- 0.3 nm rms

Before machining
- 0.32 nm rms

After machining
- 0.14 nm rms

**Powder used:** 0.1µm size SiO2 2µm size SiO2
SR sources vs FEL sources

30 ps → ns

Synchrotron bunch distribution

Compress the bunch length and see what’s happen
Brilliance

\[ P \sim N_e^2 \]

10^{10} Increase

\[ P \sim N_e \]
Differences

Intensity (photons/sec)

Photon Energy (eV)

3 GeV
- 15 cm 13 periods 0.5 X 0.5 mrad
- 16 cm 12 periods 0.5 X 0.5 mrad
- 5.6 cm 51 periods 0.5 X 0.1 mrad
- 6.5 cm 44 periods 0.5 X 0.1 mrad
- 8 cm 25 periods 0.5 X 0.1 mrad

1. rf photo-cathode gun:
   high quality electron source

2. booster accelerator:
   reduction space-charge effects

3. bunch compressor:
   increase of the current

storage ring

2 ns
electron beam
Thermal deformations

From \( \mu W \) or \( mW \) to 100W --> kW

Thermal deformations
Fluence and damage threshold

Fluence (Joules/cm²) = laser pulse energy (J) / focal spot area (cm²)
Intensity (Watts/cm²) = peak power (W) / focal spot area (cm²)
Peak power (W) = pulse energy (J) / pulse duration (sec)

FEL 1:
100 fsec; 5 GW → ~ 0.5 mJ

FEL 2:
200 fsec; 1 GW → ~ 0.2 mJ

<table>
<thead>
<tr>
<th>Material</th>
<th>Damage threshold @ 100 nm</th>
<th>Safety angle 100 nm (10/20/40 m)</th>
<th>Estimated damage threshold @ 40 nm</th>
<th>Safety angle 40 nm (10/20/40 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu/Glidcop bulk</td>
<td>~ 500 mJ/cm²</td>
<td>24° / 90° / 90°</td>
<td>~ 1000 mJ/cm²</td>
<td>41° / 90° / 90°</td>
</tr>
<tr>
<td>Au coating</td>
<td>40 mJ/cm²</td>
<td>1.9° / 7.6° / 32°</td>
<td>50 mJ/cm²</td>
<td>4.8° / 20° / 77°</td>
</tr>
<tr>
<td>Silicon bulk</td>
<td>30 mJ/cm²</td>
<td>1.5° / 6° / 23°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graphite coating</td>
<td>60 mJ/cm²</td>
<td>2.9° / 11.5° / 53°</td>
<td>240 mJ/cm²</td>
<td>9° / 40° / 90°</td>
</tr>
<tr>
<td>YAG bulk</td>
<td>70 mJ/cm²</td>
<td>3.3° / 13.4° / 68°</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
High density carbon (or B4C) are very “strong” materials but...

Proper mirror coatings (and multilayers) must be made.
Binding layers are very very important
Gold or platinum are “soft” or “tender” materials.....
Harmonic rejection and monochromatisation

Examples:
100 nm cff 0.98 $\alpha$ 80.41 11.1 l/mm $\Delta t=74$ fsec FWHM
40 nm cff 0.93 $\alpha$ 81.8 33.3 l/mm $\Delta t=65$ fsec FWHM
30 nm cff 1.25 $\alpha$ 82.65 150 l/mm $\Delta t=300$ fsec FWHM
10 nm cff 1.73 $\alpha$ 85.5 600 l/mm $\Delta t=236$ fsec FWHM

Harmonic rejection and monochromatisation

$\Delta T = N\lambda/c$

$n\lambda = d(\sin(\alpha) - \sin(\beta))$

Zero order

Internal Orders (+)

External Orders (-)
Grating’s groove

A lot of energy deposited on the grating facet

Almost normal incidence

Blaze angle = (α + β) / 2

Laminar

Grating’s groove

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Grating grooves

A lot of energy deposited on the grating facet

Blaze angle = \(\frac{\alpha + \beta}{2}\)

Energy distributed on the grating facet
**Multilayers**

Intensity $20\text{nm} (1^{\text{st}} \text{harm})$
\[ \frac{\text{Intensity} \ 6.33\text{nm} \ (3^{\text{rd}} \text{harm})}{\geq 100} \]

**Ratio eff. Multilayer**

<table>
<thead>
<tr>
<th>Total</th>
<th>6.33nm/eff. 20nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mirror</td>
<td>$\rightarrow$ 57</td>
</tr>
<tr>
<td>2 mirrors</td>
<td>$\rightarrow$ 3300</td>
</tr>
<tr>
<td>4 mirrors</td>
<td>$\rightarrow$ $10^7$</td>
</tr>
</tbody>
</table>

**Reflectivity (\(\delta\))**

- Co/C
- 100 layers
d = 4.6 nm

**Beam in**

- ml\_a
- ml\_b
- ml\_c
- ml\_d
Multilayers suffer from fast aging effect

<table>
<thead>
<tr>
<th>Material</th>
<th>Damage threshold @ 32 nm</th>
<th>Safety margin @ 50 m, 45° Full beam Absorbed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon bulk</td>
<td>87 mJ/cm²</td>
<td>48 - 48</td>
</tr>
<tr>
<td>Mo/Si</td>
<td>60 mJ/cm²</td>
<td>33 - 33</td>
</tr>
<tr>
<td>SiC</td>
<td>140 mJ/ cm²</td>
<td>77 - 77</td>
</tr>
<tr>
<td>Co/C</td>
<td>200 mJ/cm²</td>
<td>111 - 111</td>
</tr>
</tbody>
</table>

Multilayers: 0.9-1.8 mJ/cm² on the 45° mirror surface at 20 nm. 0.9-1.8 mJ/cm² adsorbed.
Multilayers

Graphite  Mo/B4C

In focus
Fluence: 180 mJ/cm²

1 mm out of focus
Fluence: 60 mJ/cm²

2 mm out of focus
Fluence: 25 mJ/cm²

3 mm out of focus
Fluence: 12 mJ/cm²

Measured at 400 nm at the EIS laser lab

<table>
<thead>
<tr>
<th>Material</th>
<th>Fluence</th>
</tr>
</thead>
<tbody>
<tr>
<td>α-C</td>
<td>60 mJ/cm²</td>
</tr>
<tr>
<td>B4C</td>
<td>200 mJ/cm²</td>
</tr>
</tbody>
</table>

D. Cocco X-Ray optics, Erice, 6-15 April 2011
Delay from -2.5ps to +35 ps
Pump with 1st Probe with 1st or 3rd (multilayer positioned in the fixed “probe” line
Delay from -2.5ps to +35 ps
Pump with 1st Harmonic
Probe with 1st or 3rd (multilayer positioned in the fixed “probe” line

Required movement range and step: ≈ 1m. few µm
**Precision required**

Spot dimension < 10 $\mu$m (could easily be less)

Beam offset = $2\delta\theta$ (angular error on mirror) * $r$

$\delta\theta = 1\mu$rad

$\delta\theta = 0.3\mu$rad

$\delta\theta = 0.1\mu$rad

---

D. Cocco *X-Ray optics*, Erice, 6-15 April 2011
Precision required

\[ \delta \theta = 0.3 \mu \text{rad} \]

\[ \delta \theta = 0.1 \mu \text{rad} \]
Delay line - Coherent beam diffraction effect
Request of higher performance

Better results

Request of better mirrors

You must be able to measure it!

Atomic Force Microscope

Visible micro interferometer

2D interferometer (Fizeau)

Long Trace Profiler (LTP II)
Long trace profiler

Reference

Surface under test

Laser beam

$F^2TL$

SUT

Linear array detector

$90^\circ$
3D measurement of optical surfaces

λ/100 precision

λ/2000 repeatability

λ usually 632.8 nm or 1100 nm

Accessories

Transmission spheres

Converger for sagittal radii and NI mirrors

Diverger for NI mirrors with R>2 m

Laser collimated beam

Beam splitter

Partially reflective transmission flat (or sphere)
Roughness measurement

Michelson Interferometer
Atomic force microscope
Roughness (SF > 1 mm⁻¹)

Slope errors (SF < 0.5 - 0.2 mm⁻¹)

AFM, 1 µm
AFM, 10 µm
Michelson microscope 40x
Fizeau interferometer

Power spectral density
Books:
A.A. Modern Developments in X-ray and Neutron Optics (Recent achievement in multilayer, metrology, ray tracing and X-ray lenses)
CXRO X-ray data booklet Lawrence Berkeley Nat. lab. (2001) free (general information and table useful when using X-ray)

Programs: Shadow (ray tracing) http://www.nanotech.wisc.edu/shadow/shadow.html
XOP (general optical calculation) http://www.esrf.fr/computing/scientific/xop
SPECTRA (synchrotron source) http://radiant.harima.riken.go.jp/spectra/index_e.html

Links: Centre for X-ray Optics http://www-cxro.lbl.gov/ (general information and on line software)
The international society for Optical Engineering http://www.spie.org
Optics.org http://optics.org
Photonics.com http://www.photonics.com/