X-ray Focusing

Compound Refractive Lenses (CRL)

Compound refractive lenses focusing monochromatic hard X-ray

Hard X-ray focusing
Standard CRL

Flexible X-ray lens system with changeable working distance
- User can optimise the working distance with removeable focusing elements
- Manually or electrically driven
- Small outer dimension of 100 mm x 120 mm x 100 mm

Multiple focusing conditions in one lens array
Multi-focus lens

Large aperture with low absorption
X-ray prism lens (XPL)

Lens arrays in 2D-grid
- Lenses optimised for different set-ups can be mounted in a single lens block
- At most 10 x 10 lens matrix available (in the case of 150 µm physical aperture)
- Multiple focal points on one plane by illuminating the whole aperture

Prisms arranged to redirect refracted ray to the focus point

<table>
<thead>
<tr>
<th>Focusing example</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.4 keV, WD = 1.6 m</td>
</tr>
<tr>
<td>Incident beam size: 1.5 mm x 1.5 mm</td>
</tr>
<tr>
<td>Focus point size: 52 µm x 46 µm</td>
</tr>
</tbody>
</table>

Delivery examples (SPring-8)
BL13XU, BL43LXU
**Compound refractive lens**

Focusing concept and standard specifications

- With more lens elements, getting shorter focal lengths

**CRL specifications**

- Lens material: SU-8 (epoxy resist)
- Entrance aperture size (physical): up to 1,500 µm
- Wide energy range applicable (> 8 keV)
- Focal point size: min. 0.5 µm x 0.5 µm
- Focal length: > several lens mm
- Lens plate dimension: 70 mm x 35 mm

**2D focusing lens**

Standard layout

**Strengths**

- Point focusing realised by crossing two lens arrays by 90°
- Optical axis does not change
- Easily installed because only one plate is required
- Can be used as collimating lens
- Fresnel lens is also available

**CRL application example**

BL10XU SPring-8 Japan

CRLs made by KIT/IMT and X-ray aperture made by microworks GmbH realised a focused beam size of 1 µm x 1 µm (FWHM).

**Delivery record**

SPring-8 and Photon Factory, Japan

First delivery: 12.2005

Lens manufacturer: Karlsruhe Institute of Technology (KIT)/IMT

<table>
<thead>
<tr>
<th>Delivery record</th>
<th>SPring-8</th>
<th>Photon Factory, Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>BL24XU (JASRI)</td>
<td>1D Standard ...</td>
<td>1D Standard ...</td>
</tr>
<tr>
<td>BL35XU (JASRI)</td>
<td>2D Standard ... 5</td>
<td>2D Standard ... 5</td>
</tr>
<tr>
<td>BL39XU (JASRI)</td>
<td>ID Customised ...</td>
<td>ID Customised ...</td>
</tr>
<tr>
<td>BL40XU (JASRI)</td>
<td>2D Customised ... 5</td>
<td>Photon Factory</td>
</tr>
<tr>
<td>BL41XU (JASRI)</td>
<td>ID Standard ...</td>
<td>1D Standard ...</td>
</tr>
<tr>
<td>BL42XU (JASRI)</td>
<td>Lens Plate Dimension</td>
<td>70 mm x 35 mm</td>
</tr>
<tr>
<td>BL43XU (RIKEN)</td>
<td>1D Standard ...</td>
<td>1D Standard ...</td>
</tr>
<tr>
<td>BL45XU (RIKEN)</td>
<td>2D Standard ... 5</td>
<td>2D Standard ... 5</td>
</tr>
<tr>
<td>BL46XU (RIKEN)</td>
<td>ID Customised ...</td>
<td>ID Customised ...</td>
</tr>
<tr>
<td>BL47XU (RIKEN)</td>
<td>2D Customised ... 5</td>
<td>Photon Factory</td>
</tr>
<tr>
<td>BL48XU (RIKEN)</td>
<td>3D Standard ...</td>
<td>3D Standard ...</td>
</tr>
<tr>
<td>BL49XU (RIKEN)</td>
<td>4D Standard ...</td>
<td>4D Standard ...</td>
</tr>
<tr>
<td>BL50XU (RIKEN)</td>
<td>5D Standard ...</td>
<td>5D Standard ...</td>
</tr>
<tr>
<td>BL51XU (RIKEN)</td>
<td>6D Standard ...</td>
<td>6D Standard ...</td>
</tr>
<tr>
<td>BL52XU (RIKEN)</td>
<td>7D Standard ...</td>
<td>7D Standard ...</td>
</tr>
<tr>
<td>BL53XU (RIKEN)</td>
<td>8D Standard ...</td>
<td>8D Standard ...</td>
</tr>
</tbody>
</table>

© 1 Karlsruhe Institute of Technology IMT

Ver. 201806

Your Local Contact: ASICON Tokyo Ltd.

www.asicon-tokyo.com microtech@asicon-tokyo.com
X-ray Gratings for Talbot Interferometry
X-ray gratings fabricated by KIT/IMT and microworks GmbH

High aspect ratio structure

<table>
<thead>
<tr>
<th>Structure examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height [µm]</td>
</tr>
<tr>
<td>Period [µm]</td>
</tr>
<tr>
<td>Material</td>
</tr>
<tr>
<td>AR</td>
</tr>
<tr>
<td>Type</td>
</tr>
</tbody>
</table>

Karlsruhe Institute of Technology (KIT)/IMT and microworks GmbH have a long experience in the LIGA process, develop and provide high AR X-ray gratings worldwide.

Very small period grating

Within a limited area and limited metal thickness, 1.0 µm to 2.0 µm period gratings have been realised.

Structure examples

<table>
<thead>
<tr>
<th>Example 1</th>
<th>Example 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period</td>
<td>2.0 µm</td>
</tr>
<tr>
<td>Metal</td>
<td>Ni</td>
</tr>
<tr>
<td>Height</td>
<td>3.2 µm</td>
</tr>
<tr>
<td>For</td>
<td>18 keV, π/2</td>
</tr>
<tr>
<td>Area</td>
<td>10 mm x 10 mm</td>
</tr>
<tr>
<td>Substrate</td>
<td>Polyimide</td>
</tr>
<tr>
<td>Design</td>
<td>Continuous</td>
</tr>
</tbody>
</table>

Large structured area

Standard
(a) 4 inch wafer: 70-90 mm round
(b) 6 inch wafer: up to 110 mm with some constraints

Optional
- Tiling multiple grating plates
- Enlarging the structured area made in a single fabrication process

Bent grating

To avoid shadow effect due to cone beam, bending can be implemented.

Food inspection

Images taken with a slot scanning set-up at 70 kVp (tube source) under a symmetric Talbot-Lau arrangement using gratings with a period of 10 µm. Gratings were linearly tiled to form a 400 mm x 25 mm area.

Non destructive testing

BL-14C Photon Factory, Japan
E = 17.8 keV with Al filter (2.0 mm)
G1: period 2.4 µm (Ni)
G2: period 2.4 µm (Au)

Your Local Contact: ASICON Tokyo Ltd.
www.asicon-tokyo.com microtech@asicon-tokyo.com
High Aspect Ratio Micro Structures

LIGA process and its applications

**X-ray aperture**
Single/multi through-holes

Examples
(a) Multi holes with 3.0 µm diameter and 80 µm gold thickness
(b) Single hole with 5.0-10.0 µm diameter and 200 µm gold thickness

**Central beam stop**

Example
Material: Au
Pillar diameter: 30-160 µm, height: 80 µm
Supporting fin thickness: 2.5-10 µm (centre / outer)

**High aspect ratio structure**

Example
Material: Ni
Height: 1,500 µm
Smallest structure: 12 µm Smallest air gap: 5-8 µm (smaller apertures feasible with smaller height)
Top surface polishable

---

**X-ray aperture and CRL application example**

BL10XU SPring-8 Japan

X-ray focusing lenses (CRLs) made by KIT/IMT and X-ray aperture made by microworks GmbH realised a focused beam size of 1 µm x 1 µm (FWHM).

Courtesy of Dr Naohisa Hirao (JASRI) and Dr Yasuo Ohishi (JASRI)

**LIGA micro fabrication process**

Example: absorption grating
(a) Resist layer preparation
(b) X-ray exposure through the mask to the resist layer
(c) Realisation of precise resist structure
(d) Gold structure realisation by electroplating

Low AR: Low aspect ratio (AR) structures can be directly drawn on the resist without mask and it can be electroplated afterwards.

High AR: Depending on the aspect ratio, one or two masks will be required.

©1 Karlsruhe Institute of Technology IMT, ©2 microworks GmbH

Your Local Contact: ASICON Tokyo Ltd.

www.asicon-tokyo.com   microtech@asicon-tokyo.com
**Institute of Microstructure Technology of Karlsruhe Institute of Technology (KIT/IMT)**

*Organisation:* In Division III of the Karlsruhe Institute of Technology (KIT), Germany

*Expertise:* Structuring diverse polymeric materials and selected metals (esp. Au and Ni) down to the nm range.

*Major technologies:* Lithographic structuring (e-beam, deep X-ray, and UV lithographies) and replication methods (hot embossing, thermoforming, and nano imprint).

---

**microworks GmbH**

*A spin-off company from KIT/IMT providing high precision metal structures*

*About:* Founded in 2007 as a spin-off from the Institute of Microstructure Technology (IMT) of Karlsruhe Institute of Technology (KIT) in Germany.

*Core competence:* X-ray lithography which realises the highest aspect ratios and a precision well below 1 μm within a wafer and from wafer to wafer.

*Production chain:* From layout and mask making to UV and X-ray lithography up to electroplating and surface finishing.

*Mission:* To serve the clients as the number-one supplier of high-precision microstructures made with X-ray and laser LIGA technology.

*Founder and Managing Director:* Dr Joachim Schulz

---

**ASICON Tokyo Ltd.**

*URL:* http://www.asicon-tokyo.com

*Contact:* microtech@asicon-tokyo.com

*Company name:* ASICON Tokyo Ltd.

*Founded on:* 25.12.2006

*Managing Director:* Tomoaki TSUGITA

*About:* In the fields of X-ray optics and microfluidics, ASICON Tokyo Ltd. offers end-user specific microstructured parts fabricated in Germany to Japanese, Korean and Taiwanese customers.

---

©1 Karlsruhe Institute of Technology IMT, ©2 microworks GmbH www.asicon-tokyo.com / Ver. 201806