## Reference Documents:

| Reference Number | Date/ Issue | Title |
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## Change log:

| Revision | Date | Summary of Change |
|---|---|---|
| 1.0 | 04/10/11 | First Issue |
| 2.0 | 06/01/12 | Vacuum vessel port details amended to suit suppliers optic cooling arrangements. Rewording of L2 mirror cooling arrangement to improve clarity. Addition of right angle tabulation for mass spectrometer – all vessels. Air guard hose to become vacuum guard hose (L1 & M1). Optic thickness increased to 60 mm (L1 and M1). Remove all references to Swagelok fittings – only Serto fittings to be used. Tolerance on tangential radius for toroidal mirror L2A reduced to ±1.5% (from ±2%). Guaranteed tangential slope error on planar optic L2B reduced to 0.2µrad (from 0.3µrad). Angled viewports for substrate changed from DN40/CF70 to DN63/CF114 for consistency with rear port and increased viewing area (L1&M1). Burst disk port added to all vessels |
| 3.0 | 20/01/12 | Beam in & out ports (L2) increased in size to DN150/CF200. Base vessel port details amended. |
| 4.0 | 02/10/12 | Carbon stripes added to optic L1. |
| 5.0 | 16/01/15 | Radii of L2A optic altered to suit amended beamline layout. Incidence angles changed on L1 and L2 to 0.575 and 0.61° respectively. |

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# 1 INTRODUCTION

The white beam section of the NIST Spectroscopy Beamline Suite starts from the DN 100/6"CF all metal gate valve that terminates the front end (not in scope of supply) and continues to the 2 off DN63/4½"CF Viton-sealed Gate Valves that exit the First Optical Enclosure leading into each beamline branch (see Figure 1 below).

This specification details the hardware requirements for the Mirror Systems (L1, M1 and L2), which FMB Oxford (FMBO) is supplying for the white beam section.

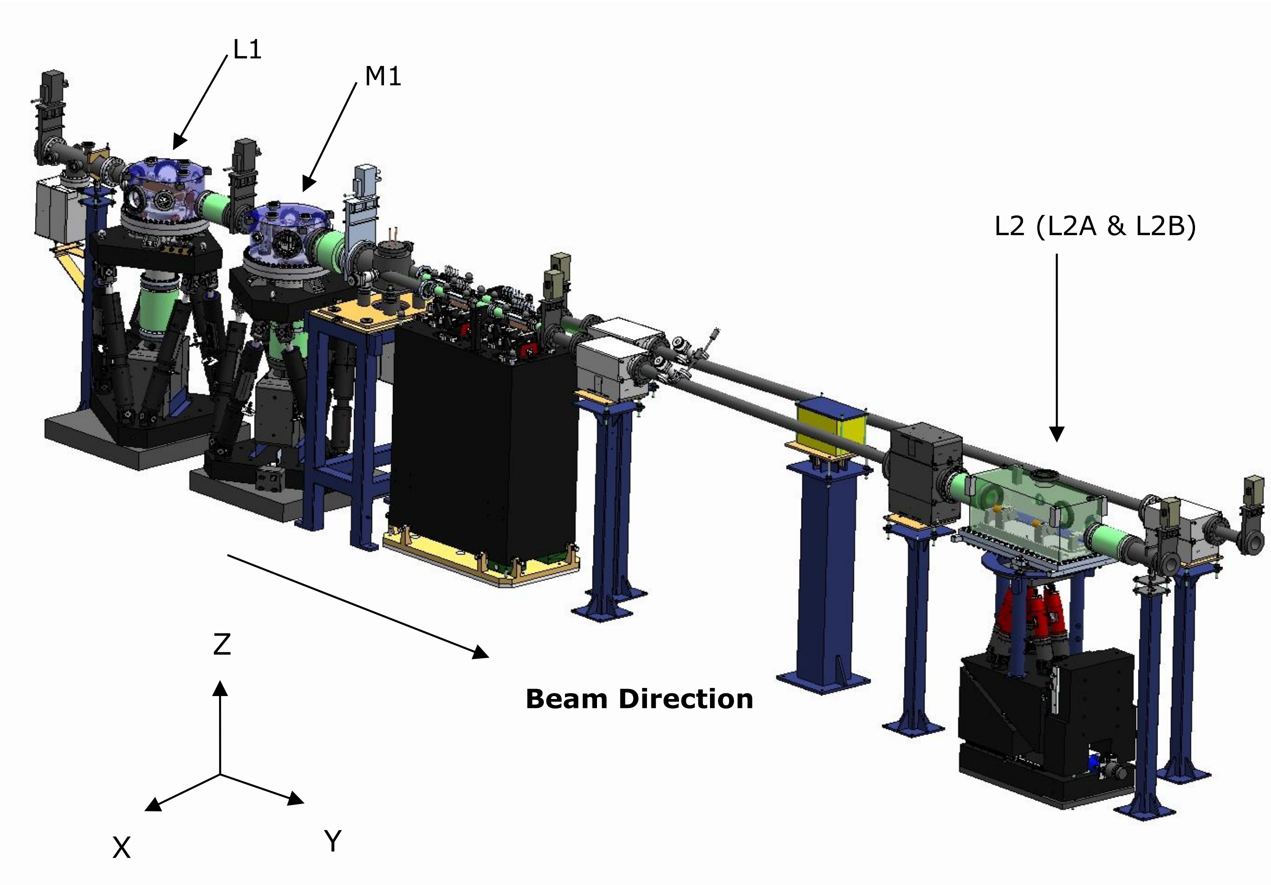


**Figure 1.** Figure 1 White Beam Section

# 2 SCOPE OF SUPPLY

FMBO will be supplying a total of three mirror systems (L1, M1 and L2) as part of the project.

The scope of supply includes the following items:

1. Tender Beamline Plane Mirror System L1 including internally-cooled, super-polished optic
2. Soft Beamline Plane Mirror System M1 including internally-cooled, super-polished optic
3. Focussing Mirror System L2A/L2B including optics
4. Packing and Shipping
5. 12 months warranty after acceptance/18 months warranty from delivery, whichever comes first

The scope of supply does not include the following items:

1. Vacuum equipment i.e. gauges and pumps
2. Water supply, conditioning and alarm elements
3. Pink beam slits
4. Motion controls
5. Beamline backbone
6. Installation.

# 3 MIRROR SYSTEM OVERVIEW

All three mirror systems use Hexapods to provide the required six degrees of freedom of the mirrors - the three conventional linear motions ($T_x$ – lateral, $T_y$ – longitudinal and $T_z$ - Vertical) as well as the three conventional rotation motions ($R_x$ – pitch, $R_y$ – roll and $R_z$ - yaw ) – see Figure 2 below.

The Hexapod consists of fixed and moving granite platforms, with six precision linear actuators positioned between the two platforms (in Stewart platform configuration). The linear actuators are driven by stepper motors and gearboxes with linear optical encoders giving position feedback. Each actuator contains two end of travel limit switches and a precision home position for the encoder.

The hexapod and vessel for mirror system L2 sit on a high rigidity vertical translation stage. The stage is required because the amount of vertical movement needed (approximately 88mm) to shift the beam from mirror L2A to L2B exceeds the range of the standard hexapod. A small hexapod provides the six degrees of freedom for optics L2A and L2B relative to the mirror vessel.

Mounted on each end of the linear actuator is a universal joint which gives the required rotational movements to allow the optical components to be moved in all 6 DOF. The universal joint mounted at the lower end of the actuator provides 2 DOF while the joint at the upper end provides 3 DOF. The universal joints use precision angular contact bearings.

All four mirror optics are single crystal silicon and require water cooling. Mirrors L1 and M1 are internally cooled, while mirrors L2A and L2B are side cooled.

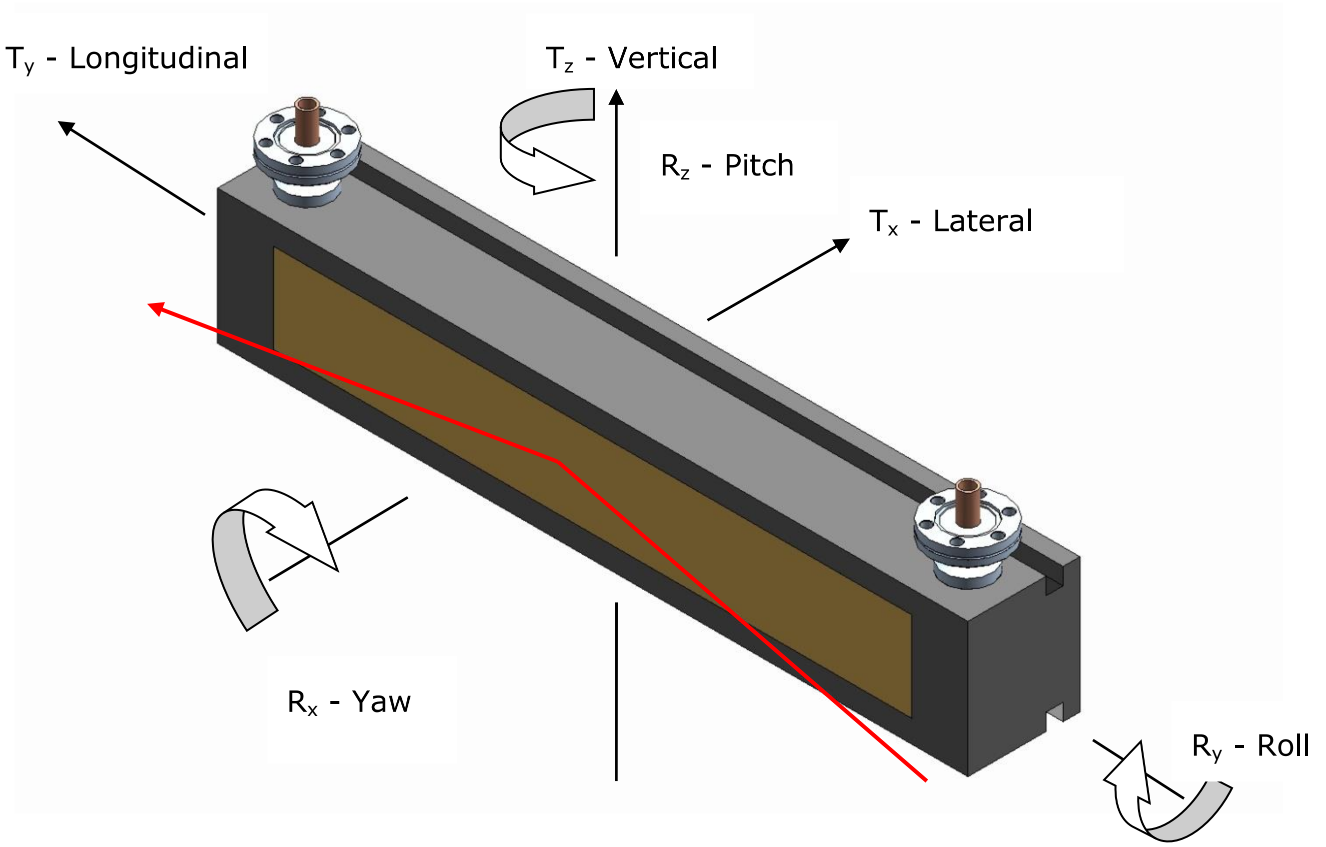


**Figure 2.** Figure 2 Mirror Motion Axes

## 3.1 MOTION SPECIFICATIONS

For all of the mirror systems, the hexapods are to produce the following range of motion:

Hexapod range of motion for all mirror systems

| **Motion** | **Parameter** | **Specification** |
|---|---|---|
| Yaw ($R_x$) | Drive | Linear actuators, fitted with limit switches and optical encoder. |
| | Range | ± 10 mrad |
| | Resolution | <5 µrad |
| | Repeatability | <10 µrad |
| Roll ($R_y$) | Drive | Linear actuators, fitted with limit switches and optical encoder. |
| | Range | ± 10 mrad |
| | Resolution | <5 µrad |
| | Repeatability | <10 µrad |
| Pitch ($R_z$) | Drive | Linear actuators, fitted with limit switches and optical encoder. |
| | Range | Nominal Position ± 10 mrad |
| | Resolution | <1 µrad |
| | Repeatability | <5 µrad |
| Vertical ($T_z$) | Drive | Linear actuators, fitted with limit switches and optical encoder. |
| | Range | ± 20 mm |
| | Resolution | <1 µm |
| | Repeatability | <5 µm |
| Lateral ($T_x$) | Drive | Linear actuators, fitted with limit switches and optical encoder. |
| | Range | ± 5 mm |
| | Resolution | <1 µm |
| | Repeatability | <5 µm |
| Longitudinal ($T_y$) | Drive | Linear actuators, fitted with limit switches and optical encoder. |
| | Range | ± 5 mm |
| | Resolution | <2 µm |
| | Repeatability | <10 µm |

In addition, the vertical translation stage in mirror system L2 is to provide the following range of motion to the vessel-hexapod system:

Mirror System L2 Vertical Translation Stage Range of Motion

| **Motion** | **Parameter** | **Specification** |
|---|---|---|
| Vertical ($T_z$) | Drive | Linear actuators, fitted with limit switches and optical encoder. |
| | Range | $\pm$ 45 mm |
| | Resolution | <1 μm |
| | Repeatability | <5 μm |
| | Repeatability of Pitch over range | <5 μrad |

Automated mirror adjustments- Note: The extreme positions of the ranges for the degrees of freedom of the mirror and support frame cannot all be reached simultaneously. The expected resolutions are ignoring backlash and are totally dependent on the "dead band" for the motor control system used. Actual resolutions may not be as expected as the motor control system may not be capable of microstepping at the same resolution as the encoders.

## 3.2 MIRROR SYSTEM L1

Mirror L1 System Specification

| | |
|---|---|
| Incoming Beam Height | Nominally 1400 mm above the floor |
| Operating position | Horizontally deflecting inboard |
| Length between vessel in/out flanges | Not more than 450 mm |
| Grazing Incidence Angle | 0.575º |
| Manual Adjustments | *x & y ($\pm$ 10 mm) adjustment of the mirror optical elements via bolts on baseplate prior to grouting*<br>*Additional x, y, z ($\pm$ 10 mm) adjustment of the vessel around the mirror optical elements via adjusting feet - also gives yaw, roll and pitch* |

### 3.2.1 L1 Mirror Optic

The L1 mirror optic is sourced from Insync.

Mirror L1 Optic Specification

| | |
|---|---|
| Substrate material | Single crystal silicon <1 0 0> |
| Substrate dimensions (±0.4mm) | 335 mm L x 60 mm W x 60 mm D |
| Active Area (centred on substrate to within ± 0.5mm) | 285 mm x 40 mm |
| Substrate Shape | Planar, Tangential Radius ≥30 km, Sagittal Radius ≥3 km |
| Tangential slope error | <0.2 μrad RMS over active length on prepared substrate at 2mm or better resolution |
| Sagittal slope error | <2 μrad RMS over active length on prepared substrate at 2mm or better resolution |
| Coating | C 300 Å ± 10% thick 13 mm wide deposited directly onto silicon substrate<br><br>Au 300 Å ± 10% thick 18 mm wide over platinum binder layer 100 Å thick<br><br>Ni 300 Å ± 10% thick 18 mm wide over platinum binder layer 100 Å thick |
| Surface Roughness | <3 Å RMS |
| Surface Quality | 0.5 scratches or points per $cm^2$ over 99% of active optical area |
| Alignment Surface | Rear polished to λ/2 and parallel to front to within 500μrad |
| Cooling Geometry | Internally Cooled : 21 channels with 20 lands to give cooled width of 41 mm. Channel size 1 mm wide x 5mm tall. Hot wall 1mm thick. Land width 1mm. Serpentine arrangement of channels with water fed through 7channels in 3 passes to give 21 channels. |

| | |
|---|---|
| Bond Integrity | Pressure test at 145 PSI/10 bar and hold for 30 minutes.<br>Leak rate for vacuum guard to UHV: max $2x10^{-9}$ $cm^3$/sec helium (after 30 minutes)<br>Leak rate for vacuum guard to cooling channels: max $2x10^{-7}$ $cm^3$/sec helium (after 30 minutes) |
| Pressure Drop | Expected pressure drop of 60 psi/4.1 bar at 4 l/min – to be confirmed following testing by Insync. |
| UHV Baking | Maximum bake out temperature 150°C. Maximum ramp rate 1°C/minute. |

### 3.2.2 L1 and M1 Mirror Cooling

The L1 optic is internally-cooled and cooling lines are taken to and from the cooling connections on the optic by flexible silicon hoses. There are no water-vacuum interfaces. Water will be fed to each cooling circuit from outside the vacuum vessel by "vacuum-guarded" hoses. Each hose will comprise a set of stainless steel bellows designed to articulate with the movement of the mirror. The bellows will seal to a Conflat on the vessel and to an external Conflat bulkhead on the mirror and will be connected to a vacuum roughing pump. The bulkhead Conflat will include a vacuum brazed water feedthrough to ensure that there is no direct water-to-vacuum joint. Each bellows will carry a flexible silicon hose with Serto terminations to connect with the external water supply.

A water-cooled white beam mask capable of absorbing the full incident beam will be located to protect the edge of the substrate in the event of beam mis-steer. Thermocouples will be fitted to the white beam mask to monitor their temperature during operation. Thermocouple conditioning electronics will be required (not in scope of supply).

### 3.2.3 L1 Vacuum Vessel

The vessel shall comprise a cylindrical stainless steel base onto which is bolted the vessel lid. Access to the mirror is obtained by removing the lid. The vessel shall be fabricated from dull polished 304 grade stainless steel plates with full penetration welds and cleaned and prepared in accordance with standard UHV requirements. All flanges, including the lid, shall be Conflats, manufactured from 304 or 316 stainless steel and sealed with copper gaskets. Viewports shall be lead glass.

Blank flanges (or blank shipping flanges as appropriate) shall be supplied for any flanges that do not have assemblies fitted as supplied.

All mechanisms inside the UHV space shall use UHV compatible materials with dull polished or machined finish, which shall be cleaned following FMB Oxford procedures for UHV cleanliness. UHV compatible joining methods (welding, vacuum brazing etc.) shall be used throughout. Lifting points shall be provided on the vessel lid.

All materials and processes are compatible with UHV levels of 2 x $10^{-10}$ mbar and a leak rate of less than 1 x $10^{-10}$ mbar.l/s (committed to 2 x $10^{-10}$ mbar.l/s).

The vessel lid shall be fitted with points for mounting fiducials (for alignment during installation) in accordance with requirements.

The overall vessel width is approximately 470mm (including sealing flange) and the flange-to-flange length is approximately 450 mm.

L1 Vacuum Vessel Ports

| **Purpose** | **Location** | **Size (OD)** | **Qty** |
|---|---|---|---|
| Beam in | Beam inlet port at end 1 | DN100/CF150 | 1 |
| Beam out | Beam outlet port at end 2 | DN100/CF150 Rotatable | 1 |
| Viewport | Incoming wall of vessel angled to look at substrate surface | DN63/CF114 | 1 |
| Viewport | Outboard side of vessel | DN63/CF114 | 1 |
| Roughing Port for RA valve | Outboard side of vessel | DN40/CF70 | 1 |
| Vacuum Gauges | Top of vessel | DN40/CF70 | 2 |
| Spare | Top of vessel | DN63/CF114 | 1 |
| Mass Spectrometer port | Inboard side of vessel – tubulation at right angle to allow mass spectrometer not to protrude into vessel | DN45/CF70 | 1 |
| Burst Disk Port | Outboard side of vessel | DN40/CF70 | 1 |
| Thermocouple Feedthroughs | Vessel base | DN40/CF70 | 1 |
| Cooling Feedthrough (Mask) | Vessel base | DN40/CF70 Rotatable | 1 |

| | | | |
|---|---|---|---|
| Cooling Feedthroughs (Optic) | Vessel base | DN16/CF34 | 2 |
| Spare | Vessel base | DN40/CF70 | 1 |
| Ion Pump | Vessel base | DN150/CF200 | 1 |

### 3.2.4 L1 Ion Pump Support

Mounting holes and brackets will be provided for a Gamma Ion pump (not in scope of supply), - type 500T with side port and titanium sublimation pump. The ion pump will be located immediately below the vacuum vessel. In order to remove the low frequency pendulum effect when the ion pump is supported off the vacuum vessel, the pump will be supported off the lower platform and connected to the vessel through an edge-welded bellows. This will provide mechanical isolation and will ensure improved stability of the system.

## 3.3 MIRROR SYSTEM M1

Mirror M1 System Specification.

| | |
|---|---|
| Incoming Beam Height | Nominally 1400 mm above the floor |
| Operating position | Horizontally deflecting outboard |
| Grazing Incidence Angle | 1.5º |
| Length between vessel in/out flanges | Not more than 450 mm |
| Distance to Source/Image (vertical) | 0 mm |
| Distance to Source/Image (horizontal) | 27 750 mm |
| Manual Adjustments | *x & y (± 10 mm) adjustment of the mirror optical elements via bolts on baseplate prior to grouting*<br>*Additional x, y, z (± 10 mm) adjustment of the vessel around the mirror optical elements via adjusting feet - also gives yaw, roll and pitch* |

### 3.3.1 M1 Mirror Optic

The M1 mirror optic is sourced from Insync.

Mirror M1 Optic Specification

| | |
|---|---|
| Substrate material | Single crystal silicon <1 0 0> |
| Substrate dimensions (±0.4mm) | 250 mm L x 70 mm W x 60 mm D |
| Active Area (centred on substrate to within ± 0.5mm) | 200 mm x 50 mm |
| Substrate Shape | Planar, Tangential Radius ≥30 km,<br>Sagittal Radius ≥ 3 km |
| Tangential slope error | <0.2 µrad RMS over active length on prepared substrate at 2mm or better resolution |
| Sagittal slope error | <2 µrad RMS over active length on prepared substrate at 2mm or better resolution |
| Coating | C 300 Å ± 10% thick 17 mm wide deposited directly onto silicon substrate.<br><br>Au 300 Å ± 10% thick 21 mm wide over platinum binder layer 100 Å thick<br><br>Ni 300 Å ± 10% thick 21 mm wide over platinum binder layer 100 Å thick |
| Surface Roughness | <3 Å RMS |
| Surface Quality | 0.5 scratches or points per $cm^2$ over 99% of active optical area |
| Alignment Surface | Rear polished to λ/2 and parallel to front to within 500µrad |
| Cooling Geometry | Internally Cooled : 27 channels with 26 lands to give cooled width of 53 mm. Channel size 1 mm wide x 5mm tall. Hot wall 1mm thick. Land width 1mm. Serpentine arrangement of channels with water fed through 9 channels in 3 passes to give 27 channels. |

| | |
|---|---|
| Bond Integrity | Pressure test at 145 PSI/10 bar and hold for 30 minutes.<br>Leak rate for vacuum guard to UHV: max 2x10-9 cm3/sec helium (after 30 minutes)<br>Leak rate for vacuum guard to cooling channels: max 2x10-7 cm3/sec helium (after 30 minutes) |
| Pressure Drop | Expected pressure drop of 60 psi/4.1 bar at 4 l/min – to be confirmed following testing by Insync. |
| UHV Baking | Maximum bake out temperature 150°C. Maximum ramp rate 1°C/minute. |

### 3.3.2 M1 Vacuum Vessel

The vessel shall comprise a stainless steel baseplate onto which is bolted the vessel lid. The overall vessel width is approximately 470mm (including sealing flange) and the flange-to-flange length is approximately 450 mm.

Access to the mirror is obtained by removing the lid. The vessel shall be cylindrical and fabricated from dull polished 304 grade stainless steel plates with full penetration welds and cleaned and prepared in accordance with standard UHV requirements. All flanges, including the baseplate, shall be Conflats, manufactured from 304 or 316 stainless steel and sealed with copper gaskets. Viewports shall be lead glass.

Blank flanges (or blank shipping flanges as appropriate) shall be supplied for any flanges that do not have assemblies fitted as supplied.

All mechanisms inside the UHV space shall use UHV compatible materials with dull polished or machined finish, which shall be cleaned following FMB Oxford procedures for UHV cleanliness. UHV compatible joining methods (welding, vacuum brazing etc.) shall be used throughout. Lifting points shall be provided on the vessel lid.

All materials and processes are compatible with UHV levels of $2 \times 10^{-10}$ mbar and a leak rate of less than $1 \times 10^{-10}$ mbar.l/s (committed to $2 \times 10^{-10}$ mbar.l/s).

The vessel baseplate shall be fitted with points for mounting fiducials (for alignment during installation) in accordance with requirements.

M1 Mirror Vessel Ports

| **Purpose** | **Location** | **Size (OD)** | **Qty** |
|---|---|---|---|
| Beam in | Beam inlet port at end 1 | DN100/CF150 | 1 |
| Beam out | Beam outlet port at end 2 | DN150/CF200 Rotatable | 1 |
| Viewport | Incoming wall of vessel angled to look at substrate surface | DN63/CF114 | 1 |
| Viewport | Inboard side of vessel | DN63/CF114 | 1 |
| Roughing Port for RA valve | Outboard side of vessel | DN40/CF70 | 1 |
| Vacuum Gauges | Top of vessel | DN40/CF70 | 2 |
| Mass Spectrometer port | Inboard side of vessel – tubulation at right angle to allow mass spectrometer not to protrude into vessel | DN45/CF70 | 1 |
| Spare | Top of vessel | DN63/CF114 | 1 |
| Burst Disk Port | Inboard side of vessel | DN40/CF70 | 1 |
| Thermocouple Feedthrough | Baseplate beneath vessel | DN40/CF70 | 1 |
| Cooling Feedthrough (Mask) | Baseplate beneath vessel | DN45/CF70 Rotatable | 2 |
| Cooling Feedthroughs (Optic) | Baseplate beneath vessel | DN16/CF34 | 2 |
| Spare | Baseplate beneath vessel | DN40/CF70 | 1 |
| Ion Pump | Baseplate beneath vessel | DN150/CF200 | 1 |

### 3.3.3 M1 Ion Pump Support

Mounting holes and brackets will be provided for a Gamma Ion pump (not in scope of supply), type 500T with titanium sublimation pump. The ion pump will be located immediately below the vacuum vessel. In order to remove the low frequency pendulum effect when the ion pump is supported off the vacuum vessel, the pump will be supported off the lower platform and connected to the vessel through an edge-welded bellows. This will provide mechanical isolation and will ensure improved stability of the system.

## 3.4 MIRROR SYSTEM L2

### 3.4.1 L2 Mirror Optics

#### 3.4.1.1 Optic L2A

The L2A mirror optic is sourced from Zeiss Laser Optics.

L2A Mirror Optic Specification

| | |
|---|---|
| Operating position | Horizontally Deflecting Outboard, horizontally and vertically focussing |
| Substrate material | Single crystal silicon <1 0 0> |
| Substrate dimensions (±0.3mm) | 400 mm L x 60 mm W x 60 mm D |
| Active Area (centred on substrate to within ± 0.5mm) | 350 mm x 40 mm |
| Substrate Shape | Toroidal,<br>Tangential Radius 2.805 km ± 56.1 m (±2%)<br>Sagittal Radius 320.9 mm ± 3.21 mm (±1%) |
| Distance to Source | 35 751.3 mm |
| Distance to Image | 25 847 mm |
| Grazing Incidence Angle | 0.61° |
| Tangential slope error | <1 µrad RMS over active length at 2mm or better |
| Sagittal slope error | <5 µrad RMS over active length at 2mm or better |
| Coating | Au 300 Å ± 10% thick 20 mm wide<br>Ni 300 Å ± 10% thick 20 mm wide |
| Surface Roughness | <3 Å RMS |
| Surface Quality | 0.5 scratches or points per $cm^2$ over 99% of active optical area |

| | |
|---|---|
| Alignment Surface | Rear polished to λ/2 and parallel to front to within 500µrad |
| Cooling | Side cooled |

#### 3.4.1.2 Optic L2B

The L2B mirror optic is sourced from Zeiss Laser Optics.

L2B Mirror Optic Specification

| | |
|---|---|
| Operating position | Horizontally Deflecting Outboard |
| Substrate material | Single crystal silicon <1 0 0> |
| Substrate dimensions (±0.3mm) | 400 mm L x 60mm W x 60 mm D |
| Active Area (centred on substrate to within ± 0.5mm) | 350 mm x 40 mm |
| Substrate Shape | Planar, Tangential Radius ≥30 km, Sagittal Radius ≥3 km |
| Grazing Incidence Angle | 0.61º |
| Tangential slope error | <0.2 µrad RMS over active length on prepared substrate (Guaranteed) measured at 2mm or better |
| Sagittal slope error | <2 µrad RMS over active width on prepared substrate measured at 2mm or better |
| Coating | Au 300 Å ± 10% thick 20 mm wide<br><br>Ni 300 Å ± 10% thick 20 mm wide |
| Surface Roughness | <3 Å RMS |
| Surface Quality | 0.5 scratches or points per $cm^2$ over 99% of active optical area |
| Alignment Surface | Rear polished to λ/2 and parallel to front to within 500µrad |
| Cooling | Side Cooled. |

### 3.4.2 L2 Mirror Cooling

The L2A and L2B optics are side-cooled by OFHC copper blocks clamped to both sides of the substrate. Thin Indium sheet is used to facilitate heat transfer. Water is connected to the copper blocks through a solid cooling line. Cooling lines are taken to and from the cooling connections on the optic by flexible silicon hoses.

A water-cooled white beam mask capable of absorbing the full incident beam will be located to protect the edge of the substrate in the event of beam mis-steer.

There are no water-vacuum interfaces. Thermocouples are fitted to both the substrate and the white beam mask to monitor their temperature during operation. Thermocouple conditioning electronics will be required (not in scope of supply).

### 3.4.3 L2 Vacuum Vessel

The vessel shall comprise a stainless steel baseplate onto which is bolted the vessel lid. The overall vessel width is approximately 840mm (including sealing flange) and the flange-to-flange length is approximately 840 mm.

Access to the mirror is obtained by removing the lid. The vessel shall be rectangular and fabricated from dull polished 304 grade stainless steel plates with full penetration welds and cleaned and prepared in accordance with standard UHV requirements. All flanges, including the baseplate, shall be Conflats, manufactured from 304 or 316 stainless steel and sealed with copper gaskets. Viewports shall be lead glass.

Blank flanges (or blank shipping flanges as appropriate) shall be supplied for any flanges that do not have assemblies fitted as supplied.

All mechanisms inside the UHV space shall use UHV compatible materials with dull polished or machined finish, which shall be cleaned following FMB Oxford procedures for UHV cleanliness. UHV compatible joining methods (welding, vacuum brazing etc.) shall be used throughout. Lifting points shall be provided on the vessel lid.

All materials and processes are compatible with UHV levels of $2 \times 10^{-10}$ mbar and a leak rate of less than $1 \times 10^{-10}$ mbar.l/s (committed to $2 \times 10^{-10}$ mbar.l/s).

The vessel baseplate shall be fitted with points for mounting fiducials for alignment during installation in accordance with requirements.

L2 Mirror Vessel Ports

| **Purpose** | **Location** | **Size (OD)** | **Qty** |
|---|---|---|---|
| Beam in | Beam inlet port at end 1 | DN150/CF200 | 1 |
| Beam out | Beam outlet port at end 2 | DN150/CF200 rotateable | 1 |
| Viewport | Outboard wall of vessel, looking at substrate surface. | DN100/CF150 | 1 |

| | | | |
|---|---|---|---|
| Viewport | Inboard wall of vessel to look at polished rear surface of mirror. | DN63/CF114 | 2 |
| Roughing Port for RA valve | Outboard side of vessel | DN40/CF70 | 1 |
| Vacuum Gauges | Top of vessel | DN40/CF70 | 2 |
| Mass Spectrometer port | Inboard side of vessel – tubulation at right angle to allow mass spectrometer not to protrude into vessel | DN45/CF70 | 1 |
| Burst Disk Port | Top of vessel | DN40/CF70 | 1 |
| Spare | Top of vessel | DN63/CF114 | 1 |
| Support Post | Baseplate beneath vessel | DN150/CF200 | 1 |
| Thermocouple Feedthroughs | Baseplate beneath vessel | DN40/CF70 | 1 |
| Cooling Feedthroughs | Baseplate beneath vessel | DN50/CF86 | 3 |
| Spare | Baseplate beneath vessel | DN40/CF70 | 1 |
| Mirror loading | Baseplate beneath vessel | Al Wire Seal | 1 |

### 3.4.4 L2 Ion Pump Support

The ion pump (not in scope of supply) will be located immediately upstream of the mirror system and separated by an edge-welded bellows (not in scope of supply). This provides mechanical isolation and ensures improved stability of the system.

### 3.4.5 Environment

| | |
|---|---|
| Ambient temperature | 0°C to 35°C |
| Storage temperature | 0°C to 40°C |
| Relative humidity | 10 – 95% non – condensing |

### 3.4.6 Vacuum System

| | |
|---|---|
| Maximum bakeout temperature | 200 °C (without optic in place) |
| Vacuum | • UHV compatible $5x10^{-10}$ mbar without optics fitted during factory bakeout.<br>• $2x10^{-10}$ mbar on site with optics fitted after bakeout (not included in scope of supply).<br>• Final vacuum of $2x10^{-10}$ mbar with beam is expected. |
| Helium leak rate | <1 x $10^{-10}$ mbar l/ sec<br>(committed to 2 x $10^{-10}$ mbar l/ sec) |

### 3.4.7 System Services

All three mirror systems are to be supplied cooled water by chillers, with the following flow rates and pressure drops expected:

| **Mirror System** | **Coolant Flow Rate** | **Coolant Pressure Drop** |
|---|---|---|
| L1 | 1 litre per minute for the mask and mirror i.e. total flow required is 2 litres per minute minimum. | 1 bar total – all cooling circuits in parallel |
| M1 | 1 litre per minute for the mask and mirror i.e. total flow required is 2 litres per minute minimum. | 1 bar total – all cooling circuits in parallel |
| L2 | 1 litre per minute for the mask and mirrors i.e. total flow required is 3 litres per minute. | 1 bar total – all cooling circuits in parallel |

Flow switches will be required for use by the EPS system (not in scope of supply). All cooling circuits to be pressure tested at 1.43x system pressure i.e. test at 10 bar.

# 4 SYSTEM WEIGHTS

| | |
|---|---|
| Mirror System L1 | 455 kg approximately |
| Mirror System M1 | 455 kg approximately |
| Mirror System L2 | 1650 kg approximately (frame with jacking castors is an additional 135kg) |

# 5 LIFTING ARRANGEMENTS

The mirror systems will be movable by castors outside of the FOE. Inside the FOE, a 500kg overhead crane will be required.

# 6 ALIGNMENT FEATURES

4 fiducial mounts will be fitted in the corners of the grouted floor plate for mirror alignment at the factory. These points are also suitable for 8 mm Laser tracker targets. These will be all externally accessible for alignment at during site installation.

# 7 FACTORY TESTING

Factory acceptance testing consists of Motion Testing, Vacuum Testing and Fiducialization.The factory tests include the following aspects of the performance:

- Vacuum tests comprising leak testing of the vessel, total pressure measurement and residual gas analysis following bake-out.
- Helium leak checking to ensure that all sealing units are vacuum tight.
- Motion tests using FMB-O controller units to ensure that all movements operate throughout their working ranges and measurement of the accuracy, resolution and repeatability of all motions, and effectiveness of limit switches

Full specifications and procedures for factory testing are to be prepared in advance and submitted to the customer prior to final design approval.

The vessel shall be baked out and vacuum tested at FMB Oxford prior to shipment. Vacuum testing shall include total pressure measurement and RGA scan of the mirror vessel.

The nominal optics active surfaces will be referenced to the fiducial mount positions and the co-ordinates (X, Y and Z) provided to a precision of ±0.2 mm to establish the horizontal and longitudinal axes of the systems. FMB-O do not have a laser tracking capability but would welcome fiducialisation to be done in the factory and alignment to be done on site using BNL laser tracking equipment and resource.

# 8 INSTALLATION

Not in scope of supply. Floor drilling plans will be supplied prior to installation.

# 9 DESIGN STANDARDS AND MANUFACTURING PROCEDURES

The mirror systems shall be designed, manufactured and tested to the agreed specification and drawings. All FMB Oxford documentation shall be written in English.

A risk assessment form shall be completed and issued to BNL for approval.

A full manual covering each mirror system shall be written and supplied to the customer. General arrangement drawings of the systems shall also be provided.

Testing procedures and results will be included in the manual.