Development of Precision, Variable Slits for Dynamic X-ray Scattering Instrument

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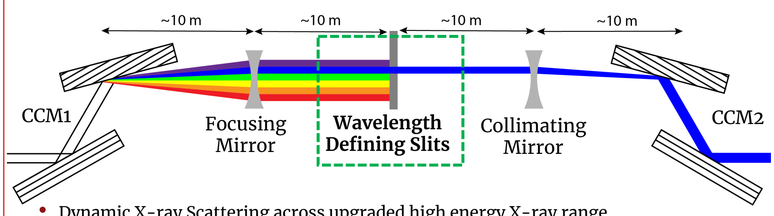
ABSTRACT

The LCLS-II-HE beamline at SLAC (Menlo Park, USA) is planned to come online in 2027. With FEL photon energies ranging from 6 keV to 22 keV at up to 1 MHz repetition rate, the upgraded beam calls for new science endstations to be developed. The Dynamic X-ray Scattering (DXS) instrument will employ experimentation methods such as X-Ray Photon Correlation Spectroscopy (XPCS) and High Resolution Inelastic X-Ray Scattering (IXS) to investigate quantum materials and condensed matter chemistry among other topics. To realize its science goals, DXS requires a tunable energy selection capability with an energy bandwidth of less than 3 meV FWHM. The key component of the DXS instrument is a 4f-High Resolution Monochromator (4f-HRM), featuring a Wavelength Defining Slit (WDS) mechanism. To achieve the necessary tunability and energy bandwidth, the WDS mechanism selects angularly dispersed photon energies using a continuously variable slit size with a minimum gap of 1.0 micron, and 0.1 micron motion resolution. The novel slit blade design cuts the beam while absorbing up to 10 W direct beam heat load. This presentation discusses the goals, design challenges, and solutions for the WDS.

HIGH RESOLUTION MONOCHROMATOR

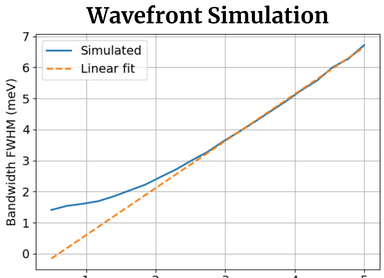


- Dynamic X-ray Scattering across upgraded high energy X-ray range
  - Photon energy: [6, 22] keV
  - Pulsed repetition rate up to 1 MHz
- HRM provides high resolution energy selection
  - Tunable bandwidth: $\Delta E \cdot \Delta T \leq 2x$ FT-limit
  - Energy bandwidth: ΔE <3 meV
- WDS selects spatially separated photon energies provided by angular dispersion of CCM1
  - Continuously Variable Slit Gap: [1,20] µm
  - Motion Resolution: 0.1 µm

REQUIRED SLIT OPENING

- Necessary slit opening depends on,
  - CCM1 dispersion
  - Beam energy, size
  - Focal length focusing mirror

Wavefront Simulation



Courtesy Matthew Seaberg

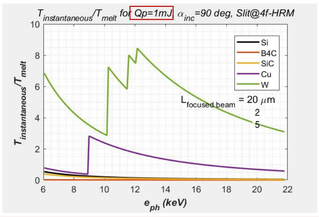
SLIT BLADE MATERIAL

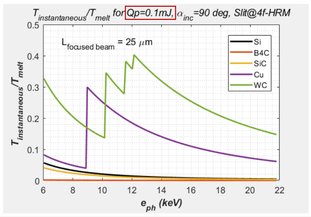
SINGLE SHOT DAMAGE

- Energy Range [6,22] keV
- Pulse rep. rate ≤1 MHz
  - Pulse Power = (Pulse Energy)*(Rep. Rate)
  - 10 W incident power based on upstream optics
- Estimated spatial beam size
  - Vertical: <1.1 mm
  - Horizontal: [25,250] µm

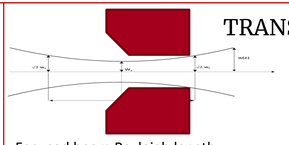
Q_p Pulse Energy (mJ)	Repetition Rate (kHz)
0.01	1000
0.1	100
1	10

Courtesy Lin Zhang

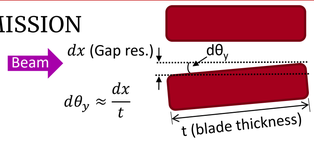




TRANSMISSION

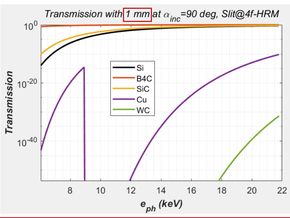


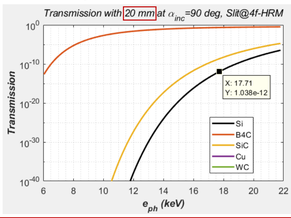
Focused beam Rayleigh length ~20mm –> blades should sit within



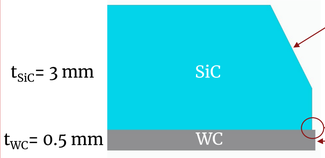
$$d\theta_y \approx \frac{dx}{t}$$

- Slit Blades must attenuate X-ray beam
  - Transmission < 10^{-11} across 6 – 22 keV
- Minimize necessary blade thickness



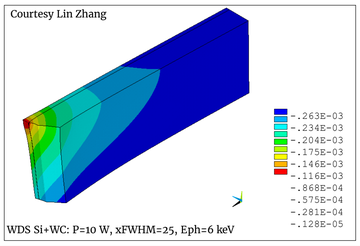


SLIT BLADE GEOMETRY



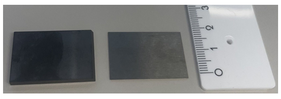
- Incline plane to distribute power
- SiC deals with heat load & single shot damage
- Offset: (0, 10] µm
- WC provides beam defining surface

Thermal Deformation of Bi-material Slit



- Water cooled
- Cooling coefficient >10,000 W/m²/°C (In foil)
- Max thermal deformation (on WC)<0.05 µm

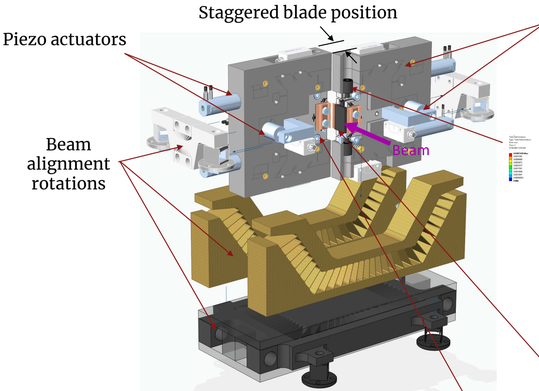
SLIT BLADE PROTOTYPING



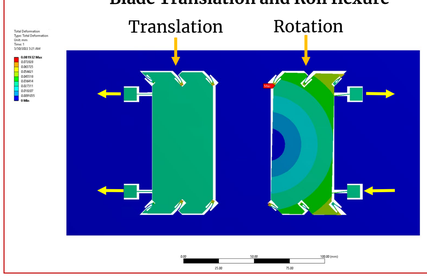
- 20mm x 30mm (H x W)
- WC critical surface: (0.5 mm x 20mm)
  - Flatness <50nm
  - R_a <20nm rms

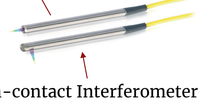
- Sn-Ag-Ti active bonding solder
- Ultrasonic (mechanical) agitation
- Thermal conductivity 50 W/mK
- Shear strength 70 Mpa
- UHV compatible

MECHANICAL CONCEPT



Blade Translation and Roll flexure





Non-contact Interferometer or Confocal distance sensors (metrology)