ENGINEERING SPECIFICATION DOCUMENT (ESD)	Doc. No. SP-391-000-65 R1	LUSI SUB-SYSTEM CXI

Engineering Specifications for the CXI 1 micron KB System

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Revision	Date	Description of Changes	Approved
R0	17OCT08	Initial release	
R1	25NOV08	Included a temperature controlled enclosure specification, Included long-trace profilometry and stitching interferometry as the technique for figure measurement, Update roughness values in the coating specification tables. Clarified the sagittal curvature and slope error requirements. Clarified language issues throughout the document Added summary of specifications at the end of the document	DCR

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1. Overview

The Coherent X-ray Imaging (CXI) instrument to be built at the Linac Coherent Light Source (LCLS) by the LCLS Ultrafast Science Instruments (LUSI) project on the SLAC National Accelerator Laboratory site requires a mirror system to produce a 1x1 micron^2 FWHM focal spot at the sample. The mirror system shall be made of 2 mirrors each with an elliptical figure and arranged in a Kirkpatrick-Baez (KB) configuration rotated by 45 degrees. The system is known as the CXI 1 Micron KB System or KB1.

The LCLS will produce a laser-like beam of X-rays in the 800 to 8300 eV range for the fundamental energy. Also, the 3rd harmonic will be present at up to 25 keV. The CXI instrument will use the hard X-ray branch which uses 2 offset mirrors that reflect energies between 2 keV and 25 keV. The KB mirrors will be located 420 m away from the source, which ranges in size from 60 μm to 78 μm FWHM, depending on the energy. The X-ray beam at the mirror location will range from 500 μm to 1500 μm depending on the energy.

The KB mirror combination shall reflect more than 75% of the X-rays over the 2-18 keV range. This will be achieved by coating the mirrors with two strips. The first strip will be a Silicon Carbide (SiC) monolayer and the second strip will be a bilayer consisting of a heavy material (either Rhodium (Rh) or Ruthenium (Ru)) deposited underneath a thin layer of Silicon Carbide (SiC).

These mirrors will be located in an Ultra-High Vacuum (UHV) environment (10^{-9} Torr). They require a very precise positioning system with the mirrors located inside a vacuum enclosure which will be mounted on a stable stand.

2. Scope

This document contains the specifications for the fabrication and delivery of a KB mirror system capable of producing a focal spot of roughly 1 μm x 1 μm (FWHM) for the CXI instrument built by LUSI at LCLS. Here, we say roughly 1 μm x 1 μm (FWHM) because the source size and location varies with the photon energy and therefore the focal spot will vary with energy and it will not be possible to obtain a 1 micron focus at all energies. The focus shall also not be smaller than 1 μm x 1 μm (FWHM) at any energy within the range of interest but may be larger than 1 μm x 1 μm (FWHM) at the lower energies. The specifications described in this document were chosen to satisfy this requirement. Multiple activities and components are required to build the complete mirror system. They are as followed.

Mirror Substrates (Described in Section 6)

Mirror Coating (Described in Section 7)

Mirror Metrology (Described in Section 8)

Mirror Mechanical Support System (Described in Section 9.1)

Vacuum Enclosure (Described in Section 9.2)

Support Stand (Described in Section 9.3)

All the requirements are summarized in Section 18 at the end of this document. The details for all these requirements are found in the Sections 3 to 17.

3. Applicable Documents, Specifications and Codes

3.1. SLAC Specifications

- SLAC document No. SP-391-000-25, "Physics Requirements for the CXI 1 micron KB System"
- SLAC document No. SP-391-000-19, "Physics Requirements the CXI Instrument"
- SLAC document No. SP-391-001-41, "Physics Requirements the CXI 1 micron Sample Chamber"
- SLAC document No. SP-391-001-42, "Physics Requirements the CXI 1 micron Precision Instrument Stand"
- SLAC drawing No. DS-391-000-36, "Mechanical Design Standards Supplement"
- SLAC drawing No. SC-700-866-47, "Specification Kly & Vac Machining Fluids"
- Fed-STD-595B, "Colors Used in Government Procurement"

3.2. Other Specifications

- MIL-PRF-13830B: "Optical Components for Fire Control Instruments; General Specification Governing the Manufacture, Assembly, and Inspection of."

4. Definitions

Mirror substrate vendor

The entity entering a contract with SLAC to provide mirrors meeting all requirements listed in Section 6.

Mirror coating vendor

The entity entering a contract with SLAC to provide coating for mirrors meeting all requirements listed in Section 7.

Mirror metrology vendor

The entity entering a contract with SLAC to provide metrology measurements on mirrors as described in Section 8.

Mirror support vendor

The entity entering a contract with SLAC to provide a mirror mechanical support system meeting all requirements described in Section 9.1.

Vacuum enclosure vendor

The entity entering a contract with SLAC to provide a vacuum enclosure meeting all requirements described in Section 9.2. This entity shall be the same entity as the mirror support vendor.

Stand vendor

The entity entering a contract with SLAC to provide a stand meeting all requirements described in Section 9.3. This entity shall be the same entity as the mirror support vendor and the vacuum enclosure vendor.

5. General Requirements

5.1. Location

The vacuum enclosure of the KB mirror system will be located in experimental hutch 5 in the Far Experimental Hall of LCLS, known as FEH Hutch 5.

The midpoint between the 2 mirrors along the x-ray beam shall be located 384 m downstream of the exit of the LCLS undulator, which produces the X-ray beam. This same midpoint shall be located 8 m upstream of the focal point. The spacing between the 2 mirrors shall be kept to a minimum to minimize the overall length of the system.

5.2. Environment

The temperature and relative humidity in the FEH Hutch 5 will be maintained at (22.2°C +/-0.3°C), and 45% +/-10%, respectively.

The LUSI project will provide a temperature-controlled enclosure to encase the KB mirror system. This enclosure shall have a thermal stability of ±0.01 degree Celcius. The mirror system shall be designed to meet the thermal stability requirements listed in this document when enclosed in this environment with temperature controlled to ±0.01 degree Celcius.

5.3. Lifetime

The expected service life of the device is 10 years.

6. Optical Requirements, Mirror Requirements

6.1. Scope

This section describes the requirements for 2 mirrors to be delivered to SLAC. The mirrors shall be polished with an elliptical figure as described below.

6.2. Mirror Definitions

A pictorial definition of relevant terminology is given in Figure 1. The dimensions of the clear aperture are listed in Table 1 and Table 2. The clear aperture represents the optical surface where the surface quality requirements must be met. The requirements to the surface listed in Table 1 and Table 2 do not apply outside the clear aperture.

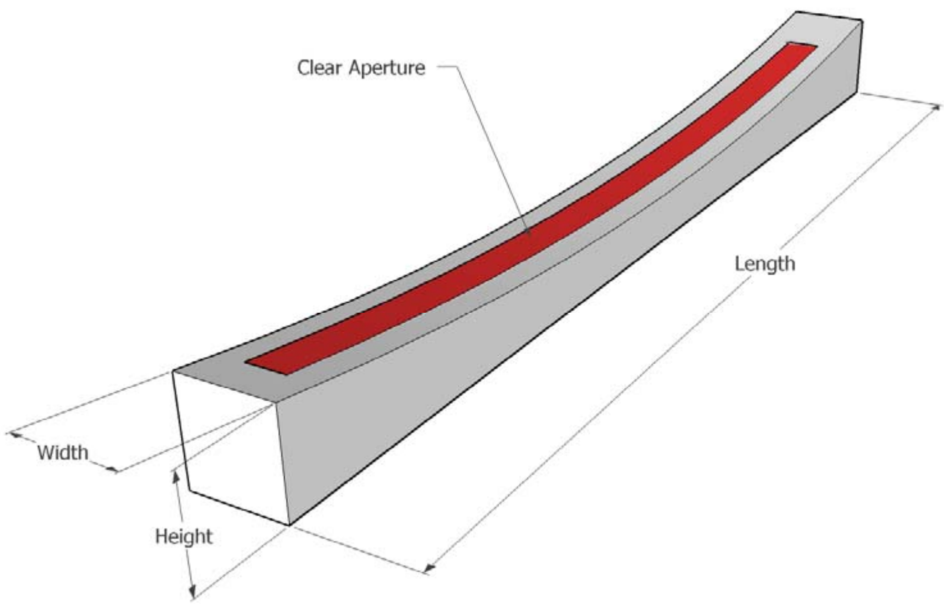

Figure 1: Pictorial definition of terminology

6.3. Performance Requirements

The mirrors will be used in a Kirkpatrick-Baez configuration rotated by 45 degrees (as shown in Figure 8) to produce a 1 micron FWHM focal spot. The mirrors will accept the full beam width (4 standard deviations or more) at all energies above 5 keV and will be > 86% reflective (each mirror for a total reflectivity > 75%) over the 2-18 keV range with the proper coating applied. The mirror parameters listed in Table 1 and Table 2 as well as the coating parameters listed in Table 3 and Table 4 were chosen to meet these requirements. The mirror vendor shall be only responsible for meeting the requirements listed in these two tables and shall not be responsible for demonstrating or meeting the reflectivity requirements, which shall be met with proper coating given that the requirements of Table 3 and Table 4 are met.

6.4. Mirror Dimensions Requirements

The mirror substrate vendor shall produce mirrors with dimensions larger than the clear aperture defined in Table 1 and Table 2. The exact dimensions of the full mirror substrates, provided they are within the range listed in Table 1 and Table 2, are to be determined by the mirror substrate vendor, with the agreement of SLAC and the mirror support vendor. The mirror substrate vendor shall provide the exact dimensions, on engineering drawings, of the mirror substrate to SLAC in response to the Request for Proposal from SLAC. These dimensions will be used as design parameters for the mechanical system of the mirrors (Section 9.1) and must be fixed from the beginning, with no possibility for change unless agreed upon by SLAC. Provisions for any mounting features such as grooves and bevels shall be agreed upon by SLAC, the mirror substrate vendor and the mirror support vendor at the time of the contract award. The leading edge of the mirror shall have a chamfered edge to minimize radiation damage issues should the beam strike the leading edge.

6.5. Optical Surface Requirements

6.5.1. Figure Requirements

The mirrors shall have an elliptical profile to provide longitudinal focusing. The elliptical profile shall be obtained by machining of the optical surface. The mirrors shall have a limited curvature in the sagittal direction with a minimum radius of 400 m. All tangential roughness and slope errors are determined after subtraction of the best-fit elliptical reference surface from the clear aperture zone, in the case of pre-figured mirrors. In the sagittal direction, the slope error shall be determined after subtraction of the best-fit sagittal radius of curvature. Best-fit elliptical tangential radius or sagittal radius, must meet the respective surface radii specifications outlined in Table 1 and Table 2.

The figure error requirements are listed in Table 1 and Table 2.

Long-trace profilometry, full-aperture, visible-light interferometry, stitching interferometry, or another metrology technique approved by SLAC shall be used to determine the surface figure at the mirror substrate vendor's facility, after processing of the mirrors surface has been completed. Verification of the mirror figure will be performed by a third party after delivery of the mirrors as described in Section 8.

The mirrors will not be arranged in the standard KB configuration. They will be rotated by 45 degrees which will cause the overall deflection of the beam to be horizontal only (the +X direction). The distortion of the figure of the mirror due to gravity in this orientation shall be taken into account and the mirrors shall meet all the specifications of Table 1 and

Table 2 when rotated to the 45 degree orientation. The first mirror shall deflect the beam 45 degrees down while the second mirror shall deflect the beam 45 degrees up, as shown on Figure 8.

It is the mirror substrate vendor's responsibility to demonstrate that the effects of interferometer measurement error and gravity distortion are either negligible or are removed from the data

	Parameter	Value	Units	Comment
1	Mirror Shape	Tangential ellipse		Pre-figured mirrors
2	Clear aperture length	350	mm	Length over which the coating will be applied and the surface specifications must be met
3	Clear aperture width	$30 \geq$ width ≥ 12	mm	Width over which the 2 coating strips will be applied and the surface specifications must be met
4	Mirror Length	$375 \geq$ length ≥ 360	mm	Extra length is to allow mounting during the coating process and mirror use
5	Mirror Width	$60 \geq$ width ≥ 45	mm	
6	Mirror Thickness	>50	mm	
7	Substrate material	Si <100>		Single crystal
8	Figure height error	<1.00	nm rms	Over dimensions from 1mm to the clear aperture size from best-fit ellipse
9	Mid-spatial roughness	<0.25	nm rms	Over the 10^{-3} to 0.5 μm^{-1} frequency range
10	High-spatial roughness	<0.25	nm rms	Over the 0.5 to 50 μm^{-1} frequency range
11	Tangential Slope error	<0.25	μrad rms	Over dimensions from 1mm to the clear aperture size from best-fit ellipse
12	Sagittal Slope error	<2	μrad rms	Over dimensions from 1mm to the clear aperture width from best-fit sagittal radius
13	Mean Tangential Radius of curvature tolerance	0.1	%	
14	Sagittal radius of curvature	>400	m	
15	Distance from source	420	m	
16	Focal length	8.2	m	
17	Maximum incidence angle	3.4	mrad	Angle of incidence at downstream end of the mirror
18	Vacuum pressure	$<10^{-9}$	Torr	
19	Temperature	22	^{o}C	
		Calculated parameters from the specifications		
A	Maximum height of surface	3.24	μm	Surface profile is shown on Figure 2 below. For pre-figured mirrors only.
B	Tangential Radius of curvature	4632-4932	m	Elliptical profile (see Figure 3 below). For pre-figure mirrors only
C	Average incidence angle	3.364	mrad	Angle of incidence at the mid-point of the mirror
D	Ellipse parameter (a)	214.1	m	
E	Ellipse parameter (b)	197.4	mm	

Table 1: Parameters for first mirror of KB1 system.

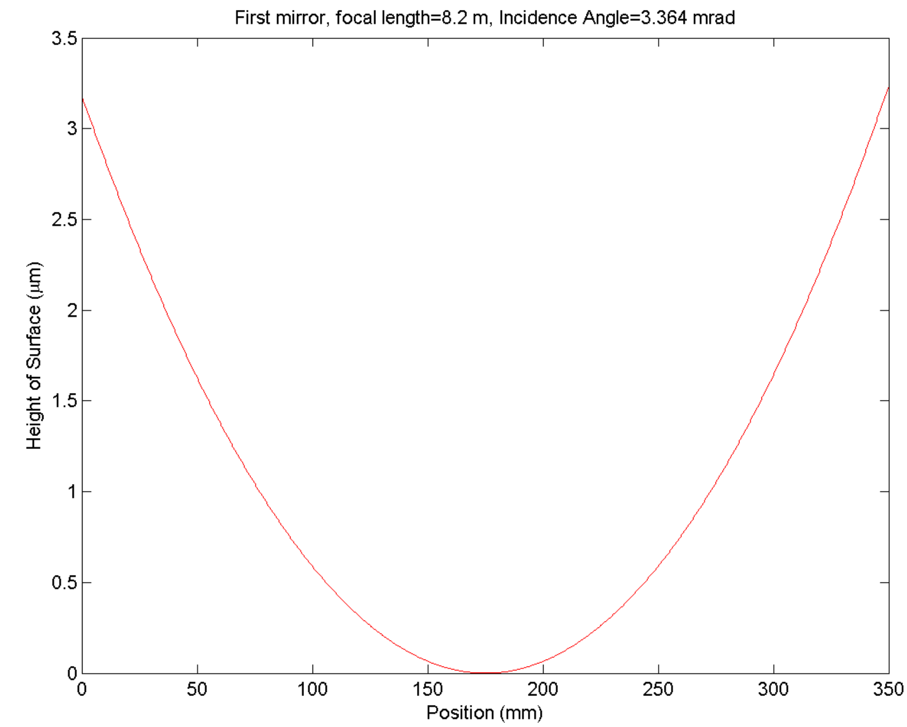

Figure 2: Surface profile of the first mirror.

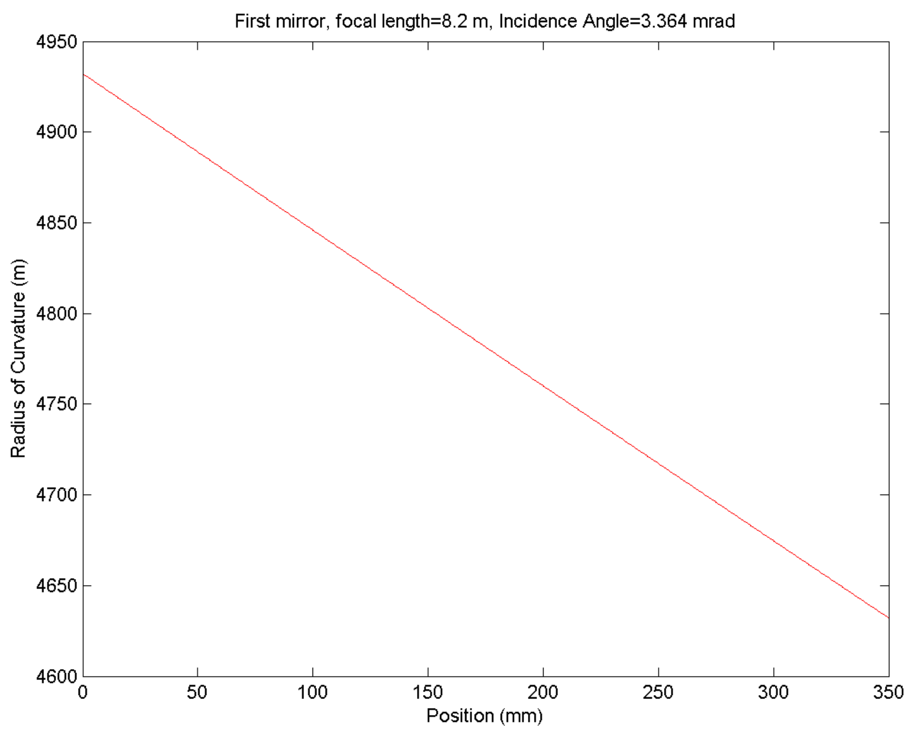

Figure 3: Radius of curvature of the first mirror surface as a function of position along the mirror.

	Parameter	Value	Units	Comment
1	Mirror Shape	Tangential ellipse		Pre-figured mirrors
2	Clear aperture length	350	mm	Length over which the coating will be applied and the surface specifications must be met
3	Clear aperture width	30 ≥ width ≥ 12	mm	Width over which the 2 coating strips will be applied and the surface specifications must be met
4	Mirror Length	375 ≥ length ≥ 360	mm	Extra length is to allow mounting during the coating process and mirror use
5	Mirror Width	60 ≥ width ≥ 45	mm	
6	Mirror Thickness	>50	mm	
7	Substrate material	Si <100>		Single crystal
8	Figure height error	<1.00	nm rms	Over dimensions from 1mm to the clear aperture size from best-fit ellipse
9	Mid-spatial roughness	<0.25	nm rms	Over the 10^{-3} to 0.5 μm^{-1} frequency range
10	High-spatial roughness	<0.25	nm rms	Over the 0.5 to 50 μm^{-1} frequency range
11	Tangential Slope error	<0.25	µrad rms	Over dimensions from 1mm to the clear aperture size from best-fit ellipse
12	Sagittal Slope error	<2	µrad rms	Over dimensions from 1mm to the clear aperture width from best fit sagittal radius
14	Mean Tangential Radius of curvature tolerance	0.1	%	
15	Sagittal radius of curvature	>400	m	
16	Distance from source	420	m	
17	Focal length	7.8	m	
18	Maximum incidence angle	3.4	mrad	Angle of incidence at downstream end of the mirror
19	Vacuum pressure	$<10^{-9}$	Torr	
20	Temperature	22	^{o}C	
Calculated parameters from the specifications				
A	Maximum height of surface	3.40	µm	Surface profile is shown on Figure 2 below. For pre-figured mirrors only.
B	Tangential Radius of curvature	4405-4706	m	Elliptical profile (see Figure 3 below). For pre-figure mirrors only
C	Average incidence angle	3.363	mrad	Angle of incidence at the mid-point of the mirror
D	Ellipse parameter (a)	213.9	m	
E	Ellipse parameter (b)	192.4	mm	

Table 2: Parameters for second mirror of KB1 system.

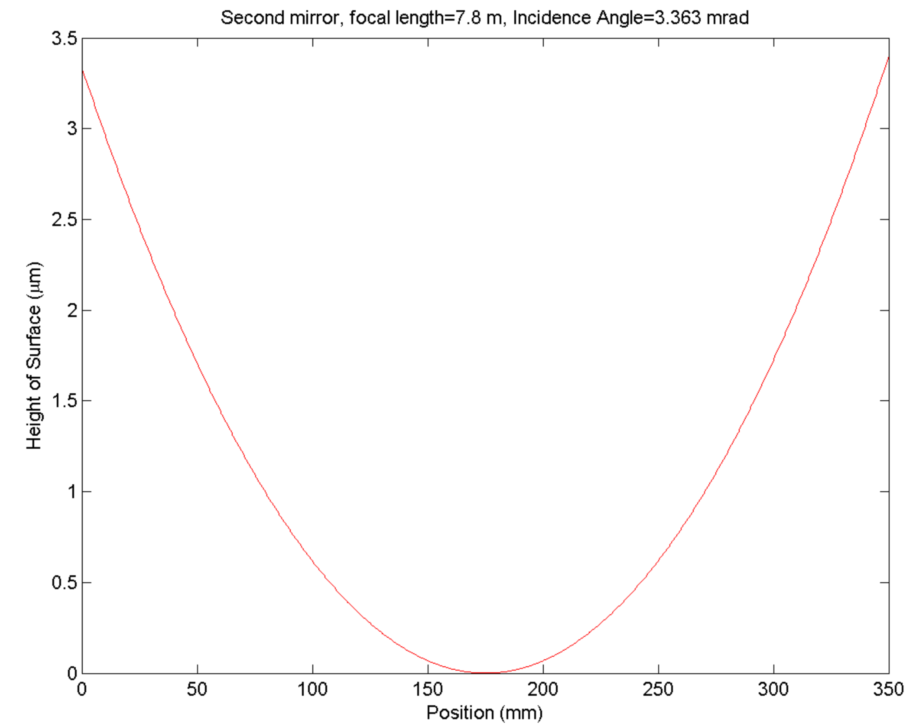

Figure 4: Surface profile of the second mirror.

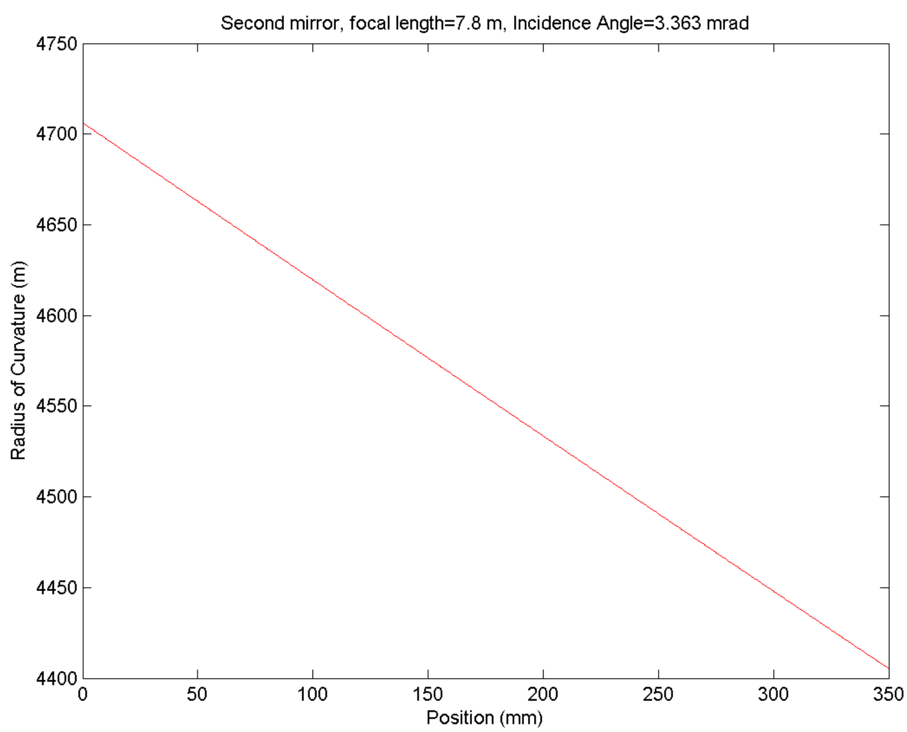

Figure 5: Radius of curvature of the second mirror surface as a function of position along the mirror.

6.5.2. Roughness Requirements

The roughness requirements are listed in Table 1 and Table 2.

Roughness shall be measured on each mirror after cleaning. A visible-light interferometer or profilometer shall be used for mid-spatial frequency measurements at the mirror substrate vendor's facility. If available, an AFM instrument shall be used for high-spatial frequency measurements at the mirror substrate vendor's facility. If an AFM instrument is unavailable, alternative arrangements must be made by the mirror substrate vendor in agreement with SLAC.

Verification of the mid-spatial frequency roughness and the high-spatial frequency roughness will be performed by a third party with white-light optical profiling microscope and AFM capabilities as described in Section 8 after delivery of the mirrors.

6.6. Design and Construction

6.6.1. Substrate Material

The mirror substrate material shall be single-crystal silicon, with a <100> direction oriented along the "Length" of the mirror. It shall additionally be free from defects such as dislocations, cracks, etc. Any other substrate material options proposed by the vendor shall be approved by SLAC.

6.6.2. Surface Finish

6.6.2.1. Optical Surface Area

The mirror optical surface shall be finished using a SLAC approved technique to remove residual sub-surface damage and leave the optical surface in a stress-free condition. The mirror vendor shall describe the polishing technique to be used in the response to the Request for Proposals.

The mirror optical surface shall have no striae under visible examination.

The mirror optical surface shall meet a scratch/dig requirement of 10/5 per MILPRF-13830B

6.6.2.2. Non-Optical Surface Areas

The mirror non-optical surface areas shall be finished using a controlled grinding process followed by wet-chemical etching to remove residual sub-surface damage and leave the non-optical surface areas in a stress-free condition. This process shall be staged such that all surfaces of the mirror shall be wet-chemical-etched before proceeding with the final polishing of the optical surface..

6.6.3. Workmanship

Workmanship shall be consistent with the quality necessary for stable operation of sensitive optical devices under long-term exposure to an x-ray, ultrahigh vacuum (UHV) environment similar to that found in synchrotron radiation user facilities.

6.6.4. Test Coupons and Substrates

6.6.4.1. Test Coupons for Coating and Surface Qualification

The mirror substrate vendor shall provide five single-crystal silicon test polishing coupons, for qualification of the SLAC reflective coating deposition process described in Section 7. In order to make use of standard tooling, these test coupons should preferably be 2 inch diameter flat disks with a thickness of 3/8 inch. The exact shape and dimensions (including thickness) of the coupons are at the discretion of the mirror substrate vendor, but subject to negotiation and approval by SLAC. Each test coupon shall be polished/figured using the same processes to be applied on the full-size mirrors. The optical surface roughness in the mid-spatial and high-spatial ranges should meet the requirements in the Section 6.5.2. The specification for the surface figure is relaxed to only include a peak-valley surface height error of ≤ 158 nm (equivalent to λ/4 at 633 nm) over the central 80% of the coupon. These test coupons should be prepared and separately-delivered to SLAC as soon as feasible following the award of the contract, to expedite qualification of the reflective coating deposition process. Also note the packaging requirements outlined in Section 6.6.7.

6.6.4.2. Silicon Blank Substrate

The mirror substrate vendor shall provide one complete single-crystal silicon mirror substrate for verification of the SLAC mirror handling and mounting procedures, described in Section 9.1. This substrate should be prepared in the same manner as the primary mirror substrates. It should be cut to size, ground, prepared with the mounting holes and grooves, and wet-chemical etched with the other substrates. However, only relaxed specifications for figuring and polishing are required for the optical surface:. A peak-valley surface height error of ≤ 158 nm (equivalent to λ/4 at 633 nm) is required over the clear aperture, after subtraction of best-fit cylinder reference surfaces (see Sections 6.5.1 and Figure 6) with a mid-spatial and high spatial roughness of ≤ 1.0 nm rms (see Section 6.5.2). This test substrate should be separately-delivered to SLAC as soon as feasible, to expedite finalization of the mirror handling and mounting procedures.

6.6.5. Handling and Cleaning

6.6.5.1. Handling

Full, UHV handling practice is required. Each mirror shall be handled in accordance with the Handling and Process Plan, as reviewed and approved by SLAC.

6.6.5.2. Cleaning

Each mirror shall be cleaned at the mirror substrate vendor's facility in a manner that is consistent with the figure, mid- and high-spatial frequency roughness requirements discussed in this section and that allows the mid- and high-spatial frequency roughness to be evaluated. Cleaning shall be performed at the mirror substrate vendor's facility in accordance with the methods outlined in the Handling and Process Plan provided by the mirror substrate vendor and approved by SLAC.

6.6.6. Packaging and Shipping

The mirror substrate vendor shall be responsible for design and fabrication of the mirror shipping container(s). Best protection against contamination and shock/vibration is essential. An all-metal, dust-free interior-most enclosure is desirable. A brief description of proposed packaging and shipping arrangements shall be included in the Handling and Process Plan.

6.6.7. Test Coupon Packaging and Shipping

The mirror substrate vendor shall be responsible for supplying test coupon shipping container(s) for the test coupons described in Section 6.6.4.1. Best protection against contamination and shock/vibration is desirable. A dust-free interior, sealed enclosure is desirable. Coupons are to be restrained at the edges of the polished surface, to preserve the surface condition. A brief description of proposed packaging and shipping arrangements shall be included in the Handling and Process Plan.

6.6.8. Handling and Process Plan

All mirror processing shall take place in accordance with the methods described in the Handling and Process Plan supplied by the mirror substrate vendor. This document shall be provided in response to the Request for Proposal from SLAC, and must be reviewed and approved by SLAC. In that way, any materials compatibility issues for the completed mirrors can be identified and settled in advance. As noted in the sections above, the Handling and Process Plan shall include brief descriptions of the following:

(1) Fabrication process
(2) UHV handling procedures
(3) Mirror cleaning procedure
(4) Packaging and shipping arrangements

6.7. Quality Assurance Provisions

6.7.1. General

Prior to contract award, SLAC may perform a quality audit at the mirror substrate vendor's facility to ascertain the existing or planned quality program implementation and procedures as it pertains to this procurement. Existing manufacturing procedures to be used for this procurement shall be reviewed during this audit.

The mirror substrate vendor shall maintain documentation for all metrology and processes during fabrication and characterization of these mirrors.

6.7.1.1. Program Management

The mirror substrate vendor shall actively manage all matters relating to the performance of this contract to ensure that all specifications, schedule, and quality objectives are fully met. A single individual shall be named to serve as the Program Manager of this subcontract. The Program Manager shall act as the single point of contact with SLAC on all technical and programmatic matters.

The subcontract shall establish and apply a program control system to track progress regarding pre-established, measurable milestones. The subcontract shall identify corrective management actions in the event shortfalls are detected or anticipated. The mirror substrate vendor shall develop and provide a detailed project schedule to SLAC. The schedule shall be periodically updated and provided at least on a monthly basis to SLAC as part of progress reporting.

In the event SLAC determines that the program success is in jeopardy because of technical, schedule, or quality shortfalls, SLAC reserves the right to conduct special program reviews and audits, as necessary, at the mirror substrate vendor's facility.

6.7.1.2. Progress Reporting

SLAC and the mirror substrate vendor shall conduct, at a minimum, monthly status teleconferences. These teleconferences shall discuss general status of the program. Any item that has immediate effect on technical performance, schedule, or deliveries shall be brought to the immediate attention of SLAC.

6.7.1.3. Reviews

The vendor shall provide necessary support for an initial Technical Interface Meeting to discuss contract planning and to discuss any open contractual or technical action items.

6.7.1.4. Responsibility for Inspection and Tests

The responsibility for performing and documenting all specified tests and metrology shall rest with the mirror substrate vendor unless noted otherwise. The mirror substrate vendor shall submit an Inspection Test Procedure to SLAC for approval, as outlined in this document, describing each test or measurement to be implemented. SLAC reserves the right to perform in-process inspections at the mirror substrate vendor's facility. The mirror substrate vendor shall notify SLAC a minimum of 5 working days prior to the start of final inspection and testing. Drawings and equipment that may be required for adequate inspection and test shall be made available to SLAC. SLAC inspection shall in no way relieve the mirror substrate vendor of responsibility for ensuring the quality of the mirrors.

6.7.1.5. Inspection Test Procedure

The mirror substrate vendor shall prepare an Inspection Test Procedure in response to the Request for Proposal from SLAC. It must be reviewed and approved by SLAC, and shall include the following at a minimum:

(1) Acceptance verification matrix that list each requirement (including pass/fail criteria) and indicate by what methods and procedures the mirror substrate vendor shall verify the requirement.
(2) Sequence of measurements, both in-process and final
(3) Equipment to be used
(4) Accuracy of measurements
(5) Calibration techniques
(6) Proposed data sheets of results and data format for the Inspection Test Report

6.7.1.6. In-Process Inspection Points

Mirror substrate vendor in-process inspection points shall be specified as part of the Inspection Test Procedure (see Section 6.7.1.5). At a minimum, inspections shall be performed at the following points:

(1) After initial shaping of the non-optical surface areas
(2) Selected points during mirror surface polishing
(3) Final inspection after the mirror is finished

6.7.2. Quality Conformance Inspections

6.7.2.1. Visual Inspection

The completed mirrors shall be visually inspected for conformance to the requirements in Section 6.6, prior to performing the measurements described in Section 6.7.2.2. If visual inspections uncover defects, additional inspections and measurements, as needed, shall be performed to determine acceptability. Visual inspections shall use techniques that enhance the visibility of defects, and shall be described in the Inspection Test Procedure (Section 6.7.1.5). Illumination of the surface shall be 200 or more foot-candles (lumens per square foot). The mirror shall be viewed against a dark background and from a direction just off the line of specular reflection.

Mirror polish shall be evaluated by visual inspection. Areas with scratches, or pits in excess of the requirements of Section 6.5 are unacceptable.

Optical surface edges shall be visually inspected for digs and chips.

Overall appearance shall be free from all visible contamination and poor workmanship indications.

6.7.2.2. Characterization Metrology

Compliance with the Optical Surface Quality Requirements specified in Section 6.5 shall be demonstrated through measurements, and the resulting data provided in the Inspection Test Report. As also stated in Section 6.7.1.5, all measurement procedures must be proposed in the Inspection Test Procedure and approved-by SLAC prior to execution.

Measurements shall be made under the following environmental conditions:

Temperature: 20°C ± 2°C.

Humidity: 30% to 70% relative humidity (RH)

During all measurements, the article under test and the test equipment shall be in thermal equilibrium within the specified temperature range.

Mid- and high-spatial frequency roughness shall be measured at the locations specified in Figure 6. These measurements shall be made after cleaning of the mirrors, as also discussed in Sections 6.5.2.and 6.6.4.

Instrumentation used for the measurement of figure, mid- and high- spatial frequency roughness should be capable of accurately measuring the spatial frequency bandwidths specified in Sections 6.5.1.and 6.5.2., respectively. All equipment should be in current and traceable calibration.

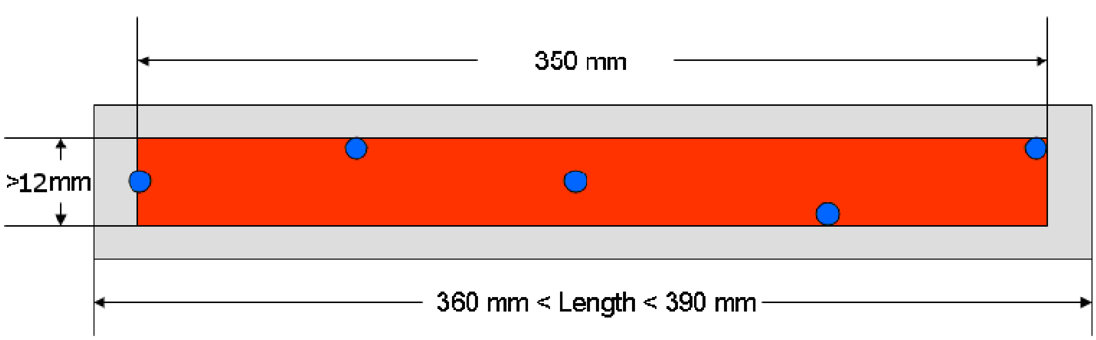

Figure 6: Location of roughness measurement sites, marked in blue. The clear aperture zone is marked in red.

6.7.3. Inspection Test Report

The mirror substrate vendor shall submit an Inspection Test Report of metrology results and associated raw data with each mirror at the time of delivery.

The Inspection Test Report shall include machine-readable raw data sets for all metrology performed. Data sets shall be in plain ASCII text, or another widely used format of mutual agreement. The mirror substrate vendor shall describe the file formats and supply necessary constants and parameters to permit independent data analysis of the raw data.

7. Coating Requirements

7.1. Coating Materials

Each mirror shall be coated with 2 reflective strips, each 5 mm wide. The first strip shall consist of a single layer of SiC.

The second strip shall consist of a bilayer. The bottom layer shall be a high atomic number material to be specified later by the SLAC group. The two likeliest candidate materials are Rhodium (Rh) and Ruthenium (Ru). The second layer material shall be Silicon Carbide (SiC).

The materials for each layer and each strip are listed in Table 3 and Table 4.

7.2. Coating Figure

The coating process of the mirrors shall preserve the figure of the polished Silicon substrates as described in Section 6. The figure error requirements listed in Table 3 and Table 4 shall not be exceeded after the coating is performed unless the mirror substrate that was delivered did not meet these specifications and a relaxed tolerance was agreed upon by the SLAC group.

Parameter	Value	Units	Comment
Coating material	SiC		
Coating thickness	50	nm	
Figure height error	<1.00	nm rms	Over dimensions from 1mm to the clear aperture size
Mid-spatial roughness	<0.25	nm rms	Over the 10^{-3} to 0.5 μm^{-1} frequency range
High-spatial roughness	<0.25	nm rms	Over the 0.5 to 50 μm^{-1} frequency range
Coating Strip width	5	mm	

Table 3: Mirror coating requirements for the first strip

Parameter	Value	Units	Comment
First coating layer material	Rh or Ru		
First coating layer thickness	30	nm	
Figure height error (1st layer)	<1.00	nm rms	Over dimensions from 1mm to the clear aperture size
Mid-spatial roughness (1st layer)	<0.25	nm rms	Over the 10^{-3} to 0.5 µm^{-1} frequency range
High-spatial roughness (1st layer)	<0.25	nm rms	Over the 0.5 to 50 µm^{-1} frequency range
Second coating layer material	SiC		
Second coating layer thickness	20	nm	
Figure height error (2nd layer)	<1.00	nm rms	Over dimensions from 1mm to the clear aperture size
Mid-spatial roughness (2nd layer)	<0.25	nm rms	Over the 10^{-3} to 0.5 µm^{-1} frequency range
High-spatial roughness (2nd layer)	<0.25	nm rms	Over the 0.5 to 50 µm^{-1} frequency range
Coating Strip width	5	mm	

Table 4: Mirror coating requirements for the second strip

7.3. Coating Roughness

Roughness shall be measured on each mirror after deposition of each coating layer and strip. A visible-light interferometer or profilometer shall be used for mid-spatial frequency measurements at the coating vendor's facility. If available, an AFM instrument shall be used for high-spatial frequency measurements at the coating vendor's facility. If an AFM instrument is unavailable, alternative arrangements must be made by the coating vendor.

Verification of the mid-spatial frequency roughness and the high-spatial frequency roughness will be performed by a third party with white-light optical profiling microscope and AFM capabilities as described in Section 8 after the coating process has been completed.

7.4. Workmanship

Workmanship shall be consistent with the quality necessary for stable operation of sensitive optical devices under long-term exposure to an x-ray, ultrahigh vacuum (UHV) environment similar to that found in synchrotron radiation user facilities.

7.5. Process Development

The coating vendor shall develop and test the coating process on test substrates before coating the final mirrors. These test substrates can consist of small thin silicon wafers. The coating vendor shall fully characterize the test coatings in a manner consistent with the final metrology to be performed on the real mirrors and the results shall be communicated to SLAC prior to proceeding with the coating of the mirrors. SLAC shall make available some of the test coupons provided by the mirror substrate vendor for the coating process development.

7.6. Handling and Cleaning

7.6.1. Handling

Full, UHV handling practice is required. Each mirror shall be handled in accordance with the Handling and Coating Process Plan described in Section 0, as reviewed and approved by SLAC.

7.6.2. Cleaning

Each mirror shall be cleaned at the coating vendor's facility in a manner that is consistent with the figure, mid- and high-spatial frequency roughness requirements discussed in this document, as well as the coating, and that allows the mid- and high-spatial frequency roughness to be evaluated. Cleaning shall be performed at the coating vendor's facility in accordance with the methods outlined in the Handling and Coating Process Plan provided by the vendor and approved by SLAC, as described in Section 0.

7.7. Packaging and Shipping

The coating vendor shall utilize the same packaging and shipping procedure as the mirror substrate vendor as outlined in the Handling and Process Plan described in Section 6.6.8. The plan developed by the mirror substrate vendor will be communicated to the coating vendor by the SLAC group and the coating vendor is expected to follow this plan or submit its own plan to be approved by SLAC.

7.8. Test Coupon Packaging and Shipping

The coating vendor shall utilize the same packaging and shipping procedure for the test coupons as the mirror substrate vendor as outlined in the Handling and Process Plan described in Section 6.6.8. The plan developed by the mirror substrate vendor will be communicated to the coating vendor by the SLAC group and the coating vendor is expected to follow this plan or submit its own plan to be approved by SLAC.

7.9. Handling and Coating Process Plan

All mirror coating processes shall take place in accordance with the methods described in the vendor-supplied Handling and Coating Process Plan. SLAC will provide to the coating vendor the Handling and Process Plan supplied by the mirror substrate vendor (described in Section 6.6.8 and the coating vendor is expected to follow this plan or submit its own plan to be approved by SLAC. Also, an addendum to this plan shall be provided by the coating vendor to include a brief description of the mirror coating procedures. This addendum shall be provided in response to the Request for Proposal from SLAC, and must be reviewed and approved by SLAC. In that way, any materials compatibility issues for the completed mirrors can be identified and settled in advance.

7.10. Quality Assurance Provisions

7.10.1. General

Prior to contract award, SLAC may perform a quality audit at the coating vendor's facility to ascertain the existing or planned quality program implementation and procedures as it pertains to this procurement. Existing procedures to be used for this procurement shall be reviewed during this audit.

The coating vendor shall maintain documentation for all metrology and processes during coating and characterization of these mirrors.

7.10.1.1. Program Management

The coating vendor shall actively manage all matters relating to the performance of this contract to ensure that all performance, schedule, and quality objectives are fully met. A single individual shall be named to serve as the Program Manager of this subcontract. The Program Manager shall act as the single point of contact with SLAC on all technical and programmatic matters.

The subcontract shall establish and apply a program control system to track progress regarding pre-established, measurable milestones. The subcontract shall identify corrective management actions in the event shortfalls are detected or anticipated. The coating vendor shall develop and provide a detailed milestone schedule to SLAC.

In the event SLAC determines that the program success is in jeopardy because of technical, schedule, or quality shortfalls, SLAC reserves the right to conduct special program reviews and audits, as necessary, at the coating vendor's facility.

7.10.1.2. Progress Reporting

SLAC and the coating vendor shall conduct, at a minimum, twice monthly status teleconferences. These teleconferences shall discuss general status of the program. Any item that has immediate effect on technical performance, schedule, or deliveries shall be brought to the immediate attention of SLAC.

7.10.1.3. Reviews

The vendor shall provide necessary support for an initial Technical Interface Meeting to discuss contract planning and to discuss any open contractual or technical action items.

7.10.1.4. Responsibility for Inspection and Tests

The responsibility for performing and documenting all specified tests and metrology shall rest with the coating vendor unless noted otherwise. The coating vendor shall submit a Coating Inspection Test Procedure to SLAC for approval, as outlined in this document, describing each test or measurement to be implemented. SLAC reserves the right to perform in-process inspections at the coating vendor's facility. The coating vendor shall notify SLAC a minimum of 5 working days prior to the start of final inspection and testing. Drawings and equipment that may be required for adequate inspection and test shall be made available to SLAC. SLAC inspection shall in no way relieve the coating vendor of responsibility for ensuring the quality of the mirrors.

7.10.1.5. Coating Inspection Test Procedure

The coating vendor shall prepare a Coating Inspection Test Procedure in response to the Request for Proposal from SLAC. It must be reviewed and approved by SLAC, and shall include the following at a minimum:

(1) Acceptance verification matrix that list each requirement (including pass/fail criteria) and indicate by what methods and procedures the mirror substrate vendor shall verify the requirement.
(2) Sequence of measurements, both in-process and final
(3) Equipment to be used
(4) Accuracy of measurements
(5) Calibration techniques
(6) Proposed data sheets of results and data format for the Coating Inspection Test Report

7.10.1.6. In-Process Inspection Points

Vendor in-process inspection points shall be specified as part of the Coating Inspection Test Procedure (see Section 7.10.1.5). At a minimum, inspections shall be performed at the following points:

(1) Upon receipt of the mirror substrate
(2) After deposition of the each layer and each strip
(3) Final inspection after the mirror coating is finished

7.10.2. Quality Conformance Inspections

7.10.2.1. Characterization Metrology

Compliance with the Optical Surface Quality Requirements specified in Sections 7.2 and 7.3 shall be demonstrated through measurements, and the resulting data provided in the Coating Inspection Test Report. As also stated in Section 7.10.1.5, all measurement procedures must be proposed-to and approved-by SLAC prior to execution.

Measurements shall be made under the following environmental conditions:

Temperature: 20°C ± 2°C.

Humidity: 30% to 70% relative humidity (RH)

During all measurements, the article under test and the test equipment shall be in thermal equilibrium within the specified temperature range.

Mid- and high-spatial frequency roughness shall be measured at the locations specified in Figure 6. These measurements shall be made after each layer has been deposited on the mirrors.

Instrumentation used for the measurement of figure, mid- and high- spatial frequency roughness should be capable of accurately measuring the spatial frequency bandwidths specified in Table 3. All equipment should be in current and traceable calibration.

7.10.3. Coating Inspection Test Report

The coating vendor shall submit a Coating Inspection Test Report of metrology results and associated raw data with each mirror at the time of delivery.

The Coating Inspection Test Report shall include machine-readable raw data sets for all metrology performed. Data sets shall be in plain ASCII text, or another widely used format of mutual agreement. The coating vendor shall describe the file formats and supply necessary constants and parameters to permit independent data analysis of the raw data.

7.11. Test Coupons

Test coupons will be provided by the substrate vendor as described in Section **Error! Reference source not found.**. These test coupons will be provided to the coating vendor for qualification of the coating process. The coating vendor shall use the test coupons to develop the coating procedure in the way that it sees fit and communicate the results to SLAC prior to proceeding with the coating of the mirrors.

8. Metrology Requirements

The surface properties of the mirrors shall be characterized at various stages of the fabrication process. This section outlines the specifications for metrology to be performed on the 2 mirrors described in Sections 6 and 7.

8.1. Frequency of Measurements

The metrology measurements described in Section 8 shall be performed after the delivery of the mirror substrates by the substrate vendor, described in Section 6, after the deposition of the first coating strip described in Section 7 and after the deposition of the second coating strip also described in Section 7. Additionally, metrology shall be performed on the test coupons provided by the substrate vendor as described in Section 6. The metrology to be performed on the test coupons shall include only the measurements of the mid and high spatial roughness.

8.2. Figure Measurements

Long-trace profilometry or stitching interferometry shall be used to determine the surface figure at the metrology vendor's facility. All roughness and slope errors shall be determined after subtraction of best-fit elliptical reference surface from the clear aperture zone.

8.3. Roughness Measurements

A visible-light interferometer or white-light optical profiling microscope shall be used for mid-spatial frequency measurements at the metrology vendor's facility. An AFM instrument shall be used for high-spatial frequency measurements at the metrology vendor's facility. The spatial frequency ranges required for the measurements are described in Table 1, Table 2 and Table 3. The metrology vendor must be capable of performing measurements over all these spatial frequencies.

Mid- and high-spatial frequency roughness shall be measured at the locations specified in Figure 6.

8.4. Power Spectral Density

All the metrology results shall be combined into a Power Spectral Density (PSD) plot showing the surface height fluctuations over the entire spatial frequency range of the measurements. This shall be provided to SLAC in the Metrology Report.

8.5. Workmanship

Workmanship shall be consistent with the quality necessary for stable operation of sensitive optical devices under long-term exposure to an x-ray, ultrahigh vacuum (UHV) environment similar to that found in synchrotron radiation user facilities.

8.6. Handling

Full, UHV handling practice is required. Each mirror shall be handled in accordance with the Handling and Process Plan described in Section 6.6.8. This plan shall be supplied by SLAC to the metrology vendor and the metrology vendor is expected to follow this plan or submit its own plan to be approved by SLAC.

8.7. Packaging and Shipping

The metrology vendor shall utilize the same packaging and shipping procedure as the mirror substrate vendor as outlined in the Handling and Process Plan described in Section 6.6.8. The plan developed by the mirror substrate vendor will be communicated to the metrology vendor by the SLAC group and the metrology vendor is expected to follow this plan or submit its own plan to be approved by SLAC.

8.8. Handling and Metrology Process Plan

All mirror metrology processes shall take place in accordance with the methods described in the Handling and Metrology Process Plan supplied by the metrology vendor. SLAC will provide to the metrology vendor the Handling and Process Plan supplied by the mirror substrate vendor (described in Section 6.6.8) and the metrology vendor is expected to follow this plan or submit its own plan to be approved by SLAC. Also, an addendum to this plan shall be provided by the metrology vendor to include a brief description of the mirror metrology procedures. This addendum shall be provided in response to the Request for Proposal from SLAC, and must be reviewed and approved by SLAC. In that way, any materials compatibility issues or process issues can be identified and settled in advance.

8.9. Quality Assurance Provisions

8.9.1. General

Prior to contract award, SLAC may perform a quality audit at the metrology vendor's facility to ascertain the existing or planned quality program implementation and procedures as it pertains to this procurement. Existing procedures to be used for this procurement shall be reviewed during this audit.

The metrology vendor shall maintain documentation for all processes during coating and characterization of these mirrors.

8.9.1.1. Program Management

The metrology vendor shall actively manage all matters relating to the performance of this contract to ensure that all performance, schedule, and quality objectives are fully met. A single individual shall be named to serve as the Program Manager of this subcontract. The

Program Manager shall act as the single point of contact with SLAC on all technical and programmatic matters.

The subcontract shall establish and apply a program control system to track progress regarding pre-established, measurable milestones. The subcontract shall identify corrective management actions in the event shortfalls are detected or anticipated. The metrology vendor shall develop and provide a detailed milestone schedule to SLAC.

In the event SLAC determines that the program success is in jeopardy because of technical, schedule, or quality shortfalls, SLAC reserves the right to conduct special program reviews and audits, as necessary, at the metrology vendor's facility.

8.9.1.2. Progress Reporting

SLAC and the metrology vendor shall conduct, at a minimum, twice monthly status teleconferences. These teleconferences shall discuss general status of the program. Any item that has immediate effect on technical performance, schedule, or deliveries shall be brought to the immediate attention of SLAC.

8.9.1.3. Reviews

The vendor shall provide necessary support for an initial Technical Interface Meeting to discuss contract planning and to discuss any open contractual or technical action items.

8.9.2. Metrology Procedure

The metrology vendor shall prepare a Metrology Procedure in response to the Request for Proposal from SLAC. It must be reviewed and approved by SLAC, and shall include the following at a minimum:

(1) Proposed tests and measurements to be performed and their method of accomplishment
(2) Sequence of measurements, both in-process and final
(3) Equipment to be used
(4) Accuracy of measurements
(5) Calibration techniques
(6) Proposed data sheets of results and data format for the Metrology Report

8.9.3. Characterization Metrology

The surface figure and roughness of the mirrors after fabrication of the substrate and after the coating process shall be characterized through measurements, and the resulting data provided in the Metrology Report. As also stated in Section 8.9.2, all measurement procedures must be proposed-to and approved-by SLAC prior to execution.

Measurements shall be made under the following environmental conditions:

Temperature: 20°C ± 2°C.

Humidity: 30% to 70% relative humidity (RH)

During all measurements, the article under test and the test equipment shall be in thermal equilibrium within the specified temperature range.

Mid- and high-spatial frequency roughness shall be measured at the locations specified in Figure 6.

Instrumentation used for the measurement of figure, mid- and high- spatial frequency roughness should be capable of accurately measuring the spatial frequency bandwidths specified in Table 1, Table 2 and Table 3. All equipment should be in current and traceable calibration.

8.9.4. Metrology Report

The metrology vendor shall submit a Metrology Report of metrology results and associated raw data with each mirror for each occurrence where metrology was required. A report shall be provided for the measurements of the bare substrate, the first coating layer and the second coating layer.

The Metrology Report shall include machine-readable raw data sets for all metrology performed. Data sets shall be in plain ASCII text, or another widely used format of mutual agreement. The metrology vendor shall describe the file formats and supply necessary constants and parameters to permit independent data analysis of the raw data.

9. Mechanical Requirements

A single vendor will be responsible for all 3 components in this section (Mirror Support, Vacuum Enclosure and Support Stand). While the document refers to 3 distinct vendors: the mirror support vendor, the vacuum enclosure vendor and the support stand vendor, these three vendors shall be one and the same company that is responsible for the delivery of the full system.

9.1. Mirror Support System Requirements

9.1.1. Scope

The section describes the requirements and specifications of the mechanical system that will be used to support and position the KB mirrors. These mirrors and their coating are described in Sections 6 and 7. The mechanical system described in this section will be used to position the mirrors inside a vacuum enclosure (described in Section 9.2) and this enclosure will be supported by a stand (described in Section 9.3). A single integrated system comprising the mirror support, the vacuum enclosure and the support stand is preferred and all the mechanical actuators can be located outside of the vacuum enclosure.

Each mirror will be between 350 and 375 mm long. The exact dimensions of the mirrors will be communicated to the mirror support vendor at the time of the Request for Proposals by SLAC.

A blank mirror made to the same specifications as the final mirrors except for a relaxed surface quality will be provided to the mirror support vendor for testing of their prototype(s) (if applicable) and final system.

9.1.2. Design and Analysis

The vendor shall provide analyses and design as required. The design items shall include, but not be limited to:

- Interface Definition
- Component Design
- Applicable Analysis
  - Stress and Thermal Analysis
  - Reliability analysis
- Stress and fracture mechanics analysis
- System Performance Analysis
- Risk and risk mitigation approach.
- Verification and Test Plans

9.1.3. Performance Requirements

The KB mirror system will be a very sensitive device which will require very precise manipulation and positioning. The mirror support system will require precise machining and precise motion in order to achieve the focusing and stability requirements. This section describes these requirements.

9.1.3.1. Precision motion

Three rotation axes and two translations shall be accurately controlled for each mirror. We define these 2 translations and 3 rotation angles for each of the two mirrors, shown on Figure 7.

x1: The direction perpendicular to the plane of reflection (sagittal direction).

y1: The direction normal to the reflecting surface.

Grazing angle (θ1): The angle between the LCLS beam and the surface of the upstream mirror. It can also be defined as the pitch angle of the upstream mirror.

In-plane rotation (ψ1): The angle between the LCLS beam and the long axis of the upstream mirror. It can also be defined as the yaw angle of the upstream mirror.

Perpendicularity (φ1): The angle between the two mirrors. It can also be defined as the roll angle of the upstream mirror.

The same angles and translations are defined for the downstream mirror (x2, y2, θ2, ψ2, φ2).

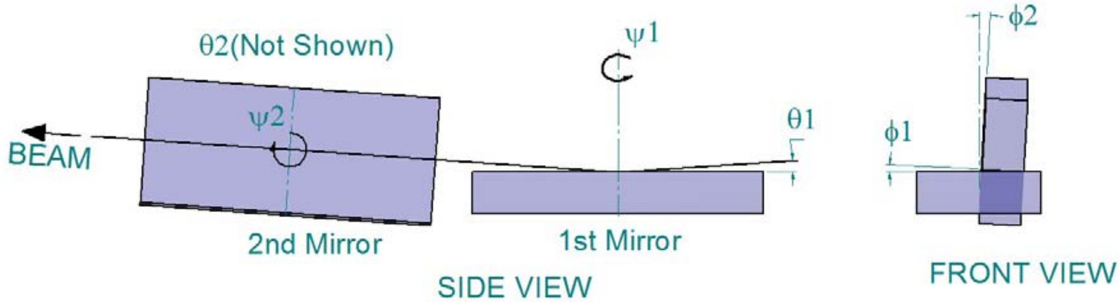

Figure 7: Rotation axes for each mirror. Note that the rotation axes are shown in the standard KB configuration but the mirrors are required to be arranged in the configuration shown on Figure 8. The mirror arrangement shown in this current figure was only chosen for clarity. The required arrangement is that of Figure 8.

The upstream mirror shall have the motions listed in Table 5. Of these motions, the x1, y1 and θ1 must be motorized. The other angles could be manually adjusted during the assembly. The downstream mirror shall have the motions listed in Table 6 . The x2, y2 and θ2 must be motorized. The other motions should preferably be motorized but could be manually adjusted. The resolution and repeatability are listed in Table 5 and Table 6. The stability requirement is over a period of ~1 minute, while the number in parentheses is the longer term (1 day) stability requirement. All motorized motions shall have encoders. It shall be possible to turn off the power to all motors when the system is aligned, without losing positions, to limit heat load into the system.

Motion	Motorization Required	Nominal Position	Range	Resolution	Repeatability	Stability
x1	Yes	0	-7 mm < x < 7 mm	4 µm	4 µm	1 (10) µm
y1	Yes	0	-10 mm < y < 4 mm	4 µm	4 µm	0.1 (1) µm
z1	Yes	-8.2 m (from focus)	± 20 mm	8 µm	8 µm	1 (1) µm
Grazing angle (θ1)	Yes	3.364 mrad	2.5 mrad < θ < 3.5 mrad	0.5 µrad	0.5 µrad	0.01 (0.1) µrad
In-plane rotation (ψ1)	No	0	-10 mrad < ψ < 10 mrad	1 mrad	1 mrad	0.1 (0.1) mrad
Perpendicularity (φ1)	Yes	0	-100 µrad < φ < 100 µrad	5 µrad	5 µrad	1 (1) µrad

Table 5: Motion requirements for the upstream mirror. The stability number corresponds to short term (~1 minute) stability while the number in parentheses correspond to long term stability (over 1 day).

Motion	Motorization Required	Nominal Position	Range	Resolution	Repeatability	Stability
x2	Yes	0	-7 mm < x < 7 mm	4 µm	4 µm	1 (10) µm
y2	Yes	0	-10 mm < y < 2 mm	4 µm	4 µm	0.1 (1) µm
z2	No	-7.8 (from focus)	Fixed	Fixed	Fixed	1 (1) µm
Grazing angle (θ2)	Yes	3.363 mrad	2.5 mrad < θ < 3.5 mrad	0.5 µrad	0.5 µrad	0.01 (0.1) µrad
In-plane rotation (ψ2)	No	3.4 mrad	-10 mrad < ψ < 10 mrad	1 mrad	1 mrad	0.1 (0.1) mrad
Perpendicularity (φ2)	No	0	-100 µrad < φ < 100 µrad	5 µrad	5 µrad	1 (1) µrad

Table 6: Motion requirements for the downstream mirror. The stability number corresponds to short term (~1 minute) stability while the number in parentheses correspond to long term stability (over 1 day).

9.1.4. Positioning

The distance between the midpoints of the mirrors in the z direction shall be 400 mm and controlled to within 8 µm. This can be accomplished either via precise machining of the support system or with independent motorized z translation for each mirror. The preferred option is to fix the second mirror and motorize the first mirror. The decision is left to the mirror support vendor and the engineering solution shall be communicated to SLAC within the first 4 months of the award of the contract.

9.1.5. Dimensions

The dimensions of the system along all 3 axes shall be minimized to the extent possible since the mirror system will interface with other devices in close proximity. Keeping the device as small as possible at the downstream end of the second mirror in vacuum is especially critical. The in-vacuum components downstream of the second mirror shall not extend beyond 200 mm from the center point of the second mirror. This in-vacuum components of the mechanical system shall be limited to a maximum total length of 800 mm. The mirror support vendor shall propose a maximum size envelope for the system is response to the Request for Proposal from SLAC. The mirror support vendor shall produce a preliminary design within 4 months of the award of the contract. SLAC and the mirror support vendor shall at this point agree to a fixed size envelope that the mirror support vendor shall not exceed for the final system to be delivered.

The mirror mechanical system, including the vacuum enclosure described in Section 9.2 must be limited to 450 mm or less in the –x direction due to the presence of a beam transport vacuum line. There are no restrictions on size in the +x direction, nor in the +y and –y directions.

9.1.6. Orientation

The vendor also provide a response to the Request for Proposals for the mirrors to be mounted in the standard KB configuration (1 vertical focusing mirror and 1 horizontal focusing mirror).

Also, as an option in the response to the Request for Proposals, the vendor shall provide a quick description of how it would achieve a 45 degree mounting of the mirrors as described below.

Following the normal convention where a counter-clockwise rotation is in the positive direction, the mirror support system shall hold the upstream mirror with reflecting surface at a roll angle at +135 degrees nominal. The roll angle of the downstream mirror shall be +45 degrees nominal. This is shown on Figure 8.

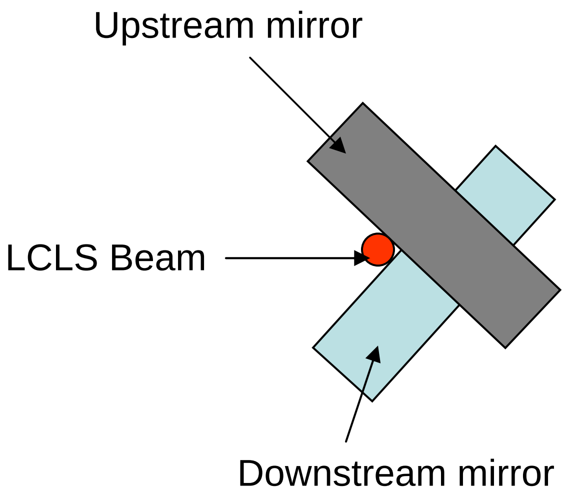

Figure 8: Orientation of the mirrors as seen from the upstream side of the mirrors.

9.1.7. Mirror Mounting

The mounting of the mirrors shall not distort the natural figure of the mirrors by more than the figure errors stated in Section 6.5 It is the responsibility of the mirror support vendor to calculate distortions to the mirror figure for their proposed design and the results of the calculations shall be communicated to SLAC. The vendor shall demonstrate that the design meets the figure distortion specifications either through calculations or measurements using a prototype of the system. The results shall be communicated to SLAC before the final manufacturing of the system begins.

The mirror mounting system shall not have any direct contact with the clear aperture area on optical surface of the mirrors.

The mounting system shall have a clear aperture at least as large as the mirror clear aperture described in Section 6 so that mounting system does not block the beam from impinging on the mirror surface.

9.1.8. Motion Limits

Limit switches shall be implemented to limit the motions of all translations and rotations as listed in Table 5 and Table 6. Hard stops shall also be implemented to limit the motions. A second set of limit switches shall be implemented to limit the motions of the system when it is aligned to only very small ranges.

9.1.9. Cyclic Requirements

The linear and rotary motions are expected to be actuated over very short ranges(<1 mm, < 0.5 mrad), during the alignment procedure, on the order of 500 times each over a period of a few days.

Once the mirrors are aligned, the system is expected to not be actuated for a period of 2 months. Overall, every motion is expected to be actuated, in small steps, on the order of 3000 times per year for a period of 10 years. All actuators shall be capable meeting these cyclic expectations.

9.1.10. Mechanical Interfaces

The mirror support system will be mounted inside a vacuum enclosure, described in Section 9.2.

9.1.11. Vacuum

This device will be used in an Ultra-High Vacuum (UHV) of 10^{-9} Torr.

The average total pressure shall be 10^{-9} Torr or better. The mirror support system must not produce carbon-containing vacuum contaminants at partial pressures above 10^{-12} Torr after normal bake-out procedures in Ultra-High Vacuum, i.e. at total pressure less than 10^{-9} Torr.

All lubricants, cutting fluids, etc., used in manufacturing shall be "sulfur-free". SLAC document No. SC-700-866-47 is a compendium of SLAC approved lubricants. The use of sanding discs, abrasive paper or grinding wheels is typically prohibited. In special circumstances good vacuum practices should be followed when grinding and polishing is required. This process shall be reviewed and approved by the engineer for its vacuum compatibility.

All parts and subassemblies shall be cleaned for UHV. Once parts are cleaned for vacuum, they shall be handled only with clean latex or nitrile gloves in/on a clean room/surface. This includes all subassemblies. For storage or transportation, they shall be placed in clean sealed vacuum grade plastic bag that has been back-filled with nitrogen.

9.1.12. Materials

All materials used shall be compatible with a vacuum level of 10^{-9} Torr. The list of materials to be used shall be communicated by the mirror support vendor to SLAC in response to the Request for Proposal from SLAC. All ceramics must be vacuum fired to minimize water content. All fastening screws used in-vacuum must be silver plated and vented. Any proposed change or addition to the list of materials shall be approved by SLAC.

9.1.13. Thermal Issues

The thermal load on the mirrors will be less than 240 mW, which is the full power of the LCLS beam. Since each mirror is specified to reflect > 86% of the beam, the maximum absorbed heat load on each mirror is expected to be less than 34 mW. It is anticipated that no active cooling is required to be provided on the mirrors.

It is anticipated that the heat deposited on the mirrors can be removed via conduction through the support system with good thermal contacts that allow the heat to flow away from the mirrors. It is however the responsibility of the mirror support vendor to design and demonstrate a system which allows for the necessary heat removal.

The system designed shall be shown by the mirror support vendor either through measurements or calculations to meet the stability, positioning and repeatability requirements of Sections 9.1.3 and 9.1.3.1, as well as the figure requirements of Section 6.5 given this heat load. The vendor shall propose a verification procedure to be approved by SLAC, as described in Section 9.1.24.2. The measurements or calculations shall be communicated to SLAC for review and approval.

9.1.13.1. Radiation Damage Issues

The grazing angle of the mirrors and the chosen coating materials will protect the mirror surface from suffering damage due to the intense LCLS beam. However, the leading edge of mirrors as well as the mirror support system could get damaged if the beam impinges directly on them.

There shall be a block made of Boron Carbide (B_4C) placed upstream of each mirror to protect the leading edges. These blocks shall be 10 mm thick. The edge of the blocks shall be slightly offset from the edges of the mirrors so that the B_4C block is closer to the beam than the leading edge of the mirrors. The offset should always be positive (with the B_4C block closer to the X-ray beam) and controlled to a precision of 10 microns.

The mirror support system shall either be fully located below the optical surface of the mirrors so that the X-ray beam cannot hit it or exposed parts of the system shall be made of light materials that are resistant to damage from the beam, in cases of beam steering misalignment. The X-ray beam shall not be allowed to hit anything other than the optical surface or the B_4C shield. The mirror support vendor shall submit the design to SLAC prior to fabrication, along with the proposed materials, so that SLAC can determine the possible radiation damage issues that are present. Three weeks shall be required by SLAC to make this determination.

9.1.14. Alignment/Fiducialization

The fine alignment of the mirrors will be performed using the LCLS x-ray beam. Only rough alignment of the system is required. Fiducials on the support system along with their position relative to the mirrors shall be provided by the mirror support vendor. These fiducials will be used to position the mirror support system inside the vacuum enclosure described in Section 9.2.

9.1.15. Stability

The stability requirements are listed in Table 5 and Table 6. The mirror positions and angles must be stable enough to keep the center of the focal spot stable to within 10% of its Full-Width Half-Maximum (FWHM) relative to the sample chamber which is located 8 meters away. The FWHM will be 1 μm and therefore the beam must be stable to within 100 nm. The stability requirement not in parentheses is over ~1 minute and represent vibrational stability requirements. The long term (thermal) stability requirement is for the beam not to move by more than its FWHM over one day, relative to the CXI Sample Chamber, where the focal plane will be located. The environmental conditions listed in Section 5.2 will be the operating conditions under which these requirements must be met. Since SLAC will provide a thermal enclosure to maintain the temperature to within 0.01 ^{o}C, the thermal stability requirement for the vendor shall be to demonstrate a pointing stability of 1 μrad per degree Celcius. The mirror support vendor shall demonstrate the stability of the system either through calculations or measurements using a prototype of the system. The results shall be communicated to SLAC before the final manufacturing of the system begins.

9.1.16. Kinematics/Supports

See Section 9.1.10.

9.1.17. Workmanship

Workmanship shall be consistent with the quality necessary for stable operation of sensitive optical devices under long-term exposure to an x-ray, ultrahigh vacuum (UHV) environment similar to that found in synchrotron radiation user facilities.

9.1.18. Handling and Cleaning

Full, UHV handling practice is required. Each component of the mirror support system shall be handled in accordance with the Mirror Support Handling and Process Plan described in Section 9.1.20. This plan shall be supplied by the mirror support vendor to and approved by SLAC.

9.1.19. Packaging and Shipping

The vendor shall be responsible for design and fabrication of the mirror support shipping container(s). Best protection against contamination and shock/vibration is essential. An all-metal, dust-free interior-most enclosure is desirable. The suggested method of accomplishing this requirement is to ship the mirror support system in a sealed state with dry nitrogen. A brief description of proposed packaging and shipping arrangements shall be included in the Mirror Support Handling and Process Plan. Design of the packaging container is subject to SLAC approval.

9.1.20. Mirror Support Handling and Process Plan

All mirror support fabrication shall take place in accordance with the methods described in the vendor-supplied Mirror Support Handling and Process Plan. This document shall be provided in response to the Request for Proposal from SLAC, and must be reviewed and approved by SLAC. In that way, any materials compatibility issues for the completed mirrors can be identified and settled in advance. As noted in the sections above, the Mirror Support Handling and Process Plan shall include brief descriptions of the following:

(1) Fabrication process
(2) List of materials
(3) UHV handling procedures
(4) Cleaning procedure
(5) Packaging and shipping arrangements

9.1.21. Electrical Requirements

The mirror support vendor shall terminate all in-vacuum electrical wires and cables (if any) with connectors that are compatible with 10^{-9} Torr vacuum. The mirror support vendor shall propose connectors to be approved by SLAC and the mirror support vendor shall communicate the complete list of connectors before the start of fabrication. It shall be the responsibility of the vacuum enclosure vendor to use the proper vacuum feedthroughs to match the connector, as described in Section 9.2.16. All electrical components shall comply, to the fullest extent possible, with applicable codes, as evidenced by appropriate certification of these components (certified, listed, or labeled by a Nationally Recognized Testing Laboratory, NRTL)

9.1.22. Quality Assurance Provisions

9.1.22.1. General

Prior to contract award, SLAC may perform a quality audit at the vendor's facility to ascertain the existing or planned quality program implementation and procedures as it pertains to this procurement. Existing manufacturing procedures to be used for this

The mirror support vendor shall maintain documentation for all testing, calculations, prototyping and processes during design and fabrication of the mirror support system.

The vendor shall supply SLAC with evidence that the completed mirror chamber meets the vacuum compatibility requirements of Section 9.1.11. The nature of the test used to ensure compliance shall be a residual gas analysis at ultra-high vacuum pressures. SLAC must approve the details of the test method proposed by the vendor and will offer guidance as to how the test shall be conducted if so requested. Use of the services of an independent testing laboratory is subject to the approval of SLAC.

9.1.23. Quality Assurance Requirements

It is SLAC's intent to use the vendor's existing procedures, manufacturing processes and methods to the maximum extent possible to meet quality assurance requirements. Any discrepancies shall be resolved before contract award. Where appropriate, individual requirements of this section may be deleted or modified with SLAC's concurrence in order to most cost-effectively meet the overall quality, reliability, and risk mitigation objectives of the system provided.

The vendor's quality assurance program shall be consistent with ISO 9001. Before contract award, the vendor shall submit for review the Quality Assurance (QA) Plan and internal relevant manufacturing procedures that ensure that QA requirements contained herein are met. The Quality Assurance Plan or internal manufacturing procedures should minimally include the following:

(1) Introduction (title, scope, table of contents, and organization introduction).
(2) The Quality policy and objectives of the organization.
(3) Description of the organization, responsibilities, and authorities (with or without a flowchart).
(4) A description of the elements of the quality system.

9.1.23.1. Configuration Control

Procedures shall be implemented for configuration control of all hardware, analysis software, and engineering documentation, including design drawings, calculations, process, fabrication and inspection standards, and test procedures. The configuration control procedures shall ensure that all such documents and document changes are properly approved; that document revision levels applicable to the piece part or assembly, test, and handling are clearly specified in the assembly procedures and records; and that required changes to fabricated hardware are completely incorporated and properly documented.

For new component and subsystem designs, fabrication of the first production unit may be performed with changes documented by a properly documented and Configuration Management controlled document markup process, provided that:

- The initial fabrication drawings are approved in accordance with normal company procedures

- Changes are annotated in a single master drawing set, with each change approved by the appropriate personnel before incorporation
- All markup changes shall be formally incorporated with normal configuration control.

In the event a markup process is adopted, the responsibilities and procedures for implementation shall be as described in the vendor's Quality Assurance (QA) Plan. For the final production units a formal change process must be instituted consistent with the vendor's Configuration Management Process and the document markup process shall not be performed.

9.1.23.2. Program Management

The vendor shall actively manage all matters relating to the performance of this contract to ensure that all specifications, schedule, and quality objectives are fully met. A single individual shall be named to serve as the Program Manager of this subcontract. The Program Manager shall act as the single point of contact with SLAC on all technical and programmatic matters.

The subcontract shall establish and apply a program control system to track progress vis-à-vis pre-established, measurable milestones. The subcontract shall identify corrective management actions in the event shortfalls are detected or anticipated. The vendor shall develop and provide a detailed project schedule to SLAC. The schedule shall be periodically updated and provided at least on a monthly basis to SLAC as part of progress reporting.

In the event SLAC determines that the program success is in jeopardy because of technical, schedule, or quality shortfalls, SLAC reserves the right to conduct special program reviews and audits, as necessary, at the vendor's facility.

9.1.23.3. Progress Reporting

SLAC and the vendor shall conduct, as a minimum, monthly status teleconferences. These teleconferences shall discuss general status of the program.

(1) Technical progress and programmatic information such as design updates, procurement actions, drawing releases, manufacturing status, integration status, and test status.
(2) A program schedule shall be provided that shows completion status against all major milestones.
(3) Status items submitted to SLAC for information, review, and/or approval.
(4) Any item that has immediate effect on technical performance, schedule, or deliveries shall be brought to the immediate attention of the SLAC Subcontract representative.

9.1.23.4. Reviews

The vendor shall provide necessary support for the following reviews. The vendor shall provide review packages for the Conceptual Design Review (CDR), Preliminary Design Review (PDR) and Final Design Review (FDR) at least 5 days before each review.

9.1.23.4.1. Technical Interface Meeting

The vendor shall host a Technical interface meeting to discuss contract planning and to discuss any open contractual or technical action items. This meeting will be held no later than one month After Receipt of Order (ARO)

9.1.23.4.2. Design Reviews (CDR, PDR, FDR) and Manufacturing Readiness Review (MRR):

The vendor shall prepare for and conduct a CDR within 2 months of contract award, a PDR within 4 months of contract award (consistent with Sections 9.1.4 and 9.1.5) an FDR and an MRR where the status of the design is presented in detail, and the readiness of the vendor to proceed is determined.

9.1.23.4.3. Pre-Ship Review (PSR)

The vendor shall prepare for and conduct a Pre-Ship Review where the system status is presented in order to determine acceptability of hardware for delivery. This pre-ship review shall occur after the final tests have taken place on the system.

9.1.24. Manufacturing and Assembly

9.1.24.1. Manufacturing

The vendor shall supply a Fabrication, Assembly, and Inspection Flow Plan (with manufacturing process/procedures numbers) that shall include a prescriptive procedure that describes the method of fabrication, assembly, procedures, and inspection from piece parts to the completely assembled system. This shall be provided prior to the Manufacturing Readiness Review (MRR). Should the vendor intend to subcontract any portion of work, such intentions, possible subcontractors, and the scope of their involvement shall be included in the vendor's proposal.

The mirror support vendor shall deliver the system fully assembled if it is deemed safe to do so by the mirror support vendor. If the possibility of damage during shipping is deemed too great by the mirror support vendor, then shipping the system disassembled is acceptable. The mirror support vendor shall in either case provide all drawings (in PDF format), all models (2D or 3D in a format to be agreed upon with SLAC) and a detailed assembly procedure to SLAC upon delivery.

9.1.24.2. Verification and Test Plans

The vendor shall provide a qualification and acceptance verification matrix that shall list each requirement and indicate by what methods and procedures the vendor shall verify the requirement.

The vendor shall include pass/fail criteria for each item to be verified. Test plans shall be provided that clearly indicate the test environments, durations, procedures, and test configurations.

9.1.24.3. Inspection Requirements

Fabrication and inspection planning shall be prepared. Manufacturing planning with inspection points shall be available for SLAC review at the vendor's facility. The plan shall describe:

(1) The fabrication steps required
(2) In-process and end item inspection points
(3) References to applicable inspection criteria

For each inspection activity, the procedure and accept/reject criteria shall be documented.

9.1.24.4. Non-Conformance Control

The vendor shall have a closed-loop system for review, analysis, and disposition of failures and discrepancies. Nonconformance reports shall be made available for SLAC review and included as part of the final documentation package.

9.1.24.5. End Item Data Package

The End Item Data Package shall include at a minimum:

1. Part Name
2. Buyer's Part Number/Source Control Drawing Number and Revision
3. Procurement Specification Number and Revision
4. Purchase Order and Item Number
5. Seller Part Number
6. Seller Serial Number
7. Material and Parts Traceability / Certification Reports
8. Analysis reports
9. Relevant data from in-process testing to verify critical processes
10. Nonconformance Reports
11. As built record (drawings and CAD files). This record shall include serial numbers of detail parts and assemblies and justification of any changes in manufacturing process from qualification article baseline

12. Acceptance Test Data Sheets
13. Cleanliness Certification
14. Certificate of Compliance
15. Notes and Comments as required.

Vendor format for this data package is acceptable.

9.1.25. Installation

The vendor shall provide be responsible for on-site isntallation of the system at SLAC upon delivery. SLAC shall provide assistance as required by the vendor.

9.1.26. Documentation

The vendor shall provide all drawings (in PDF format), all models (2D or 3D in a format to be agreed upon with SLAC) and a detailed assembly procedure to SLAC upon delivery.

9.1.27. Part Marking

The vendor shall inscribe all piece parts, sub-assemblies and assemblies with a unique serial number. Serial number shall consist of the drawing number, revision level and a unique suffix.

9.2. Vacuum Enclosure Requirements

The mirrors fabricated by the mirror substrate vendor are described in Section 6. They will then be coated by the mirror coating vendor as described in Section 7. After characterization by the metrology vendor, described in Section 8, they will be mounted on the mirror support system described in Section 9.1.

The fully assembled system will then be placed in the mirror vacuum enclosure designed and built by the vacuum enclosure vendor.

The same vendor shall be responsible for the mirror support system (Section 9.1), the vacuum enclosure (Section 9.2) and the support stand (Section 9.3) Therefore all three systems (support, enclosure and stand) may be designed as a single entity allowing motors external to the vacuum enclosure to control the positions and rotations of the mirrors described in Section 9.1. Vendors are encouraged to propose such an alternative in response to the Request for Proposal from SLAC.

9.2.1. Performance Requirements

The vacuum enclosure shall be compatible with 10^{-9} Torr or better vacuum pressure.

9.2.2. Dimensions

The exact dimensions of the in-vacuum mirror support system will be determined by the vendor. This in-vacuum system will be no more than 0.8 m long. The vacuum enclosure shall be as compact as possible given the mirror support system and shall not exceed 450 mm from the beam axis in the –x direction and 1.15 m along the x-ray beam. Of special importance is keeping the vacuum enclosure as short as possible past the end of the second mirror on the downstream end of the mirror system due to interface requirements with other devices. Other dimensions (+x, -y, +y) are not critical. The vacuum enclosure vendor shall provide SLAC with exact dimensions for the vacuum enclosure within 6 weeks of the finalization of the in-vacuum mirror support dimensions.

9.2.3. Kinematics/Supports

The vacuum enclosure shall have a kinematic mount to allow reproducible mounting to within 100 microns on the mirror support stand described in Section 9.3.

9.2.4. Mechanical Interfaces

The vacuum enclosure will be linked to its environment as follows:

Entrance port: A 6" non-rotatable flange upstream centered on a beam height of 1400mm

Exit port: A 6" rotatable flange downstream centered on a beam height of 1398.6 mm

The vacuum enclosure entrance and exit ports must accommodate the 180° included angle between the incident and reflected x-ray beam. The mirror's reflecting surface should line up with the centers of the entrance and exit ports

The downstream and upstream flanges will be able to support a gate valve that will isolate the chamber from its external environment.

Both downstream and upstream components of the KB mirror vacuum enclosure will be linked to it by a welded bellows assembly.

9.2.5. Ports

The ports listed in Table 7 shall be provided on the vacuum enclosure. The exact location of the ports shall be approved by SLAC prior to the start of fabrication.

	Port type or use	Orientation	Location	Purpose
1	Entrance Port (6" non-rotatable)	Along the beam	Upstream of chamber, centered on the beam	Let the beam in
2	Exit Port (6" rotatable)	Along the beam	Dowstream of chamber, centered on the beam	Let the beam out
3	Viewport (4.5")	Along ψ1 axis	Midpoint along z of mirror 1	Future addition of interferometer
4	Viewport (4.5")	Along θ1 axis	Midpoint along z of mirror 1	Future addition of interferometer
5	Viewport (4.5")	Along ψ2 axis	Midpoint along z of mirror 2	Future addition of interferometer
6	Viewport (4.5")	Along θ2 axis	Midpoint along z of mirror 2	Future addition of interferometer
7	Vacuum gauge (2.75")	Any	Anywhere	Measure the pressure
8	Vacuum gauge (2.75")	Any	Anywhere	Measure the pressure
9	Rough pumping (2.75")	Any	Anywhere	Pump down the enclosure from atmosphere
10	Ion Pump (6")	Any	Bottom of enclosure	Create Ultra-high vacuum
11	Feedthrough (6")	Any	Near the back side of mirror 1	Connect cables for motorized motions
12	Feedthrough (6")	Any	Near the back side of mirror 2	Connect cables for motorized motions
13	Miscellaneous (6")	Any	Anywhere	Future expansion
14	Miscellaneous (6")	Any	Anywhere	Future expansion
15	Miscellaneous (2.75")	Any	Anywhere	Future expansion
16	Miscellaneous (2.75")	Any	Anywhere	Future expansion

Table 7: List of ports required on the vacuum enclosure of the KB mirror system.

9.2.6. Vacuum Requirements

This device will be used in an Ultra-High Vacuum (UHV) of 10^{-9} Torr.

The average total pressure shall be 10^{-9} Torr or better. The vacuum enclosure must not produce carbon-containing vacuum contaminants at partial pressures above 10^{-12} Torr after normal bake-out procedures in Ultra-High Vacuum, i.e. at total pressure less than 10^{-9} Torr.

All lubricants, cutting fluids, etc., used in manufacturing shall be "sulfur-free". SLAC document No. SC-700-866-47 is a compendium of SLAC approved lubricants. The use of sanding discs, abrasive paper or grinding wheels is typically prohibited. In special circumstances good vacuum practices should be followed when grinding and polishing is required. This process shall be reviewed and approved by the engineer for its vacuum compatibility.

All parts and subassemblies shall be cleaned for UHV. Once parts are cleaned for vacuum, they shall be handled only with clean latex or nitrile gloves in/on a clean room/surface. This includes all subassemblies. For storage or transportation, they shall be placed in clean sealed vacuum grade plastic bag that has been back-filled with nitrogen.

9.2.7. Seals

Only metal seals shall be used on the vacuum enclosure.

9.2.8. Materials

All parts and materials for the device shall be new and compatible with the performance requirements of this specification. Mil source certifications, including heat number, chemical analysis for all materials used in the manufacturing of the device shall be furnished. All ceramics must be vacuum fired to minimize water content. All fastening screws used in-vacuum must be silver plated and vented. Use of Teflon is specifically prohibited.

9.2.9. Mirror Support Mount

The mirror support system described in Section 9.1 shall be mounted inside the vacuum enclosure. The vacuum enclosure vendor shall design and fabricate a suitable mount to adapt to the mirror support system. The details of the mounting surface(s) of the mirror support system will be provided to the vacuum enclosure vendor by SLAC at the time of the award of the contract.

9.2.10. Thermal Issues

The vacuum enclosure will be located in the environment described in Section 5.2. The expected environmental thermal variations shall not cause fluctuations in the position and orientation of the mirror support system larger than the requirements listed in Table 5 and Table 6. The mirror support mounts described in Section 9.2.9 shall be stable to within these requirements, independent of the details of the mirror support system. The vacuum enclosure vendor shall demonstrate the stability of the mount using either calculations or a prototype and shall communicate the results to SLAC for approval to proceed to fabrication.

9.2.11. Alignment/Fiducialization

References outside the chamber, with known relationship to the mirror positions and angles, must be provided for the purpose of surveying the vacuum enclosure into position at the beamline. The preferred references are six holes of 0.25 (+0.0003 -0.000) inch diameter, four defining the horizontal plane and the two others visible from the top defining the path of the x-ray beam.

9.2.12. Stability

See Section 9.2.10.

9.2.13. Workmanship

Workmanship shall be consistent with the quality necessary for stable operation of sensitive optical devices under long-term exposure to an x-ray, ultrahigh vacuum (UHV) environment similar to that found in synchrotron radiation user facilities.

9.2.14. Handling and Cleaning

Full, UHV handling practice is required. Each component of the vacuum enclosure shall be handled in accordance with UHV practices.

9.2.15. Packaging and Shipping

The vacuum enclosure vendor shall be responsible for design and fabrication of the shipping container(s). Best protection against contamination is essential. An all-metal, dust-free interior-most enclosure is desirable. The suggested method of accomplishing this requirement is to ship the vacuum enclosure in a sealed state with dry nitrogen. Design of the packaging container is subject to SLAC approval.

9.2.16. Electrical Requirements

The vacuum enclosure vendor shall provide all the necessary vacuum ports and feedthroughs to connect all the wires and cables needed for the mirror support system. The list of in-vacuum connectors specified by the mirror support system vendor will be provided to the vacuum enclosure vendor before the start of the final design of the vacuum enclosure. All electrical components shall comply, to the fullest extent possible, with applicable codes, as evidenced by appropriate certification of these components (certified, listed, or labeled by a Nationally Recognized Testing Laboratory, NRTL)

9.2.17. Quality Assurance Provisions

The requirements described in Section 9.1.22 shall apply to the vacuum enclosure system.

9.2.18. Quality Assurance Requirements

The requirements described in Section 9.1.23 shall apply to the vacuum enclosure system.

9.2.19. Manufacturing and Assembly

The requirements described in Section 9.1.24 shall apply to the vacuum enclosure system.

9.2.20. Installation

It will be the responsibility of the vendor to mount the support system inside the vacuum enclosure and to install the vacuum enclosure on the support stand.

9.2.21. Maintenance and Accessibility

Maintenance to the in-vacuum components of the mirror system and the mirrors themselves is expected to occur infrequently (roughly once per year). Large maintenance and repair operations are expected to require the entire in-vacuum mirror system to be removed from the vacuum enclosure as a single unit. The design shall allow for the mirror system to be removed from the vacuum enclosure without the need to remove the vacuum enclosure from the beamline.

The design shall also allow for rapid access to the mirror system, through the removal of a single CF flange for minor maintenance not requiring the entire system to be removed from the vacuum enclosure. Access shall be provided to the front and back side of each mirror. Provision (e.g. lifting fixtures on the chamber lid) to open the chamber to provide complete access to the mirror, mounting, and associated mechanism for installation and maintenance shall be provided.

The accessibility of the area where the KB mirror system will be located is most typically highly accessible. Therefore the device design should be reasonably elegant, should minimize safety issues (no pinch points, trip hazards, loose cables/hoses, etc) and should have coatings/platings and finishes that reflect high design standards.

9.2.22. Documentation

The vacuum enclosure vendor shall provide all drawings (in PDF format), all models (2D or 3D in a format to be agreed upon with SLAC) and a detailed assembly procedure to SLAC upon delivery.

9.2.23. Part Marking

The vendor shall inscribe all piece parts, sub-assemblies and assemblies with a unique serial number. Serial number shall consist of the drawing number, revision level and a unique suffix.

9.3. Stand Requirements

This section describes the requirements for the stand which supports the vacuum enclosure of the KB1 system.

9.3.1. Performance Requirements

The performance requirements of the stand are simply stability requirements. The stability requirements are listed in Table 5 and Table 6. The thermal stability and vibrational stability of the stand shall meet these requirements, independently of the stability characteristics of the mirror support system and the vacuum enclosure.

9.3.2. Mechanical Interfaces

The mechanical interface to the stand occurs only on the ground and at the vacuum enclosure for the KB mirror system. The design of the vacuum enclosure and its mounting system described in Section 9.2.3 will be provided to the stand vendor before proceeding with the final design of the stand. The stand vendor shall design and fabricate a stand which is compatible with the vacuum enclosure mounting structure.

9.3.3. Materials

Materials shall be chosen by the stand vendor for their thermal and stability properties so the stability requirements can be meet. No issues with vacuum compatibility exist.

The stand shall be painted with 2 coats of red paint that meets federal color standard FS11140. Alternative color shall be approved by SLAC.

9.3.4. Thermal Issues and Stability

The thermal stability of the stand shall be considered given the environment described in Section 5.2. The mirrors are required to be stable in position and angle with respect to the sample chamber. The thermal expansion of the vacuum enclosure stand and that of the sample chamber stand should be matched to minimize the effects of thermal fluctuations. SLAC shall provide a thermal enclosure capable of controlling the temperature to 0.01 ^{o}C in which the system will be enclosed.

9.3.5. Structural Issues

The load supported by the vacuum enclosure stand may be close to or over 400 pounds, which would require it to be certified by the SLAC earthquake safety committee. The vacuum enclosure stand vendor shall provide the final design to SLAC before start of fabrication and allow 6 weeks for SLAC to seek the necessary certification.

9.3.6. Motion

The mount of the vacuum enclosure shall allow for ±12.5 mm of coarse manual translation range (in 3 orthogonal directions) for initial positioning of the mirror system with a precision of 0.1 mm. The orientation adjustments are to be permitted via configuration of linear motions in a triangular kinematic mount with the base of the triangle perpendicular to the beam direction and its height along the beam direction.

9.3.7. Color

Should the stand structure be made of a material that requires painting or powder coating, the stand shall be red with the color meeting federal color standard FS11140, as defined in document Fed-STD-595B, *Colors Used in Government Procurement*.

9.3.8. Documentation

The stand vendor shall provide all drawings (in PDF format), all models (2D or 3D in a format to be agreed upon with SLAC) and a detailed assembly procedure to SLAC upon delivery.

9.3.9. Part Marking

The vendor shall inscribe all piece parts, sub-assemblies and assemblies with a unique serial number. Serial number shall consist of the drawing number, revision level and a unique suffix.

9.3.10. Quality Assurance Provisions

The requirements described in Section 9.1.22 shall apply to the stand.

9.3.11. Quality Assurance Requirements

The requirements described in Section 9.1.23 shall apply to the stand.

9.3.12. Manufacturing and Assembly

The requirements described in Section 9.1.24 shall apply to the stand.

9.3.13. Installation

It will be the responsibility of the LUSI project to mount and align the vacuum enclosure on the support stand and to install the support stand in the CXI instrument.

10. Major Interfaces

10.1. Stand and Vacuum Enclosure

The interface between the support stand and the vacuum enclosure is described in Section 9.3.2 and shall be defined by the stand vendor.

10.2. Vacuum Enclosure and Mirror Support

The interface between the vacuum enclosure and the mirror support system is described in Section 9.2.4 and shall be defined by the vacuum enclosure vendor.

10.3. Mirror Support and Mirrors

The interface between the mirror support system and the mirrors shall be defined by the mirror support vendor.

10.4. Differential Pumping

The base pressure of the CXI instrument will be 10^{-7} Torr. It will be the responsibility of the LUSI project to design appropriate differential pumping to maintain the 10^{-9} Torr pressure inside the vacuum enclosure of the KB1 system. The LUSI project shall provide the necessary interface information to the vacuum enclosure vendor to allow the integration of the differential pumping system.

10.5. Both LUSI KB systems must be identical

The LUSI project will be procuring a second KB system capable of producing a 100x100 nm focus, known as the CXI 0.1 Micron KB System. This system shall be identical in every aspect to the 1 micron KB system described in this document except for the curvature of the mirrors, the size and shape of the vacuum chamber and possibly the way the chamber is supported. Every other mechanical component is expected to be exactly the same. The vendors shall demonstrate, in whichever way possible, in response to the Request for Proposal by SLAC that the propose 1 micron KB system is also fully capable of producing a 100 nm beam when the mirrors are place 10 times closer to the focal plane and they have a roughly 10 times higher curvature. The Engineering Specifications Document for the CXI 0.1 Micron KB System (LUSI ESD # 391-000-64) will be provided to the possible vendors along with this current document.

11. Installation

The LUSI project is responsible for the installation of all components in the CXI instrument. The mirror substrate vendor and the mirror support system vendor shall provide on-site assistance during installation as required by the LUSI project.

12. Nonconformance and Corrective Action

Any departure from the requirements of this specification that the vendor proposes to make shall be documented and submitted to SLAC for approval.

13. Proprietary Information

Any information of a proprietary nature shall be noted in the bid response and final vendor documentation.

14. Controls

The KB mirror system will be remotely operated and controlled for all motions. If the design allows it, it is preferable but not required that the actuators used are compatible with the Experimental Physics and Industrial Control System (EPICS) software tools and have existing EPICS drivers.

Developing the controls will be the responsibility of the LUSI project. The motors and stages used by the vendors shall first and foremost meet the positioning requirements. However, if multiple options exist, the LUSI project requests that the vendors select devices for which EPICS software already exists. The list of EPICS supported hardware is available here http://www.epics.org/.

All functions of the KB system shall be controlled remotely.

An interlock shall be provided by LUSI for the vacuum system. A vacuum gauge will control the vacuum level in the KB vacuum enclosure. An interlock will trigger the closing of the upstream and downstream gate valve in the case of an abnormal pressure rise.

Software limits shall be provided by LUSI to restrict the range of motion of the mirrors once they are aligned.

An interlock shall be provide by LUSI between the PPS photon stopper and the mirror positioning stages in order to make sure the X-ray beam is turned off during large motions of the system.

15. Environmental Safety and Health Requirements

15.1. Seismic

The equipment and structures described in this document shall be designed and constructed to resist the effects of earthquake motions in a manner that ensures life safety:

- Any structure that personnel can enter, such as radiation hutches and shielding structures
- Any equipment that weighs more than 400 pounds

The seismic design criteria shall be met by using either the 2007 California Building Code for seismic design with Occupancy Category II or by using seismic acceleration = 0.7g and the following Strength Design load combinations (where "E" = effects of horizontal seismic forces):

- (1.5) x Dead Load + E
- (0.6) x Dead Load + E

In all cases, the anchors and the adequacy of the anchorage to support the design loads must be design-reviewed by a California-licensed civil engineer and approved the SLAC National Accelerator Laboratory Earthquake Committee per document I-720-0A24E-001. Submission of the seismic calculations shall be provided for SLAC approval prior to the start of manufacturing. (Allow for at least one month of time for earthquake approval.)

15.2. Radiation Physics

The KB system will be installed inside hutch 5 which is not accessible while the X-ray beam can enter the hutch. Therefore no radiation shielding for personnel protection is required.

15.3. Pressure Vessel/Vacuum Vessel

The Vacuum Enclosure for the KB Mirror System shall conform to the requirements outlines in Chapter 14 of SLAC document I-720-0A29Z-001, *SLAC Environment, Safety, and Health Manual*.

16. Demonstration of Capabilities by Vendors

The vendors shall provide SLAC with a demonstration of their capabilites in response to the Request for Proposals from SLAC. The vendors can use similar past projects as an example of their capabilities.

SLAC reserves the right to reject proposals if the vendor has not satisfactorily demonstrated the necessary capabilities to meet the requirements described in this document.

17. Acronyms

AFM: Atomic Force Microscope

ARO: After Receipt of Order

CDR: Conceptual Design Review

CXI: Coherent X-ray Imaging

EPICS: Experimental Physics and Industrial Control System

FDR: Final Design Review

FEH: Far Experimental Hall

FEL: Free Electron Laser

FWHM: Full-Width Half-Maximum

KB: Kirkpatrick-Baez

LCLS: Linac Coherent Light Source

LUSI: LCLS Ultrafast Science Instruments

MRR: Manufacturing Readiness Review

NRTL: Nationally Recognized Testing Laboratory

PDR: Preliminary Design Review

PSR: Pre-Ship Review

QA: Quality Assurance

rms: Root Mean Square

UHV: Ultra-High Vacuum

18.Summary of the Specifications

18.1. Mirror Substrates

The mirror substrate vendor shall provide 2 mirrors, 5 test coupons and 1 blank substrate meeting the requirements summarized below.

18.1.1. Substrate Specifications

	Parameter	Value	Value	Units	Comment
		Mirror 1	Mirror 2		
1	Mirror Shape	Tangential ellipse			
2	Clear aperture length	350		mm	
3	Clear aperture width	$30 \geq$ width ≥ 12		mm	
4	Mirror Length	$375 \geq$ length ≥ 360		mm	
5	Mirror Width	$60 \geq$ width ≥ 45		mm	
6	Mirror Thickness	>50		mm	
7	Substrate material	Si <100>			
8	Figure height error	<1.00		nm rms	Over dimensions from 1mm to the clear aperture size from best-fit ellipse
9	Mid-spatial roughness	<0.25		nm rms	Over the 10^{-3} to 0.5 μm^{-1} frequency range
10	High-spatial roughness	<0.25		nm rms	Over the 0.5 to 50 μm^{-1} frequency range
11	Tangential Slope error	<0.25		µrad rms	Over dimensions from 1mm to the clear aperture size from best-fit ellipse
12	Sagittal Slope error	<2		µrad rms	Over dimensions from 1mm to the clear aperture width from best-fit sagittal radius
13	Sagittal radius of curvature	>400		m	
14	Focal length	8.2	7.8	m	
15	Maximum incidence angle	3.4		mrad	
16	Average incidence angle	3.364	3.363	mrad	
17	Distance from source	420		m	
18	Vacuum pressure	$<10^{-9}$		Torr	

Table 8: Summary of the mirror substrate specifications

18.1.2. Other Requirements

Item	Comments
Surface finish on non-optical surfaces	Ground and wet-chemical etched
Operating environment and service temperature range	Normal operation in ultrahigh vacuum (UHV) at ~20°C. UHV bake out at 125°C.
Mirror Coating	Provided by Others
Test Coupons	Provide 5 test coupons polished the same way as the full mirrors
Blank Si Substrate	Provide a blank Si substrate with reduced figure and roughness requirements
Inspection	After initial shaping of the mirrors
Metrology	Provide metrology plan to SLAC. Perform metrology after final polishing is complete
Handling and Cleaning	Full, Ultrahigh Vacuum (UHV) practice required. Provide a summary of proposed handling and cleaning procedures in the "Handling and Process Plan".
Packaging and Shipping	Vendor shall be responsible for design and fabrication of the mirror shipping container(s). Best protection against contamination and shock/vibration is essential. All-metal, dust-free interior-most enclosure desirable. Include a description of proposed packaging and shipping arrangements in the "Handling and Process Plan"
Documentation	Include a description of proposed characterization metrology in the "Inspection Test Procedure".
	Supply machine-readable raw data sets for all metrology performed of mutual agreement. as part of the "Inspection Test Report".
	Describe file format and supply necessary constants and parameters to permit independent data analysis of the raw data.
Quality Assurance	Provide detailed project schedule
	Identify project manager as single point of contact
	Monthly teleconferences with SLAC

Table 9: Summary of all requirements to be satisfied by the mirror substrate vendor.

18.2. Mirror Mechanics

A single vendor shall be responsible for all the mirror mechanical system specifications and requirements summarized below. Three distinct components are identified

- The in-vacuum mirror support system (Mirror Support System)
- The Vacuum Enclosure in which the Mirror Support System is located
- The Support Stand on which the Vacuum Enclosure in mounted

All reporting, documentation and quality assurance requirements apply to each component.

18.2.1. Mirror Support System

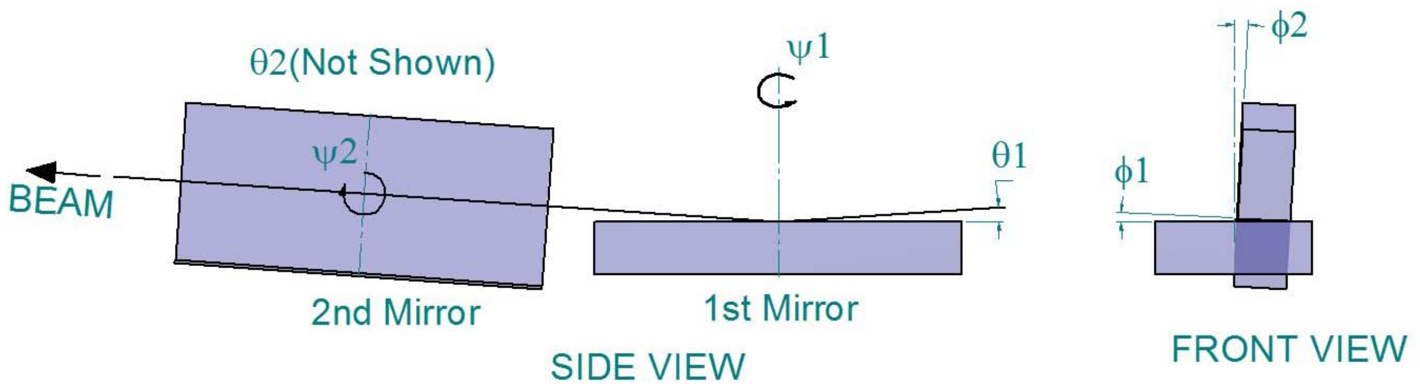

Figure 9: Definition of the KB mirror system axes of rotation

Mirror	Motion	Nominal Position	Range	Resolution	Repeatability	Motorized	Manually Adjusted	Vibrational Stability	Thermal Stability
1	x1	0	-7 mm < x < 7 mm	4 µm	4 µm	Yes	No	1 µm	10 µm
1	y1	0	-10 mm < y < 4 mm	4 µm	4 µm	Yes	No	0.1 µm	1 µm
1	z1	-8.2 m (from focus)	± 20 mm	8 µm	8 µm	Yes	No	1 µm	1 µm
1	Grazing angle (θ1)	3.364 mrad	2.5 mrad < θ < 3.5 mrad	0.5 µrad	0.5 µrad	Yes	No	0.01 µrad	0.1 µrad
1	In-plane rotation (ψ1)	0	-10 mrad < ψ < 10 mrad	1 mrad	1 mrad	No	Yes	0.1 mrad	0.1 mrad
1	Perpendicularity (φ1)	0	-100 µrad < φ < 100 µrad	5 µrad	5 µrad	Yes	No	1 µrad	1 µrad
2	x2	0	-7 mm < x < 7 mm	4 µm	4 µm	Yes	No	1 µm	10 µm
2	y2	0	-10 mm < y < 2 mm	4 µm	4 µm	Yes	No	0.1µm	1 µm
2	Grazing angle (θ2)	3.363 mrad	2.5 mrad < θ < 3.5 mrad	0.5 µrad	0.5 µrad	Yes	No	0.01 µrad	0.1 µrad
2	In-plane rotation (ψ2)	3.4 mrad	-10 mrad < ψ < 10 mrad	1 mrad	1 mrad	No	No	0.1 mrad	0.1 mrad
2	Perpendicularity (φ2)	0	-100 µrad < φ < 100 µrad	5 µrad	5 µrad	No	No	1 µrad	1 µrad
2	z2	-7.8 m (from focus)	Fixed	Fixed	Fixed	Fixed	Fixed	1 µm	1 µm

Table 10: Summary of the mirror mechanical motion specifications

18.2.2. Other Specifications

Item	Comments
45 degree geometry	Provide an option for mounting the mirrors at 45 degrees from the standard KB configuration to deflect the beam in the horizontal direction only. SLAC will decide to exercise the option or not after the receipt of the proposal
Mirror mounting	Preserve the figure of the mirrors without the specifications of the substrates Clear aperture of at least 2 mm x 12 mm
Motion limits	Two sets of limit switches, for small and large motions Motions limits to be implemented for beam confinement by SLAC Hard stops for full range of motion
Expected lifetime of device	10 years
Dimensions inside vacuum	Length: < 0.8 m Width : < 350 mm from center in the –x direction No restriction in the +x direction Height: No restriction other than the beam height of 1.4 m and ceiling of 3 m
Vacuum	Normal operation in ultrahigh vacuum (UHV) at ~20°C. UHV bake out at 125°C.
Thermal issues	<34 mW of heat will be absorbed by the mirror substrates during operations. Vendor to perform analysis to demonstrate the performance of the system given this heat load
Radiation protection	The LCLS beam will damage most materials except for light materials. Only the optical surface shall be exposed to the beam. Any other surface exposed to the beam shall be protected with a B4C shield B4C shield to protect the leading edge of the mirrors
Operating conditions	SLAC to provide a thermal enclosure stable to within 0.01 degree Celcius
Design and Analysis	Vendor design to include : Interface definition Component design Stress and thermal analysis Reliability analysis System performance analysis Verification and test plans Integration of the mirror substrates into the mechanical system

Materials	Provide list of materials to be used
Electrical	Provide all vacuum feedthroughs and UHV connectors
Controls and motors	Use device with existing EPICS drivers to the extent possible
Handling and Cleaning	Full, Ultrahigh Vacuum (UHV) practice required. Provide a summary of proposed handling and cleaning procedures in the "Handling and Process Plan".
Packaging and Shipping	Vendor shall be responsible for design and fabrication of the system shipping container(s). Best protection against contamination and shock/vibration is essential. All-metal, dust-free interior-most enclosure desirable. Include a description of proposed packaging and shipping arrangements in the "Handling and Process Plan"
Documentation	Include a description of proposed characterization fabrication, assembly and inspection in the "Inspection Test Procedure".
	Supply machine-readable raw data sets for all measurements performed of mutual agreement.as part of the "Inspection Test Report".
	Describe file format and supply necessary constants and parameters to permit independent data analysis of the raw data.
	Provide all as-built drawings to SLAC in PDF format and all 3D models in agreed upon formats
	Provide a qualification and verification matrix with pass/fail grades after final testing
	Report all non-conformance with the specifications to SLAC
Part marking	Vendor to inscribe all parts, assemblies and sub-assemblies with a unique serial number, whenever possible
Quality Assurance	Provide detailed project schedule
	Identify project manager as single point of contact
	Monthly teleconferences with SLAC
	Configuration control to be implemented by vendor with a formal change process to drawings
Reviews	Conceptual Design Review : 2 months after award
	Preliminary Design Review : 4 months after award
	Final Design Review: 10 months after award
	Manufacturung Readiness Review: Prior to start of fabrication
	Pre-Ship Review: Acceptance testing prior to shipping
Installation at SLAC	Vendor responsible for assembly and installation at SLAC SLAC will provide all necessary assistance

Table 11: Summary of all the mirror mechanical specifications and requirements

18.2.3. Vacuum Enclosure

Item	Comments
Vacuum	Normal operation in ultrahigh vacuum (UHV) at ~20°C. UHV bake out at 125°C.
Dimensions	0.8 m < Length < 1.15 m Width : < 450 mm from center in the –x direction No restriction in the +x direction Height: No restriction other than the beam height of 1.4 m and ceiling of 3 m
Mounting	Reproducible to within 0.1 mm
Environment	Vacuum enclosure to be located inside a thermal enclosure controlled to 0.01 degree Celcius Stability requirements to be met under these conditions
Fiducialization	Provide external references outside the vacuum enclosure for surveying External references to be at known positions relative to the mirrors inside vacuum
Maintenance and Accessibility	Design to allow removal of the in-vacuum components without removing the vacuum chamber from the beamline Multiple access ports to be provided for small maintenances Removal top of the chamber with fixtures for lifting with a crane No trip hazards, pinch points, loose cables

Table 12: Summary of all specifications and requirements for the Vacuum Enclosure.

18.2.3.1. Vacuum Ports

	Port type or use	Orientation	Location	Purpose
1	Entrance Port (6” non-rotatable)	Along the beam	Upstream of chamber, centered on the beam	Let the beam in
2	Exit Port (6” rotatable)	Along the beam	Dowstream of chamber, centered on the beam	Let the beam out
3	Viewport (4.5”)	Along ψ1 axis	Midpoint along z of mirror 1	Future addition of interferometer
4	Viewport (4.5”)	Along θ1 axis	Midpoint along z of mirror 1	Future addition of interferometer
5	Viewport (4.5”)	Along ψ2 axis	Midpoint along z of mirror 2	Future addition of interferometer
6	Viewport (4.5”)	Along θ2 axis	Midpoint along z of mirror 2	Future addition of interferometer
7	Vacuum gauge (2.75”)	Any	Anywhere	Measure the pressure
8	Vacuum gauge (2.75”)	Any	Anywhere	Measure the pressure
9	Rough pumping (2.75”)	Any	Anywhere	Pump down the enclosure from atmosphere
10	Ion Pump (6”)	Any	Bottom of enclosure	Create Ultra-high vacuum
11	Feedthrough (6”)	Any	Near the back side of mirror 1	Connect cables for motorized motions

12	Feedthrough (6”)	Any	Near the back side of mirror 2	Connect cables for motorized motions
13	Miscellaneous (6”)	Any	Anywhere	Future expansion
14	Miscellaneous (6”)	Any	Anywhere	Future expansion
15	Miscellaneous (2.75”)	Any	Anywhere	Future expansion
16	Miscellaneous (2.75”)	Any	Anywhere	Future expansion

Table 13: List of required vacuum ports for the Vacuum Enclosure

18.2.4. Support Stand

Item	Comments
Stability	Shall meet the vibrational and thermal requirements of the mirror support system described above
Dimensions	0.8 m < Length < 1.15 m Width : < 450 mm from center in the –x direction No restriction in the +x direction Height: Must position the mirrors at a beam heigh of 1.4 m
Structural issues	Design to be certified by the SLAC Earthquake Safety Committee is the total weight of the system exceeds 400 pounds Vendor to allow 6 weeks for SLAC approval
	Design shall satisfy the 10CFR851 requirements for pressure vessels
Positioning	Allow the vacuum enclosure and mirror support system to be positioned over a ± 12.5 mm range for coarse positioning in case of beam drifts over long periods
Color	Painted with red color matching the US Federal Standard FS11140

Table 14: Summary of all specifications and requirements for the Support Stand.